March 25, 1969 A. C. IPPOLITO 3,435,122

ELECTRONIC PIANO FEEDBACK REDUCTION

Filed March 31, 1965 Sheet 1 of 3

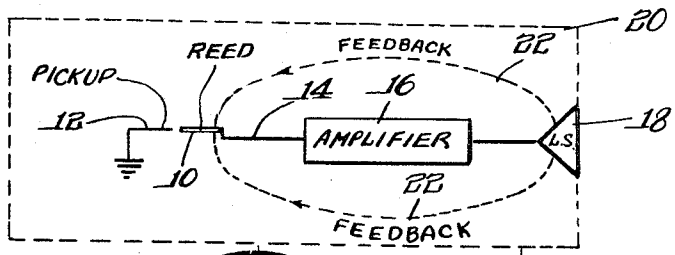

Fig. 1.

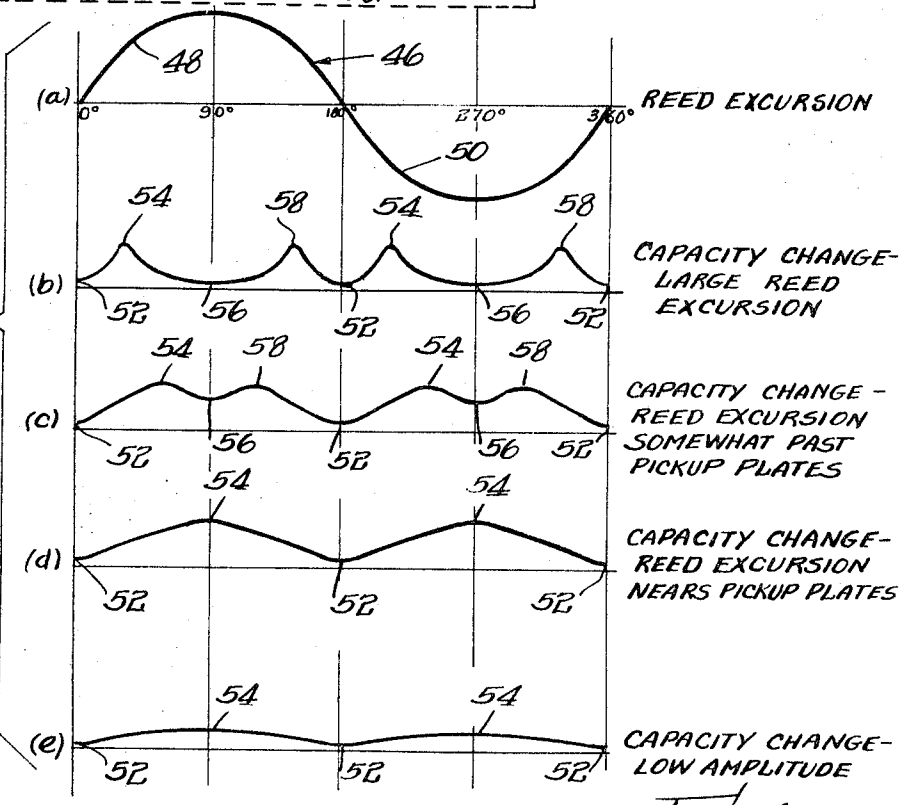

Fig. 5.

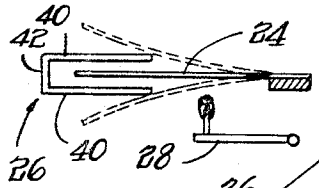

Fig. 2.

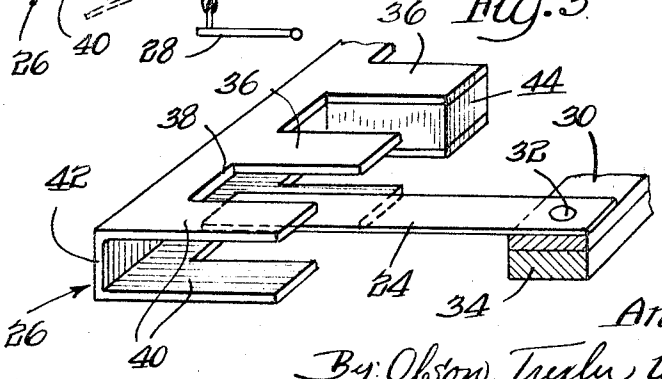

Fig. 3.

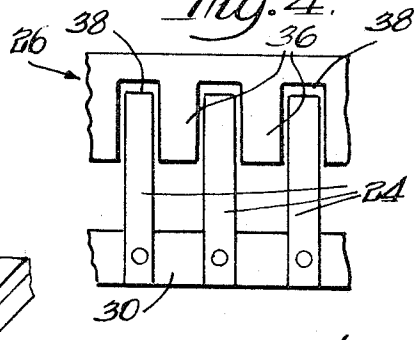

Fig. 4.

Inventor
Anthony C. Ippolito
By: Olson, Trexler, Wolters & Bushnell attys.

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Filed March 31, 1965 Sheet 2 of 3

Fig. 6.

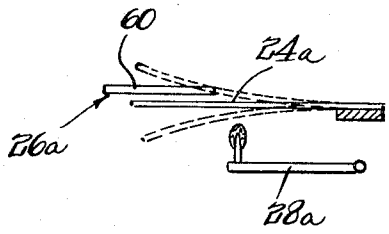
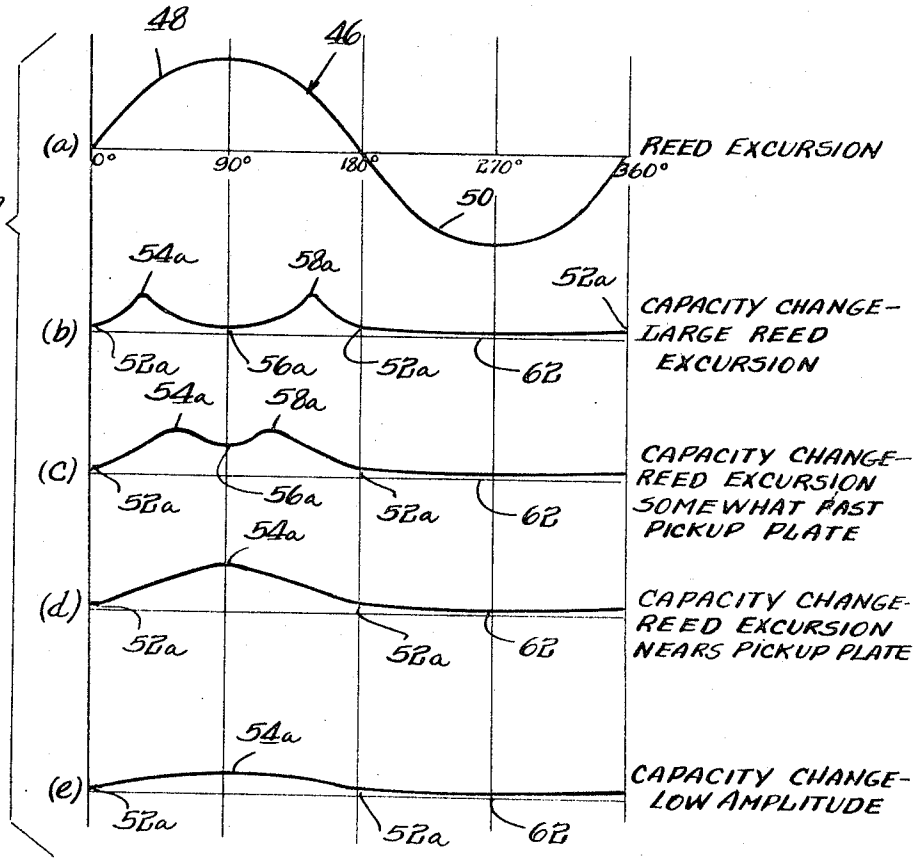


Fig. 7.



Inventor

Anthony C. Ippolito

By: Olson, Trexler, Wolters & Bushnell

attys.

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Filed March 31, 1965 Sheet 3 of 3

Fig. 8.

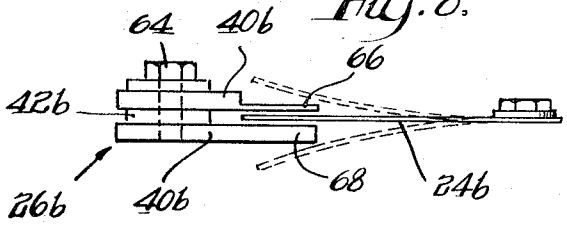
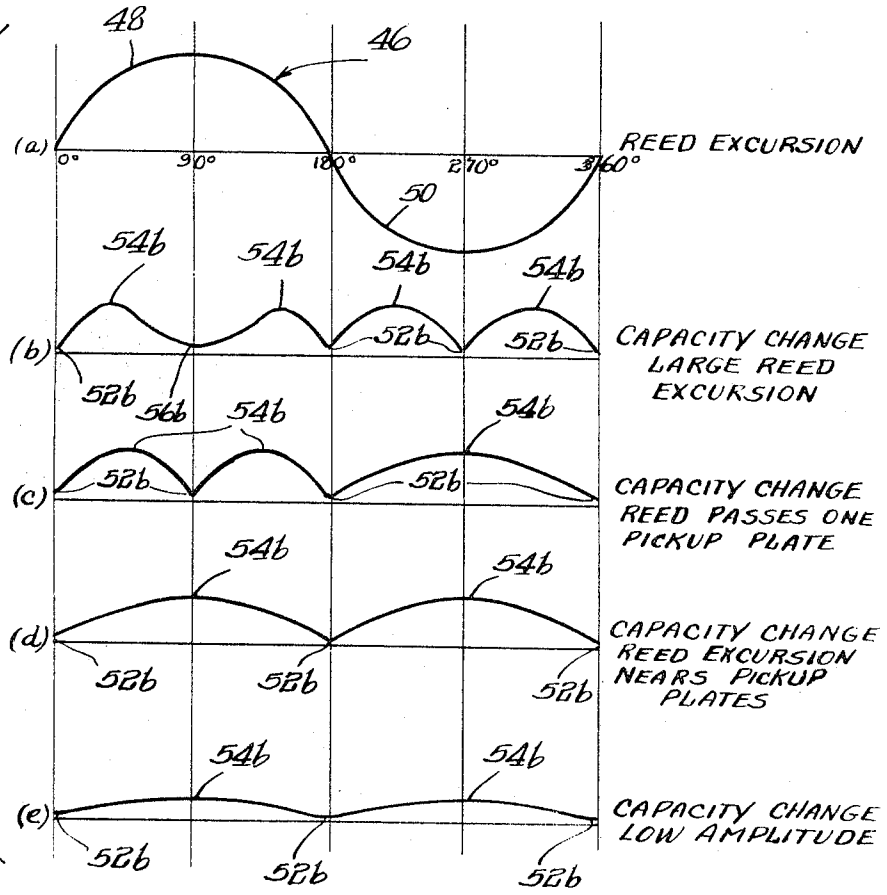


Fig. 9.



Inventor:
Anthony C. Ippolito
By: Olson, Trexler, Wolters & Bushnell
attys.

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3,435,122

ELECTRONIC PIANO FEEDBACK REDUCTION

Anthony C. Ippolito, North Tonawanda, N.Y., assignor to The Wurlitzer Company, Chicago, Ill., a corporation of Ohio

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Int. Cl. G10h 3/00; G01k 9/00
U.S. Cl. 84—1.14 4 Claims

ABSTRACT OF THE DISCLOSURE

An electronic piano utilizing cantilevered, vibratile reeds as the tone generating elements. The reeds are in electrical capacitive relation with a comb-shaped pickup, vibrating in the slots in the pickup to vary the capacity between the reeds and the pickup, which variation in capacity is electrically amplified and converted in a loudspeaker into audible piano-like tones. The positional relation of each reed to the pickup is such that, at low amplitudes of vibration, the variation in capacity contains a high percentage of second harmonic as compared with the fundamental frequency of vibration of the reed, whereby there is little fundamental frequency energy available that might be fed back from the loudspeaker to the reed, whereby undesirably to sustain reed vibration.

This invention relates to the art of electronic music production, and more particularly to improved features in an electronic piano.

The conventional string piano is generally recognized as being the most popular solo instrument, and is widely used both in concert and in homes. The conventional piano does have certain drawbacks, which in given circumstances may be quite substantial. In the best instruments, namely grand pianos, the instrument is quite large and requires a substantial amount of floor space. Even in upright pianos, the instrument is not small. Any conventional piano weighs at least several hundred pounds, and therefore is not readily portable. In addition it is impossible for a student to practice a piano without having the sound therefrom audible over a substantial area. To correct these and other deficiencies, an electronic piano has been developed and commercialized utilizing reeds which are set in vibration by more or less conventional piano actions and which vibrate in electrostatic capacitive relation with a fixed pickup. The capacity change between the reeds and pickups is applied to either a tube type or transistor type electronic amplifier, and the amplified tones are converted into audible sound by a loudspeaker, or by earphones for individual practice. The piano so made is relatively small and light in weight, and can be carried from place to place as a portable instrument.

As will be understood, undue amplitude of reed vibration shortens the service life of reeds as compared with relatively small amplitudes of vibration. It will be apparent that the smaller the amplitude of vibration, the smaller the electrical signal generated. This is readily compensated for simply by increasing the gain in the amplifier. However, increasing the gain in the amplifier increases the seriousness of an inherent difficulty, namely electro-acoustic feedback.

In the electronic piano as mentioned heretofore, all of the parts are mounted in a rather small case. A certain amount of energy from the loudspeaker is transmitted back to the reeds through the case and through the air in the case. This is obviously undesirable as it will tend to cause a reed to remain in vibration a longer period than is desired, and in an extreme case can even result in runaway of the reed, i.e. increasing amplitude of vibration until the reed would destroy itself.

Short of such an extreme case, feed-back energy can keep one or more reeds in sustained vibration, as contrasted with the desired tonal decay of a string piano.

Accordingly, it is an object of the present invention to eliminate the deleterious effects of electro-mechanical feedback in an electronic piano utilizing vibrating reeds as tone generators.

It is a concomitant object of the present invention to produce from an electronic piano tones more closely resembling those of a conventional stringed piano.

More specifically, it is an object of this invention to provide a reed and pickup structure in an electronic piano which for relatively large reed excursion produces a great deal of second harmonic relative to the fundamental tone, thereby simultaneously diminishing the effects of electromechanical feedback and producing a more 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 accompany drawings wherein:

FIG. 1 is a somewhat schematic diagram illustrating the feedback problem;

FIG. 2 is a side view of a reed and pickup substantially eliminating the problem;

FIG. 3 is a perspective view of one of a plurality of reeds and a common pickup therefor;

FIG. 4 is a fragmentary top view showing a plurality of reeds and the common pickup;

FIGS. 5(*a*)–5(*e*) comprise diagrams illustrating wave shapes of the electrical oscillations generated by the reed of FIGS. 2–5;

FIG. 6 is a side view similar to FIG. 2 showing a modification of the invention;

FIGS. 7(*a*)–7(*e*) is a diagram of wave shapes somewhat similar to FIGS. 5(*a*)–5(*e*), but corresponding to the reed and pickup of FIG. 6.

FIG. 8 is a side view similar to FIGS. 2 and 6 showing a further modification of the invention; and

FIGS. 9(*a*)–9(*e*) are wave shapes similar to FIGS. 5 and 7 but corresponding to the reed and pickup of FIG. 8.

Although the present disclosure is complete in and of itself, those who wish to become more versed in the background and in the complete electronic piano are referred to any of several United States Letters Patent issued to C. W. Anderson, including the following: 2,881,651, 2,909,093, 2,949,052, 2,949,053, 2,952,179, and 2,974,555.

Referring now in greater particularity to the drawings, and first to FIG. 1, there will be seen the tone generating or producing portions of an electronic piano comprising a vibratile reed **10** disposed adjacent a pickup **12**, the latter being grounded. The reed is connected by a suitable electric connection means indicated at **14** to an amplifier **16**, preferably employing transistors or vacuum tubes. The amplifier preferably has volume control means for playing the piano at different volume levels, and the amplifier is connected to a loudspeaker **18**. All of the foregoing parts, and also the keys and actions for setting the reeds into vibration are enclosed within a case indicated by the dashed lines **20**. As has heretofore been mentioned, there is a certain amount of feedback from the loudspeaker **18** to the reed **10**, both through the case **20** and through the air in the case. Such feedback is indicated at **22**.

Reference now should be had to FIGS. 2–4 when there will be seen a vibratile reed **24** disposed adjacent a pickup **26** and in electrostatic capacitive relation therewith. The reed is set into vibration by a piano action including a hammer **28**. The reeds are made of electrically conductive material, spring steel being one satisfactory example. A plurality of reeds mounted in side-by-side relation, is seen

in FIG. 4, being individually secured to the top of an insulating member **30**, as by screws **32**, the insulating member being supported on the top of a relatively massive metallic member **34**. All of the reeds are wired in parallel to the amplifier **16**.

The pickup **26** is comb shaped as viewed from the top (FIG. 4), comprising a plurality of teeth **36** projecting between the ends of the cantilevered reeds **24**, the reeds fitting in slots **38** between the teeth. As will be seen in FIGS. 2 and 3, the pickup is somewhat in the shape of a deep channel, having relatively wide upper and lower, spaced apart parallel plates or walls or flanges **40** spaced apart by a relatively narrow, integral web **42**. The upper and lower plates are identical to one another, having overlying fingers **36** and recesses **38**. Preferably the space between the upper and lower plates is filled with an insulating plastic material **44** (preferably a glass base phenolic). In FIG. 3 the plastic material has been removed from between the forward portions of the plates **40** for clarity of illustration, but is seen between the third fingers **36**, measured from the left foreground to the right background. The insulating material also has been left out of FIG. 2 for simplicity of illustration.

The position of the reed **24** in each instance is precisely related to the position of the plates **40** of the pickup, and the amplitude of vibration is likewise so related. Specifically, as seen in FIG. 2 most clearly, the reed **24** is precisely half way between the two plates **40**. Its amplitude of vibration, as indicated in dashed lines above and below the upper and lower plates respectively, is such that the reed is capable of vibrating beyond both of these plates.

It is to be understood that the reeds at the bass end of the scale are the largest, and that the reeds progressively diminish in size up toward the treble end of the scale. The amplitude of vibration of the reeds at the treble end, and even in the mid range is not very great, and the problems of feedback are minimal. It is at the bass end that problems are encountered, and therefore the principles of this invention are directed primarily to the bass reeds.

Attention now is directed to FIG. 5, wherein various wave forms are shown. In FIG. 5(*a*), the reed excursion is illustrated. As will be appreciated, except for some initial distortion due to the percussive impulsing of the reed, the reed vibrates with a sine wave shape **46**, having alternate positive half cycles **48** and negative half cycles **50**. In FIG. 5(*b*), the capacity between the reed and pickup, and hence the voltage generated, is illustrated. The time base is the same. It will be observed that with the reed at its central rest position, the residual capacity as indicated at **52** is rather low. When the reed is first struck with a substantial blow, it is impulsed beyond the upper pickup plate **40**. Thus, the capacity quickly reaches a maximum at **54** when the reed passes the upper plate **40**. The capacity then drops to a minimum at **56** while the reed is beyond the plate **40** and this minimum may or may not be the same as that at **52**, depending on the physical relation of the parts. The minimum is, of course, at the point where the reed has its maximum excursion, although there is a rather shallow valley, as will be appreciated, since the capacity drops to a rather low value when a reed has passed the pickup plate. Subsequently, when the reed descends past the pickup plate, another peak of capacity value is produced at **58**, and the capacity rapidly drops to its initial minimum value, again indicated as **52**, this being 180° of reed excitation or vibration after its initial rest positon. Subsequently, as the reed passes the bottom pickup plate **40** there is another peak of maximum capacity value, again labeled as **54** due to its correspondence in value and also in time relation, but delayed 180°. Likewise, there is another minimum capacity value, again indicated at **56** when the reed has reached its farthest downward excursion. Thereafter, as the reed comes up past the bottom plate **40**, there is another maximum peak **58**, following which the capacity drops off to its initial minimum **52** as the reed reaches centralized position. Thus, it will be seen that there are two pips produced for each half cycle of reed vibration. Thus, a very strong fourth harmonic is generated with the reed vibrating at substantially its maximum excursion. As will be appreciated, there is still a substantial fundamental component, but this is less than the fourth harmonic.

As the reed dies down in amplitude of excursion, there will come a time when the maximum reed excursion is just to and very slightly beyond the pickup plates **40**. This condition is illustrated in FIG. 5(*c*), where it will be seen that the first pip **54** has moved to the right, toward the 90° position relative to reed excitation. Since the reed does not swing so far past the upper pickup plate, the minimum **56** is raised quite substantially. Due to the same consideration of passage of the reed only slightly past the plate, the first pip **58** has been moved to the left, again toward the 90° position of reed excitation. The minima **52** remain as heretofore. The same condition prevails during the negative half cycle, the peaks or pips **54** and **58** moving closer to the 270° position, and the minimum **56** again being raised.

The pips **54** and **58** as described above are primarily fourth harmonic. However, it will be appreciated that from a Fourier analysis that there are other components present, including the fundamental. When the reed excursion decays to the point where the reeds just reach or do not quite reach the pickup plates, then the maximum or peak **54** shifts over to the 90° position as shown in FIG. 5(*d*). The peak **58** loses its separate identity, being merged with the peak **54**, and there is no valley or minimum **56**. The minimum **52** remains the same as heretofore.

Subsequently, as reed excursion decays still further, the wave form will remain much the same as in FIG. 5(*d*) but the amplitude of the peak **54** will be diminished, and the peak will broaden somewhat, see FIG. 5(*e*).

From the foregoing, it will be appreciated that at no time does a wave comprise primarily a strong fundamental. Generally speaking, it is only the fundamental that is a problem in feedback, since the reed does not tend to respond in vibration to fedback energy of harmonics. Also, it will be observed that the harmonic structure changes during the period of free decadent vibration of the reed after it has been percussively excited, and this causes the resulting tone to sound more like that of a stringed piano.

A modification of the invention is shown in FIG. 6. In FIG. 6, and also in FIG. 7, similar numerals are utilized with the suffix *a* to identify like parts. The essential difference, as seen in FIG. 6, is that the pickup **26***a* does not comprise two plates, but rather comprises a single plate **60**. This plate is of the comb shape heretofore described, and it lies somewhat above the reed **24***a*. The reed during its upward excursion passes beyond the plate **60**, as is shown in dotted lines, and also swings farther away from the plate during its downward excursion.

With reference now to FIG. 7, it will be seen that the reed excursion again is a sine wave, plotted exactly the same as in FIG. 5(*a*). The capacity change through the first 180 of reed excursion, as plotted opposite FIG. 7(*b*), is the same as it was in FIG. 5(*b*). However, it should be noted for the sake of accuracy that the amplitude at the zero time point and also at 180°, as indicated at **52**(*a*), is not truly a minimum, even though it is the capacity at rest position. This is due to the departure, as seen from 180° to 360° in FIG. 7(*b*) from the previous wave form. Since there is no second plate, the capacity continues to decrease past 180°, and reaches a minimum which is substantially zero somewhat before the 270° position (the maximum downward reed excursion), and remains substantially at zero to somewhat past the 270° position, rising again to the zero degree position **52**(*a*) at 360°. This rather broad, substantially zero minimum is indicated at **62**.

When the reed passes somewhat past the pickup plate **60**, the resulting wave form is as shown in FIG. 7(*c*). The

first 180° of vibration produces a wave form similar to that shown in FIG. 5(*c*). However, when the reed swings downward from its rest position it again produces a substantially zero minimum **62**, generally of somewhat lesser width.

When the reed then diminishes in amplitude of vibration to the position where it nears or just reaches the pockup plate, the peak **54***a* shifts to the 90° position, just as it did in FIG. 5(*d*). However, on the negative half cycle the capacity again reaches substantially zero, this time being even closer to a negative peak at the 270° position and of less width.

The wave form of FIG. 7(*d*) is substantially repeated in 7(*e*), although the peak **54***a* is reduced in height due to the fact that the reed does not vibrate as close to the pickup plate.

In FIGS. 7(*b*) and 7(*c*) it will be seen that a second harmonic is produced as compared with the fourth harmonic in FIGS. 5(*b*) and (*c*). In FIGS. 7(*d*) and (*e*) it is essentially the fundamental that is produced as opposed to the second harmonic in FIGS. 5(*d*) and (*e*). It will be appreciated that the amplitude of the fundamental in FIGS. 7(*d*) and (*e*) is sufficiently low that feedback problems are of no importance. It further will be appreciated that even though it is primarily a fundamental that is seen in FIGS. 7(*d*) and (*e*), there will be a certain amount of harmonics, since the wave is not a sine wave. It again will be seen that the harmonic structure shifts as the reed decays in amplitude of vibration, and hence a more natural piano-like sound is produced. Thus, in both embodiments of the invention as heretofore shown and described a very significant portion of the total energy of the reed is devoted to producing second or fourth harmonics during the time of greatest reed excursion, and hence of greatest energy. As the energy is dissipated so that problems of feedback are of little or no significance, the harmonics become of relatively less importance. Not only does the construction herein disclosed result in no substantial feedback of fundamental, but it produces a more piano-like tone due to the shifting harmonic structure with decay of vibrational amplitude.

A preferred concept of the invention is illustrated in FIG. 8. In FIG. 8, and also in FIG. 9, the numerals again are utilized to identify like parts, this time with the addition of the suffix *b*. The embodiment in FIG. 8 is generally similar to that in FIG. 2 in that two pickup plates **40***b* are provided. These plates are connected by a conductive spacer **42***b*, and are held together by a bolt **64** passing through the plates and spacer. The pickup plates **40***b* are of comb shape as heretofore described. The essential difference in the present embodiment of the invention is that one of the plates is of uniform thickness, while the other plate, shown as the upper plate is cut down to provide a thin projection **66** comprising the tooth portion of the plate. A corresponding portion of the second plate is not cut down, and is indicated at **68** as being twice or more the thickness of the cut-down plate projection **66**.

At maximum reed excursion, the reed may pass both pickup plates in the projecting portions **66** and **68**. Upon somewhat lesser excursion, the reed will pass the thin plate portion **66**, but will not pass the thick portion **68**. Furthermore, it will be appreciated that during maximum excursion, the reed passes beyond the thin pickup plate projection **66** before it passes completely beyond the thicker plate projection **68**.

The wave shapes are illustrated in FIG. 9, and the reed excursion again will be seen to be a sine wave, plotted exactly the same as in FIG. 5(*a*). The capacity change at maximum reed excursion is generally similar to what it was in FIG. 5, although it will be observed that the first two peaks **54***b* are spaced farther apart than the second two peaks **54***b*, since the reed passes the thin plate projection **66** sooner than it does the thick plate projection **68**, as noted above.

Upon lesser amplitude of vibration, as illustrated in FIG. 9(*c*), the peaks **54***b* remain during the upward half cycle of reed vibration, but during the lower half cycle of reed vibration, the reed does not pass the plate projection **68**, and hence the peaks of maximum capacity merge together as a single peak indicated at **54***b* at 270°. Subsequently, upon lesser vibrational amplitude, as illustrated in FIG. 9(*d*), the wave shape is generally the same as in FIGS. 5(*d*), and the same is true also with regard to low amplitude reed excursion, the capacity corresponding thereto being illustrated at FIG. 9(*e*).

Thus it will be observed that a fourth harmonic is produced in FIG. 9(*b*), and a second harmonic in FIGS. 9(*d*) and 9(*e*), generally similar to FIG. 5, but having somewhat different overall harmonic structure due to the difference in wave shape, particularly in FIG. 9(*b*). The greatest departure is in FIG. 9(*c*), wherein it will be observed that a strong third harmonic is produced.

Bearing in mind that none of the wave shapes is a sine wave, insofar as the capacity change is concerned, it will be apparent from a Fourier analysis that the fundamental and many other harmonics are present, but that the strongest or greatest capacity change is the fourth, third, or second harmonic, as noted.

Again, the presence of substantial energy in the harmonics during greatest reed excursion minimizes problems of feedback, tending to prevent undue sustaining or "hanging-on" of vibration. The shifting harmonic content with decay of vibration produces perhaps an even more natural piano-like sound and is produced with the two embodiments of the invention shown and described earlier.

The specific examples of the invention as herein shown and described will be understood as being illustrative only. Various changes in structure will no doubt occur to those skilled in the art, and will be understood as forming a part of the present invention insofar as they fall within the spirit and scope of the appended claims.

The invention is claimed as follows:

1. Tone generating means for an electronic piano including a case, an amplifier mounted in said case, and a loudspeaker mounted in said case, said case and air in said case tending to feed acoustic energy from said loudspeaker back to said tone generating means, said tone generating means being mounted in said case and comprising a vibratile reed and a pickup in electrostatic capacitive relation thereto, means electrically connecting said reed and said pickup to said amplifier, means mounting said reed in cantilevered position in a predetermined plane, and impulse means for percussively exciting said reed into decadent free vibration substantially perpendicular to said plane, said pickup including a pair of electrodes spaced normally from said plane on opposite sides thereof, said electrodes being of different thicknesses, said reed at different amplitudes of vibration passing beyond both of said electrodes, passing beyond the thinner of the two electrodes and not beyond the other, and not passing beyond either electrode.

2. Tone generating means for an electronic piano including a case, an amplifier mounted in said case, and a loudspeaker mounted in said case, said case and air in said case tending to feed acoustic energy from said loudspeaker back to said tone generating means, said tone generating means comprising a plurality of vibratile reeds and a pickup in electrostatic capacitive relation thereto in said case, means electrically connecting said reeds and said pickup to said amplifier, means mounting said reeds in parallelism in cantilevered position in a predetermined common plane, and impulse means for selectively percussively exciting said reeds into decadent free vibration substantially perpendicular to said plane, said pickup including a common electrode spaced normally of said plane from said reeds and comprising a substantially flat, comb-shaped plate parallel to said reed plane and having a plurality of alternate fingers and recesses, said reeds

vibrating through said recesses, each of said reeds upon initial excitation vibrating beyond said electrode plate and subsequently vibrating short of said electrode plate, whereby upon small reed vibration the capacity change between a reel and said pickup has a high second harmonic content relative to the frequency of reed vibration to minimize energy fed back from said loudspeaker to said reeds at the fundamental frequency of said reeds.

3. Tone generating means as set forth in claim 2 wherein said pickup common electrode includes a second comb-shaped plate parallel to said reed plane and spaced on the opposite side of said reed plane from the first-mentioned plate, said reed being disposed midway between said electrode plates and at different amplitudes of vibration passing beyond both plates, passing into but not beyond both plates, and vibrating short of both plates.

4. Tone generating means as set forth in claim 3

wherein the two plates are of different thicknesses, whereby at one amplitude of vibration each reed passes beyond one of said plates and does not pass beyond the other of said plates.

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ARTHUR GAUSS, *Primary Examiner.*

B. P. DAVIS, *Assistant Examiner.*

U.S. Cl. X.R.

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