

Sept. 24, 1940.

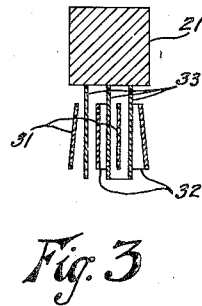
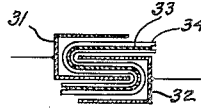
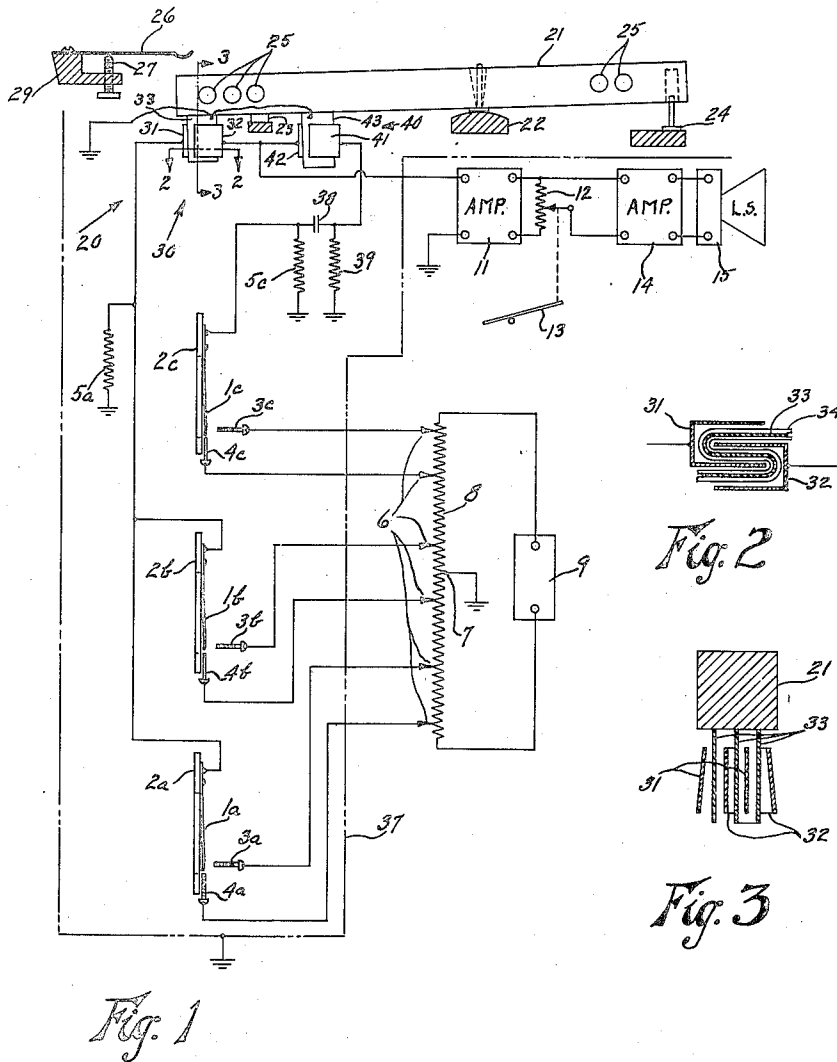
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2,215,709

APPARATUS FOR THE PRODUCTION OF MUSIC

Filed March 9, 1939

2 Sheets-Sheet 1



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APPARATUS FOR THE PRODUCTION OF MUSIC

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2 Sheets-Sheet 2

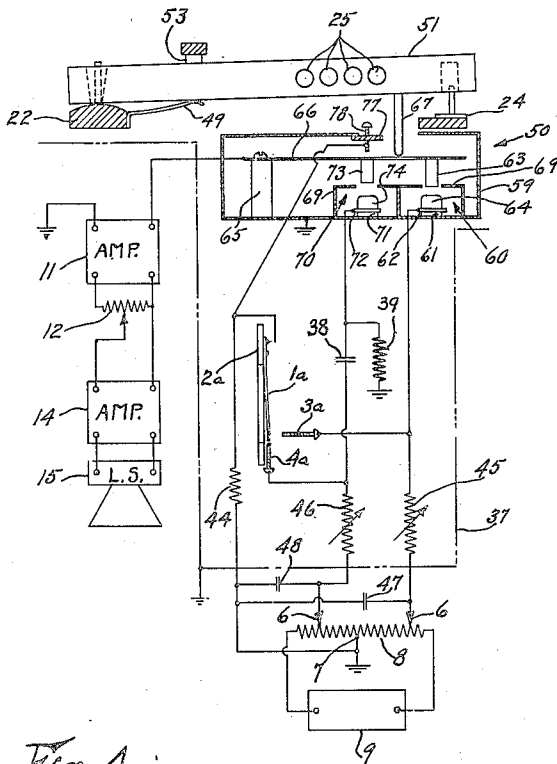


Fig. 4

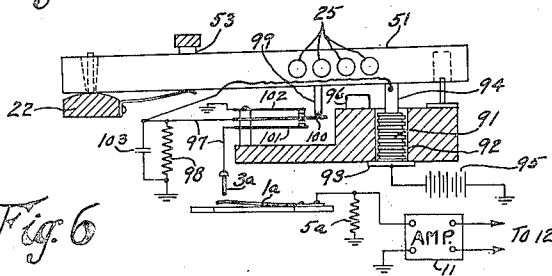


Fig. 6

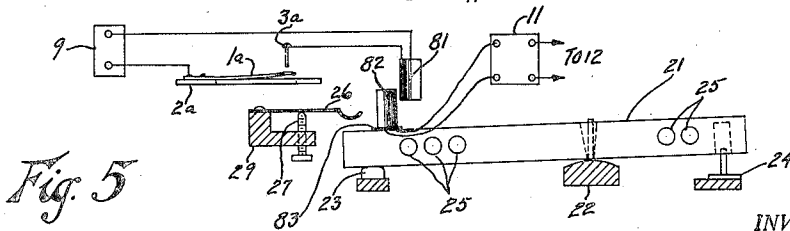


Fig. 5

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UNITED STATES PATENT OFFICE

2,215,709

APPARATUS FOR THE PRODUCTION OF
MUSIC

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Application March 9, 1939, Serial No. 260,677

14 Claims. (Cl. 84—1.26)

This invention relates to the production of music, and more particularly to music production under the control of playing keys, or a keyboard. The invention is especially adapted and has been illustrated and described for use with instruments wherein sound-representing electric oscillations are supplied to an electro-acoustic translating device for output tone production, the supply (or excitation of the translating device) being controlled by the keys—by control either of the original oscillation generation or of the transmission of the oscillations to the translating device.

An important aspect of the invention is concerned with the control over the output tone characteristics through the "touch" employed by the player on the individual keys. It is an object to provide effective such control in a simple, novel and improved manner.

It is an object to provide effective velocity-responsive control over the early tone envelope characteristics in such a manner.

It is an object to provide effective such velocity-responsive control in conjunction with effective pressure-responsive control over the later tone envelope characteristics.

It is an object to extend these controls to characteristics of the tone other than the envelope.

It is an object to adapt a simple displacement-responsive control to provide effective velocity response.

It is an object to provide, in simple and improved manner, a response of the harmonic structure of the output tones to the touch.

It is an object to provide in such a manner an initial extra brightness of tone such as characterizes the piano and other instruments.

It is an object to provide an improved combination of key and means for coupling the generating means to the translating device.

Other and allied objects will more fully appear from the following description and the appended claims.

In the description reference is had to the accompanying drawings, of which:

Figure 1 is a view, partly in elevation and partly schematic, of a portion of a musical instrument embodying my invention in one form;

Figure 2 is a horizontal cross-sectional view taken along the line 2—2 of Figure 1;

Figure 3 is a vertical cross-sectional view taken along the line 3—3 of Figure 1;

Figure 4 is a view, partly in elevation and partly schematic, of a portion of a musical in-

strument embodying my invention in another form;

Figure 5 is a view, partly in elevation and partly schematic, of a portion of an instrument embodying my invention in still another form;

Figure 6 is a view, partly in elevation and partly schematic, of a portion of an instrument embodying my invention in yet another form.

It is a well-recognized fact that an extremely effective touch-response, to which players very instinctively adapt themselves, lies in response to velocity of key depression. This is the essential touch-response of the piano; therein the amplitude of tone inception, after which the tone of course decays, is directly responsive to key velocity. This response is inherently provided in the piano type of instrument since the tonal characteristics depend on the velocity of the hammer in striking the string, and that hammer velocity is naturally dependent on key velocity. The simpler forms of key control of electric oscillation generation or transmission, however, usually provide a response to distance of key depression, or displacement. This response, in its basic form, is not one to which most players instinctively or readily adapt themselves. I have found, however, that I may very readily adapt a simple displacement-responsive system to provide an effective velocity-responsive production of decadent-type tones.

By the same arrangement I am able to provide, after an inherent initial decadence immediately following the tone inception, a continuing control over the individual tone through key-pressure. This latter feature, known in itself but not alone of very great value, is extremely useful in its integral relationship to the velocity-controlled tone inception according to my invention; thus it may be considered that the key control over the tone becomes automatically transferred from the early velocity-control to the later pressure-control. Since, throughout a very wide range of tonal variation, it is the initial portion of any tone which is principally effective in establishing the sensation of volume and tone-type, these characteristics are effectively established under the desirable velocity-control; the ability to exert a continuing control over the tone, however, frees the later portion of the tone from the limitation of uniquely fixed relationship to the early portion, and an almost endless variety of overall "envelope" effects are made available—all at the instant command of the player for every note he plays.

I establish a certain minimum volume (subject of course to variation by general or master volume-level controls) which will be reached even at low key velocities, provided the normal distance of key depression is traversed (a slow, incomplete traversal remaining available for even lower volumes). If a low key velocity is used the note will attain this volume without indulging in an initial peak and decadence therefrom; and since it may be maintained at this volume indefinitely, in view of the automatic transfer of control abovementioned, true organ-like tones may be produced—at will, among the production of pianistic and other tones, and purely in response to the touch employed.

I adapt the simple-displacement-responsive system to operate in the manner described essentially by providing an appropriate resilient stop for the downstroke of the key. This stop is arranged to be quite abruptly impinged on by the key, or some portion of the movable system of which the key is a part, at the end of a "normal" key depression; and the electrical control exerted by the key is arranged so that throughout this normal key depression the tone will be produced in a substantially smoothly rising amplitude up to a "normal" amplitude. The stop initially (i. e., when first impinged on), or after it has yielded negligibly, may have a substantial resistance, preferably of the order of the static resistance of the key to initial depression, or greater, and for example of several ounces: a light and relatively slow key depression will therefore be effectively limited by the stop to a normal depression, and will produce an organ-like tone of normal amplitude. The stop is yieldable throughout a substantial further range of key depression, however, with a resistance materially exceeding the static resistance abovementioned. Thus the stop may be said to be impinged on at an intermediate point in the operative downstroke of the key—i. e., the downstroke throughout which the key movement causes variation of the output tone amplitude.

Upon more rapid key depressions the momentum developed by the mass of and associated with the key—and, if finger contact with the key is maintained throughout the depression, the momentum developed by the mass of the player's finger and the momentum of the mass connected therewith, (hand and even fore-arm)—will cause the key momentarily to overshoot the normally depressed position, and to produce a tone with an initial peak, the distance of the overshooting and the amplitude of the peak being dependent on the momenta abovementioned. The energy stored in the now-compressed or -deflected stop will cause a prompt return of key depression and tone amplitude to lower values. In the case of only light continued pressure on the key, these lower values will be substantially the normal values; but by higher continued pressures the values to which the return occurs will be maintained correspondingly above normal. While there would appear a tendency toward return of the tone, whether of high or only slight initial peak, to a uniform normal amplitude, this is offset to a surprising degree by an inherent tendency of the player to exert a greater continuing pressure on the key the greater the velocity with which he has depressed it—thus tending toward the more usual proportionality between amplitudes of initial peak and tone continuance. Accordingly the player with touch habits developed

on the piano, for example, will instinctively produce quite pianistic effects with the instant apparatus; and so rapidly as his imagination and desire may dictate, he may develop a facility in the exploitation of the far wider expressive possibilities now opened up.

It is to be understood that the most successful use of the apparatus depends upon the establishment of a significant normal key depression, at which there will be a material (though preferably minor fraction of the maximum available) tone amplitude, up to which the reaction to rapid key depression is predominantly a mass reaction rather than a resilient reaction, and at which the reaction changes to be strongly resilient therebeyond. The apparatus thus differs from displacement-responsive systems wherein there is a smoothly continuous reaction of either or both types throughout the tone-producing range of key depression. It is also to be observed that the successful use of the apparatus requires that the tone production shall be progressively or substantially smoothly responsive to key displacement and, in contrast to the reaction to key depression, uncharacterized by any substantial discontinuity.

In general, the broader aspects of my invention are applicable to any key-controlled electro-acoustic instrument whose output tones are responsive to key displacement; obviously this comprises a wide variety of instruments. In respect of the point where control is exerted over the supply of oscillations to the output translating device, the instrument may involve for example key control of the transmission of the oscillations between the generator which produces them and the output translating device, or on the other hand key control of the generation of the oscillations; in either of these or analogous cases, of course, the controlling device when active may be said to have one or another form of operative connection with the generating means, and its broad function may be said to be the controlled subjection of the translating device to excitation by the generating means. In respect of the manner in which the control is exerted, the instrument may involve for example the variation of a coupling (for example of resistive, electrostatic or electromagnetic type, and for example in series or shunt arrangement) either for oscillations of the tone frequencies or for high-frequency oscillations modulated at the tone frequencies, or variation of a D. C. sensitization or excitation of the oscillation generators or transmitting devices, or other appropriate variation. Likewise in respect of the form of the generators, no limitations as to broader aspects are intended, as obviously there may be employed any of a variety of forms of generators and of interrelationships between the generators. It will accordingly be understood that the following description of specific embodiments is presented principally in an illustrative rather than in a limitative sense.

In Figures 1, 2 and 3 I show my invention embodied in an instrument wherein the generators are in the form of a plurality of tuned reeds for each note and a plurality of mechanico-electric translating devices or pick-ups associated with each reed. In this instrument control is exerted by the keys over the transmission of oscillations between the generators and the output loudspeaker; and this control is effected by variation of an electrostatic series coupling.

In Figure 1 there are shown three reeds, 1a, 75

1b and 1c, employed in the oscillation generating means for one note; each may be mounted on its own usual reed base (2a, 2b or 2c), and may be arranged for continuous pneumatic excitation by means not herein necessary to show. Adjacent each reed may be provided a plurality of pick-up electrodes each for example in the form of an adjustable screw, two such electrodes being shown with each reed in the figure. One of these (3a, 3b and 3c for the respective reeds) may be positioned to be approached and receded from by the free end portion of the reed once during each cycle of the reed vibration; the other (4a, 4b and 4c for the respective reeds) may be positioned to be passed by the free end of the reed twice each cycle. The reeds are connected to ground (by which is meant a reference potential) through high-resistance means; these have been shown as resistance 5a for reeds 1a and 1b, and as resistance 5c for reed 1c. Between each pick-up electrode and ground there is impressed an adjustable voltage. For this purpose there may be employed a voltage source 9 shunted by a potentiometer 8 having grounded center-tap 7; and a plurality of adjustable contacts 6, each movable over the entire potentiometer resistance independently of the positions of the others, the several contacts 6 being respectively connected to the pick-up electrodes.

The source 9 being operated as a high-voltage D. C. source, the minute capacities between the pick-up electrodes and their respective reeds are charged to high voltages through the respective high resistances 5a and 5c; the vibratory variations of these capacities cause the appearance across the respective high resistances of tone-representing oscillatory voltages each of fundamental frequency and waveform determined by the reed frequency and waveform and the relationship of the respective electrode to the reed. The amplitudes and phases of these several oscillatory voltages are respectively controlled by the adjustments of the respective potentiometer contacts 6 relative to the center-tap 7; and it will be understood that the several voltages which appear across each single one of the two high resistances 5a and 5c are therein superimposed on one another. The operation of arrangements of this character has been disclosed and more detailedly described in my co-pending applications Serial No. 758,155, filed December 19, 1934; Serial No. 67,245, filed March 5, 1936; and Serial No. 91,092, filed July 17, 1936, in which applications various claims to such arrangements have been made.

If the source 9 be operated as a high-frequency oscillation source, the capacities between the pick-up electrodes and their respective reeds serve to transmit the high-frequency oscillations from the potentiometer 8 to the respective high resistances 5a and 5c, and in that transmission to modulate those oscillations, to produce across the high resistances high-frequency voltages in which the frequencies and waveforms of the modulations correspond in general to the frequencies and waveforms of the modulations correspond in general to the frequencies and waveforms mentioned in the preceding paragraph for the tone-representing oscillations across those resistances. The operation of high-frequency modulating apparatus of this character has been disclosed and more detailedly described in U. S. Patent No. 2,140,025, issued December 13, 1938, on application of myself.

In Figure 1 the two reeds 1a and 1b and the

four pick-up electrodes associated therewith, all serving in the impression of voltage across the resistance 5a, form the main generating means for the illustrated note. It will be understood that by employing for 1a a reed tuned to the fundamental frequency of that note and for 1b a reed tuned to an upper partial (for example, the second) thereof, and by appropriately shifting the adjustments of the contacts 6 which are connected to pick-up electrodes for those reeds, the tone-representing oscillations (or the modulations of the high-frequency oscillations) across the resistance 5a may be shifted through a wide range of waveforms, for control of the timbre of the output tone. Of course any number of reeds and any number of pick-up electrodes therewith may be employed in the main generating means, the numbers shown being by way of example only.

In Figure 1 there will be seen a cascade of apparatus comprising the amplifier 11, potentiometer or volume-level control 12 operated for example by pedal 13, further amplifier 14, and loudspeaker 15; the voltages from across the high resistances (e. g., 5a) for the several notes of the instrument are controllably transmitted to the input of amplifier 11 through a displacement-responsive key-operated system 20 hereinafter described. It will of course be understood that if the source 9 be operated as a high-frequency source, to result in the development of modulated high-frequency oscillations for transmission to the input of amplifier 11, the latter element will be operated as a demodulator as well as as an amplifier. Thus in any event tone-representing audible-frequency oscillations are passed through the elements 12 and 14 to the output loudspeaker 15, to be translated by the latter into output tones.

The displacement-responsive system 20 for the illustrated note is immediately associated with the key 21. This key, for example of usual wooden form, is pivoted on the pivot rail 22; its rear portion normally rests on a hard felt or other rear downstop 23; and its front portion is depressible toward a hard felt front downstop 24, which is of the usual form, substantially incompressible and negligibly resilient, and is provided in this instance only as an ultimate stop for key depression. Both front and rear portions of the key are provided with inset weights 25. The differential weighting of front and rear portions may be such as to provide the usual 2- to 3-ounce static resistance to key depression; the total weighting of the two portions may be such as to approximate the dynamic or mass reaction to the first portion of key depression which is common in the conventional piano. Supported on a suitable rail 29, for example behind the rear key extremity, is a leaf spring 26, which extends forwardly to slightly overhang that extremity. The spring may be biased downwardly; but a limit for its response to its own bias may be provided by a screw 27 threaded upwardly through a forward portion of the rail 29 into contact with the bottom of the spring 26. The spacing of the forward spring extremity above the top of the rear end portion of the key is such that that key portion will impinge upon and encounter the resistance of the spring while the front key portion is still materially spaced above the front downstop 24. In this embodiment the spring 26 of course forms the resilient stop abovementioned, and performs the function above described.

Underneath the rear end portion of the key is provided a coupling capacity 30 serially con-

connected between the ungrounded extremity of resistance 5a and one of the input terminals of amplifier 11 (the other input terminal of which is grounded). The effective value of this coupling capacity 30 is varied by key displacement; specifically in the showing of this figure, this effective value is normally rendered zero by a grounded shield carried by the key and normally extending fully between the plates of the capacity—to be upwardly withdrawn, and to expose those plates to each other, by and in accordance with key depression. In the purely typical construction illustrated, the two plates 31 and 32 of the capacity 30 are shown as generally vertically disposed and, as seen in Figure 2, they may be of intermeshed "U-shaped" in horizontal cross-section; they may be insulatedly supported in any convenient manner. As seen in Figure 3, their outer portions may be inclined, inwardly toward the top, to render the inter-plate capacity per unit area greater in their top than in their bottom portions. The grounded shield 33 is likewise generally vertically disposed and, as seen in Figure 2, may be of "S-shape" interwoven between and in slight spaced relationship to the plates 31 and 32. Figure 2 further illustrates the optional inclusion of thin sheets of dielectric 34 secured against the surfaces of the plate 33.

When the key is in its rest position the shield 33 may extend to just below the bottom of the plates 31 and 32, rendering zero the effective interplate capacity and hence the output tone for this note. Upon key movement to its normally depressed position, wherein its rear portion is just in contact with the undeflected spring 26, the shield 33 will be upwardly withdrawn to expose approximately the lower half, or somewhat less than half, of the plates 31 and 32 to each other; the capacity between those plates is thus raised from zero to a minor fraction of the total available, and an output tone of intermediate or relatively low volume is produced. As explained above, however, depression of the key with any more than very low velocity will cause the key to execute an excursion beyond its normally depressed position; this excursion causes a corresponding upward excursion of the spring 26, of the shield 33 to expose still more of the plates 31 and 32 to each other, of the capacity between the plates (to an especial degree in view of the higher capacity per unit area toward their tops), and of output tone amplitude (to a degree corresponding to that of the capacity change). And as explained above, this excursion is followed by an automatic return of the key (by spring 26) to a position dependent on pressure—the position of shield 33, the capacity between plates 31 and 32, and the output tone amplitude executing a corresponding return.

Figure 1 illustrates another feature of my invention. This resides in the introduction into the output tone of an extra complement of higher partials at higher tone amplitudes, particularly during the initial peak above mentioned. By way of example, a generator for these higher partials may be provided by the reed 1c and its two pick-up electrodes, above described, the two adjustable contacts 6 connected with those electrodes serving to adjust the waveform of the oscillations (or of the modulations of high-frequency oscillations) appearing from this generator across the resistance 5c. The reed 1c may for example be of the fundamental frequency of the note for which it is employed; it may be of a type best adapted for a large harmonic de-

velopment. Additionally to cause the oscillations (or modulations) therefrom to predominate in higher partials, there may be connected to the resistance 5c a filter comprising series capacity 38 and shunt resistance 39 appropriately chosen for attenuation of lower partial components. The output of the filter, or ungrounded end of the resistance 39, may be connected to the ungrounded input terminal of amplifier 11 through a coupling capacity 40, whose effective value is varied by key displacement in a generally similar manner to that already described for the capacity 30.

The capacity 40, which may be positioned underneath the key slightly forwardly of the capacity 30, may comprise stationary plates 41 and 42, generally similar and analogous to 31 and 32; and its effective value may be varied by a grounded shield 43 secured to the key and functioning generally as did shield 33 for the capacity 30. The extension of shield 43 below the bottoms of plates 41 and 42, however, may be made sufficient so that the effective inter-plate capacity remains at zero until the key has been depressed to or almost to its normally depressed position; accordingly the introduction of the extra complement of higher partials will begin after the main tone has reached appreciable amplitude, and will be most significant in, if not limited to, the higher tone amplitudes temporarily occurring during the initial peaks or deliberately maintained thereafter by heavy pressure on the key. It will be understood that while I have thus shown the successive introduction of two series of progressively higher partials (main and extra), no limitation to this number of series is necessary or intended. Broadly, this successive higher partial introduction is highly useful in the simulation or approximation of the tones of conventional musical instruments, wherein the brightness or stridency of the tone varies markedly with the tone amplitude.

It will be understood that grounded electrostatic shielding will be appropriately employed to suppress sensitivity of the apparatus to stray electrostatic fields and to prevent undesired interactions between various components of the circuit, among them components for respectively different notes. The use of such shielding has been schematically indicated in Figure 1 by the dash-dot line 37, which also serves to indicate a line of division between apparatus peculiar to one note and apparatus common to all notes.

In Figure 4 I show a simple illustration of a modified arrangement wherein, by way of example, the coupling capacities are of a different form which may have a finite minimum or residual capacity, and wherein the generator circuit is re-arranged to permit a simple "bucking out" of the effect of this residual capacity. The cascade 11—12—14—15 for all notes again appears. A single reed for the illustrated note is shown as 1a, mounted on base 2a, and provided with the pick-up electrodes 3a and 4a. In this embodiment the electrodes are shown connected to respective variable contacts 6 on the grounded-center-tap potentiometer 8 (which shunts the source 9 as before) through the high resistances 45 and 46 respectively; and to render the lower extremities of these resistances substantially at ground potential as far as oscillations are concerned those extremities may be by-passed to ground through respective condensers 47 and 48. The reed 1a may be connected to ground through a resistance 44 of a value which is a minor frac-

tion of that of either 45 or 46. It will be understood that tone-representing oscillations (or modulations of high frequency oscillations if the source 9 be operated as a high frequency source) will be developed by the respective pick-up electrodes 3a and 4a across the respective resistances 45 and 46; while across the resistance 44 there will appear, in opposite phase, oscillations (or modulations) representing a superposition of those across 45 and 46, but in reduced amplitude.

In this embodiment the key is shown as 51, by way of example pivoted at its rear extremity to the rail 22, and upwardly biased by spring 49 against the upstop 53; the key is depressible toward the front downstop 24 as in Figure 1, although again the downstop is only an ultimate stop and may even be omitted. The key may be provided, preferably near its front, with inset weights 25 for dynamic or mass reaction as mentioned in connection with Figure 1; in this instance all the weighting for dynamic purposes is forward of the pivot, and the spring 49 will be chosen in view of this weighting to provide the usual static resistance to key depression.

The displacement-responsive system 50 associated with the key 51, and which may be contained within a grounded shielding enclosure 59 provided underneath the key, includes a coupling capacity 60 electrically interposed between the electrode extremity of the high resistance 45 and the ungrounded input terminal of amplifier 11. This capacity may be formed by a stationary electrode 62, mounted to the bottom of the enclosure through insulation 61, and a movable electrode 63 thereabove. This movable electrode may be in the form of a plunger conductively secured to the bottom of the front portion of a leaf spring 66, whose rear extremity is mounted to the enclosure through insulation 65. A rod 67 secured to the bottom of the key may extend downwardly to touch the top of spring 66 a little behind the electrode 63, the spring having a light upward bias against the rod and therefore moving in accordance with key movement.

On top of the electrode 62 is mounted a piece 64 of resilient, compressible dielectric; rubber may be satisfactorily employed, and a tough grade of sponge rubber may be mentioned as one particular example. This dielectric 64 functions as the resilient stop for key depression. In the first portion of that depression the electrode 63 is brought downwardly into contact with the top of the dielectric 64, raising the value of the coupling capacity from its very low minimum to a substantial value; the key has now reached its normally depressed position. A downward excursion of the key beyond this position will occur when higher velocities or high pressures are employed, the dielectric being temporarily compressed and raising the value of the coupling capacity much further; fundamentally this action is analogous to that already discussed in connection with the earlier figures, and need not be re-detailed.

The coupling capacity 60 functions to control the supply to amplifier 11 of oscillations from the high resistance 45 (i. e., translated from the reed by electrode 3a). In this embodiment, by way of example, I have shown the employment of the oscillations from the high resistance 46 (i. e., translated by the electrode 4a) as a second series, or extra complement predominating in higher partials. To control their supply to the amplifier I have shown a second coupling ca-

capacity 70 behind but similar to the capacity 60, and so comprising stationary electrode 72 mounted on insulation 71, movable electrode in the form of plunger 73 conductively secured to spring 66, and dielectric 74 mounted on top of electrode 72. The spacing of 73 above 74 may be somewhat greater than between 63 and 64, so that the increase of capacity 70 upon key depression "lags" behind that of the capacity 60. But after the plunger 63 has reached contact with dielectric 64 and the downward force of rod 67 is causing the compression of that dielectric, part of that rod force will be diverted into causing a downward bowing of spring 66, bringing plunger 73 into contact with dielectric 74 and even compressing the latter somewhat in the case of more extreme forces.

To minimize the residual or "key-up" values of the capacities 60 and 70, shielding enclosures 69 may be provided around the stationary electrodes, the enclosures being apertured for the plungers 63 and 73 and those plungers rising to outside the enclosures. Even then, however, there may be too much residual capacity for satisfactory elimination of residual tone with the key up, and to eliminate this I have shown a buckling arrangement. Thus above the spring 66 (which forms a common element connecting the two capacities to the amplifier 11) there may be mounted, in a suitable insulating block 77, a screw 78 which has an adjustable small capacity to spring 66 when the key is in up position. This screw is connected to the reed end of resistance 44, across which there has been seen to appear a superimposed, reduced-amplitude and opposite-phase replica of the oscillations across 45 and 46. By proper adjustment of the screw 78 the residual tone from either of the capacities 60 and 70 may be balanced out; and by making at least one of the resistances 45 and 46 variable and properly adjusting it relative to the other (in view of the slightly different residual values of the capacities 60 and 70), a single adjustment of the screw 78 will suffice to balance out the tone from both capacities.

It will be understood that in this embodiment the variable contacts 8 on the potentiometer 8 serve to adjust the relative amplitudes and phases of the two series of partials (from electrodes 3a and 4a respectively), thus providing a master control for the entire instrument of the degree and character of tone "brightening" at higher tone amplitudes. Although the series from the electrode 4a inherently predominates in higher partials in view of the electrode positioning, additional such predominance may be provided if desired by employing, between it and the electrode 72 in capacity 70, a filter 38-39 such as described in connection with Figure 1.

In the simple schematic illustration of Figure 5 I have shown the embodiment of my invention in another one of the many possible forms; herein the displacement-responsive system 50 functions by varying a magnetic coupling. The key appears as 21, arranged as in Figure 1 and having the inset weights 25 as described in connection with that figure; and there is again provided the resilient stop in the form of the adjustable spring 26. A generator, for example of high-frequency oscillations modulated at the tone frequencies, is shown as the voltage source 9, the reed 1a and the electrode 3a, these being connected in series with a small coil 81 held stationary above the rear portion of the key, for example with a horizontal axis extending in the longitudinal direction of the

key. The displacement-responsive system comprises a "pick-up" coil 82 mounted on top of the key, for example through a small spacer 83; displaced, for example in the longitudinal direction of the key, from the coil 81 to permit its being brought into adjacency therewith; and having its axis, when the key is in rest position, displaced below that of coil 81. The coil 81 is positioned in the vertical direction so that this axis displacement when the key is in rest position will result in zero coupling between the coils; and the vertical coil dimensions are so chosen that the full maximum possible key depression will bring the axes into substantial coincidence. The coil 82 is connected to the input of the amplifier 11, which may be operated also as a demodulator. As the key is depressed the coupling between the coils, and the tone oscillations from the amplifier 11, will be progressively increased; the resilient stop 26, however, functions as before to render the normal key depression only a fraction of the maximum possible depression, and the system functions in an ultimate sense as those above described.

In Figure 6 I have shown the embodiment of my invention in a case wherein the displacement-responsive system operates by controlling the sensitizing or polarizing voltage supplied to the generator. The key appears as 51, arranged as in Figure 4 and having the inset weights 25 as described in connection with that figure; and there is provided a resilient stop, for example in the form of a compressible piece 96 of sponge rubber, beneath the key and arranged to be impinged on by the key at an intermediate point in the full-depression range. A generator is formed by the reed 1a and pick-up electrode 3a, the electrode being connected to ground through a conductor 97 and resistance 98, and the reed being connected to ground through high resistance 5a, across which amplifier 11 is connected. The amplitude of tone-representing oscillations developed by the generator across the high resistance 5a, and hence the output tone amplitude, is a function of the amplitude of a D. C. voltage impressed across resistance 98, and the displacement-responsive system operates to control this voltage. This system may for example comprise a relatively high stack 91 of discs of carbonaceous material, positioned in a well 92 below the key and resting on a conductive plate 93 at the bottom of the well; and a conductive plunger 94 extending downwardly from the key to the top of the stack. The discs are of suitable form so that the stack is highly compressible, with an attendant wide resistance variation. A high-voltage D. C. source 95 is connected from the plate 93 to ground. The plunger 94 is connected with the ungrounded extremity of resistance 98, so that the resistance of stack 91 and the resistance 98 form a potentiometer arrangement across the source 95.

When the key is in rest position the resistance of the stack 91 may be infinite, and the voltage across resistance 98 therefore zero, there being then no oscillation supply by the generator to the amplifier 11. It is desirable, however, that the resistance of the stack 91 begin to reduce substantially with the beginning of key depression, so that a substantial voltage may have been developed across resistance 98 when the key has reached its normally depressed position; this makes it difficult in practice to arrange for a completely infinite resistance of the stack 91 at any time. Accordingly I prefer to permit the resistance of the stack with the key in

rest position to be simply an extremely high resistance, a minute D. C. voltage therefore tending to appear across the resistance 98; and to annul the effects of this tendency by either open-circuiting the generator (e. g., in the conductor 97) or grounding the sensitizing voltage supply (e. g., the upper extremity of resistance 98), or both, when the key is in its rest position. Accordingly I have shown a leaf-spring switch pole 100 underneath the key, operated by a rod 99 extending downwardly from the key; a leaf-spring switch contact 101 beneath the pole 100 and contacted thereby except when the key is in rest position, 100 and 101 being serially connected in the conductor 97; and a grounded leaf-spring switch contact 102 above the pole 100 and contacted thereby only when the key is in rest position. Since these switch members operate to change the circuit conditions only when no voltage appears across the resistance 98 and the sensitivity of the system is therefore extremely low, they introduce negligible "clicks" or disturbances into the tone; residual tendencies toward such disturbances, however, and tendencies toward noise generation in the stack 91, may be suppressed by an appropriate filtering arrangement. Such an arrangement has been indicated as a condenser 103 shunted across the resistance 98; any such arrangement, however, must be apportioned to have a very short time constant, to avoid impairing substantially instantaneous response of the voltage and tone amplitude to key displacement.

It may be noted that particularly in the embodiments of Figures 4 and 6 it is possible to obtain a relatively steep change of output tone amplitude with key depression beyond the normal depression, so that there need not be of great magnitude a further depression sufficient to double or still more greatly increase the tone amplitude; and in general I intend no unexpressed limitations in respect of the steepness of this change.

It will be understood that the various features of the disclosed embodiments, and the various groupings of features therein, are subject to wide variation without departure from the spirit or scope of the invention, that scope being defined in the following claims.

I claim:

1. In a musical instrument including electro-acoustic translating means and oscillation-generating means: the combination of a movable system comprising a depressible key; means for subjecting said translating means to excitation by said generating means, connected with said movable system for progressive operation thereby in accordance with key displacement and operatively connected with said generating means throughout the operative downstroke of said key, whereby output tone amplitude is caused to progressively vary with key displacement; and a resilient stop impinged on by said movable system at an intermediate point in the operative downstroke of the key, said stop being yieldable throughout at least an additional amplitude-doubling downstroke of the key.

2. The combination according to claim 1, wherein said movable system comprises sufficient mass to cause a substantial temporary yielding of said stop at higher key velocities.

3. In a musical instrument including electro-acoustic translating means and oscillation-generating means: the combination of a movable system comprising a depressible key; means for

subjecting said translating means to excitation by said generating means, connected with said movable system for progressive operation thereby in accordance with key displacement and operatively connected with said generating means throughout the operative downstroke of said key, whereby output tone amplitude is caused to progressively vary with key displacement; and a resilient stop impinged on by said movable system at an intermediate point in the operative downstroke of the key, yieldable through a substantial range throughout which its resistance materially exceeds the static resistance of the key to initial depression.

4. The combination according to claim 3, wherein said movable system comprises sufficient mass to cause a substantial temporary yielding of said stop at higher key velocities.

5. In a musical instrument including electro-acoustic translating means and oscillation-generating means: the combination of a movable system comprising a depressible key; means for subjecting said translating means to excitation by said generating means, connected with said movable system for progressive operation thereby in accordance with key displacement and operatively connected with said generating means throughout the operative downstroke of said key, whereby output tone amplitude is caused to progressively vary with key displacement; a resilient stop impinged on by said movable system at an intermediate point in the operative downstroke of the key; and inertia means, carried by said movable system, for causing a substantial temporary yielding of said stop at higher key velocities.

6. In a musical instrument including electro-acoustic translating means and oscillation-generating means: the combination of a movable system comprising a depressible key; means for subjecting said translating means to excitation by said generating means, connected with said movable system for progressive operation thereby in accordance with key displacement and operatively connected with said generating means throughout the operative downstroke of said key, whereby output tone amplitude is caused to progressively vary with key displacement; and means, comprising mass included in said movable system and a resilient stop impinged on by said system at an intermediate point in the operative downstroke of the key, for causing the key at higher velocities to have essentially mass and resilient reactions in the respective successive portions of its downstroke.

7. In a musical instrument including oscillation-generating means and electro-acoustic translating means excited thereby to produce output tones: the combination of a movable system comprising a depressible key; excitation-control means, connected with said key for progressive operation thereby and operatively connected with said generating means throughout the operative downstroke of said key, for rendering the output tone amplitude responsive to key displacement; and means for causing the output tone to have an initial peak of amplitude responsive to key velocity, comprising a resilient stop impinged on by said movable system at an intermediate point in the operative downstroke of the key.

8. In a musical instrument including oscillation-generating means and electro-acoustic translating means excited thereby to produce output tones: the combination of a movable system comprising a depressible key; excitation-control means, connected with said key for progressive operation thereby and operatively connected with said generating means throughout the operative downstroke of said key, for rendering the output tone amplitude responsive to key displacement; and substantially yieldable resilient stop means, impinged on by said moving system at an intermediate point in the operative downstroke of the key, for both rendering the initial portion of the output tone envelope responsive to velocity of the key and rendering the later portion of the envelope responsive to pressure on the key.

9. The combination according to claim 7, wherein said excitation-control means comprises variable coupling means interposed between said generating means and said translating means.

10. The combination according to claim 7, wherein said excitation-control means comprises a variable capacity and wherein said resilient stop comprises a dielectric in said capacity.

11. The combination according to claim 7, wherein said generating means is controllably sensitizable, and wherein said excitation-control means comprises means for controlling the sensitization of said generating means.

12. The combination according to claim 7, further including a second oscillation-generating means for oscillations of higher frequencies harmonically related to those from said first-mentioned generating means; and means, responsive to higher key displacements, for progressively subjecting said translating means to excitation by said second generating means.

13. In a musical instrument including oscillation-generating means and electro-acoustic translating means: the combination of a key depressible from rest position; a variable condenser operatively connected with said key for variation thereby, and electrically connected to said generating means and to said translating means for transferring oscillations therebetween, said condenser being characterized by a residual capacity when the key is in rest position; and capacitative means, electrically connected to said generating means in opposed phase relationship to said variable condenser, for balancing out oscillations transferred through said residual capacity.

14. In a musical instrument including an oscillation-generating device and an electro-acoustic translating device: the combination of a key depressible from rest position; variable coupling means operatively connected with said key for variation thereby, and electrically connected between said devices for transferring oscillations therebetween, said coupling means being characterized by a residual coupling when the key is in rest position; and an auxiliary coupling means, interposed between said devices and connected to one of said devices in opposed phase relationship to the connection to that device of said first-mentioned coupling means, for balancing out oscillations transferred through said residual coupling.

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