Oct. 1, 1940. L. HAMMOND 2,216,513

ELECTRICAL MUSICAL INSTRUMENT

Filed Aug. 8, 1938 3 Sheets-Sheet 1

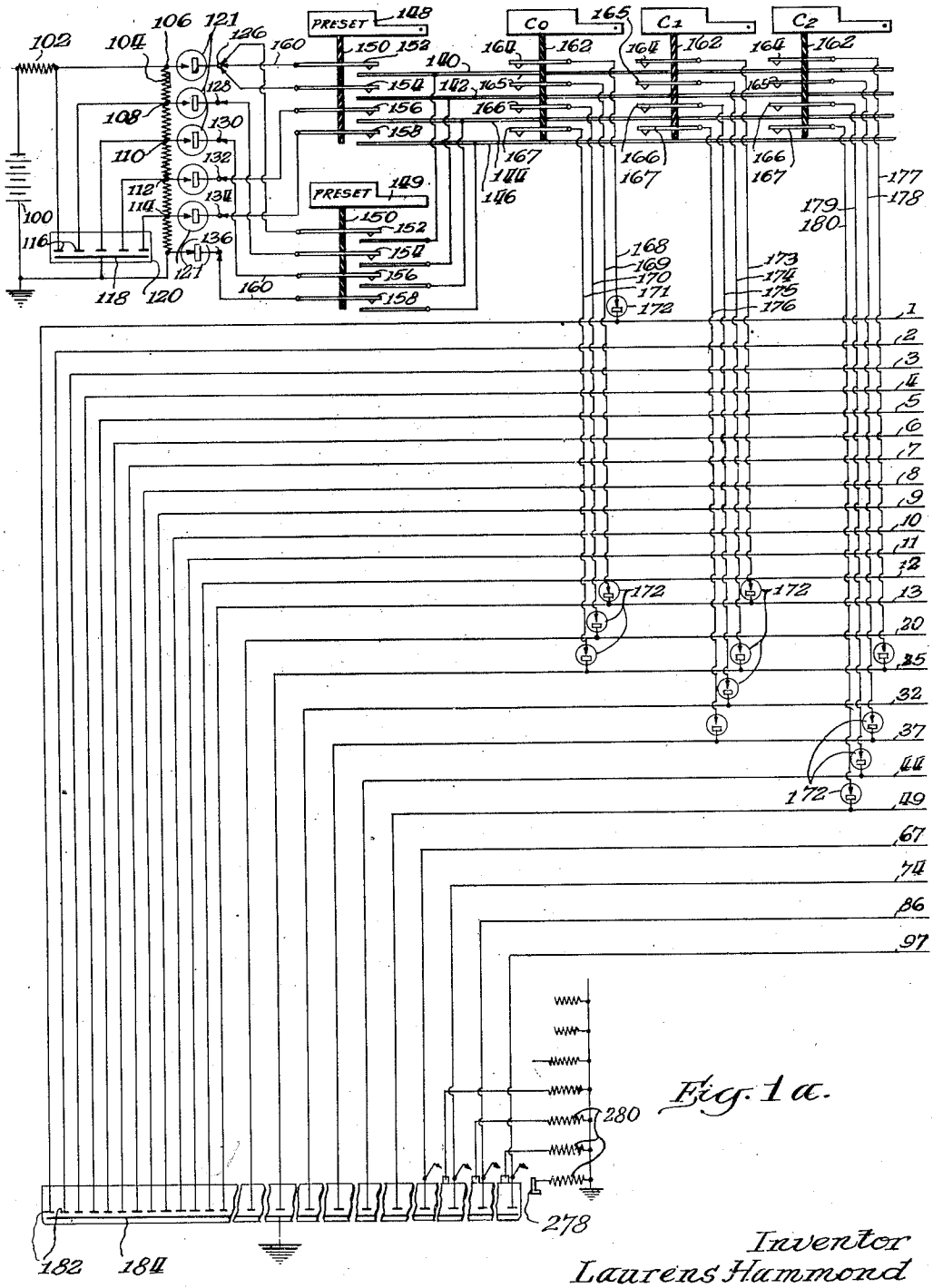


Fig. 1a.

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ELECTRICAL MUSICAL INSTRUMENT

Filed Aug. 8, 1938 3 Sheets-Sheet 2

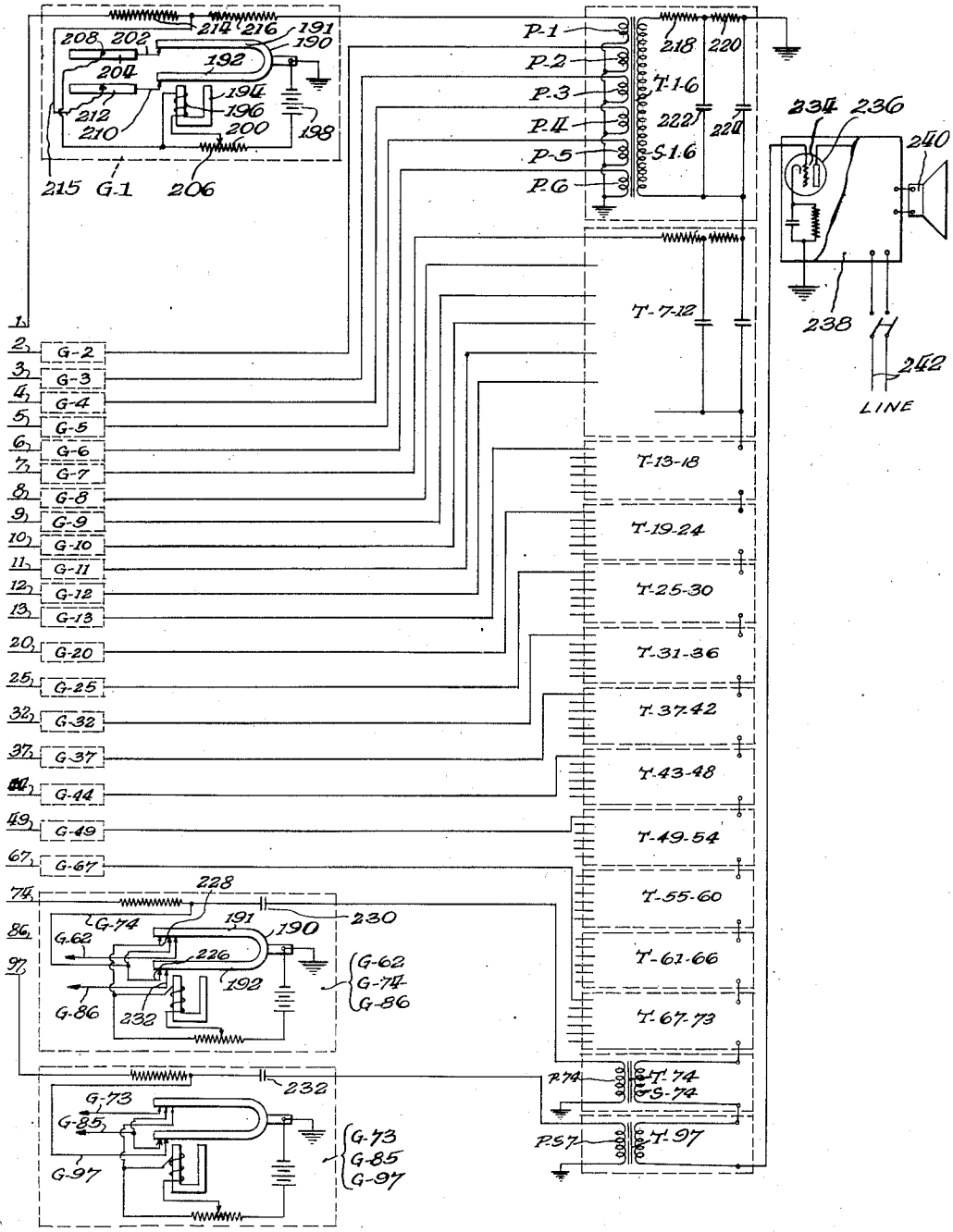


Fig. 1b.

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ELECTRICAL MUSICAL INSTRUMENT

Filed Aug. 8, 1938 3 Sheets-Sheet 3

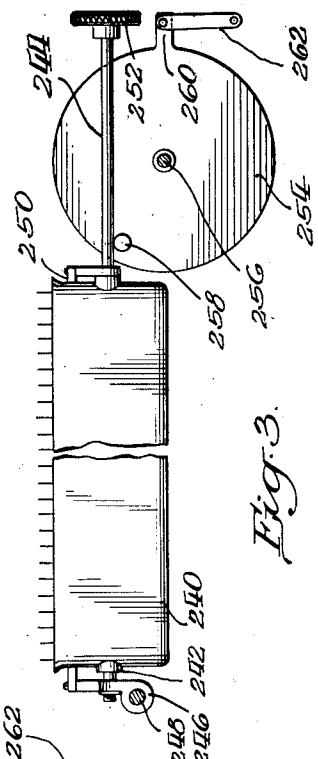


Fig. 3.

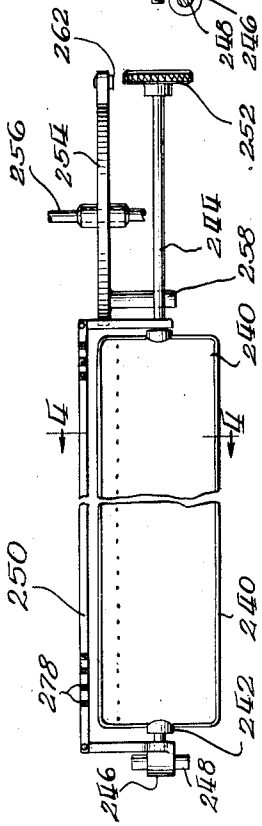


Fig. 2.

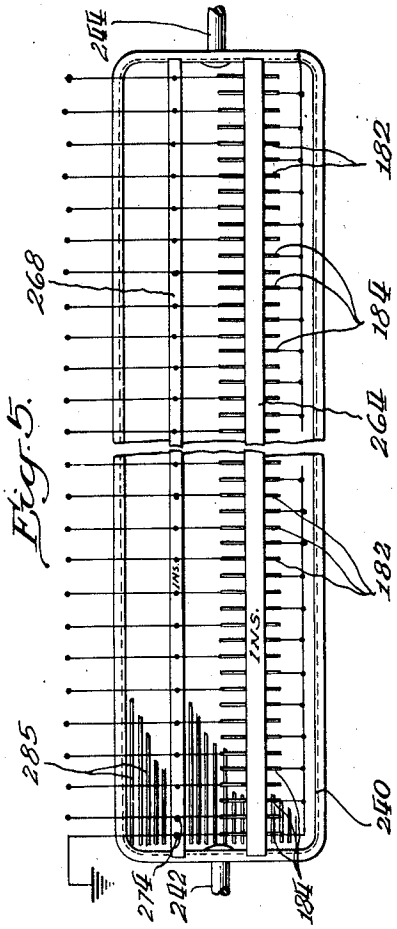


Fig. 5.

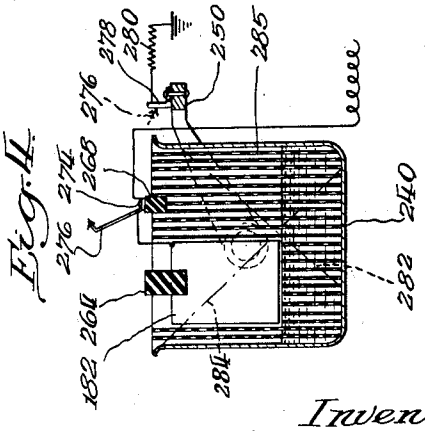


Fig. 4.

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Patented Oct. 1, 1940 2,216,513

UNITED STATES PATENT OFFICE

2,216,513

ELECTRICAL MUSICAL INSTRUMENT

Laurens Hammond, Chicago, Ill.

Application August 8, 1938, Serial No. 223,633

19 Claims. (Cl. 84—1.26)

My invention relates generally to electrical musical instruments and more particularly to electrical keyboard instruments similar, in the kind of music which may be produced, and in the method of playing them, to instruments of the piano and pipe organ type.

In playing certain kinds of music, and in playing other kinds of music in rooms which are acoustically "dead," it is desirable to produce a note which has relatively slow decay characteristics. In this way, compensation may be made for adverse acoustical conditions of the room in which the instrument is played, and the tones may be made to simulate more exactly the tones of some of the stringed instruments such as the piano, in which the intensity of the note decreases gradually providing the key is held down, or the sustaining pedal is depressed.

It is thus an object of my invention to provide an improved electrical musical instrument, in which the decay of the tones produced by the instrument may be varied at the will of the player.

A further object is to provide an improved electrical musical instrument in which the rate of decay of the tones may be varied in different portions of the scale.

A further object is to provide an improved means for controlling the relative intensities of the various harmonics of the tones of a musical instrument.

A further object is to provide an improved multiple plate condenser having improved means for varying the capacitances of the condensers all at the same rate, or at selectively different rates.

A further object is to provide an improved method and improved electrical circuits, for controlling the operation of an electrical musical instrument.

A further object is to provide an improved means and method for generating electrical impulses of the frequencies of the notes of the musical scale.

A further object is to provide an improved means for the generation of electrical impulses of frequencies of the musical scale in which some of the generators may be utilized for the generation of a plurality of frequencies.

A further object is to provide an improved output circuit for electrical musical instruments.

Other objects will appear from the following description, reference being had to the accompanying drawings in which:

Figures 1—*a* and 1—*b* together constitute a schematic wiring diagram of the instrument;

Figure 2 is a plan view of an improved multiple plate variable condenser;

Figure 3 is a side view of said condenser;

Figure 4 is a transverse sectional view of the condenser taken on the line 4—4 of Figure 2; and

Figure 5 is an enlarged plan view of the condenser.

General description

In order that the detailed description of the instrument which appears hereinafter may be more clearly understood, such description is prefaced with the following general description of the instrument.

The instrument comprises a source of direct current which by means of a voltage divider, potentiometers or other suitable means, is utilized to impress a selected potential upon each of a plurality of bus bars through rectifiers. The bus bars supply harmonically related generators with energizing current in the selected relative proportions necessary to produce the desired musical tone quality, when a playing key is depressed.

It is well recognized that the quality of a sustained musical tone depends upon the relative intensities of the fundamental of the tone and its audible harmonics, so that, by predetermining the intensities of the fundamental and its harmonics, a sustained tone of substantially any desired tone quality may be produced. As a practical matter, the higher order harmonics are usually masked by the lower pitched harmonics, or lie above the audible range, so that generally speaking, harmonics above the eighth harmonic have a relatively small effect upon the quality. In the present instrument, I contemplate means for combining the first, second, third, fourth, fifth, sixth and eighth harmonics, as well as the sub-fundamental and the sub-third harmonic, although for purposes of illustration, means for controlling only the first four partials are disclosed.

By means of key switches, manual or pedal, or both, the bus bars which carry the pre-selected direct current potentials are connected through rectifiers with suitable generators or interrupters, one for each frequency which is to be utilized in the production of the tones of the instrument, whether as fundamentals or as harmonics of such tones. In the present instrument, I have illustrated 97 such generators, some of which are actuated by a common vibratory element. By means of the key switches, the direct current po-

tentials from the bus bars are nearly instantaneously impressed upon the generators, but the rate at which the potential decays on the respective generators is controlled by means of condensers, preferably of a form hereinafter described whereby their capacitances may be varied collectively according to any one of a plurality of different systems.

The generators are connected to a common output circuit by means of a plurality of transformers. The output signal from the transformers is amplified, and then translated into sound by a loud speaker or the like.

Means for selectively impressing energizing potentials upon the generators

As previously stated, my invention contemplates the supply of energizing direct current potentials to the generators in a manner such that the voltage of the supply to a generator controls the amplitude of the tone signal produced thereby.

The means for supplying the selected energizing potentials to the generators comprises a source of direct current such as a battery 100, one terminal of which is connected through protective resistance 102 to a voltage divider resistance 104 having taps 106, 108, 110, 112 and 114, the other terminal of the resistance 104 being connected to the grounded terminal of the battery 100. The terminal 106, and the taps 108, 110, 112 and 114 are connected respectively to plates 116 of condensers which may have a common plate 118 which is grounded, and which are enclosed in a container 120. The condensers formed by these plates 116 and the plate 118 are preferably of relatively large capacity so that the voltage of the divider taps will be maintained substantially constant.

Each of the terminals 106, 108, 110, 112, and the grounded terminal 114 of battery 100 has a rectifier 121 connected between it and terminals 126, 128, 130, 132, 134 and 136 respectively.

Means are provided selectively to connect the terminals 126—134 as well as the grounded terminal 136 to any one of a plurality of bus bars 140, 142, 144 and 146 which are adapted to supply energizing current for the generators of the fundamental frequency, the second harmonic, the third harmonic and the fourth harmonic respectively. As previously stated, these four bus bars are illustrative of any greater number it may be desired to utilize in the instrument.

The connections between the terminals 126—136 and the bus bars 140—146 are selectively made by preset keys 148 and 149 which are illustrative of any larger number of preset keys which may be desired. Each preset key is provided with an actuator bar 150 of insulating material which engages resilient contact arms 152, 154, 156 and 158 to complete circuits between the terminals 126—136 and bus bars 140—146. The contact arms 152—158 may each be connected to any one of the terminals 126—136 by adjustable conductors 160. As shown in the diagram Figure 1*a*, the preset key 148 is adapted to connect the bus bar 140 for the fundamental to terminal 126; to connect the bus bar 142 for the second harmonic likewise to the terminal 126; to connect the bus bar 144 for the third harmonic to the terminal 132; and to connect the bus bar 146 for the fourth harmonic to the terminal 134. Similarly, the preset key 149 is adapted to connect the bus bars 140—146 inclusive with the terminals 126, 128, 130 and 136 respectively.

The preset keys are provided with means to hold them in depressed position and are preferably provided with means to release this holding means upon the depression of a second preset key. The mechanism is such, however, that two keys may, if desired, be simultaneously depressed. A mechanism of this character is disclosed in my prior Patent No. 1,956,350 granted April 24, 1934. In the event that the two preset keys were held depressed at the same time, it would frequently happen that one of the bus bars would be connected through different conductors 160 to several terminals 126—136, which are at different potentials. Under these circumstances, a portion of the resistance 104, or possibly all of this resistance, might be short circuited if it were not for the provision of the rectifiers 121 which are interposed between the taps 106—114 and the terminals 126—134 respectively. These rectifiers are preferably of a dry contact type, such as copper oxide rectifiers.

When, as previously indicated, two or more of the preset keys are accidentally or intentionally operated at the same time, the bus bars 140—146 will be connected to different taps of the resistance 104. This will not have any undesirable effect, but instead, the higher potential tap will impress its voltage upon the bus bar. As will be pointed out hereinafter, the musical effect of this condition is an advantage rather than a disadvantage.

A plurality of conductors numbered 1 to 97 inclusive, are provided for conducting energizing current to generators No. G—1 to G—97 inclusive. The instrument is provided with any suitable manual or manuals, and may also be provided with a pedal clavier. For purposes of illustration, three keys C_0, C_1 and C_2 for the corresponding notes in the musical scale, are illustrated in the drawings. Each key is provided with an actuator 162 of insulating material for operating a plurality of key switches 164, 165, 166 and 167 which are adapted to make contact respectively with the bus bars 140, 142, 144 and 146. The contact arms of the switches 164—167 inclusive for the key C_0, are connected by wires 168, 169, 170 and 171 with the conductors 1, 13, 20 and 25 respectively, a rectifier 172 being provided in each of the latter circuits to prevent reverse flow of current therein.

Similarly, the switches 164—167 for the key C_1 are connected by wires 173—176 with conductors 13, 25, 32 and 37 respectively, while the switch arms 164—167 of the key C_2 are connected by wires 177—180 with the conductors 25, 37, 44 and 49 respectively, a rectifier 172 being placed in series in each of these wires to prevent reverse flow of current. The keys C_0, C_1 and C_2 as well as all of the remaining keys of the manual and pedal clavier may be operated simultaneously to play chords, since even though a single generator is simultaneously connected to a number of different bus bars, and thus to a number of terminals 126—136 of different potentials, the bus bar supplying the highest potentials will be controlling in each instance, due to the provision of the rectifiers 172.

The energizing potential impressed upon the generators is provided by the circuits thus far described, the potentials upon the generators building up rapidly to the preselected values, and the resulting tone produced by the instrument would have a rapid, percussive attack, which is desirable for many types of music. To cause the decay of the tone to be gradual, I have provided a plurality of condensers, one for each of the

generators, which are charged simultaneously with the impressing of the energizing potentials upon the generators. These condensers are illustrated herein as having individual plates 182 and a common plate 184 which is grounded. This multiple condenser is preferably of a liquid electrolytic type to be described in detail hereinafter, which is so constructed and mounted that the degree of immersion of the plates 182 and the common plate 184 may be varied, thus varying the capacitances of the respective condensers.

The tone frequency generators

Although a tuning fork type of interrupter frequency generator is illustrated herein and will be described as the type of generator employed in this instrument, a large variety of different types of generators might be substituted for the tuning fork interrupters. The following are given as examples of the various types of generators which might be employed:

1. A light source might be connected to one of the conductors 1 to 97 and the beam of light provided thereby interrupted by a rotating shutter, perforated disk, or the like, and the interrupted beam utilized to energize a photoelectric cell. The voltage of the current supplied to the light source would thus control the intensity of the alternating current signal which would be generated by the photoelectric cell and which could then be amplified and translated into sound. Photoelectric systems of this general character are disclosed in the patents to DeForest No. 1,466,701 and Potter, No. 1,848,222.

2. The energizing potential in the conductors 1 to 97 could be supplied to electrostatic generators of the general type disclosed in my copending application Serial No. 157,969, filed August 7, 1937, and in the patent to Firestone No. 1,948,104 granted February 20, 1934. In electrostatic generators of this type, the direct current potential applied thereto will energize the generator, and the value of the voltage of the impressed direct current determines the amplitude of the alternating current or voltage produced by the generator. The alternating current or voltage of the generator would, of course, be amplified and translated into sound in any one of a plurality of well known ways.

3. The direct current in the conductors 1 to 97 inclusive might be utilized to energize electromagnetic generators, in which case the field windings of the generators would be connected to the conductors 1 to 97, the field core being of negligible retentivity. The rotating armature of the generator would have a plurality of high points rotatable in a path adjacent the field pole. The variable reluctance in the magnetic path of the pole would thus produce an alternating component in the field winding, which could be amplified and translated into sound, or the pole could be provided with an additional pick up winding in which the alternating voltage would be induced. An instrument employing generators of this general character is disclosed in the patent to Severy, No. 1,941,870.

4. In addition to the types of generators of alternating current of the frequencies of the tones to be produced which are described in the preceding paragraphs numbered 1 to 3 inclusive, generators utilizing vacuum tube oscillating circuits, (Patent No. 2,142,580) vibrating reeds, (Patents Nos. 1,901,985 and 2,113,347), radio frequency beat systems, (Patent No. 1,823,716) and various other types of mechanical and electrical interrupters, generators, and oscillators might be utilized and connected to the key circuits described herein in a manner such that the direct current potential of the key circuits would control the amplitude of the current generated.

As a simple and practical form of generator for the frequencies utilized in the present instrument, I have illustrated tuning fork interrupters which periodically connect the conductors 1—97 to ground. The generators are illustrated in Figure 1*b*, being designated as G—1 to G—97 inclusive, the number portion of the reference character designating the frequency of the impulses which are generated, note No. 1 being the lowest C on the keyboard and having a frequency of 32.703 c. p. s., while note No. 73 is the highest C on the keyboard and has a frequency of 2093 c. p. s. Frequencies Nos. 74—97 are not utilized as fundamentals of any note, but only as over-tones or harmonic partials for combination with a fundamental frequency, as will hereinafter appear.

In Figure 1*b*, the generator G—1 is diagrammatically illustrated as comprising a tuning fork 190 having an upper tine 191 and a lower tine 192. The fork is maintained in vibration by means of an electromagnet 194 having a winding 196 supplied with current from a battery 198 through a resistance 200, the circuit being controlled by a contact 202 cooperable with the upper tine 191 carried by a pivoted arm 204. Since the tuning fork is grounded, a circuit through the electromagnet coil 196 is completed each time the tines of the fork come together. Resistance 206 is connected in parallel with the winding 196 to correct for the delay in current build-up caused by the inductive reactance of the coil 196, by changing the time constant of the circuit. Resistance 200 also affects the time constant of the circuit, but its chief function is to limit the current flow when the fork is first started as by tapping the tines, for at such time the coil 196 offers only a small resistive impedance for the flow of current. Undesirable sparking at the contact 202 during the starting of the fork is thus prevented by the resistance 200.

The portion of the cycle during which the contact 202 is in contact with the tine 191, is determined by the distribution of the mass of arm 204 with respect to its pivot 208. If the mass to the right of the pivot (Fig. 1*b*) is increased, the portion of the cycle during which the contact is made will decrease, while if the mass to the left of the pivot is increased, the portion of the cycle that contact is made will increase.

A contact 210 is mounted on a pivoted arm 212 and is adapted to make contact with the lower tine 192 during a portion of the downward stroke of the latter. By proper distribution of the mass of the arm 212 with respect to its pivot, the portion of the cycle during which the contact is closed may be predetermined. It will be apparent that as the length of time that the contact remains closed increases, the effective impedance of the generator decreases and vice versa.

Upon closure of the switch C_0, for example, a direct current potential will be placed upon conductor 1 and current will be supplied to the contact 210 through a resistance 214 and conductor 215. Thus, upon closure of the contact

210, the direct current from the conductor 1 will be grounded through the tuning fork. The conductor 215 is, however, connected to the resistance 216 which is connected to a primary winding P—1 of an output transformer T—1—6, the opposite terminal of the winding P—1 being grounded. From the above, it will be apparent that impulses of the periodicity of the tuning fork will flow through the primary winding P—1 and induce an alternating current in the secondary winding S—1—6 of the transformer T—1—6.

The secondary winding S—1—6 is connected to a network including a resistance 218 and resistance 220 and condensers 222 and 224. This network forms a low pass filter by means of which the higher harmonics are greatly attenuated so that the output signals of the network are of substantially pure sine wave form. It will be noted that the generators G—2 to G—6 inclusive are connected to primary windings P—2 to P—6 respectively and that these primary windings form part of the transformer T—1—6 and are thus common to the secondary winding S—1—6.

The resistance 216 is provided to reduce impedance modulation of the signal to a negligible amount. If the tuning fork contact 210 were shunted directly across the winding P—1, the transformer impedance looking into the transformer from the secondary winding would be changed from its open circuit to a short circuited condition periodically with the opening and closing of the contact 210. This would be disadvantageous for the following reason:

Since the transformer T—1—6 has six primary windings, all of which are being periodically short circuited, the impedance of the circuit looking into the secondary of the transformer would be continuously changing. Assuming that the impedances of the low pass filter network is approximately 10,000 ohms at the average frequency of the notes 1—6. If, now, a direct current potential is applied to the conductor 2 so as to render the generator G—2 operative, a voltage across the winding P—2 will be impressed at the frequency of vibration of the tuning fork for the generator G—2. If this direct current potential is .01 volt, the voltage across the secondary winding will be 1 volt because the ratios of number of turns between the primaries and the secondary are each 1:100. But, for example, if at the time that the direct current potential is being impressed upon the winding P—2, the contact 210 for the winding P—1 is closed, then the effect upon the winding P—2 will be the same as if the winding P—1 were shunted across it. If the windings P—1 to P—6 each have an alternating current impedance of 1 ohm, then during the time that the winding P—1 was shunted, the effect of the voltage in winding P—2 upon the secondary would be halved, resulting in a signal of only .5 volt across the secondary. Thus, the alternating current voltage, due to the generator G—2 would fluctuate from .5 to 1.0 volt at the frequency of the generator G—1. This effect would be multiplied by the shunting of the primary windings P—3, P—4, P—5 and P—6 at their respective frequencies, and the result would be that the voltage across the secondary might vary between .167 and 1.0 volt. However, by providing a resistance 216 (having a high impedance with respect to the primary winding) in series with each of the primary windings, this impedance modulation is reduced to a negligible value which is not objectionable.

The generators for notes Nos. 2 to 97 are preferably of a construction similar to the generator G—1 described above, though if it is desired to reduce the cost of the instrument, the number of tuning forks may be reduced by utilizing the forks for one octave of notes as vibrators for the notes of the next higher octave. In Fig. 1—*b* is illustrated such an arrangement for the generation of frequencies 62 and 74, as well as for the frequency 86. This generator is thus marked G—62, G—74 and G—86 and comprises the usual single contact for engagement with one of the tines of the tuning fork for supplying the signal for note 62. The note 74 is of twice the frequency of the note 62, but this double frequency may be derived from the tuning fork for the note 62 by providing a pair of contacts 226 and 228 engageable with the lower surfaces of the lower tine 192 and the upper tine 191 respectively. Thus, a contact, grounding wire marked G—74, will be made twice during each vibratory cycle of the tuning fork.

The output circuit for the generator G—74 is supplied by the primary winding P—74 of the transformer T—74, which latter is utilized solely for the note 74. To prevent the transmission to the output circuit of undesired harmonics, a condenser 230 is provided in series with the winding P—74 to form a series resonant circuit which will attenuate all frequencies except the frequency of note 74. In view of the filtering action in the circuit of the primary winding P—74, it is unnecessary to provide a filter mesh in the circuit of the secondary winding S—74.

The tuning fork for the generator G—62 is also utilized to supply the frequency No. 86. This is accomplished by a single contact 232 engageable with the lower tine 192 of the tuning fork. Since frequency No. 86 is four times the frequency of note No. 62, a series resonant circuit is provided for the generator G—86 which effectively attenuates the first, second and third harmonics, with the result that only the fourth and higher harmonics of frequency No. 62 are present in perceptible amplitudes in the secondary winding of the output transformer for the generator G—86. Since frequency No. 86 is not utilized as the fundamental of any note of the musical scale, but is used only as an added harmonic, it is not essential that it be of pure sine wave form. In fact, the musical effect is enhanced by the use of non-sine wave signals for the higher harmonics.

In Fig. 1—*b*, the signals for the frequencies Nos. 73, 85 and 97 are similarly illustrated as derived from a common tuning fork vibrating at frequency No. 73 and the highest frequency of the instrument, namely, frequency No. 97, is thus derived from a tuning fork vibrating at a frequency two octaves lower, the first, second and third harmonics being filtered from the signal by a series resonant circuit including condenser 232 and primary winding P—97 of the output transformer T—97.

In the drawings, the output transformers and their associated filter networks are, for the most part, illustrated as dotted line rectangles to which appropriate reference characters are applied. It will be noted that there are eleven transformers similar to transformer T—1—6, that there is one transformer T—97—73 which has seven primary windings but which is otherwise similar to transformer T—1—6, and that there will be twenty-

four transformers similar to T—74. The outputs of the various transformers are connected in series, one end of the series circuit being grounded and the other being connected to the grid 234 of an amplifying tube 236 forming the first stage of a voltage and power amplifier 238 which supplies a speaker 240, the power for the operation of the amplifier being supplied from a line 242. The amplifier will have a suitable volume control device operated by a swell pedal or the like, and may have adjustable resonant circuits associated therewith to provide various musical effects.

Decay control condensers

In Figs. 2, 3, 4 and 5, is shown a variable condenser of unique construction by means of which various effects may be obtained. This condenser comprises a container 240 which has a pivot 242 secured at one end and an operating rod and pivot 244 secured to its other end. The pivot 242 has a bearing in a bracket 246 which is pivotally mounted upon a shaft 248 extending in a direction perpendicular to the axis of the pivot 242. The bracket 246 has a bail-like extension 250, the right hand end (Figs. 2 and 3) of which is supported on the operating rod 244. The rod 244 has a knob 252 by which the container may be tilted on its longitudinal axis through an angle of approximately 45 degrees in either direction from its normal position. Suitable stops will, of course, be provided to limit the extent of pivotal movement of the container.

The container 240 may also be tilted about the axis of shaft 248 by means of an actuator 254 mounted for rotatable movement on a shaft 256. The mounting is such that the actuator 254 will be frictionally held in any position to which it may be adjusted. The actuator 254 has a laterally extending pin 258 which forms a support for the rod 244. The actuator may be rotated by any suitable means, such means being diagrammatically illustrated as a lug 260 which may be manually engaged or operated through a linkage represented by a link 262.

The container 240 has two bars 264 and 268 of insulating material extending lengthwise thereof at the top of the container. The bars 264 carry a plurality of condenser plates 182, one for each of the generators G—1 to G—97 inclusive, the plates 182 being separated by similar interconnected plates 184 which are grounded. Each of the plates 182 is connected to a soldering lug 274 to which the wires 1—97 are respectively connected. Each soldering lug is provided with a contact 276 which, when the container is tilted clockwise (Fig. 4) about its longitudinal axis, is adapted to make contact with its associated contact bracket 278 carried by the bail 250. Each of the contact brackets 278 is grounded through a resistance 280.

The container 240 is filled with a liquid electrolyte which, when the container is in its normal position, is at the level indicated in Fig. 4, out of contact with the condenser plates. When, however, the container is tilted clockwise from the position in which it is shown in Fig. 4, the surface of the electrolyte will assume the position represented by the dotted line 282, while, if the container is shifted counter-clockwise from the position in which it is shown in Fig. 4, the surface of the electrolyte will assume the position represented by the dotted line 284. In this position a large proportion of the surfaces of the condenser plates will be immersed in the electrolyte. Similarly, when the actuator 254 is rotated to raise the right hand (Fig. 3) end of the container, the condenser plates 182 associated with the lower notes will have successively larger proportions of their surfaces in contact with the electrolyte, while the condenser plates 182 for the notes of the treble register will not be immersed in the electrolyte or will have only small portions of the surfaces thereof immersed. It will thus be seen that by pivoting the container about its longitudinal axis, when the latter is horizontal, the effective values of all of the condensers may be equally varied, and that by tilting the container about the transverse shaft 248 the effective capacities of the various condensers may be changed according to a predetermined pattern depending upon whether it is desired to increase the period of attack and decay of the high pitched notes or of the low pitched notes. When the container is rotated clockwise about its longitudinal axis (Fig. 4) to its maximum extent, each of the condenser plates 182 will be grounded through its associated contacts 276, 278 and resistor 280.

In order to prevent too rapid flow of the electrolyte from one end of the container to the other as it is tilted about its longitudinal axis, a plurality of baffles 285 are provided. These baffles have a large number of apertures so that the flow of the electrolyte will be fairly rapid but will not be so rapid as to cause splashing of the electrolyte from the container.

Operation

The instrument will, generally speaking, be played in the manner of an organ. As previously described, the tone quality is predetermined by depressing one of the preset keys, thereby fixing the potential of each of the bus bars 140, 142, 144 and 146. In addition to the preset keys, draw bars of the type disclosed in my aforesaid Patent No. 1,956,350 may be provided for determining the potentials on the bus bars. In the particular construction illustrated herein, there would be six draw bars for each group, the draw bars being connected respectively to the terminals 126, 128, 130, 134, 136, and each adapted selectively to make contact with one of the bus bars 140, 142, 144 and 146. If desired, two or more of the preset keys may be simultaneously depressed. If, for example, the two preset keys 148 and 149 are depressed at the same time, the potential upon the bus bar 140 would be determined by the potential of the terminal 126. The potential on the bus bar 142 would likewise be determined by the potential of the terminal 126, because the bus bar would be connected to both the terminal 126 and the terminal 128, and since the terminal 126 is of higher potential than the terminal 128, the potential of the former would be controlling. Similarly, the bus bar 144 being connected to both the terminals 130 and 132 would have its potential determined by that of the higher potential terminal 130. The bus bar 146 being connected to the terminals 134 and 136 would have its potential determined by that of the terminal 134.

Thus, the effect of depressing two or more preset keys would be generally similar to the addition of the two or more tone qualities which are determined by the preset keys. It will be understood that the values of the portions of the voltage divider resistance 104 between the various taps will be such that the intensity of the tone produced will increase at a logarithmic rate as the generator producing the tone signal is connected successively to the terminals 134, 132, 130, 128 and 126. Thus, the production of a tone

quality which is the acoustical addition of two other tone qualities is substantially achieved by producing a tone, each of the partials of which is of the maximum intensity at which such partial appears in either of the tones which are to be combined.

This non-algebraic summation of harmonic partials of like frequency is characteristic of other musical instruments. For example, when several organ pipes of the same pitch are blown at one time, the harmonic partials will most likely not be in phase and will therefore add in a manner determined by their phase angles. The probability is that a harmonic partial from one pipe will very seldom add appreciably to the loudness of a louder harmonic partial of the same frequency produced by another pipe.

Assuming that the tuning forks have been set into vibration by suitable mechanical means, the potential impressed upon the generators upon depression of a key will cause pulsating current to flow through their associated transformer primary windings as heretofore described. The alternations induced in the secondary windings of the output transformers will be filtered to remove undesired higher harmonics and the signals from all of the secondaries combined and impressed upon the grid of the tube of the first stage of the amplifier. After being subjected to the influence of a suitable volume control device, the combined signal will be translated into sound by the loud speaker **240**.

By suitable adjustment of the position of the container **240** for the condensers **182**, **184**, the effective capacitances of these condensers may be varied, as previously described, to produce different rates of decay. The adjustment may be made so that all notes are equally affected, by turning the container **140** upon its longitudinal axis, or may be made so that the change in rate of decay is progressively greater for the higher notes, or progressively greater for lower notes.

Due to the use of the rectifiers **121**, the potential upon each of the bus bars **140**, **142**, **144** and **146** will be determined by the maximum potential impressed upon it, rather than by the minimum potential, which would be the case if the rectifiers **121** were not provided. Similarly, the rectifiers **172** serve as means effectively to prevent reductions in the potentials of the bus bars when two or more of the bus bars are connected to a common wire **1—97**. If the rectifiers **172** were not provided, it would be possible, whenever two bus bars of different potential were connected to a common wire **1—97**, for the potential on the higher value bus bar to be reduced to the potential of the lower value bus bar. Thus the tone quality control would be undesirably affected.

Whenever the container **240** is tilted clockwise (Fig. 4) to the maximum extent, the condensers **182—184** are respectively grounded through their respective resistances **280** and thus any potential upon the wires **1—97** will be rapidly reduced to ground potential causing rapid decay of the notes being sounded. This effect is comparable to that obtained upon releasing the sustaining pedal of a piano which causes dampers to be pressed against the vibrating strings with the result that the notes being sounded decay rapidly to zero intensity. When the container is tilted counterclockwise the notes will decay slowly simulating the effects of percussion instruments such as chimes, plucked strings, etc.

By providing a suitable pedal operated means for tilting the condenser container **240** about its longitudinal axis as well as about its transverse axis, the attack and decay characteristics of the notes may be easily varied during the rendition of a musical composition to produce beautiful and unusual effects. By this means unfavorable acoustical conditions may be overcome also, in effect, by increasing the reverberation time.

While I have shown the novel keying circuits in conjunction with tuning fork oscillation generators, it will be apparent to those skilled in the art that the keying circuits may be used with various other forms of oscillation generating means and that similarly the tuning fork frequency generating system may be utilized with different forms of keying circuits. I therefore desire in the following claims to include within the scope of my invention all such equivalent constructions whereby substantially the results of my invention may be obtained by substantially the same means.

I claim:

1. In an electrical musical instrument, the combination of a source of direct current, a voltage divider connected to said source and having a plurality of taps, variable condensers connected between one terminal of said source and said taps respectively, a plurality of bus bars, a plurality of terminals, a plurality of rectifiers connected between said taps and terminals respectively, a plurality of multiple key switches for connecting said bus bars respectively to preselected ones of said terminals, and key switch controlled circuits for connecting said bus bars to alternating current generators.

2. In an electrical musical instrument, the combination of a plurality of generators of electrical impulses, said generators being of the type in which the amplitude of the impulses may be controlled by the value of a direct current potential impressed upon the generator, a plurality of sources of direct current potentials of different values, and a plurality of circuits selectively operable to connect said sources to said generators, each of said circuits including a rectifier for conducting current from one of said sources to one of said generators and preventing flow of current in the reverse direction.

3. In an electrical musical instrument, the combination of a plurality of audio-frequency generators of the type which is excited by direct current, a source of direct current, and selectively operable means for connecting said source to said generators, said means including for each generator a rectifier and a condenser with said condenser connected in parallel with said generator, both said condenser and said generator being supplied with current from said source through said rectifier.

4. In an electrical musical instrument, the combination of a plurality of audio-frequency generators of the type which is excited by the application of a direct current potential thereto, a source of direct current, and selectively operable means for connecting said source to said generators, said means comprising a voltage divider connected to said source and having a plurality of taps at different potentials, a rectifier for each of a plurality of said taps, each rectifier having one of its terminals connected to its associated tap to receive current therefrom, a plurality of bus bars, means for selectively connecting said bus bars to the other terminals of said rectifiers, and means for selectively connecting said bus bars to said generators.

5. In an electrical musical instrument, the combination of a plurality of bus bars, key oper-

ated means for impressing predetermined direct current potentials upon said bus bars, a plurality of generators of signals having fundamental frequencies corresponding to those of the musical scale, each of said generators being normally ineffective but being rendered effective upon impressing a direct current potential thereon, circuits including key operated switch means for selectively connecting said bus bars to said generators, each of said circuits including a rectifier, and a condenser connected in the circuit to have its charge altered by flow of current through said rectifier.

6. In an electrical musical instrument, a plurality of generators of electrical impulses of musical frequency, each of said generators having a terminal the direct current potential of which determines the amplitude of the impulses produced by the generator, selectively operable means to impress a direct current potential of predetermined value with respect to ground upon each of said terminals, a plurality of condensers each having one plate thereof connected to one of said terminals respectively, and having their other plates grounded, and means common to all of said condensers to vary the capacitances thereof.

7. The combination set forth in claim 6, in which the condensers are of the electrolytic type.

8. The combination set forth in claim 6 in which the condensers are of the electrolytic type having a liquid electrolyte, and the means to vary their capacitances comprises mechanism for tilting the condensers.

9. The combination set forth in claim 6 in which said condensers are enclosed in a container partially filled with a liquid electrolyte, and in which the means for varying the capacitances thereof comprises means for tilting the container to vary the extent of immersion of the plates of the condensers in the electrolyte.

10. The combination set forth in claim 6 in which each of said condensers comprises a plate extending into a relatively long narrow container, partially filled with a liquid electrolyte, and the means for varying the capacitances of the condensers comprises selectively operable means for tilting the container about its longitudinal axis and about a transverse axis.

11. The combination set forth in claim 6 in which each of said condensers comprises a plate extending into a relatively long narrow container, partially filled with a liquid electrolyte, and the means for varying the capacitances of the condensers comprises selectively operable means for tilting the container about its longitudinal axis.

12. The combination set forth in claim 6 in which each of said condensers comprises a plate extending into a relatively long narrow container, partially filled with a liquid electrolyte, and the means for varying the capacitances of the condensers comprises selectively operable means for tilting the container about a transverse axis.

13. The combination set forth in claim 6 in which each of said condensers comprises a plate extending into a relatively long narrow container, partially filled with a liquid electrolyte, and the means for varying the capacitances of the condensers comprises selectively operable means for tilting the container about one or more of a plurality of divergent axes.

14. The combination set forth in claim 6 in which each of said condensers comprises a plate extending into a container partially filled with a liquid electrolyte, and in which the means for varying the capacitances of said condensers comprises mechanism for changing the extent of immersion of the plates of the condensers in the electrolyte.

15. In an electrical musical instrument, the combination of a plurality of bus bars, a source of direct current potential, a voltage divider having a plurality of taps connected across said source, a plurality of condensers, one connected to each of the taps of said voltage divider, a rectifier connected to each of said taps, and selectively closeable circuits for connecting said taps to selected ones of said bus bars, each of said circuits including one of said rectifiers.

16. In an electrical musical instrument having a manual comprising a plurality of keys in which each key is operative to connect a plurality of tone controlling devices to selected bus bars, means for supplying a predetermined direct current potential to said bus bars, said means comprising a source of direct current potential, an impedance element having a plurality of taps and having its terminals connected across said source, a condenser connected between each of said taps and one of the terminals of said source, and a rectifier connected to each of said taps to prevent reverse flow of current upon connection of a plurality of said taps to a single bus bar.

17. In an electrical musical instrument, the combination of a plurality of oscillation generators for producing electrical impulses of the frequencies of the musical scale, said generators being controllable by the application of a direct current potential thereto, a plurality of bus bars of selectively adjustable potential, switches cooperable with said bus bars and connected to impress the potentials of said bus bars upon said generators, and rectifying means in each of said switch circuits to prevent flow of current from said generators to said bus bars.

18. In an electrical musical instrument, in which electrical generators of musical frequency are rendered effective by impressing a direct current potential thereupon, a source of direct current potential, a switch for keying said source to said generator, and a rectifier connected in said switch circuit to prevent flow of current in a direction from said generator to said source.

19. In an electrical musical instrument, having a generator of the frequency of a musical note and the amplitude of the output signal of which is determined by the value of a direct current potential impressed upon the generator, the combination of a direct current potential source, a voltage divider connected across said source and having a plurality of taps, a resistor in series with said voltage divider, rectifiers connected to the taps of said voltage divider, a condenser connected to each of the taps of said voltage divider, bus bars selectively connectable to the taps of said voltage divider through one of said rectifiers, conductors for supplying the direct current operating potential to said generators respectively, a variable condenser connected between each of said conductors and one of the terminals of said source, key operated switch closed circuits for selectively connecting said condensers to said bus bars, and a rectifier in each of said circuits.

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