Oct. 31, 1933. C. T. JACOBS 1,933,296

METHOD AND APPARATUS FOR THE PRODUCTION OF MUSIC

Filed April 27, 1932

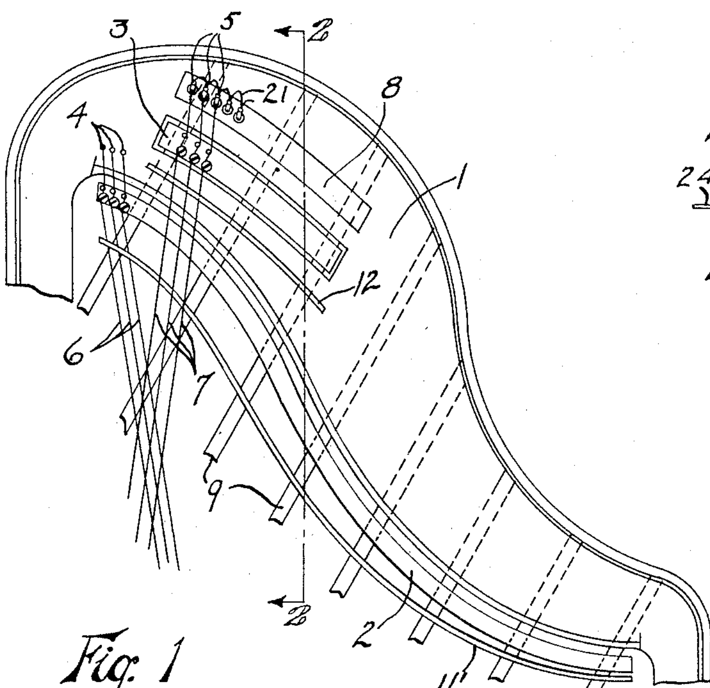

Fig. 1

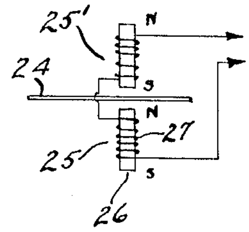

Fig. 4

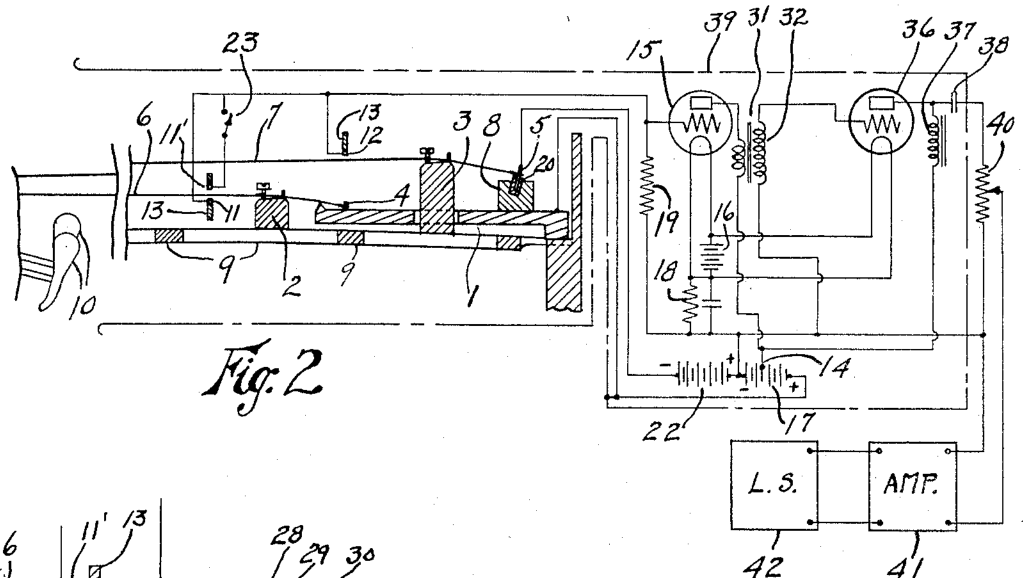

Fig. 2

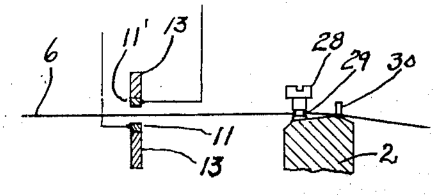

Fig. 3

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UNITED STATES PATENT OFFICE

1,933,296

METHOD AND APPARATUS FOR THE PRODUCTION OF MUSIC

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Application April 27, 1932. Serial No. 607,677

15 Claims. (Cl. 84—1)

This invention relates to musical instruments and systems and more particularly to those in which the vibrations of a plurality of vibrators are first translated into electric oscillations, these being thereafter employed for the actuation of further apparatus. It relates primarily to improving the duplication, by such an instrument as above described, of the conventional piano and other conventional instruments whose vibrators are momentarily excited, in respect of predominate harmonic structure throughout the duration of the tone, of harmonic structure change from moment to moment and of amplitude-time and other characteristics.

Thus it is an object of my invention to provide improved means and methods for controlling the harmonic structure of the electric oscillations and of the output tones in an instrument of the class described. It is a further object of my invention to provide means and methods for accurately duplicating by such an instrument the tones of conventional instruments, in respect of any and all of the characteristics abovementioned.

A more restricted object is the provision of improved means and methods for translating the vibrations of the vibrators into electric oscillations. Other and allied objects will more fully appear from the following description and the appended claims.

In the detailed description of my invention hereinafter set forth, reference is had to the accompanying drawing, of which:—

Figure 1 is a partial plan view of an instrument of the grand piano type embodying my invention;

Figure 2 is a partial cross-sectional view taken along the line 2—2 of Figure 1, in which certain electrical components are schematically shown;

Figure 3 is an enlarged view of a portion of Figure 2 for the clearer illustration of certain details thereof; and

Figure 4 is a schematic view of an alternative form of a portion of my invention.

Reference being had to Figure 1, there will be seen a plate or frame 1 of the type usually employed in grand pianos. It will be understood that reinforcing bars, although not shown, may be provided as portions of the frame in conventional manner. Strung from conventional tuning pins and agraffes or pressure bars (not shown) over main or treble bridge 2 to hitch pins 4 may be provided treble strings 6, of which as few as one per note may be employed if desired. Bass strings 7 may be similarly strung, but over bass bridge 3 to hitch pins 5 in raised portion 8 of plate 1. Both bass and treble bridges may be supported by a plurality of ribs 9 such as are usually employed for the reinforcement of a piano soundboard; but no soundboard or other resonator need be employed in association therewith. Other elements shown in Figure 1 are best described as they appear in Figure 2, a cross-sectional view taken along the line 2—2 of Figure 1. Herein will be seen hammers 10 for exciting the strings 6 and 7, it being understood that a key-operated action may be employed as customarily for the actuation of the hammers.

For translating the vibrations of the treble strings into electric oscillations I show an electrically conductive strip 11 of small cross-section, which may be adjacent and below each treble string preferably at a constant, small fractional part of its length from the rear end thereof. This strip may be cemented to the top edge of a supporting strip 13 of insulating material, which may be retained in fixed position in any convenient manner. The conductive strip 11 is spaced away from the strings in general sufficiently to avoid contact therewith under conditions of maximum vibration of the latter.

Conductive strip 11 may be electrically connected to the grid of a thermionic vacuum tube 15, whose filament may be energized as by battery 16 and whose anode current may be supplied as from a tap 14 on high voltage battery or other current source 17. The filament of tube 15 may be established at a potential higher than that of the negative terminal of battery or source 17 by the flow of anode current through condensively by-passed resistor 18; and the grid of tube 15 may be biased to the potential of such negative terminal by high resistance 19. The treble strings may be established at a D. C. potential positive with respect to that of conductive strip 11 by connection of the plate 1 (with which the strings make contact) to the positive terminal of battery or source 17. In the output circuit of tube 15 may be provided further apparatus hereinafter described.

It will be appreciated that between each treble string 6 and the conductive strip 11 a small electrostatic capacity exists, and that these capacities in parallel with each other form a total capacity between such strings and conductive strip. This capacity is charged from battery or source 17 through resistance 19, and this charge cannot change rapidly because of the high value of the latter resistance. If now any string 6 be vibrated in a vertical plane, as by striking by its hammer 10, the capacity between it and the conductive strip 11 will be varied oscillatorily in accordance with the frequency and waveform of the point of the string opposite the conductive strip. The total capacity between the treble strings and the conductive strip 11 will be likewise varied, though in reduced degree; and by virtue of the relatively constant charge in this capacity the voltage across it will likewise vary. The oscillatory variations in this voltage will be seen to be applied to the grid of tube 15 and therefore to appear as variations in its anode current. Thus in the input and output circuits of tube 15 appear electric oscillations translated from the vibrations of the points of the strings opposite the conductive strip.

A similar conductive strip 12 may be provided for translation from the overstrung or bass strings and it may be connected in parallel, and hence function together, with the treble conductive strip. It may be convenient to mount this strip 12 above its associated strings, instead of below them as the strip 11 is shown with relation to its strings. If the bridges 2 and 3 be entirely rigid, this introduces no complications. When, however, the bridges are supported by vibratile members such as ribs 9 and thus form a unitary vibratile structure, as shown, this opposite positioning of the two conductive strips relative to their respectively associated strings may prove disadvantageous unless suitable counteractive measures are employed, for the following reasons:—

Certain partials of the vibration of any particular point along any string (such as the point opposite the conductive strip) will give rise to bridge vibration in phase therewith; certain other vibration partials to bridge vibration out of phase therewith. This may be proven from the well-known principles of vibration of the strings. This bridge vibration is a portion of the total vibration which is translated when any one or more strings are excited. This results from the slight vibration of all the strings by the vibrating bridge, and from the presence of the conductive strips adjacent all the strings and not merely adjacent the particular string or strings which may have been directly excited. If now translation of string point vibration take place from the bottom of the excited string and translation of bridge vibration also from the bottom of the strings, certain partials of the translated string point vibration will be reinforced, and certain others opposed, by the translated bridge vibrations. But if the phase of translation of string point vibration be reversed—e. g., take place from above the strings—without reversal of the phase of translation of bridge vibration, the partials of the translated string point vibrations formerly reinforced by translated bridge vibrations will now be opposed thereby, and vice versa. In the arrangement shown the phase of string point translation is mechanically reversed from bass to treble; but that of bridge translation is not reversed, vibration of the entire bridge system being always translated in accordance with the algebraic addition of the translation thereof by the respective strips 11 and 12. The result of this, if uncounteracted, is lack of uniformity of the harmonic structure of oscillations translated from bass and treble strings, despite location of their respective conductive strips adjacent corresponding points thereon.

I have found that this effect may be counteracted by electrically reversing the phase of the oscillations translated from vibration of points on the bass strings. This may be accomplished in the electrostatic system shown by connecting the bass strings to a D. C. potential which, with respect to the potential of the conductive strips, is equal to that of the treble strings but of opposite sign. Accordingly the bass hitch pins 5 are shown insulated from the plate 1 by insulating bushings 20, and connected together as by leads 21 (shown in Figure 1) and to the negative terminal of high voltage battery or other source 22, the positive terminal of which may be connected to the negative terminal of battery or source 17 for the treble strings.

The response-stimulus characteristic of the above described electrostatic translation of vibration of a point on an excited string is essentially linear—i. e., the instantaneous voltages (response) produced at the grid of tube 15 are directly proportional to the instantaneous displacements of the string from mean position (stimulus). This results from the inverse variation of the value of string-strip capacity with separation, the inverse variation of voltage across the capacity with the value of the capacity, and the resultant direct variation of voltage with separation or displacement. The succeeding electrical and electro-acoustic system being essentially linear—a condition desirable in this system, which is common to all notes, for the avoidance of objectionable beat frequencies between simultaneously played notes—the entire mechanico-electro-acoustic translation chain is essentially linear. There are evidences, however, that the mechanico-acoustic, or vibration-sound, translation in the conventional piano and similar instruments is appreciably non-linear. Among these may be mentioned the following characteristics of those instruments:—

(A) The materially greater complement of upper partials, particularly even ones, in a loud than in a soft tone;

(B) The change of harmonic structure throughout the duration of the tone, particularly in the early portion of the total duration of a loud tone;

(C) The very high initial apparent rate of damping of the tones; and

(D) The tremendous range of sound amplitudes available upon different degrees of vibrator excitation (different strengths of key blow on the piano).

The principles upon which rest the production of these effects by non-linear translation, if not immediately apparent, will hereinafter appear.

For the better duplication of the conventional instruments by an instrument employing mechanico-electric-acoustic translation, I therefore employ a non-linear element in this chain of translation, preferably in a position where it is essentially individual to the several vibrators. This non-linear translation I have illustrated in connection with the treble strings. Thus a second conductive strip may be positioned adjacent the same point on each string as, but on the opposite side of the latter from, the already described conductive strip for the string. Thus in Figure 2 I show auxiliary strip 11′ positioned above the point on the treble strings below which lies main strip 11. This auxiliary strip may be positioned so that its distance from each treble string is greater than the distance of the same string from the main strip 11, and preferably so that the ratio of the distances of each treble string from the main strip 11 and the auxiliary strip 11′ is constant. The auxiliary strip 11′ may be parallelled with the main strip 11 by the closing of switch 23.

Considering a single string for the sake of simplicity, let d represent the mean distance of a string from its main strip, d' its distance from its auxiliary strip, and N the ratio d'/d; let C represent the instantaneous capacity between the string and main strip and C' the like capacity between the string and auxiliary strip; and let p represent the peak amplitude of vibration of the string point at any fundamental or harmonic frequency $\omega/2\pi$, t representing time. Then

$$C \propto \frac{1}{d+p \sin \omega t} \quad (1)$$

and

$$C' \propto \frac{1}{d'-p \sin \omega t} \quad (2)$$

Adding,

$$C+C' \propto \frac{d+d'}{dd'+(d'-d)p \sin \omega t - p^2 \sin^2 \omega t} \quad (3)$$

Then, since the instantaneous voltage E varies inversely as the total instantaneous capacity $(C+C')$,

$$E \propto \frac{dd'+(d'-d)p \sin \omega t - p^2 \sin^2 \omega t}{d+d'} \quad (4)$$

Substituting N in (4), expanding trigonometrically and multiplying through by d:—

$$E \propto \left(\frac{N}{N+1}\right)d^2 - \frac{1}{2}\left(\frac{1}{N+1}\right)p^2 + \left(\frac{N-1}{N+1}\right)dp \sin \omega t + \frac{1}{2}\left(\frac{1}{N+1}\right)p^2 \cos 2\omega t \quad (5)$$

The first term of (5) is constant over a period of vibration and the second term varies only slowly; significantly, therefore, (5) becomes

$$E \propto \left(\frac{N-1}{N+1}\right)dp \sin \omega t + \frac{1}{2}\left(\frac{1}{N+1}\right)p^2 \cos 2\omega t \quad (6)$$

This expression (6) shows that, as long as N is greater than unity and less than infinity, electric oscillations will be translated, from any given partial frequency vibration in the string, both of that frequency and of twice that frequency. It shows that while the first of these varies directly as the amplitude of the vibration (linearly) the second varies as the square of the amplitude, so that the total translation is nonlinear. It may be noted that if the auxiliary strip is omitted, d' and hence N becomes effectively equal to infinity, the second term drops out, and the first term becomes simply $dp \sin \omega t$, denoting simple linear translation. Conversely, if the auxiliary strip is spaced equally with the main strip (d' made equal to d), N equals unity, the first term becomes zero, and only the double frequency term remains.

As an example of practical nature for average purposes, the value of the spacing d' may lie between $1.1d$ and $1.5d$. Using the latter value as an example, N becomes 1½. Substituting in (6):—

$$E \propto \tfrac{1}{5}dp \sin \omega t + \tfrac{1}{5}p^2 \cos 2\omega t \quad (7)$$

In view of the fact that the initial value of p (the peak amplitude of vibration of the string point at any particular partial frequency) may on a loud tone approach the value of d (the spacing of the main strip from the string), it will be seen that at the beginning of such a tone each of the stronger partials of the string vibration may produce almost as high an oscillation amplitude at twice its own frequency as at its own frequency. But as p decays in value the double frequency oscillations die out much more rapidly than the single frequency oscillations, because of the respective p^2 and p coefficients. Thus there may be produced in the oscillations and in sound translated therefrom a high complement of even upper partials (characteristic A above); these will die out rapidly, producing a change of harmonic structure (characteristic B above) and causing the entire apparent tone amplitude to drop with extra rapidity until the amplitude of these extra partials has become negligible compared to that of the linearly translated partials (characteristic C above). Furthermore on weak tones wherein the vibration amplitude p at any partial frequency is low, the second term in (7) will be negligible compared to the first; but as p is increased, as by stronger and stronger excitation, the amplitude of the second term increases as the square of p, so that the total oscillation and sound output increases roughly according to a power, between the first and the second, of vibration amplitude. This widens the range of sound amplitude obtainable with different degrees of excitation (characteristic D above).

This analysis is limited to the action of the system in translating a single partial component of string vibration, but is sufficient to show its ability to produce various characteristic effects. Actually the string point vibrates simultaneously at a plurality of partial frequencies, and a comprehensive analysis might take into account the translation of beat frequencies between different partials; the phase relations between the double-frequency oscillation component translated from each partial vibration by the second term in (6) or (7), and the component translated from the respective double frequency vibration partial by the first term, etc. These factors all tend to increase the change of tone quality over the period of tone duration and I have found them helpful, rather than detrimental, in producing the characteristic effects desired.

Resulting from the phase relations mentioned in the preceeding paragraph, and dependent in nature on the mode of exciting and point of translating from the string, a change of tonal effects in respect of harmonic structure may be produced according as the smaller spacing of string to translating device or strip be above or below the string. Either effect will be found useful, and choice between the two is readily made by test with the particular excitation and point of translation employed.

The expression (4), and therefore the subsequent expressions derived from it, is seen to be of the well known series form $a+bx+cx^2 \ldots\ldots$ in which the cx^2 term and any subsequent terms typify a curved characteristic; and it is by virtue of this fundamental form that the above discussed, and other attendant, effects are produced. These effects are therefore not peculiar to the particular translating arrangements shown, but are generic to any translation effected in accordance with an appreciably curved characteristic—i. e., in which one or more of the higher power terms is of appreciable value.

It follows that alternative, appreciably nonlinear translating devices may be employed in carrying out my invention, such for example as electromagnetic "reversed push-pull" systems, preferably not in complete balance. Thus in Figure 4 I show a string 24, translating device 25 below a point thereon and comprising a permanent bar magnet 26 and a coil 27 surrounding the same, and a similar translating device 25' above the same point on the string. The magnets are so poled and coils so connected that their electric outputs tend to oppose each other; one device, however, is spaced further from the string than the other. While certain second order factors are different in the case of this electromagnetic translation, basically the action of this system will be similar to that shown for the electrostatic, d and d' again representing the distances of the respective translating devices from the string.

While strings 6 and 7 may be secured respectively to bridges 2 and 3 in the conventional manner, I have found it desirable to employ the adjustable securing means shown in connection with linear translating systems in the U. S. Patent 1,915,859, issued June 27, 1933, to myself and Benjamin F. Miessner. This will be seen in Figure 3, an enlargement of the like portion of Figure 2. Thus each string may be passed around and rest in the groove 29 of, a screw 28 rotatable in the bridge, then passing around fixed bridge pin 30 to its hitch pin. Adjustment of the vertical position of the rear end of the string, and hence of the relative values of the spacings d and d' from string to main and auxiliary strips, respectively, may then be effected by rotation of the screw. Since the ratio N of the spacings d' and d determines the degree of non-linearity of translation for that string, adjustment of this degree individual to each string is provided.

While I have shown the non-linear translation herein as effected by two strips, or translating devices, from opposite sides of the same portion of each string, or vibrator, it will be understood that I may translate from any two portions of a vibrator which vibrate in opposite phase to each other. Again, I may translate from two portions certain of whose partial vibrations are respectively in phase with each other, and certain others out of phase—such two portions may for example be points symmetrical longitudinally about the center of a tuned string, at which all even vibrations partials will be respectively in phase and all odd partials out of phase or vice versa. In such a case the full action of the non-linear translation will take place only as to the respectively out-of-phase vibration partials. It will further be understood that while I have preferred to make dissimilar the spacings of a vibrator from the two translating devices, I may translate purely doubled frequencies with high apparent rates of damping by making the respective spacings similar. Again, it is to be noted that switch 23 may be employed as a selective control for effecting either linear or non-linear translation, according as it is open or closed. Finally it will be appreciated that non-linear translation may of course be effected from the bass, or overstrung, strings as well as from the treble strings. With the described double translating device system for non-linear translation, it is then desirable that the smaller of the two spacings from each string to its respective two devices be either all above the strings or all below the strings—e. g., the nearer translating strips to the bass strings should be below them, as the nearer strip (11) to the treble strings is shown. In this case with the instrument illustrated, in which electrostatic translation and a common vibratile bridge system are employed, the bass and treble strings should all be electrically connected together and to the same source of potential—e. g., to battery or source 17, 22 being omitted.

It was shown above that the translated electric oscillations appeared as voltage changes on the grid, and current changes in the anode circuit, of tube 15. In this anode circuit may be provided a step-up transformer 31, across the primary of which such oscillations will develop a voltage. The voltage thereby induced in the secondary 32 of the transformer may be applied to the grid of a thermionic vacuum tube 36. The filament of this tube may conveniently be paralleled with that of tube 15; and its anode current may also be derived from tap 14 on battery or other source 17. In the output circuit of tube 36 may be provided coupling means such as choke coil or high inductance 37, across which will appear voltages applied to the grid of tube 36 and thereby amplified. These amplified voltages may be applied as through stopping or blocking condenser 38 to potentiometer 40, from which a regulable fraction thereof may be applied to amplifier 41, thereby amplified, and applied to the loudspeaker or other electro-acoustic translating device 42 for translation into sound. Electrostatic shielding may advantageously be provided about the electrical and mechanico-electric apparatus preceding volume control 40 for the reduction of the sensitivity of the system to stray fields; such shielding is shown schematically as 39.

While I have shown and described particular embodiments of my invention, directed most particularly to the improvement of the duplication of the conventional piano and similar instruments by an instrument employing mechanico-electro-acoustic translation, my invention is not limited thereto, but is intended rather to be measured by the scope of the following claims.

I claim:—

1. In a musical instrument of the type wherein the output sound is derived from the damped vibration of a momentarily excited tuned vibrator, which vibration is characterized by a fundamental frequency vibration on which are superimposed oscillations of higher frequencies harmonically related to said fundamental frequency vibration, the method of producing an output sound characterized by a progressive change in harmonic structure throughout said vibration, which consists in translating said vibration into electric oscillations according to a substantially curved characteristic of oscillation response to vibration stimulus, and in translating said oscillations into sound.

2. In a musical instrument of the type wherein output sound is derived from the damped vibration of a momentarily excited tuned vibrator, which vibration is characterized by a fundamental frequency vibration on which are superimposed oscillations of higher frequencies harmonically related to said fundamental frequency vibration, the method of producing output sounds of respectively different initial harmonic structures from vibrations of said vibrator of respectively different initial amplitudes, which consists in translating said vibrations into electric oscillations according to a substantially curved characteristic of oscillation response to vibration stimulus, and in translating said oscillations into sound.

3. In a musical instrument of the type wherein output sound is derived from the damped vibration of a momentarily excited tuned vibrator, the method of producing an output sound characterized by a greater rate of damping than that of said vibration, which consists in translating said vibration into electric oscillations according to a substantially curved characteristic of oscillation

response to vibration stimulus, and in translating said oscillations into sound.

4. In a musical instrument of the type wherein output sounds of different initial amplitudes are derived from the damped vibrations at different initial amplitudes of a momentarily excited tuned vibrator, the method of producing output sounds characterized by a greater range of respective initial amplitudes than characterizes the said vibrations from which they are derived, which consists in translating said vibrations into electric oscillations according to a substantially curved characteristic of oscillation response to vibration stimulus, and in translating said oscillations into sound.

5. In a musical instrument of the type wherein output sound is derived from the damped vibration of a momentarily excited tuned vibrator, the method of selectively controlling characteristics of such output sound, which consists in translating said vibration into electric oscillations, and in selectively adjusting the curvature of the characteristic of said translation in respect of oscillation response to vibration stimulus.

6. In a musical instrument, the combination of a plurality of tuned vibrators; mechanico-electric translating apparatus for translating the vibrations of said vibrators into electric oscillations; and means included in said translating apparatus for producing substantial curvature of the response-stimulus characteristic of said apparatus.

7. A musical instrument comprising a plurality of tuned vibrators; and mechanico-electro-acoustic translating apparatus for translating vibrations of said vibrators into electric oscillations and thence into sound; said translating apparatus including portions which are essentially individual to the several said vibrators; and means included in each of said portions for producing substantial curvature of the response-stimulus characteristic of said translation.

8. In a musical instrument, the combination of a plurality of tuned vibrators; mechanico-electric translating apparatus for translating vibrations of said vibrators into electric oscillations according to a response-stimulus characteristic having a curvature determined by the mutual relationship of said vibrators and said translating apparatus; and selectively adjustable means associated with said vibrators for altering said mutual relationship, whereby there may be varied at will the curvature of said response-stimulus characteristic.

9. In a musical instrument, the combination of a plurality of tuned vibrators; mechanico-electric translating apparatus for translating vibrations of said vibrators into electric oscillations; means included in said translating apparatus for producing substantial curvature of the response-stimulus characteristic of said apparatus; and selective means also included in said translating apparatus for eliminating at will the action of said curvature producing means.

10. In a musical instrument, the combination of a plurality of tuned vibrators; means for producing vibrations thereof; and a system for translating said vibrations into electric oscillations according to a substantially curved response-stimulus characteristic, said system including two mechanico-electric translating devices, in spaced relation respectively to two points on each said vibrator whose vibrations are opposite in phase but otherwise substantially similar to each other.

11. In a musical instrument, the combination of a tuned vibrator; means for vibrating said vibrator; an electrically conductive member in spaced relation to a point on said vibrator and forming an electrical capacity with said vibrator; a second conductive member in spaced relation to a point on said vibrator whose vibration is opposite in phase but otherwise similar to that of said first point, and also forming an electrical capacity with said vibrator; a connection between said conductive members whereby said capicities are paralleled; means for maintaining a relatively constant charge in said paralleled capacities; and apparatus responsive to oscillatory variations in the voltage across said paralleled capacities.

12. In a musical instrument, the combination of a tuned vibrator; means for vibrating said vibrator; a magnetic mechanico-electric translating device in spaced relation to a point on said vibrator; a second such translating device in spaced relation to a point on said vibrator whose vibration is opposite in phase but otherwise similar to that of said first point; and electrical connections to and between said respective devices whereby the first power oscillations thereby translated from said vibrator tend to oppose each other.

13. In a musical instrument, the combination of a tuned vibrator; means for vibrating said vibrator; mechanico-electric translating apparatus in spaced relation to a portion of said vibrator on each of two opposite sides thereof and adapted to translate vibrations of said vibrator into electric oscillations according to a characteristic determined by the relative values of said spacings; and adjustable means for moving said vibrator to increase one and decrease the other of said spacings.

14. In a musical instrument including a plurality of tuned strings, a plurality of percussive means respectively adapted to strike said strings on a given side of each; and a vibratile system coupling said strings together vibrationally: the combination of apparatus disposed in spaced relationship to said sides of certain of said strings, for translating vibrations thereof into a series of electric oscillations; apparatus disposed in spaced relationship to the opposite sides of the others of said strings, for translating vibrations thereof into a series of electric oscillations; means for combining the oscillations of said two series; and means preceding said combining means for reversing the phase of the oscillations of one only of said series.

15. In a musical instrument including two pluralities of tuned strings, a plurality of percussive means respectively adapted to strike said strings on a given side of each, and a vibratile system operative to couple all of said strings together vibrationally; the combination of an electrically conductive member disposed in spaced relationship to said sides of the strings of a first said plurality and forming an electrical capacity therewith; an electrically conductive member disposed in spaced relationship to the opposite sides of the strings of the other said plurality and forming an electrical capacity therewith; a connection between said conductive members; means for maintaining a substantially constant electrical charge with respect to said conductive members on the strings of said first plurality; and means for maintaining a substantially constant electrical charge of opposite sign on the strings of said second plurality.

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