United States Patent

Fender et al.

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[54] TONE GENERATOR WITH VIBRATORY BARS

[72] Inventors: **Clarence L. Fender**, Fullerton; **Harold B. Rhodes**, Anaheim, both of Calif.

[73] Assignee: **Columbia Broadcasting System, Inc.**, New York, N.Y.

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[52] **U.S. Cl.** **84/1.04**, 84/1.06, 84/1.16, 84/404

[51] **Int. Cl.** **G10h 3/00**

[58] **Field of Search** 84/1.01, 1.06, 1.14, 1.15, 84/404, 209, 237, 176, 402–405, 457, 1.04, 409; 331/154, 156; 310/15, 25, 36, 37

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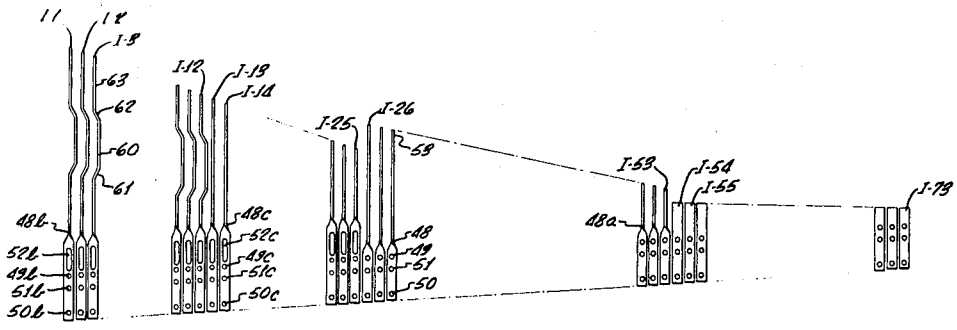
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Primary Examiner—Lewis H. Myers
Assistant Examiner—Ulysses Weldon
Attorney—Gausewitz, Carr & Rothenberg

[57] **ABSTRACT**

A tone generator for an electrical piano is formed of a circular cross section vibratory tine of relatively low mass and a high mass twisted inertia bar of oblong cross section, both cantilevered from a common base. When the tine is struck by the hammer of a piano action, its vibration is amplified by the resonant high mass inertia bar. A transducer associated with the tine produces an electrical signal representing a particular piano tone that is simulated by the individual tine. A number of advantages accrue from making the main body portion of the twisted high mass inertia bar of a cross section that is elongated in the plane of vibration of the tine of the tuning fork. Primarily, vibrations of the high mass inertia bar at overtones of the fundamental of the tine are substantially reduced.

17 Claims, 4 Drawing Figures



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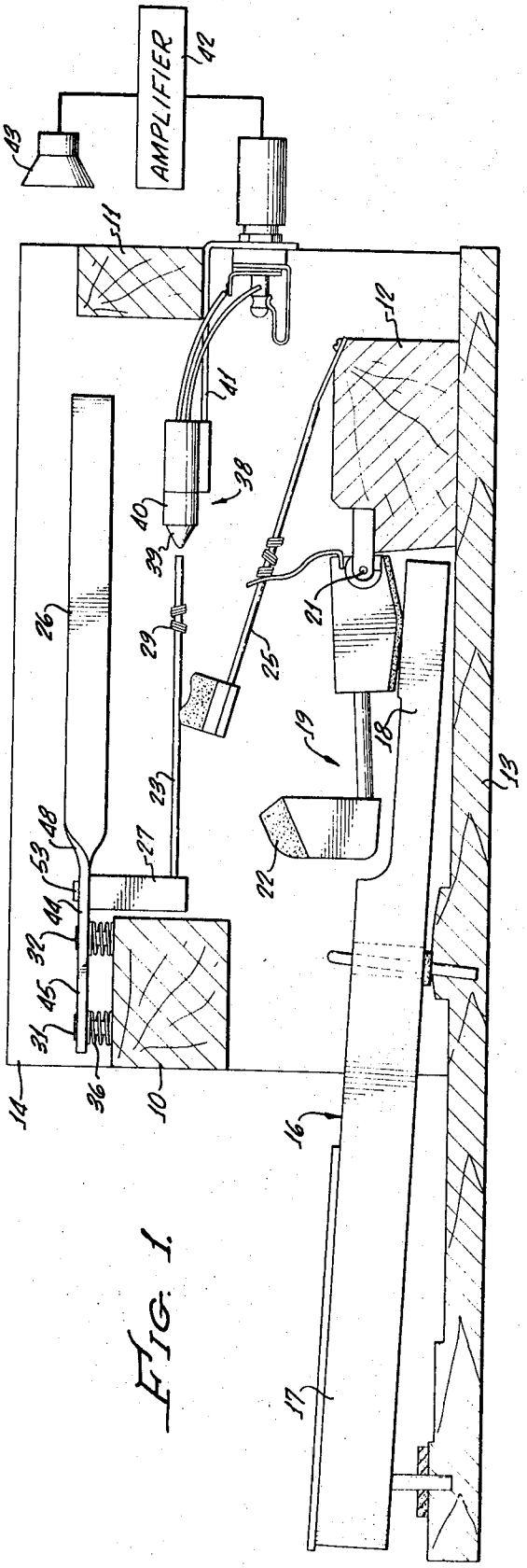


FIG. 1.

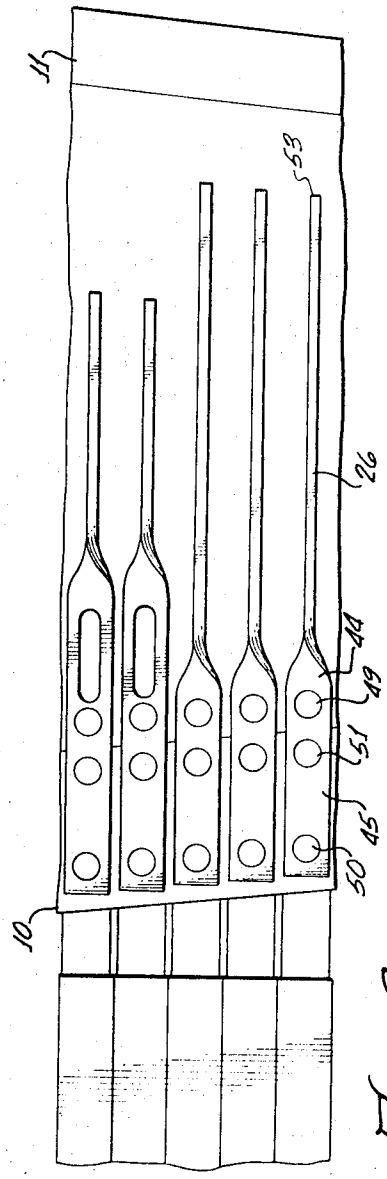


FIG. 2.

INVENTORS.
CLARENCE L. FENDER
HAROLD B. RHODES
BY
Dausenity & Cash
ATTORNEYS.

FIG. 3.

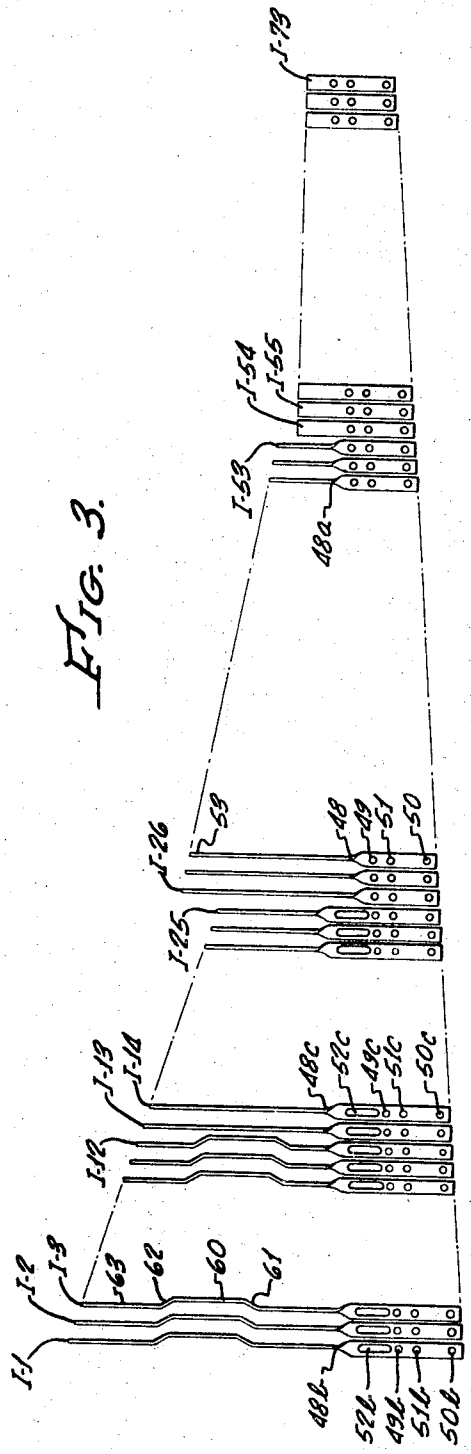
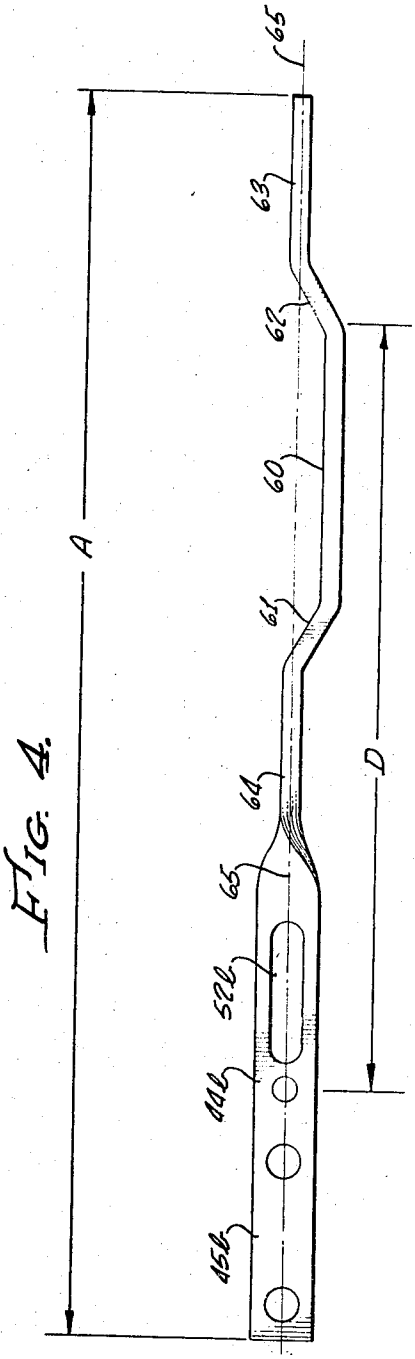


FIG. 4.



INVENTORS.
CLARENCE L. FENDER
HAROLD B. RHODES
BY
Dauserwitz & Cass
ATTORNEYS.

TONE GENERATOR WITH VIBRATORY BARS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to vibrating bar tone generators and, in one major aspect, particularly concerns an electronic piano having an improved construction and arrangement for generating an electrical signal that closely simulates a particular piano tone.

2. Description of Prior Art

Previous attempts to produce true piano sounds from an electrical piano have involved the mounting of a number of vibrating reeds on a single-large support or the use of a number of conventional tuning forks. The many disadvantages of these arrangements are set forth at length in U.S. Pat. No. 2,972,922 for Electrical Musical Instruments in the Nature of a Piano, issued Feb. 28, 1961, to Harold B. Rhodes. Recognizing the difficulties of previous arrangements for mounting of vibrating reeds or conventional tuning forks, the Rhodes patent suggested a highly modified type of tuning fork comprising a first prong of high mass and a second prong or tine of relatively low mass. In this apparatus the high mass prong functions as a mechanical amplifier or miniature resonant support for the low mass prong of this asymmetrical tuning fork. The low mass tine itself is excited by being struck with the hammer of a piano action. A transducer senses vibration of this tine to produce the output electrical signal of the tone generator.

With a relatively fixed transducer sensing tine vibration, it is essential that the plane of vibration be fixed, or tone quality may vary widely. Normally the plane of vibration of a circular cross section vibratory element will not remain fixed. For this reason tone generators for commercially produced electrical pianos, prior to the Rhodes patent, did not employ tines of circular cross section despite the fact that such tines have many advantages in quality and economy of manufacture. The high mass inertia bar, as taught by Rhodes, overcame this problem by forming, in effect, an asymmetrical tuning fork that allowed use of a circular cross section tine having a controlled plane of vibration.

The asymmetrical tuning fork of the Rhodes patent, having one high mass prong and one low mass prong, has been embodied in a number of electrical pianos produced and marketed by the common assignee of the aforementioned Rhodes patent and the present application. In the course of such manufacture and marketing, as a result of continued review and analysis, and based upon information gained from extensive field experience, a number of different improvements of the asymmetrical tone generator were designed, developed and incorporated in an electrical piano. Such improvements are described in detail in U.S. Pat. to H. B. Rhodes, No. 3,384,699 for Apparatus for Mounting A Tone Generator and For Positioning The Same Relative to a Transducer, and in U.S. Pat. No. 3,418,417 to H. B. Rhodes for an Electric Piano Incorporating Multi-component Tuning Forks.

Despite the extensive improvements in manufacturing cost and musical quality achieved by the various inventions described in the aforementioned patents, and despite the pleasing operation and musical quality of instruments incorporating arrangements of these patents, it is desired to still further enhance operative qualities and to more closely approach the goal of maximized musical excellence.

With regard to tonal quality, it is found that the asymmetrical tone generators share a disadvantage in common with the conventional tuning fork tone generator. For certain combinations of length of vibratory bar and cross section of such bar, overtones of the fundamental tone are introduced and fortified by the mutually resonating action of the two prongs of the tuning fork. Such overtones in the high mass bar are increasingly troublesome for lower frequency tone generators where the length of the prongs increases and where overtones may have a frequency much closer to the fundamental frequency.

In addition to continuing efforts to review and improve musical quality of the electrical instrument, ever present objectives are decrease in cost, facilitation of adjustment and repair, and provision of smaller, more compact and lighter weight instruments, all without loss of quality.

The above-described disadvantages of prior electric piano tone generating systems are overcome to a considerable extent and many additional and unexpected advantages are achieved by the novel arrangement and manufacture of the asymmetrical tone generator described herein.

SUMMARY OF THE INVENTION

In carrying out the principles of the present invention in accordance with a preferred embodiment thereof, an asymmetrical tone generator comprises a low mass vibratory tine and a high mass vibratory bar, both cantilevered from a common base and arranged so that the low mass tine vibrates in a plane common to both vibratory elements and the common base. The high mass bar has an oblong cross section which is elongated in a direction substantially normal to the common plane in the vicinity of the common base. The high mass bar is twisted so that, throughout a major portion of its extent, the direction of elongation of its cross section lies in the common plane and substantially normal to the axial extent of the bar.

An additional feature of the invention that decreases total mass and size of the high mass bar (also termed an inertia bar) resides in the introduction of a bar section of relatively high compliance in the vicinity of the cantilevered bar support.

Still another significant feature of the twisted inertia bar of this asymmetrical tone generator comprises the offset of a portion of the body of the bar to allow increased amplitude excursions of the associated tine.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 comprises an elevational view of a portion of an electrical piano action showing a single key, the hammer action, and the tone generating arrangement therefor,

FIG. 2 comprises a top view of parts of two groups of adjacent asymmetrical tone generators,

FIG. 3 comprises a top view having three groups of asymmetrical tone generators, and

FIG. 4 comprises a detailed illustration of a single one of the inertia bars of a group of lower frequency tone generators of FIG. 3.

GENERAL DESCRIPTION

The improved construction, arrangement, and configuration of an asymmetrical tone generator as described herein are particularly advantageous when employed for lower and middle range frequency notes and it will be with respect to such notes that an embodiment of the invention first will be described. The upper frequency limit to which the present inventive principles are applied is established largely by convenience and cost of manufacture. Furthermore, advantages of improved tonal qualities produced with the arrangement of the invention are more pronounced at frequencies below certain higher ranges. Accordingly, although the invention may be applied throughout the usual frequency range of a conventional electric piano, its advantages are most pronounced in application to certain frequency ranges as will be more particularly described hereinafter.

Illustrated in FIG. 1 is an elevational view of a single-piano key, the associated action therefor, and an asymmetrical tone generator, together with its pickup, and the piano amplifier and speaker. The illustrated piano apparatus comprises a number of horizontal support elements **10**, **11**, and **12** which may be suitably mounted above a horizontal bottom element **13**, for example, by means of upwardly extending end elements, one of which is shown at **14**. The various elements **10** through **14** support all of the components of the electrical instrument to be described herein and the operating mechanisms thereof. Operating components illustrated in

elevation in FIG. 1 are arranged to create a single electronically simulated piano tone. Thus, for a full-scale electrical piano of, for example, 73 notes, all of the operating mechanisms except for amplifier and speaker illustrated in FIG. 1 will be substantially duplicated to provide 73 sets of mechanisms, each identical to that illustrated in FIG. 1. These mechanisms will vary in certain aspects of tone generator size and configuration to accommodate differing frequencies as will be more particularly described below. The piano amplifier and speaker are common to all tone generators.

Mounted on the horizontal bottom element **13** is a piano key **16** having an outer portion **17** adapted to be struck by the pianist. The key also has an inner portion **18** adapted to actuate a hammer element **19** that is pivoted at **21** to support element **12**. Operation and construction of this mechanism are described in detail in the above-identified U.S. Pat. Nos. 3,384,699, 3,418,417, and 2,972,922, the disclosures of which are fully incorporated herein by reference. When the pianist strikes the outer key portion **17**, there is effected an upward pivotal movement of hammer element **19** in a vertical plane until the hammerhead **22** engages a tine **23** of the associated tone generator. In addition, and also as described in the aforementioned patents, upward pivotal movement of the hammer effects downward movement of an associated damper until it no longer contacts the vibratory tine.

Additional details of the illustrated piano action are described at length in the aforesaid patents to Rhodes, and no further description of this mechanism or operation is considered to be necessary herein.

The asymmetrical tone generator of the present invention is applicable not only to the piano action described in the above-identified patents, but also is useful with many different types of piano actions and with other arrangements for providing a means to strike the tone generator. Thus, it will be readily appreciated that particular details of the striking action for the tone generator of this invention may be subject to wide variation without departing from principles of the present invention.

As described in detail in the above-identified patents to Rhodes, the tine or vibratory reed **23** constitutes one vibratory element of a type of tuning fork that includes a vibratory bar **26** having a mass much greater than the mass of the vibratory tine **23**. Both elements **23** and **26** are fixedly secured to each other by being cantilevered from a common base **27**. The arrangement comprises, in effect, a tuning fork having a high degree of asymmetry. One prong of the tuning fork, vibratory tine **23**, has a relatively low mass, and the second prong, vibratory bar **26**, has a much greater mass, in the order of 10 or more times as great as the mass of the tine **23**.

Fine tuning of the asymmetrical tuning fork of the illustrated tone generator is readily effected by merely sliding along the cylindrical wire or tine **23** a helical compression spring **29**, which is bent or twisted at the midportion thereof in order to ensure against undesired movement.

Preferably the low mass vibratory tine **23** and the common base or crossmember **27** are constructed, arranged and connected to each other just as are the corresponding elements described in U.S. Pat. No. 3,418,417. Further, although the high mass vibratory bar **26** has a unique configuration, different than that shown or described in any of the above-identified patents, it is secured to the common base **27** by means of a capscrew **53** in a manner identical to that described in U.S. Pat. No. 3,418,417.

The vibratory elements **23, 26**, are fixedly secured at one end thereof to the common base **27** and are accordingly cantilevered therefrom to provide a unitary assembly. A connecting segment **44** of the high mass inertia bar **26** extends integrally and rearwardly of the tuning fork to a mounting or securing arm **45**. The entire tuning fork assembly including common base **27**, tine **23**, and inertia bar **26**, is mounted to the horizontal support member **10** in acoustical isolation therefrom by means of a pair of screws **31, 32**, that extend through apertures in the mounting arm **45** of the inertia bar. Springs **36, 37**, encircle the shanks of screws **31, 32**, and are interposed between the mounting arm **45** and support **10** to enable adjustment of the vibratory assembly and to provide acoustical isolation therefor. Further details of the tone generator mounting are shown in FIGS. **14** and **15** of U.S. Pat. No. 3,384,699.

As described in further detail in the above-cited patents, a mechanical to electric transducer **38** is adjustably mounted adjacent the free end of tine **23**. The transducer is preferably of the electromagnetic variety, incorporating a permanent magnet core **39**, a coil **40**, and support means **41** for adjustably connecting the core and coil to the element **11** or other support. Coil **40** is suitably electrically connected to amplifier **42** and loud speaker **43** so that vibrations of the tine **23** will be reproduced in the speaker as desired. Other types of transducers, such as capacitive devices for example, may be employed and details of the sensing construction and mounting may be varied without departing from principles of the invention.

TWISTED INERTIA BAR

It is to the improved and novel construction, configuration, and arrangement of the high mass vibratory bar **26** and its novel cooperation with corresponding or similar high mass vibratory bars of an assembly of asymmetrical tone generators that the present invention is most particularly directed.

The conventional tuning fork is widely used as a basic fixed frequency sound source. It consists of a pair of cantilevered bars attached to a common base. The two bars vibrate in opposition whereby the force exerted upon any external supporting means is small. Thus a massive base for acoustic absorption and isolation is not required. The resonant frequency of the conventional tuning fork is determined from dimensions of its prongs or vibratory bars. The fundamental vibratory frequency f_1 of a vibratory bar of uniform cross section is given by

$$f_1 = \frac{0.5596}{l^2}\sqrt{\frac{QK^2}{p}}$$

where

l = **length of the bar, in centimeters**

p = *density, in grams per cubic centimeter*

Q = Young's modulus, in dyes per square centimeter

K = radius of gyration

For a rectangular cross section, the radius of gyration of a cantilevered bar is

$$K = \frac{a}{\sqrt{12}},$$

where a = thickness of the bar, in centimeters, in the direction of vibration.

As indicated in the above-identified U.S. Pat., No. 2,972,922, the use of conventional tuning forks in an electrical piano is highly unsatisfactory since such tuning forks have excessively long dwells and do not produce an initial percussive effect. Such systems fail to adequately simulate an actual acoustical piano and, nevertheless, are expensive and difficult to manufacture. Circular cross section tines cannot be employed without serious degradation of tonal qualities. To overcome these disadvantages, the above-identified patents suggest various forms of asymmetrical tuning forks. The asymmetrical tuning forks of these patents all embody a primary low mass vibratory tine which is arranged to be struck by the actuating mechanism and thereupon experiences a vibration that is sensed by the transducer of the tone generator. These tuning forks are highly asymmetrical in that the inertia bar thereof is of a much greater mass. The mass of the working portions of the inertia bar of these asymmetrical tuning forks is at least 10 times the mass of the tine and preferably at least 25 times the mass thereof. Nevertheless, the fundamental

vibrational frequencies of the two elements are made substantially equal whereby the two elements are in near resonance with each other.

These asymmetrical tone generators provide many advantages as tone generators for an electrical piano as described in detail and at length in the above-cited patents. However, the cantilevered bars, including the high mass inertia bars of such asymmetrical tuning forks, vibrate in complex modes including a fundamental frequency and overtones. A cantilevered bar vibrating transversely at a fundamental frequency f_1 has a first overtone of $6.267 f_1$, a second overtone of $17.55 f_1$, and a third overtone of $34.39 f_1$. Thus the first overtone of a bar or reed has a higher frequency than the sixth overtone of a string. These overtones degrade the system output.

One advantage of the inertia bar of the asymmetrical tone generator is its resonance with the fundamental frequency of the tine. This enables its operation to increase amplitude of vibration of the tine. Accordingly, it will be readily appreciated that undesirable frequency modes of the inertia bar should be minimized. If the inertia bar has a significant overtone amplitude, this overtone, in addition to the fundamental, will also be amplified, appearing as an undesired vibratory mode of the tine itself.

With prior inertia bars, it is found that when certain relationships are present between bar length and cross-sectional area, higher overtones of the modes of vibration of the bars become more troublesome. This problem increases in severity as bar size increases, with decreasing frequency. At middle and, particularly at lower frequency ranges, not only do the amplitudes of the higher frequency overtones become increasingly undesirable, but the frequency of the overtone itself is much closer to the fundamental. For example, with a fundamental tone of frequency f_1=1,000 cycles per second a first overtone of $6 \times f_1$ is 6,000 cycles per second. On the other hand, for a fundamental tone of frequency f_2=100 c.p.s., a comparable first overtone may be 600 c.p.s., which is displaced from the fundamental by only 500 c.p.s. Thus, it will be seen that undesirable overtones are more prominent and more difficult to handle at lower frequencies.

Where a lower frequency inertia bar of an asymmetrical tone generator experiences vibrational modes that entail significant overtones, such overtone modes will also reinforce vibrational modes of the tine whereby these undesirable high frequencies are more likely to be amplified and picked up by the transducer that is primarily adapted for the lower frequency.

It is found that forming the inertia bar with an oblong cross section, and twisting the bar so that throughout its working portion, it has a significantly greater depth than width, its overtone modes of vibration are minimized.

Thus, by twisting the flat oblong cross section inertia bar, it is provided with a relatively wide connecting segment at which it may be fixedly secured to the common base, and a relatively wide mounting arm at which it may be secured to other elements of the main support. Yet the bar has the highly desirable orientation and configuration of maximized transverse dimension in the common plane of vibration and minimized transverse dimension normal to such plane. The twisting of a flat bar of elongated cross section provides the cheapest, simplest, and most effective way to achieve these results.

As illustrated in the drawings, the inertia bar **26** is formed with a twist **48** in the working portion of the bar immediately adjacent its connecting segment **44**. The connecting segment is formed with an aperture **49** to receive the cap screw **53** that rigidly secures the inertia bar to the common base **27**. Mounting arm **45** of the inertia bar is formed with a pair of apertures **50, 51**, to receive the mounting screws **31, 32**, that secure the tone generator assembly to the support member **10**.

The minimized overtone modes of the twisted inertia bar of oblong cross section may be heuristically explained as follows. One can readily visualize a bar of small cross section as capable of bending, during transverse vibration, with relatively closely spaced nodal points. With such a small cross section bar the amplitude of peak displacement of a point on the bar can be relatively great. On the other hand, a bar of relatively large cross section, or at least one having a greater dimension in the plane of its transverse vibration, will bend with much lesser peak displacements between closely adjacent nodal points.

Vibrational nodes having closely spaced nodal points are higher frequency overtones. Thus, from this heuristic example it can be understood that for a given length of transversely vibratory bar, increasing its dimension in the plane of its vibration will decrease the amplitude of its overtones.

This diminution of overtones is achieved by two different results of the twist formed in the inertia bar. First, the dimension of a major length of its working portion is increased in the plane of vibration. Second, for a given length its fundamental frequency is decreased by the much decreased dimension (in the vibratory plane) of that portion of the bar between the twist and the common base.

The overtone modes entail relatively sharp bending of the parts of the bar remote from its cantilever support. With the twisted bar such parts are of increased dimension (relative to the dimension at its clamping point) in the plane of vibration wherefor the overtones are of diminished amplitude.

In addition to the significant diminution and suppression of high overtones for lower and middle range fundamental frequencies, many additional advantages accrue from the use of the twisted inertia bars. Although the bar employs maximum available width for mounting, its twisted configuration provides relatively large spaces between working portion of adjacent bars as can be seen in FIGS. **2** and **3**. Thus, there is provided physical access to the operating mechanism and to the tine itself. This may be required for adjustment of the tuning weight of the tine **23** or for adjustment of various parts of the hammer and damper mechanism.

Further, and of equal importance, visual access to the adjacent mechanism is provided whereby various adjustments may be made while monitoring the action both through sound and sight. For example, in order to position the end of tine **23** in its proper relation with respect to the sensing edge of transducer **38**, adjustment is facilitated by both viewing the relative positioning of the two elements and simultaneously listening to the sound produced thereby.

The above-described configuration of asymmetrical tuning fork also provides for a structure of significantly lesser weight without sacrifice in tonal range or quality of the overall instrument. Decrease in weight is due to various factors including the elimination of unnecessary and inoperative mass of the working portion of the inertia bar in positions laterally displaced form its vibratory plane and, further, by the decrease in size and elimination of counterweights permitted by the use of compliance increasing slots (described in detail below) in the inertia bar connection segments.

In addition to the above-enumerated advantages, a significant decrease in cost results from the use of the above-described configuration. A low frequency inertia bar for an asymmetrical tone generator as described herein may be manufactured for less than one-fifth the cost of the equivalent low frequency inertia bar that has previously been made. Similar savings are afforded for all of the tone generators excepting the group of very highest frequencies. Whereas, for prior configurations, extruded aluminum bar stock is machined and provided with a counterweight, inertia bars for asymmetrical tone generators according to the present invention may be formed from cold-rolled steel stock in a single progressive pass through a punch press, wherein the bar is twisted, bent as required, and all of its mounting holes are punched rather than drilled.

INERTIA BAR SIZES

The actual cross-sectional dimensions of the various inertia bars may be widely varied as long as the larger of the two

cross-sectional dimensions is several times greater than the smaller.

In a piano, the width of the inertia bars is dictated by the established spacing of the keys, which is about one-half inch from center to center. Thus, the maximum cross-sectional dimension of the inertia bar is made slightly less than one-half inch in order to provide and ensure clearance and acoustical isolation between adjacent bars. Preferably the bar width is as great as possible in order to obtain strength in the mounting arm and to increase the cross-sectional dimension of the twisted body portion in the vibrating plane.

Thickness of the bar is preferably as small as is practical considering the requirements of strength, resistance to wear and tear, resistance to shock, and possibly abusive handling of the instrument. With these considerations in mind, a minimum thickness of the inertia bar stock is in the order of one-eighth of an inch. Thus, the cross-sectional area of such a tone generator inertia bar is in the order of 0.06 square inches which is considerably less than half of the cross-sectional area of the previously employed three-eighths inch square inertia bars. This diminished cross section, together with other size reducing features to be described below, permits the bars to be made of steel, rather than the much weaker aluminum previously used, and still achieve an assembly of reduced weight.

Further, use of flat, relatively thin steel stock provides maximized economy of fabrication. All holes may be punched in the thin steel, whereas holes must be drilled in the previously used three-eighths square aluminum stock. The entire bar may be formed in a single pass through a punch press.

The high mass inertia bar **26**, including its main body portion, its connecting segment **44**, and its mounting arm **45**, is preferably formed of a single length of rolled steel stock having a significantly elongated cross section. In a particular electrical piano embodying tone generators of the type herein described, the inertia bar of all the asymmetrical tuning forks are made of one-eighth inch flat stock and all but a group of the higher frequency ones of these have a width of 0.490 inch. The bars of the higher frequency group have a slightly lesser width of 0.437 inch as will be more particularly described below. Thus, the stock of which the inertia bar is made has a flattened or oblong cross section roughly in the order of one-eighth by one-half inch.

The inertia bar **26** is formed with a 90° longitudinal twist therein as indicated at **48**. With this configuration the bar is oriented so that the greater dimension of the cross section of the connecting segment **44** and mounting arm **45** extends substantially normal to the vibratory plane, whereas the greater dimension of the working portion or main body portion **26** of the bar extends in the plane of vibration.

The desired configuration of inertia bar, according to principles of this invention, provides a mounting arm of maximum transverse dimension, as limited by piano key width, and a working portion extending for most of its length with minimum transverse dimensions and increased dimension in the plane of vibration. Such configuration may be achieved by many different manufacturing processes using either integral bars machined or extruded to yield the desired shape, or using bars assembled from several parts. It is not necessary that the connecting segment and mounting arm be of oblong cross section as long as the major extent of the working portion of the bar is oblong and oriented as described. Nevertheless the disclosed integral twisted bar of flat stock is preferred because it provides a finished assembly of minimum size and weight and maximized convenience and economy of fabrication.

TWISTED BAR VARIATIONS AT DIFFERENT FREQUENCIES

As previously indicated, different characteristics of tone generators may be more pronounced at differing frequencies. Accordingly, for a full range of frequencies, several different forms of inertia bars for the asymmetrical tone generators may be employed. A portion of an exemplary electrical piano having 73 notes as illustrated in FIG. **3**. Several of the inertia bars of this piano are shown somewhat enlarged in FIG. **2**. As can be seen in FIG. **3**, the instrument includes 73 asymmetrical tone generators, each having an individual inertia bar, designated as **I–1** through **I–73**.

The inertia bars are of three general types, those designated as **I–**through **I–25** form a low frequency group, those designated as **I–26** through **I–53** form a midrange frequency group, and those designated as **I–54** through **I–73** comprise a high frequency group. Within these groups, the low frequency group itself contains two types of inertia bars, the lowermost set of bars of the low frequency group, designated as **I–1** through **I–12**, and the remainder of this group, **I–13** through **I–25**.

The inertia bar **26** illustrated in FIGS. **1** and **2** and described above, is typical of each inertia bar of the midrange frequency group designated as **I–26** through **I–53** of FIG. **3**. The various bars within this group differ solely in the length of the working portion of the inertia bar. The connecting segment and mounting arm of all bars within this group are identical, as are the location and position of the apertures therein. Each bar as previously described has a pair of apertures for receiving the tone generator mounting screws and a single aperture for receiving a cap screw to secure the common base to the inertia bar. Thus, each of inertia bars, **I–26** through **I–53**, is identical to each other bar of this group from its twist portion **48** to its fixed end. The length of the working portion of each of these bars, of course, varies to provide the specifically required natural frequency of the individual tuning fork. The cross section size and shape are all the same for inertia bars of this group.

It may be noted that precisely equal frequencies of the two vibratory bars of the asymmetrical tuning fork are not required. Preferably the high mass bar has a low Q so that it will resonate with the tine over a range of frequencies. In practice it is found that for low and midrange frequencies the natural frequency of the inertia bar may vary from that of the tine within a range of about 2½ piano tones. At highest frequencies, it is preferable to hold such variation to less than one-half tone.

Even when the two bars of a tone generator are not in precise resonance, control of the plane of vibration is still achieved, although dwell is shortened.

The bars of the low range group of inertia bars designated **I–1** through **I–25** are each similar to the inertia bars of the midrange group in that each has a securing arm with two screw-receiving apertures therein and each has a connecting segment with a screw-receiving aperture for connecting the inertia bar to the common base of the individual tuning fork. However, in each of the inertia bars of the low frequency group **I–1** through **I–25**, the twist **48***b* or **48***c*, instead of being located immediately adjacent the securing aperture **49***b* or **49***c* is displaced therefrom along the working portion of the inertia bar for a short distance. In an exemplary embodiment this distance is slightly greater than 1½ inches. An elongated slot such as slot **52***b* or **52***c* is punched in the bar between the twist and the aperture **49***b* or **49***c*. The slots **52***b*, **52***c*, which are centrally located with respect to the width of the inertia bar, are preferably one-quarter inch wide and 1 inch long for bars of the indicated dimensions and materials. It will be understood that the size, shape, and specific location of these slots may be varied in groups or individually to afford optimum tone characteristics. Nevertheless, to attain maximum similarity in manufacturing of the inertia bars, all slots of bars **I–1** through **I–25** are formed and positioned exactly alike. Accordingly, each of inertia bars **I–1** through **I–25** is identical to each other bar of this group from its twisted portion **48***b* or **48***c* to its fixed end. Again, these bars differ from other bars in the low frequency group in length only, except for a subgroup of bars **I–1** through **I–12** to be presently described.

The elongated slot **52***b* or **52***c* provides an increased compliance of the working portion of the bar immediately ad-

jacent its cantilevered connection to the common base. This increased compliance decreases the coupling of the bar to its common base and also helps to decrease overtone modes.

The slot is important in that it achieves the benefits of a counterweight added to the end of the working portion of the bar, and thus provides a relatively lower fundamental frequency without undue length and without the need for additional end mounted counterweights. The increased compliance achieved by the slots in the low range group supplements the increased compliance due to the bar's twist. The twist provides the bar at its cantilevered mounting with a substantially decreased dimension in its plane of vibration, thus introducing an increase in compliance.

The slot is a decidedly advantageous way of increasing compliance, particularly in a twisted inertia bar of the described tone generator. The slot is readily and uniformly fabricated during the single progressive manufacturing pass through the punch press in which the entire inertia bar is formed. It is precisely repeatable in dimension and location and, being centrally disposed with respect to the bar, effects less of a decrease in strength.

It will be understood, of course, that each of the inertia bars, I–1 through I–73 shown in FIG. 3 is but one of the vibratory elements of an asymmetrical tone generator of the type illustrated in FIG. 1. Accordingly each is connected through a common base, analogous to common base 27, to a cylindrical cross section vibratory tine 23 having an associated transducer pickup, all as previously described. Only the inertia bars of the assembly of tone generators are shown in FIG. 3.

Each of the vibratory tines is tuned to the desired fundamental frequency. As frequency is decreased the length of the tine is increased, although several different diameter tines may be employed in order to avoid excessively long thin tines or excessively short thick tines. Fine tuning is achieved, as previously described, by sliding weight 29 (FIG. 1). Nevertheless, for tines of increased length and decreased frequency there is an increased amplitude of excursion of the free end portion of the tine. Furthermore, as compared with inertia bars of three-eighths inch square cross section as described in the above-cited patents, the inertia bars I–1 through I–53 of the instrument illustrated in FIG. 3, have a depth normal to the plane of the paper in FIG. 3, of nearly one-half inch. For these reasons interference between the tine and the inertia bar is possible when the piano key is struck with excessive force.

The elimination of this problem is still another advantage of the described inertia bar configuration. Use of a bar of flat stock enables its relatively thin working body portion to be more readily provided with a rebated or offset bend. This will allow greater amplitude excursion of the low frequency tine without contacting the inertia bar. In prior devices, it is possible by striking a key with suitable force, to cause the end of certain of the low frequency tines to actually contact the body of the inertia bar. In the present arrangement, even though the inertia bar has a greater dimension in the vibratory plane than the comparable dimension of prior inertia bars, no such contact is possible because of the use of the rebated body section.

To provide full clearance for a maximum amplitude excursion of the associated tine, each of the lowest frequency inertia bars, identified as I–1 through I–12 in an exemplary embodiment, is formed with bends 61 and 62 that define an offset or rebated portion 60 positioned near the free end of the associated tine. Thus, part of the working portion of the inertia bar is laterally displaced from the plane of vibration of the tine and inertia bar whereby no interference occurs. It is noted that in each of the inertia bars I–1 through I–12, a significant length 63 (FIG. 4) of the free end of the bar is returned via bend 62 to extend in a plane containing the common centerline 65 of mounting arm 45*b*, connecting segment 44*b*, slot 52*b*, and a first undisplaced portion 64 of the twisted body of the bar. The return length 63 repositions the center of mass of the working portion of the inertia bar substantially in the desired common plane of vibration of bar and tine. This arrangement is required in order to ensure that the tine vibrates in a common plane containing centerline 65. If the inertia bar is merely formed with a single bend, such as bend 61, and a laterally displaced end portion, the center of mass of bar becomes laterally displaced whereby the plane of vibration of the tine is angularly displaced (pivoting about an axis normal to the plane of the paper in FIG. 4) and tends to align itself with the plane containing the center of mass of the inertia bar. For this reason, it is theoretically desirable to return the free end portion 63 of inertia bars I–1 through I–12, not only just to the centerline 65, but beyond such position in order to compensate for the laterally displaced mass of the offset or bent portion 60. However, in practice, it is found that where the free end portion has a substantial extent beyond the return bend 62, the lateral displacement of mass due to offset portion 60 has negligible adverse affects upon the tonal quality and operation of the described instrument.

Again, for convenience of manufacture of the exemplary embodiment rebated portion 60 in each of inertia bars I–1 through I–12 is made with the same dimensions, each comprising a lateral offset of about one-quarter inch and having a straight run through the rebated portion of about 2 inches. However, the position of the bend varies with different inertia bars in order to follow the different lengths of the associated tines. It will be recalled that the offset portion 60 is positioned substantially at the free end of the coacting tine. Thus, for example, in inertia bar I–1 dimension A is 11.12 inches and dimension D is 6.50 inches, whereas for bar I–12, dimension A is 8.62 inches and dimension D is 5.30 inches. Except for the position and existence of the offset portions, and except for the varying lengths required to generate the individual natural frequency, each of the inertia bars I–1 through I–25 is identical to each other.

High overtone modes of vibration of a group of high frequency tone generators including inertia bars indicated at I–54 through I–73 of FIG. 3, are considerably less of a problem than such modes at lower frequencies. The first three overtones of transverse vibration of a cantilevered bar are roughly 6, 17, and 34 times the fundamental frequency of vibration of the bar. Accordingly, at a fundamental frequency of 3,000 c.p.s., the first overtone is well above 18,000 c.p.s. which is a frequency beyond the audible range of most persons. (The average upper limit of frequency of hearing for a person under 40 years of age with good hearing is about 15,000 c.p.s.)

For example, where the set of 73 tone generators of the instrument of FIG. 3 is arranged to provide frequencies in the scale of equal temperament in the scale of C, varying from 16 to 16,000 c.p.s., the 54th tone generator (I–54) has a frequency of 2,637.0 c.p.s. (See Page 29 of Music, Physics and Engineering, Harry F. Olson, Second Edition, Dover Publications, Inc., New York, N. Y.). When multiplied by 6.26, the actual first overtone of this frequency (of a vibratory cantilevered bar) is obtained as 16,407 c.p.s. Thus, it will be seen that higher overtones of the higher frequency group of the inertia bars of the group designated as I–54 through I–73 cause no problem. For this reason the tone bars in this group of higher frequencies need not be twisted as are the inertia bars of all lower frequency tone generators.

The many advantages of the described configurations of inertia bars go beyond the improved tonal quality that derives from suppression of overtones. These additional advantages relate to the various adjustments required of the instrument from time to time as have been described in connection with the mechanism shown in FIG. 1.

One common adjustment is the tuning of the natural frequency of the vibratory tine 23. As described in the above-cited patents, the inertia bar 26 has a relatively low Q, that is, a flat and broad rather than sharply tuned natural frequency. Therefore, the natural frequency of tine 23 may be varied over a limited range while still retaining mutual resonance between the tine and the inertia bar 26. This variation of natural frequency of the tine 23 is achieved by physically sliding the weight 29 along the length of the cylindrical tine.

The vertically elongated cross section of the inertia bar provides access for a tool with which to manipulate weight **29**. Further, it allows the position of the weight to be visually monitored as it is adjusted.

An additional adjustment is that provided for the damper **25**. This damper must be adjusted so that it will just touch the tine **23** when both the hammer and the damper are at rest. The damper must be displaced from the tine just at or prior to the striking of the tine by the hammer **22**. Again, adjustment of this action of the damper is greatly facilitated by the space between the vertically elongated inertia bars that allows insertion of an adjusting tool. Still more important, this spacing allows visual monitoring of the combined operation of hammer and damper to ensure proper positioning of the latter.

Timber or tonal quality of the signal produced by the transducer **38**, is controlled by the relative position of the free end of tine **23**, when at rest with respect to the chisel edge of the transducer element **39**. Mounting elements **31**, **32**, **36** and **37** allow the tine to be moved vertically up or down in the plane of the paper of FIG. **1** when both screws **31** and **32** are adjusted, and allow the tine to be tilted when the one or the other of these screws is adjusted. The vertical elongation of the inertia bars **26** allows visual access to enable the operator to see the position of the tine end as the adjustment is being made.

Physical and visual access between adjacent tone generators is achieved even though the full width of lateral dimension available to each tone generator is employed for maximum strength and assembly of the mounting of the tone generator to the support **10**.

For each of the previously described adjustments, the arrangement of the prior art tone generators employing inertia bars of substantially square cross section allows neither physical nor visual access to the underlying operating mechanism whereby for the above-identified adjustments it was often necessary to raise the entire assembly of a complete set of tone generators or to employ an arrangement of mirrors to view the adjustments as they were made. Where the assembly of tone generators is raised, of course, the tine is moved from its contact with the damper and the adjustment of the latter cannot take place while these two elements are in normal relation.

There has been described an electrical musical instrument embodying asymmetrical tone generators of improved design. Low and midrange frequency tone generators embody inertia bars of oblong cross section that are twisted substantially at their point of cantilevered securement to thereby minimize high overtones and greatly facilitate various adjustments of the piano and tone generating mechanism.

The foregoing detailed description is to be clearly understood as given by way of illustration and example only, the spirit and scope of this invention being limited solely by the appended claims.

We claim:

1. An electric piano, which comprises: an elongated and substantially cylindrical metal tine having a low mass and a small diameter, an elongated metal bar having a high mass much greater than that of said tine,

said bar being a strip the cross-sectional shape of which is oblong, said bar being twisted about the longitudinal axis thereof and at one point along the length thereof to form a first section on one side of the twist region and a second section on the other side of the twist region,

the major dimension of the oblong cross section of said first bar section being transverse to a plane containing the major dimension of the oblong cross section of said second bar section,

a common base,

connector means to rigidly connect one portion of said base to said second bar section,

connector means to rigidly connect another portion of said base to one end of said tine,

said tine extending from said base in a direction generally parallel to said first bar section and in overlapping relationship to said first bar section,

said tine forming one prong of a two-pronged tone generator,

the other prong of said tone generator being formed by said first bar section, by said twist region, and by the portion of said second bar section between said twist region and said first-mentioned connector means,

said tine lying in a plane which extends through at least a large portion of said first bar section,

said last-mentioned plane being substantially parallel to the major dimension of the oblong cross section of aid first bar section,

means to mount said tone generator to a support, a piano action having a key and also having a hammer adapted to strike said tine in response to pressing of said key, and mechanical-electrical transducer means to sense the resulting vibrations of said tine and generate a corresponding electrical signal for amplification and conversion into sound.

2. The invention as claimed in claim **1**, in which the mass of said metal bar is at least ten times the mass of said tine.

3. The invention as claimed in claim **1**, in which said means to mount said tone generator to a support effects a loose coupling therebetween.

4. The invention as claimed in claim **1**, in which said second bar section is extended in a direction away from said first bar section to form a mounting arm integral with said bar, said mounting arm forming part of said means to mount said tone generator to a support.

5. The invention as claimed in claim **4**, in which the major dimension of the oblong cross section of said first bar section is perpendicular to a plane containing both the major dimension of the oblong cross section of said second bar section and the major dimension of the oblong cross section of said mounting arm, in which said mounting arm has opening means therethrough, and in which said mounting means further comprises two elongated elements extending through said opening means and anchored to said support, there being resilient means seated between said support and said mounting arm to create a floating relationship.

6. The invention as claimed in claim **1**, in which said second bar section has a hole therethrough, in which said base comprises an elongated rigid metal element, in which said first-mentioned connector means comprises a fastener extended through said hole to rigidly connect one end of said elongated element to said second bar section, and in which said second-mentioned connector means comprises a hole in the other end of said elongated element and in which said one end of said tine is fixed.

7. The invention as claimed in claim **1**, in which said portion of said bar between said twist region and said first-mentioned connector means is elongated.

8. The invention as claimed in claim **7**, in which said elongated portion has an opening therethrough to increase the compliance thereof.

9. The invention as claimed in claim **8**, in which said opening is a slot which extends longitudinally of said bar.

10. The invention as claimed in claim **1**, in which a portion of said first bar section is offset to insure that there will be no contacting of said tine with said first bar section when said tine is struck by said hammer, the direction of offset being generally perpendicular to said last-mentioned plane.

11. The invention as claimed in claim **1**, in which said tine and said bar are substantially tuned to each other to provide a tuning fork relationship therebetween.

12. The invention as claimed in claim **11**, in which said means to mount said tone generator to a support is connected to said tone generator adjacent the junction between said base and said second bar section, whereby said tone generator is cantilevered from said support, said mounting means effecting a loose coupling between said tone generator and said support.

13. The invention as claimed in claim **1**, in which large numbers of said tone generators are disposed in generally horizon-

tal, closely spaced relationship with the bar of each tone generator above the tine thereof, and in which the piano action for each tone generator is disposed below the tine thereof, and in which the minor dimension of the oblong cross section of each of said first bar sections is sufficiently small that substantial gaps are formed between adjacent ones of said first bar sections, said gaps serving to provide visual and mechanical access to said tines and to said piano actions.

14. The invention as claimed in claim **13**, in which said transducer means for each tone generator is an electromagnetic transducer adjustably mounted adjacent the distal end of an associated tine, and in which weights are adjustably mounted on said tines, whereby said transducers and said weights may be adjusted by means of tools extended through said gaps.

15. The invention as claimed in claim **1**, in which the twist in said bar is 90° twist.

16. The invention as claimed in claim **1**, in which the mass of said metal bar is at least 10 times the mass of said tine, in which said metal bar is generally tuned to said tine in tuning fork relationship, in which said second bar section is extended in the direction away from said first bar section to form a mounting arm integral with said bar, said mounting arm forming part of said means to mount said tone generator to a support, in which the major dimension of the oblong cross section of said first bar section is perpendicular to a plane containing both the major dimension of the oblong cross section of said second bar section and the major dimension of the oblong cross section of said mounting arm, in which said mounting arm has opening means therethrough and which receive fastener means, said fastener means cooperating with resilient means to mount said mounting arm on said support in floating relationship and with the tone generator cantilevered from said support, in which said second bar section has a hole therethrough, and in which said base comprises an elongated rigid metal element which is rigidly secured at one end to said second bar section by fastener means extended through said hole.

17. The invention as claimed in claim **16**, in which said bar is a steel bar which is about one-half inch wide and about one-eighth inch thick.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,644,656 Dated February 22, 1972

Inventor(s) Clarence L. Fender and Harold B. Rhodes

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 11, line 53 (line 1 of claim 1), "an elongated . . . " should start a main clause; line 55, (line 3 of claim 1), "an elongated . . . " should start another main clause; line 58 (line 6 of claim 1), "said bar . . . " should start a new secondary clause. Thus lines 1 through 9 of claim 1 should be indented as follows:

1. An electric piano, which comprises:
an elongated and substantially cylindrical metal tine having a low mass and a small diameter,
an elongated metal bar having a high mass much greater than that of said tine,
said bar being a strip the cross-sectional shape of which is oblong,
said bar being twisted about the longitudinal axis thereof and at one point along the length thereof to form a first section on one side of the twist region and a second section on the other side of the twist region, ---.

Column 12, line 12 (line 33 of claim 1), "a piano . . . " should start a new main clause; line 15 (line 36 of claim 1), "mechanical-electrical . . . " should start another main clause; thus lines 12 through 18 should be indented as follows:

means to mount said tone generator to a support,
a piano action having a key and also having a hammer adapted to strike said tine in response to pressing of said key, and
mechanical-electrical transducer means to sense the resulting vibrations of said tine and generate a corresponding electrical signal for amplification and conversion into sound.

Column 13, line 17 (line 2 of claim 15), after "is" insert --- a ---.

Signed and sealed this 26th day of September 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

PO-1050
(5/69)

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