Sept. 30, 1969 D. W. MARTIN ET AL 3,470,305

INTERMOTE COUPLING MEANS FOR AN ELECTROPIANO

Filed May 27, 1966 2 Sheets-Sheet 1

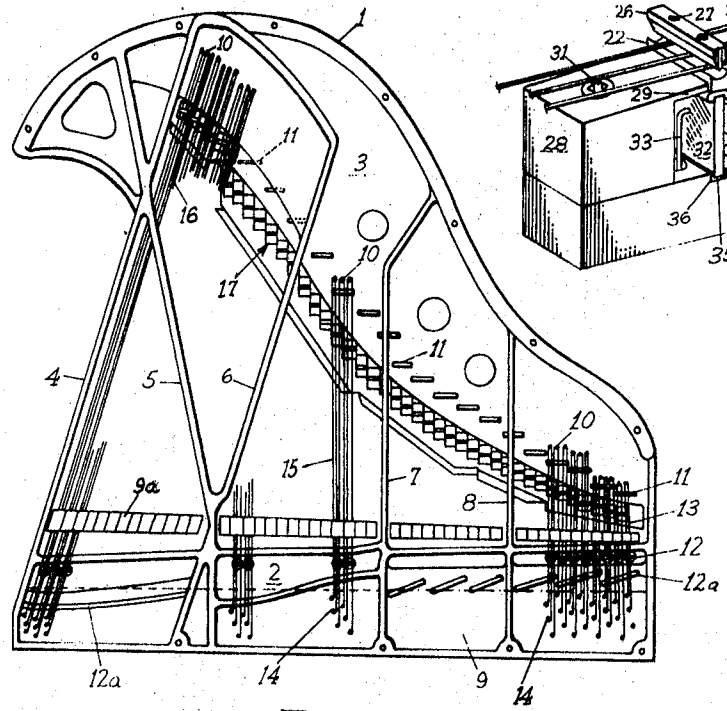


Fig. 1

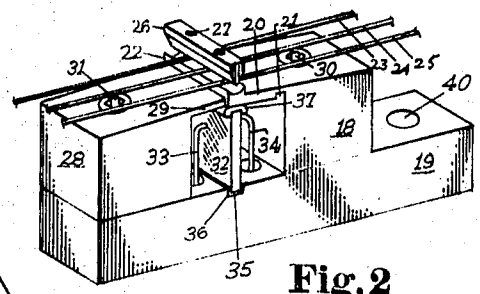


Fig. 2

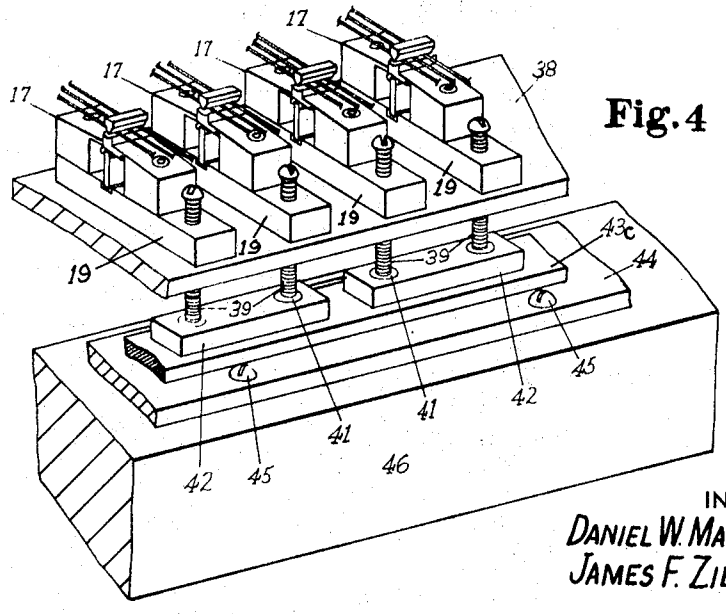


Fig. 4

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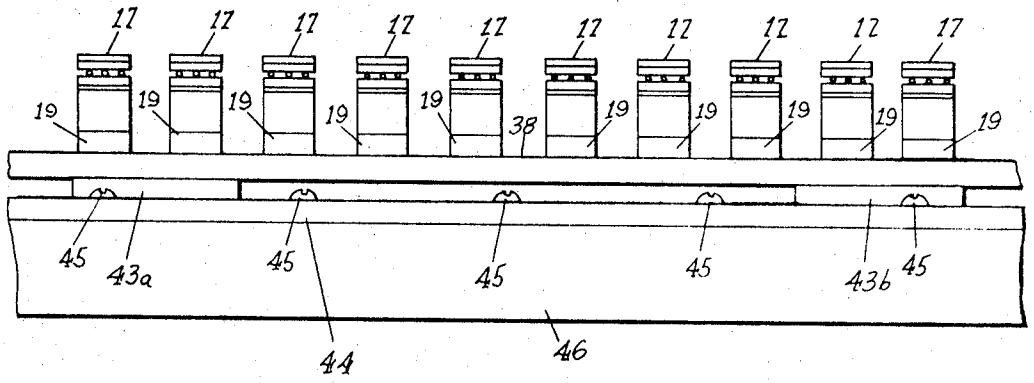



Fig. 3

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3,470,305

# INTERNOTE COUPLING MEANS FOR AN ELECTROPIANO

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U.S. Cl. 84—1.16 9 Claims

## ABSTRACT OF THE DISCLOSURE

An electrical musical instrument, such as an electropiano, wherein the mechano-electric transducers for a series of strings are mechanically interconnected, as by means of a coupling plate, so as to provide sympathetic vibration between strings tuned for different notes of the scale.

The term "electropiano" as used herein means an instrument having a string plate, strings thereon and an action whereby the strings may be set in motion, but devoid of a sounding board, while having means whereby the vibrations of the strings can be converted directly into electrical pulsations. The electrical pulsations, with such amplification as may be desired, are then converted into sound by one or more loud speakers. While the invention is not so limited, there has been felt a need for a large concert instrument of the electropiano type, so that the sound output of the instrument can be regulated in accordance with the sound output, say, of a symphony orchestra.

The present invention will therefore be described in connection with a concert grand type of instrument. It will be evident that the tones produced by such an instrument must closely match the tones of the conventional acoustical grand piano. While it is not difficult to convert the vibrations of strings into electrical pulsations, great difficulty has been experienced in achieving a true piano tone quality, and much work has been done in this field. Among the various transducers which may be used, piezoelectric crystals and barium titanate ceramic elements, coupled to the string terminations, have been found quite effective in converting all of the modes of mechanical movement of the strings which are ordinarily converted to acoustical energy by the sounding board of conventional instruments. In United States Patent No. 2,334,744, Hugo Benioff used metal elements supported by the strings as termination means for the speaking length of the strings. The elements had sufficient mass for the purpose. Mounted on the termination means was a cantilever element for each string or note-group of strings, with a piezoelectric crystal interposed between the cantilever element and the body of the termination means. This effected some improvement, but still presented a number of difficulties.

In an acoustical piano, the strings are set into motion by the hammers of the action, which immediately after striking the strings, come out of contact with them. The tone, at first at a high sound level, decays quickly due to various damping factors inherent in the instrument. One of these factors arises, of course, from the fact that the string must drive the sounding board through the medium of the bridge. But there are other damping factors which must be taken into account, including the termination of the strings and the speaking length thereof. These have to do in part with the nature of the plate and its appurtenances.

The decay of the tones occurs in a complex and distinctive manner, exhibiting a greater rate of decay at the start than later on in the tone. Moreover, the decay rate is not the same for the different frequency components



making up the tone produced by any given string or group of strings tuned to the same fundamental frequency.

Yet again, when the dampers are raised by the action of the sustaining pedal, there is in the acoustical piano a certain amount of interaction between the strings of notes of different frequencies. The interplay of these factors is extremely complex. Suffice it to say, that the acoustical piano as an instrument has distinct qualities of tone and voice which are recognizable. If these are departed from in an electropiano, the result is generally unfortunate since the basic purpose of concert electropianos, at least, is the control of the volume of the sound produced without departure from the recognized tonal quality of the instrument.

Benioff, in a later United States Letters Patent No. 3,049,958, endeavored to achieve, in his transducers, damping and other effects similar to those of a sounding board and bridge. A considerable improvement was achieved. Nevertheless the problem of providing sympathetic vibrations in adjacent strings or string groups, especially when the sustaining pedal is depressed, was not solved. There was also a tendency for the tones in the bass and tenor ranges to "run together" when played in rapid sequence (such as runs and arpeggios) with the damper pedal depressed.

Burkhard and Sabine in their United States Patent No. 3,069,955 also sought to achieve enhanced tonal quality in an electronic piano by damping groups of the strings (in a single string per note instrument) by means of resiliently supported weights mounting string contacting rigid bridge members, the weights acting to damp the fundamental frequencies at a higher rate than the higher partials, thereby tending to simulate the damping effects obtained in an acoustical piano. Such weights are interposed as separate and additional bridge members intermediate the string mounting bridges which define the speaking lengths of the springs, with the transducers remote both from the weights and bridges. This arrangement, with its multiple point string contact, interposes numerous problems of string tuning and the interjection of rattles and other extraneous noises during string vibration.

In contrast to the foregoing prior art, the instant invention provides an electropiano wherein the aforementioned difficulties are effectively reduced or eliminated, the invention contemplating a simplified construction wherein only two points are involved in positioning the speaking portion of each string, with all string modes of vibration, including non-selective bridge coupling between the strings, controlled at the termination of the strings rather than at a point or points along their speaking lengths. Thus, resonant loading and associated damping are applied to the strings at the ends of their tuned lengths, with a resiliently mounted and damped mass serving as the termination for the tuned length and additionally incorporating the transducer elements.

It is also a basic object of the invention to provide a more natural double-decay rate in the tones of the instrument.

It is an object of the invention to mount groups of transducers on a member which will be sufficiently massive to terminate the speaking portion of each string effectively, but which at the same time will permit sympathetic vibrations to occur between adjacent strings.

It is an object of the invention to mount a string terminating member or support in such a way that it will resonate at a low frequency, say 100 c.p.s., and to damp the resonance through mechanical resistance, in such a way that the lower partials of the tone decay more rapidly than the higher partials.

It is another object of the invention to control not only the shape of the decay curve and the duration of the decay

period, but to provide means for controlling the relative intensity of the fundamental and partials during the decay period.

Important objects of the invention may be summarized as the provision of more realistic and piano-like tones in electropianos, the provision of tones characterized by more rapid damping in the lower partials than in the higher partials, the provision of damping which essentially has the same effect as the damping in an acoustical piano, and the provision of internote coupling in electropianos having no sounding board, especially when the dampers are lifted from the strings by the damper pedal.

These and other objects of the invention which will be set forth hereinafter or will be apparent to the skilled worker in the art upon reading these specifications, are accomplished by that structure and arrangement of parts of which an exemplary embodiment will now be described. Reference is made to the accompanying drawings wherein:

FIGURE 1 is a plan view of the frame or plate of a grand piano including a partial showing of the stringing and the mounting of the transducers as in the Benioff Patent No. 3,049,958.

FIGURE 2 is a perspective view of a single transducer, to be used in accordance with this invention in the hereinafter set forth.

FIGURE 3 is a side elevation showing the mounting of transducers in a way to secure the benefits of this invention.

FIGURE 4 is a semi-diagrammatic perspective view with parts in section, of another embodiment of the invention.

Although the bridge of a conventional piano has a certain rigidity, it is compliant when compared to a solid metal plate. Thus while the termination means for the speaking length of strings in an acoustical grand piano are rigid in theory, there is sufficient vibration at the terminations to drive the bridge and soundboard, and to produce sympathetic vibrations in springs or strings or string groups other than the strings which are struck. In an electropiano there is no conventional bridge and no sounding board; and the termination of the speaking lengths of the strings may be very much more rigid.

The string plate of a grand piano is illustrated at **1** in FIGURE 1. It is usually, although not necessarily, in the form of a casting. The casting has a front portion **2** and a rear portion **3**, which portions are interconnected by ribs **4**, **5**, **6**, **7** and **8**. The front portion of the plate is configured to accept a pin block indicated at **9**.

The front portion of the string plate with pin block attached is frequently mounted above the front portion of the grand piano case (not shown), while peripheral portions of the string plate lie inside the outer rim of the grand piano and are fastened to the inner rim, again not shown.

FIGURE 1 illustrates a typical grand piano plate; but other plate structures may be employed. The electropiano, of course, lacks any sounding board or bridge. The plate will be supported in the piano case at such a height that an action having upwardly striking hammers will coact with the strings to set them into vibration as known in the art. The action itself is not illustrated in FIGURE 1, excepting for the individual string dampers **9***a*. The strings extend from hitch pins, such as those indicated at **10** on the rear portion of the string plate, forwardly over agraffe means **11** also positioned on the plate. Thence, they pass over a series of transducers **17** which effectively terminate the tuned length of the strings at the rear. The forwardly extending strings may pass over additional agraffe means **12** and **12***a* at the front portion of the string plate, and are ultimately engaged by the tuning pins **14** in the pin block **9**. A series of treble strings is indicated at **13**, certain intermediate strings at **15** and a series of bass strings at **16**. The agraffe means **12** effectively terminate the tuned length of the strings at the front of the string plate, and may be of various forms. They may be like the agraffe means **11**; but other means may be employed if desired, such as brass elements having shanks threaded into openings in the string plate and provided with holes through which the strings pass.

In the piano of the Benioff Patent No. 3,049,958 the transducers **17** were mounted to a heavy plate (or mechanical ground) which in turn was rigidly mounted to the rear portion of the string plate or to an extension thereof. The patentee endeavored to simulate the decay characteristics of the tones of conventional or mechano-acoustic pianos by providing in the transducers themselves an amount of damping which would be substantially equivalent to the damping effects of a sounding board and bridge. Quite pleasing tones were secured in this way; but the effects were imperfect for a number of reasons. For one thing, the interaction of a vibrating string (or strings) upon other piano strings in the assembly was not adequately achieved. In other words, the coupling between the strings of a grand piano which occurs through the bridge and the sounding board in an acoustical piano was essentially absent. In the earlier Benioff patent where the transducers were mounted on blocks which were suspended from the strings, a degree of coupling could have been achieved if the blocks had been elongated so as to contact a plurality of strings having different frequencies. But the coupling effect in that patent tended to be too great as respects those strings having pickups mounted on the same base, and absent as to strings not so directly coupled; and it was not possible to extend the coupling in any such way as was accomplished in the acoustic piano by the bridge. In the second place, the decay of the tones was not entirely piano-like for reasons which will later be set forth.

Nevertheless, the type of individual transducer used by Benioff in Patent No. 3,049,958 is suitable for the purpose of this invention and will now be described as exemplary. Referring to FIGURE 2, the transducer means comprises a block of metal **18** fastened to a base member **19** and provided with a cantilever arm **20**. This cantilever arm is reduced in thickness as at **21**. It carries a head portion **22** which is hollow as viewed from above and which furnishes one of the clamping means for a series of strings **23**, **24** and **25**. These three strings may be considered as tuned to substantially the same frequency. As is well known, the middle and upper registers of a grand piano have usually three strings per note. In the tenor section in the scale of the piano, the number of strings per note will be reduced to two, while in the bass section there will be a single string per note. As is also conventional, the strings in the bass section will usually be wound with wire so as to increase their linear density. The type of transducer illustrated in FIGURE 2 may be used for single, double or triple strings.

The strings are clamped to the portion **22** of the cantilever arm by an overhead member **26** in place by screws **27** engaging the head **26**.

In order to provide a housing for preventing damage to the piezo-electric crystal forming a part of the transducer, there is preferably provided on the base a second block of metal **28** having a forwardly extending arm **29**. The block **18** is affixed to the base **19** by means of a threaded member **30**, while the block **28** is affixed to the base by a threaded member **31**.

The transducer makes use of a pressure-responsive element **32** (e.g. a piezo-electric crystal) interposed between the cantilever arm **20** and the base **19**. Electrical contact is made to the element by wires **33** and **34** which pass downwardly through holes in the base **19** and thence along any convenient passage to an output system comprising an amplifier and one or more loud speakers.

The lower edge of the element **32** is mounted in a groove **35** in the base member with the interposition of a layer **36** of insulative material therebetween. This layer serves two purposes. It insulates the element from the

base **19**, and it is also of such character as to provide a certain degree of damping. In order to insulate the element from the head **22** of the cantilever arm **20**, use is made of another layer of damping material **37** interposed therebetween. The damping material must be satisfactorily strong for the purpose. Its nature can be varied in accordance with the effect desired. A material of suitable damping characteristics, by way of example, was found to be a resinous material sold by Astatic Corporation under the trademark Audioid. The damping material is one which must have a relatively large viscosity or internal friction in proportion to its density and elastic coefficient. Other materials which may be used are silicones, chloroprene and other synthetic rubber-like material, rubber-cork mixtures, and rubber-saturated fibrous substances.

Transducers as generally illustrated in FIGURE 2 and as described herein have been found very effective in converting the mechanical modes of motion of the vibrating strings into pulses of electrical energy. But when, as set forth in Patent No. 3,049,958, these transducers were mounted solidly upon the string plate or an extension thereof, the decay of the tones of struck strings was found to differ from the decay of the tones of an acoustical piano having a bridge and sounding board. There is a tendency in electropianos for the decay of the tones to occur at a slower rate than is normal for the acoustical piano. Also the tonal decay in an acoustical piano is not the same for all partials of the complex tone. This does not refer to the strings or string assemblies tuned to different frequencies. As the skilled worker in the art will recognize, when a string is set into vibration it has a mode of motion at a fundamental frequency; but at the same time it has modes of motion at other frequencies, bearing a nearly harmonic relationship to the fundamental frequency. Piano strings also have lengthwise or axial modes of motion.

In the present invention the individual transducers are suspended from the strings and collectively support a member which is sufficiently massive to terminate the tuned portion of the strings effectively, but transmissive enough to provide mechanical coupling between strings tuned for different notes of the scale. The coupling member, further, is of such mass that it will resonate with the combined stiffness of the strings (and other supporting members) at a low frequency (of the order of 100 c.p.s.). The resonance is damped through mechanical means to the proper degree for damping low-frequency partials more rapidly than the higher partials during the decay periods of the piano tones.

In the practice of the invention as shown in FIGURE 3, therefore, a series of transducers is mounted upon a supporting and coupling plate of metal. The best form of transducer known to applicants has been described above in connection with FIGURE 2. It is to be understood, however, that modifications may be made in the transducer without departing from the spirit of the invention. The individual transducers as shown in FIGURE 2 are relatively small since they are intended to handle the string or strings for an individual note of the instrument, to form a rear terminus for the tuned length of such string or strings, and to convert the mechanical modes of motion thereof into electrical impulses.

In the practice of this invention a series of such transducers is mounted upon a coupling plate of metal. Referring to FIGURE 3, ten transducers **17** are shown mounted upon a coupling plate **38**. This is a partial showing since a very large number, if not all, of the transducers will be fastened to the coupling plate **38**. It is possible and preferable to have one such plate common to all of the transducers in the instrument, but it does not depart from the spirit of the invention to provide separate plates for different portions of the instrument, to each of which plates a comparatively large number of transducers are attached.

The metal plate **38** is preferably formed of steel, such as AISI 1018 or AISI 8620, the steel having substantially less damping action than would be the case with other metals such for example as cast iron or brass.

The manner in which the individual transducers are fastened to the coupling plate **38** may be varied. The connection, however, should be rigid. It is possible to attach the transducers to the plate **38** by adhesive means such as epoxy resin cement. A preferable mode of attachment involves prolonging the threaded fastening means **30**, **31** of FIGURE 2, so that they extend below the element **19** of the transducer and are threaded into tapped holes in the plate **38**. In this instance they may pass through clearance holes in the elements **19**. Alternatively, the transducers themselves may comprise the coupling means, the base members **19** of the transducers being rigidly connected to each other and the base members collectively being of a mass sufficient to produce the desired resonance frequency. In such event the interconnected base members act as the coupling plate.

Since the strings of the isstrument are clamped to the several transducers as hereinabove described, and since the combination of the transducers and/or the coupling plate **38** provides sufficient mass, the transducers are enabled to serve as rear terminations for the tuned length of the strings of the instrument. At the same time, the transducers serve as an interconnection between strings or groups of strings. In other words, if a string or group of strings representing a single note in the scale of the instrument is struck by one of the hammers of the piano action, while one or more dampers **9***a* are raised from the strings, there will be an interaction between the struck string or strings and other undamped strings or groups of strings in the instrument. This interaction is not confined to other strings or groups of strings which bear a strictly harmonic relationship to the struck strings, but includes a sympathetic vibration of non-harmonically related strings as well. Such interaction is necessary for the production of a true piano-like quality.

Nevertheless, if the coupled combination of transducer elements were merely suspended from the strings of the instrument, the aforesaid interaction could be considered excessive because of the low damping characteristics of the structure. Hence, additional damping means are usually required.

A third function of the combination of transducers and connecting plates is to provide a structure which resonates on the strings at a low frequency.

The desired resonance at a low frequency is generally a resonance at about 100 c.p.s., although this may be varied. The resonating characteristic is a function of transverse string stiffness, stiffness of damping members or other members contributing to support of plate **38**, and the combined mass of the coupling plate **38** and the transducers which are attached to it. It may be controlled by the choice of the thickness of the plate **38**, and of the stiffness of the damping and supporting members hereinafter described. With transducers of approximately the size and proportions illustrated herein, and a plate width of the order of about 2½ to 3 inches, a plate thickness of about $\frac{3}{16}$ to about ¼ of an inch will insure resonance at a desirable low frequency. This value is intended to be illustrative rather than limitative.

The plate **38** rest upon pads **43***a* and **43***b* of damping material which in turn rest upon a plate **44**. The plate **44** may be rigid and serve as mechanical ground, or it may be fastened by means of screws **45** to another mass **46** of sufficient size to form a mechanical ground.

In the manufacture of pianos, mass **46** may be cast as a part of the string plate of the instrument; but it is frequently more convenient to use as the mechanical ground the framework of the piano case. A single member **46** may be used extending throughout the range of the instrument; but it does not amount to a departure of the spirit of the invention to employ bar-like pieces of

lesser length which are affixed to the rear portion of the string plate or to the piano case structure. Since the member or members **46** are intended to be so massive as to constitute a mechanical ground, the nature of the material from which they are made is not a limitation on the invention.

There are numerous materials which may be used for the damping elements **43***a* and **43***b* above described. These materials include felts and other fibrous materials. Ordinary felts made of animal or vegetable fibers have a tendency to introduce too much damping at the higher frequencies. Very good results are obtained by using precompressed strips made up of glass fibers lightly bonded together with resinous substances. Mats of this type are frequently used for mounting heavy machinery so as to minimize the transmission of vibrations to a supporting floor.

The damping elements **43***a* and **43***b* may be in the form of a continuous strip used throughout the length of the coupling bar **38**; but it is characteristic of the structures of this invention that the actual damping may be varied and controlled by using individual pieces or spaced pieces of the damping material beneath the plate **38**. Also individual pieces of damping material of differing thickness or characteristics may be employed at different points in the scale of the instrument.

It has been found that the provision of additional stiffness and damping adjustment means acting to vary resonance frequency and damping along the length of the plate **38** will give an even truer piano-like quality to the tones, and a double-decay characteristic which is substantially identical with that obtained in the coustical piano.

In order to apply the additional stiffness and damping adjustments just mentioned, a preferred form of the structure of this invention shown in FIGURE 4 involves the use of a series of bolts **39** passing through clearance holes **40** in the portions **19** of the transducers but threaded into tapped holes in the plate **38**. When these bolts are in adjustment their lower ends bottom in depressions **41** formed in the upper surfaces of short metallic bars **42**. These bars are preferably common to a small plurality of transducers. The bars **42** are preferably, but not necessarily, made of steel and rest upon a layer of damping material **43***c* of the character previously described which in turn rests on the plate **44**. As before, the damping material may comprise either a single strip, as illustrated, or it may be composed of a plurality of spaced apart pieces which may be varied in thickness and damping characteristics.

It will be understood from the structure shown in FIGURE 4, that after the piano has been strung and the strings have been tensioned substantially to their desired frequencies, the bolts **39** are turned downwardly so that they have a bearing in the socket elements **41** of the plates **42**. They should bear in these socket elements sufficiently to support a portion of the weight of the combination of transducers and coupling plate **38** upon the stiffness of damping elements **43**. It is an advantage of the described structure that the bolts **39** may be individually adjusted to vary both the stiffness and the damping in different parts of the connector plate **38**. Another way in which the resonance characteristics may be varied along the musical scale is to vary the cross-section of plate **38**, e.g., by tapering it down toward the treble end to raise the resonance frequency of the upper end of the scale. In these ways the tonal scale of the instrument may be balanced.

In using the illustrated structure of FIGURE 4 it has been found that normal piano tones are produced when the electrical pulsations from the transducers are amplified and reproduced by loud speakers. In particular, the tones, upon analysis, are substantially identical to the tones of comparable acoustical pianos having sounding boards and bridges, and the piano-like tones are substantially independent of the degree of amplification within reasonable limits. Further, the tones of the instrument exhibit the characteristic double-decay of piano tones. When the sustaining pedal is operated to remove the dampers from the strings, the interaction between struck strings and non-struck strings is characteristic of an acoustical piano having a sounding board and a bridge. The structure herein described eliminates a tendency for notes struck rapidly in succession (as in arpeggios) to run together; and it eliminates the previously noted tendency of bass notes struck rapidly in succession to become "muddy."

As should now be apparent, the resiliently mounted and damped mass is itself the termination for the tuned lengths of the strings, and consequently the resonant loading and associated damping are applied directly at the ends of tuned lengths rather than by means of a separate and additional bridge; and preferably the transducer elements are themselves a part of the termination mass which also serves as the transducer structure. With such arrangement, the damping adjustment has very little, if any, effect upon the tuned length of the strings and hence upon string tuning, and there is nothing in contact with the strings within their tuned segments which would be a vibration node for some modes of vibration and hence a source of rattles or other extraneous noises. Because only two contact points are involved in positioning the speaking portion of each string, the warping of the bridges or frame will not affect the amount of string damping, whereas a third intermediate separately supported point can add or subtract transverse stresses to the string where warping occurs. The clamping of the strings in accordance with the instant invention also assures transverse stiffness of the strings at the ends of their tuned lengths.

Modifications may be made in the invention without departing from the spirit of it, and consequently it is not intended that the invention be limited other than in the manner set forth in the claims which follow. For example, the resiliently damped coupler plate may be used to define one end of the speaking length of the strings, with the transducer means, which will be rigidly mounted, engaging the strings at the opposite ends of their speaking lengths. The instant invention will also find utility in an instrument such as a harpsichord in which the strings are vibrated by a plucking type of action rather than being struck by hammers.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

**1.** In an electrical musical instrument having a supporting frame mounting a string plate, strings supported on said plate and stretched between pairs of points defining tuned string segments, a series of mechano-electric transducer means contacting the strings comprising a series of adjoining notes of the musical scale, said transducer means each contacting said strings on one point of said pairs of points, means interconnecting said series of transducer means, said interconnected transducer means serving collectively as a mechanical internote coupling means common to the strings of a series of notes in the musical scale, and a damping material interposed between said internote coupling means and an essentially no-vibratile support forming a part of said instrument, the mass of said internote coupling means being sufficient to terminate the tuned segments of the strings but sufficiently transmissive to provide sympathetic vibration between strings tuned for different notes of the scale.

**2.** The structure claimed in claim **1** wherein the means interconnecting said series of transducer means comprises a steel plate on which said transducer means are mounted.

**3.** The structure claimed in claim **1** wherein the mass of said internote coupling means is chosen so that it will resonate at a low frequency, such as 100 c.p.s.

**4.** The structure claimed in claim **1** wherein the non-vibratile support comprises a portion of said string plate.

**5.** The structure claimed in claim **4** wherein said non-vibratile support includes a heavy metal bar attached to and supported by said string plate.

6. The structure claimed in claim 1 including means for adjusting the bearing of said internote coupling means on the non-vibratile support.

7. The structure claimed in claim 6 wherein said adjustment means comprises bearing bolts in threaded engagement with said internote coupling means, the ends of said bolts bearing against relatively small metallic plates seated on the damping material interposed between said internote coupling means and said non-vibratile support.

8. In an electrical musical instrument having a string plate, strings supported on said plate and stretched between pairs of points defining tuned string segments therebetween, mechano-electro transducer means contacting the strings at one point of said pairs of points, and a mechanical internote coupling means connected to said strings at one point of said pairs of points and being common to the strings of a large number of notes in the musical scale, the mass of said coupling means together with the transverse stiffness of said strings forming a resonant mechanical system which is sufficient to terminate the tuned segments of the strings but sufficiently transmissive to provide sympathetic vibration between strings tuned for different notes of the scale.



9. The structure claimed in claim 8 including damping means connecting said coupling means to a solid element of sufficient mass to act as a mechanical ground, said damping means acting to damp the resonant mechanical system.

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