

Dec. 23, 1958

R. H. DORF

2,865,243

ELECTRONIC TONE GENERATING DEVICE

Filed Sept. 10, 1954

FIG. 1

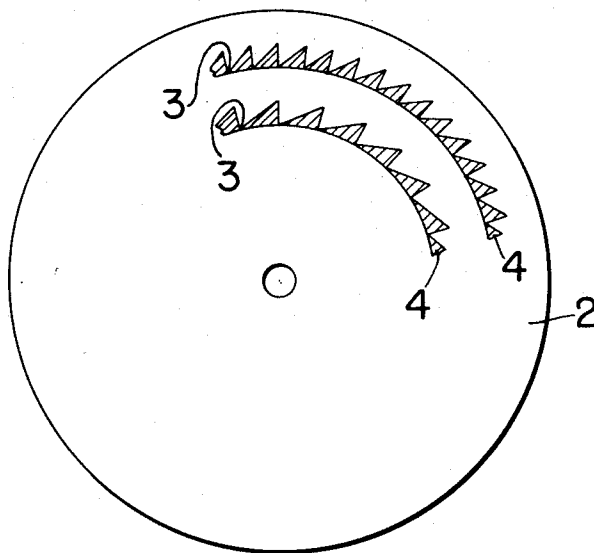
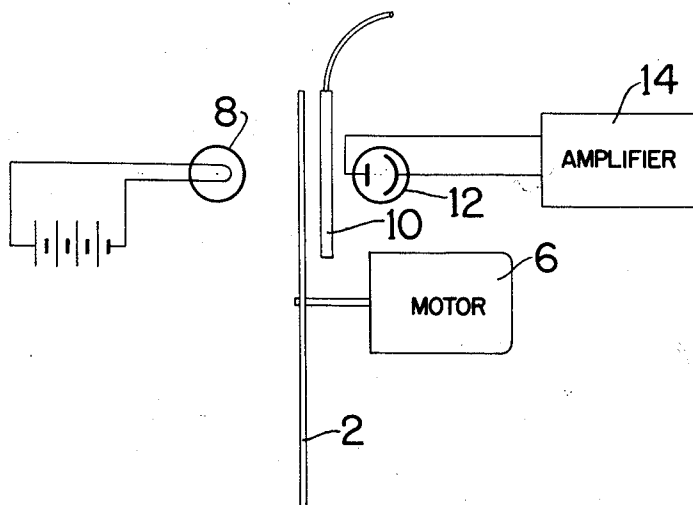


FIG. 2



INVENTOR
RICHARD H. DORF

BY
Stewart F. Moore
ATTORNEY

1

2,865,243

ELECTRONIC TONE GENERATING DEVICE

Richard H. Dorf, New York, N. Y., assignor to American Machine & Foundry Company, a corporation of New Jersey

Application September 10, 1954, Serial No. 455,131

6 Claims. (Cl. 84-1.28)

This invention relates to a method and apparatus for electrically generating musical tones. In particular, it relates to an improved musical instrument of the type wherein a light beam is modified or interrupted by moving tone patterns to produce in a photoelectric translating device electrical currents representative of said tone patterns.

Musical tones may be generated photoelectrically, electromagnetically, electrostatically, mechanically, or otherwise, with the aid of a disc or drum rotating at one or more given speeds, and a number of such tones can be generated and keyed so as to form an electronic musical instrument, such as an organ. In general, such rotating tone generators provide one or more bands of "patterns" concentrically located about the axis of rotation of the disc or drum, each pattern representing one electrical wave and each band of patterns representing a musical note. A suitable stationary scanning device is normally provided for cooperating with the pattern in such a manner that a corresponding electrical current, representative of the tone pattern, is generated by the scanning device, each time a pattern passes through the sensing portions thereof. These electrical currents are amplified and heard as musical tones.

The frequency of a tone generated by any given band of patterns depends primarily upon the number of patterns passing the scanning device in a given time interval. For example, if 100 patterns pass a scanning point each second, the note heard is 100 cycles per second. However, each band must have an integral number of patterns so that the start-end point thereof will coincide perfectly. If unmatched pattern discrepancy occurs, a sharp transient wave discontinuity will appear once per revolution at this point, resulting in a loud and objectionable click in the reproducing equipment. Unfortunately, each note of the well-tempered musical scale does not bear an integral relationship to the next adjacent note, but is generally separated in frequency therefrom by the relationship of the twelfth root of 2. Thus any attempt to record the scale or portions thereof on a disc to be rotated at a given speed will necessarily produce non-integral numbers of patterns for each tone band except those which bear a direct harmonic relationship to each other and to the speed of the disc.

Several methods for recording non-reentrant bands on rotating discs or drums have been suggested, but each method usually introduces other equally objectionable effects in attempts to minimize start-end discrepancies.

It is possible to reproduce the conventional musical scale on a tone disc in which each band of patterns is reentrant and contains an integral number of patterns, if a small amount of frequency error is tolerated. However, for the reproduction of this musical scale and for pitch accuracy satisfactory not only with single notes but with beats between harmonics of two or more notes, the disc must rotate very slowly.

One system utilizes a disc speed of no more than one half of a revolution per second (R. P. S.) which allows

2

a maximum frequency error of slightly more than one quarter cycle on any note. Such slowly rotating discs are expensive and difficult to keep in adjustment with the remainder of the mechanism of the organ. Also, reproduction of the patterns on the disc is complicated by the fact that since the total number of patterns in the higher frequency bands is so great (frequency divided by disc speed in R. P. S.), each pattern is necessarily exceedingly small. Furthermore, the smoothing effect of disc inertia is less pronounced at slow speeds, making it more difficult to keep the disc speed absolutely constant as is required for unwavering tone reproduction.

It is, therefore, an object of the invention to provide a rotating tone generator adapted to run at relatively high speed and having tone band patterns which are reentrant.

It is another object of the invention to provide a tone generator with reentrant tone band patterns in which the resulting frequency errors between tones will not be apparent to the ear when single notes are played.

It is a further object of the invention to provide a tone disc having tones whose beats between musical fifths and octaves will take place at the same rate as a normal vibrato.

It is a further object of the invention to provide a tone generator having relatively few tone patterns for the higher notes.

It is yet another object of the invention to provide a tone generator which is easy and economical to manufacture in high production quantities.

For a better understanding of the invention, together with other and further objects thereof, reference is made to the following detailed description taken in connection with the accompanying drawings, in which:

Fig. 1 illustrates several bands on a disc showing the manner in which the patterns are distributed on the band so that no discontinuity appears.

Fig. 2 shows a tone generating device for utilizing the invention.

To make possible the playing in all keys of a keyboard instrument, the tempered scale, now in common use, was devised. As a result, the third harmonic of any tone thereof is slightly sharp with respect to the second harmonic of the tone a musical fifth above it. For example, the third harmonic of C, 65.41 cycles is 196.23 cycles, but the G above C is 98 cycles, so that its second harmonic is 196.00, with respect to which 196.23 cycles is .23 cycles sharp. In a well known manner, a beat is developed between the two harmonics equal to the arithmetic difference in frequency between them and sounds to the ear as a pulsation in volume at the rate of .23 times per second. A beat of some frequency occurs between every musical fifth, the beat rate being low at the lower frequencies and high at the higher frequencies.

These beats are not annoying with correctly tuned instruments, both because the ear is accustomed to them and because the beat rates in any one portion of the musical frequency range is roughly the same small percentage of the fundamental frequencies. However, when an instrument is mis-tuned, the first unpleasant effect to be noted by the ear is an increase in the beat rates. Beat rates substantially in excess of those normally to be expected in a given fundamental note range, produce an effect of sourness which is immediately interpreted as bad tuning and is unacceptable.

In order to employ a multiple tone band disc rotating at relatively high speed with integral numbers of patterns in each band, it is necessary to accept tone frequencies which are in many cases greatly different from those in the standardized, well-tempered musical scale. If the disc speed is even as low as one revolution per second (60 R. P. M.) for example, then all frequencies must be

integral multiples of one cycle per second. By way of illustration, consider note "C." For the desired tone of 65.406 cycles per second, 65.000 cycles must be used, which is 11% of a semi-tone flat; similarly, for the desired tone of 73.416 cycles, note D, 73.000 cycles must be used, which is 10% of a semi-tone flat.

With higher disc speeds these errors become, of course, greater, although as note frequencies become higher the percentage of error which is the manner in which the ear detects error becomes small.

Heretofore, it has been assumed that high and improper beat rates would make impossible the use of a high speed tone generator disc or drum, since the beat rates which occur when all tone frequencies are a multiple of a single number, that is, equal to the speed of the rotating device in R. P. S., are themselves a multiple of that number. The beats would thus be at the same rate throughout the musical range, and would in many cases be too high in the low note register.

However, it is known that the pitch discrimination of the human ear becomes poorer as frequency decreases. I have verified by actual experiment that over the range of the octave between C-65.41 cycles and C-130.8 cycles, most individuals cannot distinguish errors of as much as 34% of a semi-tone when the notes are played as in executing a scale or melody. Thus the errors inherent in a high speed disc would not, up to a certain speed, at least, make impossible the use of such a disc as long as only single notes are played. However, when two or more notes are played simultaneously, particularly when a musical fifth or octave is played, the beats between octave and/or fifth notes preclude musical acceptance of these errors except under specific conditions, as specified below.

I have found that beat rates which are normally too high are musically acceptable if such rates are equal to or one-half the frequency vibrato or tremolo normally used in music, as the ear interprets them as tremolo and not mis-tuning. The rate at which pitch for natural vibrato or amplitude for tremolo is varied, lies somewhere between 4 and 12 times per second. Vibrato beats are for that reason pleasing rather than annoying, and are acceptable despite the large actual frequency error in the tuning which causes it. Variations at faster or slower rates are heard as errors of poor execution and are unpleasing, while variations in the normal vibrato or tremolo range are interpreted as pleasant and enhance tones. Beats which occur at one-half the tremolo rate, that is between about 2 and 6 times per second, are almost equally pleasing, apparently because the ear, in its quest for pleasing rather than unpleasing sounds, then interprets each half cycle of the amplitude variation caused by the beats as a full cycle, multiplying the beat rate, in effect, by 2 and bringing it within the tremolo rate region.

There is shown in Fig. 1, by way of illustration, a portion of a tone disc having reentrant patterns 4 thereon and adapted to rotate at a selected speed lying between 2 and 6 R. P. S. which is the range covering frequencies which are one-half the normal vibrato range of 4 to 12 cycles per second. The point at which the tone patterns begin and end is indicated at 3. Although sawtooth waves are shown for purposes of illustration, any form of wave may be employed if desired. It is understood that a disc may have any number of tones inscribed thereon. For example, at least 60 tone bands would be used in an electronic organ application, whereas up to 88 tone bands may be used if a device is to be operated in conjunction with a piano keyboard.

A suitable device for generating tones in accordance with the teachings of the invention is shown in Fig. 2. Such a device may comprise a motor 6 having the tone disc 2 attached thereto and adapted to rotate at a speed between 2 and 6 R. P. S. as may be desired. Operatively positioned adjacent to the disc 2 are a source of light 8, a light valving mechanism 10, and a photoelectric cell 12.

In operation, the light from lamp 8 passing through a tone pattern chosen by selective actuation of one or more valves in light valve box 10 impinges upon photoelectric cell 12 where the modulations of the light beam, caused by the interruption of the light beam by the tone patterns of rotating disc 2, are detected and fed to an amplifier 14. The output of the amplifier may be connected to a suitable electromechanical reproducing system as may be desired.

By placing the patterns on the disc in accordance with any of the usual techniques such as photo-engraving, drawing, or direct photographing, and by making all note frequencies integral multiples of the disc beat in R. P. S., it will be found that any fifth beat will occur at a rate of either zero beats per second, a rate equal to the disc speed of 2 to 6 times per second as may have been previously determined, or a rate equal to twice the disc speed or 4 to 12 times per second. For example, a disc revolving at 3 R. P. S. will produce musical fifth beats of zero, 3 and 6 cycles per second. With a zero beat the effect is pleasant because of lack of any disturbance. When it is 6 cycles per second, the hearer perceives only a tremolo effect, which is pleasing, and where it is three cycles per second, the hearer interprets each half cycle of beat as a full cycle and again hears the 6 cycle tremolo.

In instruments tuned strictly in accordance with the well-tempered scale, the octave notes thereof are exact multiples. That is, any C, for example, normally has exactly twice the frequency of the C next below it. When notes are generated in accordance with the invention, some of the octaves must necessarily be mistuned. In every case, however, either the octaves are correctly tuned or the difference between the frequency of a note and twice that of a similar note an octave below or above it is equal to the disc speed.

For example, when a 3 R. P. S. disc is utilized, D-73.42 cycles is recorded at 72.00 cycles, the nearest multiple of 3, and the next highest D which is 146.8 cycles is at 147 cycles. The difference between the second harmonic of the 72 cycle note and the 147 cycle note is 3 cycles, which is heard as a beat. The effect of this abnormal octave beat, however, is pleasant for the reason that it is half of the chosen tremolo rate of 6 cycles per second.

In the table below, there is shown by way of example a tuning chart for a 73 note organ when employing a tone generating device rotating at 3 R. P. S. The actual frequency for each note according to the well-tempered scale is shown along with the closest frequency which is a multiple of 3. The error in cents (hundredths of a semi-tone) is indicated, and also the resultant beats between fifth and octaves is shown. It will be noted that all beats are either 3 or 6 and well within the natural vibrato range of 4 to 12 cycles per second.

Note	Ideal Frequency	3 R. P. S.			
		Frequency	Error, Cents	Beat Down	
				Fifth	Octave
C	32.70	33	+16		
C#	34.65	36	+66		
D	36.71	36	-34		
D#	38.89	39	+15		
E	41.20	42	+33		
F	43.65	45	+53		
F#	46.25	45	-47		
G	49.00	48	-36		
G#	51.91	51	-31	6	
A	55.00	54	-32	0	
A#	58.27	57	-38	3	
B	61.73	63	+35	0	
C	65.41	66	+16	3	0
C#	69.29	69	-7	3	3
D	73.42	72	-34	0	0
D#	77.78	78	+5	3	3
E	82.41	81	-30	3	3
F	87.31	87	-6	3	3
F#	92.50	93	+9	3	3
G	98.00	99	+18	0	3
G#	103.80	105	+20	3	3
A	110.00	111	+16	6	3
A#	116.50	117	+7	0	3

Note	Ideal Frequency	3 R. P. S.			
		Frequency	Error, Cents	Beat Down	
				Fifth	Octave
B	123.50	123	-7	3	3
C	130.8	132	+16	3	0
C#	138.6	138	-7	3	0
D	146.8	147	+2	3	3
D#	155.6	156	+5	3	0
E	164.8	165	+2	3	3
F	174.6	174	-6	3	0
F#	185.0	186	+9	3	0
G	196.0	195	-9	6	3
G#	207.7	207	-5	0	3
A	220.0	219	-8	3	3
A#	233.1	234	+7	0	3
B	246.9	246	-7	0	0
C	261.7	261	-5	0	3
C#	277.2	276	-7	6	0
D	293.7	294	+2	3	0
D#	311.1	312	+5	3	0
E	329.6	330	+2	3	0
F	349.2	348	-6	6	0
F#	370.0	369	-5	0	3
G	392.0	393	+4	3	3
G#	415.3	414	-5	0	0
A	440.0	441	+4	0	3
A#	466.2	465	-4	6	3
B	493.9	495	+4	0	3
C	523.3	522	-5	0	0
C#	554.4	555	+2	3	3
D	587.3	588	+2	3	0
D#	622.3	621	-3	0	3
E	659.3	660	+2	3	0
F	698.5	699	+1	3	3
F#	740.0	741	+2	3	3
G	784.0	783	-2	0	3
G#	830.6	831	+1	3	3
A	880.0	879	-2	6	3
A#	932.3	933	+1	3	3
B	987.8	987	-1	6	3
C	1047.0	1047	0	3	3
C#	1109.0	1110	+2	3	0
D	1175.0	1176	+2	3	0
D#	1245.0	1245	0	3	3
E	1319.0	1320	+2	3	0
F	1397.0	1398	+1	3	0
F#	1480.0	1479	-1	3	3
G	1568.0	1569	+1	3	3
G#	1661.0	1662	+1	6	0
A	1760.0	1761	+1	6	3
A#	1865.0	1866	+1	6	0
B	1976.0	1977	+1	6	3
C	2093.0	2094	+1	6	0

Although the preferred embodiment of the invention has been described as applying to a photoelectric musical instrument employing rotary discs, the invention may be applied to photoelectric instruments employing drums, cones, or continuous bands; or it may also be applied to instruments employing continuously moving members

having magnetic tracks thereon, or any other pitch determining elements in endless rows which successively and continuously pass by a given point or points at rates which determine the pitch of the corresponding notes.

5 While the present invention has been disclosed by means of specific illustrative embodiments thereof, it would be obvious to those skilled in the art that various changes and modifications in the means of operation described or in the apparatus, may be made without departing from the spirit of the invention as defined in the appended claims.

I claim:

1. A musical instrument having a sound transducer and having a driving means for constantly cycling a pitch determining member therepast to produce in cooperation with said transducer tones corresponding substantially with those of the evenly tempered scale, said member comprising a plurality of endless rows of pitch determining elements, the rows on a member comprising at least one octave of said scale, and the number of elements in each row being an integer, the number of cycles per second of said member being no greater than a natural vibrato rate, and the number of elements in each row being integrally divisible by said number of cycles.

25 2. The invention defined in claim 1 wherein said member has rows of pitch determining elements operative to produce tones differing from the corresponding tone of the equally tempered scale by less than two vibrations per second.

30 3. In an instrument as set forth in claim 1, the range of said natural vibrato rate being from 4 to 12 cycles per second.

4. The invention defined in claim 1 wherein said member has rows of pitch determining elements operative to produce tones having beat frequencies between musical fifths not exceeding said natural vibrato rate.

35 5. In an instrument as set forth in claim 1, said member being annular and being rotated by said driving means at the rate of three revolutions per second, and said integers being each integrally divisible by three.

40 6. The invention defined in claim 1 wherein said driving means cycles said member at substantially one-half said natural vibrato rate.

References Cited in the file of this patent

UNITED STATES PATENTS

2,588,680 Williams ----- Mar. 11, 1952