July 7, 1964 R. E. WILLIAMS 3,140,337

PHOTOELECTRIC ORGAN

Filed Feb. 3, 1960 2 Sheets-Sheet 1

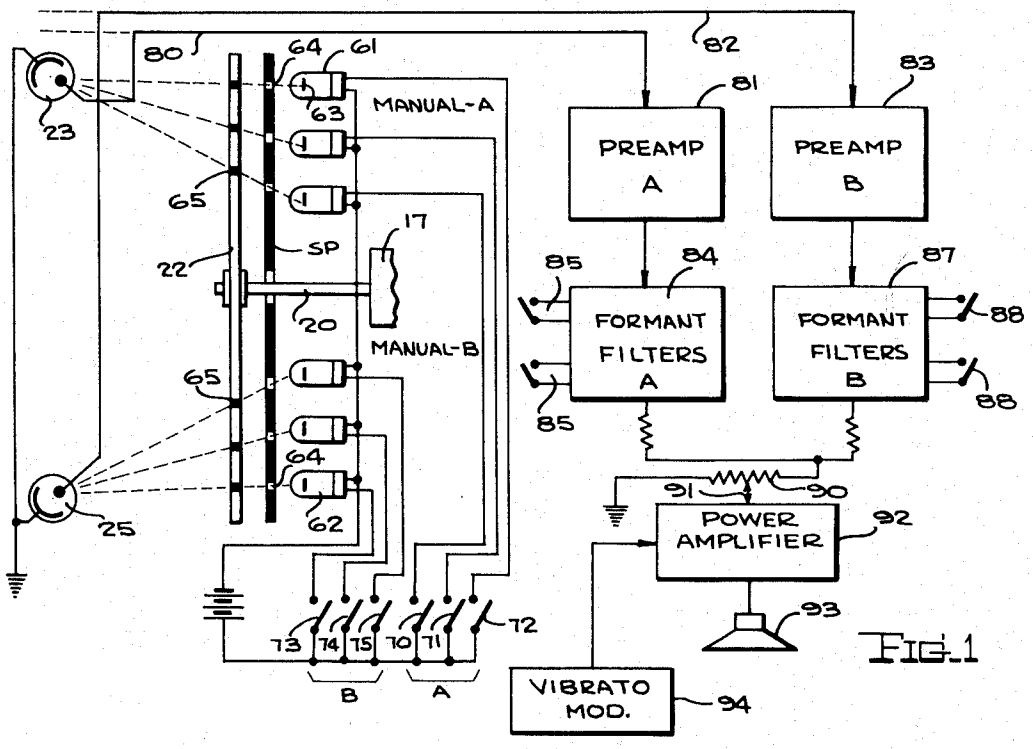


FIG. 1

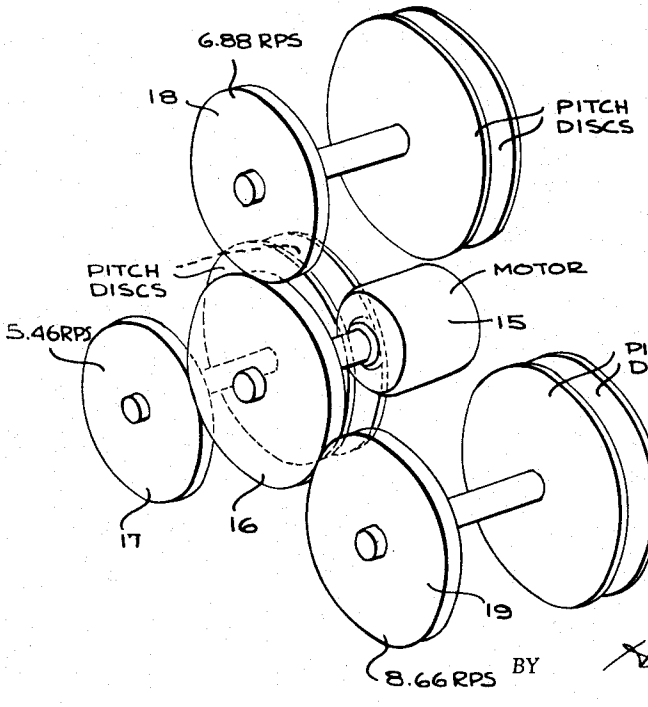


FIG. 4

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July 7, 1964 R. E. WILLIAMS 3,140,337

PHOTOELECTRIC ORGAN

Filed Feb. 3, 1960 2 Sheets-Sheet 2

FIG. 2

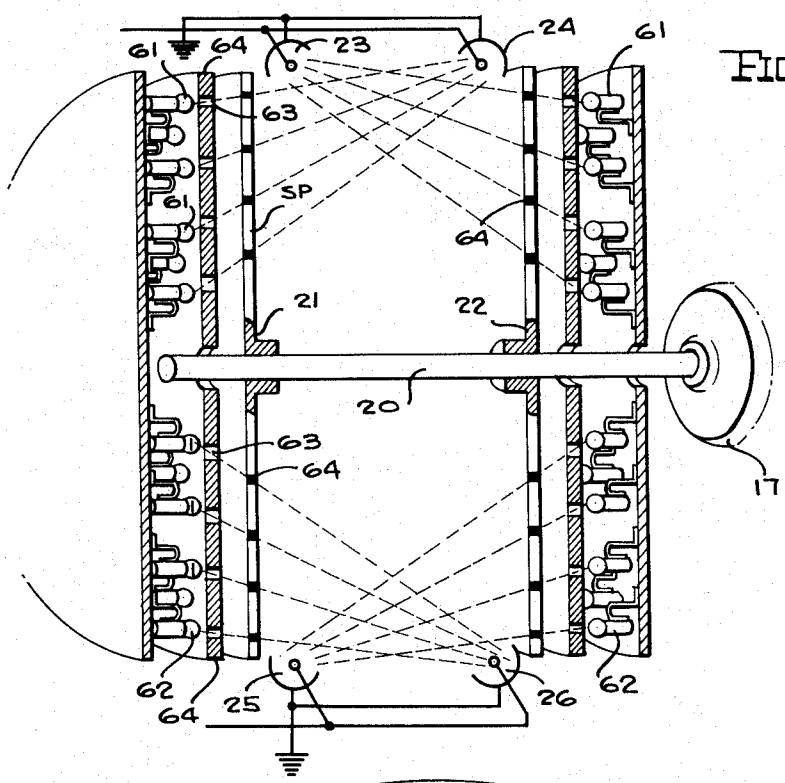
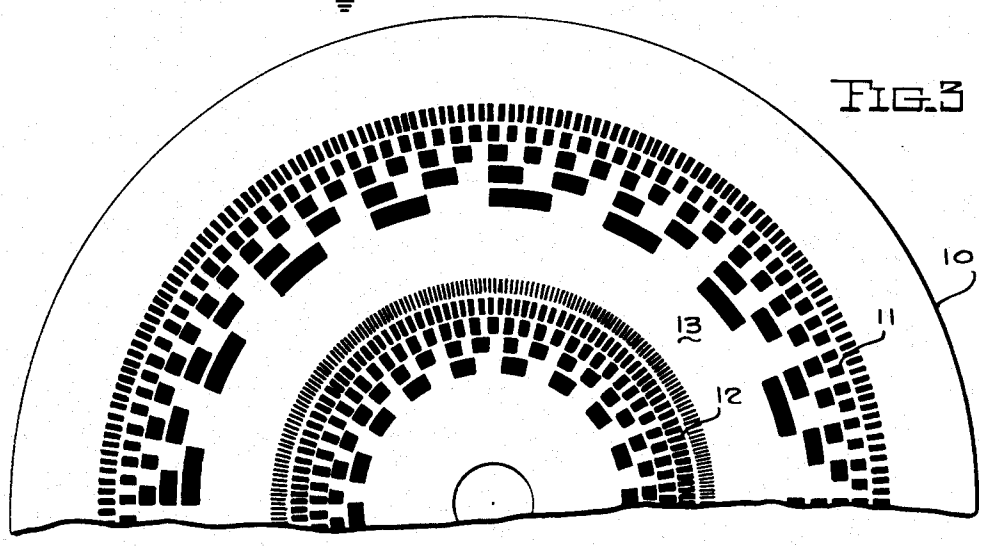


FIG. 3



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3,140,337

PHOTOELECTRIC ORGAN

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Filed Feb. 3, 1960, Ser. No. 10,829
3 Claims. (Cl. 84—1.18)

This application is a continuation-in-part of my application for U.S. patent, Serial No. 753,354, filed August 5, 1958, and entiled Photoelectric Organ.

The present invention relates generally to electronic musical instruments, and particularly to electronic musical instruments which employ photo-electric tone generators.

In principle, photo-electric musical instruments generate tones by utilizing recorded tone or pitch patterns to modulate light passing to one or more photo-electric cells. The tone or pitch patterns may be of variable density or variable area type, and the techniques involved are in some respects similar to those employed in recording and reproducing sound on film. A large number of systems have been conceived in the past for generating photoelectrically the large number of tones required in commercial electronic musical devices, and a wide variety of techniques have been developed for this purpose. For example, pitch or tone discs have been employed. Such discs are usually entirely clear or translucent except for the presence of a large number of opaque waveform patterns existing in concentric bands on the disc. If a narrow beam of light is focused on one of these bands as the disc rotates, and if a photo-electric tube is placed on the other side of the disc to intercept the light, light passing through the bands is modulated by the variations of opacity of the band, and the amount of light reaching the photo-electric tube varies in accordance with the area of clear band between the light source and the photoelectric tube. Accordingly, the phototube output current varies in exact accord with the shape of the opaque waveform pattern. If the disc is turned at a sufficiently rapid rate so that the variations of photo-electric tube current occur at an audio rate, the output current from the tube may be amplified and acoustically radiated. Key controlled systems may be provided for selectively illuminating several bands or pitch tracks, so that by suitably manipulating the keys musical selections may be generated.

The problem then arises of making the pitch tracks re-entrant, i.e., inscribing or recording on the pitch disc tracks wherein the total number of cycles per track is so related to the length of the track that an integral number of cycles is recorded on each track. This is extremely difficult of accomplishment because the ratio between adjacent frequencies in the tempered scale varies as the twelfth root of two, and because the accuracy with which frequency must be reproduced in electronic musical instruments is better than .25% for the average human ear, and is approximately .1% for the trained musical ear.

In order to generate re-entrant pitch tracks which have the required frequencies it had heretofore been found essential either to utilize a very low speed disc with extremely long tracks, which leads to discs of unreasonable size, or to utilize separate discs for tones of different nomenclature. It might appear that a relatively small disc could contain a large number of tracks provided a sufficiently large number of cycles of approximately correct

frequencies were recorded on each track, and that the tracks may be then made re-entrant without appreciable error in tone frequency. This turns out to be an inadequate solution, because the problem is then introduced of illuminating the tracks with a beam of light which is sufficiently narrow in the direction of track length that a very small fraction of a cycle is illuminated at any given instant of time, and yet to provide sufficient light at the photoelectric cell to rise above the noise level of the circuitry involved. This proves to be impossible unless a small number of cycles of tone per track is employed, and this difficulty is sometimes described as resulting from a low light storage index.

Still a further problem relates to the speed at which the disc may be rotated. If the disc is rotated with sufficient slowness, and the relatively small light storage index is somehow accommodated, a relatively large number of tone cycles per track may be employed. However, when this is attempted problems of controlling and rendering uniform the rotation of the tone disc exist because of the extremely low momentum of the mechanical system. Any slight inaccuracies or non-uniformities of pitch track rotation rate become accentuated audibly, and in practice this approach has been proven to be totally unsuccessful.

The usual solution attempted has been to provide plural tone discs, one for each note of a given nomenclature, and to gear these tone discs together so that they rotate at the appropriate speeds. Thereby each tone disc must be associated with a photocell, and since there are twelve notes of different nomenclature in the evenly tempered scale, twelve discs and twelve photocells are required, in addition to appropriate gearing systems. The system then becomes cumbersome and expensive to build and is believed to be commercially impractical.

The present invention provides a musical instrument which utilizes six pitch discs, which are driven in pairs so that only three different speeds are required. Each disc employs a total of ten tracks, representing tones of two different but adjacent nomenclatures, in five octaves for each nomenclature. For example, we may denote discs of the same rotary speed as A and B discs, respectively, and disc pairs of different speeds as #1, #2 and #3 discs. The speeds employed are 5.46, 6.88 and 8.66 r.p.s., which represent vibrato frequencies, or frequencies in the vibrato range. The tracks for these speeds may represent recorded tones as follows:

Speed	Disc A Tone	Disc B Tone
5.46 r.p.s.	F, F#	G, G#
6.88 r.p.s.	A, A#	B, C
8.66 r.p.s.	C#, D	D#, E

The recorded number of cycles per track corresponding with these tones are:

Speed	Fundamental Number of Wave-Length Representations Per Track	
	Disc A	Disc B
5.46 r.p.s.	16,17	18,19
6.88 r.p.s.	16,17	18,19
8.66 r.p.s.	16,17	18,19

It is then apparent that all the A discs are duplicates and all the B discs are duplicates, so that a total of only two different discs is required, and that the total number of wave length representations per track is small, enabling convenient utilization of, say, three inch discs with adequate high light storage factors. Since the number of cycles is always integer, i.e., $n16$, $n17$, $n18$, $n19$, where n is an integer representing the octave, the re-entrance problem is non-existent, and it is found that no generated tone is inaccurate by more than .2%.

It will be clear as the description proceeds that the principles of the invention may be applied to magnetic recording systems, in which pitch tracks on magnetic tape or drums are reproduced, as well as to photoelectric systems. For purposes of illustration of the principles of the invention in its broadest aspects, and further to indicate how a preferred form of the invention may be practiced, the system is described as photoelectric.

Rotation of the discs at different speeds, all within the vibrato range, has the effect of introducing variety into the reproduced tone, when plying chords, which is particularly pleasing, and moreover vibrato rates of rotation are relatively easy of accomplishment at constant angular velocity.

The use of small discs, and high light storage factor, i.e., length of track per period, permits the use of plastic as the disc material, and the fact that only two different discs are employed, having ten tracks per disc, reduces the spoilage factor in tone track synthesis and disc duplication to negligible factors.

In accordance with the present invention the discs may be rotated by a good quality motor, and, without more, adequate speed regulation of the discs is attained since any variations of speed during a cycle due to slight frequency misregulation of the motor power source do not produce unpleasant effects on the listener.

A further problem which exists in the production of photoelectric organs relates to the complexity of the optical system employed. Many systems which have been conceived in the past employ relatively long light paths, or complex lenses, or reflectors. These may readily become maladjusted and in adidtion are relatively expensive to fabricate. The problem of selecting tone track in a tone wheel having a great number of tracks without introducing optical or mechanical complexity is one of the serious problems which has heretofore prevented the development of a practical photoelectric organ. Not only may the tracks be quite narrow, but the distance between tracks may be still narrower. The total amount of light falling on each track must be approximately the same as for any other track, or different notes will have different amplitudes when acoustically transduced. It is necessary that the light beams relating to each track remain relatively symmetrical with respect to the track as the track rotates. It is further necessary that if the beams diverge in cross-sectional area after leaving the track and on the way to the photocell, approximately the same area of the photocell will be illuminated by all the tracks, since otherwise again different notes will have different acoustic amplitudes.

In accordance with the present invention the tracks are selected by means of light bulbs individual to the tracks. In order to illuminate each track an energizing circuit is provided to energize a specific light bulb associated with that track. The light bulbs are mounted on a plane plate behind slits. They are adjustably mounted so that small mechanical motions of the bulb will be permitted for purposes of adjustment. Positions of the slits and the sizes of the slots relative to the position of the bulb are so selected that light from any given bulb can proceed via only one slot and via one track to the photocell. Adjustment of a light bulb with respect to its slit permits adjustment of the amount of light transferred from the bulb to the photocell and also permits adjustment of the overlie of the light beam on its track and the extent to

which the light beam illuminates the cathode of the photocell. It is a simple matter to energize the bulb and thereafter to move same slightly on its adjustable mounting until only a single track generates the tone, and until that tone is of required loudness. It has been found feasible in accordance with the principles of the present invention to utilize sixty tracks on six discs, to associate one hundred and twenty different lamps with the sixty tracks (i.e., two lamps per track), and to derive undistorted tone from any one of the tracks by illuminating the corresponding lamp, and this with a minimum of mechanical complexity, by means of a structure which lends itself to economical fabrication, to ease of maintenance and to freedom from maintenance requirements as well as to ease of adjustment of the system during manufacture or thereafter, in respect to obtaining pure tones of desired amplitudes. The system, while accomplishing these objectives requires no lenses and no reflectors in the optical system.

Some assistance in providing pure tones without intermodulation between tracks is accomplished by the method adopted for grouping the sound or pitch tracks on the disc. In accordance with the present invention pitch tracks of the same nomenclature are immediately adjacent each other. Between groups of tone tracks relating to a given nomenclature a relatively large space is left, following which appear tones of another nomenclature. In this way, if there is some intermodulation by reason of the fact that light from one bulb impinges totally on one track and to some degree on an adjacent track, intermodulation is harmonic in nature and, therefore, is not unpleasant and does not detract from the musical quality of the instrument.

According to another feature of the present invention, the photocells employed in the track reading system are off-centered with respect to the disc, whereby two photocells may be employed which are independently illuminated by separate sets of lights, but via the same sound tracks. Accordingly, each sound track is doubly employed. This expedient is of particular value in two manual organs, for example, in which case the same sound track may be employed for generating sounds relating to both manuals, but each manual may utilize a different set of lights an a different photocell. Maximum manuals utilized in organs of conventional character employ sixty keys. Accordingly, by means of this expedient it is possible to employ one-hundred and twenty lamps, sixty per manual, and two photocells, by means of which the separate manuals may be completely independent of one another except for the duplicate use of tracks. In the two manually system, the separate photoelectric cells are connected to separate pre-amplifiers and separate sets of formant filters, the outputs of which are applied directly to a power amplifier and a transducer. A variety of modifications of the basic organ may be employed: For example, keys may be interlocked, so that when a key of a given nomenclature is depressed, the key of corresponding nomenclature but an octave higher may also be depressed, thereby enriching the generated tone. On the other other hand a given tone may be coupled in this way to a tone which is an octave below or above the primarily desired tone. This is equivalent in organ terminology to coupling in a four foot or sixteen foot rank to an eight foot rank.

According to a further feature of the invention, correction is made for the fact that each light bulb is at a different distance from its associated track and from its associated photocell. This fact, taken in conjunction with the further fact that light diminishes in intensity as a function of distance from its source according to a square law, leads to certain difficulties. The intensty of light falling on any track may be different from the intensity of light falling on other tracks, and the decrease in both intensity of light and in divergence of light beam in passing from a track to a photocell may also

be different for each track. The difficulty is increased by virtue of the locations of the several tracks radially, as a function of pitch, i.e., adjacent tracks do not represent adjacent pitches, but represent octavally separated pitches. The difference in light intensity for pitches of adjacent octaves may therefore, be slight, but the difference for adjacent pitches may be considerable and quite noticeable. These differences are compensated by adjusting lamp positions to increase or decrease the amount of light reaching each cell from each lamp.

It is, accordingly, a broad object of the present invention to provide a novel electronic musical instrument.

It is a further object of the present invention to provide a novel musical instrument of the electronic organ type.

Still another object of the invention resides in the provision of a photoelectric organ employing only two distinct types of tone disc for generating a complete complement of organ tones.

Still another object of the invention resides in the provision of a photoelectric organ which employs no lenses or reflectors.

A further object of the invention resides in the provision of a single mechanically simple assemblage for interrelating tones discs, light sources, photoelectric cells and light apertures in a small, compact, light unit having no reflectors and no lenses and which permits selection of any tone track at will.

Another object of the invention is the provision of a multiple pitch disc for a photoelectric organ in which the discs are rotated at different frequencies falling within the vibrato range.

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of one specific embodiment thereof, especially when taken in conjunction with the accompanying drawings, wherein:

FIGURE 1 is a schematic circuit diagram of a photoelectric organ according to the present invention;

FIGURE 2 is a partial view in perspective of a photoelectric tone read-out system, according to the present invention;

FIGURE 3 is a partial view in plan of a tone disc according to the invention, and

FIGURE 4 is a view in perspective of a drive mechanism for the plural tone discs of the invention.

The several tone discs of the present invention may be fabricated according to the general method disclosed in my co-pending application Serial No. 753,354, entitled Photoelectric Organ, and filed August 5, 1958, making such quantitative modifications as are required by the disc speeds and tone tracks of the present invention, specified herein.

Reference is made to FIGURE 3 of the accompanying drawings, wherein is illustrated a portion of a pitch disc **10**, as finally recorded and developed. Two sets of tracks **11** and **12** are illustrated, each set comprising five octavally related tracks of a given nomenclature, and the two sets being adjacent in nomenclature. Six discs are utilized, to provide for twelve nomenclatures. Of the six discs, half are designated A discs and half B discs. The A discs each contain five tracks rooted on 16 wave length representations and five tracks rooted on 17 wave length representations, but separate ones of the A discs are rotated at different speeds, i.e., 5.46 r.p.s., 6.88 r.p.s., and 8.66 r.p.s. The B discs contain each five tracks rooted on 18 wave length representations and five tracks rooted on 19 wave length representations, and are respectively rotated at the same speeds as the A discs, in pairs. Accordingly, one A and one B disc rotate at 5.46 r.p.s., one A disc and one B disc at 6.88 r.p.s. and one A disc and one B disc at 8.66 r.p.s.

The A disc, rotating at 5.46 r.p.s., has recorded thereon all tones having the nomenclatures F, F♯, and the B disc rotating at 5.46 r.p.s. all tones having the nomenclatures G, G♯, and in general the tones are distributed among the discs according to the following table:

Speed	Tone Disc A	Tone Disc B
5.46 r. p.s.	F, F♯	G, G♯
6.88 r.p.s.	A, A♯	B, C
8.66 r.p.s.	C♯, D	D♯, E

The tracks are accordingly all re-entrant, because based on integers, and yet only two different pitch discs are utilized.

The tracks **11** and **12** of the same nomenclature are closely spaced radially, but a considerable radial gap **13** subsists between the set of tracks **11** and the set of tracks **12**. Thereby, if read-out occurs with some inaccuracy of any single tone track, only octavally related frequencies can be inadvertently introduced, but not tones of adjacent nomenclature.

The mode of driving the tone discs is illustrated in FIGURE 4 of the accompanying drawings, wherein **15** is a synchronous electric motor, suitably geared down, and which rotates a central drive disc **16**, secured on the shaft of motor **15**. The central drive disc **16** frictionally drives three driven discs **17**, **18**, **19**, at the peripheries of the respective discs, and the ratios of the disc diameter of the latter are selected to provide the required driven disc speeds, i.e., 5.46 r.p.s., 6.88 r.p.s., and 8.66 r.p.s., respectively, for the several discs **17**, **18** and **19**.

The several pitch disc pairs are secured to shafts common to the driven discs **17**, **18**, **19** and the angular separations of the driven discs **17**, **18**, **19** is 120°.

Proceeding to FIGURES 1 and 2 of the accompanying drawings, a typical driven disc **17** is illustrated, having a shaft **20**. On the shaft **20** are two tone discs, **21**, **22**, i.e., one A disc and one B disc, for rotation with driven disc **17**. Located between the tone discs **21**, **22** adjacent their peripheries, are four photoelectric cells **23**, **24**, **25**, **26**. The photoelectric cells **23**, **25** pertain to and face the pitch disc **22**, and the photoelectric cells **24**, **26** pertain to and face the pitch disc **21**.

A plurality of lamps is provided, there being specifically one lamp for each key of a first manual of an organ, and one lamp for each key of a second manual of an organ, in a two manual organ.

Lamps pertaining to the first manual, i.e., manual A are designated by the reference numeral **61** while those pertaining to the second manual, i.e., manual B are designated by the reference numeral **62**. Each of the lamps includes a filament and specifically a line filament, the filament being aligned with the radii of the pitch discs. The lamps **61** are arranged in the area circumscribed by a semi-circle having a diameter passing through the shaft **20**. Similarly, the lamps **62** are located within the area defined by a further semi-circle having the same diameter. Each of the lamps is associated with a narrow radially elongated slit, as **63**, in a slit plate SP. Each slit and the associated lamp are so located with respect to an associated pitch track, as **65**, of a pitch disc, as **22**, that light from the lamp passes through a slit **64** and thence through the required pitch track, as **65**, and thence to a photocell as **24** or **25**. The A manual lamps **61** are associated with photocell **23**, and illuminate only that photocell, while the B manual lamps are associated with a separate photocell **25**, and illuminate only the latter.

In general, each separate lamp as **61** or **62** is associated with a single track, but the tracks serve a double function, in that one lamp of the A manual lamps **61** and one lamp of the B manual lamps **62** are associated with each one of the tracks **65**. It follows that the photocells **23**, and **24** may provide identical tonal outputs, i.e., of the same nomenclature and scale position, when suitable keys in the two manuals are depressed, but these identical tonal outputs are provided via separate photocell output

channels. Track sharing in this manner is a feature of economy in the present invention, and not an essential feature, in the sense that duplicate or different pitch discs may be utilized for the separate manuals if desired, and in a complex organ which may employ as many as four manuals, four separate and distinct sets of pitch discs may be employed, or fewer pitch discs may be employed by utilizing tone track sharing.

In order to produce any given tone, an appropriate one of lamps **61**, **62** is energized. In FIGURE 1 of the accompanying drawings, I have illustrated three keys **70**, **71**, **72**, taken from manual A and three keys taken from manual B. It will be observed that the manual A keys **70**, **71** and **72** connect separate ones of the lamps of the A group to a source of voltage, while the key actuated switches **73**, **74** and **75** pertaining to the B manual, control the lamps of the B group. All the lamps, nevertheless, may be energized from the same source B, or, if desired, lamps pertaining to the separate manuals may be provided with separate power supplies. Electrical signals generated by the photocell **23** in response to tone modulated light originated by any of the lamps **61** pertaining to manual A are supplied via lead **80** to a pre-amplifier **81**, which pertains to manual A only. Similarly, the output of photocell **25** is applied via a lead **82** to a pre-amplifier **83** which pertains to the B manual only. The output of the pre-amplifier A is passed through a group of formant filters **84** which pertains to the manual A, and separate filters of which are selected by means of the stop switches **85**. Similarly, the output of pre-amplifier B is applied to a group of formant filters **87** which are selected by means of stop switches **88**. The outputs of the formant filters **84**, **87** are combined in a resistance **90** which includes an adjustable slider **91** acting as a volume control for the system.

The combined outputs on the slider **91** are applied to a power amplifier **92** and thence to an acoustical radiator **93**, such as a loudspeaker. To the amplifier **92** is also supplied vibrato modulation deriving from modulator **94**, which modulates the frequency of output of the amplifier **92** at a vibrator rate suitable to the system. It is important to note that the vibrato rate employed can no longer be equal to the rate of rotation of all the pitch discs, since the latter are not identical. In my prior application, hereinabove referred to, the vibrato rate employed was equal to the rate of rotation of the single disc employed. In accordance with the present invention, any variation of speed of the pitch discs results in internally generated vibrator effects, but these are not at the same frequency as the vibrato effects introduced by the modulator **94**, in general. A vibrato frequency may be employed equal to the rotational rates of one of the pitch discs, the other then being unequal. Nevertheless, any jitter in the pitch discs is translated into a vibrator effect which is pleasant to the ear.

In the system of FIGURES 1 and 2, since generation of the tones appropriate to any single manual require the utilization of six pitch discs and since each manual includes circuitry for reading out each pitch disc, which in turn includes a photocell, all six photocells pertaining to a manual are connected in parallel, as indicated generally in FIGURES 1 or 2 of the photocells.

An important structural feature according to the present invention resides in the location of the photocells as **23**, **24** pertaining to one pair of A and B pitch discs, at locations intermediate the pitch discs. The slit discs **64** then are located outside the pitch discs and the lamp mounting plates and lamps are located outside the slit plates, as illustrated in FIGURE 2. Electrically considered, then, the signals pertaining to any one manual are identical to signals which might be provided were a single photocell and single pitch disc utilized. They may, therefore, be processed in the manner specified and described in detail in my above referred to application for U.S. patent. Similarly, the total number of lamps employed in the two systems, i.e., the present system and the system of my above identified application for U.S. patent, may be identical. And accordingly the circuitry utilized for controllably energizing the lamps may be identical in the two systems, and the circuit expedients therein described and illustrated in detail are incorporated herein by reference.

In place of a pair of lamps connected in parallel, as **23**, **24**, I may also utilize a single photocell associated with two mirrors, which reflect light deriving from the lamps via the tone tracks to the cell. Also, a single cell, as **23**, may be employed, the remaining cell of a pair, as **24**, being replaced by a mirror which directs light to the cell **23**.

While I have described and illustrated one specific embodiment of my invention, it will be clear that variations of the details of construction which are specifically illustrated and described may be resorted to without departing from the true spirit and scope of the invention as defined in the appended claims.

What I claim is:

1. A tone disc assembly, comprising a first and second rotatable variable translucency tone disc, each of said tone discs including opaque areas representing a plurality of tone tracks of different nomenclature, an aperture plate operatively associated with each of said tone discs, said tone discs located between said aperture plates, said aperture plates each including at least one aperture operatively associated with each of said tone tracks, a plurality of discrete sources of light, each of said sources of light being located adjacent one of said apertures, photoelectric cells, said cells, apertures, tracks and discrete sources of light being relatively so located that light from each source of light travels to one of said photoelectric cells via one only of said apertures and one only of said tracks in the order stated, wherein said tone discs are concurrently driven by a single shaft, one of said tone discs having only tracks representing at least five octaves of tones of each of a first and second nomenclature, the other of said tone discs having only tracks representing at least five octaves of tones of each of a third and fourth nomenclature, said four tones being in immediate succession in the musical scale and each tone track being recorded in an integral number of wave length representations, tracks representing tones of each single nomenclature on each of said tone discs being located in a group in close proximity to one another, and separate groups being relatively widely separated on said tone discs, and means for selectively reading out said tracks, said means including key switch means for selectively activating said sources of light to selectively illuminate said tracks.

2. A musical instrument, comprising a pair of tone discs on a single shaft, one of said tone discs having only tracks representing at least five octaves of tones of each of a first and second nomenclature, the other of said tone discs having only tracks representing at least five octaves of tones of each of a third and fourth nomenclature, said four tones being immediately successive in the musical scale and each tone track being recorded in an integral number of wave length representations, an aperture plate operatively associated with each of said tone discs, said tone discs located between said aperture plates, said aperture plates each including at least one aperture operatively associated with each of said tone tracks, a plurality of discrete sources of light, each of said sources of light being located adjacent one of said apertures, photoelectric cells, said cells, apertures, tracks and discrete sources of light being relatively so located that light from each source of light travels to one of said photoelectric cells via one only of said apertures and one only of said tracks in the order stated.

3. A system for producing music from photographically recorded tone tracks, comprising a re-entrant disc record carrying medium, said medium having three disc pairs moving at different speeds related in the ratio 5.46, 6.88 and 8.66, and carrying tone tracks having only 16*n*, 17*n*,

18*n* and 19*n* complete cycles of tone, where *n* are integers including 1, 2, 3 . . . denoting order of octaves of said tone in the tonal range of the system, an aperture plate operatively associated with each of said tone discs, said tone discs located between said aperture plates, said aperture plates each including at least one aperture operatively associated with each of said tone tracks, a plurality of discrete sources of light, each of said sources of light being located adjacent one of said apertures, photoelectric cells, said cells, apertures, tracks and discrete sources of light being relatively so located that light from each source of light travels to one of said photoelectric

cells via one only of said apertures and one only of said tracks in the order stated.

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