June 29, 1943. A. R. RIENSTRA 2,323,242

ELECTRIC ORGAN SYSTEM

Filed May 31, 1941

FIG. 2

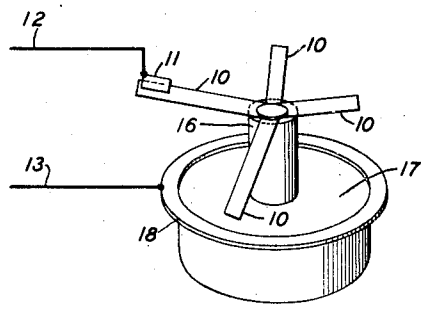
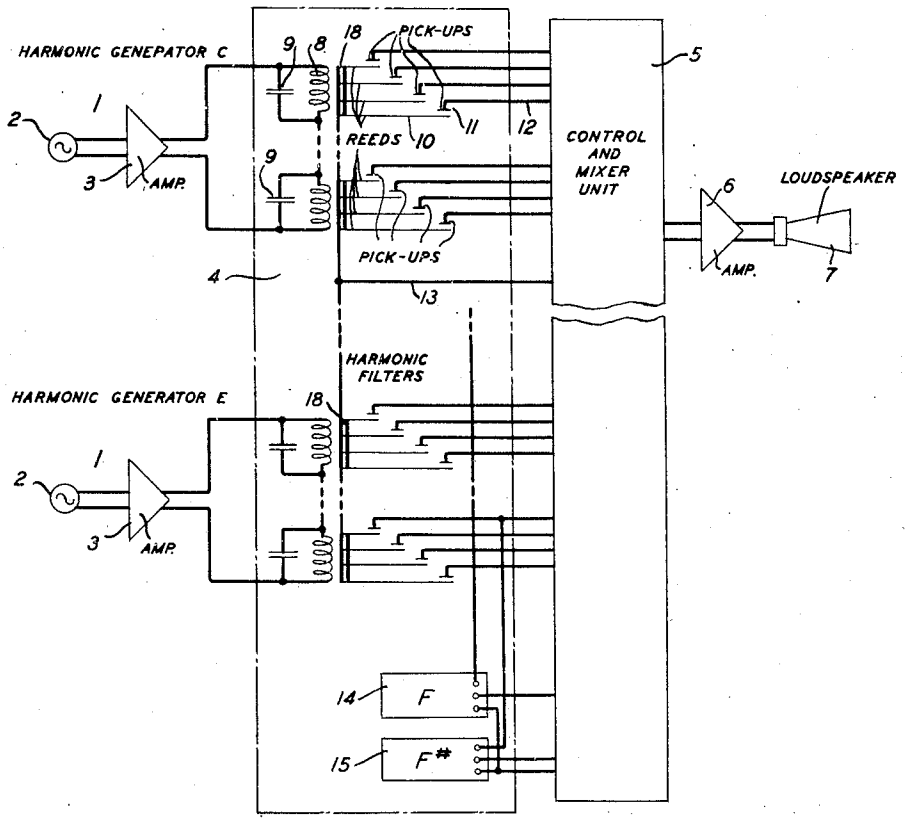


FIG. 1



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ELECTRIC ORGAN SYSTEM

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5 Claims. (Cl. 84—1.23)

This invention relates to electric musical instruments and more particularly to an electric organ system in which the tones are produced by electric generators.

In the electric organs of the prior art there have been supplied at least twelve oscillators or alternating current generators for producing the twelve tones of the chromatic scale of equal temperament. This has required a large amount of generating apparatus and it is therefore desirable to reduce the amount of generating apparatus as much as possible.

It is the object of this invention to provide an organ tone generating system with less than twelve generators capable of providing all twelve chromatic tones on a substantially correct equally tempered basis.

This invention attains the foregoing object by providing less than twelve generators, each adapted to provide an output rich in harmonics, the fundamental frequencies of these generators being tuned to particular frequencies in an octave below the lowest octave of the instrument, and a filter means for each generator adapted to segregate into separate channels, the several harmonics produced by each generator.

The invention may be better understood by referring to the drawing in which:

Fig. 1 represents schematically the tone generating system of this invention; and

Fig. 2 discloses a preferred form of filter means.

Referring now to Fig. 1, a plurality of primary generators 1, less than twelve in number, are provided to generate frequencies in the octave next below the lowest octave of the keyboard. In the particular embodiment disclosed, five such generators are used and are indicated as harmonic generator C, etc. to Harmonic Generator E, inclusive. However, as hereinafter disclosed seven such generators may be used. Each of these generators comprises an oscillator 2 and an amplifier 3, either or both of which may cause the combination to produce a highly distorted wave form inherently rich in harmonics. Generators capable of providing a plurality of harmonics are shown, for example, by United States Patent 2,023,436, issued December 10, 1935 to D. Prinz, by 2,117,752, issued May 17, 1938 to L. R. Wrathall, and by 2,181,280, issued November 28, 1939 to R. L. Miller.

The fundamental frequency of harmonic generator C corresponds to an octave below the lowest C on the keyboard, for example, 16.333 cycles per second. This, as hereinafter more fully shown, will provide A_4 with the standard frequency of 440 cycles per second. Obviously the tuning may be standardized on a pitch other than the one here chosen for illustrative purposes. The fundamental frequencies of all five primary generators are chromatically related on an equally tempered basis as shown in Table I.

TABLE I

Primary generator	Fundamental frequency
C	16.333
C#	17.304
D	18.333
D#	19.434
E	20.576
F	21.825
F#	23.125

In the foregoing table it should be remembered that the fundamental frequencies listed are those which correspond with the fundamental frequencies of the oscillators in the generator octave, that is the octave next below the lowest octave appearing on the organ keyboard. The purpose of primary generators F and F# will be described later.

As previously stated the output of each of these generators is rich in harmonics. These harmonics are segregated into separate channels by means of a filter system 4 from which it is fed into a control and mixer unit 5 where the various segregated harmonic components are synthetically combined in a well-known manner and fed to an output amplifier 6 and loud-speaker system 7. Any of the well-known control and mixer systems may be used such as, for example, those shown in United States Patents 1,953,753 to Firestone, issued April 3, 1934, 2,103,169 to Midgley, issued December 21, 1937 or 2,139,023 to Kock, issued December 6, 1938.

Each unit of the filter system comprises a plurality of mechanically vibrant reeds 10 which are electromagnetically driven from driving coil 8 connected to the output of one of the generators. Each of these reeds is resonant to some harmonic produced by its associated generator. In the specific embodiment herein disclosed an electrostatic pick-up means is shown which comprises an electrostatic pick-up plate 11 cooperating with the reed 10 so that as the reed vibrates it produces a varying capacitance. All of the reeds in the entire organ are electrically connected together and to the control and mixer unit via common conductor 13. Each electrostatic pick-up plate 11 is connected to the control and mixer unit 5 by way of its associated

conductor 12. A condenser 8 may be connected across each of the filter driving coils in order to resonate certain frequency regions to obtain desired tone qualities according to the formant theory. In this case certain frequencies are emphasized or suppressed for all notes of the keyboard, regardless of the pitch of the fundamental. The advantage of doing this here rather than in the control unit 5 is its simplicity and cheapness as only one electrical filter is required for each generator. The combination of coil and reeds forms an electromechanical filter.

Random phase relationships are thought desirable and this invention achieves this end by using reeds which inherently have no fixed phase relationships between the several harmonics of a tone.

Generators C#, D and D# have been omitted from the drawings for the sake of clarity. However, they are connected as shown for generators C and E and have the frequencies assigned to them as shown in Table I above.

Although only five generators are used, all twelve notes of each octave are produced on a substantially correct equal tempered basis. The generators which are used for producing the various notes are shown in tabular form in Table II below:

TABLE II

For five generators

Primary generator	Produces notes	Number reeds required
C	C, G	93
C#	C#, G#	92
D	D, A	91
D#	D#, A#, F	107
E	E, B, F#	106

As shown in Table II above, all of the notes denoted C and G in the entire organ of seven complete octaves are produced from harmonics of the C generator. In addition to the fundamental frequencies of notes C and G for all the octaves of the organ, nineteen additional harmonics, making twenty harmonics in all, including the fundamental, are also produced. Of course, some of the upper harmonics for the higher notes C and G become inaudible and for that reason they are not supplied. However, all twenty harmonics for each note are supplied wherever they are within the audible range. To do this 93 filter reeds are required as shown in the table.

Similarly, the fundamental frequencies for all of the C# and G# notes as well as the harmonics thereof are produced from generator C# and 92 reeds are required. Also all the notes denominated D and A are produced from generator D and 91 reeds are required. Generator D# produces all of the notes D#, A# and F requiring 107 reeds and generator E produces all of the notes denoted E, B and F#, this requiring 106 reeds. In the last two cases all of the notes D# and A#, E and B are produced as for the first three generators, but the notes F and F# are not all produced in exactly the same way. Some of the harmonics of F and F# in the first two octaves as well as all of their harmonics, including the fundamentals, for the remaining octaves are produced as previously described. However, the fundamentals and some of the harmonics of F and F# in the first two octaves of the organ are produced by a process of frequency division.

The manner in which the fundamental frequencies for the first octave of the organ are derived from the five generators is shown in tabular form in Table III below:

TABLE III

For five generators

Notes	Derived	Actual frequency	Correct equally-tempered frequency
C_1	2C	32.67	32.70
$C_1\#$	2C#	34.61	34.65
D_1	2D	36.67	36.71
$D_1\#$	2D#	38.85	38.89
E_1	2E	41.16	41.20
F_1	9/4D#	43.69	43.65
$F_1\#$	9/4E	46.30	46.25
G_1	3C	49.00	49.00
$G_1\#$	3C#	51.91	51.91
A_1	3D	55.00	55.00
$A_1\#$	3D#	58.27	58.27
B_1	3E	61.73	61.73

The first column of Table III lists the twelve notes of the first octave. The second column shows that the fundamentals of the first five notes are derived from the second harmonics of the five primary generators, the fundamentals of the last five notes are derived from the third harmonics of the same generators and the remaining two notes F_1 and $F_1\#$ are derived from primary generators D# and E, respectively by extracting the fourth subharmonics of their ninth harmonics. The third column lists the actual frequencies derived and produced by the organ and the last column lists for purposes of comparison the correct equally tempered frequencies based on $A_4=440$ cycles per second. It will be noted that the system of this invention provides a substantially correct scale of equal temperament and the errors are of no practical importance. It may also be noted that the scale contains a number of perfect musical fifths. For example the major chord on C_1 is built on an equally tempered major third and a slightly sharpened equally tempered minor third, thereby causing the interval from the tonic to the dominant to be a perfect fifth and the tonic to the mediant to be an equally tempered major third. While the chord is still not perfect, it is slightly improved by the departure from strict equal temperament.

In the second octave the notes F_2 and $F_2\#$ are obtained by extracting the second subharmonics of the ninth harmonics of the D# and E primary generators, respectively. All of the fundamental frequencies of the notes in the remaining octaves are obtained by selecting the appropriate harmonics of the five primary generators. Of the 107 filter reeds required for the D# primary generator, 88 of them are utilized for producing all of the D# and A# notes of the keyboard together with all their audible harmonics up to and including the twentieth harmonic. In addition these same reeds produce all the fundamental frequencies for the F notes of the keyboard together with many of their harmonics with the exception of notes F_1 and F_2 in the first two octaves as previously stated. The remaining nineteen reeds are used to produce the harmonics of the F notes not produced by the 88 reeds.

The necessary subharmonics are provided by two groups of multivibrators 14 and 15 shown in block form in Fig. 1. Group 14 produces the

fundamental frequencies for notes F_1 and F_2 and also those harmonics thereof as are not directly produced by the D# primary generator. Group 15 does the same for notes F_1# and F_2#. The manner in which this frequency division is accomplished is tabulated in Table IV below:

TABLE IV

For five generators

Harmonic	Derived from D# for note	
	F_1	F_2
1	9/4	9/2
2	9/2	9
3	27/4	27/2
4	9	18
5	45/4	45/2
6	27/2	27
7	63/4	63/2
8	18	36
9	81/4	81/2
10	45/2	45
11	99/4	99/2
12	27	54
13	117/4	117/2
14	63/2	63
15	135/4	135/2
16	36	72
17	153/4	153/2
18	81/2	81
19	171/4	171/2
20	45	90

The above table is specifically for notes F_1 and F_2 but notes F_1# and F_2# use the same division scheme except they derive their frequencies from primary generator E instead of D# as was also indicated by Tables II and III. Inspection of Table IV discloses that each of the multivibrator groups 14 and 15 contain ten units capable of providing the fourth and second subharmonics of the ninth, twenty-seventh, forty-fifth, sixty-third, eighty-first, ninety-ninth, one hundred seventeenth, one hundred thirty-fifth, one hundred fifty-third and one hundred seventy-first harmonics of their primary generator. All these harmonics appear among the filter reeds of their associated primary generators so that no additional reeds are needed.

The foregoing description has set forth in considerable detail the manner in which the various fundamental frequencies of a seven octave keyboard together with twenty audible harmonics thereof are produced by five primary generators, two groups of frequency dividers and a set of filter reeds. By way of restatement the invention thus far described may be summarized as follows:

1. All of the fundamental frequencies together with a wide range of their harmonics for an entire keyboard with the exception of notes F_1, F_2, F_1# and F_2# in the first two octaves are produced directly by five primary harmonic generators.

2. The frequencies thus produced are segregated for purposes of controlled synthesis by means of five groups of electromechanical filters of the reed type.

3. Notes F_1, F_2, F_1# and F_2# and most of their harmonics are obtained by multivibrators excited from the output of certain of the filter reeds driven by the D# and E generators; their remaining harmonics are derived directly from filter reeds driven by the D# and E generators.

The use of multivibrators is obviated by using seven primary harmonic generators instead of only five. In addition to the five primary generators already described, the generator octave also contains primary generators F and F# with the fundamental frequencies shown in Table I above. The number of filter reeds for each of the seven primary generators is given in Table V below.

TABLE V

For seven generators

Primary generator	Produces notes	Number reeds required
C	C, G	93
C#	C#, G#	92
D	D#, A#	91
D#	D#, A#	88
E	E, B	88
F	F	54
F#	F#	53

It will be noted that the number of reeds for the first three generators are the same as given in Table II. However, the number given for generator D# and generator E are here given as 88 which is the actual number required to segregate notes D#, A# and E, B, respectively, together with their several harmonics. Only fifty-four filter reeds are used with generator F because it provides only the note F and its audible harmonics. For the same reason only fifty-three filter reeds are used with the F# generator. The actual frequencies derived from the seven primary generators as well as the manner in which they are derived is shown in Table VI.

TABLE VI

For seven generators

Notes	Derived	Actual frequency	Correct equally-tempered frequency
C_1	2C	32.67	32.70
C_1#	2C#	34.61	34.65
D_1	2D	36.67	36.71
D_1#	2D#	38.85	38.89
E_1	2E	41.16	41.20
F_1	2F	43.65	43.65
F_1#	2F#	46.25	46.25
G_1	3C	49.00	49.00
G_1#	3C#	51.91	51.91
A_1	3D	55.00	55.00
A_1#	3D#	58.27	58.27
B_1	3E	61.73	61.73

It will be noted that all the frequencies are the same as given in Table II except for the frequencies of F_1 and F_1# which are arbitrarily made equal to the frequencies for these notes as they appear in the correct scale of equal temperament. These two notes could have followed strictly the scale of equal temperament built up from C=16.333 in which case F_1 and F_1# would have been 43.60 and 46.20 cycles/second, respectively. The differences being small, either set of values may be regarded as following substantial equal temperament.

A preferred means of driving the harmonic filters or reeds of Fig. 1 is shown more particularly in Fig. 2. In this figure, a plurality of harmonic reeds 10 are mounted by means of a suitable support 16 to a diaphragm 17. Diaphragm 17 is driven by coil 8 shown in Fig. 1 from the output of its associated primary generator in a manner well known to the art. Some shielding is required between the filter reeds. However, inasmuch as the principle of shielding is so well known in the art, no shielding is shown in this figure for the sake of clarity. One of the pick-up plates 11 is shown associated with one of the filter reeds 10. The remaining pick-up plates

have been deleted. Conductor 12 connects pick-up plate 11 to the control and mixer unit 5 as shown in Fig. 1. Conductor 13 which is connected to the diaphragm support 18 is the common conductor 13 also shown in Fig. 1 wherein is shown all of these diaphragm supports electrically connected together. All of the filter reeds 16 of each of these filter units are electrically connected to their diaphragms 17 through their supports 16 and consequently to their diaphragm supports 18 so that effectively they are all connected to their common conductor 13.

Each of the harmonic generators of Fig. 1 have connected to the output circuits thereof several of these harmonic filter units with their coils 8 serially connected as indicated in Fig. 1. The actual number of units which it is necessary to connect in series is determined only by the number of reeds which the particular design will permit to be mounted on any one harmonic filter unit.

While the invention has been described and illustrated by the disclosure of specific instrumentalities it should not be construed as limited thereto but may include all reasonable equivalents within the scope of the appended claims.

What is claimed is:

1. An electric organ system having a conventional twelve-note octave comprising the combination of five harmonic generators, the fundamental frequencies whereof are tuned in equal temperament to the first five chromatic tones of an octave below the lowest octave on the keyboard, a filter system comprising a series of harmonically related mechanically vibrant elements for each generator responsive to the output thereof for segregating into separate channels the several harmonics produced by each generator, and a frequency divider system responsive to the output of some of the channels to provide two of the twelve notes in the first two octaves and some of the harmonics thereof, whereby all of the fundamentals and audible harmonics for the entire instrument are provided on a substantially correct equally tempered basis.

2. An electric organ system having a conventional twelve-note octave comprising the combination of five harmonic generators, the fundamental frequencies whereof are tuned in equal temperament to the first five chromatic tones of the octave next below the lowest octave on the keyboard, a filter system comprising a series of harmonically related mechanically vibrant elements for each generator responsive to the output thereof for segregating into separate channels the several harmonics produced by each generator, and a frequency divider system responsive to the output of some of the channels to provide two of the twelve notes in the first two octaves and some of the harmonics thereof, whereby all of the fundamentals and audible harmonics for the entire instrument are provided on a substantially correct equally tempered basis.

3. An electric organ system having a conventional twelve-note octave comprising the combination of five harmonic generators, the fundamental frequencies whereof are tuned in equal temperament to the first five chromatic tones of an octave below the lowest octave on the keyboard, a filter system comprising a series of harmonically related mechanically vibrant elements for each generator responsive to the output thereof for segregating into separate channels the several harmonics produced by each generator, and a frequency divider system responsive to the output of some of the channels to provide some of the notes for at least one of the octaves of the keyboard and some of the harmonics thereof, whereby all of the fundamentals and audible harmonics for the entire instrument are provided on a substantially correct equally-tempered basis.

4. An electric organ system having a conventional twelve-note octave comprising the combination of seven harmonic generators, the fundamental frequencies whereof are tuned in substantial equal temperament to the first seven chromatic tones of an octave below the lowest octave on the keyboard, and a filter system comprising a series of harmonically related mechanically vibrant elements for each generator responsive to the output thereof for segregating into separate channels the several harmonics produced by each generator, whereby all of the fundamentals and audible harmonics for the entire instrument are provided on a substantially correct equally tempered basis.

5. An electric organ system having a conventional twelve-note octave comprising the combination of seven harmonic generators, the fundamental frequencies whereof are tuned in substantial equal temperament to the first seven chromatic tones of the octave next below the lowest octave on the keyboard, and a filter system comprising a series of harmonically related mechanically vibrant elements for each generator responsive to the output thereof for segregating into separate channels the several harmonics produced by each generator, whereby all of the fundamentals and audible harmonics for the entire instrument are provided on a substantially correct equally tempered basis.

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