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UNITED STATES INTERNATIONAL TRADE COMMISSION

ELECTRONIC PIANOS

Report on Investigation No. 337-31 Conducted Under the Provisions of Section 337 of Title III of the Tariff Act of 1930, as Amended

724

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Washington, D. C.
March 1975

UNITED STATES INTERNATIONAL TRADE COMMISSION

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UNITED STATES INTERNATIONAL TRADE COMMISSION
Washington, D.C.
March 17, 1975

In the matter of an investigation with regard to the importation and domestic sale of certain electronic pianos)	Docket No. 31 Section 337 Tariff Act of 1930, as amended

INTRODUCTION

On March 6, 1972, The Wurlitzer Co., of Chicago, Ill., hereinafter referred to as complainant, 1/ 2/ filed a complaint with the U.S. Tariff Commission (now the U.S. International Trade Commission) requesting relief under section 337 of the Tariff Act of 1930, as amended (19 U.S.C. 1337), alleging unfair methods of competition and unfair acts in the importation and sale of electronic pianos manufactured by Nippon Columbia Co., Ltd., of Japan. Complainant alleged that the imported electronic pianos are embraced within the claims of its U.S. Patent Nos. 3,038,363; 2,942,512; 2,949,053; and 3,154,997; that they strongly resemble complainant's product in appearance; 3/ and that the importation of electronic pianos by Electrokey, Inc., Rhythm Band, Inc., and Tommy Moore, all of Fort Worth, Tex., and the Chicago Musical Instrument Co. of Chicago, Ill., hereinafter referred to as respondents, has the effect or tendency to substantially injure an efficiently and economically operated industry in the United States.

1/ The terms "complainant" and "respondent" frequently appear in this report. The Commission wishes to enter the following: The use of these terms is limited to serving as a convenient means of identifying certain parties before the Commission.

2/ Commissioner Leonard wishes to enter further: The use of the terms "complainant" and "respondent" is not to be construed, by implication or otherwise, as an indication that the Commission proceedings are adjudicatory as opposed to fact-finding.

3/ As will be seen infra, this allegation appears to refer to "copying."

Notice of receipt of the complaint and institution of the preliminary inquiry was published in the Federal Register of April 4, 1972 (37 F.R. 6797). Interested parties were given until May 1, 1972, to file written views pertinent to the subject matter. Upon the written request of Electrokey, Inc., the Commission granted an extension of time for filing written views until May 11, 1972; notice of the extension was published in the Federal Register of April 19, 1972 (37 F.R. 7736).

On May 11, 1972, respondents filed a joint statement with the Commission in which they contended that (1) the Commission should dismiss or suspend its proceedings because the issues involved are confined to patent questions, and the same patents are the subject of litigation in the United States District Court for the Northern District of Texas, Dallas Division, which court has jurisdiction over all the parties and can grant whatever remedies are legally appropriate; (2) the scope and content of the prior art would indicate that the electronic piano is a product of evolution, not revolution; (3) the four patents in question are not pioneer patents; (4) Nippon Columbia Co., Ltd., developed its product independently and did not copy the U.S. product; (5) the imported electronic piano is not made in accordance with any of complainant's patents; and (6) there are serious questions as to the validity of the patents involved.

On August 2, 1972, complainant filed a supplement to its complaint before the Commission, requesting that, pending the institution of a full investigation, the Commission recommend to the President the issuance of a temporary order of exclusion.

The Commission conducted a preliminary inquiry, in accordance with section 203.3 of the Commission's Rules of Practice and Procedure (19 C.F.R. 203.3), to determine whether, in view of the above submissions, a full investigation was warranted and, if so, whether it should recommend to the President that a temporary exclusion order be issued pursuant to 19 U.S.C. 1337(f). 1/ On September 22, 1972 the Commission issued a notice ordering a full investigation, and on November 30, 1972, it issued a notice that a public hearing on the matter was scheduled for January 30, 1973. It declined to recommend on the earlier date the issuance of a temporary exclusion order by the President. Notice of the investigation was published in the Federal Register on September 28, 1972 (37 F.R. 20289) and notice of the hearing was published therein on December 5, 1972 (37 F.R. 25891).

Respondents filed a prehearing submission with the Commission on December 18, 1972, containing, among other motions, motions to dismiss, to suspend, or to postpone further Commission proceedings in the investigation. Complainant opposed these motions by a submission dated January 5, 1973. The Commission denied all of respondents' motions on January 11, 1973, and advised respondents to that effect.

The scheduled hearing was held January 30-31, 1973, and resumed and closed on March 29, 1973. Notice of resumption of the hearing was

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1/ The standard adopted by the Commission for deciding whether the issuance of such an order should be recommended (as indicated to the parties by letter notice) is whether a prima facie showing of violation of the provisions of sec. 337 of the Tariff Act of 1930 has been made and whether, in the absence of a temporary order of exclusion, immediate and substantial injury would be sustained.

published in the Federal Register on February 7, 1973 (38 F.R. 3554). Briefs were submitted on behalf of the complainant and on behalf of the respondents.

On July 17, 1974, the Commission ordered that an additional hearing would be held on August 15, 1974, in connection with the investigation. Notice of the hearing was published in the Federal Register on July 23, 1974 (39 F.R. 26796). 1/

The additional hearing was held as scheduled on August 15, 1974. Additional briefs were submitted on behalf of the complainant and on behalf of the respondents.

Copies of the complaint, the notice of investigation, the extension of time for filing written views, and dates of hearings were served upon known interested parties.

1/ The subject matter for the hearing was defined by the Commission's notice as follows:

> (1) to define the industry affected by imported electronic pianos allegedly covered by the claim(s) in U.S. Patent Nos. 3,038,363 and 2,949,053 owned by complainant; (2) to present evidence as to whether there is domestic production of electronic pianos allegedly covered by the claim(s) in these two patents; and (3) in the event there is domestic production under the claim(s) in these two patents, (a) to present evidence as to whether the imported electronic pianos are covered by the same claim(s); and (b) to present evidence as to the alleged effect or tendency of these imported electronic pianos to substantially injure the industry referred to in item (1) above.

FINDINGS AND RECOMMENDATION OF THE COMMISSION

The Commission (Commissioners Leonard and Minchew dissenting) finds unfair methods of competition or unfair acts in the unlicensed importation and sale of certain electronic pianos by reason of their being made in accordance with the claim(s) in U.S. Patent No. 3,038,363, the effect or tendency of which is to substantially injure an industry, efficiently and economically operated, in the United States.

The Commission does not find unfair methods of competition or unfair acts in the importation into the United States, or in the sale by the owner, importer, consignee, or agent of either, of (1) electronic pianos allegedly made in accordance with the claim(s) in U.S. Patent No. 2,942,512; (2) electronic pianos allegedly made in accordance with the claim(s) in U.S. Patent No. 2,949,053; or (3) reeds for electronic pianos allegedly made in accordance with the claim(s) in U.S. Patent No. 3,154,997, the effect or tendency of which is to substantially injure an industry, efficiently and economically operated, in the United States.

The Commission (Commissioners Moore and Ablondi dissenting) 1/ recommends that the President not issue an exclusion order to forbid entry into the United States of electronic pianos covered by the claim(s) in U.S. Patent No. 3,038,363.

1/ Commissioners Moore and Ablondi recommend that, in accordance with subsection (e) of section 337, the President issue an exclusion order to forbid entry into the United States of electronic pianos covered by the claim(s) in U.S. Patent No. 3,038,363, until expiration of the patent, except where the importation is under license of the owner of U.S. Patent No. 3,038,363.

STATEMENT OF CHAIRMAN BEDELL AND VICE CHAIRMAN PARKER

On March 6, 1972, a complaint was filed with the U.S. Tariff Commission by The Wurlitzer Co., of Chicago, Ill., alleging unfair methods of competition and unfair acts in the importation and sale of certain electronic pianos by Electrokey, Inc., et al. (which electronic pianos allegedly infringed the claims in three of Wurlitzer's patents and contained reeds which allegedly infringed the claims of a fourth Wurlitzer patent), the effect or tendency of which is to substantially injure an efficiently and economically operated industry in the United States. A supplemental complaint was filed by Wurlitzer with the Commission on August 2, 1972. The complaint, as supplemented, requested that the Commission recommend to the President that the imported electronic pianos in question be barred from entry into the United States pursuant to section 337 of the Tariff Act of 1930.

Section 337 of the Tariff Act of 1930 declares unlawful unfair methods of competition and unfair acts in the importation of articles into the United States, or in their sale by the owner, importer, consignee, or agent of either, the effect or tendency of which is (a) to destroy or substantially injure an efficiently and economically operated domestic industry, or (b) to prevent the establishment of such an industry, or (c) to restrain or monopolize trade and commerce in the United States. 1/

We have determined that the importation and sale of electronic pianos by Electrokey, Inc., et al., which are made in accordance with the claims in issue in U.S. Patent No. 3,038,363, have the effect or tendency to substantially injure an efficiently and economically operated domestic industry. There is domestic production under the claims in issue in this patent. The domestic industry in question, which consists of that portion of Wurlitzer's operations which is engaged in the domestic manufacture of electronic pianos covered by the claims in issue in U.S. Patent No. 3,038,363, 2/ is efficiently and economically operated, as is required by the statute.

With respect to the importation and sale of electronic pianos allegedly made in accordance with the claims in issue in

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1/ The effect or tendency of unfair practices to prevent the establishment of an efficiently and economically operated domestic industry or to restrain or monopolize trade and commerce is not at issue here.

2/ Wurlitzer is by assignment the owner of the U.S. Patent No. 3,038,363, which was issued on June 12, 1962. Wurlitzer has never granted a license to any party for production or sale of electronic pianos under this patent. This patent has been litigated before the U.S. District Court for the Northern District of Texas in The Wurlitzer Company v. Electrokey, Inc., et al. (C.A. No. 3-4803C) which held that the claims in issue in U.S. Patent No. 3,038,363 are valid and infringed. The decision of the court has been appealed to the fifth circuit.

U.S. Patent Nos. 2,942,512 and 2,949,053, and with respect to reeds in such electronic pianos allegedly made in accordance with U.S. Patent No. 3,154,997, we do not find a violation of section 337.

For the reasons hereinafter set forth, we do not recommend the issuance by the President of an exclusion order.

The Patents Which Are Determined Not To Involve a Violation of Section 337

In addressing ourselves initially to U.S. Patent No. 3,154,997 (relating to reeds used in electronic pianos) we note that the reeds employed in the imported electronic pianos have since August 1972 been of a noninfringing design. The issues relating to infringement of the claims in issue in this patent are now moot for an even more compelling reason--namely, that on November 14, 1974, the U.S. District Court for the Northern District of Texas entered its decision in The Wurlitzer Company v. Electrokey, Inc., et al. (C.A. No. 3-4803C), holding that all claims in issue in this patent were invalid.

Insofar as the claims in issue in U.S. Patent No. 2,949,053 are concerned, we agree with the holding of the court in the above case that there is no infringement of these claims by the imported electronic pianos. The substance of the invention in these claims is an electronic piano having a solid, integral, end-to-end pick-up structure that is designed to be built through the use of mass production techniques. However, the pick-up assembly in the imported electronic pianos is, as is indicated by the court, "comprised of many small parts that are assembled and adjusted by hand . . .". As a consequence, the imported electronic pianos do not follow the teachings in U.S. Patent No. 2,949,053 and, accordingly, we do not find any unfair methods of competition or unfair acts involving the claims in issue in this patent.

We do not find that there is domestic production under the claims in issue in U.S. Patent No. 2,942,512. The Wurlitzer pick-up structure is not one wherein the pick-up is "vibratorily passed by a longitudinally intermediate edge portion of the reed"--a requirement that is explicit in claims 1, 2, and 6 and implicit in claim 9. 1/ When properly construed in the light of the intended objectives of the patent, this language cannot be used to cover a structure where the pick-up is located not only at some longitudinally intermediate edge portion of the reed (i.e., the "nodal" point referred to in the patent) but also at the end of the reed. Since, in the domestic product, the pick-up is located not only at a longitudinally intermediate edge portion of the reed but also at the end of the reed, there is

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1/ Claims 1, 2, 6, and 9 are the only claims in issue in U.S. Patent No. 2,942,512.

no domestic exploitation of the patent in question for purposes of section 337. Accordingly, we find no violation of section 337 involving the claims in issue in this patent.

The Considerations Relating to U.S. Patent No. 3,038,363

Our determination is based upon a finding that the imported electronic pianos are the subject of unfair methods of competition and unfair acts by reason of their being made in accordance with the claims in issue in U.S. Patent No. 3,038,363. This determination rests largely on the decision of the court in The Wurlitzer Company v. Electrokey, Inc., et al. (C.A. No. 3-4803C) holding that all claims in issue in this patent are infringed by the imported electronic pianos. The unlicensed importation of such electronic pianos by Electrokey, Inc., et al. constitutes an unfair method of competition and an unfair act.

Although we recognize that the holding of the court with respect to the claims in issue in this patent is not necessarily controlling or binding on us, we would not take the position that the interpretation placed by the court on the claim coverage in this patent is untenable or clearly erroneous.

Taking independent claim 3 1/ as exemplary of the claims in issue in this patent, it must be accepted that the interpretation

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1/ See pp. A-10 through A-11 and A-25 through A-27.

of the coverage of this claim accorded by the court is a permissible one and that for purposes of the litigation is final unless reversed on appeal. When viewed in the light of the specification of the patent, the language in this claim may be susceptible to the interpretation, as was maintained by the court, that not only does it cover the mechanical aspect of the pick-up in the electronic piano but also, and more important, it covers the unitary integration of the whole pick-up assembly into one electrical circuit, which produces the cumulative capacitance disclosed in the patent. 1/ When so construed, this claim would cover the imported electronic pianos.

In our view, the public interest, as well as the interest of the parties before the Commission, would best be served if there were no conflicting interpretations of the same subject matter in two separate forums. This is particularly true in a situation where, as is the case here, one forum (the court) has already provided relief by way of an injunction prohibiting further sales of the imported electronic pianos by the respondents.

Having concluded that the infringement of the claims in issue in U.S. Patent No. 3,038,363 constitutes an unfair method of competition and an unfair act under section 337, we do not

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1/ Claim 3 covers an electronic piano which must have, among other things, "a single pick-up element for electrostatically sensing vibrations of a multiplicity of reeds, said pick-up element having a plurality of electrically conductive portions thereof . . . ."

recommend the issuance of an exclusion order. Our reasons are twofold. First, the interpretation placed upon the claim coverage in U.S. Patent No. 3,038,363 by the district court has been appealed to the fifth circuit. In our judgment, there is a likelihood that the claim coverage in this patent, when construed in the light of the prior art and the prosecution history of the patent, will be limited as a result of this appeal to a pick-up that is defined strictly in physical terms, i.e., a specific type and size of pick-up forming an electrically conductive metallic strip that is capable of sensing the vibrations of more than one reed. To have such capability, the pick-up must be constructed of, or coated with, an electrically conductive material. Since, by definition, such a pick-up would also be single electrically, it would be capable of producing the cumulative capacitance referred to in the patent. To consider the invention in the patent to consist of an electronic piano having a pick-up structure that is single electrically gives rise to serious questions of validity since virtually all known electronic pianos embody pick-up structures that are single electrically. In addition, the production of cumulative capacitance in electronic musical instruments is old in the art. The second reason for our not recommending the issuance of an exclusion order is the court injunction referred to above.

We do not see how the relief presently accorded to the complainant by this injunction would be improved materially by the issuance of an exclusion order. Such an order, under the circumstances of this case, would amount to an unnecessary additional remedy which would serve only as a burden to the U.S. Customs Service (and the U.S. taxpayer). Although we recognize that a court injunction operates in personam only against the parties before it and not in rem (as does an exclusion order), we do not believe that this consideration affects the case at hand, since all known importers of such electronic pianos were before the court and have been enjoined from further trading in these pianos.

STATEMENT OF COMMISSIONERS
LEONARD AND MINCHEW

We do not find unfair methods of competition or unfair acts in the importation into the United States, or in the sale by the owner, importer, consignee, or agent of either, of reeds for electronic pianos allegedly covered by the claims in issue in U.S. Patent No. 3,154,997, or of electronic pianos allegedly covered by the claims in issue in U.S. Patent Nos. 2,949,053, 2,942,512, and 3,038,363, the effect or tendency of which is to destroy or substantially injure an industry, efficiently and economicially operated, in the United States. We therefore conclude that there is no violation of section 337 of the Tariff Act of 1930 and recommend that the President not issue an exclusion order to forbid entry into the United States of such electronic pianos or of the reeds therefor.

U.S. Patent No. 3,154,997

In addressing ourselves first to U.S. Patent No. 3,154,997, we note that the reeds used in the imported product have since August 1972 had single radius fillets as opposed to curved inward tapers covered by the patent. If there ever was any infringement of the claims in this patent, such infringement ceased in August 1972, at which time any effect or tendency to substantially injure an industry also ceased to exist. Accordingly, the issues pertaining to the alleged infringement of the claims in U.S. Patent No. 3,154,997 (relating to a reed in electronic pianos) were moot long before the court held in The Wurlitzer Company v. Electrokey, Inc., et al. (C.A. No. 3-4803C) that all of the claims in this patent are invalid.

In view of the above, we find no violation of section 337 involving the claims in issue in this patent.

U.S. Patent No. 2,949,053

In turning next to U.S. Patent No. 2,949,053, we find that, although the domestic product is covered by the claims in issue (i.e., claims 1-4, inclusive) in U.S. Patent No. 2,949,053, the imported product is not covered by these claims. Accordingly, since the imported product is not infringing the claims of a U.S. patent, we do not find unfair methods of competition or unfair acts involving the claims in issue in this patent.

Claims 1-4, inclusive, in U.S. Patent No. 2,949,053 each cover an electronic piano having, among other things, "a pick-up member of comb-like configuration having a plurality of parallel teeth and an intermediary plurality of slots each opening at one end . . . ." When the coverage of these claims is properly construed in the light of the prior art, the specification, the drawings, and the file history of the patent, it will be seen that the substance of the invention in these claims is an electronic piano having a solid, integral, end to end pick-up structure that is designed to be built through the use of mass production techniques. The objective of this patent would, in our view, be met if the pick-up assembly in question was divided into four segments. The domestic product has four pick-ups stamped out by machinery so that each pick-up has the requisite comblike configuration, the requisite plurality of parallel teeth, and the requisite plurality of slots each opening at one end. The simplistic structure of the pick-up assembly in the domestic product indicates that it is covered by the claims in issue in this patent.

On the other hand, the pick-up assembly in the imported pianos is, as indicated by the court in The Wurlitzer Company v. Electrokey, Inc., et al. (C.A. No. 3-4803C), "comprised of many small parts that are assembled and adjusted by hand . . . ." As a consequence, the imported pianos do not follow the teachings in U.S. Patent No. 2,949,053, since, as the court put it, the substance of the invention in this patent is "a structure that can be built in simple operations by machinery whenever possible." On the basis of our concurrence with this view of the scope of the claim coverage in this patent, we agree with the court in its finding of noninfringement of the claim(s) in this patent by the imported pianos. In view of the state of the art known at the time of the invention, the only contribution that could have been made by C. W. Andersen (the inventor under this patent) concerns the mass-production feature referred to above, a feature that is present in the domestic pianos but conspicuously absent in the imported pianos.

U.S. Patent No. 2,942,512

We find that the claims in issue in the next patent under consideration i.e., U.S. Patent No. 2,942,512, cover neither the domestic nor the imported product.

The claims in issue in U.S. Patent No. 2,942,512 are claims 1, 2, 6, and 9. Claims 1, 2, and 6 each cover an electronic piano having, among other things, a pick-up structure wherein the pick-up is "vibratorily passed by a longitudinally intermediate edge portion of the reeds . . . ." This requirement is also implicit in claim 9.

To fully effectuate a basic objective of this patent (the elimination of undesirable inharmonics), the pick-up can be located only at some longitudinally intermediate edge portion of the reed (i.e., the "nodal" point referred to in the patent). The pick-up cannot be located also at the end of the reed, where the greater inharmonics generated toward the end of the reed would be detected. In the domestic and imported products, both the sides and the end of each reed are surrounded by the pick-up, thus destroying the above objective of the patent.

The court, in finding infringement of these claims in this patent in The Wurlitzer Company v. Electrokey, Inc., et al. (C.A. No. 3-4803C) placed greatest emphasis on its view that such a pick-up provides "a way of minimizing what is called dynamic shortening." The court dwelt at some length on precisely how this was accomplished in the disclosure of U.S. Patent No. 2,942,512. 1/

1/ The court states on p. 6 of its opinion that--

> . . . As a reed is struck by a hammer, the portion struck travels in the direction of the hammer strike faster than the rest of the reed and as a result has the effect of pulling the end of the reed away from the pick-up. This pulling away from the pick-up results in a large amplitude change that continues in time past the initial striking of the reed where in an acoustic piano, the amplitude is rapidly decreasing. A pick-up such as disclosed in Miessner '512 acts in relationship to a portion of the reed which is not dynamically shortened. This minimizes the effects of the shortening in relation to the total effect of the reed on the pick-up.

With all due respect to the court, we believe that a different interpretation of the claim coverage of this patent is in order. First, nowhere in the claims does the patent teach minimization of the effects of "dynamic shortening"; second, and most significantly, the inventor under this patent himself stated in the patent specification that he was not claiming a structure taking positive advantage of the dynamic shortening of the reeds, the same having been made in another patent application. 1/

The positive effect of dynamic shortening is the achievement of a "clang" tone (which is characteristic of the conventional piano tone) in electronic pianos. We conclude, by virtue of the above observations, that the existence of this tone in the imported electronic pianos proves just the reverse of the court's holding, i.e., it clearly establishes that the imported product does not embody the features claimed in this patent. Whatever was added to produce the "clang" tone in the imported product necessarily defeated one of the principal objects of the claims in issue in U.S. Patent No. 2,942,512, i.e., the elimination

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1/ In the specification of U.S. Patent No. 2,942,512, col. 15, lines 3-7, B.F. Miessner (the inventor) states:

> Furthermore, claims to a structure taking positive advantage of the dynamic shortening of the reed are not (emphasis supplied) made herein, the same having been presented in my copending application Serial No. 683,725, filed July 23, 1957.

of inharmonic tones.

In our view, the above considerations, had they been properly isolated and pursued in arguments before the court, might well have prompted the court to arrive at a different conclusion. As the record now stands before the Commission, however, it would be clearly erroneous for the Commission to base any finding of unfair methods of competition or unfair acts on the decision of the court. Accordingly, we do not find unfair methods of competition or unfair acts involving the claims in issue in U.S. Patent No. 2,942,512.

U.S. Patent No. 3,038,363

In our opinion, the imports do not fall under the claim coverage of any of the claims in issue in U.S. Patent No. 3,038,363, and, accordingly, we do not find that there are any unfair methods of competition or unfair acts.

Our views as to the coverage which may properly be accorded to the claims in issue in U.S. Patent No. 3,038,363 are set forth below.

All of the claims in issue in U.S. Patent No. 3,038,363 (i.e., claims 3-9, inclusive), whether explicitly or by way of strong implication, embody the requirements found in claim 3 for "a single (emphasis supplied) pick-up element for electrostatically sensing vibrations of a multiplicity of said reeds, said pick-up element having a plurality of electrically conductive portions thereof . . . ."

The quoted language is susceptible of at least three different interpretations: The "single pick-up element" could mean (1) a unitary, integral structure from a physical standpoint; 1/ (2) a structure that

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1/ Such a structure would, by its nature, also be single electrically.

is single from an electrical standpoint (irrespective of the physical structure); and (3) a structure wherein the particular interactions of the physical and electrical functions combine to produce a single, integrated, cumulative result.

The court essentially adopted this third interpretation in finding infringement of claims 3-9 by the imported pianos in The Wurlitzer Company v. Electrokey, Inc., et al. (C.A. No. 3-4803C). 1/ By adopting this interpretation, the court avoided the possible challenge of obviousness as to the first interpretation (i.e., since it is well known that a single mechanical pick-up may be used to sense the vibrations of a single reed, it would seemingly be obvious to have a single mechanical pick-up sense the vibrations of two (or more) reeds, depending on how much longer one would want the pick-up unit to be) and avoided having to deal with the issue of prior art which it would have confronted had it adopted the second interpretation. (Since the prior art reveals that almost all electrical systems in electromagnetic as well as electrostatic pianos are "single" electrically, there would have been no inventive contribution in this regard). It will be appreciated that, of the three, the last interpretation is most susceptible of indiscriminate application. The district court, in finding infringement of the claims in issue in this patent, placed greatest emphasis on its finding that the pick-up assembly in the imported product was "integrated into one electrical circuit . . . . This integration produces the cumulative

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1/ In support of its holding that the imported piano pick-ups (which are made up of many separate parts) infringed the claims in this patent, the court also indicated in its opinion that it "is a misreading of the [patent] disclosure" to contend "that in order for their [pick-up] structure to infringe this patent, it would have to be made of one solid piece." The court indicated that the patent disclosure covered "screws, arms, etc." which were associated with the pick-up structure in the invention. (We have, however, found no references to "arms" in the patent disclosure. We remain satisfied that the basic thrust of the claims in this patent, as revealed by the file wrapper, is simplicity in the pick-up structure and that the pick-up structure in the imported product does not meet this requirement.)

capacitance disclosed in another part of the claims as part of the invention." The invention in this patent, however, cannot be considered to consist of an electronic piano having a pick-up structure that is single electrically--virtually all known electronic pianos embody pick-up structures that are single electrically. Moreover, the prior art teaches that the production of cumulative capacitance is an inevitable consequence of electrostatic tone generation. We do not see that any useful contribution has been made merely because the concept of cumulative capacitance has been applied to an electronic piano.

The file history of the patent strongly suggests that the proper interpretation of the claim coverage in this patent is limited to the physical aspects of the pick-up. As set forth in the file history, the pick-up claimed was different from all other pick-up structures theretofore known in the art because it comprised a single pick-up which sensed the vibrations of more than one reed and not the vibrations of just one reed. 1/ When the patent specification is properly narrowed to reflect what was allowed after 12 years of prosecution of this patent before the U.S. Patent Office, it will be seen that the patent specification supports the interpretation that the claim coverage in U.S. Patent No. 3,038,363 is limited to the physical aspects of the pick-up. Magnetic-type tone generators, optical-type tone generators, and electrostatic-type tone generators (employing a single pick-up corresponding to a single reed), while still described in the patent specification, were all relinquished by the patentee during the prosecution of this patent. Insofar as they relate to the tone generator structure, the claims, as finally allowed,

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1/ As previously noted, the claimed pick-up structure would, by its nature, also be single electrically.

are supported only by that portion of the specification directed to figures 18 through 21 and figures 26 through 28 in the patent drawings. These figures, in our view, depict the only novel feature in U.S. Patent No. 3,038,363--a simply designed tone generator assembly for use in an electronic piano comprising a pick-up and reeds wherein the pick-up consists of one continuous strip of electrically conductive metal positioned so that it can sense the vibrations of more than one reed. It is this physical characteristic of the pick-up that distinguishes the tone generator described in U.S. Patent No. 3,038,363 from those disclosed in the prior art.

The other elements of the claims in issue, i.e., the key-action assembly and amplifier-speaker assembly, are supported by other corresponding portions of the patent specification. None of these other elements, whether considered together or singly, can be considered to be the invention claimed under U.S. Patent No. 3,038,363.

Our above-stated views of the proper coverage which may be accorded to the claims in issue in U.S. Patent No. 3,038,363 are also grounded in what is disclosed by the prior art. Each of the elements of this patent (with the exception of the specific nature of the pick-up in the tone generator assembly) are old in the art. The key-action assembly required by the claims (which initially sets the reeds in vibration) is clearly modeled after and operates on the same principles as the key-action assembly found in a standard piano. This type of assembly has been in use in pianos for a number of centuries and, accordingly, cannot be protected by the patent. The amplifier-speaker assembly required by the claims in issue involves no more than the art and expertise utilized since about 1923 in other electronic fields, particularly in the radio, television, and phonograph amplifier arts. The amplifier-speaker assembly cannot therefore be protected by the patent. Insofar as the tone generator assembly required by the claims in this patent is concerned, we note that reeds were first used in musical instruments near the turn of the 18th century and that the applications of electrical devices to sense the vibrations of such reeds in electronic pianos culminated in the 1930's and 1940's in the earlier electronic pianos developed and patented by B. F. Miessner (the inventor under U.S. Patent No. 3,038,363), the patents for which have now expired.

With the exception of the particular nature of the pick-up member described in the heretofore-referred-to portions of the specification of U.S. Patent No. 3,038,363, all of the specifics of the tone generator disclosed in the patent are found in the prior art, either by identical embodiment or by equivalence.

We note that a patent reference before the Commission, i.e., U.S. Patent No. 2,532,038, discloses a capacitive tone generator assembly for use in an electronic piano wherein a single elongated wire is used as a pick-up means for a plurality of vibrating tuning forks (or plates) having a common electrical connection. 1/ This reference reinforces our conclusion that the only novel feature in U.S. Patent No. 3,038,363

1/ Specification of U.S. Patent No. 2,532,038, fig. 11 (H and K). In our view, one who is skilled in the art could easily substitute reeds for tuning forks (or plates). See specification of U.S. Patent No. 2,487,420, col. 3, lines 68-75, where it is indicated that, in an electro-acoustical musical instrument (including an electronic piano), a reed may be substituted for a tuning fork.

centers on the particular nature of the pick-up. In view of this reference, the single pick-up in the tone generator assembly disclosed in U.S. Patent No. 3,038,363 cannot consist of an elongated wire; it must consist of something more than a wire and still be electrically conductive. 1/ As previously stated, such a pick-up consists of a continuous strip of electrically conductive metal positioned so that it would sense the vibrations of more than one reed.

We recognize that the claims in issue in U.S. Patent No. 3,038,363 are combination claims and that all of the elements in each claim must be looked at in terms of their interaction with one another in arriving at the proper interpretation of the scope of the coverage in each claim. In this connection, we note that when the patentee first presented claims in this patent to the U.S. Patent Office for approval (which claims then included all of the elements of the claims in issue except for the requirement that there be a single pick-up for electrostatically sensing the vibrations of more than one reed), the claims were disallowed on the ground that the claimed combination would be specifically unpatentable over two patent references cited by that office, i.e., U.S. Patent No. 2,510,094 and U.S. Patent No. 2,581,963. 2/ It was only after the patentee had amended his claims to provide for the pick-up of the type described above that the U.S. Patent Office allowed the claims. In our view, any novelty in the combination as presently covered by the claims in issue in this patent is directly traceable to and remains confined to the specific nature of the pick-up found

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1/ The tone generator assembly referred to above as disclosed by U.S. Patent No. 2,532,038 would be electrically equivalent in every way to the tone generator structure disclosed in U.S. Patent No. 3,038,363. As such, it would produce the same cumulative capacitance.

2/ File history of U.S. Patent No. 3,038,363.

in the tone generator assembly; any interaction of this type of pick-up with the other elements required in these claims would be no different from the interaction of the various elements in the claims as originally submitted, which, as noted above, were found to be unpatentable by the U.S. Patent Office.

By virtue of the reasons set forth above, we find that the rationale for the court's holding of infringement of the claims in issue in U.S. Patent No. 3,038,363 is erroneous. We do not feel that the claim coverage in this patent may properly be extended to cover the imported product. When properly construed in the light of the file history of the patent, the patent specification and drawings, and the prior art, the claim coverage in this patent, in our view, is directed to an electronic piano wherein the novel feature consists of a one-piece, continuous, electrically conductive strip of metal positioned so that it can sense the vibrations of a multiplicity of reeds. 1/ As so construed, the claim coverage does not encompass the imported product, since the pick-ups in this product, from a physical standpoint, each comprise a multiplicity of parts which, when fastened together, correspond with and sense the vibrations of only one reed. The pick-ups, as so structured, are spaced independently of each other and are mounted to a common support bar by screws. Other screws allow the individual pick-ups to be adjusted with respect to the reeds with which they cooperate, thus allowing for adjustment in tone and volume. In this connection, it is instructive to note that the imported product would clearly have fallen under the claim coverage of the claims as

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1/ As previously noted, such a pick-up would, by its nature, be single electrically.

originally submitted by the patentee to the U.S. Patent Office in Patent Application Serial No. 799,897 (filed March 17, 1959); these claims, as noted above, were disallowed.

In light of the foregoing, we make no finding of unfair methods or unfair acts on the basis of infringement of the claims in issue in this patent.

In our view, the effect of the court decision, holding that the claims in issue in this patent are infringed by the imported electronic pianos, can only be properly evaluated by reference to section 337 itself. Subsection (a) of section 337 provides in part that unlawful methods of competition and unlawful acts, when found to exist shall be dealt with "in addition to any other provisions of law . . . ."

The court, in dealing with the case at hand, implemented one of the "other provisions of law" (i.e., the patent laws under 35 U.S.C.). It is still left to the Commission to pursue its investigation in an effort to determine whether section 337 has been violated. The remedy provided by an exclusion order applies in rem to all U.S. imports of a product instead of in personam to a select importer or a select number of importers situated in a particular geographic district. The considerations motivating the Commission in finding unfair methods of competition or unfair acts under section 337 will of necessity at times be different from those which prompt a court to hold that the claims in issue in a patent have been infringed. The Commission adapts patent law to the specialized circumstances of foreign trade to effectuate the purposes of section 337; unlike a court of law, the Commission has no mandate to enforce patent law and, indeed, would be exceeding its statutory authority if it attempted to do so.

The decision of the court in the case at hand should therefore be viewed, not in terms of having some kind of imagined binding effect on the Commission nor in terms of an opinion which must in some way be given credence in the Commission's finding, but rather in terms of what it actually is--an opinion relating to a given set of facts with which the Commission, given sufficient justification, may agree or disagree, whether in whole or in part.

In the case at hand, the court's decision, holding that the claims in issue in U.S. Patent No. 3,038,363 are infringed by the imported products, if followed, would result in our giving an unwarranted extension to the claim coverage of this patent by according the patentee a monopoly to which he is not entitled. By following the court's rationale, we would in effect be finding that virtually all electronic pianos having electrostatic pick-ups are covered by the claims in issue in this patent. On the basis of the file history of this patent and the relevant prior art, we feel that the U.S. Patent Office did not allow any claims having the scope accorded them by the court.

Conclusion

In view of our finding that (1) the reeds for electronic pianos allegedly covered by the claims in issue in U.S. Patent No. 3,154,997 do not have the effect or tendency to substantially injure an industry, efficiently and economically operated, in the United States, and (2) there are no unfair methods of competition or unfair acts involving electronic pianos allegedly covered by the claims in issue in U.S. Patent Nos. 2,949,053, 2,942,512, and 3,038,363, we conclude that there is no violation of section 337.

STATEMENT OF COMMISSIONER MOORE 1/

On March 6, 1972, a complaint was filed with the U.S. Tariff Commission by The Wurlitzer Co. of Chicago, Ill., under section 337 of the Tariff Act of 1930. A supplemental complaint was filed by Wurlitzer with the Commission on August 2, 1972. Wurlitzer (hereinafter referred to as complainant) requested that the Commission recommend to the President that certain imported electronic pianos be excluded from entry into the United States.

Section 337 of the Tariff Act of 1930 declares to be unlawful unfair methods of competition and unfair acts in the importation of articles into the United States, or in their sale by the owner, importer, consignee, or agent of either, the effect or tendency of which is

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1/ Commissioner Ablondi concurs with the recommendation. In his opinion, based upon all the facts adduced in this investigation, there is a violation of sec. 337 of the Tariff Act of 1930. He has considered the judicial determination of similar factual and legal issues rendered by the U.S. district court in The Wurlitzer Company v. Electrokey, Inc., et al. (C.A. No. 3-4803C). An orderly process of justice requires that the same issues between the same parties decided by one authority should not, under ordinary circumstances, be contravened by another authority. The public and the parties to a Commission investigation would expect that the same subject matter should not be subject to differing interpretations in separate forums.

Despite the court order in The Wurlitzer Company v. Electrokey, Inc., et al. enjoining further sales of the electronic pianos by Electrokey, Inc., injunctive relief should not be considered to be dispositive of the injury issue presented under the statute. Subsec. (a) of sec. 337 expressly provides, in part, that the unfair methods of competition and unfair acts shall be dealt with "in addition to any other provisions of law . . . ." Having found a violation of sec. 337, the additional remedy expressly provided for by sec. 337 (i.e., exclusion) would operate in rem to exclude, for the remaining term of U.S. Patent No. 3,038,363, all imports of electronic pianos which are covered by the claims in issue of the patent. This relief to which the complainant is entitled is broader in scope and intended to exclude from entry all infringing articles.

(a) to destroy or substantially injure an efficiently and economically operated domestic industry, or (b) to prevent the establishment of such an industry, or (c) to restrain or monoplize trade and commerce in the United States. 1/

I determine that there is a violation of section 337. My determination is based upon a finding of unfair methods of competition or unfair acts within the meaning of section 337 in the unlicensed importation and sale of certain electronic pianos by reason of their being covered by claims 3 through 9 (inclusive) in U.S. Patent No. 3,038,363. This determination is supported by the decision of the U.S. District Court for the Northern District of Texas entered on November 14, 1974 in The Wurlitzer Company v. Electrokey, Inc., et al. (C.A. No. 3-4803C), in which the court held that the claims in issue in this patent were infringed by these imports.

In view of my determination involving the claims in issue in U.S. Patent No. 3,038,363, I do not find it necessary to consider the claims in issue in U.S. Patent Nos. 2,942,512, 2,949,053, or

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1/ The effect or tendency of unfair practices to prevent the establishment of an efficiently and economically operated domestic industry or to restrain or monopolize trade and commerce is not in issue here.

3,154,997, the infringements of which are also alleged by complainant as constituting unfair methods of competition and unfair acts under section 337. 1/

The Domestic Industry Concerned

The domestic industry which I have considered herein consists of that portion of complainant's operations which are engaged in the domestic manufacture of elecronic pianos covered by the claims in issue in U.S. Patent No. 3,038,363. Complainant is by assignment the owner of U.S. Patent No. 3,038,363, which was issued on June 12, 1962. Complainant has not granted a license to any party for production or sale of electronic pianos under this patent. This patent has been litigated before the U.S. District Court for the Northern District of Texas in The Wurlitzer Company v. Electrokey, Inc., et al. (C.A. No. 3-4803C), where it was held that the claims in this patent were valid and infringed.

The investigation discloses that the operations of complainant are efficiently and economically operated. Complainant uses modern and efficient manufacturing equipment in a modern, up-to-date facility situated in Logan, Utah.

1/ The court held in The Wurlitzer Company v. Electrokey, Inc., et al. (C.A. No. 3-4803C) that the claims in issue in U.S. Patent No. 2,942,512 were infringed by these imports, that the claims in issue in U.S. Patent No. 2,949,053 were not infringed, and that the claims in issue in U.S. Patent No. 3,154,997 were invalid.

The Domestic Product (U.S. Patent No. 3,038,363)

The complainant manufactures an electronic piano having an electrostatic tone generator assembly comprising a plurality of reeds and pick-ups. One model of this piano, the Wurlitzer Model 200, resembles a portable chord organ in outward appearance. The remaining models resemble string-type spinet pianos, but are generally smaller and lighter.

All models of electronic pianos currently manufactured by the complainant (i.e., the Model 200, the Model 203W, the Model 214, the Model 206 and the Model 207) embody the same type of pick-ups in their tone generators. These pick-ups (when properly charged with the designated electrical voltage) electrostatically sense the vibrations of reeds set in motion by key-actuated hammers and produce electronic signals which, when amplified electrically, result in a tone closely resembling that of a conventional string piano. The parts necessary to accomplish this tone are (1) electrically conductive pick-ups (the domestic product has four separate stamped-out aluminum metal strips placed end to end which serve as pick-ups; each strip has small cutout portions on one side to accommodate the insertion of different-sized reeds); (2) a plurality of electrically conductive reeds sized to vibrate within each cutout portion of the pick-ups without coming into physical contact with the pick-ups (the reeds are larger for the lower notes and smaller for the higher notes); (3) a means for striking each reed (this consists of the key-actuated hammer); (4) common electrical connecting means for all pick-ups (the pick-ups are connected by electrically conductive straps); (5) common electrical connecting means for all reeds (there is a common electrically conductive mounting base for the reeds); (6) an electrical amplifier means (which is electrically connected to one pick-up by a wire and situated close to the tone generator assembly); and (7) one or more speakers (the speakers face out to the front of the instrument, one on each end of the piano).

The pick-ups and their constituent reeds are all substantially in the same plane. Each free reed end is surrounded by a cutout portion of the pick-up corresponding in size and is slightly offset from a position of effective alinement with the pick-up when the reed is in its rest position. On that end of each reed, facing away from the respective cutout portion of the pick-up, there is a lead weight to achieve the desired reed oscilation for each note. This lead weight is generally filed down when the piano is "tuned". Once in place, however, the tuned reeds are securely fastened to a common support bar where they are expected to remain undisturbed for years. The pick-ups themselves are not susceptible to adjustment.

The electrical signals created by the tone generator are fed into an electrical amplifier means which is housed in the body of the domestic product near the tone generator assembly. Thereafter, the amplified signals are converted into sound by one or more speakers affixed inside the front portion of the piano body. A volume control is located within easy access of the keyboard.

The entire assembly in each model of the domestic product is generally delivered to the ultimate consumer in a single carton. Each unit is expected to be completely operable upon delivery.

The Imported Product

The imported product, which complainant alleges infringes the claims in issue in U.S. Patent No. 3,038,363 (and the importation and sale of which has allegedly resulted in injury to the complainant in violation of sec. 337), like all models of the domestic product except the Wurlitzer Model 200, resembles a string-type spinet piano in outward appearance, but is generally smaller and lighter.

With the exception of the physical structure and spacing of the pick-ups, the tone generator assembly in the imported product appears to be virtually identical to that of the domestic product described above. The tone generator assembly in the imported product, like that of the domestic product, electrostatically senses the vibrations of its constituent reeds, which are excited by key-actuated hammers.

The resulting electrical signals are amplified by an electrical amplifier means and are converted into sound by one or more speakers. As with the domestic product, the imported product is self contained, needing only electrical current to make it operative. The imported product enters U.S. ports and is delivered to the importers' customers, like the domestic product, in a single carton.

Instead of four separate strips of stamped-out aluminum, each having cutout portions to accommodate the free, vibrating ends of the reeds, each pick-up in the tone generator assembly of the imported product is made up of a multiplicity of parts including, among other things, an element having two pick-up plates designed to accommodate one reed. When finally assembled and fastened, the pick-up plates corresponding to each reed vary considerably in their respective angles to each other, in their angles to each of their corresponding reeds, and in their angles to the plates of the other pick-ups. Manually adjustable screws which, upon assembly in the factory, are initially held in place by a small amount of paint, are found with each pick-up and allow for easy future adjustment in the spacing of each pair of pick-up plates, thereby providing for changes in the volume and in the tonal characteristics of each note produced.

Notwithstanding the above physical differences in the structure and spacing of the pick-ups in the tone generator assemblies found in the imported and domestic products, both perform the function of producing a simulated pianistic tone through changes in the electrocapacitive relation between the pick-ups and the reeds.

The Patent In Question

The domestic product described above is made in accordance with the claims in issue in U.S. Patent No. 3,038,363. I find that the imported product described above is also covered by the claims in issue in this patent.

Taking independent claim 3 1/ as exemplary of the claims in issue in this patent, it is noted that this claim covers an electronic piano which must have, among other things, "a single pick-up element for electrostatically sensing vibrations of a multiplicity of said reeds, said pick-up element having a plurality of electrically conductive portions thereof . . . ." When viewed in the light of the specification of the patent, this language can be interpreted, as was maintained by the court, to cover not just the mechanical aspect of the pick-up in the electronic piano but, more important, also the unitary integration of the whole pick-up assembly into one electrical circuit, which produces the cumulative capacitance disclosed in the patent. When so interpreted, claim 3 covers both the domestic and imported products, since the pick-ups in each are integrated into one electrical circuit to produce such cumulative capacitance.

1/ See pp. A-10 through A-11 and A-25 through A-27.

In The Wurlitzer Company v. Electrokey, Inc., et al. (C.A. No. 3-4803C), the court indicated in its opinion that the remaining claims in issue in U.S. Patent No. 3,038,363 (i.e., claims 4 through 9) required certain additional elements that were met by the imported product. I agree with the court's interpretation of the claim coverage of each of these claims.

The Unfair Method of Competition or Unfair Act in the Importation of the Patented Product

The imported electronic pianos covered by the claims in issue in U.S. Patent No. 3,038,363 are imported and sold without license. The Commission has long held, in making recommendations to the President under section 337, that the unlicensed importation of a product which is patented in the United States is an unfair method of competition or unfair act within the meaning of section 337. 1/

I conclude that there are unfair methods of competition or unfair acts insofar as concerns the claims in issue in U.S. Patent No. 3,038,363.

Effect or Tendency to Injure

The evidence submitted to the Commission shows conclusively that imports of the electronic pianos under investigation have

1/ See In re Von Clemm, 43 C.C.P.A. (Customs) 56, 229 F. 2d 441, 443 (1955); In re Orion Co., 22 C.C.P.A. (Customs) 149, 71 F. 2d 458, 465 (1934); In re Northern Pigment Co., 22 C.C.P.A. (Customs) 166, 71 F. 2d 447, 455 (1934); and Frischer & Co. v. Bakelite Corp., 17 C.C.P.A. (Customs) 494, 39 F. 2d 247, 260, cert. den. 282 U.S. 852 (1930). See also U.S. Tariff Commission, Convertible Game Tables and Components Thereof . . ., TC Publication 705, 1974; Panty Hose . . ., TC Publication 471, 1972; Lightweight Luggage . . ., TC Publication 463, 1972; and Articles Comprised of Plastic Sheets Having an Open Work Structure . . ., TC Publication 444, 1971.

the effect or tendency to substantially injure an industry, efficiently and economically operated, in the United States.

Imports of these electronic pianos achieved a significant share of the U.S. market in 1972. Each sale of the imported product represented lost royalties to complainant. The imports displaced sales which otherwise would have gone to the domestic producer. In view of the adverse effect of these imports on the domestic industry (as defined above), I have concluded that such imports have the "effect or tendency . . ." to substantially injure such domestic industry.

In The Wurlitzer Company v. Electrokey, Inc., et al. (C.A. No. 3-4803C), the court enjoined further sales of these imports. However, the injunction only applies to the parties before the court--it does not apply in rem to all importers of electronic pianos, as would the remedy recommended herein. Other importers may still import and sell these electronic pianos in the United States in the absence of action by the Commission.

While it is true that imports of these electronic pianos virtually ceased prior to the date the court entered its injunction, I am not convinced that this decrease in imports was more than temporary pending the outcome of the litigation in the Federal courts and the Commission's determination in these proceedings. The evidence fails to reveal convincing economic reasons which would suggest that a foreign manufacturer of these electronic pianos would permanently refrain from importing the infringing pianos for sale in the United States.

Recommendation

Based on the foregoing, I recommend that, in accordance with subsection (e) of section 337, the President issue an exclusion order to forbid entry into the United States of electronic pianos covered by the claim(s) in U.S. Patent No. 3,038,363, until expiration of the patent, except under license of the owner of U.S. Patent No. 3,038,363.

EVIDENCE OBTAINED IN THE INVESTIGATION

Description of Articles Under Investigation

An electronic piano like the conventional piano, has key-actuated hammers, but the tone is picked up and amplified electrically, dispensing with the need for plate and soundboard. Although the tone of the electronic piano does not altogether match the tone of the conventional piano in quality, it has the advantage of being less expensive, lighter, smaller, and less affected by atmospheric conditions than the conventional piano, and, unlike the conventional piano, it has the further advantage of being suitable for silent practice. It is particularly valued as a teaching instrument in group instruction. Through headphones, the student can hear his own playing without disturbing others. Individual pianos can be connected to a console unit through which, by means of switching devices and a headphone, the teacher can monitor each student's performance. Systems utilizing any of several models of the Wurlitzer piano (the product manufactured by the complainant), or the imported piano which is the subject of the complaint, can accommodate up to 24 students through such an arrangement.

The Wurlitzer electronic piano has a keyboard and working parts in a case 19 inches deep and less than a foot high. Two-thirds of the Wurlitzer electronic pianos sold are mounted on detachable steel legs and weigh only about 60 pounds; the others are designed to resemble a small spinet and weigh 115 to 130 pounds (see fig. 1). Unlike most standard pianos, which contain an 88-note keyboard, they all contain a 64-note keyboard (except for one model containing a 44-note keyboard, which accounts for a very small proportion of the number sold).

The allegedly infringing imported piano, sold by Electrokey, Inc., and until mid-1974 (under the trade name Maestro) by the Chicago Musical Instrument Co., consists of a single model resembling a small spinet (fig. 2). It has a 61-note keyboard and weighs 95 pounds.

The key-actuated hammers in both the Electrokey and Wurlitzer pianos strike metal reeds charged with a direct current. The vibration of the reed produces oscillations in the current entering the pick-up portions in capacitive relationship with the reed. The reeds in the Wurlitzer piano are horizontal and are struck from beneath, while those in the Electrokey piano are vertical and are struck from the front. Further, there are some differences in the pick-up portions of the two pianos. (See exhibit A, p. A-20, for a general illustration of the Electrokey pick-up portion, and exhibit B, p. A-21, for an illustration of the Wurlitzer pick-up portion. Both illustrations also show the general relationship of the pick-up portions to the respective reeds.)

The Electrokey and the Wurlitzer are not the only electronic pianos on the market today. Other electronic pianos are the Baldwin 1/ (fig. 3) and the Rhodes 2/ (fig. 4), both produced in the United States, and two imported kinds, the Farfisa (fig. 5), manufactured in Italy, and the Hohner (fig. 6), manufactured in West Germany. The manufacture of the Hohner piano was discontinued in 1971. These other electronic pianos do not have electrostatic pick-ups, but rather have electromagnetic pick-ups.

1/ Manufactured by Baldwin [illegible] subsidiary of [illegible] Baldwin, Inc.

2/ Referred to al[illegible] as Fend[illegible] [illegible]red by the CBS Musical Instruments Division of CBS, [illegible]

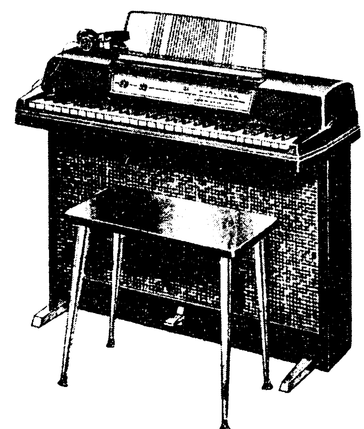
Figure 1

WURLITZER® ELECTRONIC PIANOS

Service Manual

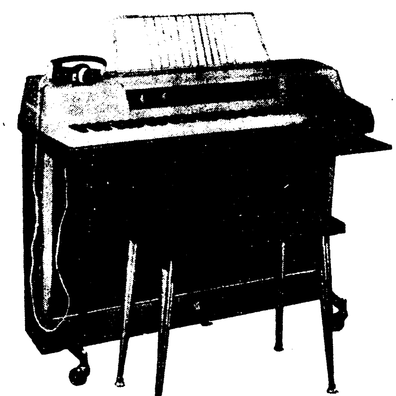
MODELS 200 • 203* • 203W • 206 • 207 • 214

Model 200



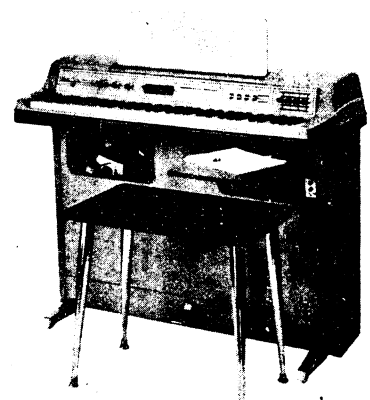
Model 203

Model 203W



Model 214

Model 206



Model 207

THE WURLITZER COMPANY - DEKALB, ILLINOIS 60115

* Discontinued model.

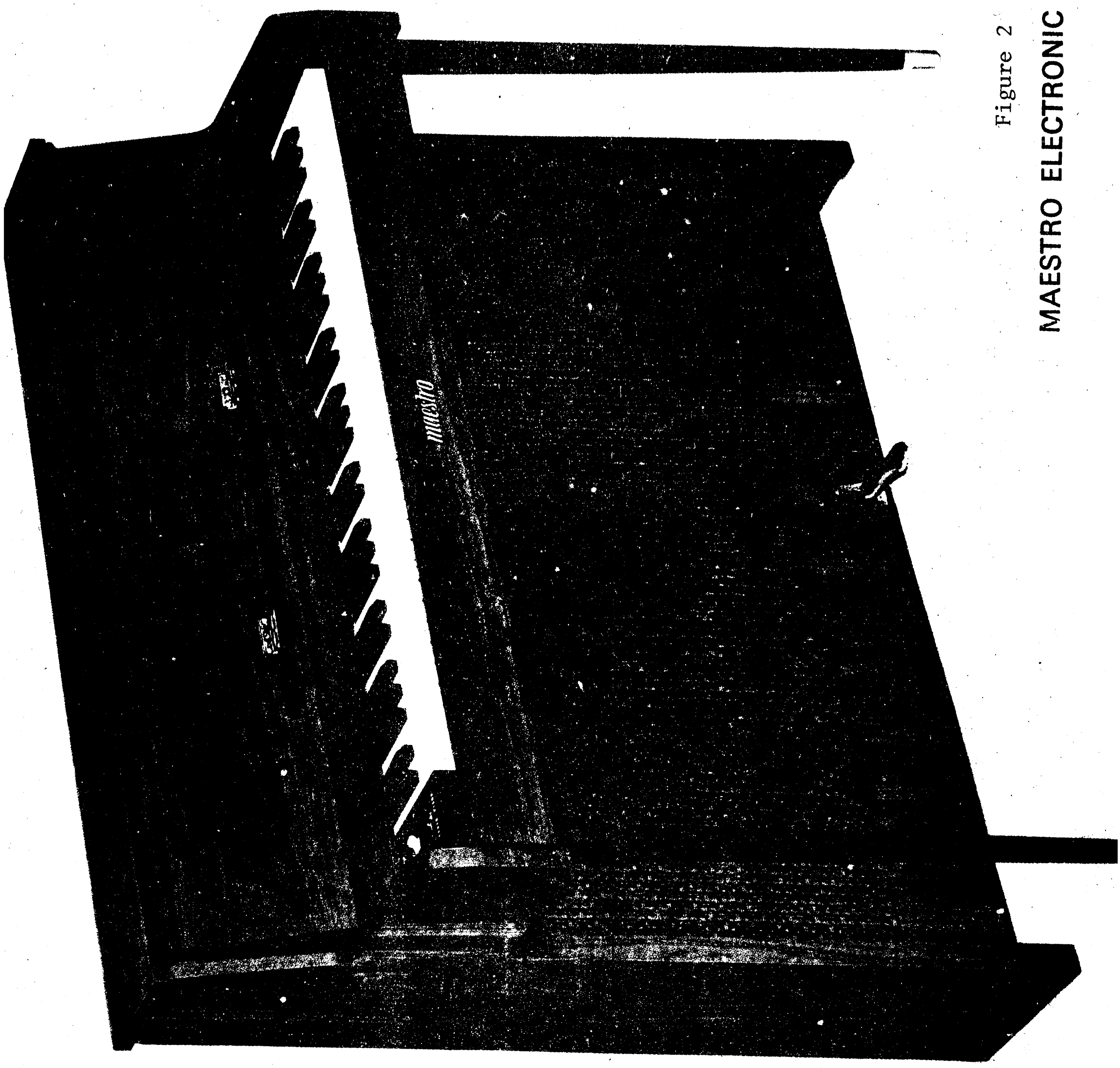


Figure 2

MAESTRO ELECTRONIC PIANO (MEP)

Figure 3.--Baldwin Electropiano

Figure 4

Rhodes
KEYBOARD INSTRUMENTS

Electronic Keyboard Classroom Instruction System

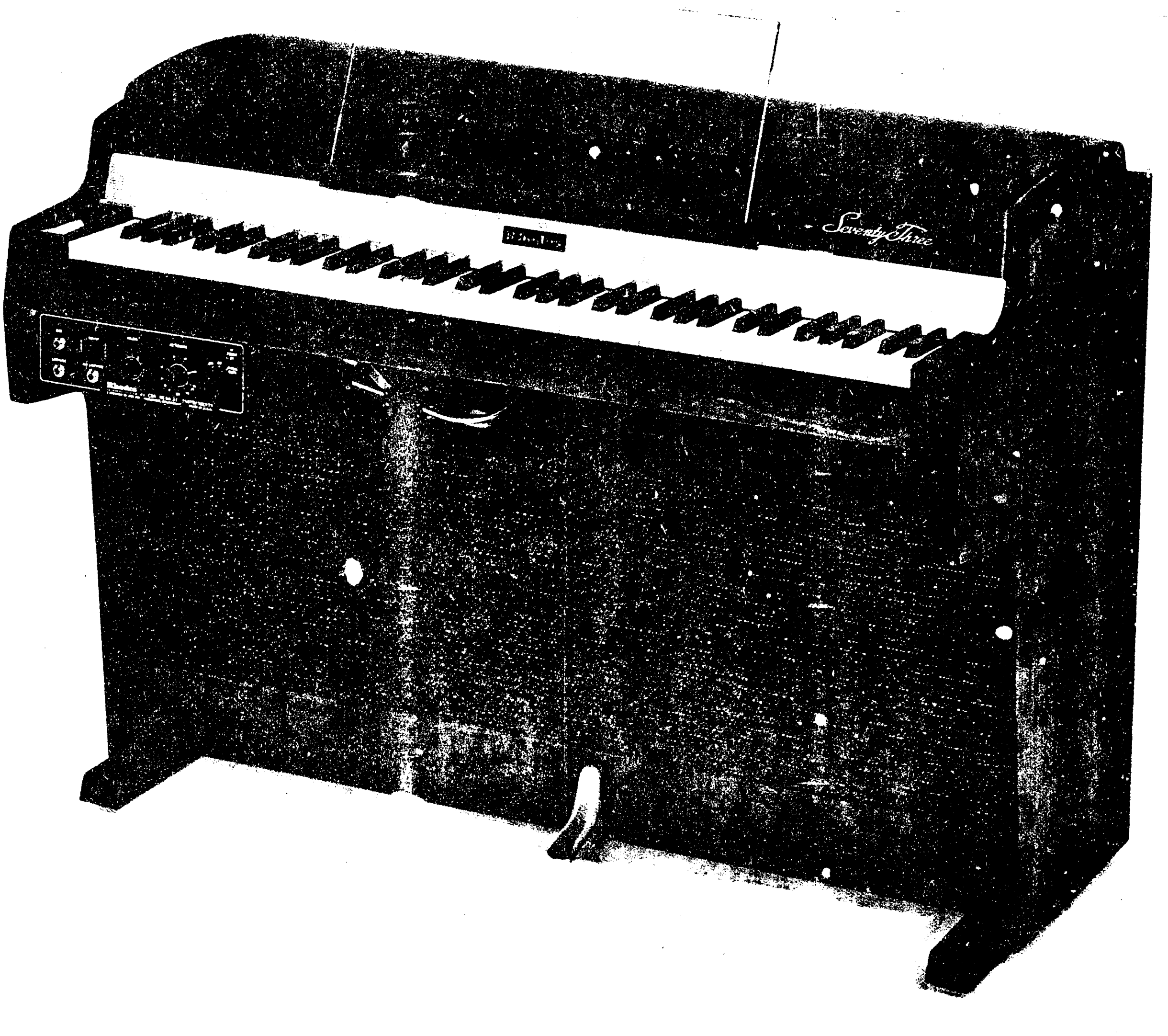


Figure 5.--Farfisa Professional Pianos.

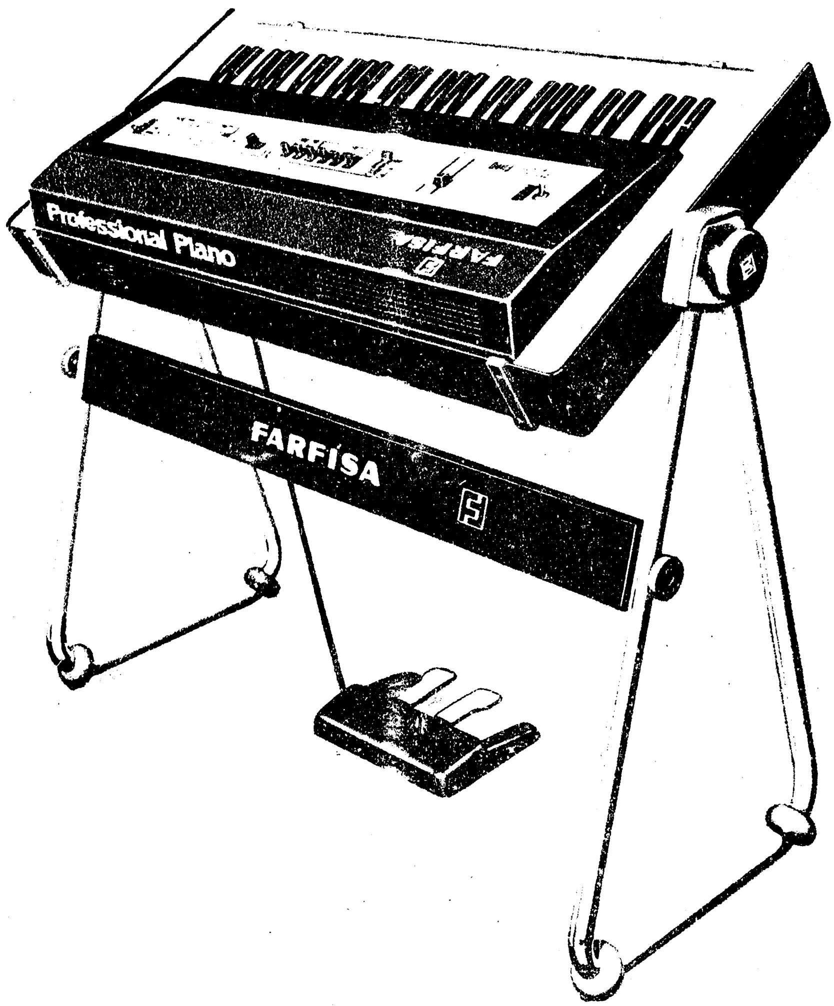
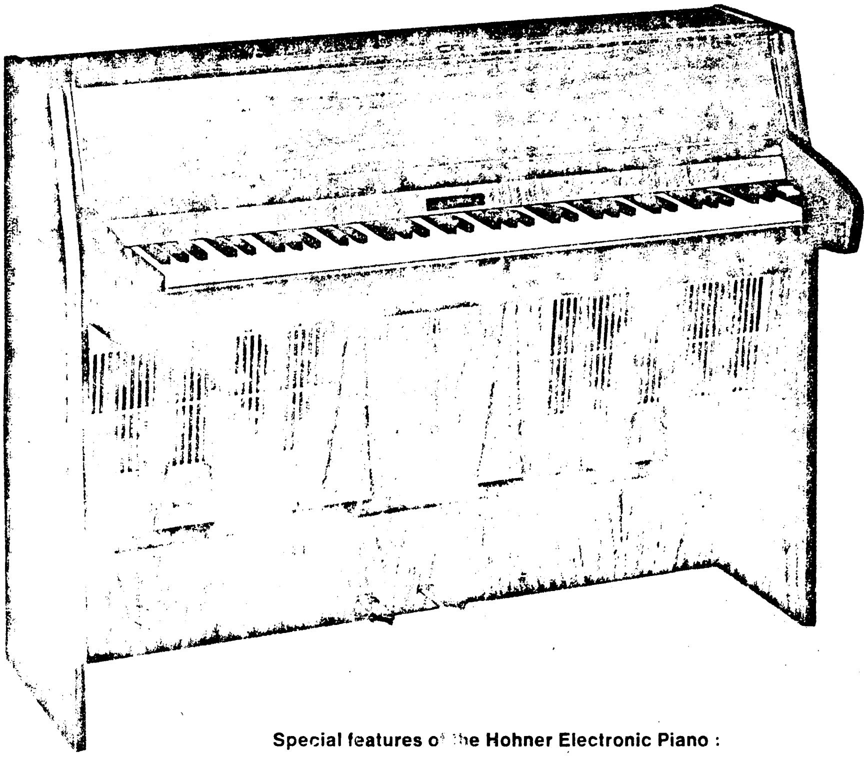


Figure 6

HOHNER ELECTRONIC PIANO



Traditional in form... New in Technology

Outwardly like a conventional piano, this new electro-mechanical keyboard instrument uses special forks which are struck by hammers in a highly sophisticated form of piano action. These forks (which are tuned for life) transmit electronically converted vibrations through a built-in fully transistorized amplifier with four loudspeakers (approx. output 20 watts).

Special features of the Hohner Electronic Piano :

Piano tone The tonal character is remarkably similar to the piano.

Keeps in Tune Because tuning f s provide the tone source.

Dynamic response Keyboard touch ntrols volume and provides precise dynamic modulation throughout, facilitated by the sy keyboard action.

Tone control Results from the e of two pedals.
left: damper pedal
right: sustain pedal

Wide Tone range The volume regulator enables the instrument to be set to suit the ze of any room.

Basic volume therefore adjusts to individual requirements.

For large premises, a connection for a second amplifier with additional speaker is provided.

There is also an earphone connection for "silent playing," which makes the Electronic Piano an ideal practice instrument.

Versatility The Electronic Piano is equally at home with all types of music and is thus ideally suited for the home, school, teaching or professional use.

Modern Design Attractive styling • neutral and compact designing • available in carefully matched walnut veneers supplemented with hardwood solids.

Easily transportable The compact design and comparatively low weight makes the Hohner Electronic Piano an easily transportable instrument.

SPECIFICATIONS

- 72 Standard size piano keys
- Tone range F-e '''' six octaves
- Two pedals — damper and sustain
- External jacks for earphones and extra amplifier
- Volume control
- On/off switch with pilot light
- Voltage selector for 110/125/150/220/240 V AC
- Cabinet is of a rich walnut veneer finish
- Lock and key on keyboard cover
- Four high quality speakers
- Weight approx. 148 lbs.
- Dimensions approx. 35" high, 46" long, 18" deep

Technical modifications reserved

Home Office: Andrews Road, Hicksville, New York 11802 / (516) 935-8500
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West Coast: 790 San Antonio Road, Palo Alto, California 94303 / (415) 326-9903

Printed in U.S.A. / For

Alleged Unfair Methods of Competition and Unfair Acts

The patents in question

Complainant alleged unfair methods of competition and unfair acts in the importation or sales of electronic pianos (1) made in accordance with its U.S. Patent Nos. 3,038,363, 2,942,512 and 2,949,053, or (2) which contain certain reeds made in accordance with its U.S. Patent No. 3,154,997, or (3) which strongly resemble complainant's products in appearance. 1/

The patents which are the subjects of the unfair methods and unfair acts alleged by complainant are U.S. Patent Nos. 3,038,363, 2/ which issued June 12, 1962, to B. F. Miessner; 2,942,512, 3/ which issued June 28, 1960, to B. F. Miessner; 2,949,053, 4/ which issued August 16, 1960, to C. W. Andersen; and 3,154,997, 5/ which issued November 3, 1964, to H. E. W. Bode. Complainant obtained all rights in these patents by assignment.

The patents expire 17 years from their date of issuance. 6/ Accordingly, the respective expiration dates of the patents are as follows:

	Patent No.	Expiration date
Miessner	3,038,363	June 12, 1979
Miessner	2,942,512	June 28, 1977
Andersen	2,949,053	Aug. 16, 1977
Bode	3,154,997	Nov. 3, 1981

1/ As will be seen infra, this allegation appears to refer to "copying."
2/ Reproduced in app. A.
3/ Reproduced in app. B.
4/ Reproduced in app. C.
5/ Reproduced in app. D.
6/ The term of such patents is provided for in 35 U.S.C. 154.

Complainant contends that it has examined the imported electronic pianos and has found them to be made in accordance with the following claims of the above-listed patents:

Miessner	Patent No. 3,038,363	-- Claims 3-9
Miessner	Patent No. 2,942,512	-- Claims 1, 2, 6, and 9
Andersen	Patent No. 2,949,053	-- Claims 1-4
Bode	Patent No. 3,154,997	-- Claims 1-6

All the patents in question are product patents issued pursuant to the provisions of 35 U.S.C. 101. 1/ The item sought to be patented in each patent must be (1) novel and (2) useful to satisfy the requirements of the statute.

Following is a list of the pertinent claims of the patents in issue, with the essential elements 2/ in each claim being preceded by an identifying letter.

Claims of U.S. Patent No. 3,038,363.--The first patent to be considered has 24 claims covering electronic pianos. The parties have agreed that only claims 3-9 are in issue.

Claim 3--An electronic piano the combination comprising--

(a) A plurality of tuned reeds supported on one end and free on the other end

(b) A key controlled hammer to strike the reeds for vibration

(c) A single pick-up element (emphasis supplied) for electrostatically sensing the vibrations

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1/ 35 U.S.C. 101 provides:

101. Invention patentable

Whoever invents or discovers any new and useful process, machine, manufacture, or composition of matter, or any new and useful improvement thereof, may obtain a patent therefor, subject to the conditions and requirements of this title.

2/ For the sake of clarity and consistency, certain immaterial wording has been omitted.

(d) Said pick-up element having a multiplicity of conductive portions disposed in proximate relation to the free ends of said reeds to provide electrical capacitance between the pick-up element and the reed 1/

(e) Means for applying a direct current potential between said pick-up element and said multiplicity of reeds

(f) An electronic tone signal connected to said pick-up element to produce electronic signals corresponding to the change in the capacitance between said pick-up element and the multiplicity of reeds

Claim 4 --An electronic piano, the combination comprising the same elements as claim 3 with the additional requirement that "each of said pick-up conductor portions registering with the normal position of the coacting reed and being shaped and positioned to extend away from a position of alignment with the normal position of the reed in only one of the two directions in which the reed swings away from its normal position

Claim 5--An electronic piano, the combination comprising--

(a) Same as claim 3 (a)

(b) Same as claim 3 (b)

(c) An electrostatic pick-up comprising a plurality of pick-up portions disposed in side-by-side co-planar (emphasis supplied) disposition to each other and in a proximate electrically capacitive relation to the projecting portions of said respective reeds

(d) Said respective pick-up portions being substantially flush with the normal positions of the respective reeds and extending along the swing of the reeds in only one direction covering substantially the full excursion of the coacting reed in said one direction

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1/ The vibration varies for each reed, thus giving different notes.

(e) Same as claim 3 (e)

(f) Same as claim 3 (f)

Claim 6--an electronic piano, the combination comprising--

(a) Same as claim 3 (a)

(b) Same as claim 3 (b)

(c) Same as claim 3 (c)

(d) Said pick-up including a plurality of electrically conductive portions thereof disposed alongside the vibrator paths of said respective reeds

(e) Same as claim 3 (e)

(f) Same as claim 3 (f)

Claim 7--Is expressly dependent on claim 6, and covers an electronic piano as defined therein with the additional limitation that "each of said electrically conductive portions of said pick-up element traverses the free end of the coacting reed and has a width with respect to the reed which substantially exceeds the corresponding transverse width of the coacting reed"

Claim 8--An electronic piano, the combination comprising--

(a) The same as claim 3 (a)

(b) The same as claim 3 (b)

(c) <u>An integral electrically conductive pick-up plate extending across the free ends of said reeds</u> (emphasis supplied) for electrostatically sensing vibrations of the reeds

(d) Same as claim 3 (d)

(e) Same as claim 3 (e)

(f) Same as claim 3 (f)

Claim 9--An electronic piano the combination comprising--

(a) Same as claim 3 (a)

(b) A key controlled striking means coacting with each of the said respective reeds to impulsively excite the reed to vibrate freely in a manner which swings the free end of the reed to opposite sides of a rest position of the reed

(c) An electrostatic pick-up including conductor portions disposed in adjacent electrically capacitive relation to the free ends of said respective reeds, each of said pick-up conductor portions being substantially flush with one longitudinal side of the coacting reed when the latter is in its normal position, each pick-up conductor portion being shaped and positioned to extend along the swing of the coacting reed in only one direction of reed movement from the normal position of the reed

(d) Same as claim 3 (e)

(e) Same as claim 3 (f)

<u>Claims of U.S. Patent No. 2,942,512</u>.--The second patent to be considered has 10 claims describing an electronic piano. Claims 1, 2, 6, and 9 of this patent are in issue:

Claim 1--In combination in an electrical musical instrument comprising--

(a) A fixed-free reed

(b) A key actuated hammer adjacent to the reed to act as an impulse exciting means used to engage the reed and set it into decadent free vibration

(c) "An electric translation pick-up adjacent the reed, said pick-up having a tone producing portion located alongside and being vibratorily passed by a longitudinally intermediate edge portion of the reed and being of an effective thickness, in the direction of reed vibration, smaller than the high-amplitude stroke of said edge"

Claim 2--In combination in an electrical musical instrument

comprising--

(a) Same as claim 1 (a)

(b) Same as claim 1 (b)

(c) Same as claim 1 (c)

(d) and being offset in said direction from effective alignment with the rest position of said reed

Claim 6--In combination in an electrical musical instrument

comprising--

(a) Same as claim 1 (a)

(b) Same as claim 1 (b)

(c) Same as claim 1 (c)

(d) "Means comprised in said mechanical system for at least substantially eliminating from the free vibration of the reed a lower one of its normally present upper partials"

Claim 9--In combination in a musical instrument comprising--

(a) Same as claim 1 (a)

(b) Same as claim 1 (b)

(c) A mechanico-electrical system consisting of a portion of the reed and pick-up means associated with and influenced by said portion for translating electric oscillations from the reed vibrations

(d) Means comprised in said mechanico-electrical system for at least substantially eliminating from said oscillations an inharmonic component corresponding to a lower one of the upper partials at which the reed tends to vibrate

Claims of U.S. Patent No. 2,949,053.--The third patent to be considered has nine claims describing a tone generator arrangement in stringless electronic pianos, in which the vibratory motion of reeds is sensed by an electrostatic pick-up. Claims 1-4 of this patent are in issue:

Claim 1--An electronic musical instrument comprising--

(a) A common reed support

(b) A plurality of reeds with bases fixed on said common support and with vibratile tongues projecting in the same direction therefrom in side-by-side co-planar parallelism from said support

(c) A plurality of hammers to strike the reeds setting them into decadent free vibration

(d) Manually engageable keys for selectively moving said hammers

(e) A pick-up member of comblike configuration having a plurality of parallel teeth and an intermediate plurality of slots each opening at one end (see app. C, fig. 5)

(f) Means mounting said pick-up member in a common plane with the reeds projecting into the slots between the teeth

(g) Said reeds and said pick-up member comprising a tone generating means establishing an electric potential between said reeds and said pick-up member

(h) Means for translating oscillations of said tone generating mechanism into audible tones

Claim 2--Expressly incorporates all elements of claim 1 and adds "wherein the plane of said reeds is displaced from the median plane of the pick-up teeth, and wherein said reeds vibrate asymmetrically about such median plane"

Claim 3--Expressly incorporates all the elements of claim 1 and adds "further including common means electrically grounding said plurality of reeds"

Claim 4--Expressly incorporates all the elements of and is dependent from claim 3 and adds "wherein the common grounding means comprises the common reed support, said support being electrically conductive, and said reeds being mounted directly on said support in physical and electrical engagement therewith"

Claims of U.S. Patent No. 3,154,997.--The fourth patent to be considered has six claims describing a vibratory reed for use in an electronic musical instrument having a curved inward taper. The six claims of this patent are intended to protect a certain taper of the body of the reed which gives it additional strength to prevent its breaking (particularly on the bass notes) when struck by the hammer which is used to set the reed into free decadent vibration. All six claims of this patent are in issue;

Claim 1--A vibratory reed for use in a musical instrument

comprising--

(a) A base adapted to be secured to a mounting surface

(b) A flat tongue having lateral and longitudinal dimensions extending out from said base

(c) Said tongue having a curved inward taper extending out from said base merging into substantially parallel edges

(d) Said curved taper comprising a substantial portion of the total length of said tongue and having a length greater than the transverse dimension of said tongue

Claim 2--A vibratory reed for use in a musical instrument

comprising--

(a) Same as claim 1 (a)

(b) Same as claim 1 (b)

(c) Same as claim 1 (c)

(d) Said curved taper comprising between substantially 10 and 50 percent of the total length of said tongue and having a length greater than the transverse dimension of said tongue

Claim 3--A vibratory reed for use in a musical instrument

comprising--

(a) Same as claim 1 (a)

(b) Same as claim 1 (b)

(c) Same as claim 1 (c)

(d) Said curved taper comprising between substantially 20 and 35 percent of the total length of said tongue and having a length greater than the transverse dimension of said tongue

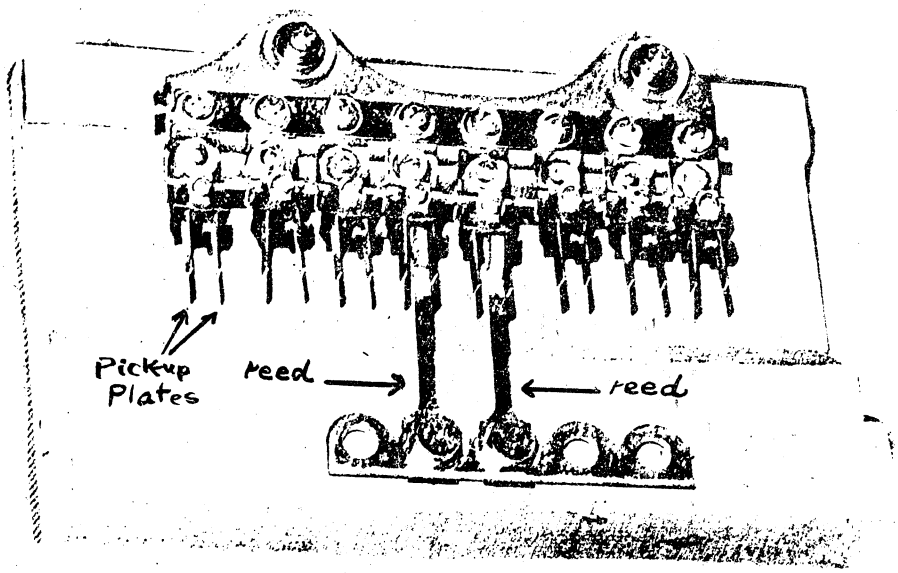
Claim 4--A vibrating reed arrangement for use in a musical instrument comprising all the elements of claim 1 and adding "a striker member adapted impulsively to engage said reed tongue to set said reed tongue in free, decadent vibration"

Claim 5--A vibrating reed arrangement for use in a musical instrument comprising all the elements of claim 1 and adding "a striker member adapted impulsively to engage said reed tongue outwardly of said tapered portion to set said reed tongue in free, decadent vibration"

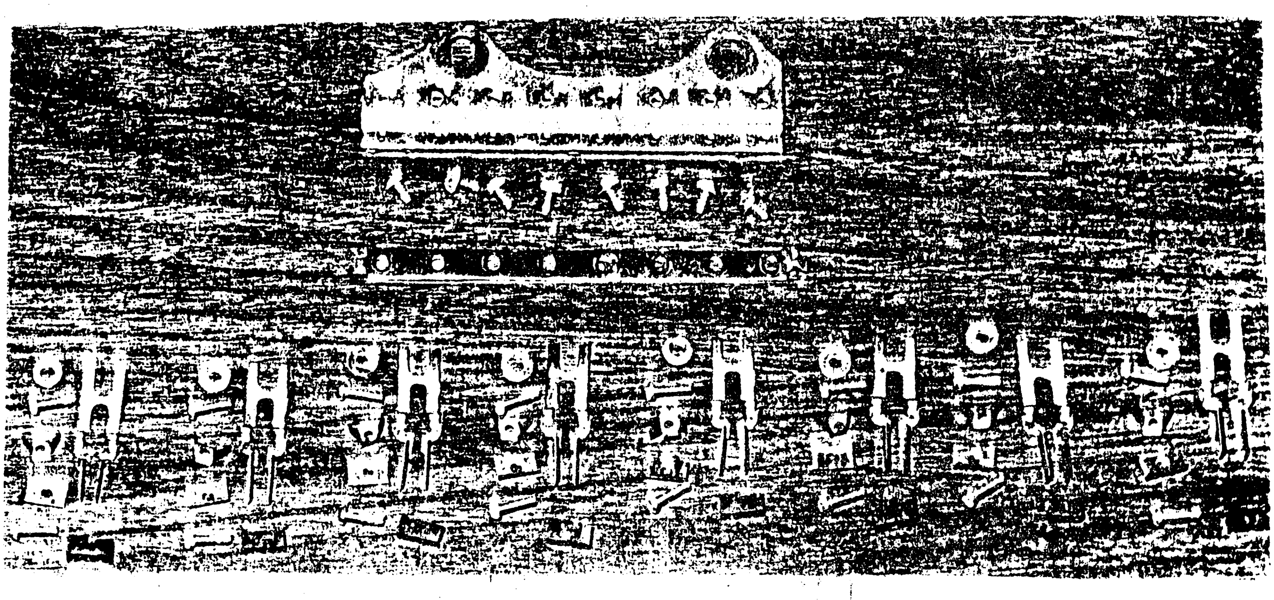
Claim 6--A vibratory reed as set forth in claim 3 wherein the curved taper is a noncircular arcuate curve.

Attention is invited to exhibits A, B, C, and D, reproduced on the next several pages in this report. Exhibit A illustrates the Electrokey pick-up structure for eight notes in assembled and not-assembled forms. This should be contrasted with exhibit B, which illustrates the Wurlitzer pick-up structure for the same number of notes in assembled and not-assembled forms. Exhibit C presents a cross-section view of the pick-up in the Wurlitzer structure and a perspective view of the pick-up in the Electrokey structure. Exhibit D illustrates an enlarged top view of a reed in each structure.

Exhibit A

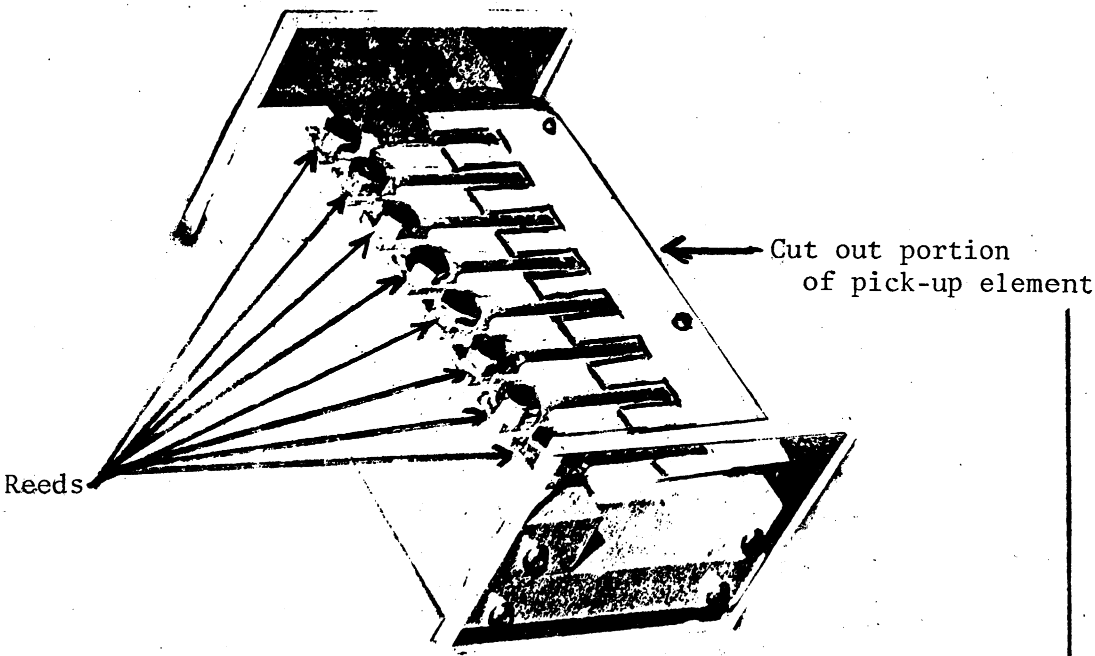


Electrokey "tone generator" structure for eight notes but including only two reeds

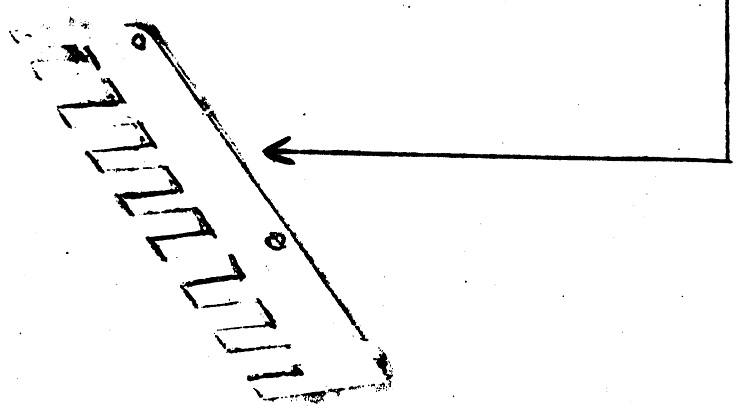


Electrokey pick-up parts required for eight notes

Exhibit B



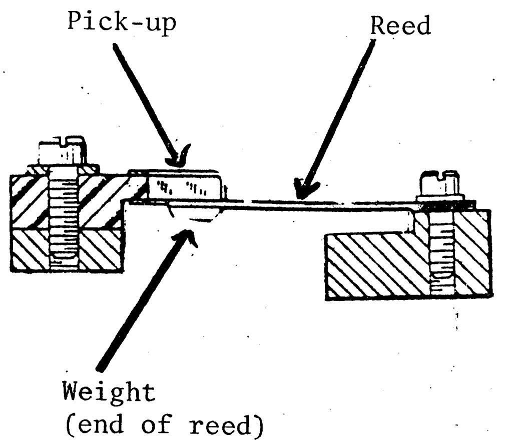
Wurlitzer Model "200" "tone generator" structure for eight notes



Wurlitzer Model "200" pick-up element for eight notes

Exhibit C

Wurlitzer "200"
Cross-section view of pick-up



Electrokey
Perspective view of pick-up

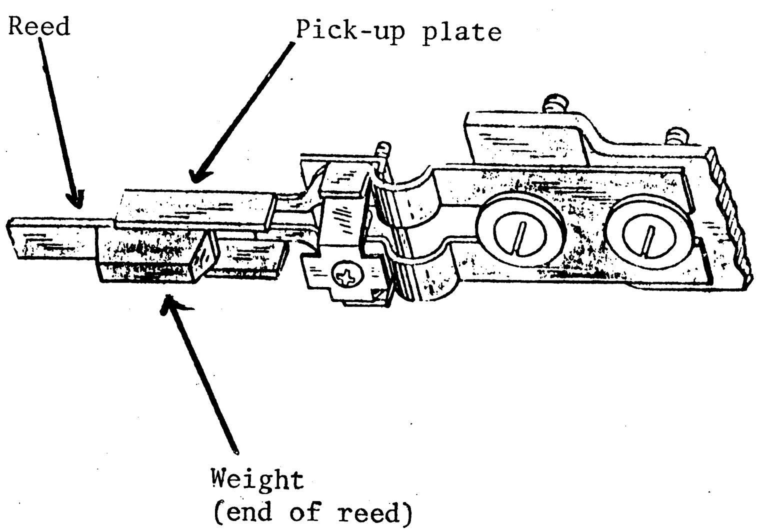
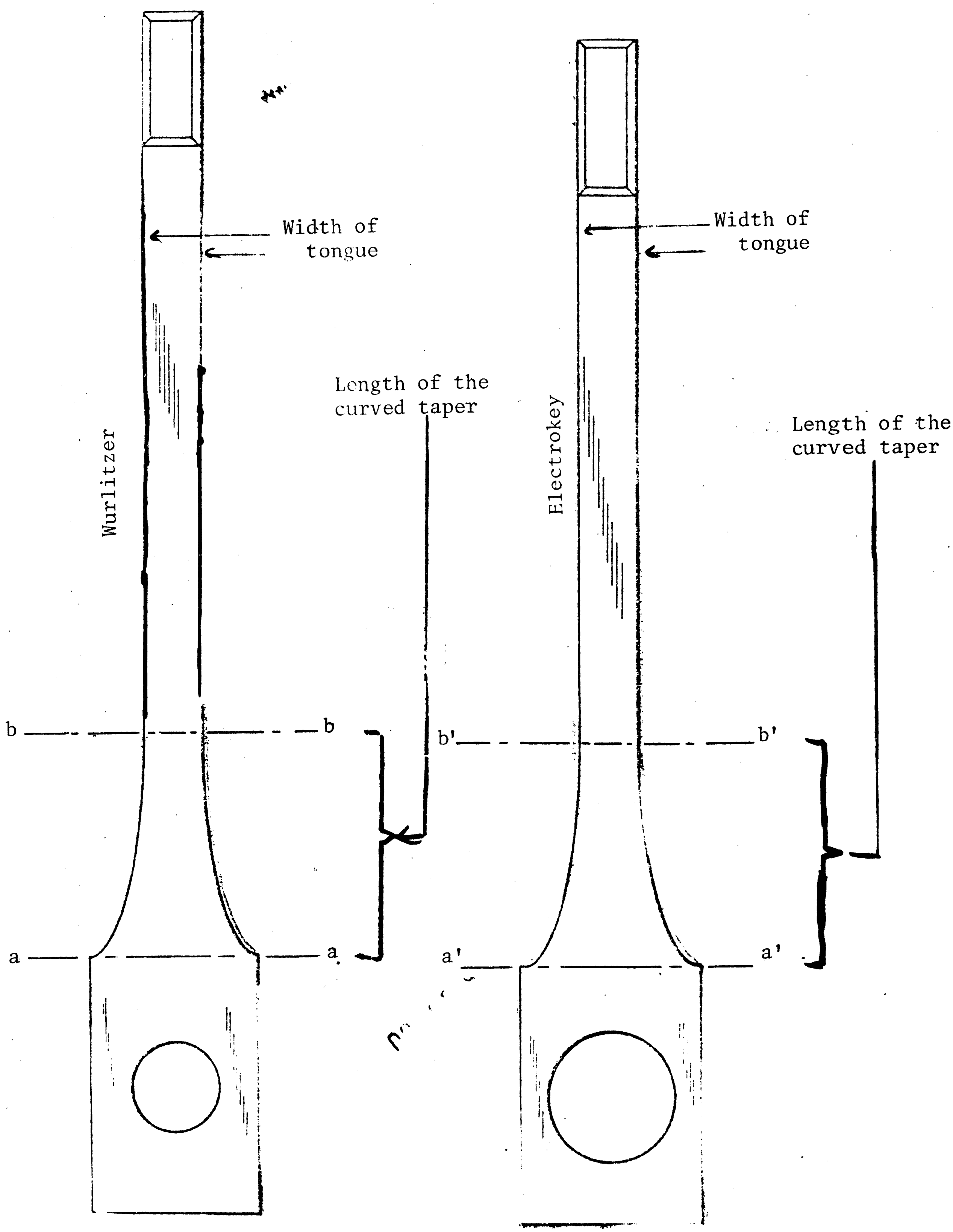


Exhibit D


Width of
tongue
Length of the
curved taper
Wurlitzer
b
b
a
a
Electrokey
Width of
tongue
Length of the
curved taper
b'
b'
a'
a'

Complainant's contentions as to the patents

In its complaint filed with the Commission, complainant alleged that (1) it is the owner of all of the above patents, (2) electronic pianos of a type incorporating the features claimed in these patents have been and continue to be imported into the United States in violation of section 337 of the Tariff Act of 1930, and (3) the importation of such electronic pianos has the effect or tendency to substantially injure an efficiently and economically operated domestic industry.

Complainant's attorney contended that complainant produces the patented product and that complainant is the only domestic producer of the patented product. 1/ He contended that "The Wurlitzer electronic piano is made in accordance with the four patents noted above." 2/ He also maintained that the claims in issue in all four patents found response(s) in the imported product. 3/

At the hearing held on August 15, 1974, and in the brief submitted to the Commission subsequent to that hearing, complainant's attorney specified that all the claims in issue in U.S. Patent Nos. 3,038,363, 2,942,512, 4/ and 2,949,053 are readable on complainant's product, and he

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1/ Transcript of the hearing, pp. 110 and 412.

2/ Complainant's brief filed Apr. 20, 1973, p. 2.

3/ Complainant's attorney used claim charts and physical exhibits at the hearing held Jan. 30-31, 1973, in an attempt to demonstrate that the claims in each patent found response in imported electronic pianos.

4/ Pursuant to the Commission's notice ordering this hearing on Aug. 15, 1974, only U.S. Patent Nos. 3,038,363 and 2,949,053 were included as the patents on which the Commission was interested in receiving evidence. No mention was made in the notice of U.S. Patent No. 2,949,512.

proceeded to apply these claims to complainant's product through the use of claim charts and physical exhibits. 1/

Complainant's attorney also maintained that the four patents in question have not been licensed by complainant to any other manufacturer 2/ and that the patents in question have never been ruled upon by any court of competent jurisdiction. 3/

At the hearing held January 30-31, 1973, complainant's attorney placed the four patents in question in the following context:

> We have claimed certain features of the tone generating portion (emphasis supplied) of the electronic piano, not irrelevant things like the keys, or the case, or the loudspeakers, or anything like that; simply the tone generating portions (emphasis supplied). 4/

The contentions of complainant's attorney as to each patent are as follows:

U.S. Patent No. 3,038,363.--Complainant's attorney testified at the hearing held January 30-31, 1973, that, from a chronological standpoint, U.S. Patent No. 3,038,363, the first Miessner patent, 5/ is the most

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1/ Transcript of the hearing, pp. 382-412. Complainant's brief filed on Sept. 11, 1974, pp. 4-5. The exhibits introduced into evidence at the hearing were represented as being copies of actual commercial structures manufactured by The Wurlitzer Co. The claim charts are reproduced in apps. E-K.

2/ Ibid., p.5.

3/ Complainant's submission dated Jan. 5, 1973, in opposition to respondent's motion filed with the Commission on Dec. 18, 1972, p. 1. See, however, the section in this report entitled "Litigation History"; on Aug. 23, 1974, the U.S. District Court for the Northern District of Texas ruled upon the four patents in question, finding infringement of the claims in U.S. Patent Nos. 3,038,363 and 2,942,512.

4/ Transcript of the hearing, p. 108.

5/ The second Miessner patent is U.S. Patent No. 2,942,512.

important and basic patent of the group. 1/ He selected claim 3 as exemplary of the claims of this patent for purposes of the hearing. He then attempted to apply claim 3 to certain illustrations in the patent disclosure (see complainant's claim chart, app. E) and to the Electrokey structure 2/ and concluded that the claim read on both. 3/

Complainant's attorney noted that the element in this claim which respondents would contend was not present in the tone generator portions of the imported electronic pianos is "a single pick-up element for electrostatically sensing vibrations of a multiplicity of said reeds." He argued that the entire metal conducting structure, together with the individual horseshoe-shaped elements found in the Electrokey tone generator portions, constitute one single pick-up element. 4/ Complainant's attorney contended that even though this pick-up element is made up of a certain number of parts, unlike complainant's structure, which is "simply cut from one piece of sheet metal", 5/ the presence of cement or white glue on the heads of screws used for fastening together the Electrokey pick-up parts indicates that in normal use the pick-up is not intended to be taken apart and, as such, it constitutes a single pick-up, whether regarded as single mechanically, single electrically, or single functionally. 6/

1/ Transcript of the hearing, p. 14.

2/ It was agreed by the parties that, for purposes of the Commission's investigation, all of the electronic pianos imported by respondents were the same. Electrokey is imported by Electrokey, Inc., one of the respondents.

3/ Transcript of the hearing, p. 54.

4/ Ibid, p. 55.

5/ Ibid. p. 56.

6/ Ibid., pp. 55-62.

Complainant's attorney referred to the deposition of Naokichi Takamatsu, chief engineer of Nippon Columbia, Ltd. 1/ (the foreign manufacturer of the imported electronic pianos in question), and pointed out that Mr. Takamatsu conceded that (1) the purpose of the white glue or cement was to hold the screws fixed and (2) all of the pole pieces in the imported electronic piano were connected together electrically. 2/ The complainant's attorney then took the position that the breaking down of a single part into two or more parts united together does not avoid infringement--the manner in which the parts are fastened together, with the screws being secured by a cement material, effectively renders the initial multiplicity of parts a single part following assembly. 3/

Complainant's attorney testified at the hearing held January 30-31, 1973, that claim 4 adds one item to claim 3 in that it "helps us determine the wave shape a bit" by reason of the fact that the "reed lines up with the top portion of the pick-up." 4/ He also testified that in claim 5 the word "single" is not used. 5/ The remaining distinctions

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1/ Portions of this deposition were received in evidence as exhibit 11.

2/ Transcript of the hearing, pp. 56-57.

3/ Complainant's brief filed Apr. 20, 1973, p. 8.

4/ Transcript of the hearing, p. 89. It should be noted that an examination of physical exhibits 26A and 26B (introduced into evidence by the complainant at the Aug. 15, 1974, hearing) reveals that some of the reeds in complainant's product line up with the bottom (not top) portion of the pick-up.

5/ Ibid., p. 90.

in the claims, he contended, were mostly semantical differences. 1/ In his brief complainant's attorney argued that claims 4-9 were also infringed by the imported electronic pianos and that claims 5, 6, 7, and 9 do not refer to a single pick-up. 2/

At the hearing held on August 15, 1974, complainant's attorney alleged that all of the claims of the patent in issue (i.e., claims 3-9) found response in the domestic product. He then attempted, through the use of claim charts and physical exhibits, to apply these claims to the actual commercial structure manufactured by the complainant, and he concluded that all of the claims in issue read on the domestic product. 3/

U.S. Patent No. 2,942,512.--Complainant's attorney testified at the hearing held January 30-31, 1973, that U.S. Patent No. 2,942,512, the second Miessner patent, grew out of the same application as U.S. Patent No. 3,038,363, 4/ and that one object in developing the subject invention of this patent was to introduce a second harmonic, a frequency twice the fundamental frequency of vibrations of the reed. 5/ He contended that in later claims of this patent an additional object was sought--viz, the elimination of a higher frequency which is called an "inharmonic partial." 6/ Complainant's attorney selected claim 1 as exemplary of the claims of this patent for purposes of the hearing. He then attempted to apply claim 1 to certain illustrations (see complainant's claim chart, app. F) in the patent disclosure and to the Electrokey structure and concluded that the claim read on both. 7/

1/ Transcript of the hearing, p. 90.
2/ Complainant's brief filed Apr. 20, 1973, p. 8.
3/ Transcript of the hearing, pp. 394-405. See complainant's claim chart (app. J).
4/ Ibid., p. 15.
5/ Ibid., p. 65.
6/ Ibid. An "inharmonic partial" is, according to complainant's attorney, inherent in a reed. He maintained that the elimination of this higher frequency is accomplished "by striking the reed at a particular point" and that this achieves a more pianistic tone.

According to complainant's attorney, the conceptual theory behind producing second harmonics consists of cutting out a portion of the sine wave--as a practical matter, this is accomplished by placing--

> . . . a pick-up . . . a little sort of a foot here, horizontal, making it somewhat L-shaped . . . as it (the reed) moves up, it will move up to or maybe even just a little bit past the horizontal portion of that brown pick-up (emphasis supplied). When it moves down, it's going to move way away from that horizontal portion of the pick-up. 1/

Complainant's attorney contended that the reed movement shown in the illustrations of the patent disclosure and in the Electrokey piano possesses a high amplitude stroke which is larger than the thickness of the pick-up, as required by claim [illegible]. 2/

1/ Transcript of the hearing, pp. 65-69.

2/ Comparison is invited between the pick-ups shown on the claim chart (app. F) and complainant's pick-up shown on exhibit C (see also the pick-up shown on the claim chart introduced into evidence by complainant's attorney at the Aug. 15, 1974, hearing (app. I)).

It should be noted that the specifications of U.S. Patent No. 2,949,053 (the Andersen patent) provide, in connection with the distance traveled by the reed relative to the pick-up, that--

> the cooperative relationship of the reeds and pick-ups whereby the reeds are coplanar with one face of the pick-up and wherein the pick-up is of sufficient thickness so that the reed does not pass beyond or through the pick-up in one direction of vibration is important in producing proper piano tones (emphasis supplied). (Specifications of U.S. Patent No. 2,949,053, col. 7, lines 7-12).

The Electrokey features a reed which in its rest position is located partially within the pick-up and passes "through the pick-up" for some distance in both directions of vibration. (See exhibit C and complainant's claim charts, app. F and app. I).

Complainant's attorney contended that the pick-up plates in the Electrokey structure had an "effective thickness" which is "smaller than the high amplitude stroke" of the reed, as is required by claim 1. 1/ He pointed out that claim 2 requires that the pick-up be offset from the rest position of the reed, and he referred to Mr. Takamatsu's deposition in which it was conceded by Mr. Takamatsu that the purpose of having the reed approximately alined with one edge of the pole piece was "to produce the second harmonics." 2/

Complainant's attorney continued:

> You can see that the reed, the end of the reed, extends on beyond the pick-up so that it is not the end of the reed that it is adjacent to the pick-up, but rather the edge portion (emphasis supplied) . . . that's really the important part of this Miessner patent, that the reed does move up and down beyond that edge portion of the pick-up (emphasis supplied). 3/

Complainant's attorney contended that claims 2, 6, and 9 in this patent were also infringed by the "Electrokey" structure. 2/ He also indicated that claims 6 and 9 are further distinguished in that the reed

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1/ Transcript of the hearing, p. 70.

2/ Complainant's brief filed Apr. 20, 1973, p. 9.

3/ Transcript of the hearing, pp. 68-69. This statement relates to the element in the claim requiring the pick-up to be vibratorily passed by a "longitudinally intermediate edge portion of the reed . . . ." Comparison is invited between the Electrokey pick-up and complainant's pick-up shown on exhibit C (see also the pick-up shown on complainant's claim chart introduced into evidence at the Aug. 15, 1974, hearing (app. I)--the pick-up in the imported product and the pick-up in the domestic product both appear to be adjacent also to the end of the reed. It should be noted that the specifications and illustrations in U.S. Patent No. 2,942,512, do not refer to a pick-up structure which also has the pick-up adjacent to the end of the reed--all of the reeds are shown as extending beyond the pick-up, which is located alongside a longitudinal edge of the reed some distance from the end of the reed.

Complainant's attorney alleged at the Aug. 15, 1974, hearing that the pick-up structure in the Wurlitzer piano embraces the end of the reed in such a manner that at least one portion of the pick-up is passed by a longitudinally intermediate edge portion of the reed (transcript of the hearing, p. 386).

is struck at a particular position by the hammer to eliminate an undesirable inharmonic overtone, and he inferred that the Electrokey structure embodied this feature because "it can be concluded that if a reed-type electronic piano does not have an objectionable inharmonic overtone in a sound output, then the reed must be struck at the right place to eliminate such inharmonic overtone." 1/

At the hearing held on August 15, 1974, complainant's attorney contended that all of the claims of the patent in issue (i.e., claims 1, 2, 6, and 9) found response in the domestic product. 2/ He then attempted, through the use of claim charts and physical exhibits, to apply these claims to the actual commercial structure manufactured by the complainant and concluded that all of the claims in issue read on the domestic product. 3/

1/ Complainant's brief filed Apr. 20, 1973.

2/ It should be noted that the notice issued by the Commission on July 17, 1974, which ordered the hearing, did not refer to U.S. Patent No. 2,942,512.

3/ Transcript of the hearing, pp. 382-393. Complainant's attorney alleged at the hearing that, although it was impossible to demonstrate this feature, by striking the reed in complainant's structure at a particular place, the lower one of the upper partials would be erased and a "klang" tone would thereby be eliminated (transcript of the hearing, p. 390). Complainant's attorney had earlier at this hearing cast this feature in terms of dynamic shortening, indicating that the dynamic shortening of the reed brought about by a strong blow to the reed caused the position of the side portion of the pick-up to change relative to a nodal point on the reed, thereby creating a "clang" tone (transcript of the hearing, pp.370-372). It thus remains unclear whether the elimination of the "clang" tone is desirable or undesirable. It should be noted, however, that in the specifications of U.S. Patent No. 2,949,512 it is provided as follows:

> Furthermore, claims to structure taking positive advantage of the dynamic shortening of the reed are not (emphasis supplied) made herein, the same having been presented in my copending application Serial No. 673,725, filed July 23, 1957. (Col. 15, lines 3-7, specifications of U.S. Patent No. 2,942,512.)

U.S. Patent No. 2,949,053.--Complainant's attorney testified at the hearing held January 30-31, 1973, that U.S. Patent No. 2,949,053 (the Andersen patent) chronologically came after the first two Miessner patents and that it was necessarily more detailed and could not be broad because the two Miessner patents had already covered the broad aspects of an electronic piano. 1/ He selected claim 1 as exemplary of the claims of this patent for purposes of the hearing. He then attempted to apply claim 1 to certain illustrations in the patent disclosure (see complainant's claim chart, app. G) and to the Electrokey structure and concluded that the claim read on both. 2/

A part of the testimony of complainant's attorney was that in complainant's product "the pick-up comprises a sheet-metal, aluminum sheet-metal with slots cut into it for the reeds to vibrate in" which formed "a pick-up member of comblike configuration" as is required by claim 1 of this patent. 3/ He maintained that the fingers in the

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1/ Transcript of the hearing, p. 72.
2/ Ibid, pp. 72-83.
3/ Ibid., p. 72. Physical exhibits 26A and 26B offered into evidence by complainant's attorney at the Aug. 15, 1974, hearing reveal that the entire pick-up in complainant's product constitutes four separate sheet-metal pieces, each with slots cut into it. In this connection, the specifications of U.S. Patent No. 2,949,053 (col. 7, lines 22-29) provide:

> The projecting teeth of the pick-up (emphasis supplied) extending between the reeds effects a greater volume change due to the greater change in capacitance . . . . The effect varies with the length of the projection, and for this reason the length of the projection varies across the keyboard in order to produce a proper tonal balance among the bass, treble, and intermediate tones (emphasis supplied).

Thus, the pick-up is conceived as extending as a single physical unit from treble to bass notes (i.e., the whole range of the piano) with the length of the teeth projection varying with each note across the keyboard.

Electrokey structure stick out just like the fingers of a comb and, accordingly, embody this feature. 1/

Complainant's attorney also contended that the pick-up in the Electrokey structure has a "plurality of parallel teeth," another element required under claim 1. 2/

It was the position of complainant's attorney that claims 2-5 (which are dependent on claim 1) present further specific details which are also embodied in the Electrokey structure. 3/

At the hearing held on August 15, 1974, complainant's attorney testified that all the claims of the patent in issue (i.e., claims 1-5) found response in the domestic product. He then attempted, through the use of claim charts and physical exhibits, to apply these claims to the actual commercial structure manufactured by complainant and concluded that all of the claims in issue read on the domestic product. 4/

U.S. Patent No. 3,154,997.--Complainant's attorney testified at the hearing held January 30-31, 1973, that the reed which is the subject of U.S. Patent No. 3,154,997 (the Bode patent) was developed because of a need for a reed that did not break easily. 5/ He selected claim 1 as representative of the claims of this patent for purposes of the hearing. He then attempted to apply claim 1 to an enlarged drawing of a reed manufactured by complainant and to an enlarged drawing of a reed

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1/ Transcript of the hearing, p.81.
2/ Ibid. His position was that the pick-up plates in the Electrokey structure are all parallel.
3/ Complainant's brief filed Apr. 20, 1973, p. 10.
4/ Transcript of the hearing, pp. 406-411. See complainant's claim chart (app. K).
5/ Ibid., p. 17.

found in the Electrokey structure (see complainant's claim chart, (app. H) and exhibit D) and concluded that the claim read on both. 1/ His contention was that the two reeds were identical, except that the reed in the Electrokey structure (1) was shorter than complainant's reed and (2) had a larger mounting hole than complainant's reed. 2/

It was contended by complainant's attorney that all of the claims of this patent were infringed by the reed found in the Electrokey structure. 3/ He indicated that under claim 6, the "curved taper" is a "non-circular arcular"; and he argued that this means that the taper of the reed is made up of a series of arcular curves, not just a portion of one circle. 4/

At the hearing held on August 15, 1974, complainant's attorney indicated that "the reeds shown in the Bode patent are identical with the reeds in the Wurlitzer piano" 5/ amd contended that this identity was "so self-evident that it would not require reading in any event." 6/

Validity of the patents.--Complainant's attorney contended that the Commission may not question the validity of any of the patents and cited In re Von Clemm (43 C.C.P.A. (Customs) 56, 229 F.2nd 441) as authority for the proposition that a patent must be considered valid unless and until a court of competent jurisdiction has held otherwise. 7/

1/ Transcript of the hearing, pp. 84-88.
2/ Ibid., pp. 86-87.
3/ Complainant's brief filed Apr. 20, 1973, p. 10.
4/ Transcript of the hearing, p. 93.
5/ Ibid, p. 411. It should be noted that the notice issued by the Commission on July 17, 1974, which ordered the hearing, did not refer to U.S. Patent No. 3,154,997.
6/ Ibid., p. 412.
7/ Complainant's brief filed Apr. 10, 1973, p. 13. On Aug. 23. 1974, the U.S. District Court for the Northern District of Texas ruled that the claims in U.S. Patent No. 3,154,997 were invalid.

Respondents' contentions as to the patents

Respondents' attorney contended that (1) the Tariff Commission should dismiss this proceeding because it presents pure patent issues which are scheduled for trial in a court having jurisdiction over all named respondents and which can grant whatever remedies are legally appropriate; 1/ (2) the electronic piano patents in question are not broad patents but claim only limited improvements over the basic construction features of electronic pianos, which were invented during the 1930's and are no longer under patent protection; 2/ (3) meticulous analysis of the claims of these patents clearly shows that the allegedly infringing electronic pianos are not made in accordance with the claims of the patents; 3/ and (4) there are serious questions as to the validity of these patents which are currently being litigated in court. 4/

Respondents' attorney contended that the development of each of the basic component groups which are utilized in electronic pianos (the action portion, the tone-generator portion and the amplifier-speaker portion) had reached a highly advanced state prior to 1950, the earliest invention date that can be accorded any of the four patents in question. 5/ The inventive contributions of

1/ Respondents' submission filed with the Commission on Dec. 18, 1972, p. 1.
2/ Respondents' brief filed Apr. 20, 1973, p. v.
3/ Ibid., p. 2.
4/ Ibid., p. v. See section in this report entitled "Litigation History," p. A-51 through p. A-52, where it is indicated that the claims in U.S. Patent No. 3,154,997 were held to be invalid by the U.S. District Court for the Northern District of Texas.
5/ Ibid., pp.5-9. See also transcript of the hearing, pp. 231-246.

of complainant's U.S. Patents Nos. 3,038,363 (the first Miessner patent), 2,942,512 (the second Miessner patent), and 2,949,053 (the Andersen patent), in his view, are best characterized as being of secondary or limited-improvement nature and could by no stretch of the imagination be characterized as being primary or pioneer. 1/ He maintained that (1) by virtue of the above and (2) by virtue of the fact that patents for combinations of old elements are to be narrowly and strictly construed, the claims in these patents should be accorded a very narrow range of equivalence, a finding of infringement being appropriate only if the same steps or precise equivalents are followed. 2/ Respondents' attorney indicated that this approach was not directed at questioning the validity of the patents; rather, it was directed at the construction which the Commission should give the claims of the patent. 3/

1/ Respondents' brief filed Apr. 20, 1973, pp. 5-9. Respondents' attorney contended that the key-action portion of the pianos in question is based on the same principle as the key action used in a standard piano and that there is no patent protection for this ancient mechanism; that the amplifier-speaker portion of the electronic piano involves the identical art and expertise used since about 1923 in other electronics fields, particularly the radio and television and phonograph amplifier arts; that since the alleged inventive concepts in complainant's patents do not involve any improvement in the amplifier-speaker, there is no protection for any of this portion of the electronic pianos in question; that the tone-generator portion of the electronic piano, which is comprised of a vibratile element (reed) for each note and the associated pick-up, is old in the art because reeds were first used in mechanical music boxes in 1814, and complainant thus cannot claim invention for this concept; that application of electrical devices to musical instruments was begun in the 19th century; that reeds in electronic pianos generate tones by creating sound waves, which sound waves can as easily be generated by magnetic-type or vibratory-ribbon-type tone generators in electronic pianos; and that the advance in this art to use a combination and coaction of an electronic piano and a vibratile reed was culminated in the 1930's and 1940's by the early Miessner electronic pianos which are no longer protected by patents.

2/ Ibid., pp. 9-10, 13, 19, and 28.

3/ Transcript of the hearing, p. 242.

Insofar as U.S. Patent No. 3,154,997 (the Bode patent) is concerned, it was the position of respondents' attorney that the issues presented pertaining to this patent were now moot, since respondents have ceased using this type of reed; that this patent is not now and has never been infringed by respondents' electronic piano structure; and that this patent is in any event invalid. 1/

Respondents' attorney contended that it should be noted that the validity of all four patents identified in the Wurlitzer complaint is seriously in doubt and has been placed in issue by the respondents in a court of law. 2/ Respondents' attorney contended that, because invalid patents cannot be infringed, complainant cannot legitimately claim a remedy under section 337 of the Tariff Act since there is no infringement by the respondents of any Wurlitzer patent, let alone infringement of a valid Wurlitzer patent. 3/

Respondents' attorney also urged the Commission to defer acting on complainant's complaint until the question of the validity of these patents was settled in court. 4/

At the hearing held on August 15, 1974, and in the brief submitted to the Commission subsequent to that hearing, respondents' attorney contended that the pertinent claims in U.S. Patents Nos. 3,038,363 and 2,949,053 do not find response in the domestic product. 5/

1/ Respondents' brief filed Apr. 20, 1973, pp. 34-37.

2/ Ibid., pp. 36-37. See section entitled "Litigation History" in this report relative to the decision made as to the patents in issue on Aug. 23, 1974, by the U.S. District Court for the Northern District of Texas.

3/ Ibid.

4/ Ibid., pp. 38-50.

5/ Transcript of the hearing, pp. 472-490, and respondents' brief filed Sept. 18, 1974, pp. 5-6.

U.S. Patent No. 3,038,363.--It was contended by respondents' attorney that claims 3-9 of this patent, if valid at all, must be construed in the light of (1) the prior art and (2) the doctrine of file wrapper estoppel 1/ to limit the pick-up structure to a single unitary or integral element for sensing the vibrations of a multiplicity of reeds. 2/ He also maintained that the long pendency of the application for this patent in the U.S. Patent Office (12 years) and the vigorous prosecution of this patent before that office should be construed as further limiting the patent claims to substantially what is shown. 3/

The prior art submitted by respondent's attorney as disclosing "a single pick-up element" was U.S. Patent No. 2,015,014 (Hoschke). 4/ He also submitted that an electrostatic-end-type pick-up was disclosed by U.S. Patent No. 2,318,936 (Fisher). 5/ He concluded that the prior art showed that a single pick-up, if taken to mean single electrically, was old; consequently, the term "single" could only be construed to mean single mechanically, 6/ in which event respondents' structure would not be infringing since it employs a separate and individual pick-up for each reed. 7/

1/ This doctrine provides that alterations made in a claim to obtain allowance thereof over prior art cited by a patent office examiner and representations made by the applicant's attorney as to the prior art (his acquiescence with regard thereto) cannot later be disavowed or ignored in order to achieve broader claim coverage.
2/ Respondents' brief filed Apr. 20, 1973, pp. 14-17.
3/ Transcript of the hearing, pp. 248-251.
4/ Respondents' brief filed Apr. 20, 1973, p. 14.
5/ Ibid.
6/ Transcript of the hearing, p. 237-238.
7/ Respondents' brief filed Apr. 20, 1973, p. 17. Attention is invited to exhibit A, showing the number of parts presented in the Electrokey pick-up structure.

Respondents' attorney also maintained that all of the original claims in the application for U.S. Patent No. 3,038,363 recited "an electrical pick-up structure" and were rejected, and that new claims were submitted (which became claims 3-9 of the patent) which recited a single pick-up element as in claim 3 or recitations of like restricted import. 1/ By virtue of the doctrine of file wrapper estoppel, complainant could not allege that one of its rejected claims was being infringed by the Electrokey structure. 2/

It was also argued by respondents' attorney that the long pendency of the application for this patent in the U.S. Patent Office and the vigorous prosecution of this patent further limited its claims to what was shown, i.e., the pertinent illustrations in the patent disclosure (the strip of metal 115 of fig. 18, or the strip of metal with upstanding tabs 123 and 124 of fig. 26). 3/

Respondents' attorney concluded that since each of claims 3-9 of this patent are in effect limited to a pick-up structure wherein there is employed a single unitary or integral element and since the respondents' Electrokey structure employs a separate and individual multipart pick-up for each reed, there is no infringement involved. 4/

1/ Respondents' brief filed Apr. 20, 1973, p. 15. In submissions to the U.S. Patent Office urging allowance of claims 3-9 over U.S. Patent No. 2,510,094 (Fleury), Miessner's attorney had argued that the distinguishing feature in these claims was that "a single pick-up (author's emphasis) is required to sense the vibrations of a plurality of reeds" (respondents' brief filed Apr. 20, 1973, pp. 16-17).

2/ Ibid., pp. 13-19.

3/ Ibid., p. 14.

4/ Ibid., p. 19.

Insofar as domestic production under the claims in issue in U.S. Patent No. 3,038,363 is concerned, respondents' attorney contended at the hearing held on August 15, 1974, that the pick-up structure in the Wurlitzer model was not substantially flush with the reeds, as is required by claims 6 and 9. 1/ He maintained that the reeds were placed somewhere in between the first and back edges of the pick-up and that they therefore were not necessarily (or "substantially") flush. 2/ Respondents' attorney speculated that to come within the claims in issue in U.S. Patent No. 3,038,363, the Wurlitzer structure might also have to embody a single pick-up for the entire keyboard (instead of four separate pieces). 3/ Respondents' attorney also contended in his brief filed subsequent to the August 15, 1974, hearing that the Wurlitzer product does not embody end-type pick-ups, end-type pick-ups being required by all of the pertinent claims except claims 5 and 6. 4/

1/ Transcript of the hearing, pp. 476-477.
2/ Ibid.
3/ Ibid., pp.475-477.
4/ Respondents' brief filed Sept. 18, 1974, p. 6.

U.S. Patent No. 2,942,512.--Respondents' attorney took the position that when claims 1, 2, 6, and 9 of this patent are properly construed in the light of (1) the specifications and drawings of the patent, (2) the prosecution history of the patent, and (3) the Andersen deposition, the scope of these claims should be confined to nodal pick-up placement such as that shown by figs. 4 and 11 in the patent and should not be extended to cover the Electrokey structure. 1/

Respondents' attorney contended that claims 1, 2, and 6 of this Miessner patent are largely devoted to structure and design of vibratory reeds and pick-up therefor and reed-exciting action for a stringless electronic piano such that "the most pianistic sounds" are achieved. 2/ He pointed out that each of claims 1, 2, and 6 contains the limiting recitation "said pick-up having a tone-producing portion located alongside and being vibratorily passed by a longitudinally intermediate edge portion of the reed." 3/

1/ Respondents' brief filed Apr. 20, 1973, pp. 19-28.

2/ Ibid., p.20.

3/ Attention is invited to col. 10, lines 52-65 of Miessner patent No. 2,942,512, which states:

> . . . To meet specification B this region [the region longitudinally of the reed of average influence of the reed on the pick-up], as to each reed, may most desirably be at the longitudinal position of the node for the second partial of the reed vibration. In the case of an unpierced reed of uniform cross-section this node falls at a position removed from the base of the reed by approximately 78% (and from the free end of the reed by approximately 22%) of the reed length--and the piercing of the reed appears to make no first-order change of this position, so that a positioning of the hole to bring the line of average influence of reed on pick-up at a position removed from the base of the reed by approximately 78% of the reed length represents a close compliance with specification B.

Respondents' attorney contended that the scope of claims 1, 2, and 6 is limited to a structure which meets the terms of this recitation--in order to infringe the claims, the imported piano would have to employ a reed that is either pierced or straddled by the pick-up element in some manner at a position approximately 78 percent of the reed length from the fixed end of the reed, leaving 22 percent of the reed beyond the pick-up. 1/ He contended that the Electrokey structure is not made in accordance with these limitations--the Electrokey pick-up not being at a longitudinally intermediate edge portion of the reed, a portion located at a position removed from the base of the reed by approximately 78 percent (and from the free end of the reed by approximately 22 percent) as required by claims 1, 2, and 6 of this patent. 2/

In claim 9 of this patent, respondents' attorney contended, the pertinent recitation is "means comprised in said mechanico-electrical system for at least substantially eliminating from said oscillations an inharmonic component corresponding to a lower one of the upper partials at which the reed tends to vibrate." 3/ He took the position that reference to the specifications of this patent reveals that the quoted recitation refers to further language found in specification B (part of which is quoted in footnote 3 on the preceding page of this report) 4/

1/ Respondents' brief filed Apr. 20, 1973, p. 23.
2/ Ibid.
3/ Ibid., p. 22.
4/ The language of this specification reads:

> (B) To arrange the mechanico-electrical system which is formed by the pick-up device and a portion of the vibrator so that in it is performed the function of substantially eliminating from the translated oscillations an inharmonic component corresponding to one of the lower-numbered of the upper partials at which the reed tends to vibrate--preferably the second partial.

which specification is met by claims 1, 2, and 6 of this patent--pursuant to specification B, the tone-producing pick-up is located so as to be vibratorily passed by a longitudinally intermediate edge portion of the reed, which edge portion turns out to be located at a position removed from the base of the reed by approximately 78 percent. 1/

Respondents' attorney next conducted that the prosecution history of this patent revealed that Miessner's attorney had to amend his claim to refer specifically to a "longitudinally intermediate edge portion" in order "to improve the correlation of language between the description and claims." 2/ He also indicated that when complainant provoked an interference between its application for what later became its U.S. Patent No. 2,974,555 3/ and the Miessner application for the patent in issue, complainant filed a motion to dissolve or dismiss on the grounds that either the claims were invalid in view of the prior art or not readable on complainant's electronic piano. 4/ If it did not read on complainant's structure, respondents' attorney argued, it could not read on the Electrokey structure, since both have pick-up structures wherein portions of the pick-up extend adjacent to the sides of the reed end portion. 5/

According to respondents' attorney, U.S. Patent No. 2,942,512 also has a vigorous prosecution history. 6/ Therefore, he maintained,

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1/ Respondents' brief filed Apr. 20, 1973, p. 22.
2/ Respondents' brief filed Apr. 20, 1973, p. 24. Complainant subsequently acquired U.S. Patent No. 2,942,512 by assignment from B. F. Miessner
3/ U.S. Patent No. 2,974,555 is not in issue before the Commission in this investigation.
4/ Ibid., pp. 24-25.
5/ Ibid., p. 25.
6/ The application for this patent was pending in the U.S. Patent Office for 5-1/2 years (Feb. 1, 1955, to June 28, 1960).

its claim coverage should be limited to what is shown in the pertinent patent illustration. 1/

Finally, respondents' attorney contended that to surround the end portion of a reed with the pick-up to develop sufficient capacitance change for effective operation is obvious, according to Mr. C. W. Andersen, complainant's manager of corporate engineering for electronic pianos, and consequently could not be inventive. 2/ Respondents' attorney contended that had the language of the pertinent recitation for claims 1, 2, and 6 been intended to cover a pick-up structure such as that found in Electrokey wherein portions of the pick-up extend adjacent to the sides of the reed end portion, then the word "intermediate" would clearly not have been used. 3/

With the exception of indicating that Miessner himself denied that his structure produced "clang" tones, respondents' attorney offered no evidence to counter the allegations made by complainant's attorney at the hearing held on August 15, 1974, to the effect that there was domestic production under the claims in this patent. 4/

U.S. Patent No. 2,949,053.--It was contended by respondents' attorney that (1) the claim scope in claims 1-4 of U.S. Patent No. 2,949,053 is clearly limited to a structure wherein a single electrostatic pick-up is employed for sensing vibrations of a multiplicity of reeds, (2) the disclosure of U.S. Patent No. 2,949,053 concerning the tone generator structure is the exact opposite of the philosophy and teachings utilized

1/ Respondents' brief filed Apr. 20, 1973, pp. 11-21.

2/ Ibid., pp. 25-26. Mr. C. W. Andersen is the inventor under U.S. Patent No. 2,949,053.

3/ Ibid., p. 27.

4/ Transcript of the hearing, p. 480. The notice issued by the Commission July 17, 1974, which ordered the hearing, did not refer to U.S. Patent No. 2,942,512.

in the Electrokey tone generator structure, and (3) claims 1-4 of U.S. Patent No. 2,949,053 contain limitations which preclude their reading on the Electrokey pick-up structure. 1/

Respondents' attorney contended that claim 1 of this patent, like claims 3-9 of U.S. Patent No. 3,038,363, contains a recitation which in effect limits the claim scope to a structure wherein there is employed a single electrostatic pick-up element for sensing the vibrations of a multiplicity of reeds. 2/ He pointed out that in claim 1, the limiting recitation is as follows:

> . . . a pick-up member of comb-like configuration having a plurality of parallel teeth and an intermediate plurality of slots each opening at one end, means mounting said pick-up member in opposition to said reeds substantially in a common plane therewith with the reeds projecting into the slots between the teeth . . . .

Respondents' attorney contended that the essence of the inventive concept is that the tone generator structure is designed to be manufactured on a precision basis so that there will be little or no need for adjustment of the reed-pick-up relation; this, he contended, is exactly the opposite of the philosophy behind the Electrokey structure, which is nonprecision, each pick-up element requiring a plurality of individual adjustments upon assembly. 2/

The above recitation, according to respondents' attorney, not only limits the scope of claim 1 to a single pick-up for electrostatically sensing vibrations of a multiplicity of reeds, but it goes further and requires that the pick-up member have a plurality of

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1/ Respondents' brief filed Apr. 20, 1973, pp. 28-34.
2/ Ibid.

parallel teeth and that the reeds be substantially in a common plane with the pick-up member. 1/ Respondents' attorney contended that the pick-up in the Electrokey structure is made of several pieces and is not comb-like in structure, and that it employs a separate and individual pick-up for each reed and does not, as required by claim 1 of this patent, employ a single electrostatic pick-up element, much less the required "comb-like configuration having a plurality of parallel teeth." 2/ Also, he contended that the pick-up plates in the Electrokey structure are adjusted individually for tone control by swinging them relative to the plane of the reed assembly, and consequently they will have random nonplanar positions and cannot be "substantially in a common plane" with the reed assembly. 2/ Accordingly, respondents' attorney contended that there is no infringement of this claim.

Respondents' attorney further contended that claims 2, 3, and 4 are dependent on claim 1 and therefore are not infringed for the reasons stated above.

According to respondents' attorney, U.S. Patent No. 2,949,053, like the two previous patents, had a vigorous prosecution history. 3/ Therefore, he maintained, its claim coverage should be restricted to what is shown in the pertinent patent illustration. 4/

At the hearing held on August 15, 1974, respondents' attorney alleged that there is no domestic production under the claims in this

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1/ Respondents' brief filed Apr. 20, 1973, pp. 28-34.
2/ Ibid.
3/ The application for this patent was pending in the U.S. Patent Office for more than 6 years (June 1, 1954, to Aug. 16, 1960).
4/ Respondents' brief filed Apr. 20, 1973, p. 12.

patent by virtue of the fact that the Wurlitzer pick-up structure is made up of four separate parts instead of one pick-up running for the entire length of the keyboard. 1/

U.S. Patent No. 3,154,997.--Respondents' attorney contended that (1) the issues regarding U.S. Patent No. 3,154,997 are moot, (2) U.S. Patent No. 3,154,997 is not now being infringed and has never been infringed by the Electrokey reed, and (3) U.S. Patent No. 3,154,997 is in any event invalid. 2/

It was pointed out at the hearing that since August 1972 respondents have utilized an alternate reed having a single radius fillet, as illustrated in the prior art. 3/

The position taken by respondents' attorney was that the claims of this patent are restricted to a reed wherein the "curved inward taper" is noncircular, whereas the "curved inward taper" of respondents' reed, being made up of two circle segments, is circular. 4/

Respondents' attorney also contended that this patent was invalid because of obviousness 5/ and because the specifications of the patent do not contain a clear description of the invention, set forth the best mode contemplated by the inventor for carrying out his invention,

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1/ Transcript of the hearing, pp. 473, 478, and 491. The same point was made in respondents' brief filed Sept. 18, 1974, p. 5.

2/ Respondents' brief filed Apr. 20, 1973, pp. 34-37.

3/ Transcript of the hearing, pp. 311-312; and see affidavit of Tommy Moore filed with the Commission on May 20, 1974 (app. M).

4/ Ibid., pp. 307-309. An examination of the prosecution history of this patent reveals that the curve in the invention is not a circular arc. In the application of Harold E. W. Bode No. 228103, Amendment dated Feb. 18, 1964, p. 4, par. 3 says:

> Accordingly, the 3 original claims, as now amended, are submitted to be allowable. New claim 6 depends from claim 3, and is allowable for the same reasons. In addition, the curve in the present invention is not a circular arc, and this is positively brought out in claim 6. Thus, claim 6 is further allowable.

5/ Respondents' brief filed Apr. 20, 1973, p. 35. This condition of patentability is set forth in 35 U.S.C. 103.

or conclude with claims particularly pointing out the subject matter of his invention. 1/

Respondents' attorney did not address himself to the matter of domestic production under the claims in this patent at the hearing held on August 15, 1974. 2/

The question as to the validity of the patents.--In his brief, respondents' attorney indicated that "respondents are aware of the limitations of a Tariff Commission hearing relative to patent validity." 3/ Respondents did not place the issue of invalidity before the Commission (except in the case of U.S. Patent No. 3,154,997, the Bode patent) and instead requested that the Commission consider the fact that the validity of these patents is seriously in question in a law suit to which complainant and all the respondents are parties. 4/

1/ Respondents' brief filed Apr. 20, 1973, p. 35. The conditions of patentability referred to are set forth in 35 U.S.C. 112.

2/ The notice issued on July 17, 1974, by the Commission, which ordered this hearing, did not refer to U.S. Patent No. 3,154,997.

3/ Respondents' brief filed Apr. 20, 1973, p. 36.

4/ Ibid., p. 40. See section in this report entitled "Litigation History," wherein it is indicated that the U.S. District Court for the Northern District of Texas found infringement of the claims in U.S. Patent Nos. 3,038,363 and 2,942,512, ruled that U.S. Patent No. 2,949,053 was not infringed, and ruled that U.S. Patent No. 3,154,997 was invalid.

The evidence presented as to "copying"

Complainant's contentions.--In its complaint before the Commission, complainant alleged that early in the 1960's, incident to negotiations between complainant and Nippon Columbia, Ltd., looking toward the licensing of complainant's patent--

> . . . technical representatives of Nippon Columbia came to the United States with the objective of obtaining from Complainant's engineering and manufacturing personnel (concerned with the development and production of the electronic piano) information as to the technology involved. 1/

Complainant also alleged that in February 1964 Nippon Columbia broke off negotiations and that in or about 1970 respondents "commenced the importation into the United States from Japan of electronic pianos which, in appearance, strongly resemble Complainant's product . . . ." 2/

Complainant alleged that this constitutes an unfair and injurious act within the meaning of section 337 of the Tariff Act of 1930, 2/ but at the hearing complainant's attorney indicated that this issue was irrelevant and that he would not press it. 3/

1/ Complaint of The Wurlitzer Co. filed with the Commission on Mar. 6, 1972, p. 3.
2/ Ibid.
3/ Transcript of the hearing, p. 5.

Respondents' contentions.--Respondents' attorney contended that the claim of "copying" alleged in the complaint is groundless in fact and in law. 1/ He maintained that respondents' electronic pianos were developed by Nippon Columbia, Ltd., independently and that no copying of complainant's structure was involved. 2/ He indicated that a certain Mr. Ohizume developed this type of piano in Japan in 1960, that Mr. Ohizume acquired the capital to manufacture it by entering into a joint venture with Nippon Columbia, and that a revised model of this electronic piano was ready by 1966. 2/ He conceded that Nippon Columbia had brought one of complainant's electronic pianos into Japan in 1962-63 and that Nippon Columbia "looked at it . . . probably made an engineering analysis of it"; however, he maintained that Nippon Columbia already possessed the know-how, saw nothing it wanted to emulate in complainant's model, and was more concerned about whether complainant had filed its patents for electronic pianos in Japan. 2/

1/ Respondents' submission filed with the Commission on May 11, 1972, pp. 12-15.
2/ Transcript of the hearing, pp. 225-230.

Litigation History

On May 12, 1971, complainant filed a civil action in equity for patent infringement against Chicago Musical Instrument Co. (one of the respondents named in the Tariff Commission proceeding) in the U.S. District Court for the Northern District of Illinois. At a later date this action was transferred to and consolidated with another action brought by complainant against the remaining respondents in the U.S. District Court for the Northern District of Texas (C.A. No. 3-4803C).

This action came to trial before Judge W. M. Taylor, Jr., during October 1973. Subsequent to the trial, complainant's and respondents' proposed findings of fact and conclusions of law were filed with the court. On August 23, 1974, the court handed down its opinion. 1/

The issues brought before the court involved respondents' alleged infringement of the same claims in the same four patents involved in the Tariff Commission proceeding. The court held that--

(1) Claims 3-9 in U.S. Patent No. 3,038,363 were infringed by respondents' pianos. The rationale given by the court was that "a single pick-up element" meant single electrically as well as single mechanically--electrical integration produced the cumulative capacitance disclosed in the specifications of the patent. Although the patent disclosure indicates the desirability of having a solid pick-up, it also discloses that the pick-up may have screws, arms, and the like attached to it to act as sensing devices. Thus, respondents' pianos, in which the pick-up is made of a number of parts, are covered by the claims in this patent.

1/ This opinion is reproduced in app. N.

(2) Claims 1, 2, 6, and 9 in U.S. Patent No. 2,942,512 were infringed by respondents' pianos. The rationale given by the court was that (a) the cited reference (U.S. Patent No. 2,542,611) for disclosing a pick-up alongside an edge portion of the reeds relates to an organ patent, not a piano patent; (b) the subject patent relates peculiarly to electronic pianos; (c) the subject patent teaches more than the admitted obviousness of achieving greater volume by surrounding the end of the reed with a pick-up--it teaches the positive effects of dynamic shortening. 1/

(3) Claims 1-5 in U.S. Patent No. 2,949,053 were not infringed by respondents' pianos. The rationale given by the court was that the claims in this patent looked towards a pick-up structure that could be built in simple operations by machinery. Respondents' product was made up of many parts and assembled by hand; it was not a machine-made monolithic structure.

(4) The claims in U.S. Patent No. 3,154,997 were invalid. The rationale given by the court was that as early as 1934, methods of minimizing stress in fillets were known in the art. Bode disclosed nothing new.

Respondents' attorney indicated that respondents will appeal this decision to the U.S. Court of Appeals for the Fifth Circuit. 2/ On December 16, 1974, respondents filed a notice of appeal to the Fifth Circuit.

1/ Complainant's brief filed Apr. 20, 1973, p. 9.
2/ Respondents' brief filed Sept. 18, 1974, p. 2.

The Definition of the Domestic Industry Concerned

At the hearing held on August 15, 1974, the Commission requested the attorney for complainant and the attorney for respondents each to define the domestic industry affected by imports of the allegedly infringing pianos.

Complainant's attorney contended that the industry in question was limited to The Wurlitzer Co., since it was the only domestic manufacturer of electronic pianos with electrostatic type pick-ups covered by the claims of the patents in issue. 1/ He also contended that none of the 10 patents introduced into the hearing record by the Commission, 2/ when taken individually, teach the inventions disclosed and claimed in these patents. 3/

Respondents' attorney contended that the domestic industry in question was not limited to The Wurlitzer Co. but included also Fender-Rhodes, Baldwin, and Musitronics. 4/ He took the position that the definition of the industry as the production under the claims of the patents in issue

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1/ Transcript of the hearing, pp. 382 and 450-453.

2/ The patents introduced into the hearing record as collective exhibit no. 25 by the Commission were U.S. Patents Nos. 2,015,014 (Hoschke), 2,187,251 (Severy), 2,318,936 (Fisher), 2,487,420 (Brown), 2,510,094 (Fleury), 2,532,038 (Sebouh), 2,581963 (Langloys), 140,814 (Salt), 401,537 (Palmgren), and 434,421 (Midgley).

3/ Transcript of the hearing, pp.373-380. See also complainant's brief filed on Sept. 11, 1974, pp. 9-12.

4/ Transcript of the hearing, pp. 453-457. Later in the course of the hearing respondents' attorney seemed to concede that Musitronics, which produced electronic organs, not electronic pianos, was not part of the domestic industry for purposes of this case (transcript of the hearing, pp. 458-459).

is unduly narrow and maintained that the industry must be defined in terms of real market competition. 1/ He contended that even if the domestic industry was limited to The Wurlitzer Co., there would be none because there was no production under the claims of the patents in issue when these claims are properly construed. 2/ He indicated that the 10 references introduced into the hearing record by the Commission each disclosed individual elements found in the claims of the patents in issue (although he conceded that not one of the cited references included all of the elements disclosed in U.S. Patent No. 3,038,363) and alleged that the claims in the patents in issue should be regarded as being limited by these references and by other references cited in the "Pertinent Content Analysis of Prior Art Patents" which he introduced into the hearing record. 3/

1/ Transcript of the hearing, pp. 454-455.
2/ Respondents' brief filed on Sept. 18, 1974, pp. 5-6.
3/ Transcript of the hearing, pp. 464-473. The "Pertinent Content Analysis of Prior Art Patents" is reproduced in app. L.

U.S. Imports

U.S. imports of electronic pianos are dutiable under item 725.47 of the Tariff Schedules of the United States (TSUS) as "other" electronic musical instruments at a rate of 17 percent ad valorem. This rate was not reduced in the sixth (Kennedy) round of trade negotiations conducted under the General Agreement on Tariffs and Trade; it has been 17 percent since the effective data of the TSUS (Aug. 31, 1963).

Official statistics do not provide separate data on imports of electronic pianos. The imports from Japan, however, all by Electrokey, Inc., are known to comprise by far the bulk of the total. They increased from 1,201 units in 1970, when they were first of consequence, to 2,741 units in 1971, but they declined to 1,300 units in 1973 and to only 200 units in January-June 1974, as shown in the table below.

Electronic pianos: U.S. imports for consumption from Japan, 1969-73 and January-June 1974

Period	Number	Value	Unit value
1969	75	$10,935	$145.80
1970	1,201	158,895	132.30
1971	2,741	364,621	133.85
1972	1,860	284,803	153.12
1973	1,300	214,807	165.24
1974 (January-June)	200	48,808	244.04

Source: Compiled from data furnished the U.S. International Trade Commission by the importer, Electrokey, Inc.

The unit value of imports (before duty and other costs of importation) increased from $134 in 1971 to $165 in 1973 and to $244 in January-June 1974. The decline in imports is attributable to the increase in price as well as to the patent suit by Wurlitzer (filed in May 1971) and the present investigation (begun in March 1972).

After the decision of the district court in the patent suit, Electrokey announced in September 1974 that, except for 200 pianos then on order, it would cease importing electronic pianos unless or until the decision of the district court was reversed or a license was granted. 1/

Shipments of electronic pianos by Nippon Columbia, the foreign producer of Electrokey pianos, began in the Japanese home market as early as 1962. Exports, nearly all to the United States, commenced in 1969.

U.S. Importers

Electrokey, Inc.

Electrokey, Inc., situated in Fort Worth, Tex., is sole importer of the Japanese electronic piano. Rhythm Band, Inc., named with Electrokey in the complaint, is in the same premises and under the same ownership as Electrokey. Sales are made primarily to schools and, to a lesser extent, to teachers.

The Chicago Musical Instrument Co. (CMI), situated in Chicago, Ill., named by the complainant along with the others as a respondent, was national distributor of Electrokey electronic pianos (under the brand name

1/ Respondent's brief filed Sept. 18, 1974, p. 8.

"Maestro") to retail outlets. Maestro sales increased in 1971, when they accounted for a considerable part, although much less than half, of domestic consumption; they declined in 1972, however, and dropped sharply in 1973, when CMI decided to halt all purchases of Electrokey pianos.

Other importers

Farfisa.--Imports of the Farfisa electronic piano, from Italy, began in 1970 and are relatively small. Farfisa was distributed in the United States exclusively by CMI until late 1973 and is presently distributed by its own sales organization, located in Chicago, Ill. The Farfisa electronic piano contains a 61-note keyboard and is similar in appearance to a portable electronic (chord) organ. The Farfisa piano does not utilize an electrostatic pick-up, and is not included in the complaint by Wurlitzer.

Hohner.--Imports of the Hohner electronic piano, formerly manufactured in West Germany, began in 1970 but ceased in 1972 when production was terminated. The Hohner electronic piano contained a 72-note keyboard, weighed approximately 148 pounds, and was similar in appearance to the Electrokey Maestro instrument. The Hohner piano does not utilize an electrostatic pick-up and, like the Farfisa, was not the subject of complaint by Wurlitzer.

The Wurlitzer Co.

Corporate operations

The Wurlitzer Co., the complainant, is a diversified firm established in 1856, with manufacturing operations in the United States producing pianos, electronic pianos, and electronic organs. Wurlitzer produces electronic organs in its Corinth, Miss., establishment and electronic pianos in establishments in Holly Springs, Miss., and Logan, Utah. Keys and actions for electronic pianos are produced in the Holly Springs plant for assembly into complete instruments in the Logan facility. Wurlitzer has seven foreign subsidiaries, six of which are selling organizations. The seventh produces electronic organs, coin-operated phonographs, vending machines, and auxiliary equipment for the foreign market. Wurlitzer operates 42 retail stores, mainly in eastern and midwestern metropolitan cities and suburban areas. The Wurlitzer line of pianos and electronic pianos is sold through about 800 independent music merchants in the United States and abroad, as well as through the company's own stores. Net sales of all articles by The Wurlitzer Co. incrased steadily from $57 million in 1970 to $72 million in 1972 and to $90 million in 1974. 1/ Electronic pianos accounted for about 3 percent of the total. 2/ Total employment by Wurlitzer in 1973 was about 4,000 persons, of which between 50 and 100 were engaged in the manufacture of electronic pianos.

Production and sales of electronic pianos

The marketing of electronic pianos by Wurlitzer started in 1955. The Holly Springs establishment, where keys and actions are produced along with conventional pianos, is a 205,000-square foot structure, built in 1961, with later expansions; it is considered one of the most modern plants of its type in the entire piano industry. The Logan plant,

1/ Fiscal year ending Mar. 31.
2/ Transcript of the hearing, p. 142.

where electronic pianos are assembled, is a plant like that at Holly Springs, but primarily engaged in the manufacturing of conventional pianos. It was completed in September 1971 and has 200,000 square feet of space.

Unit sales of electronic pianos by Wurlitzer approximately doubled from 1967 to 1972 and increased 12 to 15 percent from then to mid-1974. Dollar sales increased nearly 200 percent from 1967 to 1972 and increased 50 percent from then to mid-1974; an increase in quantity was accompanied by a difference in the mix of pianos, as well as an increase in the price. 1/

Sales have been buoyed by a strong upward trend in consumption in recent years, with growing realization of the potentialities in professional as well as educational use.

Profit-and-loss and other financial data

The Wurlitzer Co. of Chicago, Ill., submitted complete financial statements for the fiscal years 1967-73. The financial statements contained profit-and-loss data on global company operations, total domestic operations, and operations covering the manufacture and sale of electronic pianos. Total company sales increased from about $60 million in fiscal year 1967 to about $90 million in fiscal 1973. The net profit before income taxes on global company operations was about $3.4 million in fiscal 1967, $3.9 million in 1968, $2.6 million in 1969, $2.3 million in 1970, $3.9 million in 1971, and $4.2 million in 1972. There was a net loss of $11.3 million in fiscal 1973, chiefly from disposal of Wurlitzer's coin-operated-phonograph production facilities

1/ Transcript of the hearing, pp. 30, 430, and 431.

in the United States.

Wurlitzer's sales of electronic pianos have increased markedly in the last few years. In the fiscal year ended March 1972, when they were about 3 percent of the company's total sales ($72 million), sales of electronic pianos were half again as large as in 1971, 1/ and they increased with the increase in total sales by Wurlitzer in 1973 and 1974.

Wurlitzer has realized a profit on its electronic pianos, though not on its total sales, in every recent year, but the margin has varied widely. Its pretax profits on electronic pianos amounted to 20 percent of sales in the fiscal year ended March 31, 1967. Such profits dropped sharply in 1968 because of a complete reengineering, recovered to about 15 percent of sales in 1969, then drifted down to about 4 percent of sales in the year ended March 31, 1972. The reduced ratio in 1970-72 is attributed to costs incurred in the transfer of production from DeKalb, Ill. to Logan, Utah, as well as to the inability to raise prices in the face of import competition. Consolidation of operations on electronic pianos in the new plant at Logan was achieved during the year ended March 31, 1972. 2/ The profits amounted to 10 percent of sales in 1973 but dropped to 6 percent in 1974. The reduction in 1974, when imports were hardly a factor, was attributed to the expense in launching a new corporation, WEPCO, for sales to schools. 3/

1/ Transcript of the hearing, pp. 18, 142, and 169.
2/ Ibid., pp.30-31.
3/ Ibid., p. 431.

Other U.S. Producers

Baldwin

The Baldwin Electropiano is produced by Baldwin Piano & Organ Co., a subsidiary of D. H. Baldwin, Inc., Cincinnati, Ohio, in its Fayetteville, Ark., plant. Production began in September 1968. One of the two models manufactured has a 64-note keyboard, and the other, an 88-note keyboard. Unlike other electronic pianos, the Baldwin contains strings instead of metal reeds; this piano does not utilize an electrostatic pick-up. The sound from the strings is picked up and amplified electronically. The piano is similar to a small spinet, having a formica case with walnut or driftwood finish. A console attachment accommodating as many as 24 students can be used with either model in group instruction. The Baldwin is much higher priced than the Wurlitzer electronic piano.

Rhodes

The Rhodes electronic piano has been produced by CBS Musical Instruments Division of CBS, Inc., Fullerton, Calif., since manufacture began in 1965. It uses rods rather than reeds and has electromagnetic pick-ups with a separate core and winding for each vibratory rod; this piano does not utilize an electrostatic pick-up. The piano has a 73-note keyboard and can be used as a teaching instrument in group instruction. In 1974 Rhodes began the manufacture of a model containing an 88-note keyboard. The Rhodes electronic piano, like the Baldwin, is similar to a small spinet and is higher priced than the Wurlitzer electronic piano.

Prices

Electrokey, Inc.

About 80 percent of the pianos entered by Electrokey were consigned direct from Seattle, the port of entry, to Chicago Musical Instrument Co. (CMI) at Chicago, for sale to retailers. The remainder were consigned to Electrokey in Texas on large orders for delivery to schools and, to a very limited extent, to teachers. The price to CMI ranged from $192 to $243 a unit, and the price to schools and teachers ranged from $299 to $499 a unit. The price was lowest in 1970 and 1971 and increased rapidly from then until 1974, as shown in the table below. The period 1970-71, as has already been shown, was one of rapid increase in imports, and the period 1972-74, one of rapid decline.

Electronic pianos: Net prices charged by Electrokey, Inc., by sales outlet, on Mar. 1, 1969-74

Date	Sales outlet		
	CMI	Schools	Teachers
Mar. 1--			
1969	$200	$399	$399
1970	192	299	349
1971	198	299	349
1972	229	429	429
1973	243	449	449
1974	1/	499	499

1/ Orders ceased.

Source: Compiled from data submitted to the Commission by Electrokey, Inc.

The Wurlitzer Co.

Wurlitzer sells electronic pianos exclusively to retailers, which in turn sell to schools, teachers, and individuals. Most of the sales are made to 42 retail outlets owned by the concern. One model (No. 200), standing on detachable steel legs and having a 64-note keyboard, accounts for 70 percent of the sales. A second model (No. 206), having the same keyboard but resembling a small spinet, accounts for most of the remainder. The first of these was priced in 1966-67 at $235 wholesale and $390 retail. The second, a "school piano," was priced at $331 wholesale and $510 retail. The prices of both models have increased about 45 percent since 1967, as shown in the table below. Both models sold for more than the imported Electrokey piano, and the second of them, which most resembled the Electrokey in appearance, sold for a good deal more.

Wurlitzer electronic pianos: Wholesale and retail prices for leading models on specified dates, 1966-74

Item	1966-67	July 15, 1968	Nov. 16, 1970	Apr. 1, 1972	Oct. 8, 1973	Mar. 30, 1974
Model 200:						
Wholesale-----	$235	$291	$291	$315	$337	$344
Retail--------	390	485	485	525	565	575
Model 206:						
Wholesale-----	331	395	434	460	496	505
Retail--------	510	565	620	660	710	1/

1/ No suggested retail price established.

Source: Transcript of the hearing, pp. 27-29 and 428.

Consumption

Somewhat more than half of the electronic pianos sold in the United States are used for entertainment, and the rest, for instruction. Sales of such pianos, like those of keyboard instruments as a whole, have multiplied since 1969 but are believed to be far short of the potential. Educators stress the advantages of the electronic piano in periodic seminars conducted for teachers throughout the United States. In professional use, moreover, the electronic piano has peculiar advantages for transport and for composition and practice. The sales are still not one-twentieth as large, however, as those of either the electronic organ or the standard acoustical piano widely used in music schools and homes.

Evidence as to Injury

At the hearing held January 30-31, 1973, and August 15, 1974, complainant and respondents submitted evidence pertaining to the question of injury to the domestic industry under consideration, allegedly caused by the imported electronic pianos. The parties also submitted data pertaining to this issue in their briefs.

The evidence presented by complainant as to injury

Complainant's attorney elicited testimony from Mr. Roy W. Carlson, vice president and comptroller of The Wurlitzer Co., at the hearing held January 30-31, 1973, to the effect that pretax profits on electronic pianos dropped from 20 percent of sales in the year ended March 31, 1967 to about 5 percent of sales in the year ended March 31, 1972, even though sales had approximately doubled in the same time period. 1/ Mr. Carlson testified that the main reasons for the lower profit figure in 1970-72 were (1) the costs associated with transfers of production facilities from Corinth, Miss., to DeKalb, Ill., and from DeKalb, Ill., to Logan, Utah; (2) the increase in factory overhead per unit; and (3) the startup costs associated with the Logan, Utah, plant (which went into operation on March 31, 1972), which costs "are not yet down to target" 2/ (i.e., costs higher than anticipated average long-run costs).

Mr. Carlson further testified that profits on electronic pianos had not kept up with the volume of sales because complainant had not increased its prices. 2/ He conceded that phases I, II, and III of the

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1/ Transcript of the hearing, pp. 30-31 and 111-112. It should be noted that electronic pianos were first imported by respondents in 1969.

2/ Ibid., pp. 30-31.

U.S. Government's price-control program had had some effect on complainant's prices; however, he maintained that competition was the main reason complainant had not increased its prices prior to that time and at present. 1/

Complainant's attorney also elicited testimony from Mr. Morris C. Bristol, executive vice president and general counsel of The Wurlitzer Co., at the January 30-31 hearing to the effect that the only significant competition came from Electrokey 2/ and that complainant's dealers had lost contracts or bids for sale of electronic pianos to educational institutions. 3/

Complainant's attorney at the same hearing introduced into evidence a list of electronic piano sales lost by complainant because of price competition. 4/ He indicated that the lowest priced electronic pianos produced by complainant retail for $525 (for a portable model) and $645 (for a console model), as opposed to the Electrokey piano, which sells for about $400; 5/ that sales of electronic pianos, although slow at first owing to the reluctance of pianists and teachers to forsake conventional pianos, showed marked increases in the early 1970's, at which

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1/ Transcript of the hearing, pp. 30-31.
2/ Ibid., p. 37.
3/ Ibid., p. 35.
4/ Complainant's list (exhibit 7) contained the names of 12 educational institutions that allegedly purchased respondents' electronic pianos. The Commission through independent investigation obtained information from 11 of these institutions. Bids had been entered for both the imported and the domestic electronic pianos with only five of the institutions during the period in question. Four of these institutions purchased only imported electronic pianos, while one purchased both domestic and imported electronic pianos.
5/ Complainant's brief filed Apr. 20, 1973, p. 11.

time profits in no way kept pace with the dollar volume of sales; 1/ and that complainant had made substantial investments in the new Logan, Utah, plant which should ultimately reduce costs and increase profits. 1/ In addition, there was testimony to the effect that complainant would have attempted to raise prices, thereby getting a reasonable profit, had it not been for competition from the imported electronic pianos; 2/ that complainant's sales volume would have been greater than the expanded 1972 volume in the absence of foreign competition; 3/ and that it was complainant's policy not to capitalize startup costs such as those involved at the Logan, Utah, operations. 4/

Complainant's attorney discounted the competitive effect of electronic pianos produced by Baldwin, Rhodes, and Hohner, on the grounds that (1) they used electromagnetic and not the capacitive type of tone generators required by the claims of the patents in question and (2) complainant's product accounted for as much as 99 percent of the total number of electronic pianos manufactured by domestic sources. 5/ Complainant's attorney contended that section 337 does not require that a complainant be driven to the precipice of economic ruin, it being enough that the importer's action has tended to substantially injure the patent owner. 6/

1/ Ibid., p. 12.
2/ Transcript of the hearing, p. 106.
3/ Ibid., p. 105.
4/ Ibid., p. 119.
5/ Complainant's brief filed Apr. 20, 1973, p. 6.
6/ Ibid., p. 13.

At the hearing held on August 15, 1974, complainant's attorney elicited testimony from Mr. Roy W. Carlson to the effect that the ratio of pretax profit to sales of electronic pianos was 9.9 percent for the year ended March 31, 1973 and 5.7 percent for the year ended March 31, 1974, 1/ that unit sales during fiscal year 1974 were expected to be 12 to 15 percent above those in 1972, 2/ that dollar sales were currently four to five times greater than in 1967, 3/ and that the cause for the decrease in profit ability in 1974 was the unexpected expenses associated with setting up a separate corporation to market educational products such as complainant's electronic pianos. 4/

Mr. Carlson indicated at the hearing held on August 15, 1974, that because of a decrease in the number of units imported, imports of electronic pianos were not affecting complainant as much at that time as they had earlier. 5/ He also indicated that he agreed that Fender-Rhodes was in competition with Wurlitzer on electronic pianos in the "combo" market, 6/ though complainant's attorney had alleged in his brief that every sale made by respondents was one that would otherwise have been made by complainant. 7/

1/ Transcript of the hearing, p. 424.
2/ Ibid., p. 430.
3/ Transcript of the hearing, pp. 430-431.
4/ Ibid.
5/ Ibid., p. 435.
6/ Ibid., p. 432. The term "combo" designates a small musical ensemble.
7/ Complainant's brief filed Sept. 11, 1974, pp. 6-7.

The evidence presented by respondents as to lack of injury

Respondents' attorney contended that there is no evidence that the imported instruments afford significant competition to complainant, 1/ that the imported instruments were sold to different outlets and afforded a source for dealers that were not company owned or franchised by Wurlitzer, Baldwin, or Rhodes, 2/ that there is no credible evidence that complainant had lost any sales to respondents, 3/ and that complainant's sales and gross profits have increased over the years (especially the last 2 years). 4/ Respondents' attorney maintained that available data revealed that every domestic manufacturer of electronic pianos is prospering "in this large, relatively untapped, market" while, at the same time, sales of the imported electronic pianos have declined. 5/

Respondents (and their witnesses) contended at the hearing held January 30-31, 1973, that electronic pianos serve two principal markets--the console market and the portable market--and that the console market (i.e., the market for electronic pianos used for teaching) is principally served by consoles produced by complainant, respondents, Baldwin, Musitronics, and Fender-Rhodes. 6/ It was pointed out that complainant's sales of electronic pianos of the console type to teachers or schools accounted for only about 32 percent of its total sales of

1/ Respondents' brief filed Apr. 20, 1973, p. v.
2/ Transcript of the hearing, p. 198.
3/ Respondents' brief filed Apr. 20, 1973, pp. v-vi.
4/ Ibid.
5/ Respondents' brief filed Apr. 20, 1973, pp. v-vi.
6/ Transcript of the hearing, pp. 152-201.

electronic pianos, 1/ while respondents' sales of electronic pianos are confined almost exclusively to these purchasers. 2/ Therefore, it was argued by respondents' attorney, to the degree that imports do compete with complainant's electronic pianos, the imports could affect only a third of the total electronic piano sales made by complainant. 3/ Respondents' attorney elicited testimony from Mr. Neil Kjos, president, of Neil A. Kjos Music Co., Park Ridge, Ill., to the effect that an estimated potential institutional market of 1 1/2 million units exists for the electronic pianos in question. 4/ Mr. Kjos also gave the following testimony as to the effect of this large market on competition:

> It's as if the five makers of electronic pianos at this point are moving around on a vast ocean hardly in view of each other . . . an equation of a sale by one of the five makers as a loss of sales by another one of those makers is, I think, premature and perhaps absurd. It's our guess really that less than 1 percent of that $600 million potential market was sold by one of the five [electronic] piano manufacturers last year. 5/

Respondents' attorney urged the Commission to consider the industry in question to be composed of the manufacturers of electronic-piano-type keyboard instruments. 6/

1/ Ibid., pp. 134-135.

2/ Ibid., pp. 152-155 and 173. It should be noted, however, that the bulk of the Chicago Musical Instrument Co.'s sales took place at the retail level to individual purchasers.

3/ Respondents' brief filed Apr. 20, 1973 (confidential attachment), p. 57. It is also indicated in this brief that respondent's imports of electronic pianos accounted for approximately 11 percent of apparent domestic consumption in 1972.

4/ Transcript of the hearing, pp. 158-166.

5/ Transcript of the hearing, p. 162.

6/ Respondents' brief filed Apr. 20, 1973, p. 58.

Respondents' attorney elicited testimony at the hearing held January 30-31, 1973, to the effect that complainant's dealers had not (with one exception) even placed bids in those instances where complainant alleged it had lost sales to the allegedly infringing instruments. 1/

It was argued by respondents' attorney that in a situation where domestic producers' sales of electronic pianos are up and their gross profits are up (particularly where potential market sales volume has not begun to approach its maximum) the imports, whether infringing or not, cannot be said to have a tendency to destroy or substantially injure an efficiently and economically operated industry in the United States. 2/ He contended that between 1970 and 1971 complainant's electronic piano sales were up 82 percent in dollars and 91 percent in units, and that in 1972, after the imports had appeared on the market, complainant's sales were up from those in the preceding year by 54 percent in dollars and 63 percent in units. 2/ In contrast, respondents' sales of the imported electronic pianos were down 32 percent in dollars and 42 percent in unit volume in 1972, 3/ owing largely to the increase in the cost of the imported product caused by currency realinements and increases in freight costs. 4/

Respondents' attorney also contended that complainant's witness had conceded that the apparent drop in complainant's net profit before

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1/ Transcript of the hearing, pp. 156-182.
2/ Respondents' brief filed Apr. 20, 1973, pp. 63-67.
3/ Transcript of the hearing, p. 169.
4/ Ibid., p. 186.

taxes over the past 2 years was primarily due to complainant's practice of including startup costs only in the year in which they were incurred. 1/ Under these circumstances, he argued, it could not be said that sales of electronic pianos by respondents contributed to the lowering of complainant's profits. 1/

At the hearing held on August 15, 1974, respondents' attorney alleged that imports of electronic pianos had decreased drastically in 1973 and would be negligible in 1974, 2/ that the prices of the imported pianos had increased to the point where they were no longer competitive, 2/ that Electrokey lost the Chicago Musical Instrument Co. in 1973 and thus no longer had a distributor in the retail trade, 3/ and that the lawsuit instituted by complainant against respondents had further discouraged sales. 4/

The Efficiency and Economy of the Domestic Industry

On June 26, 1974, the Commission visited the Logan, Utah, facilities of the complainant, where the electronic pianos in question are currently produced. The portion of the facilities devoted to the manufacture and assembly of electronic pianos (covering an area of approximately 11,500 square feet) appeared to be modern, up to date, and well managed.

1/ Respondents' brief filed Apr. 20, 1973, pp. 64-65.
2/ Transcript of the hearing, p. 495.
3/ Ibid., p. 496.
4/ Ibid., pp. 496-497.

The evidence submitted by complainant to establish efficient and economic operation

There was testimony at the hearing held January 30-31, 1973, to the effect that the manufacture of electronic pianos had now been consolidated at the new Logan, Utah, plant and that it was an "up to the minute" operation. 1/ There was also testimony to the effect that this plant was built for the very reason that complainant's facilities would thereby be more efficiently and economically operated. 2/

At the hearing held on August 15, 1974, Mr. Roy W. Carlson testified that complainant had brought in management consultants to improve the efficiency of its electronic-piano plant; he also maintained that complainant had instituted an incentive system for direct labor and noted that labor efficiency had improved considerably. 3/

The evidence submitted by respondents to negate the allegation of efficient and economic operation

Respondents' attorney, in cross-examining Mr. Roy W. Carlson at the hearing on January 30, 1973, elicited the following testimony pertaining to the efficiency and economy of complainant's operations in 1971-72:

> . . . we were not efficient. We were starting out. We were aiming towards efficiency. 4/

At the hearing held on August 15, 1974, respondents' attorney offered no evidence relative to this issue.

1/ Transcript of the hearing, pp. 18-19.
2/ Ibid., p. 101.
3/ Ibid., p. 424.
4/ Transcript of the hearing, p. 117.

APPENDIX A
U.S. PATENT NO. 3,038,363
(MIESSNER)

June 12, 1962 B. F. MIESSNER 3,038,363

ELECTRONIC PIANO

Original Filed June 22, 1950 13 Sheets-Sheet 1

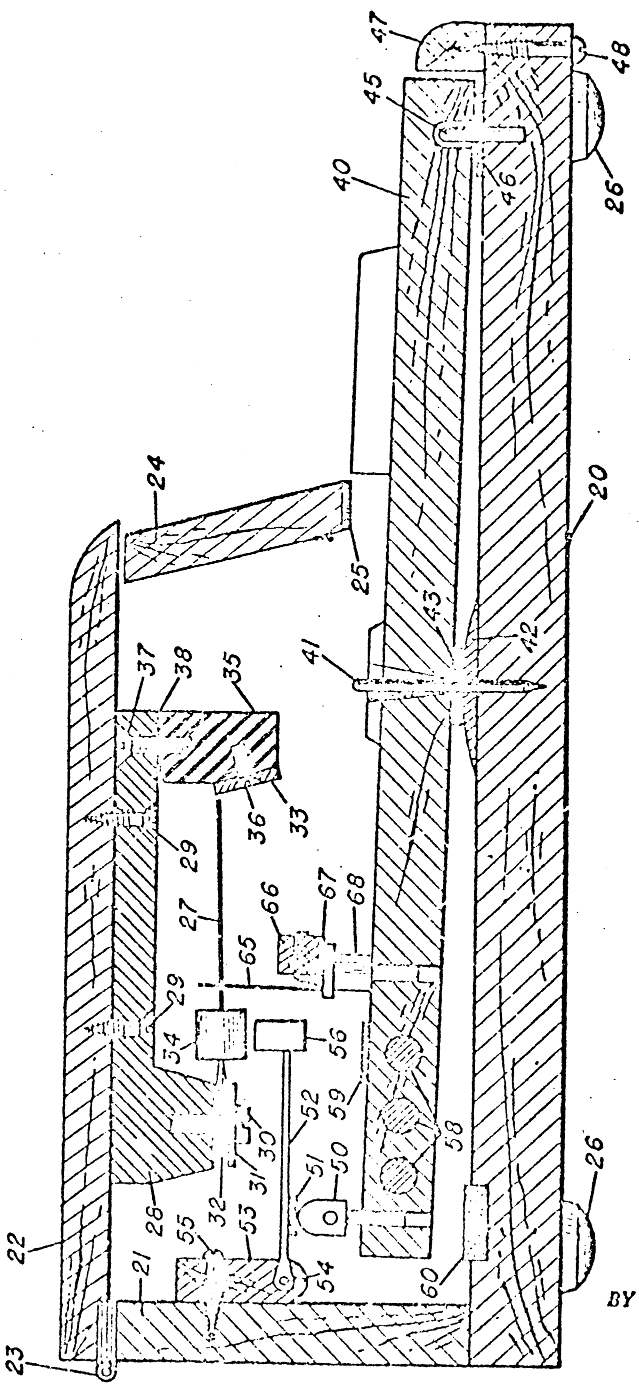

Fig-1

BENJAMIN F. MIESSNER
INVENTOR.

BY Rudolph J. Gluick
ATTORNEY

June 12, 1962 B. F. MIESSNER 3,038,363
ELECTRONIC PIANO
Original Filed June 22, 1950 13 Sheets-Sheet 2

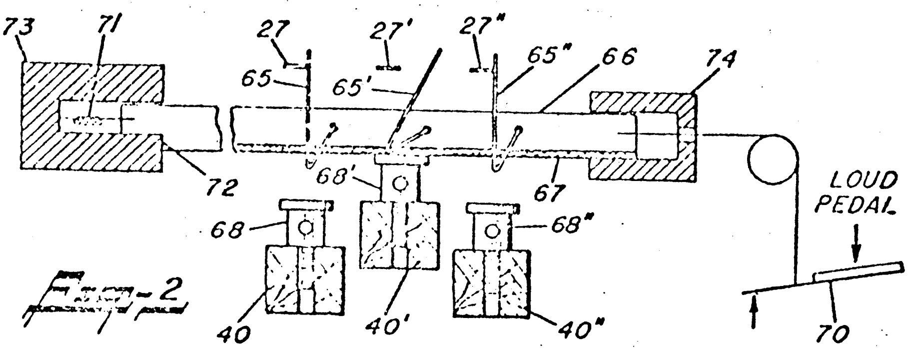

Fig-2

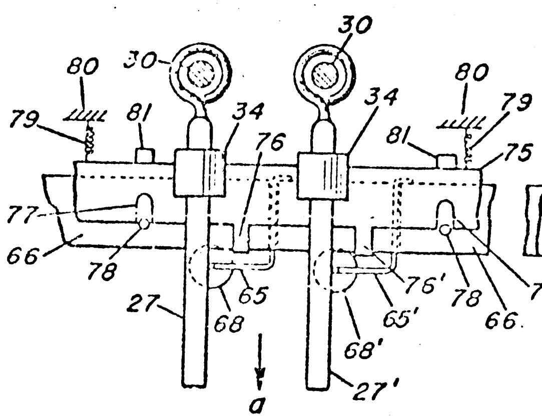

Fig-3

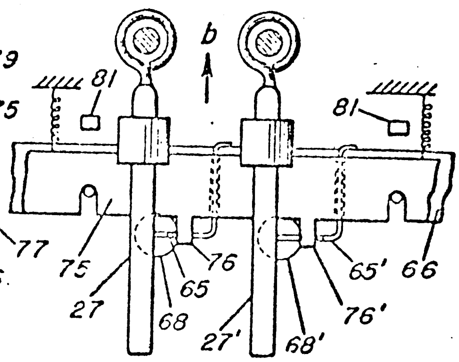

Fig-4

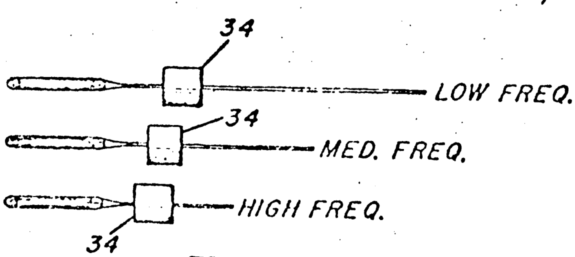

Fig-5

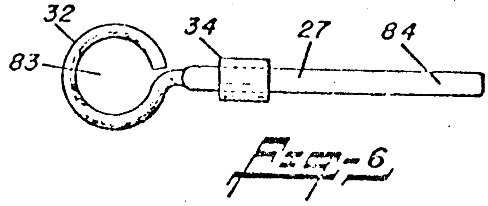

Fig-6

BENJAMIN F. MIESSNER
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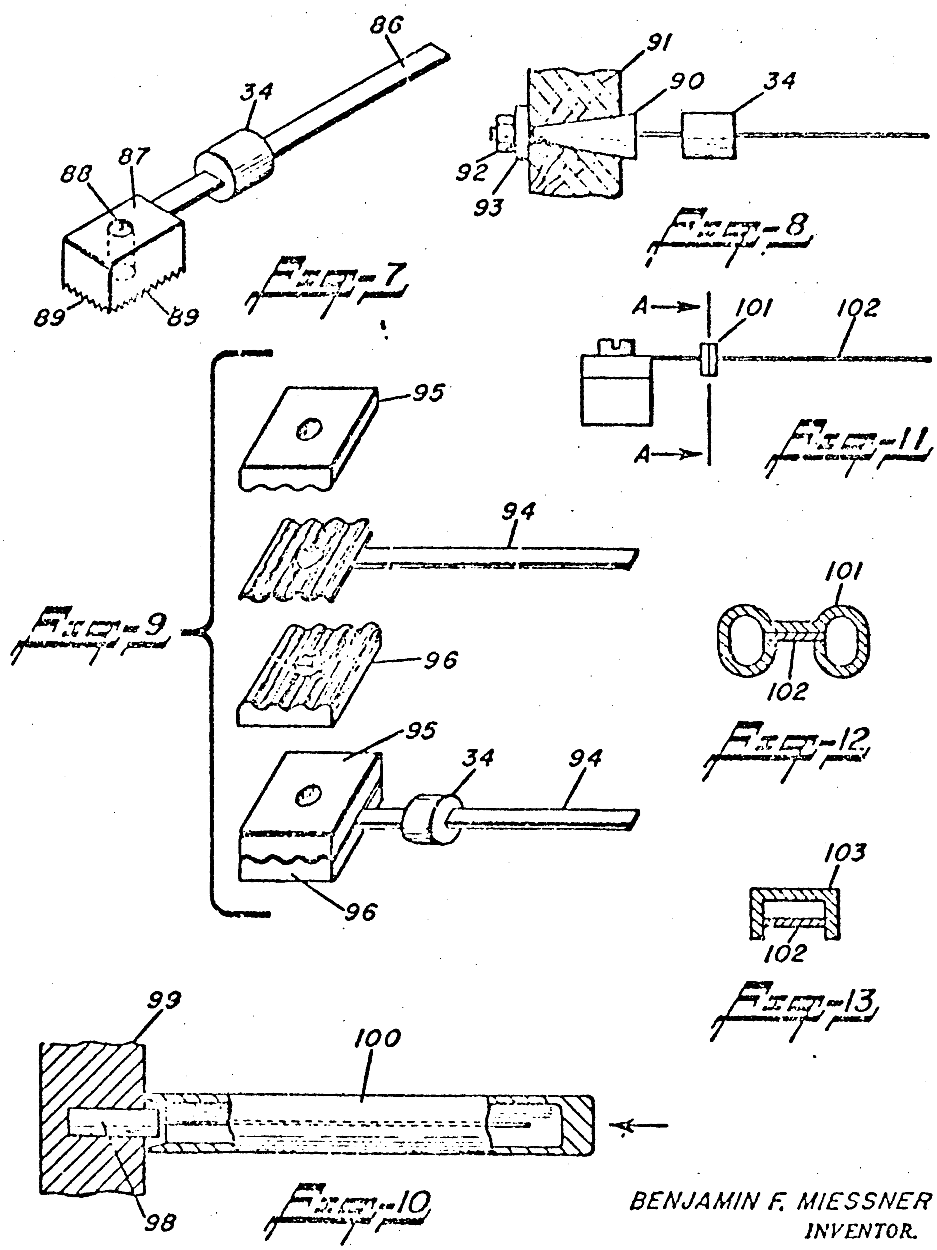

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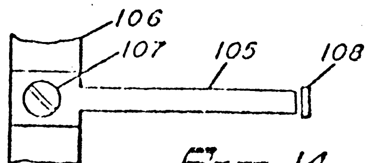

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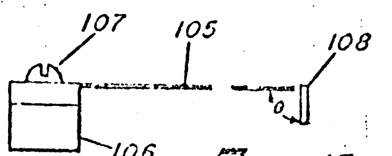

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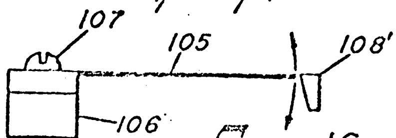

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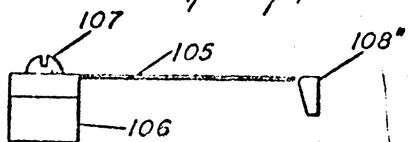

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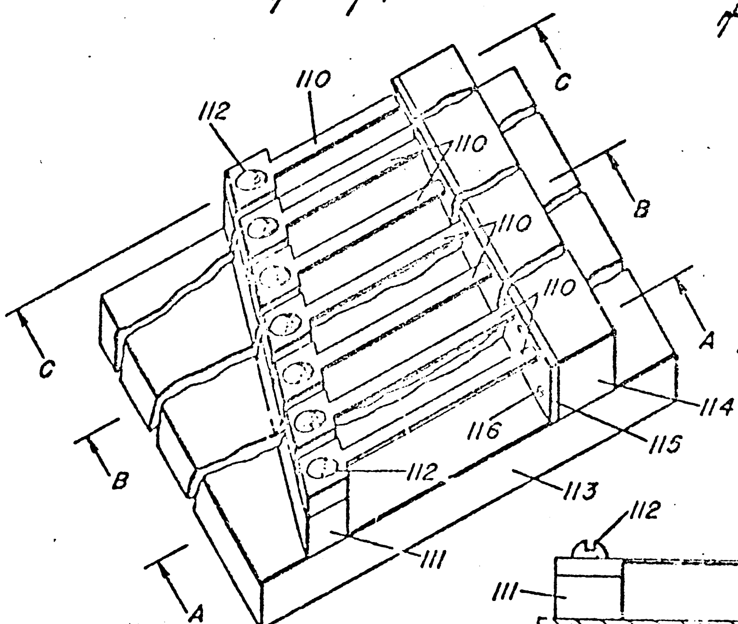

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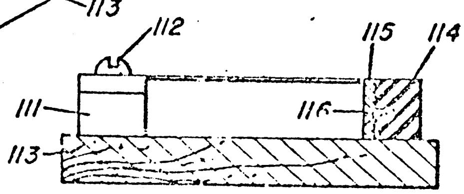

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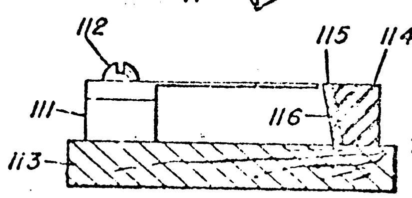

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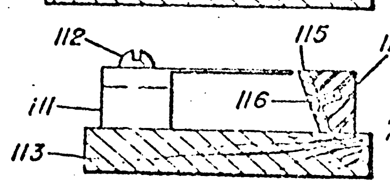

Fig-21

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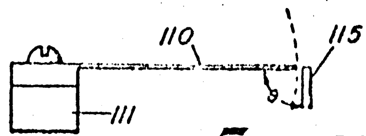

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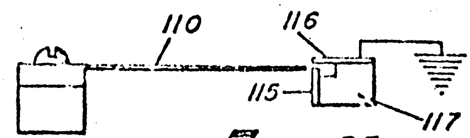

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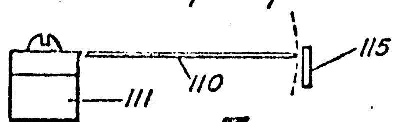

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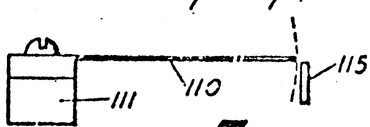

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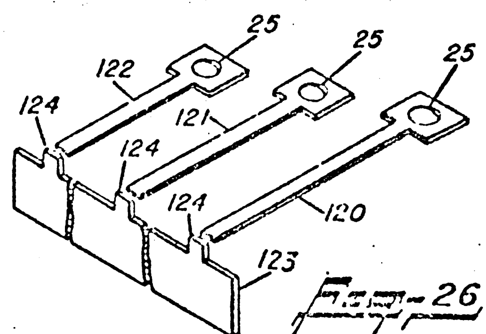
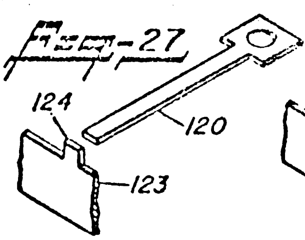
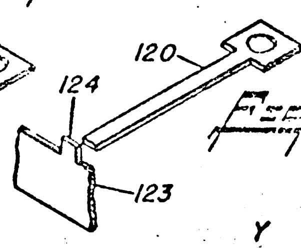


Fig-26

Fig-27





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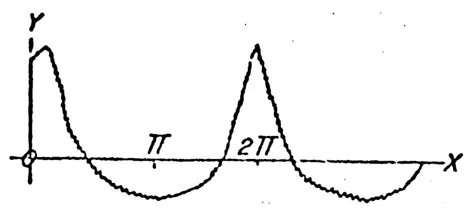

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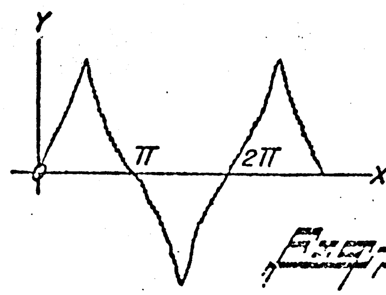

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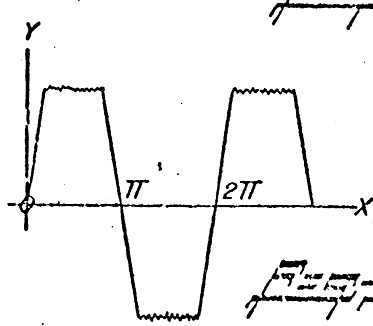

Fig-30

BENJAMIN F. MIESSNER
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June 12, 1962 B. F. MIESSNER 3,038,363

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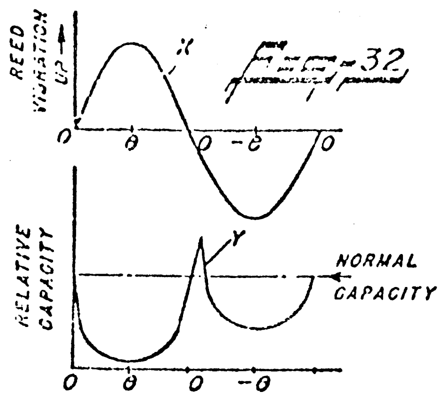

Fig-32

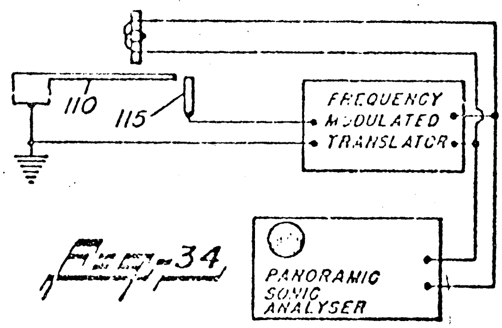

Fig-34

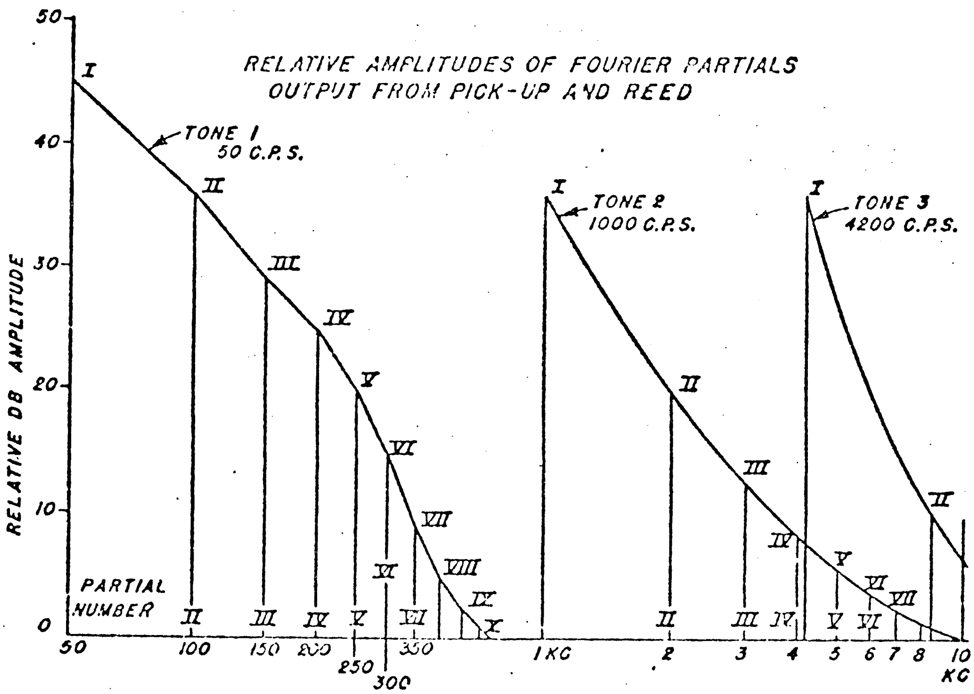

Fig-33

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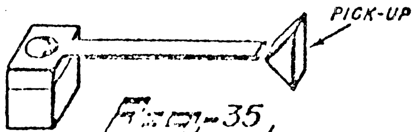
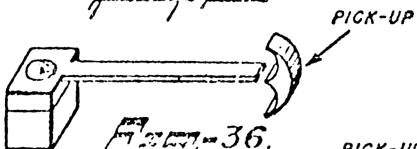


Fig-35



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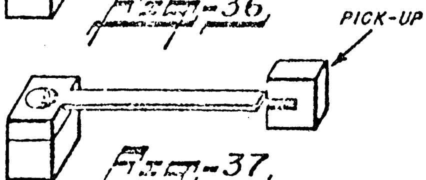

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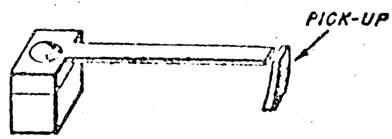

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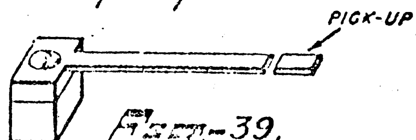

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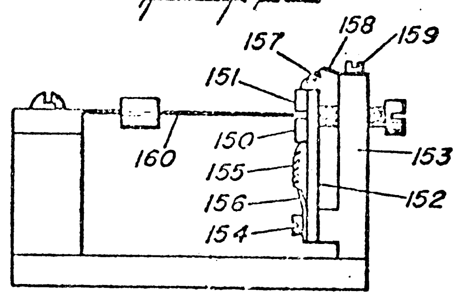

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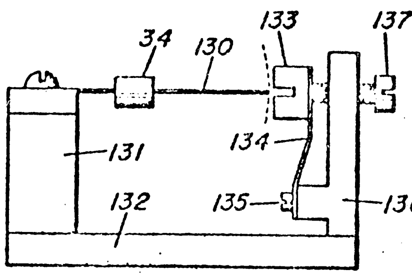
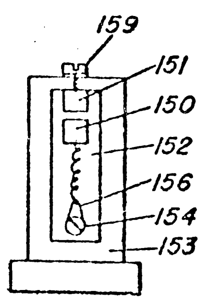


Fig-40

Fig-42



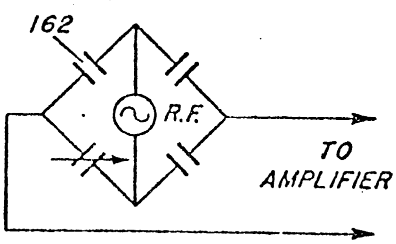


Fig-43

BENJAMIN F. MIESSNER
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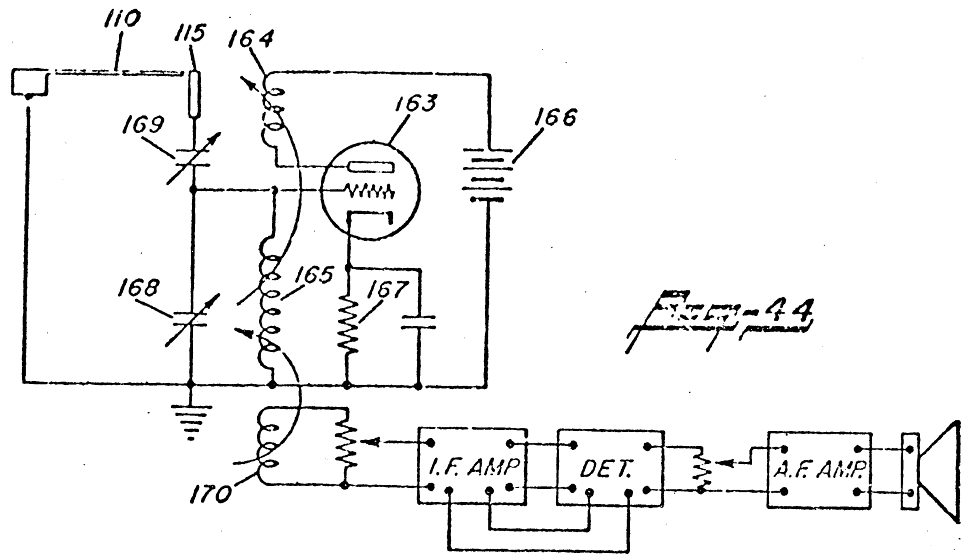

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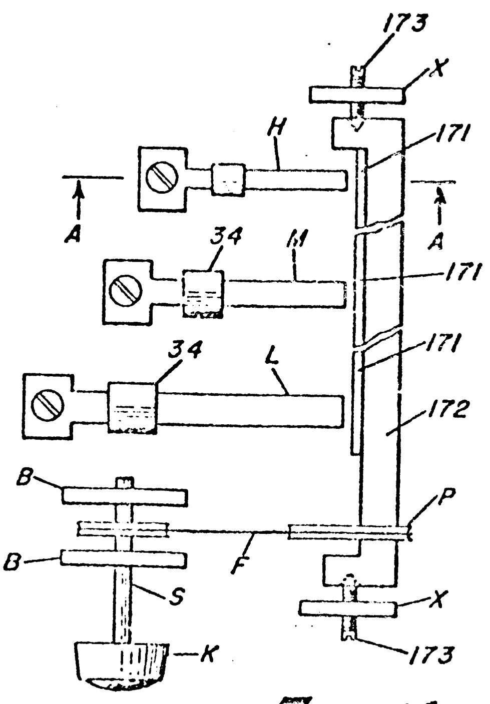

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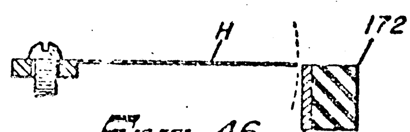

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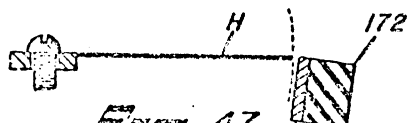

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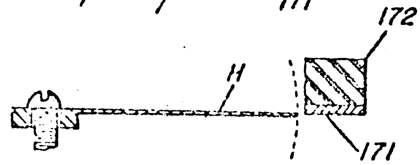

Fig-48

BENJAMIN F. MIESSNER
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June 12, 1962 | B. F. MIESSNER | 3,038,363

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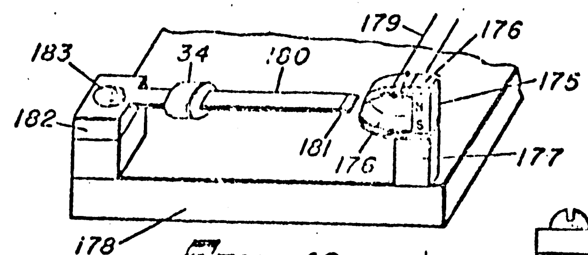

Fig-49

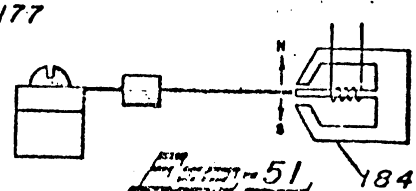

Fig-51

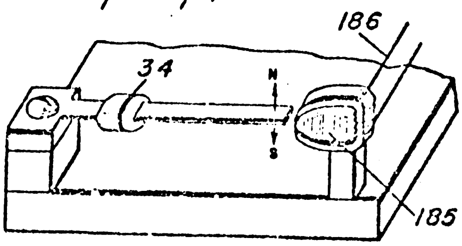

Fig-50

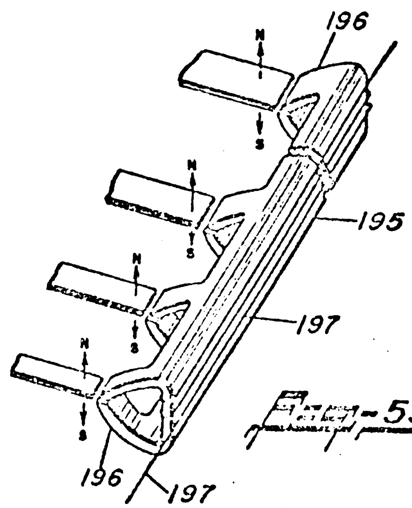

Fig-53

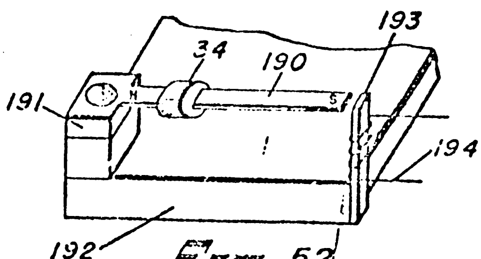

Fig-52

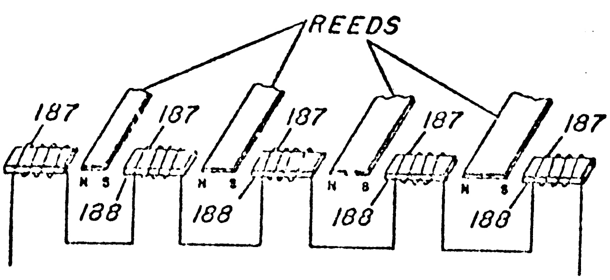

Fig-54

BENJAMIN F. MIESSNER
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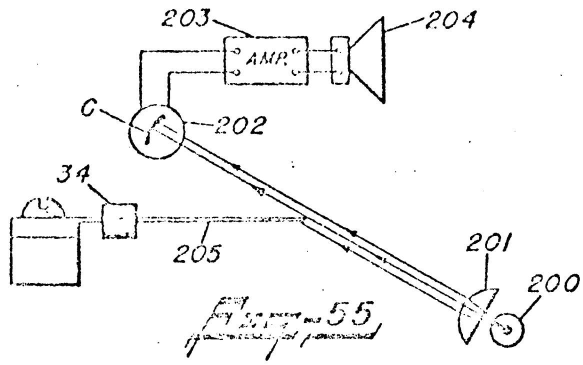


Fig-55

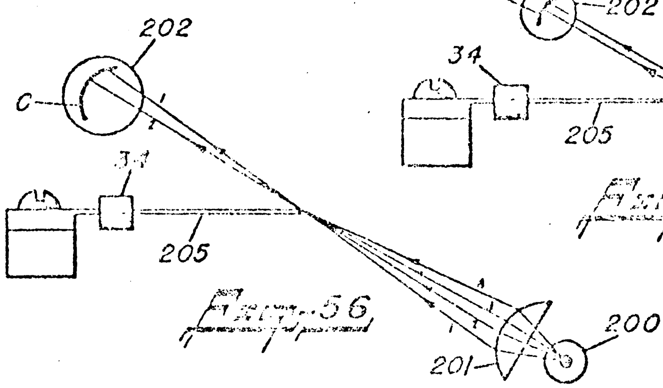
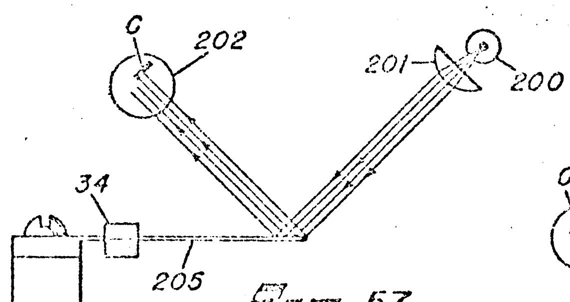


Fig-56



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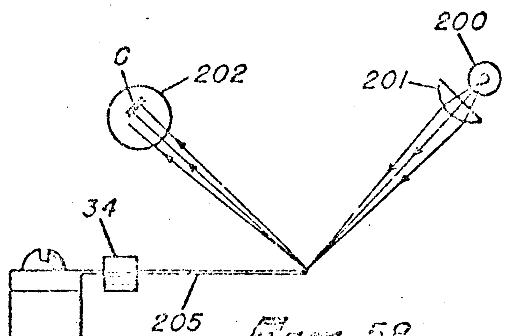

Fig-58

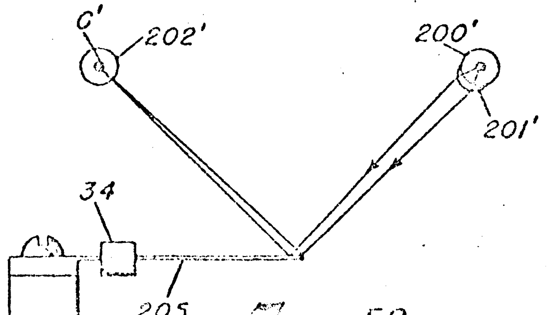

Fig-59

BENJAMIN F. MIESSNER
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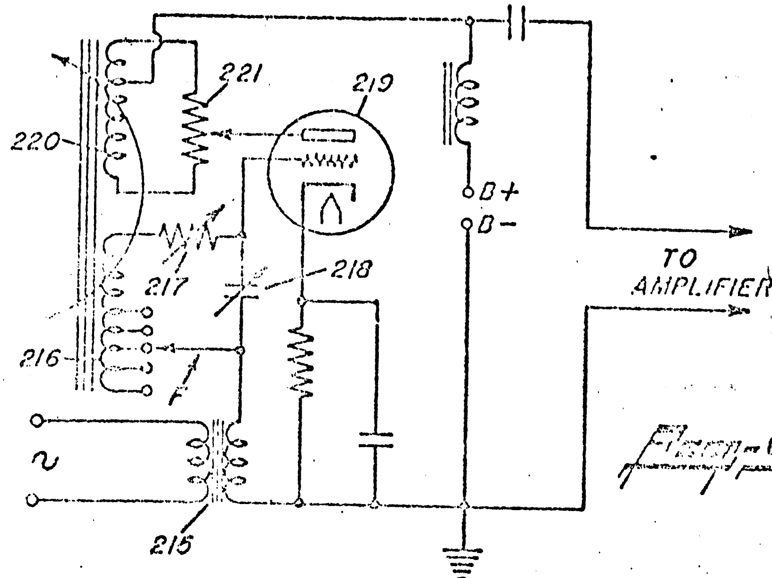
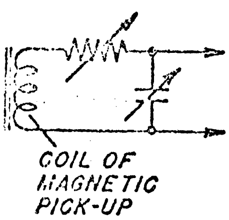


Fig-60



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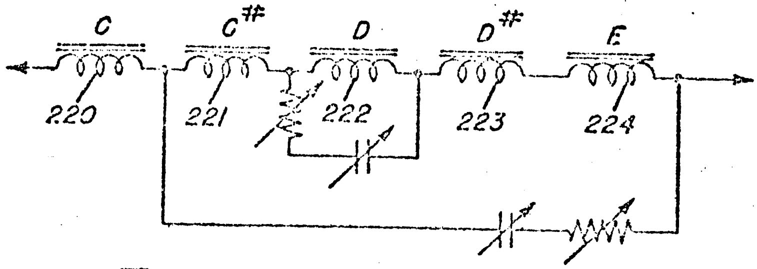

Fig-62

BENJAMIN F. MIESSNER
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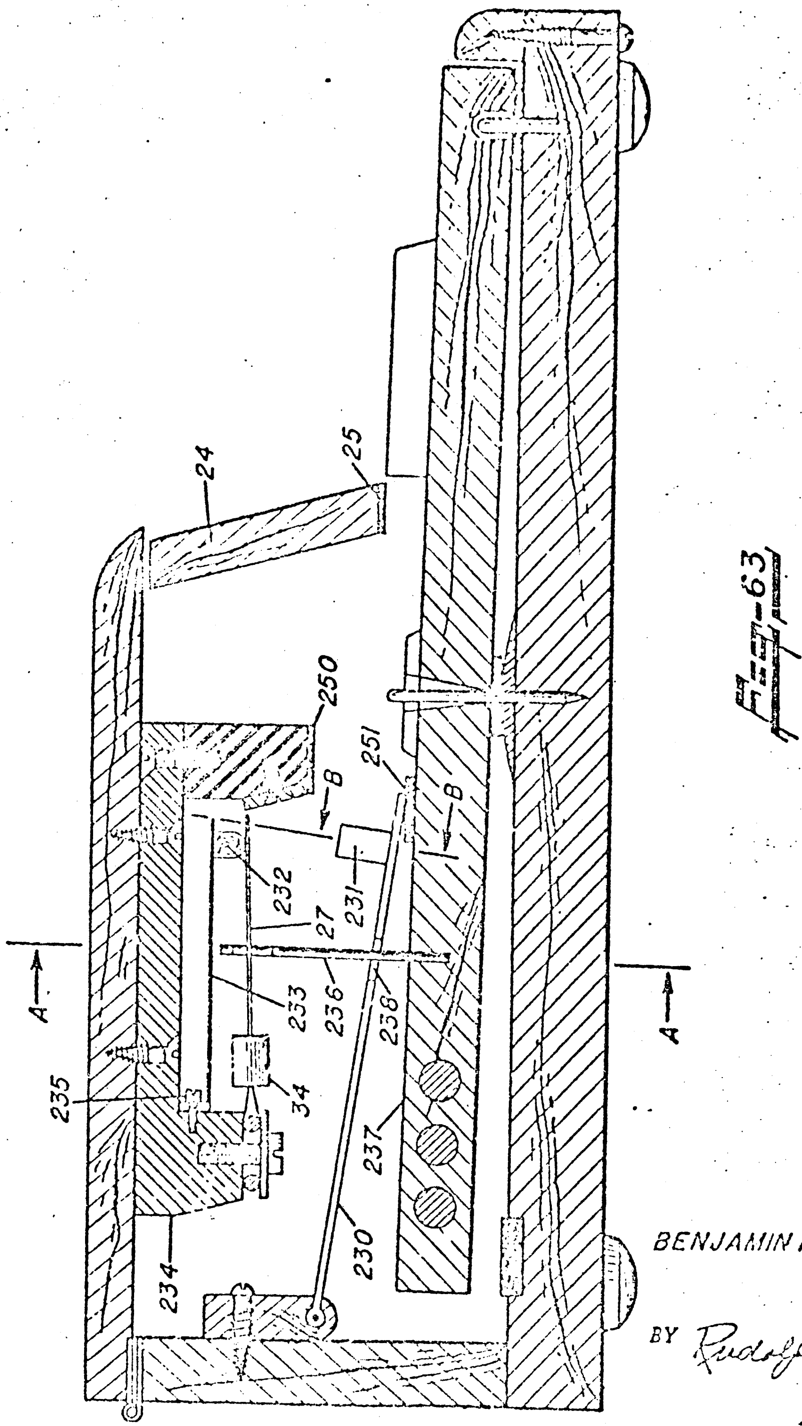

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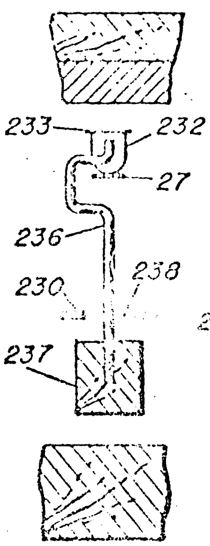
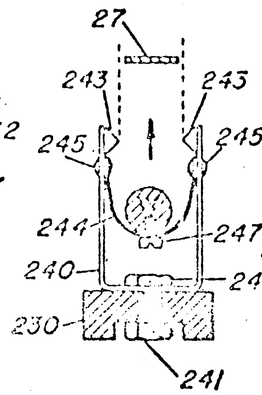


Fig-64



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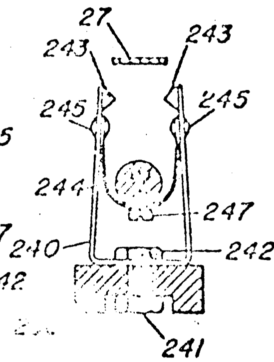
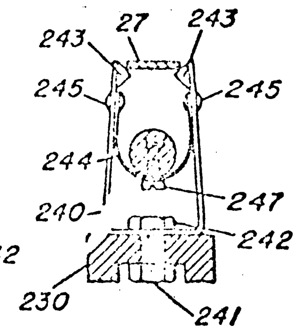


Fig-66



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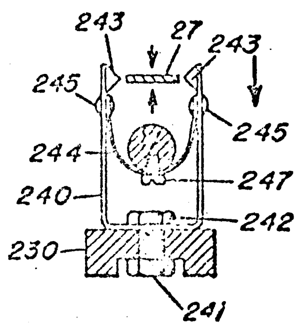

Fig-68

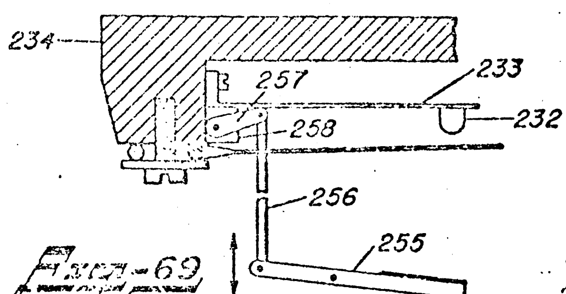

Fig-69

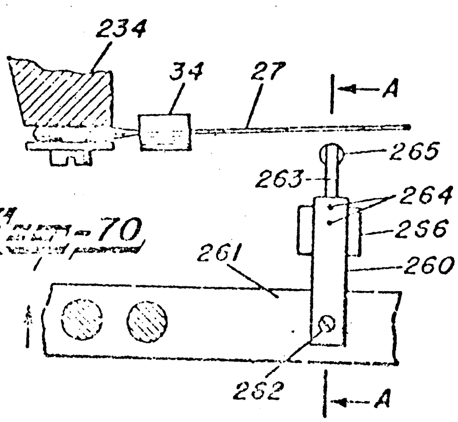

Fig-70

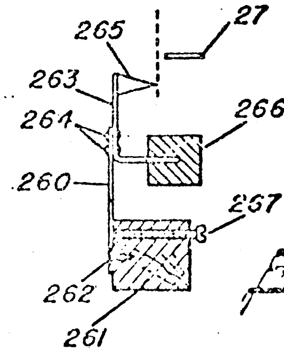

Fig-71

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ATTORNEY

United States Patent Office

3,038,363

Patented June 12, 1962

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3,038,363

ELECTRONIC PIANO

Benjamin F. Miessner, Miami Shores, Fla., assignor, by mesne assignments, to The Wurlitzer Company, Chicago, Ill., a corporation of Ohio

Continuation of application Ser. No. 169,714, June 22, 1950. This application Mar. 17, 1959, Ser. No. 799,897
24 Claims. (Cl. 84—1.14)

This invention relates to an electronic musical instrument and more particularly to a novel system and apparatus for producing the characteristic tones of a piano but without the use of strings.

Instruments such as the piano, harpsichord, harp and the like produce damped tone vibrations which tones are developed by striking, plucking or otherwise exciting tensioned strings. While the features of my invention are applicable to any instruments of this class, the description will be related to the piano, because of its universal popularity.

In instruments of the impulsively-actuated, tensioned-string family, steel or other strings are used as the vibratory tone generators. The strings are maintained under considerable tension and for exacting musical requirements the strings must be tuned frequently to the frequencies of the equitempered musical scale used by all instruments. The frequency of these strings is affected by:

(1) Minute, gradual elongation with time, especially during the initial period, that is, when the string is first placed under tension;

(2) Temperature variations of the string and its supporting string frame, and of the wood bridge, wood sound board, etc.;

(3) Moisture content variations in the wood bridge, wood sound board, and other wood parts.

Therefore, with changes in temperature and humidity, every tensioned-string instrument undergoes changes which shift the frequencies of the string vibrators and these shifts in the frequency of the individual strings are not necessarily uniform for all strings.

Furthermore, the aggregate string tension may be so great that exceedingly heavy and massive iron or wood structures are required to withstand these forces. For example, in a piano having some 200 strings, each at about 180 pounds tension, the aggregate string tension is approximately 18 tons. Consequently, a grand piano exceeds 1500 pounds in weight and requires a length up to 9 feet to accommodate the long strings required for the low frequencies. Even in small grand and console type pianos the weight may be 500 pounds or more and the height (or length) may be 36 to 40 inches.

Theory discloses that the tensioned string, as a musical tone generator, never attains the theoretically ideal tone in which the overtones are all exactly integral multiples of the fundamental frequency. These overtones, in fact, have been proven to lie higher in frequency than the true, integrally related Fourier partials of theory, and this heightening of frequency increases with the lower relative tension of a given string. Actually, with the normal "beats" method of tuning pianos wherein a first overtone (2nd partial) of a lower tone is used as the fundamental frequency of the next upper octave, there results a scale of fundamental frequencies which becomes progressively more sharp in the upper scale regions. This is due to the slightly sharp frequency relationship between the 2nd partial and the fundamental of any such tensioned string tone.

While in a given tone the 2nd partial is only a little sharp relative to the fundamental, or 1st partial, when this effect is carried through several octaves of progressive tuning, the top treble tone fundamental frequencies are very considerably sharp relative to the fundamental tone frequencies. This effect upsets the tone temperament of the scale. Further, in any given tone the higher the relative number of a given partial of the complex tone spectrum of a single string, the more sharp it is with respect to the fundamental or 1st partial so that the higher partials of a given string are progressively more and more sharp.

In the method of tone production herein disclosed, all of the partials of a given tone are in exact, integral relationship among themselves, so that they are all in exact tune with one another. The partials above the fundamental are derived from such fundamental rather than from a string whose vibration characteristics change with the frequency of individual partials. In this respect the tone produced by my apparatus is musically superior to that of the conventional piano and similar instruments.

Apart from, or in addition to, the above stated feature of providing by electronic means a tone musically superior to that of the conventional piano, there exist the problems of producing, in all respects, a good, pianistic, musical tone controlled by percussively actuated piano keys, utilizing completely the conventional playing techniques used in the piano, and capable of faithfully rendering the available, accumulated piano literature with which musicians are familiar.

Instruments have been proposed having short, small-diameter, low-tensioned strings, with vibratory bridges, or other piano-like vibratory systems coupled tightly to a string system so as to obtain similar actions and reactions—with suitable mechanico-electro-acoustic translating systems. None of these have been fully satisfactory as to the production of the particular type of musical tone well-known and recognized by musicians as realistic piano tone.

A piano tone starts in a particular way with hammer impact and is influenced markedly by the weight, compliance and damping characteristics of the exciting hammer during its very brief period of contact with the string. After the hammer leaves the string, other factors markedly influence the tone quality and damping characteristics. Among these are the material, stiffness, size, length and tension of the string; the mass, stiffness and damping characteristics of the bridge and sound board at various positions; the vibrational characteristics of the piano case parts and their sound conductive and sound radiating coupling to the air; the shape and volume of the more or less confined air chambers which are inherent in the piano structure; the size and disposition of the sound board; etc. For example, the sound board in upright pianos is in a vertical plane where it itself is an acoustic baffle-board which retards the arrival, particularly of low frequency tones, at the listener's ears (in front of the piano) of the negative (air rarefaction) half cycle of a given tone wave from the back side of the soundboard, so that it cancels only to a small degree the positive half cycle compression wave radiated from the front side of the soundboard. In a grand piano the soundboard is disposed in a horizontal plane so that there is but little of this baffle action especially for the lower frequency tones. Here, considerable neutralization for the lower frequency components occurs since the listener's ears are normally near to, or exactly in, the plane of the soundboard, where positive and negative halves of the same wave cycle reach the ears at practically the same instant and at practically equal amplitudes, especially if the top lid of the piano is in the open position.

Another important factor in piano tone quality results from the use of two or more strings for each note. While these multiple string notes employ identical strings as to size, length and tension, and are struck simultaneously by the same hammer, their combined unison tones are never in fixed phase relation, especially with respect to

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their higher overtones, so that these produce, among themselves, a great many combination or beat tones of varying frequency due to summation and difference effects on the asymmetric human ear. The combined tone, therefore, shifts constantly in quality as it subsides in amplitude. Even for single strings the tone quality shifts constantly as its amplitude subsides due to the various damping influences. Among these are mechanical hysteresis in the string itself, air friction of the vibratory string, mechanical hysteresis in the coupled bridge and soundboard and sound radiation losses from the soundboard. Also, the soundboard is not a flat-frequency responsive device; it has broad resonance frequencies which vary along the bridge from end to end so that it responds more or less to different frequency components of a given string. Its action, in these respects, varies from point to point along the entire bridge so that different individual strings (of the scale of strings) positioned along it and bearing down upon it are responded to in different manners, and the bridge and soundboard react back upon the individual strings in varying manner to change their vibrational characteristics.

The lateral vibrations of piano strings cause modulations of their downward pressure on the bridge. The soundboard is arched upwardly, with its edge restrained from lateral expansion by iron plates plus a massive wood construction, so that the downwardly pressing strings and the upwardly arched soundboard form a normally balanced system of forces. When a string vibrates laterally, therefore, its varying tension causes a varying pressure on the bridge and soundboard, and this then vibrates in a direction perpendicular to its plane. The strings, within their elastic limits, are almost perfect strings, whatever the direction of their lateral motion, vertical or horizontal planar, or constantly varying in orbital, conic-section, curvilinear motion within the cycle. The soundboard, however, may be compared to a very short, stiff spring whose force-displacement curve is non-linear, so that increasing, downward force-modulations cause less and less downward deflections but the upward force-modulations cause more and more, nearly linear, displacements. Thus, the bridge and soundboard constitute an asymmetri device which does not respond linearly to the modulations of the string pressure. The "bearing" of the string on the bridge refers to the small angle of the string axis as it passes over the bridge and down to the hitch pin. For moderate, lateral amplitudes of string vibration this angle is never zero degrees so that whether the string moves up, down, or horizontally, the bridge feels chiefly only a change of downward pressure. It, therefore, has a strong frequency-doubling action on the soundboard and on the string vibration as heard.

For very large amplitudes of string vibration, however, the bearing angle may become zero, or even reversed, so that when the string is vibrating upwardly it will actually pull the soundboard upwardly. Lateral and downwardly directed string motions, however, continue to set up downward motion of the soundboard, as at the lower vibration amplitudes. For orbital string motions then, where the string motion direction is constantly changing, the soundboard response characteristic is also constantly changing and along with it the tone quality as the string amplitude subsides after excitation.

The piano is, indeed, a complex instrument not even today fully understood and its peculiar characteristic tone is the result of this complex nature.

The piano tone must, in general, have a characteristically unique distribution of energy among its partial frequencies and this must vary in a characteristically unique manner as the tone subsides. Further, these characteristics vary in a particular manner through its scale of tones from low bass to high treble. The low bass is very rich in harmonic content due to the great length and relative flexibility of the strings, while the high treble is a relatively simple tone with but a few overtones. In the extreme treble, at over 4,186 cycles per second, the first overtone is 8,372 cycles per second, the second overtone is 12,558 cycles per second and the third overtone is 16,744 cycles per second, which is virtually at the upper hearing limit of the human ear. In addition these overtone frequencies have but low energy due to the shortness and relative stiffness of the string.

Piano strings also develop another system or series of vibrations entirely unrelated to the lateral vibrations ordinarily considered. When the hammer strikes the string a longitudinal impulse is set up in the string which impulse travels to the near and far fixed ends from which it is reflected back to the opposite end where further reflection takes place. This back and forth longitudinal vibration continues in the string until the energy of the vibration is dissipated. It has a fundamental and harmonic partials forming an essentially Fourier series of tone components but this system of tone partials has only a fortuitous relationship with the lateral system of vibrations. It is also much higher in fundamental frequency due to the much higher speed of propagation in the steel wire for longitudinal than for the lateral displacement wave motion of the string. Both, however, are translated into sound by the action of the bridge and the soundboard. The longitudinal vibration is heard by the ear, especially in the lower pitched strings, as a ringing kind of tone superposed on the normal lateral, much lower pitched, vibration tone and can only by chance be harmonically related to it. At the middle and higher pitch registers this longitudinal-vibration tone disappears insofar as the human ear is concerned merely because its pitch rises beyond the range of audibility.

Another entirely foreign part of piano tones is the broad continuous band of frequencies comprising what is termed the piano hammer "thump" or "crack." This is most pronounced in the higher treble tones, is of short duration and is, in effect, a transient. It adds no musical quality to the string tone but, rather, produces only a disturbing impact noise which momentarily blankets the much weaker tone of the string. Since for these higher tone strings the hammer strikes them very near their fixed end, and since the strings are relatively very stiff, the hammer, in effect, strikes an extension of the bridge thereby causing the characteristic, rapidly damped, complex, noise vibration heard as the hammer "thump." This grows lower and lower in amplitude relative to the string tone as the strings become longer and longer. The longer strings are relatively more flexible at the striking point toward the bass end of the scale since the striking point of the hammer is further removed from the end of the string.

Another characteristic of piano tones (in common with percussive tones generally) is that they are more complex at the higher amplitudes, that is, for stronger hammer blows the tone is not only louder but its overtone content is relatively greater than at low loudness levels. At low levels the tone is "smooth," "soft," "round," "sonorous" in quality due to the relatively strong lower partials compared to the weaker and fewer higher partials. At high levels, however, the upper partials increase both in number and in amplitude relative to the fundamental so that the tone becomes somewhat "strident," "wheezy" or "forceful." This is caused by the relatively linear translation of the string vibration by the bridge and soundboard for small amplitudes, and the relative asymmetric translation at high amplitudes which causes doubling and higher order frequency multiplication effects, as previously discussed. In more colloquial English at low volume the tone "purrs" while at high volume it "snarls." These tonal effects are tremendously useful in the expression of musical moods. They are completely absent in the organ and many other instruments whereby such instruments are not nearly as expressive as the piano.

The tone decrement, that is, the rate at which the tone amplitude subsides, varies throughout the range of piano tones. For low frequency tones it is small while for high frequency tones it is large. Furthermore, this rate of tone decay generally obeys the logarithmic law. At high amplitudes of string vibration the damping losses are higher than at low vibration amplitudes. For this reason a loud piano tone decreases very rapidly at first and then more and more slowly as the tone continues. Consequently, a weakly struck string continues its vibration almost as long as a strongly struck one.

Piano literature has all been composed to suit these characteristics of the piano. In general slower moving passages are kept in the bass tonal range because these tones die down at a relatively slow rate. A quick succession of low tones would hardly allow recognition, by the ear, of the individual notes or tones of the series and the whole series of differently-pitched bass tones and would be heard merely as a jumble of clashing tones. Consequently, the bass tones are generally used for sustaining quality to maintain a harmonious background for the more rapid and agile passages devoted to the higher pitched tones. The fastest, and generally the most agile, passages of piano literature are reserved for the quick-acting treble tones. The middle regions are devoted to the moderately fast passages. Actually, the very low tones may continue in audible vibration for 25–50 seconds while the highest tones may last only 1 or 2 seconds.

The piano is also provided with damper (that is, pedal) controls which also alter its performance. The soft pedal in a grand piano may shift the exciting hammers so that only one or two of the trio of unison strings are struck. This reduces both the amplitude and the complexity of the combination tone since there are only one or two instead of three unison or near unison tones. In an upright piano, the length of the hammer stroke is reduced so that a given force imparted to the playing key will produce a weaker tone.

The "sostenuto" pedal of the piano operates a cam mechanism which holds the damper pads away from the strings for those keys which have been struck after the pedal is depressed. This allows such tones to continue free of the dampers while the hands are free to go on with other keys and tones.

The "loud" pedal removes all the dampers from all damper-controlled strings leaving all strings free to vibrate instead of damping each string as soon as the playing key is released. Its use results in maximum loudness but also in much masking of the individual tones. For specific purposes, in the hands of an artist, the loud pedal has many valuable uses. For example, a given chord, or progression of harmonically related tones is much enriched in tonal value because such strings as are not struck by the hammer are free to resonate with components of the struck-string vibrations.

Among the desirable qualities of the highest types of musical instruments, not found in the piano, is variation of the overall quality of its tone. The organ possesses this quality to a high degree because of its use of many different types of tone producers. Electronic organs also possess this very valuable feature, even to a degree much beyond that of a pipe organ, through controlled variations of the electrical circuits whereby the artist has available the entire gamut of musical tone color, each under easy control by a stop tab. Conventional pianos, however, have but one color of tone which must be used for all types of musical literature, irrespective of their moods. This one color tone may, it is true, be varied from strong to weak, that is, from bright to dark, but only with accompanying changes in loudness. It can never be changed to another family of colors or to any one of many colors.

As stated hereinabove, a tensioned string, as a musical tone generator, never attains the theoretically ideal tone in which the overtones are all exactly integral multiples of the fundamental frequency. The present invention makes use of fixed-free, cantilever-beam type of vibrators in the form of small, tuned reeds of novel design and vibration characteristics. These reeds are of small size requiring only small exciting devices whereby I am able to produce an instrument of small size and weight and low cost. The reeds will retain their mass and compliance characteristic constant over long periods of time eliminating all considerations of periodic or subsequent tuning. Associated with each reed is a novel electrostatic magnetic or photoelectric pick-up and electronic translating arrangement whereby my stringless piano produces tones of piano characteristic.

An object of this invention is the provision of a stringless, electronic piano capable of producing the characteristic tones of a piano and employing similar playing techniques.

An object of this invention is the provision of apparatus for producing impulsively-excited string tones without the use of strings.

An object of this invention is the provision of apparatus for producing impulsively-excited string tones having a large and adjustable range of harmonic content.

An object of this invention is the provision of electronic apparatus for producing string like tones having damping rates similar to those of pianos and like instruments.

An object of this invention is the provision of electronic apparatus for producing string-like tones of the impulsively-actuated type with harmonic contents that vary with time in the manners characteristic of the piano and the like.

An object of this invention is the provision of a light weight, low cost, simple, electronic instrument of the piano type but without use of tensioned strings.

An object of this invention is the provision of apparatus for producing tones of impulsively-excited, string-like characteristics in which the harmonic frequencies are exactly integral multiples of the fundamental frequency.

An object of this invention is the provision of impulsively-excited, string tones from the mechanico-electro-acoustic translation of the vibrations of simple, pendular mechanical vibrators.

An object of this invention is the provision of a simple, inexpensive, mechanical vibrator giving essentially simple pendular vibrations.

An object of this invention is the provision of mechanico-electric translating apparatus capable of transforming a simple, pendular mechanical vibration of a vibrator into strongly peaked electrical vibrations or oscillations.

An object of this invention is the provision of electronic apparatus for transforming strongly-peaked electrical oscillations into tones of adjustable harmonic content.

An object of this invention is the provision of an electronic piano provided with arrangements for producing "loud" pedal and "sostenuto" pedal effects identical to such effects available in the best, conventional pianos.

An object of this invention is the provision of a vibratory reed type of electronic piano including vibration dampers of novel construction whereby termination of the reed vibration does not produce a change in the pitch frequency of the reed.

An object of this invention is the provision of a novel vibratory reed construction for a stringless piano.

An object of this invention is the provision of a vibratory reed provided with a visco-elastic tuning damper whereby the second and third vibration partials are harmonic with the fundamental vibration.

An object of this invention is the provision of a vibratory reed provided with a non-energy-absorbing tuner that tunes the second frequency partial to an exact, integral frequency ratio with the fundamental frequency without significant loss of vibration amplitude.

An object of this invention is the provision of a vibratory reed provided with a tuning member that retunes the first and second vibration frequencies to an exactly integral ratio without significant increase in the normal damping rate of the reed and without significant retuning effect upon the higher frequency partials.

An object of this invention is the provision of an electrostatic pick-up and vibratory reed arrangement whereby vibrations of the reed produce asymmetrical modulations of the capacity between the reed and pick-up.

An object of this invention is the provision of a vibratory reed and translating arrangement whereby vibrations of the reed produce a translated voltage or current wave of maximum steepness and minimum rate of decay.

An object of this invention is the provision of an electronic piano in which adjustments of tone quality, tone volume and tone damping are obtained by axial and lateral adjustments of a vibratory reed relative to a suitable pick-up.

An object of this invention is the provision of a stringless piano employing vibratory reeds as tone generators, capacitive pick-up electrodes associated with the reeds and including means selectively operable to vary the angular disposition of the pick-up electrodes with respect to the reeds whereby the character of the capacity modulations between the reeds and pick-up electrodes may be altered at will.

An object of this invention is the provision of a vibratory reed and magnetic pick-up arrangement for producing highly-peaked, asymmetrical voltage pulses in response to reed vibration.

An object of this invention is the provision of an electronic piano employing tuned vibrators as tone producers and photoelectric apparatus for translating vibrations of the tuned vibrator into electrical oscillations.

An object of this invention is the provision of an electronic piano having tuned vibrators as tone producers and including a key-operated plucker for exciting the tuned vibrators.

These and other objects and advantages will become apparent from the following description when taken with the accompanying drawings illustrating several embodiments of the invention. The drawings are for purposes of description and are not intended to define the scope or limits of the invention, reference being had for the latter purpose to the appended claims.

In the drawings wherein like reference characters denote like parts in the several views:

FIGURE 1 is a general, side view, with parts in cross-section, showing the internal arrangement of the parts in an electronic piano made in accordance with this invention;

FIGURE 2 is a fragmentary end view showing the action of the reed vibration dampers in response to depression of the playing keys and an arrangement for producing a "loud" pedal effect;

FIGURES 3 and 4 are fragmentary plan views illustrating an arrangement for producing the "sostenuto" effect;

FIGURE 5 is a side view of three representative reeds each provided with a visco-elastic tuner-damper;

FIGURE 6 is a plan view of the low frequency reed shown in FIGURE 5;

FIGURE 7 is an isometric view of a reed of different construction;

FIGURE 8 is a side view of another type of reed construction;

FIGURE 9 is a composite and exploded view in isometric, of a three-piece reed construction;

FIGURE 10 is a central, longitudinal, cross-sectional view of another reed construction and showing also a tool for securing the reed lug to the reed base;

FIGURE 11 is a side view of a reed with a non-damping type of vibration tuner thereon;

FIGURE 12 is a transverse, cross-sectional view taken along the line A—A of FIGURE 11;

FIGURE 13 is similar to FIGURE 12 but showing a non-damping tuner of another form;

FIGURE 14 is a plan view of a vibratory reed and electrostatic pick-up;

FIGURE 15 is an elevation view of the FIGURE 14 reed and pick-up.

FIGURES 16 and 17 are similar to FIGURE 15 but showing other forms of the pick-up.

FIGURE 18 is an isometric view showing an assembly of reeds of different pitch cooperating with a single electrostatic pick-up.

FIGURES 19 to 21 are longitudinal, cross-sectional views taken along the lines A—A, B—B and C—C, respectively, of FIGURE 18 to show the progressive change in the angle between the various reeds and the face of the pick-up;

FIGURES 22 to 24 are side views of a reed and electrostatic pick-up and showing various positions of the pick-up with respect to the reed end, all positions of the pick-up being such that the face of the pick-up remains normal to the reed axis;

FIGURE 25 illustrates a grounded shield employed in conjunction with the pick-up to increase the abruptness of the capacity changes between the reed and pick-up as the reed vibrates;

FIGURE 26 illustrates a single, pick-up having tooth-like projections cooperating with the individual reeds;

FIGURE 27 illustrates the longitudinal adjustability of the reed relative to the pick-up tooth;

FIGURE 28 illustrates the lateral adjustability of the reed relative to the pick-up tooth;

FIGURE 29 is a curve showing an asymmetrical wave having both odd and even numbered components;

FIGURES 30 and 31 illustrate symmetrical waves having only odd numbered components;

FIGURE 32 illustrates the variation in capacity, due to reed vibration, between the reed and pick-up arrangement such as that shown in FIGURE 22;

FIGURE 33 illustrates the relative amplitudes of the Fourier series partials obtained from three different reeds with individual pick-ups arranged in accordance with this invention, and as obtained from the test set-up as shown in FIGURE 34;

FIGURE 34 illustrates a test set-up for analysing the vibration characteristics of a reed in terms of capacity modulations between the reed and a pick-up;

FIGURES 35 to 39 are isometric views showing other specific forms of the electro-static pick-up;

FIGURE 40 is a side view showing a simple arrangement for adjusting the spacing between the pick-up and the end of the reed;

FIGURE 41 is a side view showing a vibratory reed associated with a bridge type of pick-up;

FIGURE 42 is a front view of the dual pick-up arrangement shown in FIGURE 41;

FIGURE 43 is an electrical bridge circuit useful for increasing the translating efficiency of the capacitive pick-up arrangement;

FIGURE 44 is a wiring diagram of a representative electronic translating system for transducing the modulations in capacity between the vibratory reed and pick-up;

FIGURE 45 is a fragmentary, plan view of an arrangement whereby the performer may alter the angular disposition between the reed and the pick-up to thereby alter tone quality;

FIGURE 46 is a cross-sectional view taken along the line A—A of FIGURE 45 and showing the face of the pick-up electrode lying in a plane normal to that of the reed;

FIGURES 47 and 48 are similar to FIGURE 46 but showing other angular dispositions of the pick-up electrode with respect to the reed;

FIGURE 49 is an isometric view of a vibratory reed and a magnetic type of pick-up having a polarizing magnet;

FIGURE 50 is an isometric view of a magnetic reed and electromagnetic pick-up;

FIGURE 51 is somewhat similar to FIGURE 50 but showing a tri-polar magnetic pick-up;

FIGURE 52 illustrates a magnetic pick-up and reed arrangement wherein the reed is made of magnetic material and magnetized longitudinally;

FIGURE 53 illustrates a magnetic pick-up arrangement wherein the core carrying the electrical pick-up coil has a plurality of discrete poles alined with individual reeds.

FIGURE 54 illustrates a magnetic pick-up arrangement wherein a plurality of series-connected, electrical pick-up coils and individual cores are disposed between adjacent reeds;

FIGURE 55 illustrates a photoelectric arrangement for translating reed vibrations and in which the optical system provides a parallel-ray beam of light;

FIGURE 56 illustrates a photoelectric arrangement wherein the light rays are brought to a focus at the edge of the reed;

FIGURE 57 illustrates a photoelectric arrangement wherein a parallel beam of light-rays is reflected from the surface of the reed;

FIGURE 58 is also a reflected light system but in this case the beam of light rays is brought to a focus on the reed surface;

FIGURE 59 is similar to FIGURE 58 but in this arrangement the light beam is brought to a focus on the cathode of the photocell;

FIGURE 60 is a wiring diagram illustrative of a formant circuit useful for controlling the output tone quality of my instrument;

FIGURE 61 illustrates a resistance-capacitance arrangement for regulating the band width of the mean frequency generated in a magnetic type pick-up;

FIGURE 62 is a circuit representation to illustrate various shunting arrangements of resistors and condensers that may be used to alter the character of the output tone;

FIGURE 63 is similar to FIGURE 1 but showing a key-operated plucker arrangement for setting the tuned reeds into vibration;

FIGURE 64 is a cross-sectional view taken along line A—A of FIGURE 63 to illustrate the mechanical linkage between the playing key and the vibration damper;

FIGURES 65 to 68 are cross-sectional views taken along the line B—B of FIGURE 63 and showing the plucker device in various positions relative to the reed;

FIGURE 69 is a fragmentary view showing a mechanical arrangement for providing a "loud" pedal effect in the plucker arrangement shown in FIGURE 63;

FIGURE 70 is a side view illustrating another type of plucker device for exciting the vibratory reed; and

FIGURE 71 is a cross-sectional view taken along the line A—A of FIGURE 70.

Referring now to FIGURE 1, my instrument may be housed in a cabinet comprising a base 20, a back 21 and a lid 22 that is pivotally attached to the back by a hinge 23. The cabinet is substantially closed by a slidably-removable front board 24 having a felt strip 25 cemented, or otherwise secured, along the lower edge, as is common in piano construction. Inasmuch as my instrument does not employ tensioned strings the cabinet can be much smaller and lighter than conventional piano cabinets. In fact, as shown in the drawing the entire device is portable and may be placed upon a table, rubber feet 26 being provided for this purpose. The vibratory reeds 27 are individually secured to a metal reed base 28 that is fastened to the inner surface of the lid by the screws 29, each reed being held in contact with the said reed base by a cap screw 30 and associated washer 31. It may here be stated that the individual reeds have an end formed in a closed loop 32 which, in combination with the cap screw and washer, provides not only a convenient means for mounting the reed but also affords a means for adjusting the angular position of the reed and its spacing from the electrostatic pick-up electrode 33. Each reed carries a tuning-damper 34. A more detailed description of the reed construction and the function of the tuning damper will be given hereinbelow. The pick-up electrode 33 (of which there is one associated with each reed) is secured to an insulating bar 35 by a screw 36, said bar being secured to the reed base 28 by screws 37. A shim 38, of flat or of wedge shape, may be provided (if necessary) to adjust the position of the pick-up electrode with respect to the free end of the reed. It will be noted that the reeds and pick-up electrodes are mechanically attached to the reed base and, therefore, the entire assembly is readily accessible for adjustment, inspection, or replacement of elements by merely raising the hinged lid 22. The electrical circuit for translating the vibration of the reed into electrical variations will be described in detail below.

The keyboard of my instrument is identical to that of the conventional piano (except that all keys are straight), each key 40 being pivotally retained in position by a pivot pin 41 extending upwardly from the cabinet base and passing through a tapered hole in the key. Smooth rocking motion of the key, in response to finger pressure applied to the outer end, is provided by the curved, pivot rail 42 spaced from the key by a resilient washer 43. Excessive lateral motion of the key is prevented by the key guide pin 45 that is secured to the cabinet base and extends into a bore in the key, a resilient stop pad 46 serving to limit its downward motion and to deaden the contact noise when the key is depressed vigorously. A wood strip 47 secured to the base by screws 48 prevents the entrance of foreign objects between the base and the key and also enhances the general appearance of the instrument.

The inner end of the key 40 carries a capstan screw 50 adapted to strike the visco-elastic anti-rebound pad 51 secured to the hammer stem 52 that is pivotally attached to the hammer flange 53 by a pin 54, said flange being secured to the cabinet back 21 by the screw 55. Alternatively, the pad 51 may be mounted on the head of the capstan screw 50, or in an axial recess provided in the head for this purpose. A hammer head 56, made of suitable material, and carried by the free end of the hammer stem, is adapted to excite the reed by striking the tuning damper 34. It will be apparent that when the outer end of the key is depressed, energy imparted to the hammer stem will cause the hammer head 56 to strike the tuning damper 34 of the reed due to its momentum even though the angular motion of the inner end of the key is limited to a predetermined, minimum value. Consequently, the hammer head remains in contact with the tuning damper for a brief instant only after which it returns, by gravity action, and by the spring action of the reed, to the position shown in the drawing. Upon removal of the finger pressure from the key it will rotate in a counter-clockwise direction by reason of the key balance weights 58, of lead, inserted therein. Return of the key to its normal position results in the hammer head 56 coming to rest on the down stop pad 59. The key stop pad 60 cushions the contact between the key and the base 20. I prefer to make the various pads of a visco-elastic material of soft, yieldable composition whose deformation requires energy expenditure and which remains constant over wide changes of temperature and humidity. Such materials as Vinylite, or butyl rubber in soft grades, are satisfactory. These are disclosed in more detail in my United States Patent #2,271,460, issued January 27, 1942.

To terminate the vibrations of the reed I provide a simple and efficient damper consisting of a thin, bent wire 65 carried by a damper rail 66 that is secured in relatively fixed position with respect to the instrument as a whole. The free end of the wire normally contacts the side of the reed 27. The loop portion of the wire extends slightly below the surface of a felt pad 67 affixed to the rail 66 and is adapted to be contacted by the head of a flathead screw 68 carried by the key 40.

The action of the damper mechanism is better illustrated in FIGURE 2, which shows a series of three reeds, dampers and keys, as seen from the inner end of the keys. The keys 40, 40″ are shown in the normal (inner end down) position wherein the flathead screws 68, 68" are spaced from the damper wires 65, 65" and, consequently, the wires 65, 65" will normally be in contact with the side of the respectively associated reeds 27, 27". When the playing key is depressed the inner end of the key rises, as shown by the key 40', causing the flathead screw 68' to strike the bent portion of the damper wire 65'. As the fixed end of the wire is displaced laterally with respect to the point of contact between the wire and the screw head, the wire is twisted out of contact with the associated reed 27'. The adjustment of the reed exciter mechanism is such that the flathead screw 68' removes the damper wire from contact with the reed just prior to the moment of impact between the hammer-head and the tuning damper. Therefore, the reed is set into free vibration and will continue vibrating until the playing key is released. Upon release of the playing key the flathead screw 68 falls away from the wire loop and the damper wire contacts the edge of the reed thereby terminating the vibrations by sliding friction of the reed on the damper wire. This type of damper wire, which may be a wire or a strip, does not change the vibration frequency of the vibrator and the vibration decay time depends upon the pressure exerted by the damper wire against the edge of the vibrator. The decay time is not constant for all reeds and it will be apparent that the dampers associated with the low frequency, bass reeds should be stiffer than those for the higher frequency, treble reeds. By proper bending of the individual dampers associated with specific reeds, the decay time, or damping characteristics, of my instrument can be made equivalent to the same characteristic in a conventional, tensioned-string piano.

An effect corresponding to that obtained when the "loud" pedal of a piano is depressed, is achieved, in my device, by moving the damper rail 66 as a whole, so that the damper wires, while in their normal positions, are spaced from their associated reeds. Mechanisms for accomplishing this are quite apparent to those skilled in the art and, therefore, one such mechanism is shown diagrammatically in the drawing, wherein depression of a foot-pedal 70 causes a movement of the damper rail to the right. Release of the foot-pedal results in a movement of the damper rail to the left in response to the action of the spring 71. A ledge 72 in the damper rail serves as a stop against the fixed member 73 to thereby assure a return of the individual damper wires to a preset, operative position with respect to the individual reeds. The other end of the damper rail slides within the fixed member 74 thereby assuring proper alinement of the rail with respect to the heads of the screws 68, 68', 68", for all lateral positions of the rail. As in a conventional piano, operation of the "loud" pedal permits free, undamped vibration of all reeds struck while the pedal is depressed as well as resonant vibration of all other reeds.

A "sostenuto" arrangement may also be provided. For this, all dampers whose keys are depressed before the "sostenuto" pedal is depressed will be caught and held away from their reeds until the pedal is released, while all other dampers will react normally.

Reference is now made to FIGURES 3 and 4 which are fragmentary, plan views of an arrangement for providing a "sostenuto" effect in my vibratory reed piano. The showings are rather diagrammatic to facilitate an understanding of the mechanism for achieving this effect. As shown in FIGURE 3, the two reeds 27, 27' are of the type shown in FIGURE 1 being secured to the reed base by the screws 30 passing through the loop formed in the reed end (see FIGURE 1). Each reed is provided with a tuning damper 34. The damper wires 65, 65' are pivotally carried by the damper rail 66 and normally engage the edge of the associated reed, as shown. Disposed over the top of the damper rail is a slidable strip 75 that constitutes the working element of the "sostenuto" mechanism. This strip includes a set of fingers 76, 76' and transversely cut notches 77, the latter cooperating with the individual pins 78, that extend upwardly from the damper rail, to assure sliding, linear motion of the strip. A set of springs 79 each having one end secured to the slidable strip 75 and the other end secured to fixed members 80 normally bias the slidable strip against the fixed stops 81. In the normal position of the slidable strip the fingers 76, 76' lie spaced from the damper wires 65, 65' so that these damper wires are free to move in response to the motion of the individual capstan screws 68, 68' (see also FIGURES 1 and 2), as explained hereinabove. If, however, the slidable strip 75 is moved forward, in the direction indicated by the arrow *a*, in response to depression of the "sostenuto" pedal (not shown in the drawing) while one or more playing keys are retained in the depressed position, the fingers 76, 76' are brought forward into the path of travel of the damper wires 65, 65'.

The operative position of the "sostenuto" mechanism is shown in FIGURE 4. In this figure the slidable strip 75 has been brought forward after the playing key has raised the capstan screw 68' associated with the reed 27'. Consequently, the damper wire 65' is caught behind the finger 76' of the slidable strip 75 and, therefore, the damper wire is prevented from returning to its initial position against the edge of the reed 27'. This reed (and all others that may have been activated by depression of the playing keys prior to depression of the "sostenuto" pedal) will vibrate freely. Release of the "sostenuto" pedal permits the slidable strip 75 to move in the direction of the arrows *b* to its normal, inactive position, as shown in FIGURE 3 thus freeing the damper wires for return to their normal position in contact with the associated reed edge. It will be noted that when the slidable strip 75 is moved forward before the playing key has been depressed the damper wires are free to act in the normal manner. This is shown in connection with the reed 27, FIGURE 4, wherein the finger 76, while extending into the path of travel of the damper wire 65, nevertheless, permits free movement of this damper wire between the limits defined by the reed edge and the adjacent edge of the said finger. Thus, when the capstan screw 68 is raised, in response to depression of the playing key, the damper wire 65 occupies the position shown in FIGURE 4, that is, the free end of the damper wire is moved out of contact with the reed edge whereby the reed may be set into normal vibration. Upon release of the playing key the damper wire returns into contact with the reed edge terminating the vibrations.

It will now be apparent both reeds 27 and 27' may be re-excited by their respective hammers irrespective of whether the "sostenuto" pedal is or is not depressed. Furthermore, the "loud" pedal may also be used in either case to hold all of the damper wires out of the reed-damping position. I, therefore, provide in my novel piano means for providing artistic rendition of piano music in a manner duplicating that available in the conventional, tension-string piano.

As stated above, and shown in the drawings, my invention makes use of fixed-free, cantilever-beam type vibrators in the form of small reeds that are tuned to provide the entire tonal range of the particular instrument. These reeds are securely anchored at one end and are free for unrestricted vibration between the fixed and free end. Their frequency is determined primarily by the length, mass per unit of length, thickness in the direction parallel to the direction of vibration and the material of which they are made. To raise the pitch of a reed, mass may be removed from the free end and for lowering the pitch, the compliance may be increased by grinding the reed to a thinner cross-sectional area at the fixed end. The material per se, the reed area normal to the direction of vibration, heat treatment and other factors relating to the internal structure, determines very largely the damping rate of the vibrations after excitation.

These reeds may be formed into a musical scale by variation of the length with fixed thickness, by variation of thickness with fixed length, by variation of thickness from end to end, by variation of width from end to end, by variation of loading at or near the free end, or by combinations of these variables. For purposes of simplicity the description will be restricted to reed scales in which discrete pitches are produced by variation of only the length of the reed.

Since reeds require, for best results, attachment to a relatively massive support, I prefer to make the reeds of relatively small size. As the reeds vibrate, they exert torsion forces on their support and these torsion forces tend to vibratorily rotate the support. Such support vibration may be communicated to the air as sound waves, or to the enclosing cabinet whose vibration will set up sound waves, both of these effects resulting in the dissipation of energy from the reeds and thus increasing their damping rate. Such vibration may also be communicated to other reeds having one or more partial tones in tune with the excited reed. Such other reeds will be excited resonantly through the vibration coupling, extracting energy from the excited reed. Even with dampers operative on these other reeds they will tend to vibrate resonantly and while the vibration will be absorbed by the dampers and dissipated as heat, the effect, nevertheless, is still extraction of energy from the excited reed.

I, therefore, prefer to use reeds of small mass and stiffness so that the mass and moment of inertia (about the point of attachment to the mounting support) may be reduced to a minimum consistent with the desired degree of damping of the reeds. This degree of damping should fall within the degree of damping range of acceptably good or excellent piano tones. On the other hand, the damping range may, in response to artistic demands, be made smaller or greater, as desired. The exciting devices may also be of small size, weight and space requirements made possible by the small amount of excitation energy required by the very small reeds. Furthermore, such small size reeds will radiate a minimum of direct acoustic sound because of their small area of coupling to the air, and because of the very much smaller vibration of the reed support which, relatively, has considerable air-coupling surface area. Small reeds, therefore, reduce, in general, all essential requirements of space, weight and exciting energy required and thus operate to keep the instrument small, low in weight, inexpensive, and having a very low direct sound output.

The reed material should be one that has a low internal hysteresis for vibration; is free from crystallization under continued vibration; has resistance to oxidation in salt air, and other deteriorating influences; can readily be formed in manufacture; and has ability to withstand slight bending adjustments without breakage. Preferably, the reed should be electrically conductive so that it may be used as a capacitive electrode for a pick-up device. However, for electromagnetic types of pick-up devices the reeds may be made of a material having magnetic properties. Also, for certain types of electrostatic pick-ups, the reeds may consist of a material having good dielectric properties whereby precision plastic molding techniques may be used for their manufacture. Such molded reeds are sufficiently accurate without further tuning adjustments and they may be molded in groups of many such reeds having specific, individual pitches, as in all-plastic harmonicas and accordions.

I have found that beryllium copper particularly, and also bronze alloys in spring tempered hardness, are satisfactory in all listed factors and some types of hard silver and nickel-silver alloys are also fairly acceptable.

For pitch scales of 4 to 5 octaves, variations of reed length alone is sufficient for practical musical scale design. For a range of 7 to 8 octaves it is generally, desirable to vary other factors of pitch control.

Reeds of the type under discussion are poorly suited for the direct production of sound or for the production of good musical tones by use of customary methods of translating its motion, i.e., pick-ups placed on one side or the other of the reed face. This is particularly true when percussive excitation is employed.

No tension string ever attains the ideal called for by classical theory which demands a perfectly flexible strand. Actual piano strings would come much closer to the ideal string were they 50 or 100 feet long in the base section and entirely unloaded. In the theoretically ideal string the partial tone components are all, up to the highest number, exactly integrally related in frequency to the fundamental and follow precisely the mathematical relationships set down by Fourier.

In practice, however, the strings, of even the largest concert grand piano, never attain this ideal because they are not perfectly flexible. This inherent stiffness, as shown by Seebeck and as proven by Schuck, Young and others, sharpens the pitch of each partial component somewhat more or less (depending on the string design) and progressively more so as the partial number increases in numerical value. For example, in a typical F3 piano string the second partial is 0.7 cent sharp (a cent being 1/100 of a semi-tone) while the thirteenth partial is 40.3 cents, or nearly ½ of a semi-tone, sharp. Furthermore, subjective fundamentals derived from neighboring partials have been shown to be as much as 1.4 cents sharp for the first partial and as much as 112.2 cents, or over one semi-tone, sharp for the twelfth partial.

In reed type vibrators, however, none of the partial frequencies are harmonically related and, in addition, there are large gaps in the series of partial tones. If we use Roman numerals to designate the partial number and Arabic numerals to designate the frequency ratios, we may compare the partial frequencies of idealized strings with those of fixed-free vibrators such as reeds.

Partial Number	I	II	III	IV	V	VI
Relative Ideal String Frequency	1	2	3	4	5	6
Relative Reed Frequency	1	6.27	17.5	34.4	56.9	85

It is seen that no two partials of the reed have integrally related partial frequencies, which is a requirement for perfect harmony. Further, the partials of the reed are very far apart in frequency at the lower end of the series, and decreasingly so as the partial numbers increase in value. It is obvious, therefore, that when all of the partials of a reed type vibrator are reproduced, either directly or by electronic techniques, the resultant tone is a mixture of wholly inharmonic components. Such vibrators with pick-ups placed at one side of the reed may serve fairly well for tones typical of bells or chimes, in which inharmonic partials are characteristic, but such vibrator is entirely unsuited for use in the production of piano tones by previously known methods. Another reason for this is that, as in a piano and other types of vibrators, the fundamental is always the strongest component (in amplitude) and the higher and higher numbered partials (Roman numerals) decrease progressively in amplitude, generally in inverse relation to the absolute frequency. The second partial II of a reed, which has a frequency of 6.27 times the fundamental, therefore, has an amplitude of vibration of about ⅕ to ⅒ that of the fundamental I, while the third partial III may have a vibration amplitude of only 1/15 to 1/20 of the fundamental partial I.

For my stringless piano I have devised methods for use of vibratory reeds without the introduction of the inharmonic partials inherently characteristic of the reed. I provide combined loading and damping devices in the form of more or less visco-elastic masses, attached by cementing or otherwise, around the reed at critical positions along the axis thereof. This, I have found, effectively eliminates, or reduces to inconsequential magnitude, the amplitude of all partials above III. At the same time the partials I, II and III are returned so that these are brought into harmonic relationship with one another, and, further, the partials II and III are considerably reduced in amplitude. These damper-load devices, which I shall term tuning-dampers, progress in size, length and position, from treble to bass, being shorter and nearer to the reed's fixed end in the treble range. In the upper treble regions where the partials II and III rise toward the upper limit of audibility, such tuning dampers are not required.

FIGURE 5 illustrates three representative reeds of relatively low, medium and high vibration frequencies, with the tuning dampers 34 attached thereto. With the tuning damper attached, the reed acts effectively as a vibrator of preponderantly one frequency, namely, the fundamental. The second partial II is much weaker than normal (without the damper) and the third III partial is very much weaker and hardly discernable, but both partials are harmonious with the fundamental, as shown in the following table.

Partial Number	I	II	III	IV	V	VI
Relative Reed Frequency:						
Without Damper	1	6.27	17.5	34.4	53.9	85
With Damper	1	5	15	------	------	------

The higher partials above III are so weak that they are not heard.

What is desired here is a vibrator having but one frequency, and which is small, light in weight, inexpensive to manufacture and which is capable of large vibration amplitude, for reasons hereinafter explained. In practice I have found that reeds from 1 to 4 inches in length, .016 inch thick and .096 inch in width are entirely satisfactory for a five octave scale extending in pitch range from F—43.65 to F—1396.9 cycles per second. While the width of the reed does not affect the frequency of vibration, I prefer to make the width an exact multiple of the thickness, and only wide enough to insure vibration in only one direction.

The positions, lengths and weights of the tuner-dampers has been found empirically so that no detailed information can be given for predetermination of these factors. Their adjustment is found by "cut and try" methods with frequent auditory tests to indicate when the correct adjustment has been achieved for a given reed. The criterion for this correct adjustment is a good musical chord of two tones (partials I and II) when the reed is struck very close to its fixed end with a hard, sharp-edged, wooden hammer. This two tone chord is that, for example, between a given C tone and an approximate E tone 2⅓ octaves above the C tone, except that the harmony is better.

FIGURE 6 is a plan view of the low frequency reed shown in FIGURE 5 and illustrates the construction of the reeds involving the use of round rod material which is formed into an eye 83 at one end and which is pressed flat for the vibratory portion 84. The eye end of the reed is the full wire diameter whereas the vibratory portion is pressed to the required width and thickness. The length is obtained by cutting, grinding or etc. As shown in FIGURE 1, the inside diameter of the eye is made to have some clearance, say 1/32", all around the clamping screw 30 that secures the reed to the reed base 28. Also, the clamping screw should have either a large head to over-reach the eye outside-diameter, or a suitable washer 31 should be employed, to assure very secure clamping for all parts of the eye to the reed base. The round form of the eye cross-section (wire or rod) aids in establishing intimate contact with the reed base, as the eye will flatten slightly when compressed if the reed base material is harder than the reed material, or in the event the reed base is of softer material, such material will be indented by the eye. I prefer a softer material for the eye than the base since the eye, for certain adjustment reasons, must seat securely in various positions, as will be explained in more detail hereinbelow. Reeds of the type described are easily removable and readily adjustable angularly and radially with respect to the clamping screw.

In general, for minimum damping, the reed must terminate in a fixed end of relatively large cross-sectional area and mass and this end must be very securely clamped for intimate, microscopically-vibration-free contact with the reed base which itself should be relatively massive. The rod type reed just described serves very well in these respects.

Another type of reed construction is shown in FIGURE 7 wherein the vibratory portion 86 is obtained by milling or grinding a relatively thick, flat bar of metal leaving the lug portion 87 of original thickness and providing a mounting hole 88 therein. The face of the lug that is to contact the reed base may be serrated to provide teeth 89 for assuring intimate, nonrocking contact therewith. A reed of this construction may also be made by casting or pressing. It is preferable to have the grain, if such exists, extending along the reed axis.

Another type of reed may have a lug of cone-shaped or tapered form as shown in FIGURE 8. Here the tapered lug 90 terminates in a threaded end and the reed is clamped securely within a tapered hole in the reed base 91 by means of a nut 92 and washer 93.

The terminal, or lug, end of the reed may be made of two pieces as shown in FIGURE 9. In such design the reed 94 is punched from flat-stock beryllium copper with the wide end crimped by a pressing or forming operation. The opposing faces of the thicker, face plates 95, 96, have pressed into them corresponding corrugations so that the three pieces fit together snugly. Then the three pieces are spot-welded together at the extreme ends so that no microscopic slippage can occur between the reed faces and the face plates when the reed is in vibration and, therefore, no energy dissipation will occur in the reed termination.

Still another type of reed construction and mounting is illustrated in FIGURE 10 wherein the lug portion 98 is of circular cross-section and is fitted into a bore in the reed base 99. A very tight fitting engagement between the lug and the reed base may be obtained by making the bore in the reed base slightly undersize, heating the reed base and cooling the lug, and then pressing the lug into the bore. Upon return to normal temperature, the bore contracts and the lug expands thereby providing intimate and firm contact between the lug and reed base. Alternatively, the lug may be secured by squeezing the reed base material tightly around the lug by means of impact force exerted upon a hollow, tapered, cylindrical tool 100 having a sharp, cylindrical outer edge similar to a round hole punch.

Other methods for constructing the reed may be employed, such as, forging, high-pressure forming, precision casting, drawing, extrusion, rolling, electrodeposition, vaporized spraying, etc. It is important that the reed terminate in a suitable, vibration-free, relatively heavy end section. This is essential not only to prevent chattering (even of microscopic degree) of the reed end relative to the base (which would be communicated to the free end of the reed) but also to insure a minimum damping for the reed's vibration.

By providing vibrators having an essentially sinusoidal vibration without inharmonic partials I have the first essential requirement for the production of characteristic piano tones by electronic means. It may here be stated that I then convert the sinusoidal vibrations of the reed into asymmetrical, highly-peaked electrical waves by proper design and location of the electrical pick-up electrode with respect to the reed. These electrical, peaked waves are, in turn, electronically treated to produce audible tones of selectively variable quality, as will be described hereinbelow.

As explained hereinabove, reeds provided with the tuner-damper 24 act effectively as vibrators of preponderantly one frequency. The second II and third III partials are harmonious with the fundamental but relatively weak, and the higher partials (above III) are so weak that they cannot be heard. Where it is desirable to include a group of the higher inharmonic partials (similar to those present in conventional piano string tones and caused by longitudinal, molecular vibrations of the string) I provide a tuning-load device which has but little or no damping characteristic.

FIGURES 11 and 12 show one form of such non-damping tuning-load member 101 attached to the vibratory reed 102. The member 101 may be made from a square or hexagonal-shaped wire rod of spring material, such as beryllium copper, and it may be tinned so that after critical adjustment of its position along the reed it may be soldered to the reed without changing its mass or position. As shown, the tuning-load member is symmetrical about the reed center line so that it does not introduce a tendency towards torsional vibration of the reed. The spacing between the inner faces of this dumb-bell-shaped member may be somewhat smaller than the reed thickness so that the thicker reed will spring apart these faces when the member is slidably forced on the reed longitudinally. The square, or hexagonal shaped rod is used to provide a flat, yet very short, contact surface between the tuner-load member and the reed, axially of the reed length.

For a typical steel reed having a fundamental frequency I=142 cycles per second, a length 1⅝ inches, a width of .096 inch and a thickness of .016 inch, I have found that a load of this general type may be made of a piece of brass wire ¾ inch long and .092 inch in diameter. The following tabulated data shows how the partials I and II of this particular reed are affected in frequency by critically-adjusted positions of such a tuning-load along the reed length, measured from the fixed end of the reed.

Load	Frequency in c.p.s.		Frequency Ratio of Partials, II/I
	Partial I	Partial II	
No load	142	890	6.27
Load at 1/8"	141	846	6.00
Load at 5/16"	140	700	5.00
Load at 7/16"	130	650	5.00
Load at 15/32"	135	540	4.00

The above frequencies were measured to an accuracy of approximately 1% by means of a "beats" method with an audio frequency oscillator. For the exactly integral frequency relationships between the partials I and II a steady state wave pattern was observed on an oscilloscope when the critical position adjustment of the load on the reed was achieved.

As disclosed in my United States Patent No. 2,413,062, issued December 26, 1946, there is no nodal point for the partials I, II, III, IV, and V within a distance of ¼ (one-quarter) of the reed length from its fixed end. Thus, all of these partials will undergo a lowering of frequency when the load is applied within that limit as to position. The greatest relative frequency shift is produced in that partial which has an antinode of vibration at the point where the load is attached, whereas no frequency shift would be produced for any partial having a nodal point at the load-position point. All partials having a vibration amplitude greater than zero at the load-position point will, therefore, undergo a change in frequency when the load is applied. Since partial III is normally 17.5 times partial I in frequency, and since partial IV is 34.4 times partial I in frequency, these partials are so high in frequency and damping rate, and so low in energy, relative to the partial I, that they (even when reduced as much as ½ in frequency by the tuning-load device) are heard principally only as a transient at the beginning of high amplitude reed vibrations.

If, however, the load be so massive, or placed so far from the fixed end, that partial II is lowered to, say, 4 times partial I in frequency, then these higher partials are reduced in frequency to values where they (particularly partial III) become slightly disagreeable in combination with the Fourier series partials generated by the pick-up electrode, resulting in a transient, rough or raspings sound at high reed excitation amplitudes. The pick-up arrangements useful in conjunction with my novel, tuned vibrators will be explained in detail hereinbelow. I, therefore, prefer to tune partial II to either 5 or 6 times partial I in frequency, whereby the effect of partials III, IV (and higher reed partials) is strikingly similar to the "ringing" inharmonic transients of the lower pitched tones of piano strings.

Since retuned partial II is, thus, of exactly the same frequency as partials 5 or 6 of the Fourier series of integrally related partials generated by the pick-up, it can cause neither discordance nor amplitude modulation by beats with it. Contrasted with the visco-elastic type of tuner-damper which strongly damps all partials above the fundamental I (and even damps partial I somewhat), this non-absorptive tuning-load 101 leaves all partials undamped, except for internal hysteresis, air damping and other damping factors associated with the reed or its support. The fact that partial I is undamped by the loading member insures an output tone of maximum duration, or minimum rate of decay.

My primary purpose is to secure an essentially pendular reed vibration, to retune partial II to an exact integral frequency ratio with partial I, to reduce the amplitude of partial II, and to wipe out the higher numbered partials. With this type of vibrator and pick-up electrode arrangements to be described, the output tone consists wholly of Fourier-related partials uncontaminated by discordant transient components. Since, however, a group of inharmonic transient components is present in conventional piano tones of the most acceptable type, and since this concept of a good piano tone is firmly established in the minds of musicians, it may be considered preferable to include such transient, dissonant components in my reed vibration in order to reproduce them in the output tone and, therefore, satisfy the generally accepted concept of conventional piano tone. Their inclusion does afford a wider change in output tone quality than is obtainable without them since, for low amplitude reed vibration they are very weak and the output tone is soft and sonorous while at higher and higher reed vibration amplitudes they become more and more strident, thus changing the mood of the tone to a more and more "snarling" type, characteristic of the best pianos. The quality and touch-responsiveness of the instrument is thus much widened by a brightening of its quality change with its increase in loudness.

FIGURE 13 is a transverse, cross-sectional view similar to FIGURE 12 but showing a tuning-load member 103 of different form. Here the load member 103 comprises a U-shaped piece of square or hexagonal-shaped wire of spring material. The distance between the inside faces of the legs of the U is somewhat smaller than the width of the reed 102 so that the member 103 will not move relative to the reed when the latter is vibrated during the adjusting procedure. The inside surfaces of the legs may be tinned so that after the critical adjustment of the load member along the reed it may be soldered to the reed without changing its mass or position.

Vibratory reeds of the type described hereinabove, and which are useful in the practice of my invention, may be set into vibration by one of several excitation means, namely,

a. Hammer action,

b. Plectrum action,

c. Electromagnetic attraction or repulsion,

d. Electrostatic attraction or repulsion.

In general, the hammer type of mechanical exciter is preferred with reeds having damper toners, as above described, because such action is essentially a pianistic type familiar in action and feel to all pianists. Also, such action yields better operation for variation of excitation amplitude in response to variable-velocity of key depression. For such actions I prefer to employ the mechanisms disclosed in my prior patents, #1,992,438 issued February 26, 1935; #2,271,460 issued January 27, 1942, and #2,469,568 issued May 10, 1949. These key and hammer actions offer very much simplified mechanical, key-operated, hammer actions well suited to the low kinetic energy requirements of these diminutive reed vibrators, and afford various degrees of perfection of performance. It is desirable for such hammer actions that the hammers fall in a straight line so that the reeds and the reed base must, therefore, be so designed that the correct striking points on the reeds also be a straight line. For this purpose the reed base ends, as well as the reed free ends, fall in suitable curves to conform to this condition. In certain designs, however, the free ends of the reeds may also desirably fall in a straight line so that the pick-up electrodes employed to translate the reed vibrations into electrical oscillations may extend in a straight line. In such case the base ends of the reeds form a more pronounced curve.

I have found that light weight, high velocity hammers are superior to heavy, low velocity hammers for excitation of the vibratory reeds. The travel distance of such high velocity hammers must be large relative to the reed vibration amplitude at the striking point. Also, such hammers deliver an equal amount of kinetic excitation energy to the reed in a much shorter time period and, therefore, the hammer remains in contact with the reed for only a very short period of time. This reduces the damping effect upon the reed vibration which varies directly with the time period during which there is physical contact between the reed and the hammer. It will be apparent the longer path of travel of a high velocity hammer also reduces the antirebound requirements of the hammer mechanism after the hammer has returned to its impelling device which is moved by the playing key. It also permits of better adjustment for insuring hammer contact with the reed for weak key blows. While the FIGURE 1 representation is not intended to show the numerous components drawn to an exact scale, it will be noted that the exciter mechanism comprising the hammer stem 52 and the hammer head 56 are substantially smaller than those of a conventional piano.

In an electronic musical instrument the translating system is active at all times and, consequently, some means must be provided to terminate the reed vibrations except in such instances where the artist purposely desires selected tones to continue after the playing key has returned to the initial position. While ordinary felt dampers of the type used on conventional pianos, and other known instruments, may be used with my vibratory reeds these, in general, are not entirely satisfactory because they alter the pitch of the reed tone as they are applied. Upon release of the playing key and the attendant damper action the tone changes slightly, but objectionally, in pitch as the tone dies out. Furthermore, such dampers are made of soft, yieldable, low-loss material such as felt. Such material sheds fibres in use and these fibres may interfere with the operation of the reeds or their associated pick-up electrodes. Also, for relatively compliant vibrators as the small reeds employed in my device, the felt dampers are slow acting in damper action when the material is too soft and, on the other hand, harder grades of damper material may cause a rattling of the reed as the damper comes into contact therewith. I, therefore, prefer the entirely new type of damper as discussed hereinabove and shown in FIGURES 1 and 2. Such dampers are of simple construction, rugged and inexpensive and they serve to damp out the vibrations as rapidly as desired without changing the vibration frequency of the reed. These damper wires 65, FIGURES 1 and 2, should be made of steel, such as music wire, or flat strip material, and, additionally, may be coated, as by plating, with a very hard material such as chromium for abrasion resistance, protection from oxidation, etc. They are preferably of softer material than the reeds so that they and not the tuned reeds will suffer whatever wear may occur.

Conventional pick-up electrodes as presently used with mechanical vibrators are wholly unsatisfactory for the purposes herein described. Such pick-ups are located to one side of and in the plane of the vibrators vibration and will faithfully translate the mechanical vibration, without distortion and without the addition of other vibrations not present in the vibrator. This has been the object of all such prior vibrator pick-ups and every possible distortion factor has been most carefully avoided. For my purposes, however, such prior arrangements are quite useless. The reason for this is that such arrangements will translate practically only the fundamental partial I of the reed since this is 5 to 10 times partial II in amplitude, and 15 to 20 times partial III in amplitude.

An electronic instrument employing plucked reeds has been disclosed by the prior art. This instrument can produce only dull, simple tones, similar to that of tuning forks, having most of its energy in only one component, i.e. partial I. Whatever amplitude of partials II and III are reproduced by the translating apparatus will be relatively weak and strongly inharmonic since partial II is 6.27 times partial I and since partial III is 17.5 times partial I, in frequency. These results are obtained with the pick-up located near the free end of the reed. If the pick-up be placed closer to and adjacent to the fixed end of the reed the partials above I will be relatively stronger but, since these partials are badly inharmonic with I, the reproduced tone is even worse than before.

The use of plectrum excitation means with prior devices tends to reduce the production of partial components above the fundamental I, especially for those reeds of lower pitch which are loaded. Consequently, such reed tones, while not ruined by inharmonic overtones, are nevertheless dull and uninteresting musically. When such reeds are percussively excited by hammers the production of partials is much more developed, with the obnoxious results above described. This is particularly the case when an already vibrating reed is restruck by its hammer at the moment the reed is moving toward the hammer. In this case, the free end of the reed continues in its vibration direction, which is opposite to the direction of that portion of the reed which receives the hammer blow. Short duration transients of other frequencies are produced until the reed has resumed its own natural mode of vibration. These transients produce very unmusical sounds. Such percussive excitation, therefore, for conventional reeds with conventional translating devices, cannot be used where there is even a moderate requirement for a good musical tone. I omit reference hereto bell type tones which are characterized by a jumble of mostly inharmonic partials unless their vibrators are specially designed to make at least two (or more) of the partials harmonic with one another. Bell tones, generally, are not considered good musical tones.

Some relief, at least as to partials II and III may be obtained from such percussively-excited reeds if the hammer be made to strike the reed at a nodal point for one of the partials and the pick-up be placed opposite to the nodal point of the other partial. When such critical adjustments are made partials II and III disappear because one of them is not excited in the reed due to the hammer striking point, and the other, while excited in the reed will not be translated by the pick-up. Also, reversely phased pick-ups may be used to cancel out an unwanted partial. However, when (as above described) the normal mode of vibration of the reed is completely changed by re-excitation of a vibrating reed at such instant when the direction of motion is opposite to that of the hammer then the aforesaid transient vibrations are produced and the tone is ruined. This is particularly true at high vibration amplitude. Such action may occur very noticeably in one out of 5 or 10 such re-excitations, as in repeating a given tone at short intervals, but this is enough to render unsatisfactory the entire method of tone production, as I have learned by experiment.

Conventional pick-up arrangements, therefore, cannot be used with reed vibrators for the production of piano tunes, nor, for that matter, for producing any other type of tone with integrally related partials falling in a Fourier series. If, however, the reeds are provided with damping and loading devices such as the tuner damper 34, described with reference to FIGURE 1, above, and if the percussive excitation be applied to the reed against or near such tuner damper, then the above described objectionable transients will not be produced and conventionally located pick-ups may be used. Partials II and III will be reduced considerably in amplitude but they will be harmonic with each other and with partial I so that the electronically reproduced tone (as well as the direct tone if the vibrator be large enough to produce it in useable amplitude) will have some musical value. Since partials III and above are very strongly attenuated by the damping action of the tuner-damper 34 these tones will have only three partials, i.e. I, II, and III, of which I is quite strong and II and III are progressively much weaker. Such tones while considerably better than those having but one partial, and very much better than those with inharmonic partials, are still not sufficiently good for use as piano tones. They may serve useful purposes where relatively dull tones are desired and I wish to make it clear that I may employ conventionally placed pick-ups with my damper loaded reeds for the production of tones of this type, which tones, while not entirely comparable to the characteristic tones of a piano are, nevertheless, better in this respect than tones produced by prior devices.

To produce electronically the characteristic tones of a piano by means of mechanical vibrators I start by making the vibrator such that it produces a sinusoidal vibration that is free of unwanted harmonics and then convert these vibrations into asymmetrical electrical waves having sharp peaks which, in turn, are electrically treated to give the desired audible tones. To accomplish this I provide a new and highly useful type of pick-up electrode used in conjunction with the damper-loaded reeds described hereinabove. These pick-ups, instead of being placed at the side of the vibratory reed, are positioned approximately opposite the reed tip, that is, the free end. They may take many specific shapes for various tone qualities and they may be placed at various positions along or near the arc of travel of the reed tip. I choose these positions for various reasons, not the least of which is that here the desired fundamental partial I is strongest compared to other partials in which I am not interested for the production of piano tones. In general, the pick-ups are very close to the arc of travel of the associated reed tip, say 1 to 10 mils separation. In this position it is never possible for the reed to strike the pick-up, as may occur with pick-ups placed over one side of the reed, in the plane of its vibration. I prefer to so locate the pick-up with respect to the reed that any vibration of the reed other than in the plane of its flat side will have little or no effect upon the translation system. Percussively excited reeds generally vibrate only in the direction of the hammer blow which may be made normal to the flat side. However, as an added precautionary measure, in case there is some small component of vibration normal to the side edge of the reed, I prefer to make such transverse vibration harmonic with the normal vibration by making the reed width an exactly integral number of times its thickness. With reeds so proportioned, the preferred position of the pick-up is opposite the tip or free end of the reed.

As shown in FIGURE 14, which is a plan view of a mounted reed and pick-up, the reed 105 is mounted firmly on the reed base 106 by the screw 107. The pick-up electrode 108 is alined with and spaced from the free end of the reed, it being noted that the pick-up electrode is wider than the reed. In such arrangement the pick-up will not translate any lateral components, or any torsional components that may be present in the reed due to off-normal excitation direction, non-homogeneous reed material non-planar flat sides, or other effects. Thus, the requirement for exact, integral, dimension relationship between width and thickness of the reed is not critical. Any small lateral vibrations of the reed tip change neither the effective distance between the reed and pick-up nor the effective area of the electro-static field between them, so that no translation occurs.

Although the pick-up may present a flat surface to the reed tip, as shown in FIGURE 15, which is a side view of the FIGURE 14 arrangement, I have found that a blunt, wedge-shaped pick-up is preferable for pianistic tones, see FIGURE 16. For some regions of the musical scale the top edge of the pick-up may be rounded in the region of the at-rest position of the reed, as shown in FIGURE 17.

The shape of the pick-up on the side facing the reed tip importantly affects the quality of the reproduced tone, and it acts differently in different parts of the scale of reeds, principally because the amplitude of these various reeds varies from bass to treble. For example, a 3½ inch long, F=43.65 cycles per second reed may vibrate a maximum of one (1) inch overall, while a ⅝ inch long, F=1396.9 cycles per second reed may vibrate only a maximum of 1/32 inch. The shapes of the individual pick-up electrodes may be varied progressively, if desired, from lowest base to highest treble, in order to secure tone qualities of uniformly pianistic types along the scale, or they may be varied in shape where other than pianistic tone qualities are desired at portions of the scale.

It is not necessary that the pick-ups be made of solid metal blocks since only the side facing the reed tip is predominantly effective as a pick-up electrode. They may be constructed of conductive strips having the flat side facing the reed end, or indeed, of a single strip for all the reeds where independent adjustability of position relative to each reed tip is not required, as where the adjustments are made in the reed itself. When a progressive shifting, along the scale of reeds, for the angle θ between the face of the reed and the face of the pick-up electrode, see FIGURE 15, is desired, the single pick-up strip may be attached to the block that has a face cut at a varying angle to its base, as shown in FIGURES 18 to 21.

As shown in FIGURE 18, the individual reeds 110 are secured to the reed base 111 by the screws 112, said reed base being secured to a base plate 113. The reed base 111 is angularly disposed with respect to the insulating block 114, also secured firmly to the base plate 113 and which has secured to one face the metal plate or strip 115, as by screws 116, that constitutes a common pick-up electrode for all the reeds. Such arrangement results in the free tips of the varying-length reeds falling along a straight line. The face of the insulating block 114 varies progressively from a vertical position at one end thereof whereby the pick-up plate 115 presents a varying-spaced surface to the shorter length reeds. This construction is better illustrated in the cross-sectional views shown in FIGURES 19 to 21. FIGURE 19 is a longitudinal, sectional view through the low frequency or bass reed (line A—A of FIGURE 18) and it will be noted the surface of the pick-up plate 115 is normal to the plane of the reed. In FIGURE 20, which is a cross-sectional view of a shorter, intermediate frequency reed (line B—B of FIGURE 18) it will be noted that the angle between the reed and the plate 115 is increased. In FIGURE 21 (taken along the line C—C of FIGURE 13), the shortest, high treble reed, shows a still further increase in the angle between the reed and the plate 115.

It is important that the pick-up (or pick-ups) be rigidly secured so that it cannot vibrate relative to the reed tip as any such vibration will be translated by the electronic circuit introducing spurious tones or transients into the desired tone. For the same reason both the reed base and the pick-up support must be mounted on a common, very rigid base plate, as shown in FIGURE 1. Should these parts be mounted otherwise, any slight torsional or other vibration of the reed or pick-up mountings would alter the distance between the reed tips and the pick-up and again spurious vibrations will be introduced into and ruin the desired tone. Such objectional effects may readily be introduced when the playing keys are struck. Other objectionable effects such as acoustic feed-back from an included loud speaker may also be produced. Since for this type of vibration all pick-ups are influenced simultaneously, and in aiding phase, the requirement for fixed spacing between the reeds and the pick-ups is very important. Only such variations in spacing as occur with proper reed vibration are desired. By mounting the reeds, reed base, pick-up and pick-up support on a common, relatively heavy base plate, any extraneous vibrations will not result in a relative vibration between the reed tips and the associated pick-ups. Where large sound energies are radiated or conducted to the base plate, as by a loud speaker contained in the same cabinet, the base plate may be vibrationally insulated from the cabinet by well-known means.

While the distance between the reed tip and the pick-up determines the degree of translation efficiency, it also controls to a considerable degree the quality of the output tone since the spacing influences the shape of the capacity-variation curve as the reed vibrates. This spacing must either be determined in advance for each tone for a desired tone quality or amplitude, or the individual spacings must be capable of adjustment either by adjusting the pick-up or the reed. I have found that such adjustment of the reed is preferable because it is simpler and less expensive. Reeds, such as shown in FIGURES 5 and 6, having clearance between the reed lug and the clamping screw (see FIGURE 1) are well suited to this type of adjustment. Other simple methods for adjusting a reed axially will be known to those skilled in this art.

Another very important factor which determines not only the output tone quality, but also the decrement of the output tone, is the position of the top side or edge of the pick-up with respect to the normal, at-rest, position of the reed tip, i.e. the specific location of the pick-up along the arc of travel of the reed tip. This affects the point, along the vibration cycle, at which the capacity between the reed and the pick-up becomes a maximum. It affects the rapidity with which the capacity rises and falls. When exactly opposite the reed tip, or more accurately, when the top edge of the pick-up bisects the end surface of the reed when the latter is in the at-rest position, the reed tip travels past this edge at maximum velocity and more or less tangent to the reed travel arc. This arrangement is shown in FIGURE 22, wherein, as in other similar figures, the air-gap between the reed and pick-up is much enlarged for the sake of clarity. The capacity-variation rate here is consequently maximum for a given spacing between the reed tip and the pick-up. This, in turn, results in a translated voltage or current wave of maximum steepness and a tone quality of maximum complexity, as explained hereinbelow. It is also at this point where the decrement of the reproduced tone is the lowest. Here the translation of the reed vibration continues down to extremely low vibration amplitudes of the reed and the capacity between the reed and the pick-up continues to be modulated by these minute vibrations. As a result of this type of placement, and very small spacing between the reed and pick-up, this arrangement produces long-continuing tones, fully as long or longer than like-pitched piano tones. Such long-continuing tones are utterly unobtainable with conventional pick-up arrangements.

With the position of the pick-up electrode as shown in FIGURE 22 wherein the top edge of the pick-up bisects the end surface of the reed, and the reed vibration is symmetrical on each side of its at-rest position, the fundamental frequency of the translated vibration will have a component double that of the reed fundamental frequency. It, therefore, results in a maximum Fourier series of partials and a minimum damping rate. However, if the pick-up is so placed that its top edge is slightly above the top surface of the reed (as shown in FIGURE 23) or below the bottom surface of the reed (as shown in FIGURE 24) the character of the capacity variation between the reed and pick-up and the decrement of the reproduced tone will be altered. Since, as explained in more detail hereinbelow, this type of pick-up arrangement produces a full complement of exactly integrally related partial frequencies, the adjustmen, just described is extremely valuable in adjusting the output tone quality as well as the damping rate of this tone. Since these adjustments need only be of small degree to obtain the desired tone quality variations, they may be made by slight bending adjustments of the reed rather than displacement of the pick-up. For this reason it is desirable to use for the reeds a material such as beryllium copper which will undergo these small bending adjustments without breakage. To further increase the abruptness of capacity changes between the reed and the pick-up, a grounded shield 116 may be employed with the pick-up, as shown in FIGURE 25. The pick-up 115 and the grounded shield 116 may be mounted upon an insulating support 117.

A third type of adjustment is also desirable, namely, an adjustment for output tone volume alone. Since the sound output of sound reproducers, such as a loud speaker, is never uniform with varying frequency and constant energy of its electrical input, and since it is very desirable to obtain a uniform loudness for all tones, or a smooth linear shift of loudness from bass (where it is loudest) to treble (where it is weakest) as in a piano, an adjustment of this character is essential. Otherwise the tone loudness from note to note would vary considerably and uncontrollably.

For the immediately above stated adjustment I vary the effective area of the immediately opposite portions of the reed and pick-up by a lateral adjustment of one relative to the other. This is most effectively and easily obtained if the pick-up comprises a comb-like member whose teeth have widths substantially equal to that of the associated reeds. Such an arrangement is illustrated in FIGURE 26.

In FIGURE 26, which illustrates three representative reeds 120, 121 and 122 of different widths, the single pick-up electrode 123 is provided with integral teeth 124. These teeth have widths corresponding substantially to the width of the reed with which the particular tooth is associated. The mounting hole 125 passing through the lug of each reed is somewhat larger than the mounting screw used to secure the reed to the reed base. Such oversize clearance holes permit axial movement of the individual reed to adjust the spacing of the reed tip from the tooth of the pick-up electrode as shown on an exaggerated scale in FIGURE 27 and lateral alinement of the reed with respect to the associated electrode tooth, as shown in FIGURE 28. The axial ajustment effects tone quality and volume, and the lateral adjustment affords a means for matching the volume of individual reeds. Since there are 61 to 88 reeds and pick-ups in a piano, the capacity between a single reed and associated pick-up is but a small part of the total capacity of the entire system. Lateral adjustment of the reed, before clamping the reed with its screw, fixes the capacity variation produced by this reed's vibration compared to that of the other reeds. The loudness of individual reed-produced tones may, therefore, be adjusted for all reeds, greatest loudness being obtained with minimum spacing and exact alinement of the reed with the pick-up. Reduced volume is obtained by lateral adjustment of the reed to one side or the other of the true alined position.

It will now be understood that the three vital adjustments, tone volume, tone quality and tone damping, are all obtainable easily, simply and inexpensively by adjustment of the reed axially, and/or laterally on its mounting and by bending the reed slightly up or down in the plane of its vibration. When these adjustments have been made correctly, as determined by the ear or by instrumental tests, the clamping screws may be tightened and such tonal quality and characteristics remain constant thereafter, barring accidental damage to any of the functional parts.

The above arrangement permits a smooth, pianistic transition from bass to treble tones as to loudness, tone quality and decrement. These are important factors of musical tones. Other factors present in imperfect tones, such as "hammer crack," spurious vibrations occasioned by longitudinal modes of conventional piano strings, etc., may well be forgotten; they are present in imperfect tones only because it has heretofore been impossible to remove them.

Having described a method of providing an essentially pendular vibrator having only harmonious partials and electrostatic pick-up electrodes associated therewith I shall now explain the theory underlying the translation of the essentially single, fundamental vibration frequency of the reed into a maximum of Fourier series spectrum components.

It can be shown by mathematical analysis, or synthesis, that steep wave front pulses generate various harmonic series according to the shape of the pulse or its time rate of change. For example, a wave of the type shown in FIGURE 29 results from the compounding of 30 terms of the series,

$$y=2[\sin(x+90°)+\tfrac{1}{2}\sin(2x+90°)+\tfrac{1}{3}\sin(3x+90)\ \ldots]$$

Conversely, a pulse shape of this type contains 30 components, even and odd, of the Fourier series.

A wave of the type shown in FIGURE 30 is obtained by compounding 15 terms of the series,

$$y=2[\sin x+\tfrac{1}{3}\sin 3x+\tfrac{1}{5}\sin 5x\ \ldots]$$

Conversely, a wave of this shape contains 15 components, all odd, of the Fourier series.

A wave of the shape shown in FIGURE 31 is also obtained by compounding 15 terms of the series,

$$y=2[\sin x+\tfrac{1}{3}\sin(3x+180°)+\tfrac{1}{5}\sin 5x+\tfrac{1}{7}\sin(7x+180°)\ \ldots]$$

or

$$y=2[\sin x-\tfrac{1}{3}\sin 3x+\tfrac{1}{5}\sin 5x-\tfrac{1}{7}\sin 7x+\ \ldots]$$

Here the phases of alternate terms of the odd-term series are changed by 180°.

While curves 30 and 31 appear very different, both are symmetrical about the axis of variation. Both, therefore, contain only odd numbered harmonics or components, and, because phase relations among the components have little or no bearing on the output tone quality as heard by the ear, they will sound alike.

The FIGURE 29 wave having, by inspection, asymmetry, contains both even and odd terms of the Fourier series. This is the type of capacity variation desired for a good musical tone of the piano class. The FIGURES 30 and 31 waves containing only odd-numbered partials will have a characteristic "hollow" type of sound, suitable for some musical purposes but not characteristic of piano tones.

Piano tones contain odd and even harmonics. Hence, to produce tones of piano quality it is necessary to generate a wave form like that shown in FIGURE 29. In order to secure the maximum of Fourier partials it is necessary to develop highly-peaked variations of capacity so that the pick-up electrode must be designed to produce very rapid changes of capacity as the reed vibrates past it. Furthermore, its action should be asymmetrical so that both odd and even partials will be produced. Still further, the harmonic spectrum should increase in richness with increasing amplitudes of reed vibration, and should become simpler with low amplitude vibration. Also, the pick-up should be sensitive to very small amplitudes of reed vibration in order that the translated tone may have a low decrement. A still further desired effect is a gradually increasing decrement and a gradually decreasing harmonic content with increase in the fundamental tone pitch from bass to treble.

All of these desirable characteristics are provided by my electrostatic transducer. As stated above, I start out with a vibratory reed having an essentially sinusoidal vibration in which the greater part of its own inharmonic partials are entirely eliminated and those remaining (partials II and III) are brought into harmony with the fundamental frequency. Associated with such reed is a novel arrangement of the pick-up electrode whereby sharply-peaked, asymmetrical wave forms are obtained yielding a maximum of Fourier series spectrum components from the single, fundamental frequency.

FIGURE 32 illustrates the variation of capacity between the reed 110 and the pick-up 115 arranged as shown in FIGURE 22. The curve X represents one cycle of reed vibration having an amplitude θ. As the reed moves upward the capacity, curve Y, drops sharply to a minimum value. As the reed returns to the initial, at rest, position the capacity increases and reaches a maximum value when the reed passes just below the at-rest position, after which it again decreases. It will be apparent that with the pick-up arranged as in FIGURE 22 (upper edge of the pick-up bisecting the edge of the reed), even minute amplitude vibrations of the reed will produce sharp capacity variations. Such asymmetrical, highly peaked oscillations produce both odd and even components or Fourier partials.

FIGURE 33 illustrates the relative amplitudes of the Fourier series partials for three tones, namely, the low piano tone of 50 c.p.s., a middle piano tone of 1,000 c.p.s., and the top piano tone of 4,200 c.p.s. These spectrograms of my reed tones were obtained by regenerative, electromagnetic feed back for maintaining the reed vibrations at constant amplitude, as shown in FIGURE 34. This amplitude does not represent the peak, hammer-excited amplitude, but one of moderate value, which, for each of the three tones, produced a moderately complex tone quality. The constant-amplitude vibration mode was arranged to obtain a steady indication on the cathode ray tube of the panoramic, sonic analyser. The exactly-integrally-related, perfectly harmonic partials were generated by the translated capacity modulations with the pick-up electrode 115 spaced about .005 inch from the reed 110 and the reed vibrating about 8 times its thickness in amplitude.

As stated above, an asymmetrical, highly-peaked capacity modulation produces a full complement of odd and even Fourier series partials making for a rich, full tone such as is characteristic of the piano. The complexity, or quality, of the tone is a function of the wave shape which, in turn, is determined by the shape and location of the pick-up relative to the reed.

There is considerable latitude in the design and construction of the specific electrostatic pick-up employed to translate the pendular vibration of the reed into highly-peaked, asymmetrical wave forms to provide the desired

Fourier series spectrum for the electronic production of pianistic tones. The pick-up constructions, above described, serve admirably for this purpose as they provide asymmetrical wave forms having both odd and even partials.

Other specific forms for the electrostatic pick-up, to provide asymmetrical wave forms, are illustrated in the isometric drawings of FIGURES 35 to 38 which, it is belived, are self-evident. In FIGURE 38 the pick-up strip has the same curvature as the arcuate vibration path of the reed tip, this curved surface having its center of curvature at or near the fixed end of the reed.

The specific shape of the electrostatic pick-up and its position with respect to the reed tip determines the character and complexity of the generated wave form. As noted above, an asymmetrical vibration of the reed relative to the active, or effective, portion of the pick-up is required to produce both odd and even partials necessary for the production of pianistic tones. However, if a different type of output tone is desired this can be achieved by a different location of the pick-up relative to the reed. For dell tones, conventionally placed screws, plates, etc., may comprise the pick-up electrode, such electrodes being disposed adjacent to one or both flat sides of the reed. For other types of tones the pick-up may comprise a strip of metal having an edge facing the reed end, as shown in FIGURE 39. This arrangement produces abrupt capacity changes but the output wave form is symmetrical about its time axis and, consequently, the wave will include only odd numbered partials such as I, III, V, etc.

FIGURE 40 illustrates a mounting arrangement that facilitates adjustment of the spacing between the reed and the pick-up. The reed 130, carrying the tuner-damper 34, is secured to the reed base 131 which, in turn, is mounted on the base plate 132. The pick-up electrode 133 is soldered or brazed to a metal, leaf-spring 134 having an end secured to the support 136 by the screw 135, said support being mounted on the base plate 132. In this case the leaf spring is relatively thick and exerts good pressure against the tip of the adjusting screw 137 whereby the spacing between the reed and the pick-up may be set to a desired value by merely turning the said screw.

FIGURES 41 and 42 illustrate a bridge type pick-up which can be used with a dielectric reed if the gap between the pick-up plates 150, 151 is small compared to the thickness of the reed. The plates 150, 151 are carried by an insulating strip 152 that is secured to the support 153 by the screw 154. A wire 155 is soldered between the plate 150 and a soldering terminal 156, while a wire 157 is soldered between the plate 151 and a soldering terminal 158 that is secured to the support by a screw 159. The reed 160, or entire groups of such reeds, may be made by a precision plastic molding process, as developed in the mouth organ art, with sufficient accuracy to obviate further tuning thereof. In an arrangement of this type the dielectric reed may vibrate in an electrostatic field between the two sections of the pick-up electrode as shown in my United States Patent 2,027,074 issued January 7, 1936. Such dielectric material reeds may also be made conducting by coating the surface with a metal or graphite deposit as is well-known in the art.

For translating the capacity variations between the vibratory reeds and the pick-ups I may utilize various principles of mechanico-electric translation apparatus which energizes suitable amplifiers and sound reproducing devices.

The capacity modulation pick-ups may be used with A.F. translating systems by applying a constant electrical charge across the reed and pick-up and coupling the pick-up capacity to the A.F. system through a suitable high resistance. This arrangement, due to slow leakage, requires a connection to a source of constant D.C. voltage, or must be made self-replenishing by the phenomena of charge separation well-known in electrostatics. Such systems are well-known in condenser microphone practice and need not be further discussed herein.

The capacity modulations between the reed and pick-up may be employed with R.F. amplitude modulation-translation system. In these the modulated pick-up capacity is utilized as a variable resistance in a circuit carrying radio frequency current as shown in my Patent No. 2,140,025, issued December 13, 1938. With such a system the combined pick-up capacities for all reeds may be included as an element in a radio frequency bridge circuit in which the masking effects of non-vibrating reed capacities are greatly reduced by bridge balancing adjustments and the translating efficiency of the vibrated reeds is greatly increased. Such a bridge arrangement is illustrated in FIGURE 43 wherein the capacitance 162 represents the total capacity of the entire series of reeds and associated pick-ups. The capacity values of the other bridge arms can be made substantially equal to that of capacitance 162 and one or all of these capacities may be adjustable to obtain a bridge balance when all reeds are in the at-rest position.

The modulations of the reed-to-pick-up capacity may also be translated by a R.F. phase modulation system as disclosed in United States Patent No. 2,321,370 issued June 8, 1943, to William Dubilier in connection with a condenser microphone for hearing aid apparatus.

The reed-to-pick-up capacity modulations may be translated by a R.F. frequency modulation translation system of the type disclosed in my United States Patent No. 2,273,975 issued February 24, 1942. In this patent I disclose the principles of frequency-modulation, mechanico-electric translating systems for strings, reeds, etc. In my Patent No. 2,319,622, issued May 18, 1943, I show such a system for use with a capacity modulating phonograph pick-up. Translating systems of this type are preferred for the electrostatic pick-ups as applied to my stringless piano employing vibratory reeds. The reason for this preference is the system's exceedingly high translation efficiency, its low A.F. impedance, its simplicity, and its low cost. A single triode vacuum tube, or a double triode tube with one triode section acting as the oscillator-detector and the other serving as an audio amplifier, will deliver very ample signal power for operation of head telephone sound reproducers which may be used with my stringless piano for practice purposes. A following one stage power amplifier is ample for ordinary loud speaker requirements.

FIGURE 44 illustrates, by way of example, a wiring diagram for a frequency modulated electronic system satisfactory for converting capacity modulations between the reed and pick-up into musical tones. The oscillator circuit comprises a three element oscillator tube 163, an inductance coil 164 connected in the output circuit of the tube and variably coupled to a coil 165, a source 166 of plate potential included in the output circuit, and a grid bias resistance 167 common to the input and output circuits. The total capacity which, with the coil 165, forms the tuning circuit of the oscillator includes the variable condenser 168 shunted across that coil the variable condenser 169 connected between the condenser 168 and the pick-up 115, and the capacity between the reed 110 and the pick-up 115. With the coupling of the coil 164 to 165 suitably adjusted in phase and degree, the circuit will oscillate at an average frequency determined by the capacity value of the several condensers and the capacity between the reed and pick-up. Upon vibration of the reed the oscillatory variations of the reed to pick-up capacity will vary oscillatorily the total tuning capacity of the oscillator and hence the frequency of its oscillations. The amplitudes, frequencies, and wave forms of the swings of the oscillator frequency will be directly responsive to the amplitudes, frequencies and wave forms of the reed vibrations as seen by the pick-up system. As explained hereinabove, the vibration of the reed is essentially sinusoidal but the capacity modulations between the reed and the pick-up are asymmetrical and sharply-peaked, resulting in a Fourier series of frequency variations in the oscillator circuit. These frequency-modulated oscillations of the oscillator circuit are made available to a tuned I.F. amplifier by the coil 170 coupled to the coil 165 (or coil 164 if desired). The I.F. amplifier is followed in cascade by a detector (or demodulater), an A.F. amplifier, and a loud speaker or other electro-acoustic translating device.

A more detailed description of the electronic translating system will be found in my United States Patent No. 2,273,975, issued February 24, 1942. The description given above is sufficient for an understanding of the reed-pick-up arrangements for converting mechanical vibrations of the reeds into musical tones.

FIGURE 45 is a fragmentary plan view showing a mechanical arrangement whereby tone quality may be altered by the performer. Here I show three reeds L, M, and H (representative of low, medium and high frequency tones), said reeds carrying the tuner-damper 34. Spaced from the reed tips is a pick-up strip 171 carried by the supporting rail 172, the latter being pivoted for rotation about an axis formed by the pointed bearing screws 173 threaded into stationary members X. A pulley P, rigidly secured to the supporting rail 171, is mechanically coupled to the pulley P', as by a flexible member F, said pulley P' being secured to a shaft S journaled between the bearing blocks B. The outer end of the shaft S carries a knob K. Although the drawing is of a fragmentary character intended to convey an understanding of the principle involved rather than detailed mechanical structure, it will be apparent turning of the knob K will alter the angle between the plane of the reeds and the face of the pick-up strip.

FIGURE 46 is a cross-sectional view taken along the line A—A of FIGURE 44 and shows the face of the pick-up strip 171 normal to the plane of the reed H. FIGURES 47 and 48 illustrate other angular dispositions between the reed and pick-up as established by rotation of the knob K in one direction or the other. It is pointed out that the pivot axis formed by the screws 173, FIGURE 45, coincides with the top edge of the strip 171 adjacent to the reed. Thus, the initial spacing between the reed and the pick-up (when the reed is in the at-rest position) will remain constant for all relative positions of the pick-up strip but the curve of the capacity modulations (when the reed is vibrating) will vary widely from position to position. It is also pointed out that the limits of the angular rotation of the supporting rail 172 and pick-up strip 171 are set so that in no case will the strip or rail extend into the reigon defined by the arc along which the reed tip vibrates.

Other translating systems, than those presented above, for use with the electrostatic pick-up arrangements, will suggest themselves to those skilled in this art. However, it is not to be assumed that my stringless piano is limited to such pick-up arrangements as other translating systems for the sinusoidal reed vibration may be used with good results.

In fact an electromagnetic type of pick-up may be used but such pick-up requires a special design if the full possibilities of my instrument are to be realized. The electromagnetic pick-up offers advantages in that its voltage output is relatively high, but it is more expensive to manufacture. These pick-ups employ magnetic reeds, or at least reeds with magnetic tips, and they are subject to difficulties resulting from the attraction of metal chips and filings to the magnetic poles. Additionally, and importantly, there may be a shifting of the frequency of the reeds at low amplitudes of vibration due to the magnetic attraction between the reed and pick-up structure if this be high in value. This frequency shift may be minimized by use of a very small amount of magnetic material at the reed tip or by reducing the magnetic bias between the pole tips of the pick-up to a low magnitude. This effect may be substantially eliminated if the pick-up is placed adjacent to the face of the reed in the plane of the reed's vibration. Such conventional magnetic pick-ups placed in such conventional location with respect to the reed may be used where very dull types of tones may be desired. The reason why the conventional arrangement of magnetic pick-up and reed produces dull tones is due to the fact that the pick-up must be spaced far enough from the surface of the reed so that the reed cannot contact the pick-up at the strongest vibration amplitude. The pick-up, therefore, responds fairly well to the lowest partial, I, of the reed vibration but practically not at all to the partials II and III which are present to a much weaker degree.

For effective use in the development of the new series of Fourier series partials, above described, a magnetic pick-up must not only be placed at the reed tip (or at the reed edge very near the reed tip) and provided with a weak magnetic bias but, and very importantly, it must develop very steep, voltage pulses as the reed tip sweeps past it. For this purpose I have devised magnetic pick-ups with weak polarizing magnets and very closely spaced pole tips.

One such arrangement is shown in FIGURE 49, wherein the pick-up comprises a relatively weak, permanent magnet 175 having laminated or powdered iron pole pieces 176 secured thereto, the assembly being mounted upon an insulating block 177 which, in turn, is mounted upon a rigid base 178. A pick-up coil 179 surrounds one of the pole pieces. The vibratory reed 180 may be made of magnetic material or, alternatively, the reed may be made of non-magnetic material having a soft-iron tip 181 provided thereon, said reed being secured to the reed base 182 by a mounting screw 183. It will be noted that the magnetic flux-field is of small size and very concentrated. When the reed tip vibrates very close to the pole pieces the flux suddenly rises and falls through the coil carrying member thereby generating strongly peaked voltage waves in the coil. The magnetic attraction of the magnet poles for the reed, or reed tip is of a very low order to prevent undesired modulation of the reed's vibration frequency. This, of course, reduces the amplitude of the voltage wave, compared to that which would be obtained with a stronger magnetic field, so that the design results in a compromise between frequency shift and output voltage. The most important aspect of the pick-up design, other than that stated, is that the external flux-field adjacent to the reed tip is highly contrated close to the pole tips.

An alternative design utilizes a non-magnetically biased pick-up construction in which the entire core and pole piece structure is made of high quality magnetic material such as "Permalloy" having a very high initial permeability. Such material will develop very high magnetic flux concentration in the core and thus relatively high output voltages in the pick-up coil. If the core material saturates readily with low intensity magnetomotive forces applied to its poles, so much the better, since this will accentuate the steepness and abruptness of the flux changes as the reed vibrates. For a pick-up of this type the magnetomotive force must be provided by the reed or some other source close by whose magnetic influence on the pick-up will be modified abruptly by the passage of the reed tip across the pole tip's non-magnetic gap. As shown in FIGURE 50, the pole piece and core structure may be built around a non-magnetic material 185, such as a plastic, which also fills the gap between the pole pieces. Such construction serves to prevent any possible vibration of the pick-up poles and, at the same time, prevents accumulation of foreign particles in the gap. In the illustrated construction, the reed is made of magnetic material magnetized at the tip across the flat surfaces to provide a diminutive magnet having a length equal to the reed thickness and a width equal to the reed width. The external field of such a magnet will be highly concentrated across and around the reed tip end and vibration of the reed generates magnetic impulses in the pick-up core and highly peaked voltage pulses in the coil 186. The entire reed may be made of highly coercive magnetic steel or, if made of ordinary high carbon steel, the reed may be magnetized from time to time merely by sending a strong, direct current through the pick-up coil 186. Where other than magnetic materials are used for considerations such as lower vibration decrement, greater resistance to deterioration, etc., the reed tips only may be made of high quality magnet steel attached to the reed proper as by welding, soldering, brazing, etc.

FIGURE 51 illustrates a tri-polar, magnetic pick-up wherein the electrical pick-up coil is disposed over the center leg of the soft-iron core 184. The air gaps formed by the outer legs of the core and the coil-carrying center leg are of unequal lengths whereby vibration of the magnetized reed produces asymmetrical voltage waves including both odd and even partials, as has been already explained.

FIGURE 52 illustrates another type of magnetic pick-up construction wherein the reed 190 is made of magnetic material and magnetized longitudinally as indicated by the polar markings N, S. In this case the reed base 191, base plate 192, as well as the core 193 carrying the coil 194, are made of good permeability material providing a low reluctance flux path that is a closed circuit except for the small gap at the reed tip.

Magnetic pick-ups may be of single or multiple reed form. When, as is preferred, all required adjustments can be made by changing the reed position relative to the pick-up, the multiple form of construction offers obvious economies. FIGURE 53 illustrates a multiple reed pick-up, that is, a unitary pick-up structure having discrete pole pieces associated with the individual reeds. The core 195, which may be solid, or laminated, high quality magnetic material, extends the length of the entire reed complement and includes the discrete, tooth-like pole pieces 196, each alined with an individual reed. A single pick-up coil 197 is wound around the core. The reeds may be magnetized either axially or transversely whereby vibration of one or more of the reeds produces abrupt magnetic flux changes within the core and corresponding peaked voltage pulses in the coil 197.

FIGURE 54 illustrates another multiple arrangement of a magnetic pick-up in which the electrical coils 187 are wound upon individual cores 188, each core being disposed between adjacent reeds having laterally magnetized tips as indicated by the polar markings N and S. The cores are disposed right at the reed tips whereby all vibration partials of the reed are translated into a corresponding electrical wave yet there is no possibility of the reeds contacting the cores during reed vibrations of any magnitude.

Having set forth the essential requirements for magnetic pick-up arrangements satisfactory for use with my stringless piano, and having illustrated and described several such arrangements, other arrangements and systems will suggest themselves to those skilled in this art.

In addition to the capacitive and magnetic pick-up and translating arrangements already described, I have developed various photoelectric translating systems for use with my reed vibrators and which provide performance of good quality.

The essential requirements for a photoelectric translating system are:

(1) A steady, very narrow light source (or individual such sources for each individual reed) of high light intensity, preferably providing a beam of light rays having a width and thickness comparable to that of the reed (alternatively, a single light source may provide a thin sheet of light rays extending in the general direction of the reed axes and having a span which extends across all reeds of the assembly of reeds);

(2) A photoelectric cell extending the full length of the assembly of reeds, or individual light collectors for guiding the light rays from each individual reed to a single, small area photocell, or individual, small area photocells for each individual reed;

(3) A suitable audio frequency amplifier and sound reproducer.

FIGURE 55 illustrates a photoelectric arrangement wherein the light source 200 and the lens 201 provide a parallel-ray beam of light that strikes the cathode C of the photocell 202. The photocell is connected to a suitable amplifier 203 which in turn drives the loud speaker 204. The vibratory reed 205, carrying the toner-damper 34, is so arranged that its free end partly intercepts the thin beam of light rays that is projected across the reed to the photocell.

An alternate arrangement of the light beam is shown in FIGURE 56 wherein the lens is so arranged that the light rays are brought to a focus at the edge of the reed from which point they diverge to strike the photocell.

A light-reflecting arrangement may also be employed as shown in FIGURES 57 and 58. In FIGURE 57 the light system provides a parallel beam of light that is reflected to the photocell cathode by the reed surface whereas in FIGURE 58 the light rays are focused to a point on the reed surface and then reflected to the photocell as a diverging beam.

In the FIGURE 59 arrangement the light source 200' includes an integral lens 201' having a focal length such that the beam of light rays are focused upon the surface of the minute cathode C' of the photocell 202' after said light rays have been reflected from the surface of the reed.

In any of the above arrangements optical leverage may be used to increase the speed of motion of the light beam as it varies the illumination falling on the photocell cathode with reed vibrations. Known optical systems may be used to suit particular requirements, to improve the light efficiency, and to provide the necessary light beam modulation for small reed vibration amplitudes.

For the light source I prefer a discharge in a capillary, or small diameter, tube to provide small width, high intrinsic brightness and, more importantly, a non-microphonic characteristic. High concentration of such filamentary type light sources increases the photocell output variations in response to on-off modulation of the light beam and provides the small width required for good focusing by the optical system; as contrasted with a microphonically vibratable wire filament. The electrical discharge through a small-bore tube provides great mechanical stability and consequent freedom from vibration which would set up spurious modulations of the light beam striking the photocell. Additionally, the glass envelope surrounding such luminescent discharge may be sufficiently thick to provide a cylindrical lens, as by molding or extrusion (see FIGURE 59) for focusing a thin strip of light rays that eventually strike the photocell. Both the lamp and the photocell may extend the entire length of the reed scale so that but one lamp and one photocell are required.

The beam of light rays must not be modulated at audio frequency since this would introduce a constant, loud hum into the sound output of the piano. Consequently, the lamp must be operated either from a D.C. source or from an A.C. source of sufficiently high frequency, say 20,000 cycles per second or higher. Both the lamp and the photocell must also be mounted rigidly to the reed-supporting base so that there will be no modulation of the light beam striking the photocell other than that due to reed vibration.

Variations in the sharpness of focus of the light rays, and the position of the lamp and/or photocell with respect to the reeds, may be made to vary the tone quality, or complexity or volume as described hereinabove with respect to the electrostatic pick-up arrangements. Also, adjustments of the individual reeds as to lateral, vertical or axial positions may be made to effect such tonal adjustments for reproduced tone quality, loudness and damping.

It will be apparent that with a light source and photocell, as above described, the photoelectric reed-vibration translating apparatus offers a very simple and effective system.

Adjustments of the optical system may be used to alter the width of the flat light beam modulated by the reeds, or the location of the beam with respect to the reed modulation point along, or lateral to, the reed-swing-arc, or the cross-sectional shape of the beam. These adjustments will vary the reproduced tone quality. When the beam is thinnest the light interruption will be most abrupt and will result in a harmonically-rich tone. Also, with a thin light beam arranged so that one half of the beam is cut off by the reed when it is in the at-rest position, the tone decrement will be lowest. When a thicker light beam is used the harmonic content of the tone will be less and the tone decrement will be relatively higher. Amplitude voicing may be accomplished by displacing the light beam laterally so that a smaller portion of the total light beam will be modulated by the reed.

Since the outputs of the pick-ups (capacitive, magnetic or photoelectric) are rich in harmonics (overtones) I can control the output tone quality of the instrument by employing one or more formant circuits of either low pass, band pass, band suppression or high pass types, with or without regeneration or degeneration in the amplifier circuits. Formant circuits in electronic musical instruments have been employed heretofore. These circuits function to introduce into each successive fundamental cycle of the oscillations passed through them a train of damped oscillations, which train is re-initiated with each new fundamental cycle; the train in the previous cycle having either been substantially entirely damped out or being terminated by the initiation of the new train. The frequency or frequencies of these damped oscillations are normally higher than the fundamental frequency of the oscillations passed through the circuit, but have no necessary harmonic relationship to those fundamental oscillations; nevertheless, since their effect on the oscillations is a strictly recurring one with each fundamental oscillation cycle, the composite output oscillations from the formant circuit may still be resolved wholly into a series of strictly harmonically related components and thus remain a good musical tone. Formant circuits operate electrically in the same manner as various peculiarities in the configuration of, and various resonance cavities in, the air columns of acoustic instruments. However, in acoustic instruments the air cavity characteristics are fixed whereas the constants of the formant circuits may be varied at will to produce desired effects.

A typical such circuit is shown in FIGURE 60. In this circuit the pick-up tone signals are fed to the audio frequency transformer 215, to the formant circuit F (comprising the inductance 216, variable resistor 217 and the variable condenser 218) to the grid of the tube 219. Variably coupled to the inductance coil 216 is another audio frequency coil 220 arranged for varying the inductance between the coils 216 and 220 and, preferably, with provision for reversal of phase from regenerative to degenerative phase as follows. The coil 220 has a mid-tap and a potentiometer 221 connected across the ends. The potentiometer slider permits use of any amount of coil 221 from zero to maximum in either phase, and thus permits any amount of regenerative or degenerative coupling between the plate and grid circuits of the tube.

For regenerative adjustment a band of frequencies whose width is determined chiefly by the resistor 217 and whose mean frequency is determined by the values of coil 216 and condenser 218, are regeneratively increased in amplitude with a damping rate controlled by resistor 217 and with amplitude controlled by the potentiometer 221. For degenerative operation, a band of frequencies whose mean frequency is set by coil 216 and condenser 218, whose decrement and width are set by resistor 217, and whose amplitude suppression is set by potentiometer 221, are suppressed. With the potentiometer set at the mid-point, and resistor 217 set at a high value, but little or no regenerative or degenerative action is obtained so that this arrangement affords a wide variation of these formant effects.

Where desired two or more of such formant-control circuits may be included and operative in different frequency bands to obtain still further tone quality control through an extended frequency range of audio frequency tone signals.

For obtaining further distortion of the simple pendular, sine wave motion of the reed, as developed in the pick-up device, each of the pick-ups such as, for example, the magnetic types hereinabove described, may have connected to it a rectifier device, such as germanium, silicon or other crystals, provided with contact electrodes. Such a rectifier device connected in one phase will allow say the positive peaks of the pick-up to pass with but little reduction in amplitude while the negative peaks will be greatly reduced. If connected in the reverse phase, the positive peaks will be depressed while the negative peaks will pass relatively unimpeded. These rectifiers should be connected across or in series with each individual pick-up for individual tones of the scale to avoid cross-modulation effects in chordal playing, as would be the case if the rectifier is connected across two or more pick-ups.

Another type of tone control is obtained by use of individual condensers across the individual pick-ups for tuning the pick-up inductance coil to a particular formant frequency. A variable, series resistance for regulating the band width of the mean frequency may also be desirable, as shown in FIGURE 61.

Various arrangements and combinations of these shunting circuits can be employed with individual pick-ups, as shown in FIGURE 62 wherein is shown the pick-up coils 220, to 224 of the individual magnetic pick-ups associated with reeds corresponding to the notes C, C♯, D, D♯ and E respectively.

Furthermore, if desired, simple resistors may be used across single pick-ups, or groups of pick-ups, to regulate their tone voltage amplitudes as for amplitude voicing and the like.

Thus far I have described in detail a stringless piano employing hammer excitation of the vibratory reeds. While this type of excitation is preferred I have also developed a simple plucker excitation mechanism that is responsive to key-touched, that is, velocity of key depression.

FIGURE 63, which is similar to FIGURE 1, illustrates an inertia and momentum type of plucker. In this case the pivoted hammer stem 230 carries the plucker device 231 instead of the above described hammer head. A visco-elastic damper 232 normally lies in contact with the face of the reed 27, said damper being carried by a relatively weak, leaf spring 233 that is secured to the reed base 234 by the screw 235. A vertical rod 236 having an end threaded into the playing key 237 and the opposite end slightly spaced from the leaf spring 233 passes through an aperture 238 in the hammer stem. Thus, when the outer end of the playing key is depressed in playing, the rod raises the damper 232 so that the reed is free to vibrate. FIGURE 64, which is a cross-sectional view taken along the line A—A of FIGURE 63, illustrates the off-set in the rod 236 to clear the reed 27.

Reference is now made to FIGURES 65 to 68 for a description of the plucker action, said figures being cross-sectional views taken along the line B—B of FIGURE 63. The plucker comprises a thin, U-shaped, metallic spring 240 secured to the hammer stem 230 by the bolt 241 and nut 242. A pair of rubber, leather or etc., pluckers 243 are carried by the ends of the spring 240 being secured thereto by cement or other suitable means. A thin tape 244, made of flexible material such as Vinylite, is secured at points intermediate the ends of the spring 240 as by the rivets 245 said tape having a weight W secured thereto as by the screw 247, substantially as shown.

FIGURE 65 shows the relative disposition of the plucker components when the hammer stem is in the normal position as shown in FIGURE 63. It will be noted that the spacing between the facing tips of the rubber fingers or pluckers 243 is slightly greater than the width of the associated reed 27. Thus, if the playing key is depressed slowly these pluckers will clear the reed and the reed will not be set into vibration. This effect corresponds to that of a conventional piano. Now, if the playing key is depressed with increased velocity, such velocity is imparted to the plucker device through the hammer stem 230. As the plucker device moves upward the weight W resists upward acceleration, that is, it tends to remain stationary, thereby causing the arms of the U shaped spring to move inward toward each other as shown in FIGURE 66. Consequently, the rubber fingers 243 impart a slight upward deflection to the reed 27, as shown in FIGURE 67. Then, as the weight W gains velocity the arms of the U shaped spring 240 expand such that when the velocity of the weight equals that of the hammer stem 230 the arms will again occupy the normal position, whereby the pluckers 243 clear the sides of the reed. Inasmuch as the reed has been deflected upward before being released by the pluckers 243, the reed is set into vibration. When the hammer stem reaches its extreme upward position by striking the pad 25 (FIGURE 63) carried by the piano front board 24, the weight W continues upward somewhat permitting the side arms of the U shaped spring to spread further apart. As the hammer stem moves to its initial position, after the playing key is released, the arms of the U shaped spring have had time to contract to their normal position and the pluckers 243 clear the reed as the plucker device moves downward. Bouncing of the hammer stem is prevented by the pad 251 carried by the playing key, as shown in FIGURE 63.

It will now be apparent that as the plucker device moves upward, in response to operation of the playing key, the plucker fingers first move toward each other to push the reed upward and then expand with more than normal clearance. At this point (when the fingers 243 are spaced furthest from the reed) the reed is at maximum vibration amplitude. It will also be apparent that with playing key velocity increase the pressure of the plucker fingers against the reed also increases thus increasing the vibration amplitude of the reed. Likewise, with such increased vibration amplitude of the reed, the fingers 243 spread further apart, following release of the reed, due to the increased upward momentum of the weight W, thus assuring positive clearance of the reed as the plucker device moves downward to its initial position. The Vinylite, or other visco-elastic tape 244, in which the weight W is slung, strongly resists any tendency toward oscillation of the arms of the U shaped spring 240 as such material has high visco-elasticity to bending deformations.

The plucker device is mounted on a flat, pivoted lever arm (hammer stem 230, FIGURE 63) which offers three advantages:

(1) The plucker device is kept alined with the reed so that the plucker fingers exert equal pressure against the reed sides thereby assuring a strictly rectilinear, vertical, vibratory motion of the reed with no torsional vibration.

(2) The pivoted lever arrangement increases the plucker velocity which greatly increases the reliability of the action and decreases its sensitivity to slight misadjustments.

(3) The increased motion of the plucker device substantially increases the vertical clearance between the plucker fingers and the reed for the up and down plucker positions, so that large amplitudes of reed vibrations can be used with no danger of damping contact between the reed and the pads.

The arms of the U shaped spring 240 must be long enough so that in the up position of the plucker there is no possibility of the reed contacting the weight W for maximum velocity of key depression.

While the FIGURE 63 device is sufficiently small so that it can be placed upon any flat surface, such as a table, it is apparent it can be housed in a conventional piano cabinet, either upright or grand. In such case foot-operated pedals may be provided. One such pedal can be the "loud" pedal which permits free, undamped vibrations of the reeds. Such arrangement can be provided with plucker excited reeds as is shown somewhat diagrammatically in FIGURE 69. The pedal is represented by the pivoted lever 255 having a rod 256 pivotally secured to one end. The other end of the rod 256 is pivotally attached to a U shaped bar 257 that has its side arms pivotally secured to a bracket 258. The bracket 258 may be secured rigidly to the reed base 234, or to any other fixed surface of the instrument. When the pedal 255 is depressed the bar 257 raises all the dampers 232, thereby permitting undamped vibration of reeds set into vibration by the playing keys.

FIGURES 70 and 71 show a somewhat simpler plucker arrangement wherein contact with the reed is established only on one edge. The plucker device comprises a thin, flat spring 260 secured to the side of the playing key 261 by the screw 262. An L-shaped, rigid member 263 is fastened to the free end of the flat spring, as by the rivets 264, or soldering, brazing, or etc., said member having a tapered rubber plucker 265 affixed to one end and a weight 266 carried by the offset section, as shown. When the playing key is in the normal, at-rest position the plucker device is so disposed that the tip of the rubber finger 265 is spaced laterally from the side edge of the reed 27, as shown in FIGURE 71. When the playing key is struck the rear end thereof flies upward and the inertia of the weight 266 causes the spring 260 to bend in a clockwise direction such that the rubber finger 265 engages the edge of the reed. Further upward motion of the plucker flexes the reed vertically until the velocity of the weight 266 equals that of the playing key whereupon the spring 260 bends in a counter-clockwise direction thereby freeing the reed suddenly. During the downward, return motion of the playing key and plucker device as a whole, the plucker pad 265 moves clear of the now vibrating reed. It will be apparent this device is also touch-responsive in that the greater the acceleration imparted to the playing key the greater the bending moment applied to vertical spring, and consequently, the greater will be the vibration amplitude of the reed. The set screw 267 permits ready adjustment of the initial, lateral clearance between the rubber pad 265 and the edge of the reed.

In inertia types of touch-responsive, plucker-exciter devices it is apparent that not only do the plucker fingers contract (toward and under the reed edge) more and more with increase key-depression velocities to produce larger and larger reed vibration amplitudes, but that they also expand outwardly away from the reed edges more and more with increasing downward velocity of the released key. In the latter case (key release) the weights W (FIGURES 65 to 68) and 266 (FIGURES 70 and 71) resist downward acceleration and, consequently, they lag somewhat behind the key motion thereby causing the respective fingers of the pluckers to move away from the reed edges or edge.

Having now described my invention in detail the many advantages of my stringless piano, as compared to the conventional, tensioned string piano, may be summarized as follows.

(1) A very substantial reduction in the size of the tone-producing assembly.

(2) A very substantial reduction in the weight of instrument.

(3) A substantial reduction in the cost of producing the instrument.

(4) Selective adjustability of tone quality as by adjustment of the reed and pick-up relative to each other.

(5) Easy adjustability, removability and replacement of individual tone producing elements.

(6) Long, permanently-tuned life of the tone generators as by employing beryllium copper vibrators.

(7) Production of a perfect tone comprising odd and even numbered partials.

(8) Positive and easily adjustable vibration dampers which produce no noise, no distortion of the tone and which shed no lint.

(9) A simple arrangement for producing the "loud" pedal and "sostenuto" effects.

(10) Provision of a low-mass, high-velocity hammer action wherein the hammer rebounds from the reed instantly.

(11) Inasmuch as the Fourier series partials introduced in the pick-ups are exactly integrally related, the original tuning of the reeds by the customary "beats" method does not result in octave stretching as is the case with tensioned strings.

(12) The harmonic output of the tones increases progressively with vibration amplitude.

(13) The harmonic content as produced and as heard by the ear, is progressively greater with change of pitch frequency from highest treble to lowest bass, due to the greater vibration amplitude of lower pitched reeds and to the limitations of the ear at high audio frequencies.

(14) The tone quality is ideal as it is totally devoid of spurious characteristics such as is occasioned by longitudinal modes of string vibrations, and excessive "hammer crack," and more importantly, the amplitudes of the partials fall off with increase in the partial number, yielding a smooth, beautiful tone in which the fundamental is strongest.

(15) The direct acoustic tone output of the reeds is inaudible due to their small area, low mass and low stiffness. The reeds radiate no perceptible sound themselves and the vibrations of the reed base, and the cabinet (which has a much larger air coupling area), are so low in amplitude that they do not radiate sound perceptibly.

(16) The freedom from sound radiating effects is reversible so that the reeds are also free of any appreciable reception of sound radiated by other sources, such as a self-contained loud speaker, thereby eliminating for practical purposes acoustic feed-back.

(17) The absence of direct-radiated reed tones makes the instruments operation inaudible unless the amplifier and speaker are placed into operation. Consequently, the performer, by using head phones, can practice without disturbing others.

(18) Where loud speakers are used the inaudible, direct sound output insures complete control of the instrument tone since the electrical output is completely controllable as to quality and volume.

(19) The tone quality of my instrument changes smoothly from bass to treble getting less complex in the higher frequencies.

(20) The tone quality decreases in complexity with reduction in reed vibration amplitude.

(21) The tone decrement increases smoothly from a very low rate in the bass to a high rate in the upper treble. However, the decrement in the treble is not so high as that in conventional pianos, which is a very desirable feature long sought after by piano manufacturers.

(22) With loud speaker operation any desired level of tone power may be produced depending only on the amplifier and speaker power. Thus, the volume range is from complete inaudibility to that which is many, many times that of a conventional string piano.

(23) Tone quality is adjustable by the performer during actual playing of the instrument.

(24) The sound reproducer can be located remote from the reed and pick-up assembly since the F.M. oscillator output can be radiated or induced into a distant demodulator, A.F. amplifier and loud speaker. Alternatively, the A.F. output of the translator system (located in the cabinet) can be carried via a cable to a reproducer apparatus.

(25) If desired, the F.M. translator tube may be powered by batteries to make a truly portable instrument.

(26) If the frequency of the F.M. oscillator translator be chosen in the F.M. broadcast band, a home type F.M. receiver may be used to receive, demodulate, A.F. amplify, and reproduce the reed vibrations with or without connecting wires. Thus, for practice purposes, the performer may listen with his headphones alone, in which case he adjusts his oscillator frequency above or below the F.M. band of his home receiver so that the receiver is available for normal reception of broadcast programs. Then, if the performer wishes to dispense with the head-phones, or if others wish to hear his playing, he can retune his translator oscillator to some frequency in the F.M. band but which is not occupied by a broadcast station, set his receiver to this frequency, and then listen to his music on his head-phones or through the speaker of the receiver.

(27) For recording or broadcast purposes either the F.M. radio frequency signal or the A.M. output of the reed translator may be fed (the former by radiation, induction or conduction and the latter by conduction or induction) directly to the appropriate channel of the recording or broadcast apparatus, without the intervention of sound-reproducing apparatus such as loud speakers. This reduces overall distortions for such use.

(28) For restricted keyboard models my piano may be made portable so that it can be carried or hung from shoulder straps. In such case the instrument is provided with a battery-operated translating F.M. radio frequency system, and the F.M. receiver may be located anywhere in the room. A capacity type microphone may be included for voice superimposition upon the music.

(29) Since the reeds are low in cost, two reeds per note can be provided. These reeds may be tuned slightly off unison to give a chorus of two unison tones. Additional reeds tuned 7 cycles per second from the true frequencies may also be provided to provide tremolo effects.

The principles involved in the present invention are unique in that they utilize for mechanical reasons of space, weight, excitation requirements and complete freedom from periodic tuning adjustments a type of vibrator which has heretofore been considered absolutely worthless for impulse excitation. Also, because the greater part of the reeds own inharmonic frequency components have been entirely eliminated by the tuner-damper, and the remaining components are brought into harmony with the fundamental and at reduced amplitude, these harmonic reed vibrations are converted into entirely new, musically perfect tones by the shape and disposition of the pick-up electrode. All of this has been accomplished with an apparatus so small, simple, rugged and inexpensive, as to exceed the fondest expectation of men skilled in this field. Well qualified and competent musicians have pronounced the tones produced by my stringless piano not only equal to but actually superior to piano tones of the best types, when judged by a side-by-side comparison. Such musicians recognize the tone superiority but rarely know why these tones are better since they are unacquainted with the physical principles of tones or tone production.

Acoustical physicists, however, need not even hear these tones to pronounce them superior since mere knowledge of the methods used in their production will indicate at once the exactly-integral frequency relationships, the absence of spurious vibration modes, the ascence of spurious noise transients, the change in harmonic content from bass to treble, and the smooth decrease in amplitude from low numbered to high numbered partials. These characteristics are confirmed by instrumental measurement data such as spectral analysis of the tone partial systems throughout the pitch range, by means of a sonic analyser. Oscillograms of the complete tones from beginning to end show the damping rates correspond to those characteristic of piano tones throughout the scale.

In summary, my stringless piano produces tones of piano character because:

(1) It yields tones having a harmonic content like that of a piano string;

(2) The harmonic content changes with tone amplitude as does that of a piano;

(3) The decrement of the tone (reduction of amplitude with time) is like that of a piano throughout its pitch range;

(4) It yields tonal dynamics and quality in accordance with a touch-responsive control of vibrator amplitude through a keyboard hammer action.

Additionally, the tone of my stringless piano is musically superior to that of a tensioned string tone because all of its partials are in exact tone harmony with one another.

Having now described in detail my basic invention and numerous embodiments of the individual components as well as functional associations therebetween, variations in the components and arrangements thereof will suggest themselves to those skilled in this art. It is intended that such variations shall fall within the spirit and scope of the invention as set forth in the following claims.

The invention is claimed as follows:

1. In an electrical musical instrument, the combination of a fixed-free vibratory reed and means in spaced relation to a vibratable portion of said reed for translating electric oscillations from its vibrations, said reed having a normally non-integral ratio between the frequencies of its second-partial and fundamental vibrations, and weight means, carried by said reed and effectively centered at a longitudinal point therealong at least substantially within the first quarter of the length of said reed from its fixed extremity, for reducing said non-integral ratio to a lower, integral one.

2. The invention according to claim 1, wherein said weight means comprises a visco-elastic material, whereby the same means both reduces said ratio and damps vibrations of said vibrator.

3. In an electronic piano, the combination comprising a plurality of juxtaposed tuned reeds each of which cantilevers from a supported end thereof to a free end thereof, key controlled hammer means for impulsively exciting said respective reeds for vibration, a single pick-up element for electrostatically sensing vibrations of a multiplicity of said reeds, said pick-up element having a plurality of electrically conductive portions thereof disposed in proximate relation to the free ends of said respective reeds of said multiplicity to provide electrical capacitance between said pick-up element and each reed which is varied by impulse induced vibration of the reed relative to the pick-up element, means for applying a direct current potential between said pick-up element and all of said multiplicity of reeds to charge said reeds to a uniform voltage with respect to said pick-up element, and electronic tone signal means connected to said pick-up element to produce electronic tone signals corresponding to the changing cumulative capacitance between said pick-up element and said multiplicity of reeds coacting therewith.

4. In an electronic piano, the combination comprising a multiplicity of tuned reeds mounted alongside each other in a manner such that each reed cantilevers from a supported end thereof to a free end thereof, key controlled striking means coacting with each of said respective reeds to impulsively excite the reed to vibrate freely in a manner which swings the free end of the reed to opposite sides of a rest position thereof, a single electrostatic pick-up conductor having portions thereof disposed in adjacent relation to the free ends of said respective reeds, each of said pick-up conductor portions registering with the normal position of the coacting reed and being shaped and positioned to extend away from a position of alignment with the normal position of the reed in only one of the two directions in which the reed swings away from its normal position, means for charging all of said multiplicity of reeds to a uniform potential with respect to said pick-up conductor, and electronic tone signal means coacting with said pick-up conductor to produce tone signals controlled by the cumulative capacitance between said conductor and said multiplicity of reeds coacting therewith.

5. An electronic piano comprising a plurality of electrically conductive reeds disposed in side by side coplanar relation to each other and being of progressively varying length, each of said reeds being fixedly mounted at one end and free at its other end, a plurality of hammers one for each reed selectively operable for impulsively exciting the reeds into decadent free vibration, keys for operating the hammers, an electrostatic pick-up comprising a plurality of pick-up portions disposed in side by side coplanar disposition to each other and in a proximate electrically capacitive relation to the projecting portions of said respective reeds, said respective pick-up portions being substantially flush with the normal positions of the respective reeds and extending along the swing of the reeds in only one direction of reed movement away from the normal positions of the reeds, the extent of each pick-up portion in said one direction covering substantially the full excursion of the coacting reed in said one direction, means for charging said pick-up to a substantial electrical potential relative to the coacting reeds, and electronic tone signal means coacting with said pick-up and said reeds to produce tone signals controlled by the electrical capacitance between said pick-up and said reeds.

6. In an electronic piano, the combination comprising a plurality of juxtaposed tuned reeds each of which cantilevers from a supported end thereof to a free end thereof, key controlled striking means for impulsively exciting said respective reeds for vibration, a pick-up for electrostatically sensing vibrations of said reeds, said pick-up including a plurality of electrically conductive portions thereof disposed alongside the vibratory paths of said respective reeds in proximate relation to the normal positions of the respective reeds, to provide electrical capacitance between said pick-up element and each reed which is varied by impulse induced vibration of the reed relative to the pick-up element, means for applying an electric potential between said pick-up and said reeds to charge said reeds to a substantial voltage with respect to said electrically conductive portions of said pick-up, and electronic tone signal means coacting with said pick-up and said reeds to produce electronic tone signals controlled by the instantaneous capacitance between said pick-up and said reeds coacting therewith.

7. An electronic piano as defined in claim 6 in which each of said electrically conductive portions of said pick-up element traverses the free end of the coacting reed and has a width with respect to the reed which substantially exceeds the corresponding transverse width of the coacting reed.

8. In an electronic piano, the combination comprising a multiplicity of juxtaposed tuned reeds each of which cantilevers from a supported end thereof to a free end thereof, key controlled striking means for impulsively exciting said respective reeds for vibration, an integral electrically conductive pick-up plate extending across the free ends of said reeds for electrostatically sensing vibrations of the reeds; said pick-up plate having a plurality of electrically conductive portions thereof disposed in proximate, electrically capacitive relation to the normal positions of said respective reeds to provide electrical capacitance between said pick-up plate and each reed which is varied by impulse induced vibrations of the reeds relative to the pick-up plate; means for applying a substantial electrical voltage between said pick-up plate and said reeds, and electronic tone signal means coacting with said pick-up plate and said reeds to produce tone

signals controlled by the cumulative capacitance between said pick-up plate and said reeds.

9. In an electronic piano the combination comprising a multiplicity of tuned electrically conductive reeds mounted alongside each other in a manner such that each reed cantilevers from a supported end thereof to a free end thereof, key controlled striking means coacting with each of said respective reeds to impulsively excite the reed to vibrate freely in a manner which swings the free end of the reed to opposite sides of a rest position thereof, an electrostatic pick-up including conductor portions disposed in adjacent electrically capacitive relation to the free ends of said respective reeds, each of said pick-up conductor portions being substantially flush with one longitudinal side of the coacting reed when the latter is in its normal position, each pick-up conductor portion being shaped and positioned to extend along the swing of the coacting reed in only one direction of reed movement from the normal position of the reed, the orientation of each reed in its coacting pick-up conductor portion being such that the electrically capacitive spacing between the reed and the conductor portion progressively increases as the reed swings away from its normal position in said one direction of reed movement, means for charging said pick-up to a substantial electrical potential relative to said reeds, and electronic tone signal means coacting with said pick-up and said reeds to produce tone signals controlled by the capacitance between said pick-up and said reeds.

10. In an electronic piano, the combination of a horizontal series of parallel tuned reeds supported in side by side relation to each other in a manner such that each reed cantilevers forwardly in relation to the piano from a supported end of the reed to a free end thereof, a horizontal series of horizontal keys corresponding to said respective reeds and mounted in underlying generally parallel relation to said reeds, a horizontal series of vertically swingable reed striking hammers pivotally mounted between said reeds and said keys and projecting forwardly in underlying relation to the reeds toward the free ends thereof, means connecting said keys to swing said respective hammers upwardly to strike said respective reeds; an integral electrostatic vibration sensing plate extending across the free ends of said reeds and including a plurality of electrical conductor portions disposed in adjacent, electrically capacitive relation to the free ends of said respective reeds; each pick-up conductor portion registering with the normal position of the coacting reed and being shaped and positioned to extend away from a position of alignment with the normal position of the reed in only one of the two directions in which the reed swings away from its normal position, means for charging all of said reeds to a substantial electrical potential with respect to said pick-up plate, and electronic tone signal means coacting with said pick-up plate and said reeds to produce tone signals controlled by the cumulative capacitance between said plate and said reeds.

11. In an electronic piano, the combination of a horizontal series of parallel tuned reeds supported in side by side relation to each other in a manner such that each reed cantilevers forwardly in relation to the piano from a supported end of the reed to a free end thereof, a horizontal series of horizontal keys corresponding to said respective reeds and mounted in underlying generally parallel relation to said reeds, a horizontal series of vertically swingable reed striking hammers pivotally mounted between said reeds and said keys and projecting forwardly in underlying relation to the reeds toward the free ends thereof, means connecting said keys to swing said respective hammers upwardly to strike said respective reeds, an electrostatic vibration sensing pick-up located at the forward ends of said reeds and including conductor portions disposed in adjacent electrically capacitive relation to the free ends of said respective reeds, means for charging said reeds to a substantial electrical potential with respect to said pick-up, and electronic tone signal means coacting with said pick-up and said reeds to produce tone signals controlled by the cumulative capacitance between said plate and said reeds.

12. In an electronic piano, the combination of a horizontal bank of horizontal reeds mounted alongside each other in a manner such that each reed cantilevers forwardly in relation to the piano from a supported end of the reed to a free end thereof, a horizontal bank of piano keys disposed in underlying relation to said reeds, a horizontal series of vertically swingable reed striking hammers pivotally mounted between said reeds and said keys and projecting forwardly in underlying relation to said reeds toward the free ends thereof, means operated by said keys and coacting with said respective hammers to swing the latter upwardly to strike said reeds, a plurality of swingable reed dampers pivotally mounted for movement about horizontal axes and normally engaging the sides of said respective reeds intermediate the ends thereof, damper release means associated with said respective keys and coacting with said respective dampers to disengage the latter from said reeds upon operation of the keys, an electrostatic pick-up coacting with the forward ends of said reeds and including conductor portions thereof disposed in proximate relation to the normal positions of said respective reeds to provide electrical capacitance between the pick-up and each reed which is varied by vibration of the reed relative to the pick-up, means for charging said reeds to a substantial potential relative to said pick-up, and electronic tone signal means coacting with said reeds and said pick-up to produce tone signals controlled by the capacitance between said pick-up and said reeds.

13. In an electronic piano, the combination of a horizontal bank of generally horizontal reeds mounted alongside each other in a manner such that each reed cantilevers forwardly in relation to the piano from a supported end of the reed to a free end thereof, a horizontal bank of piano keys disposed in underlying relation to said reeds, a horizontal series of vertically swingable reed striking hammers pivotally mounted between said reeds and said keys and projecting forwardly in underlying relation to said reeds toward the free ends thereof, means operated by said keys and coacting with said respective hammers to swing the latter upwardly to strike said reeds, an electrostatic pick-up at the forward ends of said reeds and including pick-up conductor portions thereof disposed alongside the vibratory paths of said respective reeds in proximate relation to the normal positions of said respective reeds to provide electrical capacitance between the pick-up and each reed which is varied by vibration of the reed relative to the pick-up, means for charging said reeds to a substantial potential relative to said pick-up, and electronic tone signal means coating with said reeds and said pick-up to produce tone signals controlled by the capacitance between said pick-up and said reeds.

14. In an electronic piano, the combination of a horizontal bank of generally horizontal reeds mounted alongside each other in a manner such that each reed cantilevers forwardly in relation to the piano from a supported end of the reed to a free end thereof, a horizontal bank of horizontal keys disposed in underlying relation to said reeds, a horizontal series of vertically swingable reed striking hammers pivotally mounted between said reeds and said keys and projecting forwardly in underlying relation to said reeds toward the free ends thereof, means on said keys for swinging said respective hammers upwardly to strike said reeds, a plurality of reed dampers normally engaging said respective reeds, damper release means associated with said respective keys and coacting with said respective dampers to disengage the latter from said reeds upon operation of the keys, electrical pick-up means disposed between the vibratory paths of adjacent reeds, and electronic tone signal means coacting with said pick-up means to produce tone signals controlled by the pick-up means.

15. In combination in an electrical musical instrument, a vibrator comprising a fixed-free reed, said reed comprising an elongated metal strip having a width many times its thickness, said reed inherently tending to vibrate with a fundamental frequency and a plurality of inharmonic partials and with no true harmonics, an impulse exciting means adjacent the reed and engageable therewith for setting it into decadent free vibration, means including a weight adjustably positioned on the reed adjacent the fixed end thereof for rendering the frequency of the second partial of its vibration an integral multiple of the frequency of its fundamental vibration instead of an inharmonic partial, and an electric translation pick-up, said pick-up being located adjacent and being vibratorily passed by a portion of the reed in its vibratory movement.

16. In an electrical musical instrument, the combination set forth in claim 15 wherein said pick-up has a portion located alongside the reed intermediate the length thereof, vibratorily passed by a side-edge portion of the reed.

17. In an electrical musical instrument, the combination set forth in claim 15 wherein said pick-up has an effective thickness in the direction of reed vibration smaller than the high-amplitude stroke of the adjacent reed portion.

18. In an electrical musical instrument, the combination set forth in claim 15 wherein said pick-up has an effective thickness in the direction of reed vibration smaller than the high-amplitude stroke of the adjacent reed portion, and is offset in said direction from effective alignment with the rest position of said reed portion.

19. In combination in an electrical musical instrument, a plurality of aligned vibrators of progressively increasing length each comprising a fixed-free reed, each said reed comprising an elongated metal strip having a width many times its thickness and each said reed inherently tending to vibrate with a fundamental frequency and a plurality of inharmonic partials and with no true harmonics, a plurality of impulse exciting means adjacent the reeds and selectively engageable therewith for setting them into decadent free vibration, a weight adjustably positioned on each reed for rendering the frequency of the second partial of its vibration an integral multiple of the frequency of its fundamental vibration instead of an inharmonic partial, said weights when in operative position being disposed on said reeds at progressively increased distances from the fixed ends of the reeds, and an electric translation pick-up for each said reed, each said pick-up being located adjacent and being vibratorily passed by a portion of its associated reed during the vibratory movement of the reed.

20. In an electrical musical instrument, the combination set forth in claim 19 wherein the weights progressively farther from the fixed ends of the reeds are of progressively increased size.

21. In an electrical musical instrument, the combination set forth in claim 19 wherein said pick-ups are provided with portions located alongside the reeds intermediate the length thereof, vibratorily passed by side-edge portions of the reeds.

22. In an electrical musical instrument, the combination set forth in claim 19 wherein said pick-ups have an effective thickness in the direction of reed vibration smaller than the high amplitude stroke of the adjacent reed portions.

23. In an electrical musical instrument, the combination as defined in claim 19 wherein said pick-ups have an effective thickness in the direction of reed vibration smaller than the high amplitude stroke of the adjacent reed portions, and wherein said pick-ups are offset in said direction from effective alignment with the rest position of the associated reed portions.

24. In combination in an electrical musical instrument, a vibrator comprising a fixed-free reed, said reed comprising an elongated metal strip having a width many times its thickness, said reed inherently tending to vibrate with a fundamental frequency and a plurality of inharmonic partials and with no true harmonics, an impulse exciting means adjacent the reed and engageable therewith for setting it into decadent free vibration, an electric translation pick-up located adjacent the reed with a portion disposed alongside the reed intermediate the length thereof and vibratorily passed by a side-edge portion of the reed, and means including a weight adjustably positioned on the reed between the fixed end thereof and the portion of the pick-up alongside the reed for rendering the frequency of the second partial of its vibration an integral multiple of the frequency of its fundamental vibration instead of an inharmonic partial.

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APPENDIX B
U.S. PATENT NO. 2,942,512
(MIESSNER)

June 28, 1960 B. F. MIESSNER 2,942,512

ELECTRONIC PIANO

Filed Aug. 14, 1957 3 Sheets-Sheet 1

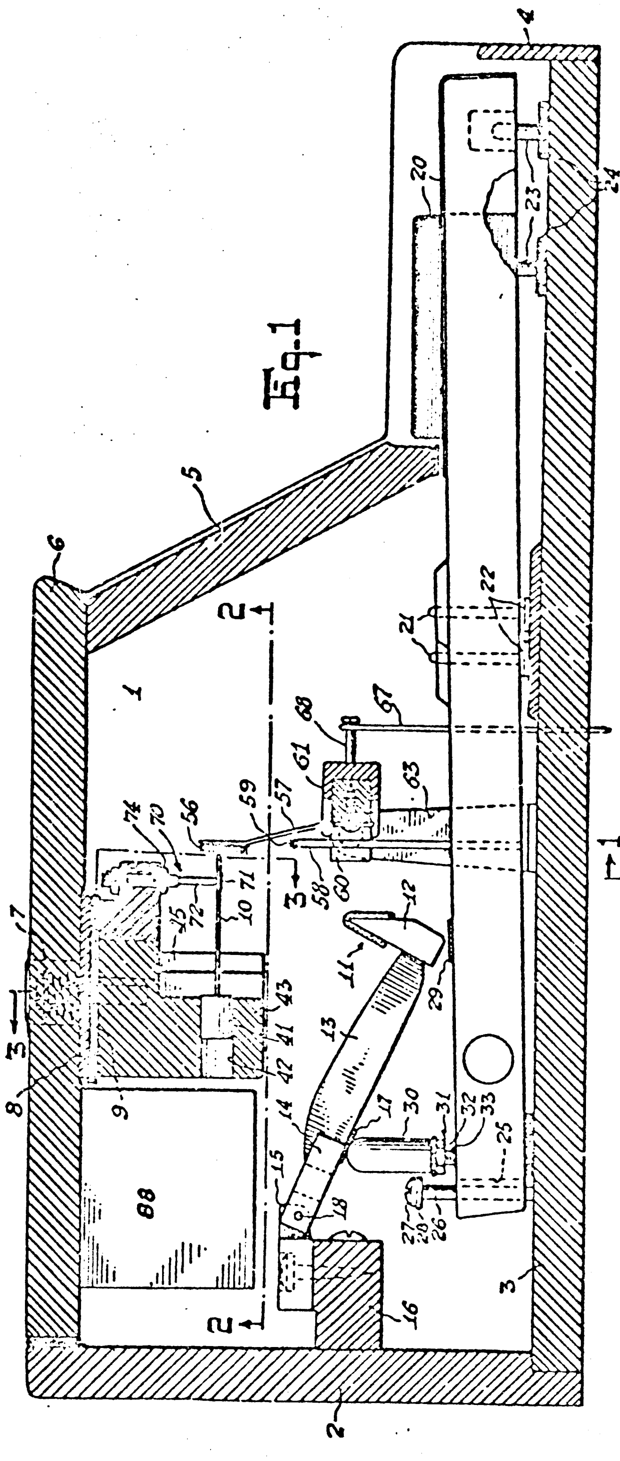

Fig. 1

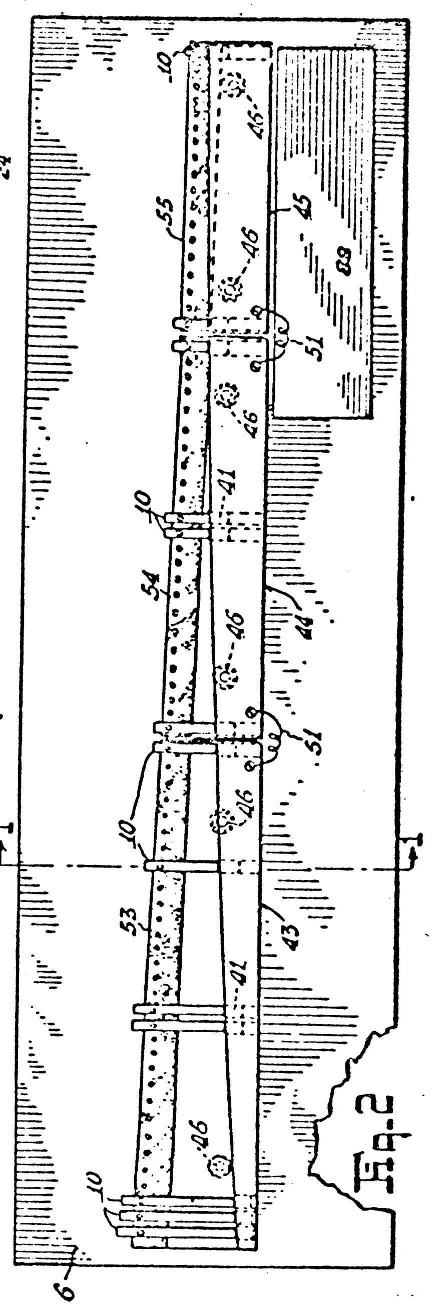

Fig. 2

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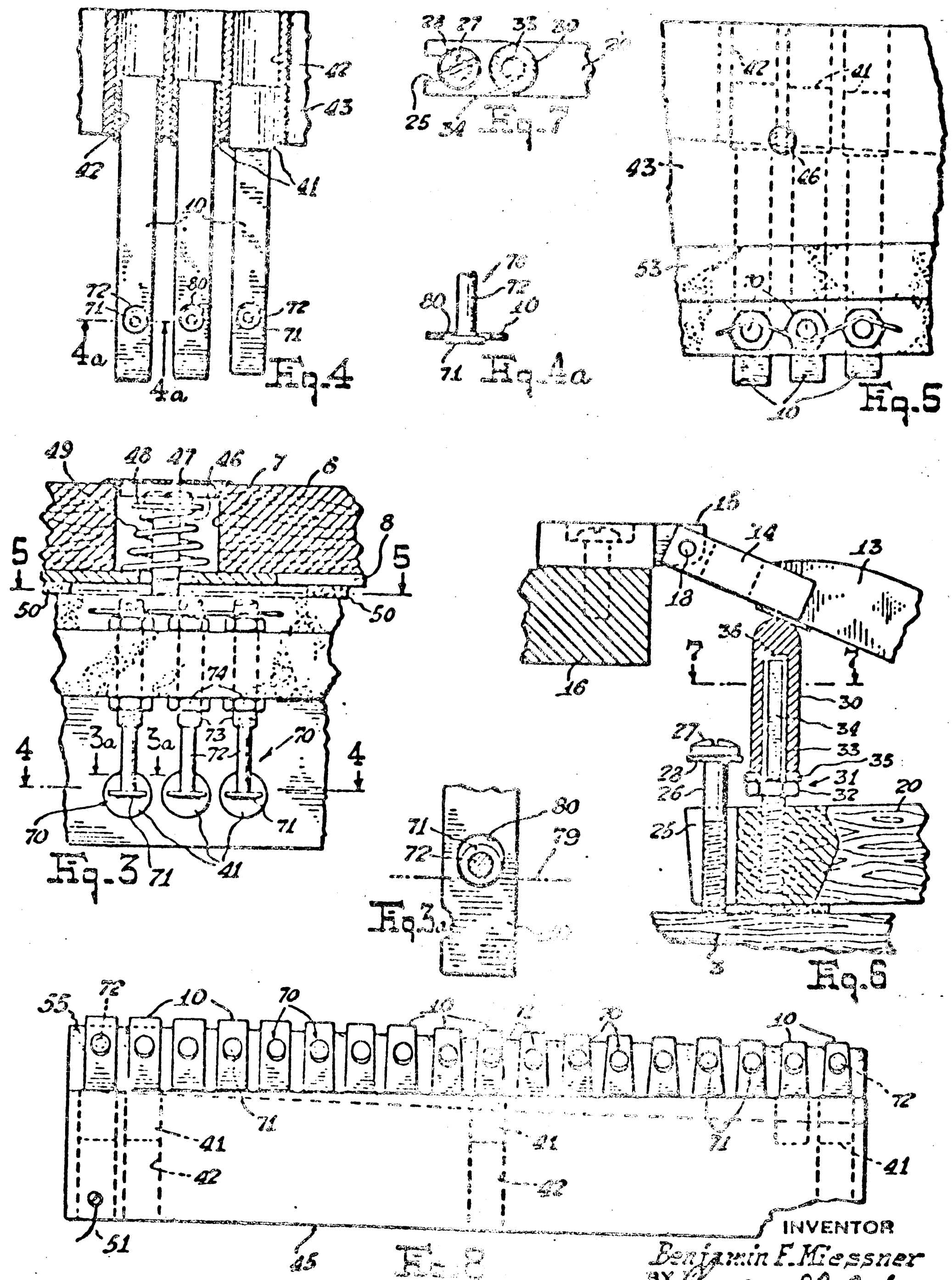
June 28, 1960 B. F. MIESSNER 2,942,512

ELECTRONIC PIANO

Filed Aug. 14, 1957 3 Sheets-Sheet 2



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June 28, 1960 B. F. MIESSNER 2,942,512

ELECTRONIC PIANO

Filed Aug. 14, 1957 3 Sheets-Sheet 3

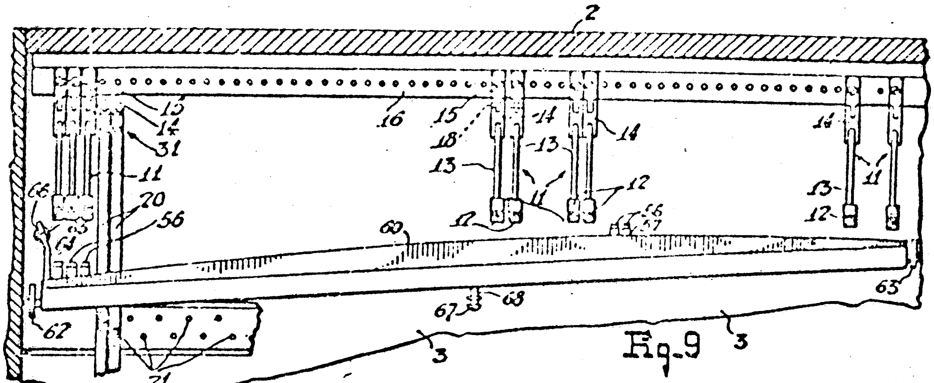

Fig. 9

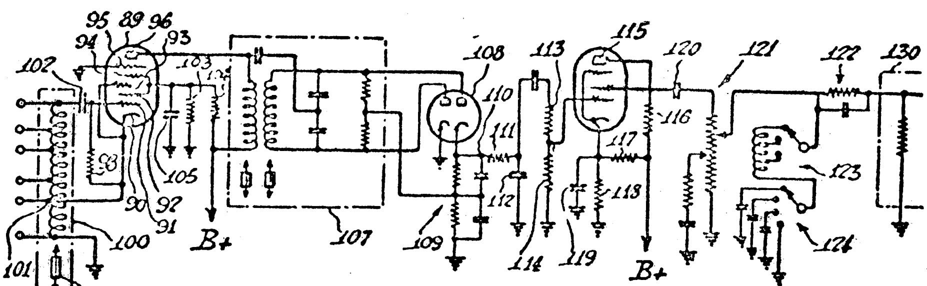

Fig. 10

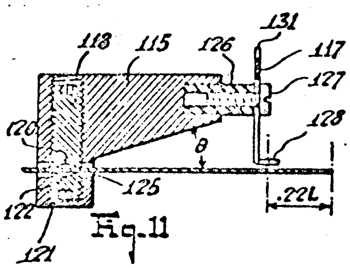

Fig. 11

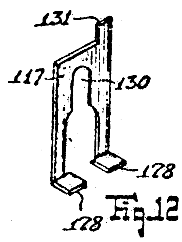

Fig. 12

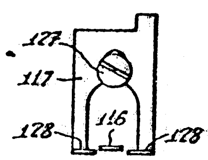

Fig. 13

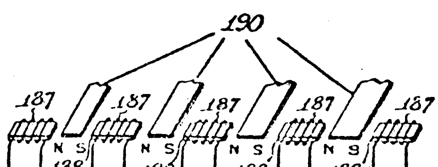

Fig. 14

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United States Patent Office

2,942,512

Patented June 28, 1960

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2,942,512

ELECTRONIC PIANO

Benjamin F. Miessner, Harding Township, Morris County, N.J., assignor, by mesne assignments, to The Wurlitzer Company, Chicago, Ill., a corporation of Ohio

Filed Aug. 14, 1957, Ser. No. 678,101

10 Claims. (Cl. 84—1.14)

This invention relates to electronic musical instruments and more particularly to such instruments for the production of pianistic tones. In certain copending applications of mine hereinafter referred to I have disclosed such instruments utilizing as vibrators, instead of tuned strings, simple fixed-free reeds, whose vibrations are translated into electric oscillations which, after amplification and control, are translated into sound. An object of the present invention is the provision of an improved such instrument.

In the use of reeds instead of strings a problem is presented by the inharmonicity of the relationship of the upper partials (i.e., all above the first, or fundamental) of the vibration to the fundamental—whereas it is a requisite of the output tone that it contain very small development of inharmonic partials and a rich development of harmonic ones. An object of this invention is the provision of a solution to this problem.

In a tone produced by a conventional piano there is a strong initial burst, including a rich harmonic development, followed in the very early instants by an apparent rapid amplitude decay or decrement. Heretofore in electronic instruments utilizing reeds as the vibrators such early rapid decrement has been lacking—or even reversed, into a slight initial increment. An object of this invention is to minimize such increment or to increase such decrement in the reed type of instrument. An allied object is to approximate the early rapid decrement characteristic of a conventional piano.

Another object is the provision of improved arrangements of translating device, or pick-up, with reed.

Other and allied objects will more fully appear from the following description and the appended claims:

This application is a continuation-in-part of my copending application Serial No. 485,471 filed February 1, 1955, now abandoned.

This application discloses and claims subject matter disclosed in my copending application Serial No. 485,471, filed February 1, 1955, subject matter disclosed in my copending application 255,383, filed November 8, 1951, and subject matter disclosed in my copending application Serial No. 169,714, filed June 22, 1950, now abandoned.

In the description of my invention hereinafter set forth reference is had to the accompanying drawings, of which:

Figure 1 is a vertical sectional view of an electronic piano embodying my invention in one form (line 1—1 in Figure 2 indicating the plane along which Figure 1 is taken);

Figure 2 is a horizontal view taken looking upwardly toward the plane indicated by the line 2—2 of Figure 1 (or a vertical view seen when looking rearwardly toward the cover 6 of the instrument when the cover is in raised position) and, for simplicity, showing only a few of the reeds 10;

Figure 3 is an enlarged vertical view, in section, taken along the line 3—3 of Figure 1;

Figure 3a is an enlarged fragmentary view of a portion of Figure 4;

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Figure 4 is a horizontal sectional view taken along line 4—4 of Figure 3;

Figure 4a is an enlarged sectional view taken along line 4a—4a of Figure 4;

Figure 5 is a horizontal sectional view taken along line 5—5 of Figure 3;

Figure 6 is an enlarged fragmentary view, partly in section, of a portion of Figure 1;

Figure 7 is a horizontal sectional view taken along line 7—7 of Figure 6;

Figure 8 is an enlarged view of a righthand portion of Figure 2;

Figure 9 is a partial plan view of the instrument as seen when the cover 6 is raised, showing for simplicity only a few of the hammers 11, keys 20 and dampers 56;

Figure 10 is a schematic showing of the early portions of the electronic system of the instrument;

Figure 11 is a vertical sectional view of a base, reed and pick-up embodying my invention in another form;

Figure 12 is a perspective view of the pick-up structure of Figure 11;

Figure 13 is a front view of a portion of the assembly of Figure 11 illustrating a readjustment of the pick-up structure relative to the reed; and

Figure 14 is a perspective view of a number of reeds and pick-ups embodying my invention in still another form.

The drawings illustrate a 73-note instrument, but it will be understood that this is by way of illustration only.

In Figure 1 the elements 1, 2, 3 and 4 respectively represent righthand and, back, bottom and front portions of the cabinet for the instrument, these portions together with the lefthand end portion (not shown) being for example permanently secured together. A removable sloping fall board 5 may extend between the two end portions, while a cover 6 may be hinged at its rear to the top of the back portion 2. As disclosed in connection with such a cabinet in my copending application Serial No. 169,714 abovementioned, the reeds and pick-ups may be carried by the bottom of the cover 6, the hammers may be supported by the back portion 2, and the hammer-actuating keys may be supported on the bottom portion 3.

The reeds appear as 10; their mounting, the translation of their vibrations, and related matters are set forth in detail hereinafter. The excitation of each reed is by a respective hammer 11 positioned therebelow, the head 12 of the hammer being propellable upwardly to strike the reed (typically, at approximately the mid-reed nodal point for the third partial vibrating of the reed, as hereinafter mentioned). The hammer head 12 may consist of a chisel-shaped block of wood, preferably covered with felt, or sponge rubber, of progressively greater thickness the lower the frequency of the associated reed. The head 12 is affixed to the forward extremity of a shank 13, which is preferably of rectangular cross section with the major dimension of that section vertically disposed. The rear extremity of the shank 13 is in turn secured in the butt 14, which is pivoted at 18 to the flange 15. All the flanges 15 are secured on top of a transverse rail 16 fixed to and extending forwardly from the cabinet back 2.

It may be mentioned that the material of the covering of the hammer head may desirably be characterized by some viscosity, to aid in the damping of upper partials of the reed vibration during the short period of hammer-head contact with the reed.

Each hammer is propelled to strike the respective reed by a respective key 20, acting through a respective coupling member 30. The keys 20 may be pivoted about conventional pins 21, each key resting on a stack 22 of washers surrounding its respective pin, and may be guided by conventional front guide pins 23 each surrounded by a conventional stack 24 of washers forming a front-end downstop. The rear end of each key is bifurcated by a vertical slot 25 (see Figure 9), which freely embraces a respective post 26 screwed into the cabinet bottom 3 and having an enlarged head 27 immediately under which may be provided a thin slightly viscous and elastic washer 28; the head 27 and washer 28 form an upstop for the rear end of the respective key. The relative adjustments of this rear-end upstop 27—28 (effected by rotation of post 26) and of the front-end downstop (effected by choice of washer thicknesses) are such that when the key is operated the primarily effective stop is the rear-end upstop 27—28—the front-end downstop being a secondary one whose function is to limit deformation of the key which may result from front-end finger pressure continued after the rear-end upstop has acted.

Near its rear extremity each key carries a respective capstan member 31 screwed into the key (fully seen in Figure 6). A little above the keystop this member may have the enlarged hex portion 32 engageable by a wrench for vertical adjustment of the capstan member 31. From the hex portion 32 upwardly the capstan member 31 may consist of a rod 33 preferably quite smoothly cylindrical excepting for a longitudinal flat 34 several thousandths of an inch wide (shown in exaggerated width in Figure 6).

The respective coupling member 30 may comprise a vertically disposed cylinder 30 having, upwardly from its bottom, a circular central bore closely fitting about the rod 33 (excepting for the flat 34 of the latter) but slidable therealong (which action may be aided by a light film of silicone grease on the rod), the upper end of the member 30 being solid and exteriorly rounded into substantially hemispherical configuration. Normally the lower extremity of the cylinder 30 rests on the capstan hex portion 32, if desired through the intermediary of a quite thin slightly viscous and elastic washer 35—and when the cylinder 30 so rests the air chamber 36, formed between the bore of the cylinder and rod 33 at the top of the latter, may be of quite small vertical dimension. Normally on the upper end of each coupling member 30 rests the forward portion of the respective hammer butt 14, if desired through the intermediary of a quite thin layer 17 of slightly viscous and elastic material secured to the bottom of the hammer butt. When the respective hammer butt so rests the lower extremity of the respective hammer head 12 is preferably slightly spaced above a felt pad 29 secured therebelow on the top of the respective key 20.

Operation of the key 20 (i.e., depression of its forward extremity by the finger), if carried out extremely slowly, will of course raise the capstan member 31 and coupling member 30 without disturbance of the normal interrelationship between the latter members, and will swing the hammer upwardly about its pivot without any breaking of the contact of the hammer but with the coupling member. Preferably the components are so geometrically interrelated that this raising will continue to, but be stopped (by the upstop 27—28), at, a position of the hammer head slightly spaced from the bottom of the respective reed 10. No impact of hammer head with reed will occur—just as there occurs in the conventional piano no hammer-string impact when the key is extremely slowly operated. When, however, the key 20 is operated with any substantial velocity, its own sudden stoppage by the upstop 27—28 will not be accompanied by stoppage of either the coupling member 30 or the hammer 11. The hammer will continue under its own momentum, and with negligible change in velocity, to strike and rebound downwardly from the reed. Correspondingly the coupling member 30 will continue upwardly under its own momentum—but in the case of this member there is a substantial and steady loss of velocity, since this coupling-member movement can only occur with an enlargement of the air chamber 36, which can only occur with a flow of air thereinto along the narrow passage formed between the bore of the coupling member 30 and the flat 34, which in turn involves substantial energy dissipation through air friction.

Assuming the key remains operated and the capstan member 31 thus in an elevated position, then in the relatively high-velocity rebound of the hammer from the reed its downwardly moving butt 14 will quickly come into impact (through 17 if employed) against the still-rising but now relatively low-velocity coupling member 30. I have found it desirable to make the mass of the coupling member several times the effective mass of the hammer (i.e., the hammer mass as seen at the region of contact between hammer and coupling member). If this be done, the conditions at the time of impact will be such that at the instant after impact the hammer velocity will be very small, while the coupling member will possess most of the kinetic energy previously in the rebounding hammer and will itself be in downward motion toward its normal relationship to the capstan member 31—a motion which involves the diminution of the air chamber 36, which can only occur with a flow of air therefrom along the narrow passageway formed as abovementioned between the bore of the coupling member and flat 34, which in turn involes substantial energy dissipation. Thus although the coupling member while the key remains operated is in a region where it will be struck by the rebounding hammer, a re-rebound of the hammer from it to restrike the reed—which would occur with all higher-velocity key operations in a conventional system of this general no-escapement type—is precluded by the transfer of the rebounding hammer's kinetic energy to the coupling member and the harmless dissipation from the coupling member of that energy.

It will be understood that a function of the early enlargement of the air chamber 36 is to prepare it for its later diminution and that a function of the energy dissipation during that enlargement is the rapid deceleration of the upwardly moving coupling member, while the function of the energy dissipation in the later air-chamber diminution is the ultimate one (of precluding hammer rebound) just outlined.

In a preferred embodiment of the vibrator-exciting action above outlined I minimize incidental compliances which at the time of impact of the rebounding hammer against the coupling member might yield and thereby divert from the coupling member some of the kinetic energy which desirably is transferred from hammer to it for harmless dissipation as outlined above. Thus I prefer to avoid the use of felt or similar bushings at the pivoting point 18 of butt 14 to flange 15, and to use instead a relatively large diameter brass pivoting pin; I prefer to utilize the vertically stiff hammer stem described above; I prefer to minimize the compliance of (or even to omit altogether) the thin washer 35 under the coupling cylinder, and likewise as to the layer 17 above that member (on the bottom of the hammer butt); I prefer to omit yieldable elements from the washer stacks 22 about the pivots 21; and I prefer to use a stiff material for the keys 20 themselves.

In certain aspects the vibrator-exciting action just outlined has some similarities to those described in U.S. Patent No. 2,767,608 issued to me October 23, 1956 and in my copending application Serial No. 376,543, filed August 26, 1953 (which is a continuation-in-part of a prior application Serial No. 292,096, filed June 6, 1952 and since abandoned)—but there are several distinctions of importance.

Attention may now be directed to the mounting of the reeds 10 the translation of their vibrations, etc.

The reeds, being of the fixed-free variety, are of course supported in cantilever. The base of each reed is preferably surrounded by a plug 41 of deformable material, and this plug is axially force-fitted into a horizontal hole 42 in an appropriate base member so that the reed effectively extends horizontally from the base member—the base member appearing in section in Figure 1 being 43. This structure and method of mounting each reed to a base—whose advantages comprise exceptionally rigid, dissipationless and determinate basing of each reed—are described in detail in my copending application Serial No. 291,829, filed June 5, 1952.

The base member 43 does not support all the reeds of the instrument. In may copending application Serial No. 284,133, filed April 24, 1953, I have described, for an instrument of this general character, the subdivision of the total base means into a plurality of individual base members each supporting a respective series or group of sequentially tuned reeds; as brought out in that application, this subdivision is so carried out that each individual base member has a lowest natural frequency of vibration higher than the fundamental frequency of any reed extending therefrom.

In accordance with the present invention a further limitation is observed: that the fundamental frequency of any (in effect, of the highest-frequency) reed secured to any base member shall be higher than the second-partial frequency of any other (in effect, of the lowest-frequency) reed secured to that base member. I have found this limitation important to avoid the possibility that the fundamental-frequency energy of a reed be dissipated by transfer of that energy to second-partial-frequency vibration of another reed secured to the same base member. Since the ratio of second-partial frequency to fundamental frequency in a normal reed without special shaping, aperturing or the like is 6.27, and since even with such practises it tends to remain at least 6.0, this specification is readily met for example by limiting the fundamental-frequency ratio between highest- and lowest-frequency reeds secured to any one base member to less than 6.0—or, in the tempered scale, to some 31 progressively tuned reeds.

Accordingly in the drawings it will be seen that the base member 43 carries the thirty-one lowest-frequency reeds, the base member 44 carries the twenty-four mid-frequency reeds, and the base member 45 carries the eighteen highest-frequency reeds—it being understood that each base member individually obeys the specification set forth in the next-to-last preceding paragraph.

All three base members are individually vibrationally insulated to some extent from the cover 6 by which they are supported and, since they may be devoid of any vibrational intercoupling other than through the cover, they may accordingly be considered as vibrationally insulated from each other to a substantial extent. In connection with their mounting, there is secured to the bottom of the cover 6 a transverse metal plate 8 above the positions to be occupied by the base members. Extending upwardly from each base member through respective oversize holes 9 in the plate 8 and into still larger holes 7 in the cover are a pair of studs 46 each screwed into the base member, one near each end of the latter. As best seen in Figure 3, each stud terminates in an enlarged head 47, underneath which may be a metal washer 48. About each stud, between the washer and plate 8, there is disposed a conically spiralled compression spring 49. One half of the weight of each base member appears at a respective spring 49, as a compressing force exerted thereon through the respective washer 48, each pair of these springs thus providing the mounting of a respective one of the base members.

The studs 46 are so located in the front-and-back dimension that the base members will have limited tendencies to rock either forwardly or rearwardly, and such tendencies are in any event restrained by strips 50 of sponge rubber or the like placed between the base members and plate 8 near the front and the back edges of the latter (each base member being in effect "floated" by the two respective springs 49 and the sponge rubber strips 50 just mentioned). There is, however, ample opportunity for sufficient rocking of each base member in response to forces applied thereto so that each reed is to some extent vibrationally coupled to all other reeds on the same base member—thus simulating the coupling which exists in the conventional piano between the strings of different notes. If desired, this effect may be carried further by deliberately introducing a modest amount (though it should not be too large) of coupling between the three base members, over and above that which occurs through their mounting to the single cover.

Each of the base members 43, 44 and 45 may comprise a main metal portion, for example of relatively hard aluminum, and a portion of insulating material appended to the metal portion. The cross-section of the metal portion of the low-frequency base member 43 may be of the shape of an inverted L whose horizontal leg is forwardly directed, is of appreciable and constant vertical dimension, and is the length or forward extent varying from a maximum at the lefthand extremity, to a moderate value at the righthand extremity, of the member 43—and whose vertical leg is of constant height and of thickness varying from a minimum at the lefthand extremity, to a substantial value at the righthand extremity, of the member 43. The cross-section of the metal portion of the base member 44 may likewise be of the shape of an inverted L, and at the lefthand extremity of the base member 44 the dimensions of the legs of the L may be similar to those found at the righthand extremity of member 43; proceeding rightwardly, the length of the horizontal leg may continue to diminish, while the thickness of the vertical leg may continue to increase, for example so that at the righthand extremity of the base member 44 the cross-section of the metal portion has become a simple thick I. At the lefthand extremity of the base member 45 its metal portion may have the cross-section of a simple thick I, for example similar to the cross-section of the righthand extremity of member 44; proceeding rightwardly, the upper portion may be cut away in front to a small and progressive degree, so that at its righthand extremity the metal portion of the base member 45 may have a cross-section of the shape of an upright L (as indicated by the solid and dotted lines 45' in Figure 1).

It is in the vertical legs of the base members that the reeds 10 are secured (through plugs 41 as above described) and from which they extend forwardly. It will of course be understood that with a constant width and thickness—which I prefer to employ at least for the reeds extending from base members 43 and 44—then for the required progressive tuning the reed lengths will decrease progressively from a maximum at the lefthand extremity of base member 43 to a relatively short length at the righthand extremity of base member 44. I prefer to maintain the longitudinal mid-points (more precisely, the mid-reed nodal points for third-partial vibration) of all the reeds in straight alignment transverse of the instrument—this being so that the hammers, which I prefer to have strike the reeds in each instance at this position, may be arranged in a straight transverse line—and I arrange the front surfaces of the vertical legs of base members 43 and 44 in a gradual curve appropriate to that maintenance. At the same time the rear surfaces of those legs may lie in a transverse vertical plane—which is permitted by the thickness specifications set forth in the preceding paragraph.

The progressive decrease of reed length (and with it the curving of the front surface of the vertical leg of the supporting base member) may be continued throughout the highest-frequency group of reeds (and their supporting base member 45) as a sole way of accomplishing the required progressive tuning throughout this group. Because of the relatively short reed-length dimension already reached at the righthand extremity of base member 44, however, I prefer to minimize the further reduction of reed length throughout that highest-frequency group—supplementing the effect of a small length reduction, in achieving the required progressive increase in frequency, by making the sides of the reeds oblique and the free ends thus narrower in progressively increasing degree toward the righthand extremity of the base member 45, as seen in Figure 8. A further expedient which may be resorted to, in minimizing the reduction of reed length throughout this highest-frequency group, is of course a progressive increase in the thickness of the reeds.

The insulating portions of the base members are designated as 53, 54 and 55, respectively; each of them may extend forwardly from the upper forward surface of the respective metal base-member portion. (Each of 53 and 54 may form a forward projection of the horizontal leg of the respective metal portion of 43 or 44, and 55 may form a forward projection from the cut-away upper part of 45.) In turn the forward part of each of the insulating portions 53, 54 and 55 may conveniently be cut away at the top (as seen in Figure 1) to reduce somewhat that forward-part vertical thickness. It is in this forward part of the base-member insulating portions that the pick-ups are mounted.

Before turning to the translation of the reed vibrations into electric oscillations it will be convenient to complete the description of the mechanical portions of the instrument by reference to the tone-terminating dampers. These may be seen in Figures 1 and 9. The dampers proper, which are designated as 56, may each consist of a small pad of relatively soft material, preferably such as mohair which presents an active surface of generally parallel and closely spaced outwardly extending hairs. Each damper 56 may be secured on the rear upper surface of a respective generally vertical spring 57, of which the lower portion is secured to a rail 60 described below. Normally each damper is lightly biased by its associated spring 57 into contact of its active surface with the free (forward) end of a respective reed 10. When in this relationship to that reed it will effectively suppress any significant vibration of the reed—and if brought into that relationship to the reed while the reed is vibrating it will effectively and promptly terminate that vibration.

When there is operated the key 20 associated with a reed against which a respective damper 56 is biased, for excitation of that reed, it is of course necessary that the damper be removed from contact with the reed. To accomplish this each such key may be provided, somewhat behind its pivot 21, with an upstanding heavy-wire arm 58 extending to a position closely spaced behind the normal position of the mid-portion of the respective damper spring 57, and there folded over into a short horizontal portion 59. When the key is operated the arm portion 59 will be rocked diagonally upwardly and forwardly, and in this movement will impinge against and move forwardly the respective damper spring 57, thus placing the respective damper 56 out of contact with the respective reed—a condition which normally will be maintained until release of the key, whereupon the damper will return to contact with the reed and will terminate its vibration.

To provide the conventional "loud pedal" action all the dampers may collectively be removed from contact with their respective reeds. To this end the rail 60—whose rear surface may be a gradual curve conforming to the similar curve formed by the free ends of the reeds—may have a straight forward edge which in turn is inset into a U-cross-section channel member 61. The assembly 60—61 at its extremities may be pivoted to left- and righthand standards 62 and 63.

The assembly 60—61 may be biased about its pivots (counterclockwise as seen in Figure 1) to a predetermined position by the combination (partially seen in Figure 9) of an arm 64 extending rearwardly therefrom, a spring 65 urging the rear extremity of that arm downwardly, and a stop 66 limiting the response of the arm to that bias—this predetermined position establishing the normal position of the rail 60 which was postulated in prior-paragraph references to that rail. The assembly 60—61 may be rocked against its bias (i.e., clockwise as seen in Figure 1)—thus removing all dampers collectively from contact with their associated reeds—by downward longitudinal movement of a rod 67 which at its upper extremity is loosely secured to an arm 68 extending forwardly from the channel member 61. Such downward movement of the rod 67 may be effected in any convenient manner, most typically by a pedal (not shown) with which its lower extremity may be suitably associated.

Dampers need not usually be associated with the very top notes of the instrument, and accordingly in its righthand portion the damper system has been shown as embracing, of the reeds of the highest-frequency group (i.e., those extending from base member 45), only the most leftward few.

I have found it highly desirable in the production of the most pianistic tones from impulsively excited fixed-free reeds—whose upper-partial vibrations (i.e., all above the first, or fundamental) are well known to be normally inharmonically related to the fundamental—to observe several specifications:

(A) To utilize means in the mechanical system which is formed by the exciting means and the vibrator to substantially eliminate from the translated oscillations an inharmonic component corresponding to one of the lower-numbered of the upper partials at which the reed tends to vibrate—preferably (if the preference under B below be followed) the third partial;

(B) To arrange the mechanico-electrical system which is formed by the pick-up device and a portion of the vibrator so that in it is performed the function of substantially eliminating from the translated oscillations an inharmonic component corresponding to one of the lower-numbered of the upper partials at which the reed tends to vibrate—preferably the second partial;

(C) To arrange the mechanico-electrical system abovementioned so that by it is performed the function of introducing, into the electric oscillations which it translates from the reed vibrations, a series of upper partials harmonically related to the fundamental—preferably a series which diminishes in composite magnitude (relative to the magnitude of the fundamental) as the vibration of the reed dies away after its impulse excitation; and

(D) To arrange the mechanico-electrical system abovementioned so that the greater deformations of the reed attendant on high-amplitude vibration, though involving quite inharmonic upper partials, are utilized to enhance the generation of the abovementioned harmonically related upper partials, as well as to enhance the translation of the fundamental, in the electric oscillations during the very initial instants following the impulse excitation of the reed.

Each of the first three of these specifications is disclosed in one or another manner in my copending application Serial No. 169,714 abovementioned or my copending application Serial No. 255,383 abovementioned. They are, however, interrelated in a particularly favorable manner in the structure of Figures 1 through 9, and with them is combined the very valuable fourth specification above set forth.

Specifications A and B, taken together and utilized with respect to the second and third reed-vibration partials, serve the highly important function of rendering harmless the significant ones of the inharmonic (i.e., all upper) partials at which the reed tends to vibrate—since partials above the third are normally sufficiently weak so that their translation has a negligible deleterious effect on output tone. Stated in other words, they cause the reed—though actually still excited in the simple impulsive manner required for a pianistic type of tone—to approximate in its effect a vibrator whose vibration is free of partial development (i.e., whose vibration occurs only at its fundamental frequency).

The function just mentioned—highly important since substantial inharmonic components, especially continuing (as distinguished from transient) ones, are intolerable in tones intended to be pianistic—would result, taken alone, in an unusably dull output tone, quite unpianistic because it would lack the rich development of upper partials harmonically related to the fundamental which is characteristic of the piano. It is to cure this lack, by creating just such a rich development of harmonic upper partials, that specification C is combined with A and B.

It will be convenient first to describe the pick-up means and how the structure meets specifications A, B and C, and then to bring out the importance f specification D and how the structure meets it.

Specification C may be met by arranging the pick up means so that it is principally influenced by an edge portion of the reed, which preferably will most fully influence it twice in each cycle of vibration at substantial amplitude—it being preferably so arranged that the instants of greatest influence, though bicyclic, are never separated by precisely 180 degrees (thus avoiding pure double-frequency translation). Reference being had to Figures 3, *3a*, 4 and *4a*, there will be seen for each reed a pick-up means 70. Each such pick-up means may comprise a threaded portion 73 conveniently passing vertically through the forward part of the associated base-member insulating portion (e.g., through the forward part of 53) and there anchored by means of two nuts 74 threaded on the portion 73 and tightened against the base-member insulating portion, one on top and the other on the bottom. Each pick-up means may further comprise a rod portion 72 preferably of reduced diameter forming a downward projection of the threaded portion, and may finally comprise an active pick-up portion 71—typically in the form of an abrupt enlargement of the rod portion at its end into a thin transverse end plate (for example, of thickness generally similar to that of the associated reed). Seen in plain view of reed and end plate (e.g., in Figure *3a*), the end plate 71 is closely spaced from an edge portion of the reed. Vertically, the pick-up means may be so adjusted (by nuts 74) that the end plate 71 is very nearly at the level of the reed when the latter is in its at-rest position, for example (see Figure 3) so that its central plane approximately coincides with the plane of the bottom of the at-rest reed.

It is of course desirable that the natural frequency of each pick-up device be higher than the fundamental frequency of the highest-frequency reed of the instrument. It is further desirable that the material be soft enough to permit accurate placement of the end plate 71 horizontally, relative to the reed, by slight bendings of the rod portion 72, preferably effected with the aid of an appropriate bending tool.

It will be understood (I) that when the reed moves upwardly the capacity between it and the end plate 71 will progressively reduce; that as the reed moves downwardly from an upward excursion that capacity will progressively increase, reaching its original value when the reed reaches its at-rest position; that as the reed continues to move downwardly that capacity will at the very first still further increase somewhat, to a maximum when the reed and end plate are in alignment (i.e., when the central planes of the two coincide), and will then progressively decrease; and that as the reed moves upwardly from a downward excursion that capacity will progressively increase, reaching its abovementioned maximum when the central planes of reed and end plate coincide, and will then decrease to reach its somewhat smaller original value when the reed reaches its at-rest position—this analysis of course assuming that the reed movement is of sufficient amplitude so that in its downward excursion it proceeds beyond a position of alignment with the end plate 71. It will further be understood (II) that the higher the amplitude of the reed movement, or vibration, and thus the greater its velocity in passing its positions of maximum capacity abovementioned, then in the waveform of the capacity variations the greater will be the steepness of the approaches to and recessions from maximum capacity. It will still further be understood (III) that if the reed be vibrating at very high amplitude the intra-cyclic instants of maximum capacity—both occurring in the downward-excursion half-cycle—will be separated by almost (but never fully) 180 degrees; that as the amplitude reduces that separation will reduce; and that when the reducing amplitude has reached a value only sufficient (at the peak of the downward excursion) to align the reed with the end plate that separation will have reached zero—after which there will be in each cycle only one instant of maximum capacity.

As will hereinafter more fully appear, with this type of pick-up means the translated oscillations are a function of the variations of the capacity between the reed and the pick-up means. Also, as is well understood, an intracycle departure from pure sinusoidal character, if repeated from cycle to cycle (subject to no more than minute amplitude shifts from one cycle to the next) gives rise to the generation of partials which are limited to integral multiples in frequency, or true harmonics, of the fundamental. Accordingly it is the action described in (I) above (in fully understanding which (II) and (III) above are helpful) which meets the basic portion of specification C—that the pick-up means, in its translating action, introduce into the translated oscillations a series of upper partials harmonically related to the fundamental. Further, it is the actions described in (II) and (III) above which meet the supplementary portion of specification C—that the series of harmonic upper partials diminish in composite magnitude as the vibration of the reed dies away ("magnitude" being used in the sense of amplitude relative to the amplitude of the fundamental).

In the structure specifically illustrated in Figures 1 through 9 the edge portion of the reed which principally influences the active portion of the pick-up (i.e., end plate 71) is an internal edge portion, created for example by piercing the reed with a somewhat elongated hole 80. The outer portion (i.e., the portion toward the free extremity of the reed) of the periphery of the hole may, for example and as illustrated in Figure *3a*, be of semicircular formation, and it is from this portion that the active pick-up portion or end plate 71—which in this case may for example be circular—is closely spaced. In Figure *3a* the dash-dot line 79 may be taken as very approximately illustrating the region, longitudinally of the reed, of average influence of the reed on the pick-up. To meet specification B this region, as to each reed, may most desirably be at the longitudinal position of the node for the second partial of the reed vibration. In the case of an unpierced reed of uniform cross-section this node falls at a position removed from the base of the reed by approximately 78% (and from the free end of the reed by approximately 22%) of the reed length—and the piercing of the reed appears to make no first-order change of this position, so that a positioning of the hole to bring the line of average influence of read on pick-up at a position removed from the base of the reed by approximately 78% of the reed length represents a close compliance with specification B.

It is to meet specification A that the hammers have been called for above preferably to strike the reed at the mid-reed node for the third-partial reed vibration—which node in the case of an unpierced and uniform cross-section reed falls almost precisely at the longitudinal mid-point of the reed, and is not substantially altered by the piercing. Other means of meeting specification A have been disclosed in my copending application Serial No. 169,714 abovementioned; in my copending application Serial No. 189,345, filed October 5, 1950; now abandoned and in my U.S. Patent No. 2,755,697 issued July 24, 1956—consisting generally in rendering integral the normally non-integral ratio between the frequencies of the second and first partials of the reed vibration, and thus rendering the second partial a useful harmonic of the fundamental. Still another means of meeting specification A has been disclosed in my copending application Serial No. 248,947, filed September 29, 1951, which is now abandoned but whose subject matter is continued in my copending application Serial No. 549,589, filed November 29, 1955—consisting generally of the use of a substantially softer-than-normal hammer to substantially eliminate the excitation of the upper partials, at least of those above the second, of the reed vibration.

It will of course be understood that the manner in which the mid-reed nodal striking of the reed meets specification A—i.e., in which it substantially eliminates from the translated oscillations an inharmonic component corresponding to the third partial at which the reed tends to vibrate—is by substantially eliminating the presence of that partial in the reed vibrations on a selective basis. The difference between this and each of the other means of meeting specification A above referred to will be apparent.

When a fixed-free reed is vibrated at high amplitude—which is the case initially after strong excitation—at a plurality of its partial frequencies the deformation attendant on the upper-partial vibration components produces an effective shortening of the reed; this might be termed a temporary or dynamic shortening. Considering the first-partial (or fundamental) vibration, which is the one of course relied on in the abovementioned functioning of the structure, this dynamic shortening will temporarily increase the spacing of the locus of the vibrating-reed extremity from any pick-up located just beyond that extremity (such as the one disclosed in most of the figures of my copending application Serial No. 169,714 abovementioned). Since the efficiency of translation is a sharp inverse function of such spacing, there takes place during the initial high-amplitude vibration a very noticeable reduction of translation efficiency. Thus, with a pick-up located just beyond the free extremity of the reed, there can and does occur an actually observable increase of amplitude of the translated oscillations during the early instants after reed excitation, as the dynamic deformation subsides and the translation efficiency therefore increases.

This time is one when, in a normal piano, a very noticeable decrement of the output sound occurs; indeed, an especially high initial decrement—i.e., decrement during the first few instants of a tone—is a strong distinguishing feature of piano tone.

By arranging the pick-up means so that the edge portion of the reed which most actively influences it is a longitudinally intermediate edge portion, or portion other than the free extremity of the reed, the disadvantage just discussed is obviated. Thereby a worthwhile improvement in respect of tone-inception characteristics is achieved. The arrangement of the pick-up in the structure of Figures 1 through 9 of course observes this specification (in addition to which it observes a further one, hereinafter set forth, for the obtainment of still further advantage). In meeting the specification of this paragraph, however, it will be understood that the edge portion of the reed which most actively or fully influences the pick-up need not be an internal edge portion. Thus in my copending application Serial No. 255,383 and in Figure 54 of my copending application Serial No. 169,714, both abovementioned, I showed structures in which that edge portion was a side-edge region; such structures I now describe.

Reference being had to Figure 11, there will be seen an alternative construction in which the metal reed base, of approximately L-cross-section, is designated as 115, a reed as 116 and the associated pick-up structure as 117; it will be understood that the base 115 will carry other reeds and pick-ups therefor, not here necessary to show. Each reed may for example be individually clamped in position between upper and lower large-diameter fine-thread socket-head hardened-steel set-screws, 118 and 121 respectively, having slightly concave ends resulting in respective small circumferential ridges 120 and 122 axially aligned with each other and "biting" into the respective reed surfaces thereby to provide a sharply defined and positive securing of the reed; a respective horizontal hole 125, larger than the width of the reed, through the downhanging part of the base 115 provides clearance space through which the reed reaches its clamping set-screws and within which the forwardly extending or active part of the reed may freely vibrate. Extending forwardly from the front surface of the forwardly extending part of the base 115 may be a respective insulating bushing 126 internally threaded to accommodate a respective screw 127 by which the respective conductive pick-up structure is secured.

As shown in Figure 12, the pick-up structure may be punched from a sheet of suitable metal and may be generally of inverted-U formation, its downhanging ends 128—which form the pick-ups proper—being internally widened and folded forwardly so that when the pick-up is secured in position against the front of bushing 126, by the screw 127 passing through an upwardly extending central notch 130 in the pick-up structure, these ends 128 will be in a plane substantially parallel to that of the respective reed. The pick-ups (i.e., ends) 128 straddle that reed, forming therefor a pair of pick-ups, and the transverse center line of the pick-ups may be made to coincide with the nodal point of the second partial of the reed vibration (which is typically removed from the secured end of the reed by 78%, and from the free end by 22%, of the active length of the reed). Appropriate vertical elongation of the notch 130 permits vertical adjustment of the pick-ups relative to the reed—which is illustrated by the fact that in Figure 11 the pick-ups appear as having their bottoms above the top of the reed, whereas in the front view constituted by Figure 13 they appear in the more typical position of partial overlap (vertically) between their thicknesses and that of the reed. Other precise adjustments of pick-ups relative to reed are readily made by appropriate bendings of the pick-up.

An electromagnetic pick-up may be used if the reeds be of magnetic material—such a pick-up being desirably provided with only a relatively weak magnetic bias in order to minimize shifting of the frequency of the reed at low amplitudes of vibration due to the magnetic attraction between the reed and pick-up structure. For effective use in the development of the series of upper partials harmonically related to the fundamental, an electromagnetic pick-up may be placed at the reed edge near the reed tip; it should develop very steep voltage pulses as the reed sweeps past it, and accordingly may have a pole tip very closely spaced from the reed. One type of design utilizes a non-magnetically-biased pick-up construction in which the entire core and pole-piece structure is made of high-quality magnetic material such as "Permalloy" having a very high initial permeability; for a pick-up of this type the bias or magnetomotive force may be provided by the reed (or some other source close by), whose magnetic influence on the pick-up will be modified abruptly by the passage of the reed adjacent the pick-up. Figure 14 illustrates an arrangement of an electromagnetic pick-up in which the electrical coils 187 are wound upon individual cores 188, each core being disposed between adjacent reeds 190 which are laterally magnetized as indicated by the polar markings N and S.

It will readily be appreciated that in the structures of Figures 11 through 13 and of Figure 14 the locus of vibration of the portion of the reed which principally influences the pick-up is left unchanged, in effect on the pick-up, by the dynamic shortening of the reed, thereby avoiding any temporary diminution of the translation efficiency at and immediately after the excitation of the reed. I have found, however, that important still further improvement is possible. It is achieved by arranging the pick-up means so that the locus of the portion of the reed which principally influences it—instead of being brought further away from it, or left unchanged, by the dynamic shortening of the reed—is by that dynamic shortening brought closer to it. It is for this reason that I have employed, for the portion of the reed which principally influences the pick-up means, an internal edge portion—and have selected for that edge portion the outer (rather than the inner or an intermediate) peripheral portion of the hole 30. This represents a longitudinally intermediate edge portion specially selected for positive additional advantages.

It will be understood that the effect of this favorable utilization of the dynamic shortening of the reed during the early instants following the excitation of the reed is not only to enhance the translation of the fundamental (thereby increasing the initial decrement, as is desirable), but also then to increase the generation of harmonically related upper partials—since the steepness of the wave-form of capacity variation is likewise increased by this utilization. It is so that specification D is met. This is of especial importance since a distinguishing feature of piano tone, over and above the high initial decrement, is a very initial burst of momentarily accentuated harmonic development.

The pick-up means of Figures 1 through 9 and of Figures 11 through 13 will be recognized as of the capacitative type, and those of Figure 14 as of the electromagnetic type, and as to broader aspects of the invention it will be understood that no limitation as to type is intended. For the capacitative type, in turn, no limitation as to broader aspects is intended, as between those operating for example on a D.C., on an amplitude-modulating, or on a frequency-modulating basis. I have preferred, however, to employ the capacitative type of pick-up means operating on a frequency-modulating basis—i.e., to employ a system in which variations of the capacity between the pick-up means and the reeds, each taken collectively, are used to modulate a high-frequency carrier, which in turn is demodulated to produce the translated tone-representing oscillations, which in turn may be amplified and translated into sound by a final audio amplifier and electro-acoustic translating device (not shown).

Reference being had to Figure 10, there will be seen an electronic system comprising a pentagrid converter tube 89 such, for example, as a 6BA7, of which the second and fourth grids are interconnected and, by-passed by condenser 105, are supplied with positive potential through voltage divider 103—104 from a source B-1 of plate current, and of which the first grid 91 is connected to the upper extremity of an oscillator coil 100 through grid condenser 102 and also to the cathode 90 of tube 89 through grid leak 98. The lower extremity of the coil 100 is connected to ground, while the cathode 90 may be connected to a tap 101 on the coil 100 appropriate to the setting up of the system 100—90—91—92 as a high-frequency oscillator system. In tube 89 the third grid 93 may be connected to cathode 90 and the fifth (or suppressor) grid to ground; in the plate current flowing between plate 96 and the source B1 of plate current, through the load mentioned below, will appear the oscillations generated by the high-frequency oscillator abovementioned, amplified by the action of tube 89 and rendered suitable, impedancewise, for feeding into that load.

The several reeds may be electrically interconnected, as by interconnection of the metal portions of the three base members 43, 44 and 45 by flexible wires 51, and connected to ground. The several pick-up means 70 may be electrically interconnected in any suitable manner, as by a conductor 75 intertwined around the upper extremities of the threaded portions 73, and connected to a suitable tap on the coil 100—several such taps being provided so that they may be selected between. These connections place the aggregate capacity, between reeds and pick-up means, in parallel with a selected portion of the coil 100; that portion will be selected so that the combination of that capacity with the coil will resonate the oscillator system abovementioned to approximately the desired frequency, fine tuning to that frequency being accomplished for example by adjustment of a variable iron core 99 associated with the coil.

It will be understood that upon vibration of a reed the aggregate reed-to-pick-up capacity will be varied oscillatorily, and that as a result the frequency of the oscillator system abovementioned will be varied oscillatorily—i.e., will be modulated by the reed vibrations, it being the thus frequency-modulated oscillations which appear in the plate current of the tube 89. The load connected in the plate circuit of that tube may be the input of a discriminator-transformer 107 (tuned to the carrier frequency) of any conventional type, to the output of which may be connected in conventional fashion a double-diode discriminator tube 108 and the demodulated-oscillation load system 109 of any conventional type. It will accordingly be understood that across the demodulated-oscillation load system 109—i.e., between its upper terminal 110 and ground—will appear the electric oscillations translated from the reed vibrations.

Between the terminal 110 and the final amplifier and electro-acoustic translating device (not shown) the translated electric oscillations may be passed through a low-pass filter 111—112 to eliminate supersonic components; may be attenuated to any desired amplitude by attenuator 113—114; and may be preliminarily amplified by tube 115, shown for example as a triode-connected pentode with load resistance 116, bleed resistance 117 and cathode resistance and condenser 118—119. From load resistance 116 the oscillations may be applied through condenser 120 to a volume control 121, preferably of the well-known amplitude-compensated type illustrated.

From the output of the volume control 121 the oscillations may be fed to the final amplifier 130 through a network 122 which, in cooperation with the input impedance of the amplifier 130, serves to impart thereto a frequency characteristic rising with increasing frequency. Additionally there may be associated with the output of the volume control, as by shunting thereacross, a resonant circuit (which should be of the series variety for the shunt connection) consisting of variable inductance 123 and variable capacity 124, for further shaping of the frequency characteristic of the system. I have found that for most pianistic tones it is desirable that the series circuit 123—124 be resonated at a frequency corresponding to the fundamental of a tone at or near the bottom of the scale of the instrument (which in the 73-note instrument illustrated may typically extend from 65.4 cycles to 4186 cycles), under which circumstances its attenuation is greatest at the lower frequencies and its effect thus cumulative with that of the network 122. Interesting and important variations of effect can, however, be achieved by varying the resonance of 123—124.

The electronic system above described (other than the amplifier 130 and the controls proper of elements 121, 123 and 124) may be mechanically arranged in the form of a compact unit 83 which, if desired and as indicated in Figures 1 and 2, may be physically disposed below the cover 6 behind the base members 45 and 44 at the treble extremity of the instrument.

Claims to the vibrator-exciting action disclosed herein are not made in this application, the same having been made in my copending application Serial No. 660,787, filed May 22, 1957; likewise claims to the subdivision of base means in accordance with specifications set forth above are not made herein but rather in that copending application just mentioned. Furthermore, claims to structure taking positive advantage of the dynamic shortening of the reed are not made herein, the same having been presented in my copending application Serial No. 673,725, filed July 23, 1957.

While I have disclosed my invention in terms of particular embodiments thereof, it will be understood that unnecessary limitations are not thereby intended, since by the disclosure various modifications will be suggested to those skilled in the art. Such modifications will not necessarily constitute departures from the scope of the invention, which I undertake to express in the appended claims.

I claim:

1. In combination in an electrical musical instrument, a fixed-free reed, an impulse exciting means comprising a key actuated hammer adjacent the reed selectively engageable with the individual reed for setting it into decadent free vibration, and an electric translation pick-up adjacent the reed, said pickup having a tone producing portion located alongside and being vibratorily passed by a longitudinally intermediate edge portion of the reed and being of an effective thickness, in the direction of reed vibration, smaller than the high-amplitude stroke of said edge portion of the reed.

2. In combination in an electrical musical instrument, a fixed-free reed, an impulse exciting means comprising a key actuated hammer adjacent the reed selectively engageable with the individual reed for setting it into decadent free vibration, and an electric translation pick-up adjacent the reed, said pickup having a tone producing portion located alongside and being vibratorily passed by a longitudinally intermediate edge portion of the reed, being of an effective thickness, in the direction of reed vibration, smaller than the high-amplitude stroke of said edge portion of the reed, and being offset in said direction from effective alignment with the rest position of the reed.

3. The combination claimed in claim 1, wherein said edge portion of the reed is located substantially at a node for a lower one of the upper partials of the free vibration of the reed.

4. The combination claimed in claim 1, wherein said edge portion of the reed is substantially nodal for the second partial of the free vibration of the reed.

5. The combination claimed in claim 1, wherein said edge portion of the reed is substantially nodal for the second partial of the free vibration of the reed and wherein, in the direction of reed vibration, said pick-up portion has an effective mid-point offset from the rest position of the effective mid-point of said edge portion of the reed.

6. In combination in an electrical musical instrument, a mechanical system comprising a fixed-free reed and an impulse exciting means comprising a key actuated hammer adjacent the reed selectively engageable with the individual reed for setting it into decadent free vibration, an electric translation pick-up adjacent the reed, said pick-up having a tone producing portion located alongside and being vibratorily passed by a longitudinally intermediate edge portion of the reed and being of an effective thickness, in the direction of reed vibration, smaller than the high-amplitude stroke of said edge portion of the reed, and means comprised in said mechanical system for at least substantially eliminating from the free vibration of the reed a lower one of its normally present upper partials.

7. The combination claimed in claim 6, wherein said edge portion of the reed is substantially nodal for another lower one of the upper partials of the free vibration of the reed.

8. In combination in an electrical musical instrument, a fixed-free reed, an impulse exciting means adjacent the reed and effective thereon substantially at a node for one of the two lowest of the upper partials of the free vibration of the reed for setting the reed into decadent free vibration, and an electric translation pick-up adjacent the reed, said pickup having a tone producing portion located alongside and being vibratorily passed by a longitudinally intermediate edge portion of the reed and being of an effective thickness, in the direction of reed vibration, smaller than the high-amplitude stroke of said edge portion of the reed, said edge portion of the reed being substantially nodal for the other of said two lowest upper partials.

9. In combination in a musical instrument, a fixed-free reed, single-impulse exciting means comprising a key actuated hammer selectively engageable with the individual reed for setting it into decadent free vibration, a mechanico-electrical system consisting of a portion of the reed and pick-up means associated with and influenced by said portion for translating electric oscillations from the reed vibrations, means comprised in said mechanico-electrical system for at least substantially eliminating from said oscillations an inharmonic component corresponding to a lower one of the upper partials at which the reed tends to vibrate, and means also comprised in said mechanico-electrical system for introducing into the oscillations translated from the fundamental reed vibrations a series of upper partials harmonically related thereto.

10. In combination in a musical instrument, a mechanical system comprising a fixed-free reed and single-impulse exciting means for setting it into decadent free vibration, a mechanico-electrical system consisting of a portion of said reed and pick-up means associated with and influenced by said portion for translating electric oscillations from the reed vibrations, means comprised in said mechanical system for at least substantially eliminating from said oscillations an inharmonic component corresponding to one of the two lowest of the upper partials at which the reed tends to vibrate, means comprised in said mechanico-electrical system for at least substantially eliminating from said oscillations an inharmonic component corresponding to the other of said two partials, and means also comprised in said mechanico-electrical system for introducing into the oscillations translated from the fundamental reed vibrations a series of upper partials harmonically related thereto.

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APPENDIX C
U S. PATENT NO. 2,949,053
(ANDERSEN)

Aug. 16, 1960 C. W. ANDERSEN 2,949,053

TONE GENERATOR

Filed June 1, 1954 2 Sheets-Sheet 1

Fig. 1.

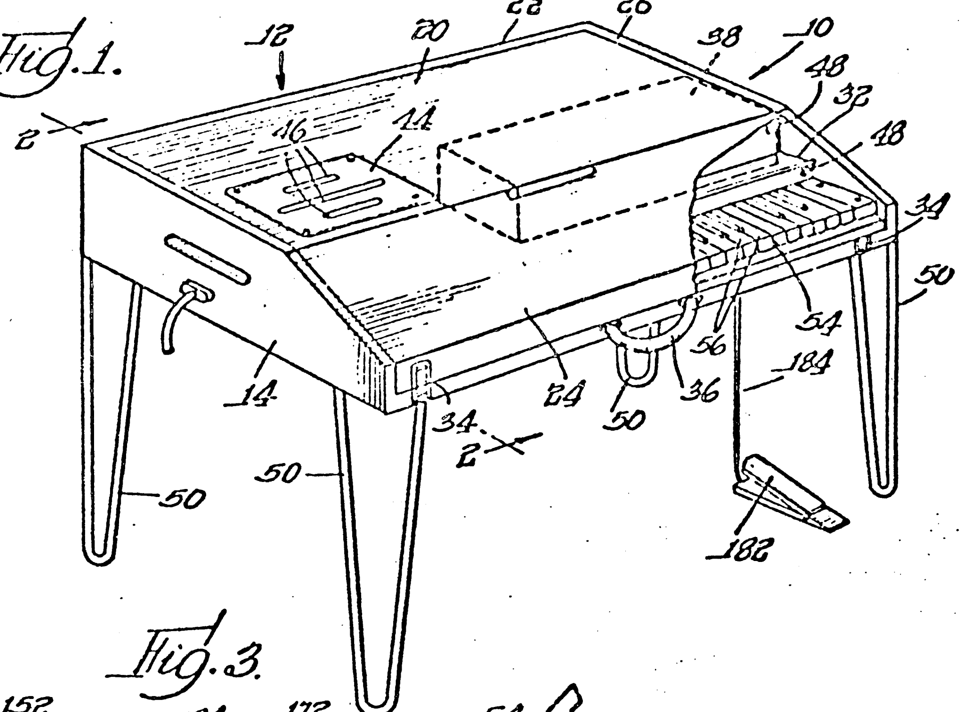


Fig. 3.

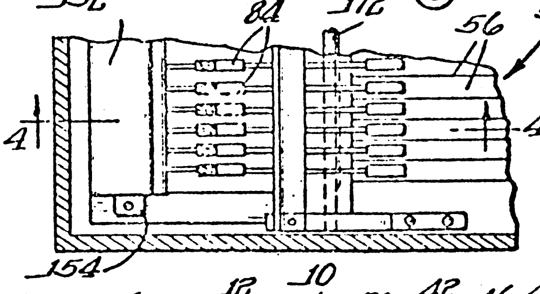
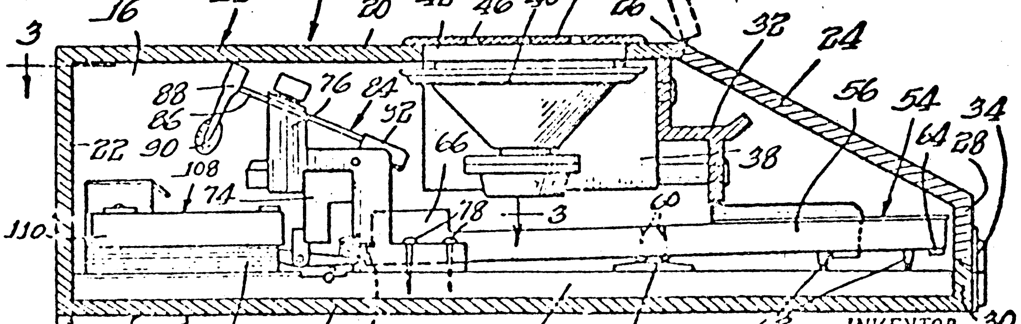


Fig. 2.



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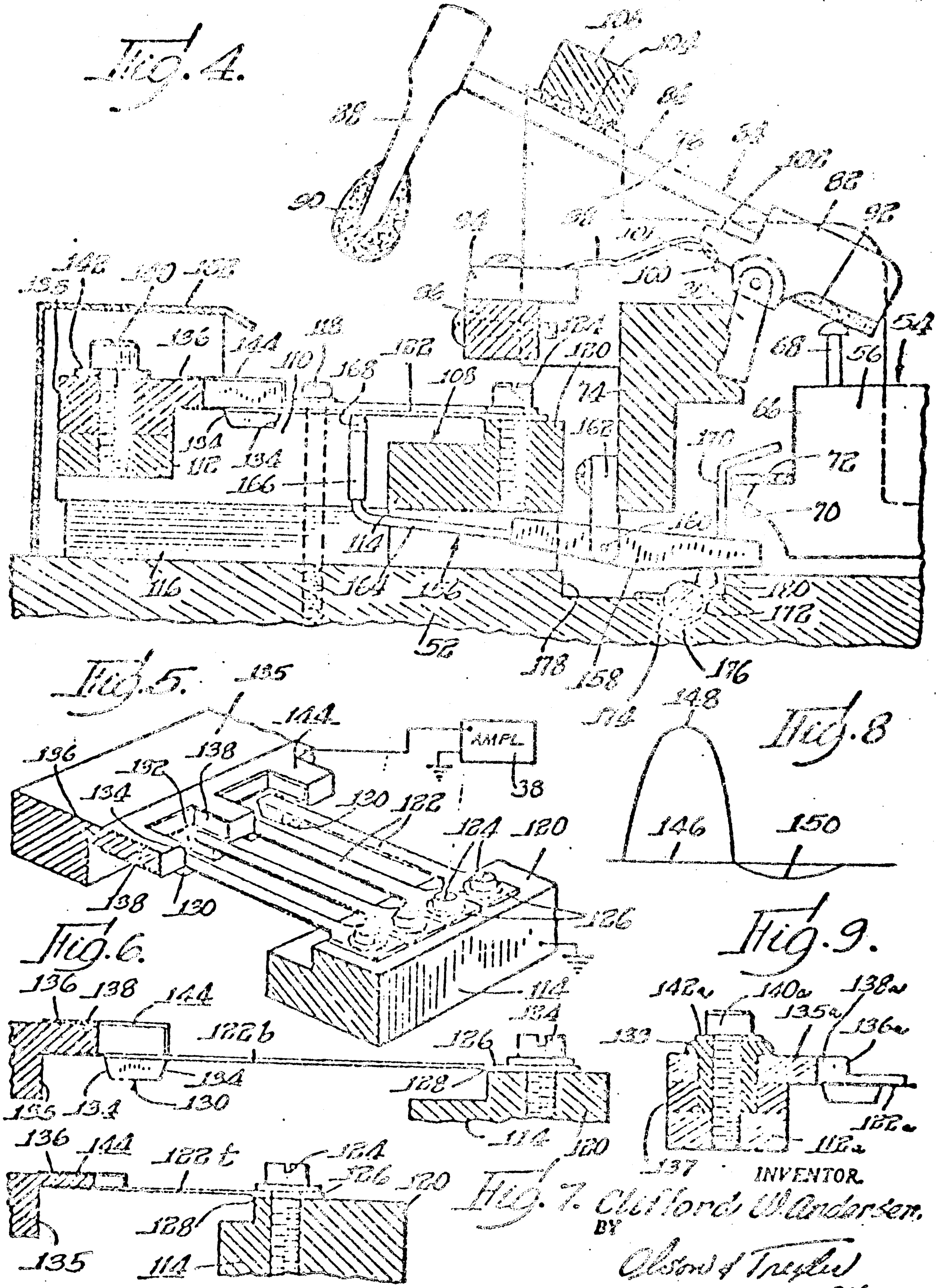
Aug. 16, 1960 C. W. ANDERSEN 2,949,053

TONE GENERATOR

Filed June 1, 1954 [illegible] Sheets-Sheet 2



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2,949,053

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TONE GENERATOR

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Filed June 1, 1954, Ser. No. 433,564

9 Claims. (Cl. 84—1.06)

This invention is concerned generally with key actuated percussive instruments, and more particularly with a portable electronic piano utilizing vibrating reeds as tone generators.

For many hundreds of years the piano and its historical predecessors have utilized vibrating strings as tone generators. These string tone generators are stretched under substantial tension, and are subject to gradual detuning due to stretching of the strings, loosening of the mechanism holding the strings, changes in size with temperature, changes in the supporting and associated structure due to temperature and atmospheric changes, and due to corrosion of the strings which changes their physical dimensions.

The bass strings of a piano are of considerable length and therefore require that a piano be a large size instrument. The aggregate tension of all of the strings of a piano typically may run on the order of eighteen tons. This requires a large and massive supporting structure, commonly made of cast iron or the like, and further requires an instrument of large size. The cast iron or other massive supporting structure leads to great weight in a piano, the smallest pianos weighing on the order of five hundred pounds, and grand pianos weighing as much as fifteen hundred pounds or more. The minimum length of bass strings is on the order of three to four feet, thus requiring a piano dimension of at least this much in the direction of the bass strings, and grand pianos may be as much as nine feet in length to accommodate the long bass strings.

The large size and weight of conventional pianos makes them unsuitable for use in many homes, and seriously crowds student practice rooms. Efforts have been made to reduce the size and weights of pianos by utilizing sound generators other than tensioned strings, or by changing the dimensions of the strings. These efforts generally have been unsuccessful. I have found that by suitably shaping and dimensioning a vibratile metallic reed, the reed can be struck by a hammer and utilized as an electrostatic generator which when suitably electronically amplified and transduced produces sounds practically indistinguishable from those of a conventional piano. Such a musical instrument is adapted for the use of earphones as transducers so that the pianist may listen to his own playing without disturbing others in the vicinity. Of course, for general use a loudspeaker would be used rather than earphones.

It is an object of this invention to provide a portable electronic piano utilizing a vibratile reed and corresponding pickup as an electrostatic tone generator wherein the reed and pickup are so correlated as to produce a proper balance of fundamental and harmonics.

A further object of this invention is to provide an electronic piano utilizing vibratile reed tone generators wherein the reeds are provided with a mount which will not absorb the reed vibrations and thereby damp the reeds.

A further object of this invention is to provide a vibrating reed electronic piano in which the reeds are so formed

as to insure vibration from a predetermined point, whereby more accurately to control their vibrational characteristics.

A further object of this invention is to provide a vibrating reed tone generator electronic piano wherein the reeds are reduced to a minimum size.

Yet another object of this invention is to provide a vibrating reed electronic piano having a pickup cooperable with the reeds which is of economical and readily fabricated construction.

A further object of this invention is to provide a vibrating reed electronic piano having a pickup cooperable with the reeds which provides a very large change in capacitance, thereby increasing the volume of the output and masking random noises.

Yet another object of this invention is to provide, in an electronic piano having vibrating reed tone generators, a pickup cooperable with the reeds which is shaped to produce a proper graduation of tonal volume along the length of the instrument.

Other and further objects and advantages of the present invention will be apparent from the following description when taken in connection with the accompanying drawings wherein:

Fig. 1 is a perspective view of a piano constructed in accordance with the principles of my invention with parts broken away for clarity of illustration;

Fig. 2 is an enlarged cross sectional view through the piano taken substantially along the line 2—2 of Fig. 1;

Fig. 3 is a fragmentary horizontal sectional view taken substantially along the line 3—3 in Fig. 2;

Fig. 4 is an enlarged cross sectional view taken along the line 4—4 of Fig. 3 and showing the piano action;

Fig. 5 is a perspective view showing the cooperation of the reeds and pickup;

Fig. 6 is a sectional view showing the cooperation of one of the bass reeds and pickup and is similar to the center portion of Fig. 4 on an enlarged scale;

Fig. 7 is a view similar to Fig. 6 showing a treble reed and its association with the pickup;

Fig. 8 is a diagram illustrating the type of electrical wave produced by one of the reeds and the pickup; and

Fig. 9 is a view similar to Fig. 6 showing a modified form of the pickup.

Reference first should be had to Figs. 1 and 2 for a general understanding of the piano. The piano is indicated generally at 10 and comprises a case 12 of generally rectangular configuration having parallel end walls 14 and 16, a bottom 18 and a top 20 parallel thereto, and a rear wall 22. The top 20 is of lesser depth than the bottom 18, and a cover 24 is hingedly connected at 26 to the front edge of the top 20. The cover is provided with a depending flange 28 which abuts an upstanding front wall 30. When the cover is tilted back to the dashed line position shown in Fig. 2 it cooperates with a tray 32 to form a music rack. When it is closed, it is inclined downwardly over the keyboard shortly to be described.

The front wall 30 and depending cover flange 28 are provided with complementary fasteners 34 of conventional construction for holding the cover closed, and a handle 36 is provided on the front wall 30 for carrying the piano.

An electronic amplifier 38 of suitable design is mounted within the case for amplifying the oscillations generated by the reeds and pickups as hereinafter will be set forth. A loudspeaker 40 is positioned in the cabinet beneath the opening 42 which is covered by a cover plate 44 having suitable sound transmitting slots 46 therein. A pair of jacks 48 is mounted adjacent the right hand end of the shelf 32 as shown in Fig. 1 for the receipt of earphone plugs. When a plug is associated with one of the jacks, the sound is audible only through the earphones, while the sound is audible both through the speaker and through the earphones when the earphone plug is associated with the other jack.

The piano as heretofore described is of relatively small size, being on the order of three feet long and two feet in depth, the height being substantially less than one foot. The weight of the piano is well under one hundred pounds, and it thus will be appreciated that the piano is readily portable and can be placed on a table or desk for operation. Alternatively, wrought iron legs 50 of the type currently popular may be attached to the underside of the piano case by any suitable means such as screws, it being understood that these legs probably would be used only for semi-permanent installations.

The piano is provided with a base or support 52 preferably constructed of wood and lying along the bottom 18. A keyboard 54 extends across the front edge of this base or support and comprises a plurality of keys 56 as shown in Figs. 1–4. The keys are pivoted on a fulcrum rail 58 by means of the usual balance key pins 60, and are provided with the usual guiding front key pins 62 and a limit stop 64 of felt or other suitable material.

The inner end of each key is provided with a raised portion 66 having a capstan screw 68 (Fig. 4). The extreme inner end of each key further is provided with a shelf 70 having a pad 72 of felt or other suitable material thereon.

A main rail 74 extends across the keyboard between a pair of supporting brackets 76 secured to the base or support 52 by any suitable means such as screws 78. Butt flanges 80 are spaced along the main rail 74 and pivotally support the butts 82 of a plurality of hammers generally designated by the numeral 84 and further including hammer shanks 86, and hammer heads 88 having strikers 90 of felt or other suitable material. The underside of each butt 82 is provided with a pad 92 of suitable material such as felt and is engaged by the corresponding capstan screw 68.

A spring rail 94 extends between the brackets 76, being mounted thereon by means of auxiliary brackets or blocks 96. A plurality of springs 98 is spaced along the spring rail 94, and each spring corresponds to one of the hammers 84. The end of each spring 98 is curled over as at 100, and the curled over end is received in a groove or slot 101 in a forwardly projecting portion 102 of the corresponding hammer butt 82. Each spring thus urges the pad 92 of its hammer butt against the corresponding capstan screw 68, and all of the hammer shanks are urged up against a felt pad 104 on the bottom of a hammer rail 106 extending between corresponding top portions of the brackets 76.

A generally rectangular reed and pickup supporting frame 108 is provided in the piano forwardly of the piano actions just described. This frame comprises a pair of end pieces 110 of heavy steel, a back piece or rail 112 likewise of heavy steel and welded to the end pieces 110 at right angles thereto, and a front piece or rail 114 which likewise is of heavy steel and is welded between the end pieces 110. The treble end piece is slightly shorter than the bass end piece, and the front rail 114 is not quite parallel to the back rail 112, but rather tapers toward the back rail from the bass end of the piano to the treble end due to the physical sizes of the reeds as hereinafter will be brought out. It will be appreciated that the mass of the supporting frame 110 precludes any vibration thereof which would tend to damp the reeds or otherwise to affect tone generation adversely. A pair of rubber blocks 116 is mounted on the base or support 52 substantially at opposite ends of the piano, and the end pieces 110 rest on these blocks, suitable screws 118 passing through said end pieces and said blocks and being threaded into the support or base 52 for holding down the frame.

The front frame rail 114 is provided with a raised portion 120, and a plurality of vibratile metallic spring steel reeds 122 is spaced along this raised portion, each reed being mounted by means of a cap screw 124 passing through a widened base portion 126 of the reed and threaded into the raised portion 120 of the front rail 114. The reeds 122 necessarily vary in physical size from a maximum at the base end of the piano to a minimum at the treble end. Reference to Figs. 6 and 7 reveals the difference in sizes, a bass reed being indicated at 122t 122b in Fig. 7, and a treble reed being indicated at 122t in Fig. 7. The thickness of the bass reeds preferably is greater than that of the treble reeds to limit the amplitude of vibration, and the width also may be greater to limit undesirable lateral vibration. The reeds are undercut as illustrated at 128 in Figs. 6 and 7, preferably by grinding, so that the reeds will vibrate from the undercut or shoulder portion out toward their free ends. Accordingly, the position at which the reed bases 126 are clamped by the heads of the cap screws 124 is not critical. The undercut portion or shoulder of each reed further has been found to delay the decay of vibration in a desirable manner.

In order to avoid making the bass and some of the other reeds too large, lead weights 130 are provided on the outer ends of these reeds. This causes the weighted reeds to vibrate at a lower frequency than they would without the weights. The weights also provide inertia which acts to eliminate high frequency harsh transients or partials which otherwise would be generated upon striking of the reed, and which would lead to a non-piano-like tone. The lead weights also delay the decay of vibration in a highly desirable manner. In addition to the foregoing, the lead weights simplify tuning of the reeds, as such tuning can be done merely by adding a little extra lead, or by filing some off. The lead weights preferably are tapered on their sides as indicated at 132 in Fig. 5, and at their ends as indicated at 134 in Figs. 4–6. This tapering provides physical clearance so that there is substantially no danger of striking the pickup now to be described.

The pickup comprises a plastic member 135 having a shelf portion 136 projecting forwardly toward the reeds 122. The outer edge of the shelf portion is of generally comb-like construction having a plurality of extending fingers 138. The plastic pickup 135 is secured on top of the back frame rail 112 by means of a series of cap screws 140 having washers 142 beneath their heads, the cap screws passing through the plastic member 135 and being threaded into the back rail 112. The plastic pickup 135 and the reeds 122 are so mounted that the reeds are coplanar with the bottom surface of the shelf 136 with the outer ends of the reeds fitting in the spaces between the fingers 138. As may be seen in Fig. 5 it is preferable that two bass reeds fit in the space between two of the fingers 138. The treble reeds likewise could be arranged with two per space, but it is preferred that the treble reeds be arranged with only one between each pair of fingers, and it is contemplated that the bass reeds also could be arranged with only one reed between a pair of fingers. The importance of the coplanar relation of the reeds and the bottom of the shelf 136 will be apparent shortly.

The top and bottom surfaces, as well as the projecting end surfaces, of the shelf 136 of the pickup are provided with a conductive coating 144. This conductive coating preferably comprises metal which may be plated, sputtered, deposited, or otherwise placed on the plastic. Various techniques for providing such metal coatings are known in other arts, for instance the art of manufacture of printed electrical circuits. Silver has been found to be a preferable metal for such coating due to its excellent conducting characteristics and due to the use of coating silver onto an insulating base. The coating is sufficiently thin that only a small amount of metal is needed, and the cost of silver therefore is not prohibitive. The reeds 122 all are grounded through the frame 108, and the conductive coating 144 of the pickup is connected to the input of the amplifier 38. It will be evident that a capacity field exists between the reeds and the conductive coating on the pickup when a potential is applied to the pickup. When each reed is struck by its corresponding hammer to set the reed into vibration, the capacity field varies to produce oscillations which result in piano tones when properly amplified and transduced.

The thickness of the shelf 136 varies from end to end of the pickup 135. The thickness of the shelf is greatest at the bass end of the piano, and decreases to a minimum at the treble end. The thickness is correlated with the swing of the corresponding reeds so that when the reeds swing upward from their rest position (this being coplanar with the bottom of the shelf as previously noted) the reeds never swing above the top surface of the shelf. The entire lower half cycle of reed swing is beneath the shelf. As a result, a change in capacity is produced as illustrated in Fig. 8. The median line 146 represents the capacity between a reed and the pickup when the reed is at rest. When the reed swings down below the shelf, the capacity between the reed and pickup coating 144 changes by a maximum amount as indicated at 148. This change in capacity has been indicated as approximately a sine wave for simplification of representation, but it is to be understood that the wave actually closely corresponds with the sound wave generated by a vibrating piano string, such sound wave being complex and comprising a fundamental and series of harmonics. When the reed swings upwardly above its rest position, the capacity changes only very slightly as indicated at 150, and for all practical purposes this change can be ignored. The fundamental thus generated is strong and bears the proper relation to the harmonics to represent a piano sound.

It will be apparent that if a reed were centralized with respect to the shelf 136 and conductive coatings 144, there would be no oscillation generated except when the reed swung beyond the upper and lower surfaces of the shelf. Each time the reed would swing beyond the extremities of the shelf in such manner a strong second harmonic would be generated, and the resulting sound would have a distinctly guitar-like quality. Placement of the reeds in the slots between the fingers engenders a maximum change in capacity for a given reed swing, thereby giving rise to a reasonably strong initial signal so that random noises will be inaudible.

It has been noted previously that the front rail 114 progressively approaches the back rail 112 from the bass to the treble end of the instrument. This is necessary due to the progressive decrease in length of the reeds, and it will be apparent from Fig. 6 that in addition to the progressively decreasing spacing between the front and rear rails the upper projection 120 on which the reeds are supported becomes progressively wider to position the reeds progressively closer to the pickup 135, the pickup being mounted directly on top of the back rail. The length of the shelf 136 of the pickup, specifically the fingers 138, also decreases from the bass to the treble end so that not too high a percentage of the length of a treble reed extends into the space between adjacent fingers. This maintains a proper balance among the various tones generated by the several reeds of the piano.

It has been noted heretofore that the large change in capacity engendered by projection of the reed ends between the projecting fingers of the pickup renders background or stray noise substantially inaudible. The use of the relatively small pickup area of the coating 144, as opposed to a metallic bar which would have to extend to the back edge of the pickup element 135, further helps to eliminate background or stray noise. Such pickup or stray noise further is minimized by a conductive shield 152 preferably of aluminum, covering the top and back of the pickup and mounted on the support or base 52 by means of outwardly directed ears 154 (Fig. 3) which may be held down by screws or other suitable fasteners. It is to be understood that the shield 152 is suitably grounded.

It is well known that the various strings of a piano have different vibrational decay characteristics; more particularly stated, the bass strings tend to vibrate much longer than the treble strings. Accordingly, dampers are provided to arrest the vibration of piano strings when the corresponding keys are released. The reeds utilized in my electronic piano likewise have different vibrational decay characteristics. Accordingly, I have provided dampers for the reeds, and these are illustrated in Fig. 4.

Each damper is indicated generally at 156, and includes a damper lever 158 pivotally connected at 160 to a damper lever flange 162, the damper lever flanges being spaced along the lower front edge of the main rail 74. A damper wire 164 extends from each lever 158 toward the back of the piano, and extends upwardly to support a damper head 166 having a suitable reed engaging pad 168 of felt or other material. The butt end of each damper lever is provided with a hook-like or substantially L-shaped wire 170 extending upwardly and overlying the felt pad 72 on the corresponding key shelf 70. Whenever a key is depressed, the shelf thus raises the butt end of the damper lever, and accordingly retracts the pad 168 from the corresponding reed so that that reed is free to sound. At the same time, the capstan screw engages beneath the hammer butt 82 to start the hammer head in motion toward the corresponding reed. The pad 64 beneath the outer end of the key engages the base or support 52 to stop the key before the hammer head pad 90 engages the corresponding reed, and inertia of the hammer continues the hammer in motion to effect such engagement. The hammer then rebounds and is returned by the spring 98 against the capstan screw which holds the hammer partially depressed until the key is released. The spring 98 then returns the hammer to its rest position as shown in Fig. 4, and the damper is returned to damping position by a spring (not shown) encircling the pivot 160.

In order to play forte, it is necessary to release all of the dampers. This is effected by means of a rod 172 (Fig. 4) extending completely across the piano and journaled in a graphite impregnated felt bearing 174 in a generally semi-circular groove 176 extending across the base or support 52, this base or support being provided with a rectangular channel or groove 178 in the vicinity of the rod 172. A bar 180 is welded longitudinally along the rod 172 and engages beneath the butt end of all of the damper levers 158. A foot pedal 182 (Fig. 1) is provided for the piano and is detachably connected thereto by push pull control 184 of the type comprising a flexible wire movable within a flexible sheath. This control is so connected to the rod 172, as fully illustrated in my copending application Ser. No. 433,563, filed June 1, 1954, now Patent No. 2,888,851, and entitled "Piano Action," as to effect counterclockwise rotation of the rod 172 when the foot pedal is depressed. This causes the bar 180 to cam under the bottom edge of the lever 158 to pivot each damper to released or retracted position and to hold it there until the foot pedal is released.

It now will be apparent that the structure disclosed in this case causes the reeds to vibrate at a predetermined point, thereby actually controlling their pitch frequency and precluding the necessity of critical positioning of the holding means. The massive support of the reeds precludes damping thereof by the support bar, and therefore the support does not affect the vibrational characteristics of the reeds.

The lead weights on the reeds enable the reeds generating the lower tones to be constructed with a reasonable physical size. These weights also act to absorb or eliminate hard transients or partials which tend to be generated when the reed initially is struck. Furthermore, the lead weights lead to improved decay characteristics and simplify initial tuning of the reeds in allowing the reeds to be tuned by the addition of a bit more lead or by filing off a bit of lead.

The cooperative relationship of the reeds and pickups whereby the reeds are coplanar with one face of the pickup and wherein the pickup is of sufficient thickness so that the reed does not pass beyond or through the pickup in one direction of vibration is important in producing proper piano tones. The balance of fundamental and harmonics achieved in this manner is substantially indistinguishable from that of a conventional piano.

The metal coating of the plastic pickup bar has several important advantages over a metallic pickup bar. Insulating problems are greatly simplified, and in fact are substantially eliminated. The mounting structure therefor is simplified. The cost of production is lowered, and there is a lesser area which could pick up stray signals or noise.

The projecting teeth of the pickup extending between the reeds effects a greater volume change due to the greater change in capacitance than is achieved by any means in the prior art with which I am familiar. The effect varies with the length of the projection, and for this reason the length of the projection varies across the keyboard in order to produce a proper tonal balance among the base, treble, and intermediate tones. The tonal balance further can be obtained and is influenced by whether there are one or two reeds between each pair of teeth or projections, and this is borne in mind in determining the length of the projections to obtain proper tonal balance.

A modified form of pickup is shown in Fig. 9. This pickup is functionally similar to that previously described, and similar numerals with the addition of the suffix *a* are utilized to identify similar parts. The pickup 135*a* comprises a metal plate, preferably aluminum, with a forwardly projecting shelf 136*a* having slots 138*a* in which the reeds 122*a* vibrate. An insulating slab 137 spaces the pickup 135*a* from the back bar or rail 112*a*, and a grommet 139 insulates each cap screw 140*a* and washer 142*a* from the pickup. The pickup 135*a* may comprise a plurality of pieces arranged end to end and electrically interconnected, or may be made in one piece.

The specific example of the invention herein shown and described is to be understood as being for illustrative purposes only. Various changes in structure will no doubt occur to those skilled in the art, and are to be understood as forming a part of my invention insofar as they fall within the spirit and scope of the appended claims.

I claim:

1. An electronic musical instrument comprising a common reed support, a plurality of reeds with bases fixed on said common support and with vibratile tongues projecting in the same direction therefrom in side-by-side substantially coplanar parallelism from said support, a plurality of hammers respectively percussively engageable with the tongues of said reeds respectively to set said reed tongues in decadent free vibration, a plurality of manually engageable keys respectively operatively connected to said hammers for selectively moving said hammers into such percussive engagement with said reed tongues, a pickup member of comb-like configuration having a plurality of parallel teeth and an intermediate plurality of slots each opening at one end, means mounting said pickup member in opposition to said reeds substantially in a common plane therewith with the reeds projecting into the slots between the teeth, the teeth on opposite sides of a reed extending substantially the same distance therealong, there being at least one reed tongue in each slot, and each reed being closely adjacent a pickup tooth along a longitudinal edge of said reed, said pickup teeth terminating at free ends short of the reed bases, the hammers respectively percussively engaging the reed tongues between the reed bases and the free ends of the adjacent pickup teeth, said reeds and said pickup member comprising electrostatic tone generating means, means establishing an electric potential between said reeds and said pickup member, electric oscillations being generated in accordance with the change in capacity between said reeds and said pickup member resulting from free decadent vibration of said reeds relative to said pickup member, electronic amplifying means connected to said reeds and said pickup member for amplifying the oscillations generated by the decadent free vibration of said reed tongues, and electro-acoustic translating means connected to said amplifying means for converting the amplified oscillations into audible tones.

2. An electronic musical instrument as set forth in claim 1 wherein the plane of said reeds is displaced from the median plane of the pickup teeth, and wherein said reeds vibrate asymmetrically about such median plane.

3. An electronic musical instrument as set forth in claim 1 and further including common means electrically grounding said plurality of reeds.

4. An electronic musical instrument as set forth in claim 3 wherein the common grounding means comprises the common reed support, said support being electrically conductive, and said reeds being mounted directly on said support in physical and electrical engagement therewith.

5. An electronic musical instrument as set forth in claim 1 wherein the reed tongues and the teeth of the pickup are substantially rectangular in cross-section and in outline to provide a sharp tonal reaction.

6. An electronic musical instrument as set forth in claim 1 wherein the reed support and the pickup member support comprise parts of a common support which is massive relative to said reeds.

7. An electronic musical instrument as set forth in claim 1 wherein the pickup member comprises an insulating base and an electrically conductive coating on surfaces thereof.

8. An electronic musical instrument as set forth in claim 7 wherein the coating is on the top, bottom and end surfaces of the pickup member fingers.

9. An electronic musical instrument as set forth in claim 1 wherein a plurality of reed tongues extends into each of at least some of the pickup slots.

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APPENDIX D
U.S. PATENT NO. 3,154,997
(BODE)

Nov. 3, 1964 H. E. W. BODE 3,154,997

REED WITH CURVED TAPER

Filed Oct. 3, 1962

Fig. 1.

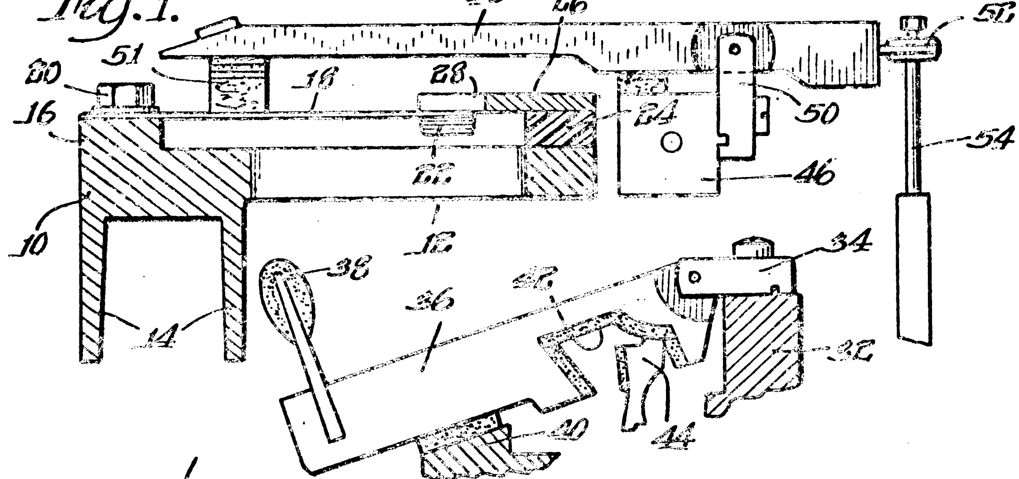


Fig. 2.

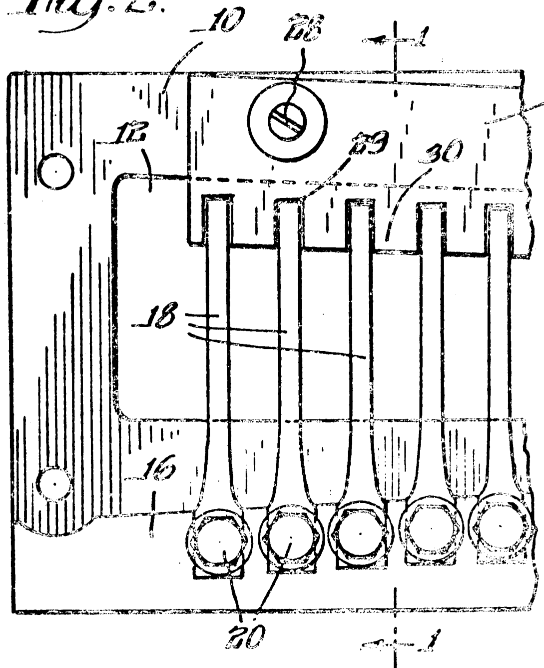


Fig. 5.

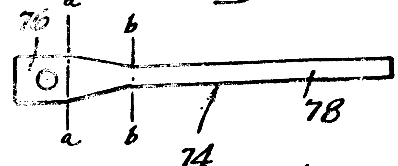


Fig. 4.

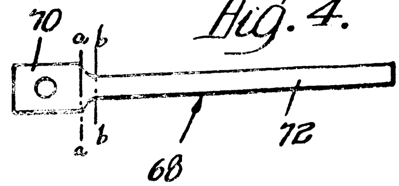
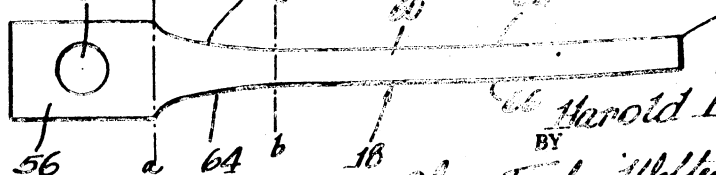


Fig. 3.



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United States Patent Office

3,154,997

Patented Nov. 3, 1964

3,154,997

REED WITH CURVED TAPER

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Filed Oct. 3, 1962, Ser. No. 228,103
6 Claims. (Cl. 84—408)

This invention relates to the art of electronic sound generation, and more particularly to a vibratory reed serving as an impulsively actuated electrostatic tone generator.

The use of a vibratory reed in capacitive relation with a pickup as an electrostatic tone generator is well known in the electronic musical art. Such reeds have long been used in wind driven electronic organs, and are generally similar in nature to the reeds which have been used for a great many years in reed organs and in accordions. More recently efforts have been made to utilize similar reeds in an electronic piano. Two difficulties have been encountered here; one in the stresses imposed on the reeds, and another in the inherently different vibrational characteristics of reeds as contrasted to strings.

An impulsively actuated reed is practically instantaneously driven to a large excursion, and thereafter is allowed to vibrate in free, decadent fashion. The shock of the impulse actuation is quite substantial, and both this shock and the initially rather great excursion of the reed tend to break the reed. As a result, the useful life of an impulsively actuated reed is quite substantially less than that of the practically infinite life of a wind driven reed which is not subjected to shock loading, nor to great excursions.

Accordingly, it is an object of this invention to provide an improved reed for use in an electronic piano which will far outlast conventional reeds.

Yet another object of this invention is to provide a reed for use in an electronic piano, which reed has no well-defined breaking point.

As is well known, a vibrating string vibrates essentially with a fundamental and a plurality of harmonics. A reed, on the other hand, vibrates essentially with a fundamental and with a series of inharmonic partials. Thus, a reed piano inherently tends to sound somewhat different from a string piano.

In view of the foregoing, it is yet another object of this invention to provide a vibratory reed for an electronic piano which will produce a remarkably piano-like tone.

Other and further objects and advantages of the present invention will be apparent from the following description when taken in connection with the accompanying drawings wherein:

FIG. 1 is a cross sectional view through a piano action constructed in accordance with the principles of the present invention;

FIG. 2 is a fragmentary plan view of the reed frame;

FIG. 3 is a plan view of a reed on an enlarged scale constructed in accordance with the present invention;

FIG. 4 is a plan view of a prior art reed; and

FIG. 5 is a plan view of another prior art reed.

Referring now in greater particularity to the drawings, and first to FIGS. 1 and 2, there will be seen a reed frame 10 of generally rectangular configuration having a substantially rectangular opening 12 therein. Actually, the reed frame tapers somewhat in depth (front to back) from a maximum at the bass end to a minimum at the treble end, since the treble reeds inherently are of shorter length than are the bass reds. One long side of the frame 10 is provided with depending reinforcing rib means 14, and with an upstanding shelf 16. A plurality of reeds 18 is secured to the top of the shelf 16 by means of a respective plurality of cap screws or bolts 20 extending respectively

through the reeds and threaded into the raised portion or shelf 16 of the reed frame 10. The reeds are made of metal, conveniently steel, although other resilient metals can be used. Each reed at its free end is provided with a weight 22 for tuning, and for emphasizing the fundamental mode of vibration.

The opposite long side of the reed frame 10 has an insulating spacer 24 extending therealong, and a capacitive pickup 26 is secured thereto. The pickup and insulating spacer may be held in place by means such as bolts and washers 28 extending through the pickup and through the insulation and threaded into the reed frame. As will be appreciated, the bolts 28 are electrically insulated from the pickup, as by means of a conventional bushing. The pickup 26 conveniently is of metal, aluminum being a preferred example, and is of generally comb-like configuration comprising a plurality of slots 29 into which the free ends of the reeds 18 extend for vibration. Fingers 30 are defined between the slots 29, and these fingers extend between adjacent reeds. As is shown in FIG. 1, the top of each reed is substantially coplanar with the bottom of the pickup 26. Furthermore, the thickness of the pickup is such that a reed generally does not vibrate above the top of the pickup, while it does vibrate below the pickup through at least 180 degrees of each vibrating cycle.

A rail 32 extends parallel to the frame 10, and is secured thereto through the intermediary of a case (not shown), or by means of suitable brackets (not shown). The rail 32 is provided with a plurality of butt flanges 34 on which is pivotally mounted a like plurality of hammers 36, each having a felt head or impulsing member 38. A padded rest 40 extends beneath the hammers, as shown. Each hammer is provided near the butt thereof with an underlying recess 42, and the upper end of a jack 44 bears within each recess. The jacks are respectively actuated by more or less conventional piano actions (not shown).

Another rail 46 extends parallel to the long dimension of the frame 10 and is disposed close thereto. A plurality of damper release levers 48 is mounted along the rail 46, respectively by means of damper flanges 50. Each damper release lever is provided with a pad 51 of resilient material, such as felt, bearing against a respective reed 18 to damp or inhibit vibration thereof. At the opposite end of each damper lever 48, there is a connection indicated at 52 with a damper release rod 54 suitably connected to the piano action in a manner not shown, whereby each damper pad 51 is lifted from engagement with the corresponding reed 18 before engagement of the corresponding hammer head 38 therewith.

Reference now should be had to FIG. 3 for a detailed understanding of the reed forming the subject matter of this invention. Thus, the reed 18 is provided with a generally rectangular base 56 having an aperture 58 therethrough through which the respective bolt or cap screw 20 extends to clamp the base 56 against the raised portion or shelf 16 of the reed frame 10. The reed further has a tongue 60 extending from the base 56 to a free end 62, beneath which is positioned the weight 22. The tongue is provided with parallel edges throughout the major portion of its length. The remainder of the reed comprises a long tapered portion. Specifically, the tapered sides 64 extend from the line *a—a* at the limit of the base 56 forming an external shoulder therewith, to the line *b—b*. The reed sides or longitudinal edges 66 are parallel from this point to the extremity or free end 62.

No definite limits can be set as to the length of the tapered portion of the reed relative to the portion having parallel sides. It will be observed in the drawing that the taper comprises roughly 25 percent of the reed tongue, and this may be considered to be typical. The proportion is empirical and is not constant from one reed to another. However, it will be understood that the curved taper (the distance from line *a—a* to line *b—b*) would generally be on the order of 20–35 percent and would never be less than substantially 10 percent and would never be more than substantially 50 percent of the total length of the reed tongue. Typically, the hammer head strikes the reed tongue outwardly of the tapered area.

By extended simulated life tests, it has been found that a reed as shown in FIG. 3, when impulsively excited to oscillations at extreme amplitude (as by striking with the hammer head 38) eventually will break anywhere in the region bounded by the lines *a—a* and *b—b*.

A supposedly improved prior art reed is indicated at 74 in FIG. 5. This reed has a base 76 joined to a tongue 78 by straight tapered sides between the lines *a—a* and *b—b*. This reed also will break along the line *b—b*. In short, both of the reeds in FIGS. 4 and 5 are subject to fracture at a well-defined location, whereas the reed in FIG. 3, with the long curved taper has no well-defined area of fracture. Hence, by actual test, the reed of FIG. 3 lasts longer by a factor of about four to one than does the reed in FIG. 4 when submitted to impulse excitation.

Furthermore, in about the lowest twenty notes of a piano, the reed shaped as in FIG. 3 has been found to give a substantially better sound than that shaped as in FIG. 4. The reasons for this are not at the present time fully understood. However, it is thought that in the reed of FIG. 3, the fundamental mode of vibration tends to dominate somewhat more over the inharmonic partials than in the usual reed of FIG. 4 with the longer parallel sides.

It might be thought that a reed with straight tapering sides would be desirable as providing no definite fracture line. This would be the same as if the line *b—b* in FIG. 5 were moved all of the way out to the end of the reed, with a uniform straight taper from the line *a—a* to the line *b—b*. However, such a reed is highly undesirable. It provides a very low Q, and this leads to an extremely undesirable ringing time.

Operation of the combination shown in FIGS. 1 and 2 will be obvious to those skilled in the art. A more or less conventional piano key is depressed and acts through a more or less conventional action to raise the jack 44 thereby sending the hammer head 38 up into impulsive engagement with the reed 18. At the same time, the action has lowered the damper release rod 54 to move the damper pad 51 up out of engagement with the corresponding reed 18, to allow free vibration thereof. The action, as is usual, holds the damper in retracted position as long as the key is depressed.

An electrostatic field is established between the reeds 18 and the pickup 26 by establishing a direct current potential therebetween. Preferably, the reeds and the reed frame 10 are at ground potential, while the pickup is maintained at an elevated potential through a resistor from a suitable source of direct current potential. Upon vibration of one or more reeds, the capacity between the vibrating reed or reeds and the pickup 26 changes, thereby developing a complex alternating current potential across the resistor. The potential developed across the resistor is suitably amplified and transduced to provide an audible, piano-like sound.

Changes in structure relative to the specific example shown and described herein may well occur to those skilled in the art, and will be understood as forming a part of the invention insofar as they fall within the spirit and scope of the appended claims.

This invention is claimed as follows:

1. A vibratory reed for use as in a musical instrument comprising a base adapted to be secured to a mounting surface, and a flat tongue having lateral and longitudinal dimensions extending freely out from said base, said tongue having a curved inward taper extending out from said base merging into substantially parallel edges, said curved taper comprising a substantial portion of the total length of said tongue and having a length greater than the transverse dimension of said tongue.

2. A vibratory reed for use as in a musical instrument comprising a base adapted to be secured to a mounting surface, and a flat tongue having lateral and longitudinal dimensions extending freely out from said base, said tongue having a curved inward taper extending out from said base merging into substantially parallel edges, said curved taper comprising between substantially 10 and 50 percent of the total length of said tongue and having a length greater than the transverse dimension of said tongue.

3. A vibratory reed for use as in a musical instrument comprising a base adapted to be secured to a mounting surface, and a flat tongue having lateral and longitudinal dimensions extending freely out from said base, said tongue having a curved inward taper extending out from said base merging into substantially parallel edges, said curved taper comprising between substantially 20 and 35 percent of the total length of said tongue and having a length greater than the transverse dimension of said tongue.

4. A vibrating reed arrangement for use as in a musical instrument comprising a fixed mounting base, a reed including a base and a tongue having lateral and longitudinal dimensions extending freely out therefrom, means mounting said reed base on said mounting base, said reed tongue having a curved inward taper extending out from the reed base merging into substantially parallel edges of said tongue, said curved taper comprising a substantial portion of the total length of said tongue and having a length greater than the transverse dimension of said tongue, and a striker member adapted impulsively to engage said reed tongue to set said reed tongue in free, decadent vibration.

5. A vibrating reed arrangement for use as in a musical instrument comprising a fixed mounting base, a reed including a base and a tongue having lateral and longitudinal dimensions extending freely out therefrom, means mounting said reed base on said mounting base, said reed tongue having a curved inward taper extending out from the reed base merging into substantially parallel edges of said tongue, said curved taper comprising a substantial portion of the total length of said tongue and having a length greater than the transverse dimension of said tongue, and a striker member adapted impulsively to engage said reed tongue outwardly of said tapered portion to set said reed tongue in free, decadent vibration.

6. A vibratory reed as set forth in claim 3 wherein the curved taper is a non-circular arcuate curve.

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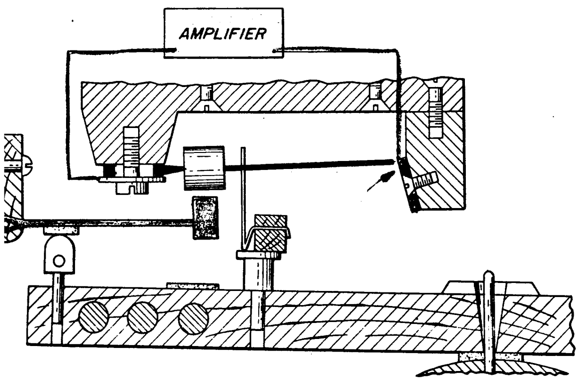

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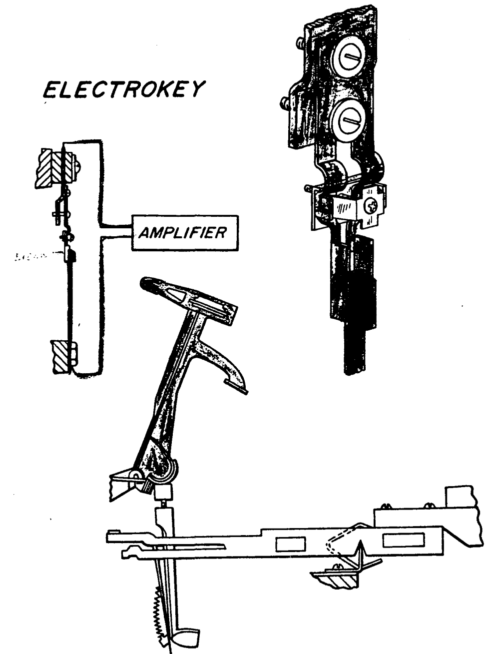
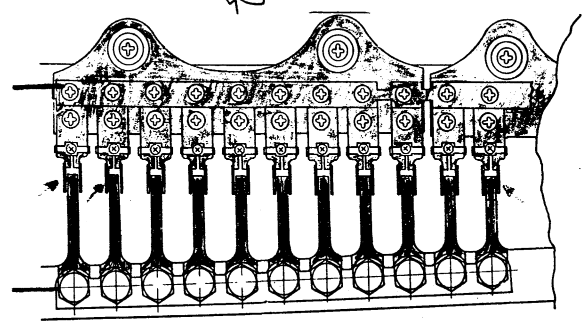
Claim 3

In an electronic piano, the combination comprising

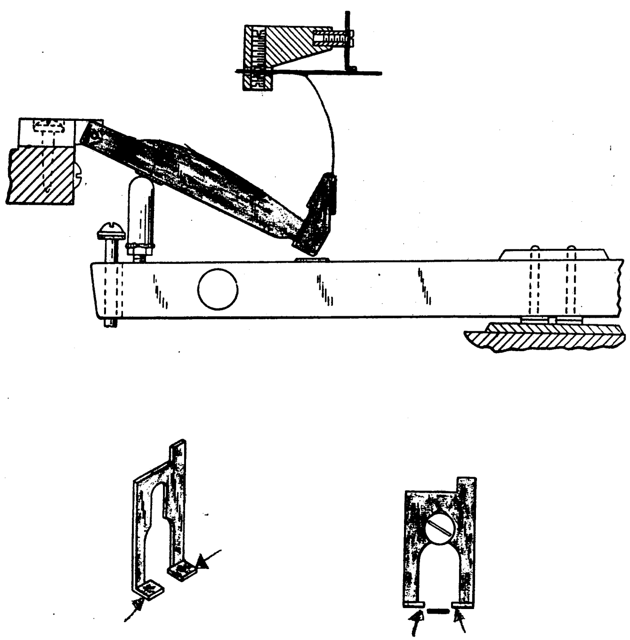
- a plurality of juxtaposed tuned reeds each of which cantilevers from a supported end thereof to a free end thereof,
- key controlled hammer means for impulsively exciting said respective reeds for vibration,
- a single pick-up element for electrostatically sensing vibrations of a multiplicity of said reeds,
- said pick-up element having a plurality of electrically conductive portions thereof disposed in proximate relation to the free ends of said respective reeds of said multiplicity to provide electrical capacitance between said pick-up element and each reed which is varied by impulse induced vibration of the reed relative to the pick-up element,
- means for applying a direct current potential between said pick-up element and all of said multiplicity of reeds to charge said reeds to a uniform voltage with respect to said pick-up element,
- and electronic tone signal means connected to said pick-up element to produce electronic tone signals corresponding to the changing cumulative capacitance between said pick-up element and said multiplicity of reeds coacting therewith.

ELECTROKEY





B. F. MIESSNER 2,942,512



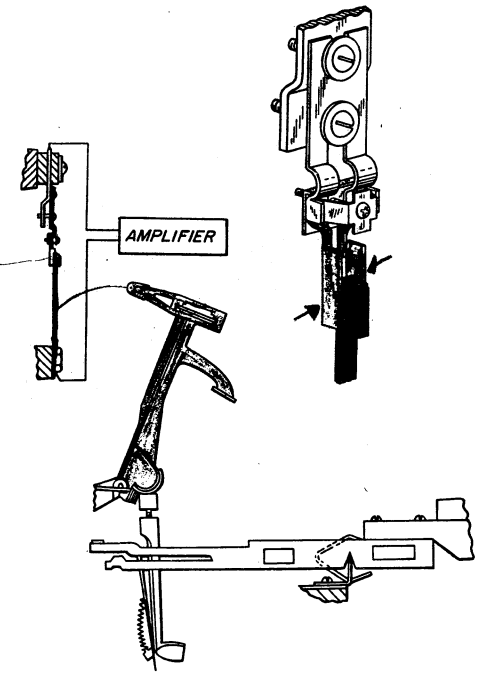
MIESSNER 2,942,512

Claim 1

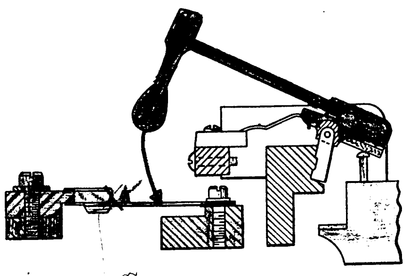
In combination in an electrical musical instrument,

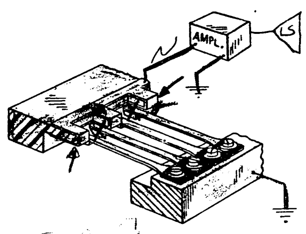
- a fixed-free reed,
- an impulse exciting means comprising a key acutated hammer adjacent
- the reed selectively engageable with the individual reed for setting it into decadent free vibration,
- and an electric translation pick-up adjacent the reed,
- said pickup having a tone producing portion located alongside and being vibratorily passed by a longitudinally intermediate edge portion of the reed
- and being of an effective thickness, in the direction of reed vibration,
- smaller than the high-amplitude stroke of said edge portion of the reed.

ELECTROKEY



C.W. ANDERSEN 2,949,053





Claim 1

ANDERSEN 2,949,053

An electronic musical instrument comprising

a common reed support,

a plurality of reeds with bases fixed on said common support

and with vibratile tongues projecting in the same direction therefrom in side-by-side substantially coplanar parallelism from said support,

a plurality of hammers respectively percussively engageable with the tongues of said reeds respectively to set said reed tongues in decadent free vibration

a plurality of manually engageable keys respectively operatively connected to said hammers for selectively moving said hammers into such percussive engagement with said reed tongues,

a pickup member of comb-like configuration

having a plurality of parallel teeth

and an intermediate plurality of slots each opening at one end,

means mounting said pickup member in opposition to said reeds substantially in a common plane therewith with the reeds projecting into the slots between the teeth,

the teeth on opposite sides of a reed extending substantially the same distance therealong,

there being at least one reed tongue in each slot,

and each reed being closely adjacent a pickup tooth along a longitudinal edge of said reed,

said pickup teeth terminating at free ends short of the reed bases,

the hammers respectively percussively engaging the reed tongues between the reed bases and the free ends of the adjacent pickup teeth,

said reeds and said pickup member comprising electrostatic tone generating means,

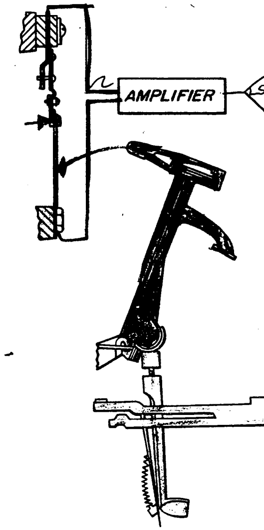
means establishing an electric potential between said reeds and said pickup member,

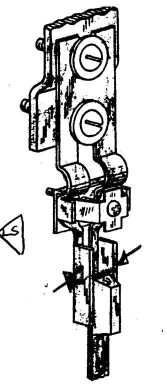
electric oscillations being generated in accordance with the change in capacity between said reeds and said pickup member resulting from free decadent vibration of said reeds relative to said pickup member,

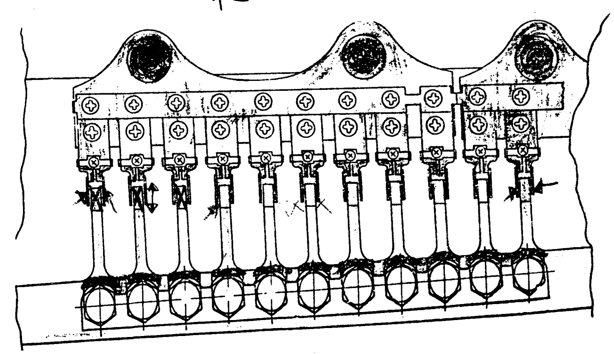
electronic amplifying means connected to said reeds and said pickup member for amplifying the oscillations generated by the decadent free vibration of said reed tongues,

and electro-acoustic translating means connected to said amplifying means for converting the amplified oscillations into audible tones.

ELECTROKEY







BODE 3,154,997

Claim 1

A vibratory reed for use as in a musical instrument comprising

a base adapted to be secured to a mounting surface,

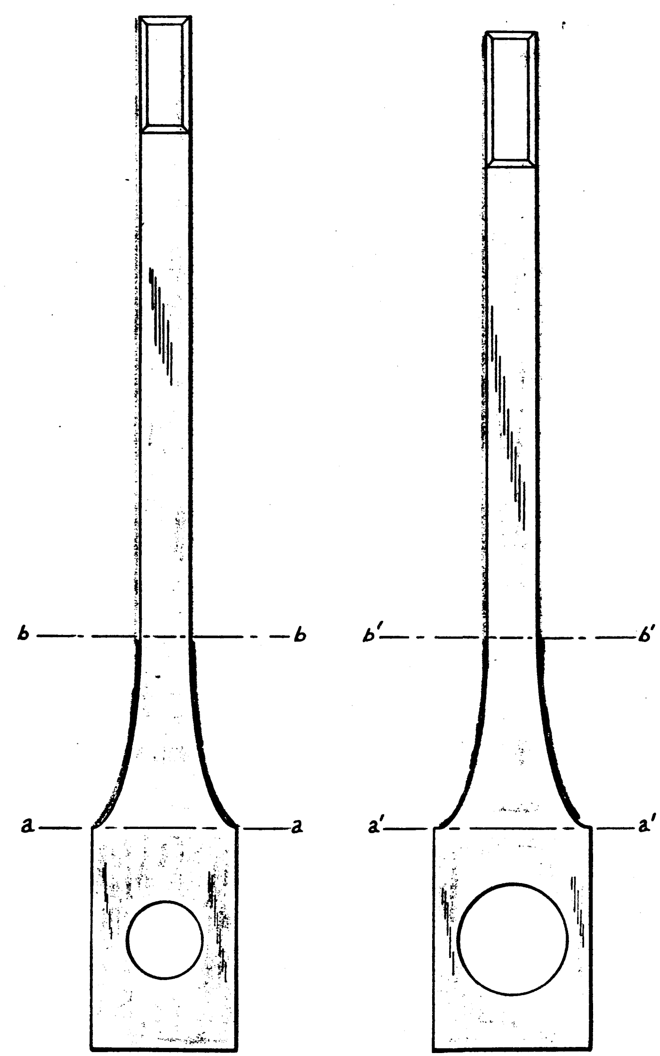
and a flat tongue having lateral and longitudinal dimensions extending freely out from said base,

said tongue having a curved inward taper extending out from said base

merging into substantially parallel edges,

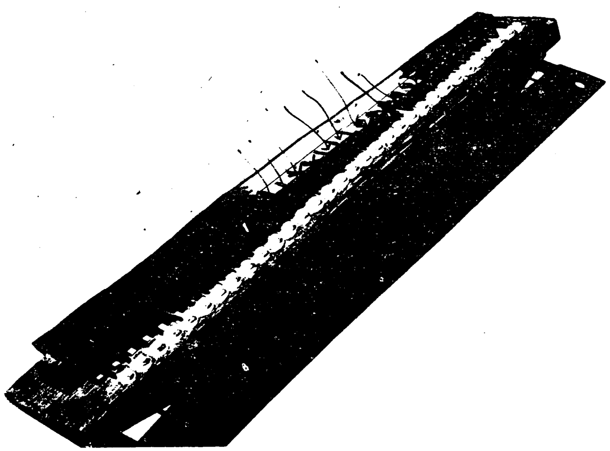
said curved taper comprising a substantial portion of the total length of said tongue and having a length greater than the transverse dimension of said tongue.

H.E.W. BODE 3,154,997 ELECTROKEY



APPENDIX I A-141 MIESSNER 2,942,512

Claim 1	Claim 2	Claim 6	Claim 9
In combination in an electrical musical instrument,	In combination in an electrical musical instrument,	In combination in an electrical musical instrument,	In combination in a musical instrument,
a fixed-free reed,	a fixed-free reed,	a mechanical system comprising a fixed-free reed	a fixed-free reed,
an impulse exciting means comprising a key actuated hammer adjacent the reed selectively engageable with the individual reed for setting it into decadent free vibration,	an impulse exciting means comprising a key actuated hammer adjacent the reed selectively engageable with the individual reed for setting it into decadent free vibration	and an impulse exciting means comprising a key actuated hammer adjacent the reed selectively engageable with the individual reed for setting it into decadent free vibration,	single impulse exciting means comprising a key actuated hammer selectively engageable with the individual reed for setting it into decadent free vibration,
and an electric translation pick-up adjacent the reed,	and an electric translation pick-up adjacent the reed,	an electric translation pick-up adjacent the reed,	
said pickup having a tone producing portion located alongside and being vibratorily passed by a longitudinally intermediate edge portion of the reed,	said pickup having a tone producing portion located alongside and being vibratorily passed by a longitudinally intermediate edge portion of the reed,	said pick-up having a tone producing portion located alongside and being vibratorily passed by a longitudinally intermediate edge portion of the reed	
and being of an effective thickness, in the direction of reed vibration, smaller than the high-amplitude stroke of said edge portion of the reed.	being of an effective thickness, in the direction of reed vibration, smaller than the high-amplitude stroke of said edge portion of the reed,	and being of an effective thickness, in the direction of reed vibration, smaller than the high-amplitude stroke of said edge portion of the reed,	
	and being offset in said direction from effective alignment with the rest position of the reed.		
		and means comprised in said mechanical system for at least substantially eliminating from a lower one of its normally present upper partials.	a mechanico-electrical system consisting of a portion of the reed and pick-up means associated with and influenced by said portion for translating electric oscillations from the reed vibrations,
			means comprised in said mechanico-electrical system for at least substantially eliminating from said oscillation an inharmonic lower one of the upper partials at which the reed tends to vibrate,
			and means also comprised in said mechanico-electrical system for introducing into the oscillations translated from the fundamental reed vibrations a series of upper partials harmonically related thereto.



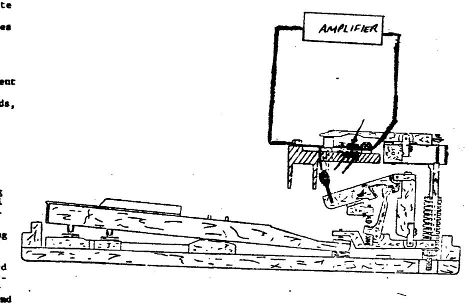
APPENDIX J

MIESSNER 3,038,363

Claim 3	Claim 4	Claim 5	Claim 6	Claim 8	Claim 9
In an electronic piano, the combination comprising	In an electronic piano, the combination comprising	An electronic piano comprising	In an electronic piano, the combination comprising	In an electronic piano, the combination comprising	In an electronic piano the combination comprising
a plurality of juxtaposed tuned reeds each of which cantilevers from a supported end thereof to a free end thereof,	a multiplicity of tuned reeds mounted alongside each other in a manner such that each reed cantilevers from a supported end thereof to a free end thereof,	a plurality of electrically conductive reeds disposed in side by side coplanar relation to each other and being of progressively varying length, each of said reeds being fixedly mounted at one end and free at the other end,	a plurality of jextaposed tuned reeds each of which cantilevers from a supported end thereof to a free end thereof,	a multiplicity of juxtaposed tuned reeds each of which cantilevers from a supported end thereof to a free end thereof,	a multiplicity of tuned electrically conductive reeds mounted alongside each other in a manner such that each reed cantilevers from a supported end thereof to a free end thereof,
key controlled hammer means for impulsively exciting said respective reeds for vibration,	key controlled striking means coacting with each of said respective reeds to impulsively excite the reed to vibrate freely in a manner which swings the free end of the reed to opposite sides of a rest position thereof,	a plurality of hammers one for each reed selectively operable for impulsively exciting the reeds into decadent free vibration, keys for operating the hammers,	key controlled striking means for impulsively exciting said respective reeds for vibration,	key controlled striking means for impulsively exciting said respective reeds for vibration,	key controlled striking means coacting with each of said respective reeds to impulsively excite the reed to vibrate freely in a manner which swings the free end of the reed to opposite sides of a rest position thereof,
a single pick-up element for electrostatically sensing vibrations of a multiplicity of said reeds,	a single electrostatic pick-up conductor having portions thereof disposed in adjacent relation to the free ends of said respective reeds,	an electrostatic pick-up comprising a plurality of pick-up portions disposed in side by side coplanar disposition to each other and in a proximate electrically capacitive relation to the projecting portions of said respective reeds,	a pick-up for electrostatically sensing vibrations of said reeds,	an integral electrically conductive pick-up plate extending across the free ends of said reeds for electrostatically sensing vibrations of the reeds;	an electrostatic pick-up including conductor portions disposed in adjacent electrically capacitive relation to the free ends of said respective reeds,
said pick-up element having a plurality of electrically conductive portions thereof disposed in proximate relation to the freeends of said respective reeds of said multiplicity to provide electrical capacitance between said pick-up element and each reed which is varied by impulse induced vibration of the reed relative to the pick-up element,	each of said pick-up conductor portions registering with the normal position of the coacting reed and being shaped and positioned to extend away from a position of alignment with the normal position of the reed in only one of the two directions in which the reed swings away from its normal position,	said respective pick-up portions being substantially flush with the normal positions of the respective reeds and extending along the swing of the reeds in only one direction of reed movement away from the normal positions of the reeds the extent of each pick-up portion in said one direction covering substantially the full excursion of the coacting reed in said one direction,	said pick-up including a plurality of electrically conductive portions thereof disposed alongside the vibratory paths of said respective reeds in proximate relation to the normal positions of the respective reeds, to provide electrical capacitance between said pick-up element and each reed which is varied by impulse induced vibration of the reed relative to the pick-up element,	said pick-up plate having a plurality of electrically conductive portions thereof disposed in proximate, electrically capacitive relation to the normal positions of said respective reeds to provide electrical capacitance between said pick-up plate and each reed which is varied by impulse induced vibrations of the reeds relative to the pick-up plate;	each of said pick-up conductor portions being substantially flush with one longitudinal side of the coacting reed when the latter is in its normal position, each pick-up conductor portion being shaped and positioned to extend along the swing of the coacting reed in only one direction of reed movement from the normal position of the reed, the orientation of each reed in its coacting pick-up conductor portion being such that the electrically capacitive spacing between the reed and the conductor portion progressively increases as the reed swings away from its normal position in said one direction of reed movement,
means for applying a direct current potential between said pick-up element and all of said multiplicity of reeds to charge said reeds to a uniform voltage with respect to said pick-up element,	means for charging all of said multiplicity of reeds to a uniform potential with respect to said pick-up conductor,	means for charging said pick-up to a substantial electrical potential relative to the coacting reeds,	means for applying an electric potential between said pick-up and said reeds to charge said reeds to a substantial voltage with respect to said electrically conductive portions of said pick-up,	means for applying a substantial electrical voltage between said pick-up plate and said reeds,	means for charging said pick-up to a substantial electrical potential relative to said reeds,
and electronic tone signal means connected to said pick-up element to produce electronic tone signals corresponding to the changing cumulative capacitance between said pick-up element and said multiplicity of reeds coacting therewith.	and electronic tone signal means coacting with said pick-up conductor to produce tone signals controlled by the cumulative capacitance between said conductor and said multiplicity of reeds coacting therewith.	and electronic tone signal means coacting with said pick-up and said reeds to produce tone signals controlled by the electrical capacitance between said pick-up and said reeds.	and electronic tone signal means coacting with said pick-up and said reeds to produce electronic tone signals controlled by the instantaneous capacitance between said pick-up and said reeds coacting therewith.	and electronic tone signals means coacting with said pick-up plate and said reeds to produce tone signals controlled by the cumulative capacitance between said pick-up plate and said reeds.	and electronic tone signal means coacting with said pick-up and said reeds to produce tone signals controlled by the capacitance between said pick-up and said reeds.

Claim 7 (Dep.)

An electronic piano as defined in claim 6 in which each of said electrically conductive portions of said pick-up element traverses the free end of the coacting reed and has a width with respect to the reed which substantially exceeds the corresponding transverse width of the coacting reed.



Claim 1

An electronic musical instrument comprising a common reed support,

a plurality of reeds with bases fixed on said common support and with vibratile tongues projecting in the same direction therefrom in side-by-side substantially coplanar parallelism from said support,

a plurality of hammers respectively percussively engageable with the tongues of said reeds respectively to set said reed tongues in decadent free vibration,

a plurality of manually engageable keys respectively operatively connected to said hammers for selectively moving said hammers into such percussive engagement with said reed tongues,

a pickup member of comb-like configuration having a plurality of parallel teeth and an intermediate plurality of slots each opening at one end,

means mounting said pickup member in opposition to said reeds substantially in a common plane therewith with the reeds projecting into the slots between the teeth,

the teeth on opposite sides of a reed extending substantially the same distance therealong,

there being at least one reed tongue in each slot, and each reed being closely adjacent a pickup tooth along a longitudinal edge of said reed, X

said pickup teeth terminating at free ends short of the reed bases, X

the hammers respectively percussively engaging the reed tongues between the reed bases and the free ends of the adjacent pickup teeth,

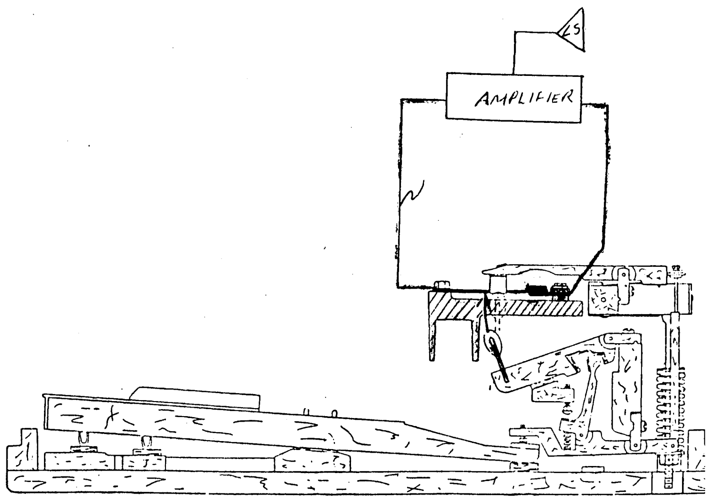
said reeds and said pickup member comprising electrostatic tone generating means, C

means establishing an electric potential between said reeds and said pickup member,

electric oscillations being generated in accordance with the change in capacity between said reeds and said pickup member resulting from free decadent vibration of said reeds relative to said pickup member,

electronic amplifying means connected to said reeds and said pickup member for amplifying the oscillations generated by the decadent free vibration of said reed tongues,

and electro-acoustic translating means connected to said amplifying means for converting the amplified oscillations into audible tones. LS



Claim 2

An electronic musical instrument as set forth in claim 1 wherein the plane of said reeds is displaced from the median plane of the pickup teeth, and wherein said reeds vibrate asymmetrically about such median plane.

Claim 3

An electronic musical instrument as set forth in claim 1 and further including common means electrically grounding said plurality of reeds.

Claim 4

An electronic musical instrument as set forth in claim 3 wherein the common grounding means comprises the common reed support, said support being electrically conductive, and said reeds being mounted directly on said support in physical and electrical engagement therewith.

APPENDIX L

DT-45

EX 3

PERTINENT CONTENT ANALYSIS OF PRIOR ART PATENTS (DT-~~7~~ 3)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
REED		x			x		x		x	o	x	x	o		x	x	x	x	o	x	x	x	x	x	x	x	x	x		x	x	
WEIGHTED REED			x								x				x						x	x			x	x	x					
REED SHAPING FOR DURABILITY														x																	x	
HAMMER EXCITATION	x									x		x	x			x			x	x	x				x	x	x			x		
SELECTED STRIKE POINT												x	x			x																
MAGNETIC PICKUP					x				x			x			x	x		x		x	x	x		x	x							
M 363 CAPACITATIVE PICKUP			x		x		x	x		x					x		x	x	x			x	x		x	x	x	x	x	x		
INTEGRAL PICKUP							o	x									x	x				x						x	x			
EDGE PICKUP																	x						x	x			x			x		
M 363 ASYMMETRICAL PICKUP			x		x		x	x	x	x		x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
NODAL PICKUP							x	x				x				x									x	x						
M 363 SHAPED PICKUP			x				x		(x)						x			x			o	x	x						(x)			
AMPLIFIER AND LOUDSPEAKER					x		x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		

ADDITIONAL NOTES: Jacobs (8) gives good discussion of charge system.
Brown (19) asserts that reeds may be used as well as forks.
Langloys (25) states that symmetrical (end) pickup provides second harmonic of reed fundamental.
The symbol O indicates that some interpretation or explanation is necessary to establish the indicated categorization.

APPENDIX M A-149

RECEIVED

'74 MAY 20 PM 12:55

Office of the SECRETARY
U.S. TARIFF COMMISSION

Before the
UNITED STATES TARIFF COMMISSION
Washington, D. C.

In the Matter of ELECTRONIC PIANOS	No. 337-31

AFFIDAVIT

OF

TOMMY MOORE

I, Tommy Moore, being duly sworn, depose and state as follows:

1. I am President of Electrokey, Inc. which is the exclusive importer of Electrokey and Maestro Pianos.

2. I am familiar with the stipulation of Mr. Robert M. Wolters, Attorney for Complainant, made at the Deposition of Toshiyuki Kobayashi. The stipulation appears on page 4 of the Kobayashi Deposition, which is Item No. 19 of Respondents' Patent Exhibit 16 and reads as follows:

> "...it's the position of Wurlitzer that only the reeds with the long taper, that is, reeds Nos. 1-17, infringe the Bode Patent. That's in the Deposition Exhibit 11, the collection of reeds.
>
> The remaining reeds, 18-61, have straight sides and a single radius

between the reed base and the reed tongue and Wurlitzer does not charge that those reeds infringe the Bode Patent."

3. I am also familiar with Point I. J. 1. of Respondents' Brief before the United States Tariff Commission, filed April 20, 1973, which reeds as follows:

> "1. The issues presented by this proceeding regarding Bode Patent 3,154,997 are now moot.
>
> As pointed out at the full hearing (R pages 311, 312) and further confirmed in a letter dated February 13, 1973 to Mr. Kenneth Mason, Respondents' electronic pianos no longer utilize reeds of the type allegedly covered by Bode Patent 3,154,997 (long curved inward taper) but have at least since August 1972 utilized an alternate reed which is like the ones admittedly in public domain (having a single radius fillet as illustrated as prior art in Fig. 4 of 3,154,997)."

4. There has been no change since February 13, 1973 in the type reeds used by the electronic pianos which have been imported by Electrokey, Inc.. In other words, all electronic pianos imported by Electrokey, Inc. since February 13, 1973 continue to utilize the alternate reed mentioned in Statement No. 3, above.

5. Further, Deponent saith not.

Tommy Moore
President
ELECTROKEY, INC.

STATE OF TEXAS ⁑
⁑ ss
COUNTY OF TARRANT ⁑

Sworn to and subscribed before me this 27th

day of April, 1974

SEAL

[signature]

Notary Public in and for said
County and State

My Commission Expires 6-1-75

APPENDIX N

DECISION OF THE U.S. DISTRICT COURT FOR THE NORTHERN DISTRICT OF TEXAS (C.A. No. 3-4803C)

UNITED STATES DISTRICT COURT
NORTHERN DISTRICT OF TEXAS
DALLAS 75202

W. M. TAYLOR, JR.
CHIEF JUDGE

August 23, 1974

Mr. Earl Levy
United States Tariff Commission
Office of the General Counsel
8th & E Streets, N.W.
Washington, D. C. 20383

Re: CA 3-4803-C
The Wurlitzer Company vs.
Electrokey, Inc., et al

Dear Mr. Levy:

Please find enclosed copy of opinion filed today in the above styled and numbered cause.

Yours very truly,

W. M. Taylor, Jr.

W. M. Taylor, Jr.

Enclosure

IN THE UNITED STATES DISTRICT COURT
FOR THE NORTHERN DISTRICT OF TEXAS
DALLAS DIVISION

THE WURLITZER COMPANY	)	
	)	
vs.	)	CA 3-4803-C
	)	
ELECTROKEY, INC.,	)	
RHYTHM BAND, INC.,	)	
TOMMY MOORE, and	)	
NIPPON COLUMBIA CO., LTD.	)	

OPINION

This is a patent infringement case brought under 28 U.S.C. § 1338 and 35 U.S.C. § 281.

Plaintiff is a Delaware corporation with its principal place of business in Illinois. Defendants Electrokey and Rhythm Band have their principal place of business in the Northern District of Texas. Defendant Moore is a resident of the Northern District of Texas. Defendant Chicago Musical Instrument is a resident of Illinois and was a party to a suit filed there by Plaintiff that was subsequently dismissed upon Chicago Musical Instrument's addition into this suit. Defendant Nippon Columbia is a Japanese corporation which was served through its agent, Defendant Moore.

The broad question here is whether the electronic piano manufactured and distributed by the Defendants infringes four patents owned by Plaintiff.

The first patent is B. F. Miessner No. 3,038,363 originally filed June 22, 1952, and patented June 12, 1962. Plaintiff contends that Defendants' device infringes claims 3, 4, 5, 6, 7, 8 and 9 of that patent.[1/]

The second patent is B. F. Miessner No. 2,942,512, filed August 14, 1957, and patented June 28, 1960. Claims 1, 2, 6 and 9 are claimed to be infringed.

Plaintiff's third patent in dispute is C. W. Andersen No. 2,949,053, filed June 1, 1954, and patented August 16, 1960. Claims 1-5 are in dispute.

These first three patents involve the construction of tone generators for electronic pianos. Defendants do not contest their validity but claim that when they are construed in the light of the prior art, they do not read on Defendants' piano. 2/

The fourth patent in suit is H. E. W. Bode No. 3,154,997, filed October 3, 1962, and patented November 3, 1964. All six claims are said to be infringed in Plaintiff's view and invalid in Defendants' view. This patent pertains to musical instrument reeds with an inward curved taper extending from the base.

I.

First, a word on the devices in dispute. Any piano, acoustic or electronic, has three essential parts. First is the action. That is the portion consisting of the keys, the hammers, the dampers and the interconnecting bits and pieces. Next is the tone generator. In an acoustic piano, it is comprised of the strings and their tightening mechanisms. In an electronic piano, at least of the type in dispute, it is comprised of a set of flat metal reeds fixed on one end and with the other end free to vibrate and a lead weight attached to the free end. It also has some means with which to sense the vibrations of the reed. The third part is an amplification device. It is the sounding board and case of an acoustic piano. Our electronic pianos have electronic amplifiers and loudspeakers connected to the sensory pick-ups instead.

There are two or three principal advantages to an electronic piano. In the first place, it has a tremendous weight saving advantage. The sound board in an acoustic piano must be extraordinarily strong as it must withstand tensions of up to 18 tons, as in the case of large grands. The weights of acoustic pianos therefore go as high as 1,500 pounds. This is in contrast to some models of Plaintiff's manufacture that have weights as low as 60 pounds.

Another big advantage is the ability of an electronic piano to stay in tune. String pianos must be constantly retuned in order to be musically correct and pleasing to the ear. The reeds in an electronic piano do not require frequent retuning. This is a significant saving in both time and bother.

A third major advantage of an electronic piano is its ability to be used with closed circuit devices such as headphones and teaching consoles. The pupils can then be given group instruction or separate instruction at the same session at the discretion of the teacher. Whether they hear only themselves or the whole group or only the teacher can be controlled by the teacher. Headphones also allow the pupil to practice without disturbing others.

Other advantages are portability, low incidence of reed failure and possibly lower purchase price.

II.

Defendant Nippon Columbia manufactures the purportedly infringing pianos in Japan and exports them to our country. Electrokey and Rhythm Band are the importers of them. Rhythm Band sells Nippon Columbia's pianos under the name "Electrokey" directly to schools for educational purposes. Electrokey sells them to Chicago Musical Instrument under the name "Maestro". Chicago Musical Instrument then wholesales them to local music dealers for retail sale to mainly the educational market. The parties agree that the two brands of Nippon Columbia built pianos have no differences material to this case. Also no questions of jurisdiction and venue have been raised. The Court finds jurisdiction is proper in this District after an independent evaluation.

III.

The first patent shall be referred to as the Miessner '363 patent.[3/] Defendants say that their pianos do not infringe this patent because their tone generators do not contain "a single pick-up element for electrostatically sensing vibrations of a multiplicity of said reeds", an element of each of the claims of this patent that are in dispute. This position is untenable.

Defendants' pickup is composed of many small parts which are screwed together and to a large stable plate. Their contention is, in effect, that in order for their structure to infringe this patent, it would have to be made of one solid piece. This is a misreading of the disclosure. The full pertinent language of the claims is "a single pickup element for electrostatically sensing vibrations of a multiplicity of said reeds, said pick-up element having a plurality of electrically conductive portions thereof ..." This language discloses two things when taken in conjunction with the drawings and description contained in the patent. This is not to say that the drawings and description must be looked at in order to make sense of the claims, but that they do show that Defendants' reading of the claims is incorrect.

The first thing disclosed by this language is that it is desirable to have a solid base for various reasons and second, that it may have screws, arms, etc. attached to it which are the parts in close proximity to the reeds and act as the sensing surfaces. This is the apt reading of this language of the claims and a description of Defendants' structure.

Defendants' view only takes into account the mechanical aspects of this disclosure. The mechanical aspect of the solid base is the more important part of the disclosure as to the base. But the whole pickup assembly is integrated into one electrical circuit which is the important aspect of the whole assembly. This integration produces the cumulative capacitance disclosed in another part of the claims as part of the invention.

Each of the claims beyond No. 3 contains at least one new element. Defendants have put strained interpretations on such terms as coplanar in order to be able to contend that these new phases do not apply to their structure. The Court refuses to put such attenuated interpretations on these words and phrases. A view of the pianos in question, the models, booklets, technical manuals and testimony entered into evidence show that when the new phrases of the claims are given a reasonable and rational interpretation, each of the elements as claimed in claims 3-9 of the Miessner '363 patents are present in Defendants' structure in a form contemplated by the claims.

IV.

The second patent is another Miessner patent which will be referred to as the '512 patent. Defendants say that their piano does not infringe this patent when it is construed in the light of prior art.

Defendants have made much of the claims saying musical instrument and not piano. But the patent is clearly entitled "Electronic Piano" and the description sets out the principal object of the invention to be the production of pianistic tones from an electronic musical instrument. There can be no mistake that the device disclosed pertains to an electronic piano.

Defendants cite a Zuck patent, No. 2,542,611 for disclosing a pickup that is alongside an edge portion of the reeds. This citation, though, is an organ patent and of no relevance to the construction of an electronic piano. Electronic organ reeds are vibrated by the passage of a volume of air over them. Therefore, their vibrational characteristics are far different from those of an electronic piano. A wind driven reed vibrates symmetrically and produces a constant tone. A hammered reed has a much more complex vibration with a large initial tone that rapidly decays. The characteristics are so different that for these purposes the disclosures of the Zuck patent are of little value to an electronic piano constructor. Therefore it is not relevant prior art in this proceeding.

Defendant also cites some testimony from Mr. C. W. Andersen who was Plaintiff's Manager of Corporate Engineering for Electronic Pianos. His offhand testimony given at his deposition some years after the patent was granted was to the effect that it was obvious to surround the end of a reed with a pick-up in order to achieve a greater volume. This is undoubtedly true. But Miessner's '512 disclosure is much more particularized and calculated to achieve more effects than just a greater volume.

The disclosure of ". . . an electric translation pick-up adjacent the reed, said pick-up having a tone producing portion located alongside and being vibratorily passed by a longitudinally intermediate edge portion of the reed. . ." is a way of minimizing what is called dynamic shortening. As a reed is struck by a hammer, the portion struck travels in the direction of the hammer strike faster than the rest of the reed and as a result has the effect of pulling the end of the reed away from the pick-up. This pulling away from the pick-up results in a large amplitude change that continues in time past the initial striking of the reed where in an acoustic piano, the amplitude is rapidly decreasing. A pick-up such as disclosed in Miessner '512 acts in relationship to a portion of the reed which is not dynamically shortened. This minimizes the effects of the shortening in relation to the total effect of the reed on the pick-up. 4/

In claim six of the Miessner '512 patent, Defendants have attacked the portion ". . . means comprised in said mechanical system for at least substantially eliminating from the free vibration of the reed a lower one of its normally present upper partials. . ." Mr. Conner, Defendants' technical expert said that this may be inconsequential from a musical standpoint. This statement alone is not of much weight, particularly in light of Plaintiff's thorough explanation of the interaction of the various elements of the claims.

The Court finds that Defendants' structure when the Miessner '512 patent is properly construed does infringe upon each of the contested claims.

V.

Defendants do not contest the validity of the third patent in suit which will be referred to as the Andersen '053 patent. They again allege that their structure does not infringe the claims in dispute. The Court agrees.

Mr. Andersen's patent is concerned with producing a specific structure that is economically feasible to produce in the United States. The disclosure of this patent adds one element in substance over the two previous Miessner patents, the '363 and the '512, that have been discussed. This is a solid comb-like pick-up structure.

The United States is a capital intensive country. An inventor in this setting will be trying to come up with a structure that can be built in simple operations by machinery whenever possible. This is the substance of Mr. Andersen's invention. He contemplated a pick-up structure made of a solid piece of plastic, coated with a metal in order to have an electrode. Contrary to the disclosure of the Miessner '363 patent, his concern was not with the electrical properties of his device, particularly as they had been disclosed in the Miessner patents. He was concerned with the mechanical structure and its ease of construction in a capital intensive economy.

Nippon Columbia's designers were trying to come up with a structure economically producible in Japan. As pointed out by the Japanese witnesses of the Defendants, Plaintiff's structure would not be economically producible in Japan. Japan is labor intensive and not capital intensive. It is cheaper for Japanese industry to have many workers assembling small parts than it is to have one or two large machines stamp out a large plastic part and coat it with metal. Defendants' pick-up structure is comprised of many small parts that are assembled and adjusted by hand and not a monolithic structure.

The doctrine of equivalents does not apply in this instance. It would apply as to the two Miessner patents in suit, if, it were necessary to invoke it. Those patents are far broader than the Andersen '053 patent as they are basic to the electronic piano division of the electronic musical instrument field. But the Andersen '053 patent must be substantially construed to the structure described and depicted in the patent to keep the claims from running afoul of the Miessner patents. The range of equivalents available to Plaintiff in any event would not include the structure produced and sold by the Defendants. The Court finds no infringement of the Andersen '053 patent.

VI.

Defendants do attack the validity of the fourth patent in issue, the Bode '997 patent. The Court agrees that this patent is invalid.

There is little difference between the Bode '997 patent and a Radtke et al patent No. 2,309,714. Bode discloses a longer taper of fillets leading out from the base of musical instrument reeds than Plaintiff claims is disclosed by Radtke. Also Plaintiff claims a non-circular arcuate curve in the fillets.

Defendants also attack the Bode '997 patent for not meeting the requirements of 35 U.S.C. § 112 as to requisite specificity in the disclosures of the claims. This is the key to the answer to our problem.

Defendants have shown that as early as April, 1934, methods were known how to minimize stress in fillets. An article published in Project Engineering of that date (p.133) gives proper formulas with which to compute stress in fillets. This is what is left out of the Bode '997 claims as being empirical. This shows the Bode '997 disclosure to be less sophisticated than the knowledge that had been published 32 years before the patent application was filed.

Mr. Bode's claims were allowed as an improvement over the Radtke patent teachings. The only differences being the increase in the curve of the fillets and an arcuate curve.

This presents the question of whether the Bode disclosure is of a patentable type? Clearly, no. The Product Engineering publication demonstrated the empirical mathematical method used in finding the ideal curve of fillets in general six years before the Radtke patent was applied for. Mr. Bode's discovery is shown by this publication to be of a type not patentable for being the empirical procedure used to maximize the benefits of the Radtke teachings. Radtke is not limited to any certain curve in the fillets. By saying that the curve of the fillets should be longer but not too long and non-circular, one is really saying in far less sophisticated terminology, that one should use the formulas disclosed in the 1934 publication to determine just what curve to use to insure a long life for the reeds. In sum, Mr. Bode stated nothing new. The Court concludes that the Bode '997 patent is invalid.

VII.

Having found infringement of the Miessner '363 and '512 patents, the question of relief is raised. Plaintiff has prayed for an injunction against further infringement, an accounting for general compensatory damages, that such damages be trebled, punitive and exemplary damages, assessment of costs against Defendants and reasonable attorneys' fees.

Clearly, Plaintiff is entitled to an injunction restraining infringement of the two Miessner patents and the accounting for general compensation purposes. Costs will be taxed against the Defendants by the Clerk upon the entry of a judgment that disposes of all claims, interests and parties.

The extraordinary remedies of treble, punitive and exemplary damages and attorneys' fees are more difficult matters.

35 U.S.C. § 285 allows attorneys' fees in only exceptional cases. The Court is of the opinion that this is not an exceptional case in that Defendants have not been vexatious and in view of the varied findings and conclusions of the Court as to infringement and invalidity. No attorneys' fees are therefore awarded.

Plaintiff's prayer for treble, punitive and exemplary damages appears to have a redundancy in it. The latter two types of damages are a part of the first. The actual question of increasing damages up to three times the amount found should not and will not be addressed until after the accounting is made. 5/ But the predicate for increased damages is a proper inquiry at this time.

The standard for laying a predicate is knowing, willful, intentional or deliberate infringement as it may be variously stated. 6/

Defendant Nippon Columbia engaged in negotiations with Plaintiff as to the trade secret knowledge of Plaintiff and Plaintiff's patents in the electronic piano field in 1963 and 1964. This exchange of correspondence was quite extensive. In one letter, dated February 29, 1964, (Plaintiff's Exhibit 15-Y), Mr. Seya, President of Nippon Columbia, stated that he was familiar with all of Plaintiff's patents registered in the United States. Nippon Columbia continually sought to get information as to pending patent applications before any agreement was reached as to licensing.

The developer of Defendants' tone generator, Mr. Takamatsu, testified that Nippon Columbia purchased one of Plaintiff's pianos in February, 1963. He also said that he was familiar with the results of Nippon Columbia's investigation of Plaintiff's electronic piano when he designed the structure that is claimed to be infringing. Nippon Columbia had sold a string electronic piano and a reed electronic piano in turn without as much success as desired when it redesigned the reed piano in the period from March 1965 to February 1966. Mr. Takamatsu testified that he referred to the Wurlitzer piano in general but not to any particular feature while redesigning the tone generator of Defendants' piano. He testified further that he made a modification with the intent of avoiding an infringement of the Andersen '052 patent.

Mr. Takamatsu's redesign came after the licensing negotiations, the purchase of one of Plaintiff's pianos and the issuance of the four patents in suit.

Mr. Andersen testified that the electronic pianos of Plaintiff and Defendants were so much alike that the employees in Wurlitzer's laboratory were able to plug the pick-up of one of their pianos into one of Defendants' pianos and play the two together. A simple visual comparison of the sets of reeds from the two pianos shows them to have virtually no differences other than the size of the mounting hold. The main difference between the two pianos appears to be the difference discussed in relation to the Andersen '052 patent above.

The evidence clearly shows that Nippon Columbia knew of the Wurlitzer patents in question and designed their structure with Plaintiff's structure in mind. Its infringement can be termed nothing other than willful and deliberate. A predicate has been laid for increased damages which will be considered after the accounting by Defendants. Also the question of just whom increased damages may be awarded against in our factual situation will be inquired into at that time. The parties are requested to submit briefs on the liabilities of the respective Defendants if they believe them necessary in light of the indemnification agreement running in favor of the American Defendants.

W. M. Taylor

UNITED STATES DISTRICT JUDGE

Aug 23, 1974

DATE

FOOTNOTES

1/ The claims of the four patents in dispute are set out in Appendix "A" to this opinion.

For the Supreme Court's view of the law of patent cases since the last major change in the patent statutes see the following cases which the Court has used for its principal guidance:

Graham, et al, v. John Deere Co. of Kansas City, et al, 383 U.S. 1, 86 S.Ct. 684, 15 L.Ed.2d 545 (1966).

United States v. Adams, et al, 383 U.S. 39, 86 S.Ct. 708, 15 L.Ed.2d 572 (1966).

Anderson's Black Rock, Inc. v. Salvage Co., Inc., 396 U.S. 57, 90 S.Ct. 305, 24 L.Ed.2d 258 (1969).

2/ Defendants have made many contentions, but at final argument they narrowed their contentions to those discussed here.

They also stated their contentions in the converse. They contend that if the first three patents are construed broad enough to include their structure, they are invalid as they would also include the prior art. This opinion will speak in terms of the first way of stating Defendants' contentions but the second has not been ignored.

3/ This notation using the three last digits of the patent number will be used throughout this opinion.

Also, the long and varied histories of these patents in the patent office will not be discussed in view of the findings and conclusions of the Court made herein.

4/ Mr. Conner, Defendants' technical expert of fine academic qualifications, based his opinion as to this patent on experiments conducted on an apparatus entered into evidence as Defendants' Trial Exhibit 11. The reed used in this apparatus is quite a crude one. It consists of a flat piece of steel about six inches long. Though it might be excellent for theoretical experiments, Mr. Conner never correlated it or his tests to any of the mechanisms put before the Court in the disclosures of the patents or any workable musical structures. Mr. Conner deflected his reed in some undisclosed manner but not by striking it with a hammer as in the Miessner '512 patent. He said that he was not concerned about the differences in methods of excitation of the reed. That method is a major factor in an electronic piano according to the rest of the evidence presented.

5/ Anchor Hocking Glass Corp. v. White Cap. Co., 47 F.Supp. 451 (D.C., D.Del. 1942); McCulloch Motors Corp. v. Oregon Saw Chain Corp., 245 F.Supp. 851 (D.C., S.D. Calif. 1965).

6/ See American Safety Table Co. v. Schreiber, 415 F.2d 373 (2d Cir., 1969), cert. den., 396 U.S. 1038, 90 S.Ct. 683, 24 L.Ed.2d 682, for example.

3. In an electronic piano, the combination comprising a plurality of juxtaposed tuned reeds each of which cantilevers from a supported end thereof to a free end thereof, key controlled hammer means for impulsively exciting said respective reeds for vibration, a single pick-up element for electrostatically sensing vibrations of a multiplicity of said reeds, said pick-up element having a plurality of electrically conductive portions thereof disposed in proximate relation to the free ends of said respective reeds of said multiplicity to provide electrical capacitance between said pick-up element and each reed which is varied by impulse induced vibration of the reed relative to the pick-up element means, for applying a direct current potential between said pick-up element and all of said multiplicity of reeds to charge said reeds to a uniform voltage with respect to said pick-up element, and electronic tone signal means connected to said pick-up element to produce electronic tone signals corresponding to the changing cumulative capacitance between said pick-up element and said multiplicity of reeds coacting therewith.

4. In an electronic piano, the combination comprising a multiplicity of tuned reeds mounted alongside each other in a manner such that each reed cantilevers from a supported end thereof to a free end thereof, key controlled striking means coacting with each of said respective reeds to impulsively excite the reed to vibrate freely in a manner which swings the free end of the reed to opposite sides of a rest position thereof, a single electrostatic pick-up conductor having portions thereof disposed in adjacent relation to the free ends of said respective reeds, each of said pick-up conductor portions registering with the normal position of the coacting reed and being shaped and positioned to extend away from a position of alignment with the normal position of the reed in only one of the two directions in which the reed swings away from its normal position, means for charging all of said multiplicity of reeds to a uniform potential with respect to said pick-up conductor, and electronic tone signal means coacting with said pick-up conductor to produce tone signals controlled by the cumulative capacitance between said conductor and said multiplicity of reeds coating therewith.

5. An electronic piano comprising a plurality of electrically conductive reeds disposed in side by side coplanar relation to each other and being of progressively varying length, each of said reeds being fixedly mounted at one end and free at its other end, a plurality of hammers one for each reed selectively operable for impulsively exciting the reeds into decadent free vibration, keys for operating the hammers, an electrostatic pick-up comprising a plurality of pick-up portions disposed in side by side coplanar disposition to each other and in a proximate electrically capacitive relation to the projecting portions of said respective reeds, said respective pick-up portions being substantially flush with the normal positions of the respective reeds and extending along the swing of the reeds in only one direction of reed movement away from the normal positions of the reeds, the extent of each pick-up portion in said one direction covering substantially the full excursion of the coacting reed in said one direction, means for charging said pick-up to a substantial electrical potential relative to the coacting reeds, and electronic tone signal means coacting with said pick-up and said reeds to produce tone signals controlled by the electrical capacitance between said pick-up and said reeds.

6. In an electronic piano, the combination comprising a plurality of juxtaposed tuned reeds each of which cantilevers from a supported end thereof to a free end thereof, key controlled striking means for impulsively exciting said respective reeds for vibration, a pick-up for electrostatically sensing vibrations of said reeds, said pick-up including a plurality of electrically conductive portions thereof disposed alongside the vibratory paths of said respective reeds in proximate relation to the normal positions of the respective reeds, to provide electrical capacitance between said pick-up element and each reed which is varied by impulse induced vibration of the reed relative to the pick-up element, means for applying an electric potential between said pick-up and said reeds to charge said reeds to a substantial voltage with respect to said electrically conductive portions of said pick-up, and electronic tone signal means coacting with said pick-up and said reeds to produce electronic tone signals controlled by the instantaneous capacitance between said pick-up and said reeds coacting therewith.

B. F. Miessner #3,038,363 cont'd.

7. An electronic piano as defined in claim 6 in which each of said electrically conductive portions of said pick-up element traverses the free end of the coacting reed and has a width with respect to the reed which substantially exceeds the corresponding transverse width of the coacting reed.

8. In an electronic piano, the combination comprising a multiplicity of juxtaposed tuned reeds each of which cantilevers from a supported end thereof to a free end thereof, key controlled striking means for impulsively exciting said respective reeds for vibration, an integral electrically conductive pick-up plate extending across the free ends of said reeds for electrostatically sensing vibrations of the reeds; said pick-up plate having a plurality of electrically conductive portions thereof disposed in proximate, electrically capacitive relation to the normal positions of said respective reeds to provide electrical capacitance between said pick-up plate and each reed which is varied by impulse induced vibrations of the reeds relative to the pick-up plate; means for applying a substantial electrical voltage between said pick-up plate and said reeds, and electronic tone signal means coacting with said pick-up plate and said reeds to produce tone signals controlled by the cumulative capacitance between said pick-up plate and said reeds.

9. In an electronic piano, the combination comprising a multiplicity of tuned electrically conductive reeds mounted alongside each other in a manner such that each reed cantilevers from a supported end thereof to a free end threof, key controlled striking means coacting with each of said respective reeds to impulsively excite the reed to vibrate freely in a manner which swings the free end of the reed to opposite sides of a rest position thereof, an electrostatic pick-up including conductor portions disposed in adjacent electrically capacitive relation to the free ends of said respective reeds, each of said pick-up conductor portions being substantially flush with one longitudinal side of the coacting reed when the latter is in its normal position, each pick-up conductor portion being shaped and positioned to extend along the swing of the coacting reed in only one direction of reed movement from the normal position of the reed, the orientation of each reed in its coacting pick-up conductor portion being such that the electrically capacitive spacing between the reed and the conductor portion progressively increases as the reed swings away from its normal position in said one direction of reed movement, means for charging said pick-up to a substantial electrical potential relative to said reeds, and electronic tone signal means coacting with said pick-up and said reeds to produce tone signals controlled by the capacitance between said pick-up and said reeds.

B. F. MIESSNER #2,942,512

1. In combination in an electrical musical instrument, a fixed-free reed, an impulse exciting means comprising a key actuated hammer adjacent the reed selectively engageable with the individual reed for setting it into decadent free vibration, and an electric translation pick-up adjacent the reed, said pick-up having a tone producing portion located alongside and being vibratorily passed by a longitudinally intermediate edge portion of the reed and being of an effective thickness, in the direction of reed vibration, smaller than the high-amplitude stroke of said edge portion of the reed.

2. In combination in an electrical musical instrument, a fixed-free reed, an impulse exciting means comprising a key actuated hammer adjacent the reed selectively engageable with the individual reed for setting it into decadent free vibration, and an electric translation pick-up adjacent the reed, said pick-up having a tone producing portion located alongside and being vibratorily passed by a longitudinally intermediate edge portion of the reed, being of an effective thickness, in the direction of reed vibration, smaller than the high-amplitude stroke of said edge portion of the reed, and being offset in said direction from effective alignment with the rest position of the reed.

6. In combination in an electrical musical instrument, a mechanical system comprising a fixed-free reed and an impulse exciting means comprising a key actuated hammer adjacent the reed selectively engageable with the individual reed for setting it into decadent free vibration, an electric translation pick-up adjacent the reed, said pick-up having a tone producing portion located alongside and being vibratorily passed by a longitudinally intermediate edge portion of the reed and being of an effective thickness, in the direction of reed vibration, smaller than the high amplitude stroke of said edge portion of the reed, and means comprised in said mechanical system for at least substantially eliminating from the free vibration of the reed a lower one of its normally present upper partials.

9. In combination in a musical instrument, a fixed-free reed, single-impulse exciting means comprising a key actuated hammer selectively engageable with the individual reed for setting it into decadent free vibration, a mechanico-electrical system consisting of a portion of the reed and pick-up means associated with and influenced by said portion for translating electric oscillations from the reed vibrations, means comprised in said mechanico-electrical system for at least substantially eliminating from said oscillations an inharmonic component corresponding to a lower one of the upper partials at which the reed tends to vibrate, and means also comprised in said mechanico-electrical system for introducing into the oscillations translated from the fundamental reed vibrations a series of upper partials harmonically related thereto.

C. W. ANDERSEN #2,949,053

1. An electronic musical instrument comprising a common reed support, a plurality of reeds with bases fixed on said common support and with vibratile tongues projecting in the same direction therefrom in side-by-side substantially coplanar parallelism from said support, a plurality of hammers respectively percussively engageable with the tongues of said reeds respectively to set said reed tongues in decadent free vibration, a plurality of manually engageable keys respectively operatively connected to said hammers for selectively moving said hammers into such percussive engagement with said reed tongues, a pick-up member of comb-like configuration having a plurality of parallel teeth and an intermediate plurality of slots each opening at one end, means mounting said pick-up member in opposition to said reeds substantially in a common plane therewith with the reeds projecting into the slots between the teeth, the teeth on opposite sides of a reed extending substantially the same distance therealong, there being at least one reed tongue in each slot, and each reed being closely adjacent a pick-up tooth along a longitudinal edge of said reed, said pick-up teeth terminating at free ends short of the reed bases, the hammers respectively percussively engaging the reed tongues between the reed bases and the free ends of the adjacent pick-up teeth, said reeds and said pick-up member comprising electrostatic tone generating means, means establishing an electric potential between said reeds and said pick-up member, electric oscillations being generated in accordance with the change in capacity between said reeds and said pick-up member resulting from free decadent vibration of said reeds relative to said pick-up member, electronic amplifying means connected to said reeds and said pick-up member for amplifying the oscillations generated by the decadent free vibration of said reed tongues, and electro-acoustic translating means connected to said amplifying means for converting the amplified oscillations into audible tones.

2. An electronic musical instrument as set forth in claim 1 wherein the plane of said reeds is displaced from the median plane of the pick-up teeth, and wherein said reeds vibrate asymmetrically about such median plane.

3. An electronic musical instrument as set forth in claim 1 and further including common means electrically grounding said plurality of reeds.

5. An electronic musical instrument as set forth in claim 1 wherein the reed tongues and the teeth of the pick-up are substantially rectangular in cross-section and in outline to provide a sharp tonal reaction.