Nov. 8, 1932. C. T. JACOBS 1,886,687

METHOD AND APPARATUS FOR THE PRODUCTION OF MUSIC

Filed March 28, 1931 3 Sheets-Sheet 1

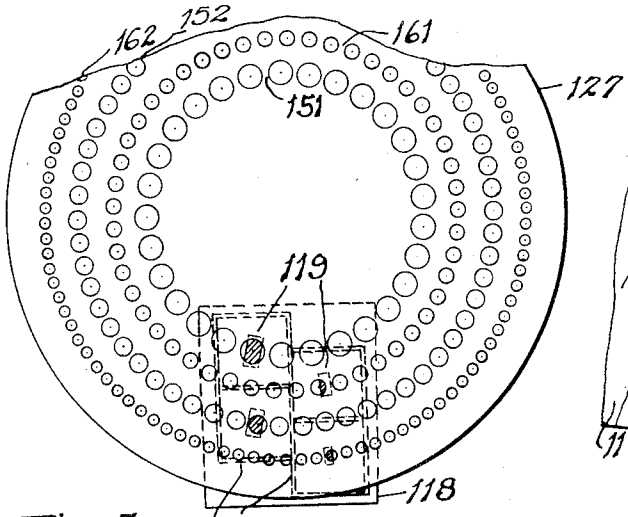
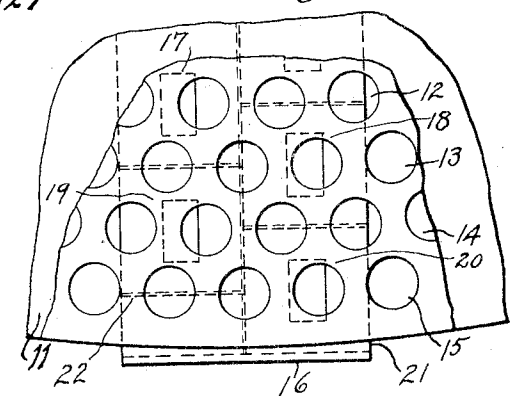


Fig. 5.

Fig. 2.



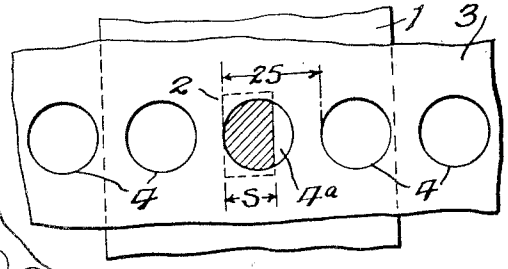


Fig. 1

Fig. 4

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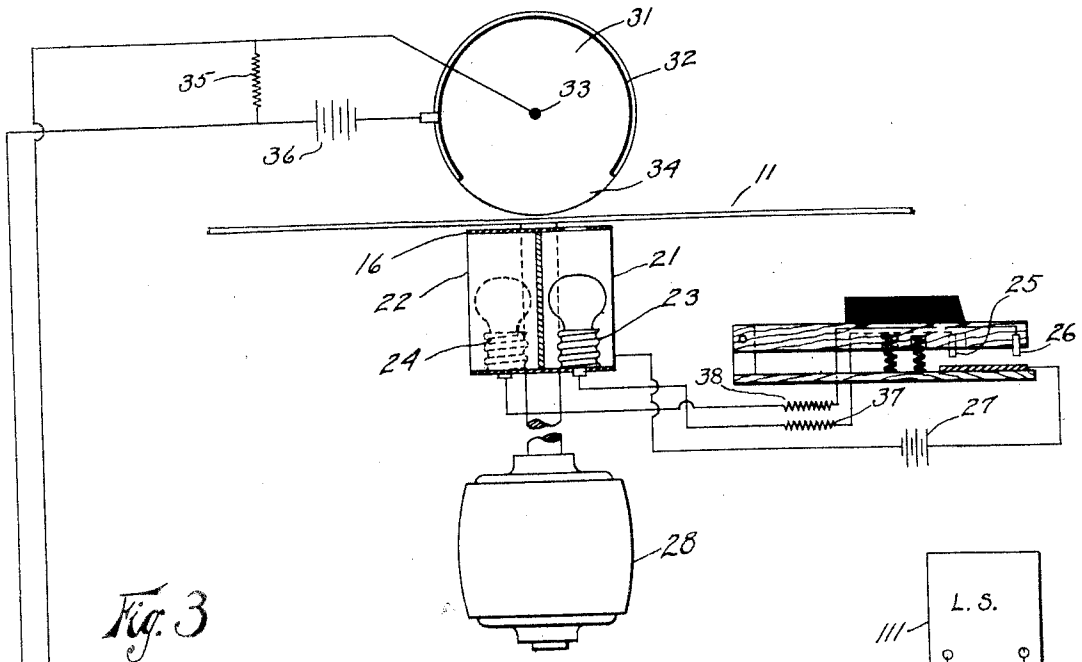
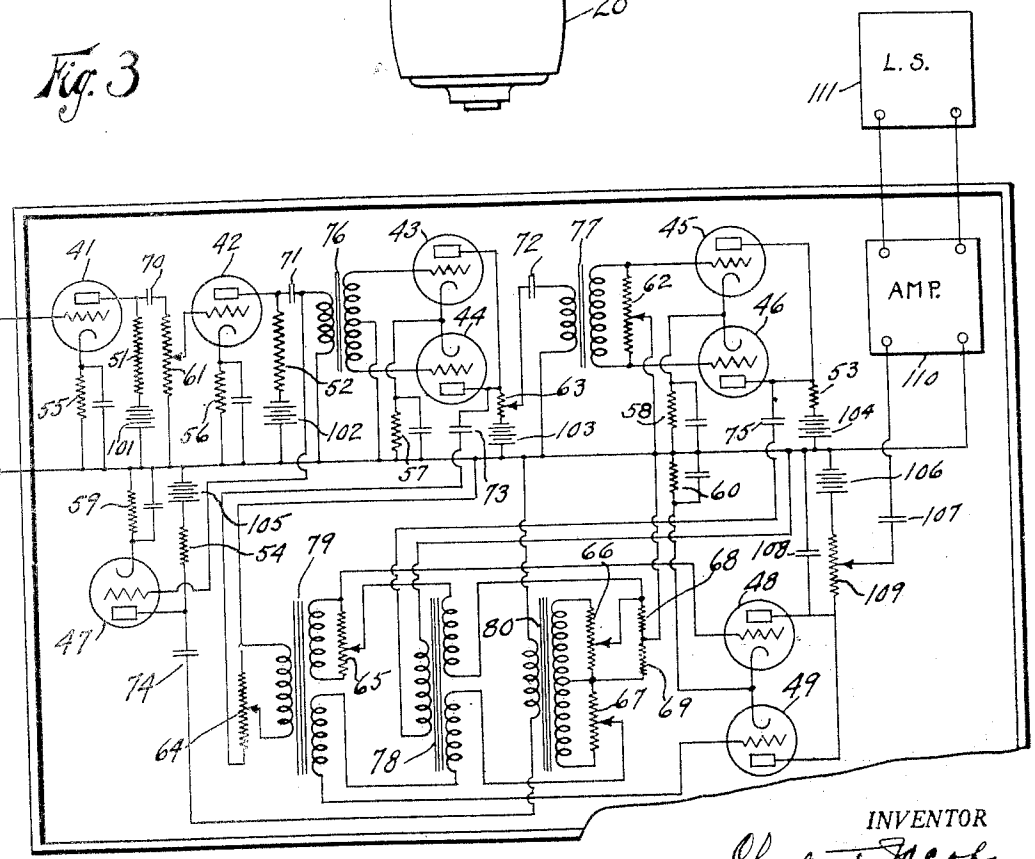


Fig. 3



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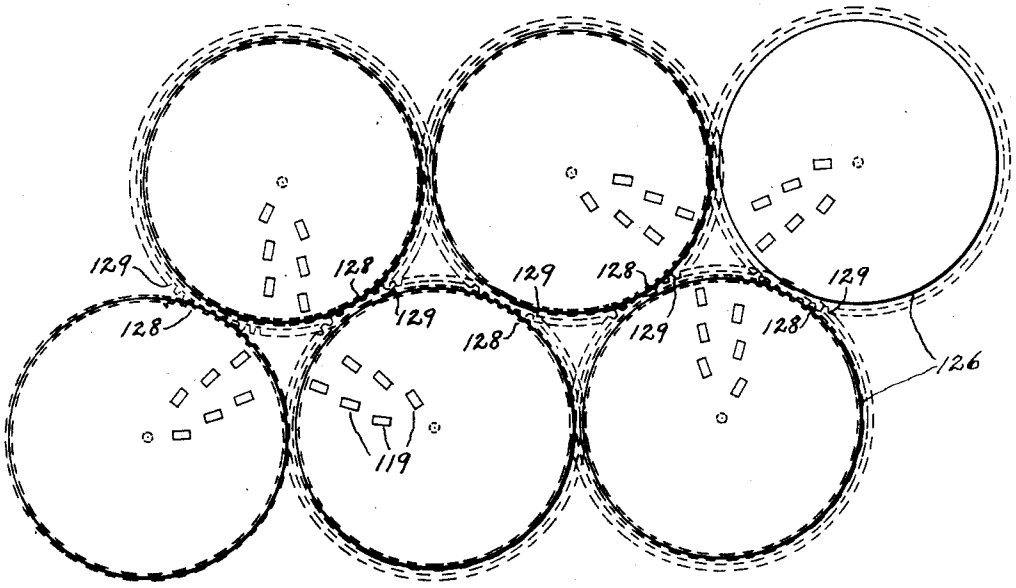


Fig. 6

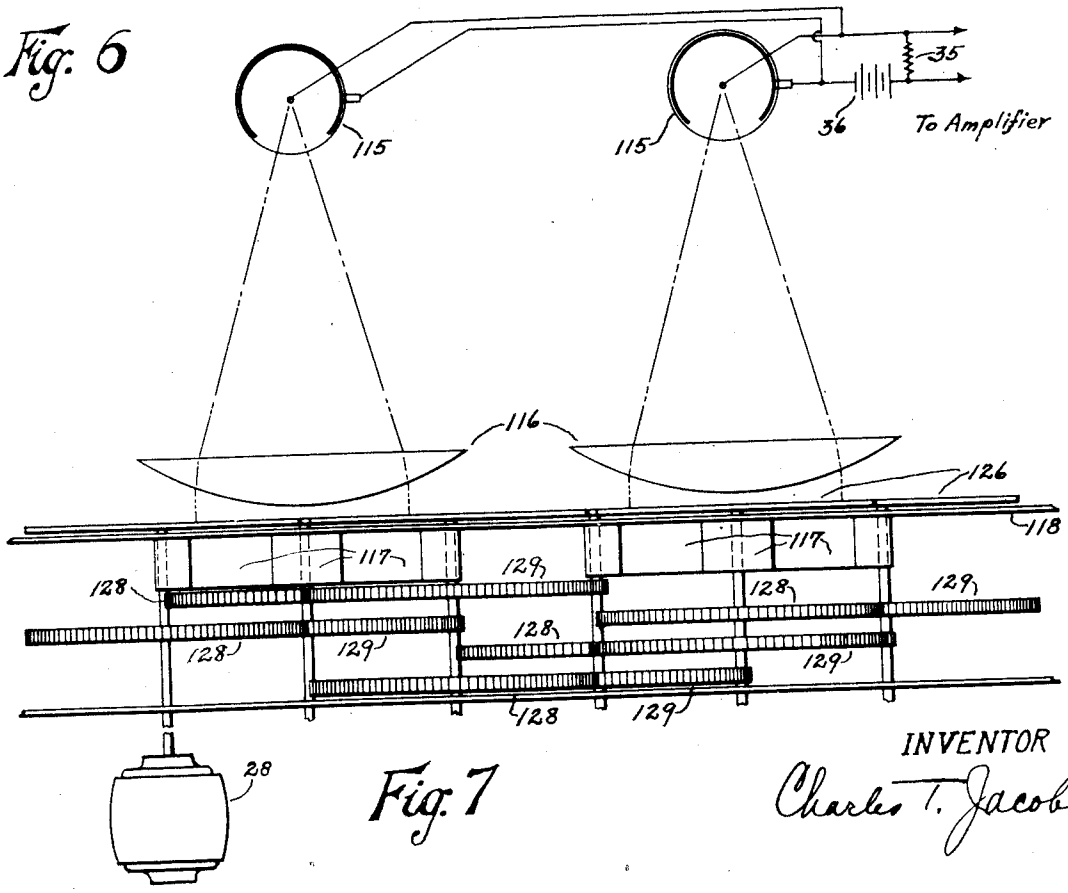


Fig. 7

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UNITED STATES PATENT OFFICE

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METHOD AND APPARATUS FOR THE PRODUCTION OF MUSIC

Application filed March 28, 1931. Serial No. 526,002.

This invention relates to methods and apparatus for the production of music electrically and more particularly for the generation of electric oscillations, for the control and alteration of their waveform, and for their amplification and translation into sound waves.

It is an object of my invention to provide a musical instrument wherein electric oscillations of various musically related frequencies may be produced and their waveform controlled and altered at will, and wherein the same may be amplified and translated into sound waves. It is a further object to provide a simple method and apparatus for the generation of approximately sinusoidal electric oscillations. It is a still further object to provide means for musically relating the frequencies of such oscillations. A further object is the provision of methods and apparatus for the control and alteration of the waveform of such oscillations. Other and allied objects will more fully appear from the following description and appended claims.

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

Figure 1 is a view of a detail of the oscillation source embodied in my invention;

Figure 2 is a view illustrating a larger portion of such source;

Figure 3 is a view, partly schematic, of a musical instrument embodying my invention;

Figure 4 is a plan of a disc employed in a further embodiment of my invention;

Figure 5 illustrates an alternative plan of disc which may be employed in this embodiment of my invention;

Figure 6 is a front view of a portion of a musical instrument embodying six such discs as are illustrated in Figure 4 or Figure 5; and

Figure 7 is a top view of a portion of such instrument.

In Figure 1 I show a shield which possesses, when operated, a continuously varying aperture, for use between a source of energy and an energy collecting device which yields an electrical output depending on the degree of its exposure to such energy source. As a source and collecting device I have employed respectively a light and a photo-electric cell; but the detail of my invention shown in Figure 1 is not necessarily limited to use with this particular apparatus. Such shield may consist of a stationary plate or sheet 1, which may be of metal and is preferably thin, having therein a rectangular aperture 2 of width S; and a plate or sheet 3, which may be of similar material to plate 1, carrying a row of circular holes 4 of similar diameter and spacing, continuously moving when in operation so that the holes 4 progressively pass in front of aperture 2 in plate 1. Plates 1 and 3 are preferably as close together as possible without actual contact which would introduce frictional resistance to the continuous motion of plate 3. The row of holes 4 should be endless; and to the attainment of this objective 3 may take any of a variety of forms; for example, a continuous moving belt or the periphery of a cylinder rotating about its axis or a section of either, or a section of a flat disc, in which last case row of holes 4 instead of forming a straight line as shown may be curved following a circle about the center of rotation of the disc.

The exact length of aperture 2 (i. e., the dimension perpendicular to the row of holes 4) is not of importance, it being desirable only that it equal or slightly exceed the diameter of each hole 4; the diameter and spacing of holes 4, however, are of importance. These characteristics in relation to the aperture 2 are elements of my invention. I have found that if the spacing between the centers of successive holes be equal to 2S (twice the fixed aperture width) and the radius of each hole be of a value between $\frac{1}{2}S$

and S, the exposed area will vary, in a motion of plate 3 of distance 2S, according to the following formula:—

$$\text{Area} = R^2\left[\cos^{-1}\frac{M}{R} - \frac{M}{R}\sin\left(\cos^{-1}\frac{M}{R}\right)\right] - R^2\left[\cos^{-1}\frac{S+M}{R} - \frac{S+M}{R}\sin\left(\cos^{-1}\frac{S+M}{R}\right)\right] + R^2\left[\cos^{-1}\frac{S-M}{R} - \frac{S-M}{R}\sin\left(\cos^{-1}\frac{S-M}{R}\right)\right]$$

This formula is one wherein the angles are expressed in radians, wherein R is the radius of the holes 4, and M is the distance between one side of aperture 2, say the left-hand side in Figure 1, and the center of one of the holes 4, as 4*a* in the figure; M being considered negative when the center of such hole is to the right and positive when to the left of such side of aperture 2. Thus as shown in Figure 1 the value of M may be considered to be $-R$; and if the plate 3 move in a leftwardly direction, the value of M will change toward and pass through zero and increase positively, the formula showing the area for any value of M between $-R$ and $(2S-R)$. Since the holes 4 are similar and are spaced by a distance of 2S, the formula becomes a repeating one for continuous motion of plate 3 and will be found to give rise to a successively increasing and diminishing value of area, which increasing and diminishing values are symmetrical about the mean value.

Empirically I have discovered from the formula that if the ratio S/R equals 7/5 (i. e., if the radius of holes 4 equals 5/7 times the slot width) the variation in area about the mean is almost exactly sinusoidal. Holes of appreciably smaller radius relative to the slot width tend to impair this sinusoidal character by rendering the peaks of the wave excessively pointed. The holes may be increased in radius almost to the slot width. If the radius be equal to that width, however, the holes become contiguous, due to the center spacing thereof of 2S (twice the slot width). I have therefore preferred to employ a ratio of S/R of approximately 7/5.

In Figure 2 I show a section of a rotatable disc 11 provided with concentric rows of holes as 12, 13, 14 and 15. Behind such disc I show plate 16, carrying apertures as 17, 18, 19 and 20. The dimensioning of each row of holes and its associated aperture is preferably carried out according to the principles above disclosed. Behind the plate 16 may be mounted lamp housings, one for each row of holes in the disc, the lower such housings being designated as 21 and the upper as 22. These housings, as well as the apertures in plate 16, are shown staggered in order that the rows of holes may lie closer together than the width of such housings. While this staggering is shown only to the extent of the use of two rows of apertures and housings, three or more rows may be used if desired.

In order to avoid objectionable breaks in the tones produced by such apparatus as this, it is desirable for each tone to have the number of cycles per revolution of the disc or cylinder an exact integer. In this case this requires an integral number of holes in each row, each of which rows is arranged to produce a different frequency tone. But since each octave of the usual equally tempered musical scale is made up of twelve tones related to each other in frequency by or having intervals consisting of powers of the twelfth root of 2, the first eleven of which are irrational, it is impossible to obtain the exact frequency relationships desired for such a scale from any combination of integers. When a single disc is used to supply all the tones in an octave, therefore, I prefer to employ a large number of holes in each row, so that the errors in frequency relationships of intervals between the various tones may be reduced to a minimum. This, of course, requires relatively small holes; and this in turn relatively small apertures, in order that the dimensioning relationships shown above may be adhered to.

In Figure 3 I show a musical instrument employing a disc and the associated apparatus shown in Figure 2. The sides of disc 11 and plate 16 appear; also those of lamp housings 21 and 22, which are provided with lamps as 23 and 24, wired to keyboard switches as 25 and 26. The common side of the switches and the common side of the lamps may conveniently be connected together through battery 27 or other source of current. Motor 28 is shown for rotating disc 11. A tubular photo-electric cell 31, having cathode 32 and anode 33 is shown with its window 34 on the opposite side of the disc 11 from plate 16. The electrical terminals of cell 31 may form a series circuit with resistor 35 and battery or other voltage source 36 if polarizing voltage be required for the particular cell used.

The output of cell 31 is applied to the input of thermionic amplifying and controlling apparatus, which may include vacuum tubes shown consecutively numbered from 41 to 49, the cathodes of which may be energized in any suitable manner, as will be understood. The grid of vacuum tube 41 may be biased negatively with respect to its cathode by resistor 55 through which the plate current of tube 41 flows. Similarly tube 42 may be biased by resistor 56, tubes 43 and 44 by resistor 57, tubes 45 and 46 by resistor 58, tube 47 by resistor 59 and tubes 48 and 49 by resistor 60. These resistors may be by-passed by condensers, if desired. Plate current supply for the tubes is shown as comprising various batteries, consecutively numbered from 101 to 106; it will be understood however that

(c) Equal amplitudes of fundamental from tube 47 controllable by potentiometer 66.

And to the grid of one of the tubes, 49, alone, may be fed fundamental controllable by potentiometer 67.

Such components as are fed to the grids of the two tubes in equal amplitude appear in the output of the tubes doubled in frequency, and further produce beats with other frequency components being fed to either or both tubes—i. e., sum and difference frequencies. Such components as are fed to the grid of one tube only or in larger amplitude to the grid of one tube than to that of the other produce the same effects but in addition appear without frequency doubling in the output. It will thus be seen that by the use of the controls 63, 64, 65, 66 and 67 a single frequency output of the photo-cell may be caused to appear in the output of tubes 48 and 49 in a large variety of altered waveforms which may include, in addition to the fundamental, components of second, third, fourth, fifth, sixth, and eighth harmonics, the odd harmonics being the result of beating of even harmonics with the fundamental and the sixth harmonic being the result of beating of the second and fourth. Each of these five controls may be calibrated with a scale to facilitate duplication of settings for different harmonic structures.

In order that the amplifying and controlling system may have a similar effect on the waveform of different frequency oscillations it is desirable that the photo-cell yield approximately equal amplitudes at different fundamental frequencies. It is necessary, however, for musical purposes to reduce the amplitude of the oscillations in a degree increasing with frequency if apparently equal sound intensity at different frequencies is to be obtained in the output. When uniform output of the photo-cell is obtained at all frequencies as above suggested, I prefer to shunt a condenser such as 108 across the output of tubes 48 and 49, the function of which condenser is to produce a decrease of amplitude with increasing frequency. It is to be noted that this condenser will reduce the amplitude of the harmonics generated by various parts of the amplifying and controlling system and that such harmonic generation must therefore be carried to a greater extent than would be necessary were condenser 108 or its equivalent not present. I also prefer to locate the main control of output volume in the output of these tubes, potentiometer 109 being shown in Figure 3 for this control. From this potentiometer the oscillations may be fed through stopping condenser 107 to a customary amplifier 110 for such further amplification as may be desired and thence into a loudspeaker or other electro-acoustic translating device 111.

It will be understood, of course, that a simpler circuit may be employed, which may if desired comprise the circuit shown in Figure 3 with certain components omitted; as, for example, transformer 77, tubes 45 and 46, transformer 78, and apparatus associated therewith. In this case the harmonic generation would be substantially limited to second, third and fourth. It will further be obvious that various modifications may be made in the arrangement of the controls; that other frequency doubling apparatus may be substituted for tubes 43 and 44 and for tubes 45 and 46 and their associated circuits; that tube 47 and its circuit, included in Figure 3 for further amplification of the fundamental before application to tubes 48 and 49, may be omitted if desired; and that other re-arrangements and substitutions may be effected without departing from the principles disclosed.

A further embodiment of my invention is illustrated in Figures 4, 5, 6, and 7. This embodiment has for its object the provision of simple means for relating the frequencies of the various notes in an extremely close approximation to the intervals of the equally tempered scale, free from the requirement of the generation of a large number of cycles per revolution of the disc or other moving members employed. In this embodiment six similar discs are employed, geared together by five similar gearing combinations. I am aware that various geared arrangements of frequency generators have been heretofore disclosed for similar purposes. They have suffered, however, from one or both of the limitations that at least twelve moving members have been required and that the gearings between the varous moving members have been dissimilar.

In Figure 4 I show the plan of a disc 128 which may be employed in this modification of my invention. The disc is arranged for the generation of two notes separated by a half-tone interval, and two upper octaves of each of said notes. The inside row 121 contains 17 holes; the second row 131 contains 18 holes; the third row 122 contains twice the number of the first, or 34; the fourth row 132 contains twice the number of the second, or 36; the fifth row 124 contains four times the number of the first, or 68; and the sixth row 134 contains four times the number of the second, or 72. The disc is thus arranged to provide each of its two notes in their different octaves; this range may be extended if desired by adding rows containing 8 times the number of holes of the first and second rows, respectively, 16 times such numbers, etc. The two notes produced by the disc are of course related to each other in frequency by the ratio 17:18, or 1:1.0588, which is less than the equally tempered half-tone interval by only six hundredths of one per cent (.06 per cent).

a single suitable power supply yielding appropriate voltages may be substituted therefor.

The output of tube 41, which is arranged to function as an amplifier, appears across fixed resistor 51 and is applied through stopping condenser 70 and potentiometer 61 to the grid of tube 42, also arranged to function as an amplifier. The output of tube 42 appears across resistor 52 and is applied through stopping condenser 71 both to the primary of transformer 76 and to the grid of tube 47. The output of tube 47, also functioning as an amplifier, appears across resistor 54 and is applied through stopping condenser 74 to the primary of transformer 80.

The secondary of transformer 76 may be center-tapped; and the voltage appearing across it is applied to the grids of tubes 43 and 44, the voltages on these two grids being always 180 degrees out of phase with respect to each other. All of the voltages thus far discussed have been cyclic with respect to the output voltage of the photo-cell. Tubes 43 and 44, however, by virtue of suitable choice of operating conditions, are operated on the curved portion of their dynamic grid-voltage, plate-current characteristic—i. e., as modulators—and hence their output includes not only the fundamental frequency applied to them but also an appreciable quantity of harmonics, largely second harmonic. The plates of these tubes are paralleled, and hence the fundamental output of one tube is cancelled by that of the other; and across the output resistor 63 there therefore appears principally second harmonic, or a voltage bi-cyclic with respect to the photo-cell output. The resistor 63 is in the form of a potentiometer; and by virtue of the adjustability thereof there may be applied through the stopping condenser 72 to the primary of transformer 77 a controllable potential of second harmonic of the photo-cell output. Through stopping condenser 73 this second harmonic also reaches potentiometer 64 and the primary of transformer 79.

The secondary voltage of transformer 77 is applied to the grids of tubes 45 and 46, also functioning as modulators, 180 degrees out of phase one with respect to the other; and potentiometer 62 may be provided for a nice adjustment of the amplitude of these voltages between themselves. Such a potentiometer may be employed across the secondary of transformer 76; or the secondary of transformer 77 may be center-tapped, according to convenience, the two arrangements having been shown in their respective positions by way of illustration only. The bi-cyclic input to tubes 45 and 46 is made to produce a quadri-cyclic output therefrom in the same manner as that in which tubes 43 and 44 were caused to yield a bi-cyclic output for cyclic input. Such quadri-cyclic output, or fourth harmonic of the photo-cell output, appears across resistor 53 and is applied through stopping condenser 75 to the primary of transformer 78.

It will be seen that the function of tubes 43 and 44 and of tubes 45 and 46 is in each case frequency-doubling; and there may therefore be substituted for such tubes and their associated apparatus any other suitable form of frequency-doubling devices. When the arrangement shown is employed, it is desirable that the output resistors 63 and 53 be lower in value than in the case of straight amplifying tubes; that the bias resistors 57 and 58 be chosen, in connection with the plate supply voltage used for these tubes, to restrict the plate current of the tube to a rather low value; and that the A. C. voltage applied to the grids of the tubes be held within certain limits according to the type of tube and the value of plate current used. Potentiometer 61 may be employed to regulate the voltage supplied to tubes 43 and 44; and this is its principal function, it being not intended for use as a volume control in the playing of the instrument. Potentiometer 63 may regulate the voltage supplied to tubes 45 and 46.

The transformers 78, 79 and 80 are shown with split secondaries. Across one half-secondary of transformer 79 is shown potentiometer 65; across one half-secondary of transformer 80 potentiometer 67; and across the other half-secondary of transformer 80 potentiometer 66, the output terminals of which are shunted with equal resistors 68 and 69 in series. In the grid circuit of tube 48 appears half the voltage output of one half-secondary of transformer 80 (controllable by 66); the voltage output of one half-secondary of transformer 80; and the voltage output of one half-secondary of transformer 79 (controllable by 65). In the grid circuit of tube 49 appears one half the voltage output of one half-secondary of transformer 80 (controllable by 66) and the voltage output of the other half-secondary of transformer 80 (controllable by 67); and the voltage outputs of a half-secondary each of transformers 78 and 79. Tubes 48 and 49, like the two preceeding pairs of tubes, are operated as modulators; and as a result of the connections of the secondaries of transformers 78, 79 and 80 above mentioned there may be supplied the grids of these two tubes, out of phase on the grid of one with respect to that of the other:—

(*a*) Equal amplitudes of fourth harmonic from tubes 45 and 46, controllable by potentiometer 63;

(*b*) Equal or unequal amplitudes, according to the adjustment of 65, of second harmonic from tubes 43 and 44, controllable by potentiometer 64; and

Figure 5 illustrates the inside rows of an alternatively arranged disc 127 also designed for the producton of two notes and octaves thereof. The inside row of holes 151 is provided with 29 holes, the second row 161 with 41 holes, the third row 152 with twice the first, or 58 holes, the fourth row 162 with twice the second, or 82 holes. In this disc additional rows may be provided for greater octave ranges, as in the disc of Figure 4, having respectively 4, 8, 16 etc., times the number of holes of the first and second rows. In this case the two notes produced by the disc are related to each other in frequency by the ratio 29:41, or 1:1.14138, which is less than the equally tempered interval of six half-tones by only three hundredths of one per cent (.03 per cent).

The holes in the discs of both Figure 4 and Figure 5 preferably are dimensioned and spaced according to the principles hereinabove disclosed—i. e., the diameter is made approximately equal to 5/7 times the center spacing—and are employed with an aperture for each row of holes in each disc, each aperture having a width of half the center spacing of the holes in the row with which it is associated. Such apertures are shown in Figures 4 and 5 as 119 in aperture plate 118; and lamp housings 117, similar to 21 and 22 in Figures 2 and 3, are shown behind the aperture plate.

In Figure 6 I show geared together six of the discs illustrated as Figure 4, with holes omitted for the sake of clarity; but with the apertures 119 appearing. Five similar gears 128 couple 129 and five other similar gears 128 couple the discs together rotatively so that the rotation of any one of the discs will cause all six to rotate in the proper speed ratios. For use with the discs of Figure 4 each gear 129 should contain 55 teeth and each gear 128, 49 teeth; gears 129 and 128 may however contain respectively 110 and 98 teeth, 220 and 196 teeth, etc., it being necessary merely that the ratio 55:49 be preserved. The decimal value of this ratio is 1.1224:1, which is less than the equally tempered full-tone interval by only three thousandths of one per cent (.003 per cent). The discs of Figure 5 may alternatively be employed in the assembly shown in Figure 6; but in this case each gear 129 should contain 107 teeth and each gear 128, 101 teeth; or other respective numbers in the ratio of 107 and 101. The decimal value of this ratio is 1.0594:1, which is less than the equally tempered half-tone interval by only six thousandths of one per cent (.006 per cent). In either case the inside two rows of the six discs will supply the twelve notes of one octave and each succeeding pair of rows of the six discs the same notes of a higher octave.

A top view of the assembly shown in Figure 6 appears as Figure 7. Herein is also shown an optical system comprising condensing leases 116, each lens serving to concentrate roughly to a point the light beams passing through the apertures and holes associated with and in three of the discs. At each of the two such points may be located a photo-cell 115, the terminals of which may be connected in parallel or otherwise, according to the type of cell, as will be understood. Resistance 35 and battery or other voltage source 36 may be employed if polarizing voltage be required for the particular cells used. In any event the output of the cells may be applied to the input of thermionic amplifying and controlling apparatus, such as that shown in Figure 3. It will be understood, of course, that a single photo-cell may be employed having a window large enough to embrace the two points of concentration of the light rays; or that a single large condensing lens or another optical system may be employed for concentrating all the rays to a single point or region, wherein may be located a single photo-cell. The lamps in lamp housing 117 may be wired to individual key-board switches, through resistances if desired, similarly as in Figure 3.

While I have shown and described the six discs in this embodiment as being geared together, it will be understood that they may be otherwise coupled mechanically in the integral relationship shown without departing from the spirit of my invention; and while I have shown and described the rotating members as discs provided with rows of holes I do not wish to limit this embodiment of my invention thereto, it being suitable for use in any musical instrument in which are employed rotating members carrying tracks for the production of different frequency notes. It will further be understood that other suitable combinations of integers than those mentioned may be employed in the basic arrangement of six moving members, each carrying tracks for the production of two different frequency notes and octaves thereof.

Various modifications may of course be made in the choice and arrangement of component parts without departing in the manner of their employment from the methods herein described or from the spirit or scope of my invention, as hereinabove disclosed and in the appended claims defined.

I claim:—

1. In a musical instrument, a source of energy; an energy collecting device; a shield between said source and said collecting device, said shield comprising a stationary member having therein an aperture with two substantially parallel sides and a movable member having therein an endless row of similar circular holes, the centers of the holes in each of said rows being spaced approximately twice the separation of said sides of the associated aperture and the diameter of said holes being greater than said separation; and

means for so moving said movable member that said holes continuously pass in front of said aperture in a direction substantially at right angles to said sides thereof.

2. In a musical instrument, a source of energy; an energy collecting device; a shield between said source and said collecting device, said shield comprising a stationary member having therein an aperture with two substantially parallel sides and a movable member having therein an endless row of similar circular holes, the centers of said holes being spaced apart approximately twice the separation of said aperture sides and the radius of said holes being approximately equal to 5/7 times said separation of said aperture sides; and means for so moving said movable member that said holes continuously pass in front of said aperture in a direction substantially at right angles to said sides thereof.

3. An electrical musical instrument comprising, in combination, a plurality of electric lamps; at least one photo-electric cell; at least one shield between said lamps and said cells, each said shield comprising a stationary member having therein for each of said lamps an aperture with two substantially parallel sides, and a movable member having therein an endless row of circular holes for each of said apertures, the center of the holes in each of said rows being spaced apart approximately twice the separation of said sides of the associated aperture and the radius of said holes being approximately equal to 5/7 times said separation of said aperture sides; means for so moving said movable members that the holes associated with each of said apertures continuously pass in front thereof; means for selectively energizing said lamps; thermionic apparatus connected in the output circuit of said cell; and an electro-acoustic translating device connected in the output circuit of said thermionic apparatus.

4. An electrical musical instrument comprising, in combination, a source of electric oscillations including six rotatable discs, each provided with at least one group of two endless rows of holes, each group containing numbers of holes in its two said rows in the ratio of 17 : 18, at least one stationary member provided with an aperture for each row in each disc, means for so rotating said discs that the holes in each row continuously pass in front of the aperture associated therewith, means for relating the speed of rotation of said discs substantially in the ratio of 49 : 55, each to its successor in arrangement, an electric lamp behind each of said apertures, means for selectively energizing said lamps, and at least one photo-electric cell in front of said discs and arranged to receive light rays from said lamps through said apertures and holes; thermionic apparatus connected in the output circuit of said cells; and an electro-acoustic translating device connected in the output circuit of said thermionic apparatus.

5. An electrical musical instrument comprising, in combination, a source of electric oscillations including six rotatable discs, each provided with at least one group of two endless rows of holes, each group containing numbers of holes in its two said rows in the ratio of 29 : 41, at least one stationary member provided with an aperture for each row in each disc, means for so rotating said discs that the holes in each row continuously pass in front of the aperture associated therewith, means for relating the speed of rotation of said discs substantially in the ratio of 101 : 107, each to its successor in arrangement, an electric lamp behind each of said apertures, means for selectively energizing said lamps, and at least one photo-electric cell in front of said discs and arranged to receive light rays from said lamps through said apertures and holes; thermionic apparatus connected in the output circuit of said cells; and an electro-acoustic translating device connected in the output circuit of said thermionic apparatus.

6. In an electrical musical instrument, a source of electric oscillations including six continuously movable members, each carrying endless tracks for the generation of oscillations of frequencies in the ratio of the integers 17 and 18 and of multiples thereof in powers of 2; means for continuously moving said members; and means for relating the speed of motion of successively arranged such members substantially in the ratio of the integers 49 and 55.

7. In an electrical musical instrument, a source of electric oscillations including six continuously movable members, each carrying endless tracks for the generation of oscillations of frequencies in the ratio of the integers 29 and 41 and of multiples thereof in powers of 2; means for continuously moving said members; and means for relating the speed of motion of successively arranged such members substantially in the ratio of the integers 101 and 107.

8. In an electrical musical instrument, a source of electric oscillations including six continuously movable members, each carrying endless tracks for the generation of oscillations of two frequencies bearing to each other a ratio less than 2 : 1 and expressible by integers, and of oscillations of frequencies respectively multiples of said two frequencies in powers of 2; and means for uniformly relating the speed of each said member to that of the next slower said member.

9. The method of relating the frequencies of twelve series of oscillations to provide substantially the musical intervals of an equally tempered scale, which consists in relating the frequencies of the first and second said series in the ratio of the integers 17 and 18, and of the third and fourth, of the fifth and sixth,

of the seventh and eighth, of the ninth and tenth, and of the eleventh and twelfth in the same ratio; and in relating the frequencies of the first, third, fifth, seventh, ninth and eleventh said series, each to its successor substantially in the ratio of 49 : 55.

10. The method of relating the frequencies of twelve series of oscillations to provide substantially the musical intervals of an equally tempered scale, which consists in relating the frequencies of the first and seventh said series in the ratio of the integers 29 and 41, and of the second and eighth, of the third and ninth, of the fourth and tenth, of the fifth and eleventh, and of the sixth and twelfth in the same ratio; and in relating the frequencies of the first, second, third, fourth, fifth and sixth said series, each to its successor substantially in the ratio of 101 : 107.

11. In an electrical musical instrument, the combination of a group of devices in cascade, said devices comprising consecutively a source of electric oscillations of musically related frequencies and at least one frequency doubling device; a separate modulating device; and substantially aperiodic means for supplying to said modulating device oscillations from said source and oscillations from the output of each of said frequency doubling devices.

12. An electrical musical instrument comprising, in combination, a group of devices in cascade, said devices comprising consecutively a source of electric oscillations of musically related frequencies and at least one frequency doubling device; a separate modulating device; substantially aperiodic means for supplying to said modulating device a potential from said source and a potential from the output of each of said frequency doubling devices; means for controlling the amplitude of at least one of said potentials; and an electro-acoustic translating device actuated by the output of said modulating device.

13. An electrical musical instrument comprising, in combination, a group of devices in cascade, said devices comprising consecutively a source of electric oscillations of musically related frequencies and at least one frequency doubling device; two thermionic vacuum tubes each having at least a cathode, a grid and an anode; a connection between said anodes; substantially aperiodic means for supplying in opposite phase to said two grids a potential from the output of each of said frequency doubling devices and a potential from said source; means for controlling the amplitudes of said potentials; and an electro-acoustic translating device actuated by the combined anode current of said tubes.

14. An electrical musical instrument comprising, in combination, a group of devices in cascade, said devices comprising consecutively a source of electric oscillations of musically related frequencies and at least one frequency doubling device; two thermionic vacuum tubes each having at least a cathode, a grid and an anode; a connection between said anodes; substantially aperiodic means for supplying in opposite phase to said two grids a potential from each of said frequency doubling devices and a potential from said source; means for controlling the amplitudes of said potentials; means for varying the relative amplitudes of at least one of said potentials between said two grids; and an electro-acoustic translating device actuated by the combined anode current of said tubes.

15. An electrical musical instrument comprising, in combination, a source of electric oscillations of musically related frequencies and of substantially uniform amplitudes; substantially aperiodic thermionic apparatus, for amplifying said oscillations and for varying their wave-form, connected to said source; a condenser shunted across the output terminals of said apparatus for progressively attenuating higher frequencies; and an electro-acoustic translating device actuated by the output of said thermionic apparatus.

16. In a musical instrument of the type wherein electric oscillations of a plurality of musically related fundamental frequencies are selectively produced, are controlled by a common, substantially aperiodic system, and are thereafter translated into audible tones, the method of controlling the harmonic structure of said tones, which includes generating in said common system and from said oscillations, other oscillations having frequencies which are multiples of the frequencies of said first mentioned oscillations in at least one power of two; and thereafter generating in said common system, and from said first-mentioned oscillations and said oscillations of multiple frequencies, oscillations of the beat frequencies therebetween and oscillations of double the frequency thereof.

17. In a musical instrument of the type including a source of electric oscillations of musically related fundamental frequencies, including a common, substantially aperiodic controlling system comprising at least one frequency doubling device for electric oscillations and a modulating device, and including further apparatus arranged to be actuated by the output of said modulating device, the method of regulating in said common system the waveform of the oscillations supplied to said further apparatus, which consists in generating by said frequency doubling devices and from said first mentioned oscillations, other oscillations having frequencies which are multiples of the frequencies of said first-mentioned oscillations in at least one power of two; in applying said first-mentioned oscillations and said oscillations of multiple frequencies to said modulating device; and in regulating the amplitudes of said

first-mentioned oscillations and said oscillations of each multiple frequency so applied to said modulating device.

18. In a musical instrument of the type including a source of electric oscillations of musically related fundamental frequencies, including a common, substantially aperiodic controlling system comprising at least one frequency doubling device for electric oscillations and two modulating thermionic vacuum tubes, and including further apparatus arranged to be actuated by the combined output of said tubes, the method of regulating in said common system the waveform of the oscillations supplied to said further apparatus, which consists in generating by said frequency doubling devices and from said first-mentioned oscillations, other oscillations having frequencies which are multiples of the frequencies of said first-mentioned oscillations in at least one power of two; in applying said first-mentioned oscillations and said oscillations of multiple frequencies to the inputs of each of said modulating tubes; and in selectively regulating the amplitudes of said first-mentioned oscillations and of said oscillations of each multiple frequency so applied to the input of each of said tubes.

19. In a musical instrument of the type including a source of electric oscillations of musically related frequencies, including substantially aperiodic apparatus for generating from and combining with said oscillations other oscillations having frequencies which are integral multiples of the frequencies of said first-mentioned oscillations, and including further apparatus arranged to translate said combined oscillations into sound, the method of securing substantial uniformity both of frequency-loudness characteristics of said sounds and of action of said aperiodic apparatus on oscillations of different frequencies from said source, which consists in generating at a substantially uniform amplitude said oscillations of various frequencies in said source, and in progressively attenuating oscillation components of higher frequency in the output of said aperiodic apparatus.

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