Nov. 27, 1951 E. M. JONES ET AL 2,576,760

SYSTEM FOR THE PRODUCTION AND USE OF ELECTRIC OSCILLATIONS FOR CONTROL PURPOSES

Filed Sept. 22, 1949 2 SHEETS—SHEET 1

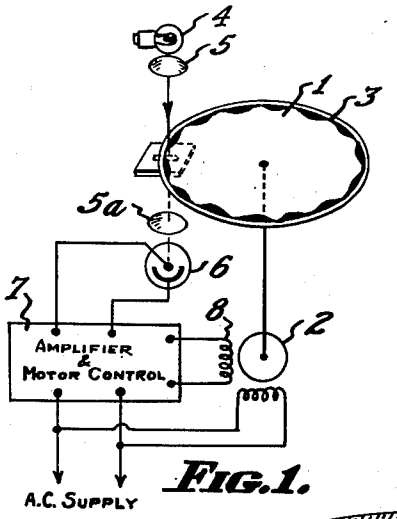


FIG. 1.

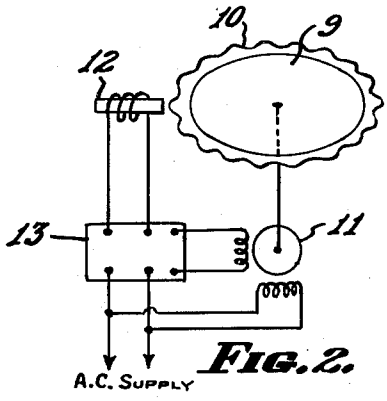


FIG. 2.

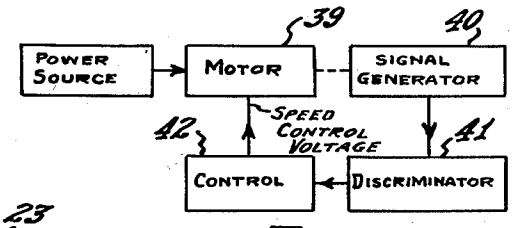


FIG. 4.

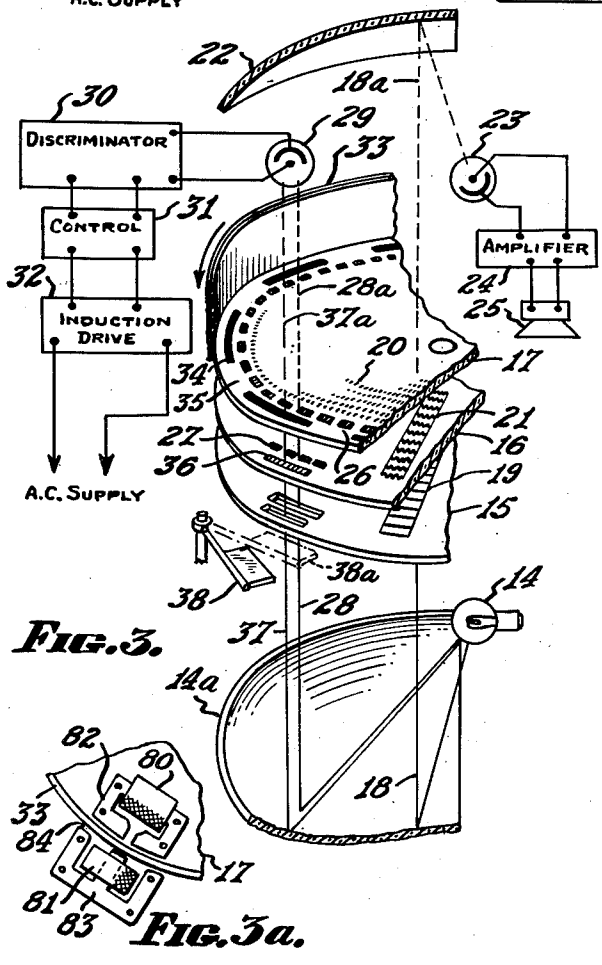


FIG. 3.

FIG. 3a.

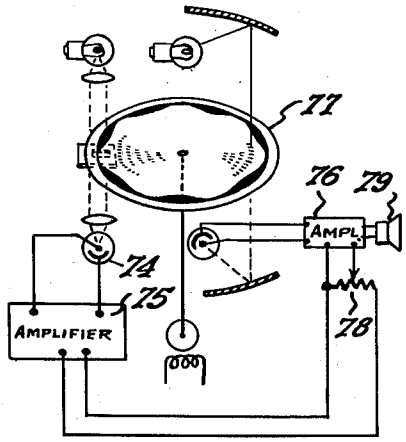


FIG. 12.

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SYSTEM FOR THE PRODUCTION AND USE OF ELECTRIC OSCILLATIONS FOR CONTROL PURPOSES

Filed Sept. 22, 1949 2 SHEETS—SHEET 2

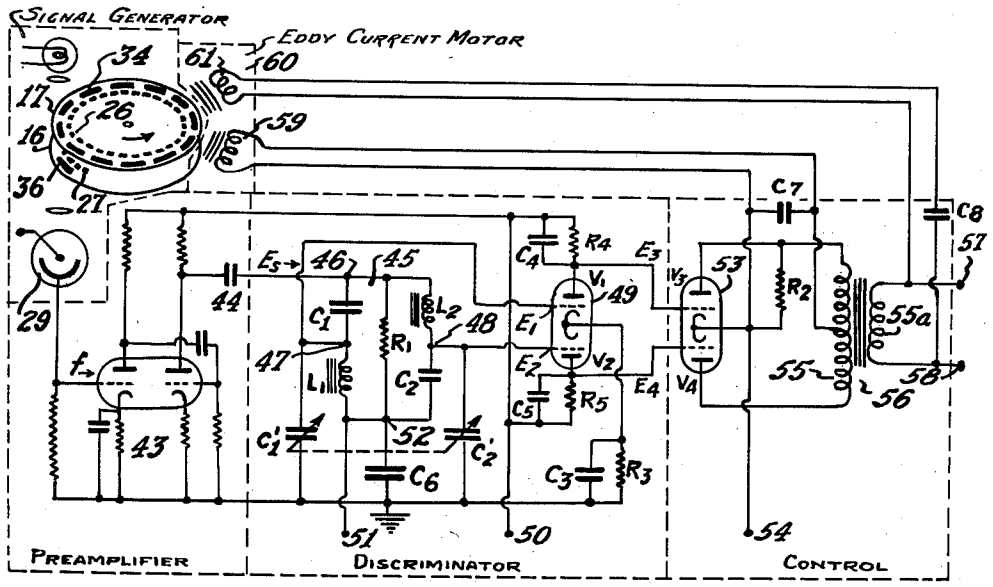


FIG. 5.

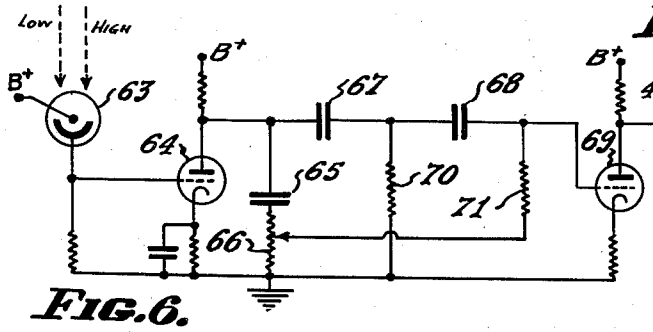


FIG. 6.

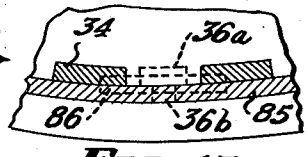


FIG. 13.

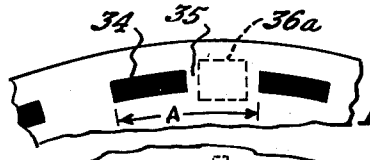


FIG. 8.



FIG. 9.

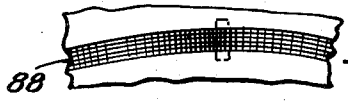


FIG. 10.

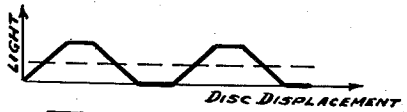


FIG. 11.

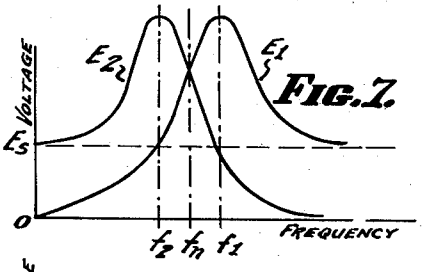


FIG. 7.

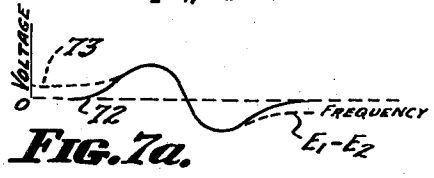


FIG. 7a.

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Patented Nov. 27, 1951

2,576,760

UNITED STATES PATENT OFFICE

2,576,760

SYSTEM FOR THE PRODUCTION AND USE OF ELECTRIC OSCILLATIONS FOR CONTROL PURPOSES

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Application September 22, 1949, Serial No. 117,240

27 Claims. (Cl. 84—1.18)

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Our invention relates generally to systems for the production and use of electric oscillations or pulsations for control purposes. Specifically, our invention relates to the generation, preferably by means associated with a continuously moving member, of (*a*) audio frequency oscillations and their use in maintaining the speed of the member constant and/or (*b*) sub-audio oscillations for rendering the speed periodically variable or for periodically varying a quantity having some functional relationship with the moving member. The particular use to which we have put our invention is that of driving a pitch determining member in a musical instrument at a constant speed to produce tones of steady pitch or at a speed periodically variable about the constant speed as a mean, for introducing frequency tremolo (vibrato) in the tones produced by the instrument.

By way of example, we shall describe our invention as employed in an instrument of the photoelectric type, the specific use being in connection with the pitch disc in the generator unit disclosed in a co-pending application in the name of Edward M. Jones, entitled Generator for Electric Pulsations of Audio Frequency, filed August 6, 1949, Serial No. 108,946 now U. S. Patent No. 2,558,653, granted June 26, 1951. However, it will be obvious to those skilled in the art on reading these specifications that the utility of our invention may be extended to other musical instruments employing continuously moving pitch determining members, or into other fields such as recording and/or reproducing wherein constant speed control is desired and/or wherein periodically variable speeds may be desired for the introduction of synthetic tremolo effects or for other purposes. (In our disclosure, the word "tremolo" is used in the broad sense to include effects which are due to variations at a sub-audio rate in the frequency and/or amplitude of a musical tone or tones. The word "vibrato" is herein applied only to frequency tremolo.)

In musical instruments wherein a gamut of tones may be produced from one or more rotating members such as discs, drums, and the like, it is necessary that the speed of the rotating elements be held within extremely close limits if the tones produced are to be perceived as being of steady pitch. Those familiar with the art are aware that a vibrato may be introduced into musical tones by periodically varying the speed of a rotary pitch-determining member about a nominal mean speed at which the normal pitches for the tones are produced. Various systems have been proposed for accomplishing in musical

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instruments constant and periodically variable speeds. Some such systems employ constant speed motors, with variable transmission or coupling means for changing at a sub-audio rate the speed of the pitch member itself periodically for vibrato purposes. Examples may be found in U. S. Patents Nos. 2,033,232 to Emereeff and No. 2,314,496 to L. Hammond.

Persons familiar with this art are aware also that amplitude tremolo may be produced in the tones of a musical instrument of the photoelectric type by using a variable translucency disc for periodically varying at a sub-audio rate the total amount of light falling upon a main photocell used for converting light pulsations to electric pulsations corresponding to musical tones, as taught by Emereeff in U. S. Patent No. 2,031,764.

We have not found in any of the proposed systems of which we are aware, one which meets the various requirements of a photoelectric device of the type disclosed in the above mentioned co-pending application. In that application there has been disclosed the mechanical design of a device with which our invention may be employed to control the speed of a rotating pitch disc of the light-chopper type well known in the art. Features of this design pertinent to our application will be discussed hereinafter.

Therefore, it is one of the objects of our invention to provide, for use with a continuously moving member, a system whereby the speed of the member may be periodically varied by control means associated with the member itself.

It is also an object of our invention to provide a combination system for a continuously moving member whereby the member may be driven at either a constant speed or a periodically variable speed.

A specific object of our invention is to provide a system for a photoelectric musical instrument, wherein the pitch determining member may be driven at a constant speed or at a periodically variable speed about the constant speed as a mean for the purpose of producing steady tones or tones with vibrato, respectively.

A further object of our invention is to provide a unitary frequency responsive circuit arrangement acting to maintain the speed of a continuously moving member constant or to vary it periodically, as desired.

A primary object is to provide for a pitch member in a musical instrument motive means and a control system therefor, which will accelerate the member from rest to a desired speed quickly

and will maintain that speed with no perceptible variation in pitch of the tones produced, unless or until the speed is periodically varied for vibrato purposes by means of the control system or by other means.

Still another object of our invention is to provide a speed control system for a motor-driven pitch disc in a photoelectric musical instrument, whereby light from a source is modulated by a speed control track and a vibrato track both located on the disc and is collected by a photocell connected in a circuit operative to control the torque applied by the motor to the disc as required to keep the speed of the disc constant or to vary it periodically, as may be desired.

A further object is to provide a system whereby a driving force, susceptible to automatic control for producing either constant or periodically variable speed, may be applied to a pitch determining member without mechanical contact therewith.

It is another object of our invention to provide a system whereby the tremolo in the tones of a musical instrument may be controlled by a track or the like on the pitch determining member of the instrument.

These and other objects which will be set forth hereinafter or will be apparent to those skilled in the art upon reading these specifications, we accomplish by circuits, constructions and arrangements of parts of which we shall now set forth exemplary embodiments. Reference is made to the accompanying drawings wherein:

Figure 1 is a diagrammatic representation, partially in perspective, of elements of a speed control system;

Figure 2 is a diagrammatic representation, partially in perspective, of a modified system;

Figure 3 is a diagrammatic representation, partially in perspective, showing a preferred form of our invention as adapted to a photoelectric musical instrument;

Figure 3*a* is a plan view of a preferred form of induction drive for a pitch disc;

Figure 4 is a block diagram of a speed control system employing our invention;

Figure 5 is a complete circuit diagram of a preferred form of our invention;

Figure 6 is a circuit diagram of a modified form of a preamplifier circuit for use with the circuit of Figure 5 and incorporating an electric vibrato control;

Figure 7 is a graph showing the variation with respect to frequency of the electric potentials to ground at certain points in the circuit diagram of Figure 5;

Figure 7*a* is a graph of the differences between the potentials plotted in Figure 7;

Figure 8 shows a preferred form of vibrato track for a pitch disc in a photoelectric control circuit;

Figures 9 and 10 show modified forms of vibrato tracks;

Figure 11 is a graph in which light value is plotted against displacement, and illustrates an effect such as would be produced by the track and aperture relationship shown in Figure 8;

Figure 12 is a diagrammatic representation, partially in perspective, of a form of our invention as used for the introduction of an amplitude tremolo; and

Figure 13 illustrates a shutter and aperture relationship such as may be used to eliminate the effects of transient speed changes caused by shutter operation.

In Figure 1 a disc indicated generally at 1 may be driven by an induction motor indicated generally at 2. According to our invention, a circular track 3, which may be of different forms as will be described hereinafter, is located upon the disc 1. On one side of the disc 1 and opposite the track 3 may be a source 4 of light which is directed by a suitable lens system such as indicated at 5 and 5*a* so that the light is modulated by the track 3 before impinging upon a photocell 6. Variations in light falling upon the photocell 6 may be converted to current variations in a suitable circuit 7 for amplifying the variations and providing a current variable as to magnitude and/or phase to a winding 8 of the induction motor 2. The current variations in the winding 8 result in corresponding torque variations exerted upon the rotor of the motor 2. The variations in torque will result in corresponding speed variations in the disc 1 in accordance with the characteristics of the track 3, depending of course upon such factors as the frequency and magnitude of the torque variations and upon the inertia of the rotor.

In Figure 2 a disc 9 having a scalloped periphery 10 may be driven by an induction motor 11. The periphery 10 may be of magnetic material so that as the disc 9 rotates, the scalloped portions will affect the characteristics of an electromagnet 12. The variations in current in the magnet circuit may be amplified in a suitable circuit 13 and used to vary the speed of the motor 11 in a manner similar to that of the system in Figure 1.

The torque exerted upon the rotors of the motors 2 and 11 respectively of Figures 1 and 2 must oscillate between values above and below the torque required for constant speed if the speeds of the motors are to vary about their normal speeds as a mean. Mechanical or electrical braking torque may be applied periodically if so desired by such systems as those illustrated in Figures 1 and 2, but the periodic variation will in these cases be from a normal speed to a speed below normal, rather than about the normal speed as a mean.

Description of preferred system

We shall now describe in detail the system of Figure 3 wherein is shown a preferred embodiment of our invention, comprising a combination speed control and vibrato system in a photoelectric musical instrument having a generator of the type described in the above mentioned Jones application. Figures 3 and 3*a* show the essential mechanical elements of the instrument, a preferred circuit diagram being shown in detail in Figure 5.

In the system of Figure 3 light from a source 14 is converted to parallelism by a parabolic reflector 14*a* from which the light passes through a suitable shutter plate 15, a voice disc 16, and a pitch disc 17, as will be explained below. Rays of light such as 18 are permitted to pass through apertures 19 in the shutter plate 15 and are divided into moving rays such as 18*a* by slots 20 in the pitch disc 17. The rays 18*a* are caused to scan wave form patterns 21 in the voice disc 16 in a manner well known in the art. The modified rays such as 18*a* are then focused by a parabolic mirror 22 upon a photocell 23 connected to an appropriate amplifier 24 and loudspeaker system 25. In the practice of our invention in this type of instrument, we prefer to maintain the speed of the pitch disc 17 constant by means of a system employing a constant speed track on the pitch disc, composed of a circular row of equally

spaced transparent areas or slots 26. One or more similar slots 27 may be located in the voice disc 16 opposite the slots 26 and having the same spacing so that one or more beams such as 28 are used to fluctuate in intensity. Such fluctuations in a ray 28a will result in a pulsating current in the circuit of a photocell 29 at a frequency which will be proportional to the rotational speed of the pitch disc 17. The pulsations in the photocell current are fed to a frequency responsive circuit, or discriminator 30 to which may be connected a circuit 31 for controlling the magnitude and/or direction of the force which must be applied by an induction driving means 32 in order to maintain the pitch disc 17 at a constant speed. A cylindrical rim 33 may serve as the armature means for receiving the torque applied to the disc by an induction drive 32, a preferable form of which is illustrated in Figure 3a, wherein windings 80 and 81 are located respectively on laminated core structures 82 and 83. The laminated, conductive rim 33 of the pitch disc 17 rotates through the air gap 84 between the cores 82 and 83. This drive means is an adaptation of the type drive employed in alternating current induction watt-hour meters wherein current and potential windings are respectively located on C- and E-shaped cores to drive a flat circular disc at a speed proportional to the power transmitted therethrough. It is known that in such a device the interactions between the magnetic fields present, and the eddy currents which they induce in the moving element, result in forces which drive the moving element. As will be pointed out hereinafter, the proper phase relationship between the currents in the coils 80 and 81 is obtained by the use of a capacitor.

In the motive system of Figure 3a, as will be explained in detail hereinafter, a fixed potential is supplied to one winding, while to the other is supplied a nominal A. C. potential sufficient to maintain the speed of the disc at approximately normal speed. Then if the speed of the pitch disc 17 varies from normal, the discriminator circuit and control circuits act to supply to the other winding speed-error voltages as required to bring the speed of the disc back to normal. The preferred circuits will be discussed in detail hereinafter.

In the application of tremolo to the system just described, we prefer to employ a vibrato track composed of alternate transparent and opaque areas 34 and 35, preferably located near the periphery of the pitch disc 17. Cooperating with the areas 34 is a transparent aperture 36 located on the voice disc 16 directly opposite the row or track composed of the areas 34 and 35. A ray of light 37 may pass through the aperture 36 provided a shutter 38, operated by any suitable means (not shown), is in an open position, the closed position being indicated by the dashed outline 38a of the shutter. We prefer to make the circumferential length of the aperture 36 one-third of a distance A in Figure 8, in which the pitch track is shown in enlarged form. The dashed outline 36a of Figure 8 corresponds to the aperture 36 of Figure 3. If the aperture 36 is thus proportioned with respect to the areas 34 and 35 the amount of light permitted to pass through these areas will vary in a manner shown in the graph in Figure 11. These periodic variations in the ray 37a are converted by the photocell 29 into periodic variations in current which are in turn used to vary the torque exerted upon the rim 33, thereby causing periodic variations in the speed of the disc.

Since the alternating component of the wave of Figure 11 is completely devoid of all even harmonics and devoid of the third harmonic, and since the inertia of the pitch disc 17 and associated parts prevents response to high frequency components of the wave, the result is a nearly sinusoidal variation in the speed of the disc 17. The number of areas 34 and 35 in the pitch track will, of course, be determined by the speed at which the pitch disc normally rotates, and by the vibrato rate desired. For example, if the disc 17 has twelve transparent areas 34 and revolves at 30 R. P. M., a vibrato frequency of six cycles per second will be produced. It will be obvious that additional vibrato tracks may be used with similar shutters 38 if a choice of vibrato rates is desired.

The manner in which the electric system of the preferred embodiment of our invention operates may be explained in principle by referring to the block diagram in Figure 4. A motor 39 is driven at a desired speed by power from a suitable source. In the system of Figure 3 the motor comprises the induction drive 32 and a rotary element which includes the pitch disc 17 with the rim 33 attached thereto. Associated with the motor 39 is a signal generator 40 producing a signal whose frequency is proportional to the speed of motor 39. The signal generator of Figure 3 comprises the photocell 29 operating in conjunction with the slots 26 and 27 which chop the beam 28 at the signal frequency. The signal from the generator 40 is fed to a discriminator 41 which compares the signal with a reference as will be explained below, and feeds speed-error voltages to a control circuit 42 which in turn feeds speed-control energy to the motor 39 to bring its speed back to normal when there is any variation therefrom. The manner in which a vibrato variation is introduced into the speed of the motor 39 will be explained below in the description of the operation of the circuit diagram of Figure 5.

Description of preferred circuit

Referring to Figure 5, we shall now describe in detail an exemplary circuit which may be used in a photoelectric musical instrument for providing steady tones or tones with vibrato. The circuit diagram of Figure 5 has been divided by means of dashed lines into sections corresponding to the block diagram of Figure 4, except that a preamplifier, indicated generally at 43, has been added between the signal generator and the discriminator. The indicia referring to the mechanical elements in Figure 5 are the same as those of corresponding ones in Figure 3. Assuming that the pitch disc 17 is running at some speed, a signal voltage having a frequency f is generated in the circuit of the photocell 29 by the constant speed track composed of the slots 26 cooperating with the slots 27 as described above. This signal voltage is amplified by a conventional preamplifier circuit 43, and is fed through a coupling condenser 44 to a discriminator circuit indicated generally at 45. According to our invention, the discriminating elements are two series-resonant circuits connected in parallel between the input points 46 and 52, the first circuit comprising a capacitor C_1 and an inductor L_1 and the second comprising an inductor L_2 and a capacitor C_2. The inductors L_1 and L_2 have a high Q (ratio of reactance to resistance) and their values together with those of the capacitors C_1 and C_2, are selected so that branch L_1—C_1 resonates at a frequency slightly higher than that of a fre-

quency f_n, corresponding to the desired normal speed of the pitch disc 17, and so that branch L_2—C_2 resonates at a frequency slightly lower than f_n. The junction points 47 and 48 are connected respectively to the grids of the two triode sections V_1 and V_2 of a double triode 49. Separate tubes may be employed for V_1 and V_2, of course, if so desired. The cathodes of V_1 and V_2 are connected together and to ground through a resistor R_3, by-passed by a capacitor C_3. The plates of the triodes V_1 and V_2 are supplied from a source of positive potential connected at a point 50 through load resistors R_4 and R_5 respectively, by-passed by condensers C_4 and C_5 respectively. The capacitors C_3, C_4, and C_5 are of such value with respect to the corresponding resistors as to by-pass the signal frequency f but not low frequencies at which speed changes may occur in the disc 17. The grids of V_1 and V_2 are supplied with a positive bias voltage applied at a point 51, the grid of V_1 being fed as shown through the inductor L_1 and the grid of V_2 being fed through a resistor R_1 and the inductor L_2 as shown. The point 52 is by-passed to ground by a suitable capacitor C_6. Ganged trimmer capacitors C_1' and C_2' connect respectively the junction points 47 and 48 to ground and serve to adjust the resonant frequency of the circuits L_1—C_1 and L_2—C_2, as may be desired.

The output voltages from the discriminator are fed from the anodes of V_1 and V_2 to the grids of the triode sections V_3 and V_4 of the second double triode 53 in the motor control section of the system. The cathodes of the triodes V_3 and V_4 are connected together and to a source of positive potential connected at a point 54. The anodes of the triodes V_3 and V_4 are connected respectively to the ends of the secondary winding 55 of a transformer 56, the primary 55*a* of which is connected to a source of alternating current at terminals 57 and 58. A resistor R_2 connects the cathodes of V_3 and V_4 to the upper end of the winding 55. Between the center tap of the winding 55 and the cathodes of V_3 and V_4 is connected the control winding 59 of the eddy current motor indicated generally at 60. A capacitor C_7 is connected, as shown, across the winding 59, resonating it at the frequency of the supply voltage in order to raise its effective impedance. The fixed-potential winding 61 of the eddy current motor is connected to the supply terminals 57 and 58, as shown, through a phase-shifting capacitor C_8.

Operation of circuit with respect to speed control

A signal voltage E_s at the frequency f is fed to the resonant circuits L_1—C_1 and L_2—C_2 at the point 46. The voltages E_1 and E_2, between the point 47 and ground and the point 48 and ground, respectively, will be determined by the frequency f. In Figure 7 are shown curves illustrating the variation of E_1 and E_2 with respect to the frequency f of the signal voltage E_s. As the frequency f is increased from 0 to f_1, the resonant frequency of L_1—C_1, the voltage E_1 rises from 0 to a maximum at f_1 and then decreases with frequency and approaches a value of E_s. E_2, on the other hand, increases from a value of approximately E_s to a maximum at f_2, the resonant frequency of L_2—C_2, from which it decreases toward 0 as shown. It will be understood that if the circuit is properly adjusted, the voltages E_1 and E_2 will be equal at f_n, the frequency generated at a desired normal speed of the pitch disc 17. If the speed of the disc is lower than normal, the frequency f will be below f_n and the voltage E_2 will be greater than E_1. And if the speed of the disc is higher than normal, E_1 will be greater than E_2.

The voltages E_1 and E_2 are fed to the grids of V_1 and V_2 respectively, wherein the differences between these AC voltages E_1 and E_2 are transformed into two D. C. voltages the algebraic difference of which will be positive, zero or negative, depending upon whether E_1 is less than, equal to, or greater than E_2, respectively. With no signal on the tubes V_1 and V_2, there will be reached, by virtue of the positive bias voltage applied at 51, an equilibrium point near cut-off for the values chosen. That is, the cathode voltage will rise to an amount sufficiently higher than the bias voltage to operate the tubes near their respective cut-off points. Under these conditions the voltages E_3 and E_4, applied respectively to the grids of tubes V_3 and V_4, will be equal. Then, if equal A. C. voltages are applied to the girds of V_1 and V_2, the voltages E_3 and E_4 will still be equal to each other but will be slightly different from the values when no A. C. voltages are applied. The amount by which the equilibrium point for the tubes V_1 and V_2 shift is a function of the ratio of the voltages E_1 and E_2 to the D. C. bias voltage on V_1 and V_2. The greater this bias voltage—and corresponding cathode voltage—the smaller the change of equilibrium point with a given set of equal voltages E_1 and E_2. The positive voltage applied to the grids of V_3 and V_4 at normal speed is that which exists at the frequency f_n, the crossover point of the E_1 vs. f and E_2 vs. f curves of Figure 7. This voltage, together with the fixed positive bias on the cathodes of V_3 and V_4, determines the normal operating point for V_3 and V_4, which is near cut-off.

If the disc 17 is caused to run below a desired speed *s* for a moment, the voltage E_2 will be greater than E_1, causing the plate current of the triode V_2 to increase, thus causing the cathode voltage to rise and to cut V_1 off; therefore, E_3 will rise above the equilibrium value and E_4 will fall below it. If, on the other hand, the disc is caused to rotate too fast for a moment, E_1 will be predominant, causing E_4 to rise and E_3 to fall.

The net result up to this point is a pair of D. C. voltages for biasing the control tubes V_3 and V_4, where:

a. E_3 will rise if the disc 16 is going too slowly and fall if it is going too fast.

b. E_4 will rise if the disc 16 is going too fast and fall if it is going too slowly.

As is known in the art, the windings 59 and 61 of the eddy current motor 60 must be energized with voltages 90° out of phase if maximum torque is to be exerted upon the rim 33. The disc 17 will run backward or forward depending upon whether the voltage on one winding leads or lags the voltage on the other by 90°.

The winding 61 is arranged to have its voltage lead the supply voltage applied at the terminals 57 and 58 by means of the phase-shifting series condenser C_8. Since the winding 61 is at 90° to the line voltage and since the transformer 56 is fed directly from the line, the voltage between one end of the secondary winding 55 and the center tap will be 90° out of phase with respect to the voltage across winding 61 and the voltage between the other end and the center tap will be 90° out of phase with respect to the voltage across winding 61 in the opposite direction. The resistor R_2 permits a flow of current from the upper half of the winding 55 of the transformer to the winding

59 of the motor sufficient to maintain approximately the correct speed under normal conditions. If the disc speed is reduced, E_3 will rise and cause an additional, half-wave rectified component of current at the supply frequency to flow through the winding 59 from the upper end of the winding 55 of the transformer 56, thus boosting the torque already exerted on the disc by normal current through the winding 59. At the same time E_4 falls and cuts off V_4. The disc 16 will then speed up until equilibrium is reached.

If the disc 16 is going too fast V_4 will conduct and V_3 will cut-off thereby resulting in half-wave rectified current flow through the winding 59 from the lower half of the winding 55 of the transformer 56, which will oppose the normal current supplied through the resistor R_2. The resultant current will be lower than, or even opposite in direction to, the normal current, depending of course upon their relative magnitudes. Thus the torque exerted upon the disc will be lower or opposite in direction to that which exists at normal speed, so the disc will slow down until the equilibrium point is reached. There will be no "hunting" in this type of system because the correction potentials applied are proportional to speed errors rather than errors in displacement from a synchronous position.

Operation of combined speed control and vibrato system

In accordance with our invention a vibrato variation in the speed of the pitch disc 17 may be introduced into the speed control system described above. Pulsations of light at vibrato frequency produced by the transparent areas 34 on the pitch disc 17 cooperating with the aperture 36 on the voice disc 16 introduce pulsations at vibrato frequency in the input to the discriminator circuit at the point 46. The vibrato voltage will then appear across the resonant circuits L_1—C_1 and L_2—C_2 and will be transmitted to the grid of V_2 along with the speed control voltage E_2 through the inductance L_2. The vibrato signal will not, however, reach the grid of V_1 because of the relatively high impedance of C_1 and low impedance of L_1 to ground at the vibrato frequency.

The impedance to ground at point 46 will be much greater for the low (vibrato) frequency than for the signal frequency, since for the latter the L—C branches are near the series resonant condition. Therefore, the vibrato frequency will receive greater amplification by the preceding amplifier stage than the signal frequency, which will tend to make the relative magnitudes of the vibrato and signal frequencies of the same order when they reach the grid of V_1. This greater amplification of the lower frequencies also assists in the self-starting of the disc which is discussed hereinafter.

The function of the vibrato voltage on the grid of V_2 is to unbalance the difference-amplifier V_1—V_2 at the vibrato rate and thereby cause variation in the speed of the disc at this rate in the manner described above. The speed of the disc will return to normal each time the A. C. component of the vibrato voltage passes through zero.

In the system just described, a shutter such as that shown at 38 in Figure 3 is used to expose the aperture 36 in the voice disc 16 so that pulsations of light at vibrato frequency may impinge the photocell 29. This provides a mechanical system for varying the amplitude of the vibrato from zero to maximum as desired. An electrical system may also be provided, an example being shown in Figure 6. The vibrato pulsations are permitted to impinge on photocell 63 at all times, along with the pulsating light for controlling the normal speed of a pitch disc. The two signals thereby produced in the photocell circuit are fed simultaneously to an amplifier tube 64 connected as shown in a conventional manner. However, a condenser 65 and a potentiometer 66 are connected between the plate of the tube 64 and ground as shown. The plate of the tube 64 also has a connection through condensers 67 and 68 to the grid of a second amplifier tube 69, a resistor 70 being connected between the junction of the condensers 67 and 68 and ground. The grid of the tube 69 is also connected through a resistor 71 to the moving contact of the potentiometer 66. If the relative values of the condensers 65, 67 and 68, comprising a high-pass filter, are so chosen that the speed control signal but not the vibrato signal is permitted to pass through 67 and 68 to the grid of the tube 69 and the vibrato signal is by-passed through condenser 65 to potentiometer 66, then an adjustable vibrato voltage may be supplied to the grid of the tube 69 by moving the contact of the potentiometer 66. So far as the operation of the discriminator is concerned, there is no difference between the mechanical and electric systems for vibrator control.

An exemplary set of circuit elements and values for the system of Figure 5 is as follows:

R_1—10^6 ohms	C_4—.01 mf.
R_2—50,000 ohms	C_5—.01 mf.
R_3—10^6 oms	C_6—10 mf.
R_4—10^6 ohms	C_7—.4 mf.
R_5—10^6 ohms	C_8—.75 mf.
L_1—2 henrys	Potential applied at:
L_2—2 henrys	
C_1—400 mmf.	50, +280 volts
C_2—500 mmf.	51, +100 volts
C_3—.01 mf.	54, +200 volts

Phototube 29 is a type 919.
All other tubes are type 6SN7 (double-triode).
Q of L_1 and L_2 is approximately 20–25 at f_n.
Transformer 56 is 115/480 volt, center-tapped secondary.
Normal speed of pitch disc 17 is 33.75 R. P. M.
Number of areas 26 is 7424 in a 12-inch diameter circular path.
Frequency f_n is 4186 C. P. S.
Number of areas 34 is 12.
Frequency of vibrato is 6.75 C. P. S.
Resonant frequency L_1—C_1 is 4286 C. P. S.
Resonant frequency L_2—C_2 is 4086 C. P. S.
Winding 59 is approximately 8000 turns #34 copper wire on a ¼ square inch laminated steel core.
Winding 61 is 7500 turns #34 copper wire on a ½ square inch laminated steel core.

An important consideration concerning our discriminator circuit and its use in conjunction with the eddy current motor 60 is that, regardless of the speed of the disc, there is always a torque tending to bring the pitch disc back to its normal speed. This fact makes it possible for the pitch disc to respond to torque variations at a vibrato rate. Also, there is a torque when the pitch disc is at rest, and therefore the system provides for self-starting of the disc. This advantage is not found in the usual discriminator circuits such as those employed in detectors of

frequency-modulation radio receivers. The characteristic of the usual discriminator follows a curve such as that shown by the solid line 72 in Figure 7a. A curve representing E_1—E_2 in the circuit of Figure 5 follows qualitatively a curve such as 73, indicated in dashed lines.

We should like to point out that the amplifier portion of our discriminator 45 as illustrated in Figure 5 need not be limited to the specific arrangement shown therein. It will be obvious to those familiar with the art that two rectifiers and D. C. amplifiers of any suitable type may be used to convert the discriminator voltages E_1 and E_2 to a pair of D. C. voltages for biasing the tube 53 as needed. Also, if we choose to control a circuit which may be dependent upon the variations in a single D. C. voltage—for instance, a two-winding eddy-current system such that is disclosed above, driving a disc to which is continuously applied a braking torque by mechanical or electrical means, the disc being brought up to normal speed by the driving means and down to normal speed by the braking means—we may employ a circuit such as that centering around the tube 49, with or without modification, to supply the single D. C. control voltage. For example, the potential between either anode of the tube 49 and ground may be employed. Or, resistor R_5 and capacitor C_5 may be omitted from the circuit of Figure 5 and the potential drop across resistor R_4 used for control purposes.

We do not wish to limit ourselves to the type of vibrato track shown in Figure 8. We may employ a variable area type as shown at 87 in Figure 9 or a variable density type as shown at 88 in Figure 10. If a radially operated shutter is used to control vibrato, the tracks of Figure 8 and Figure 10 are preferable to that of Figure 9, because the wave form of the vibrato pulsations changes from the zero to the maximum vibrato position of the shutter in the case of the wave form of Figure 9.

It should be pointed out that in the mechanical shutter system for control of vibrato, transient changes in speed may occur due to the change in light level on the photocell as the shutter is opened or closed. These transients are caused by the change in D. C. level on the grid of the preamplifier tube and to the charging or discharging time of the cathode by-pass condenser of the preamplifier. The effect of transients may be eliminated, if so-desired, by the use of a compensating track adjacent to the vibrato track and an additional aperture in the voice disc 17 so that as the vibrato track is exposed the compensating track is closed. The purpose of this additional track is to maintain a constant light level on the control photocell so that the D. C. level of the preamplifier is kept constant regardless of the opening and closing of the vibrato shutter. In Figure 13, the aperture 36a is shown as extended at 36b to expose a portion of a transparent track 85 adjacent to the vibrato track composed of areas 34. The circumferential length of 36b may be one-half the length of 36a, so that an amount of light may pass through 36b which is equal to the average amount passing through 36a. As a shutter 86 covers 36b, it exposes 36a and vice versa. It is possible also to make the section 36b of other lengths, modifying the opacity of the compensating track to obtain an average amount of light equal to that through vibrato track.

It is also within the scope of our invention to employe a tremolo track on a pitch disc for the purpose of introducing an amplitude tremolo in the output of a musical instrument employing a moving pitch-determining member. In Figure 12, are shown the essential elements of such a system. A tremolo signal picked up by a photocell 74 may be amplified in a suitable amplifier 75 and transmitted to the main amplifier 76 of a musical instrument of the photoelectric type indicated generally at 77. Variable control means, such as a potentiometer 78, may be used to determine the amount of amplitude tremolo which will be introduced into the tones produced by a loud speaker system 79.

It will be understood that a combination of the systems of Figures 3 and 12 will produce means for obtaining amplitude and frequency tremolo together or individually.

It is also within the scope of our invention to employ a discriminator circuit such as that of Figure 5 for constant speed control only, employing separate mechanical or electrical means for speed variation at a sub-audio rate. For example, a friction wheel and spring arrangement of the type disclosed in Figure 1 of Patent No. 2,474,847 to Edward M. Jones, issued July 5, 1949, may be employed, the driving motor shown therein not being required, of course.

It will also be obvious to those skilled in the art that numerous other modifications can be made in our invention without departing from the spirit of it. Having thus described our invention in certain exemplary embodiments, what we claim as new and desire to secure by Letters Patent is:

1. In an instrument for the production of musical tones, a moving member having pitch determining means thereon, motive means for said member, a source of power for said motive means, a tremolo track on said member and an electric system associated with said track for introducing a tremolo into said tones.

2. In an instrument for the production of musical tones, a moving member having pitch determing means thereon, motive means for said member, a source of power for said motive means, a tremolo track on said member and an electric system associated with said track for introducing a tremolo into said tones, wherein variations in current in said electric system, produced by said tremolo track, cause periodic variations in the speed of said moving member at a tremolo rate.

3. In an instrument for the production of musical tones, a moving member having pitch determining means thereon, motive means for said member, a source of power for said motive means, a tremolo track on said member and an electric system associated with said track for introducing a tremolo into said tones, including a light source, a photocell connected in said system and located in a position to receive light from said source as modulated by said tremolo track at a tremolo rate.

4. In an instrument for the production of musical tones, a moving member having pitch determining means thereon, motive means for said member, a source of power for said motive means, a tremolo track on said member and an electric system associated with said track for introducing a tremolo into said tones, including a light source, a photocell connected in said system and located in a position to receive light from said source as modulated by said tremolo track at a tremolo rate, including shutter means having an intercepting and a non-intercepting position

with respect to said light and actuating means for moving said shutter means between said positions.

5. In an instrument for the production of musical tones, a moving member having pitch determining means thereon, motive means for said member, a source of power for said motive means, a tremolo track on said member and an electric system associated with said track for introducing a tremolo into said tones, wherein variations in current in said electric system, produced by said tremolo track, cause periodic variations in the speed of said moving member at a tremolo rate, including an additional track on said member having equally spaced gradations for producing a constant-speed control signal, the frequency of which is directly proportional to the speed of said moving member.

6. In an instrument for the production of musical tones, a moving member having pitch determining means thereon, motive means for said member, a source of power for said motive means, a tremolo track on said member and an electric system associated with said track for introducing a tremolo into said tones, including a light source, a photocell connected in said system and located in a position to receive light from said source as modulated by said tremolo track at a tremolo rate, including an additional track on said member modulating light from said source to produce in said system a constant-speed control signal, the frequency of which is directly proportional to the speed of said moving member.

7. In an instrument for the production of musical tones, a moving member having pitch determining means thereon, motive means for said member, a source of power for said motive means, a tremolo track on said member and an electric system associated with said track for introducing a tremolo into said tones, wherein variations in current in said electric system, produced by said tremolo track, cause periodic variations in the speed of said moving member at a tremolo rate, including an additional track on said member having equally spaced gradations for producing a constant-speed control signal, the frequency of which is directly proportional to the speed of said moving member, wherein said system includes a frequency responsive circuit in connection with a control circuit for said motive means, said frequency responsive circuit and said control circuit operating to translate frequency variations in said control signal into corresponding variations in the power supplied to said motive means from said source.

8. In an instrument for the production of musical tones, a moving member having pitch determining means thereon, motive means for said member, a source of power for said motive means, a tremolo track on said member and an electric system associated with said track for introducing a tremolo into said tones, said moving member comprising a disc having an electrically conductive rim, said motive means comprising a C-shaped and an E-shaped core respectively, located on either side of said rim and a winding located on each core, at least one of said windings being connected in said electric system controlled by said track.

9. In a system responsive to frequency changes in a relatively high frequency signal and responsive to instantaneous values of amplitude of a relatively low frequency signal, a network comprising two series resonant paths connected in parallel between two input terminals, the inductive element of one path being connected to one of the input terminals and the capacitive element of the other path being connected to the same input terminal, the resonant frequency of one of the paths being slightly above a reference frequency of the order of said relatively high frequency, and the resonant frequency of the other path being slightly below the reference frequency, and a voltage difference amplifier including two tube circuits for amplifying the difference between the voltage across the inductive element of one of said pairs and the voltage across the capacitive element of the other path, whereby departures in the frequency of said high frequency signal from said reference frequency and instantaneous values of amplitude of said lower frequency signals unbalance said amplifier and produce two unidirectional output potentials whose difference is proportional to said departures in frequency and to said instantaneous values of amplitude.

10. The combination claimed in claim 9, including a pair of control tubes, each having an anode, a grid and a cathode, a control transformer having a secondary winding, a center-tap thereof and a primary winding connected to a source of alternating current, the anodes of said control tubes being connected respectively to ends of said center-tapped winding, the two output potentials of said difference amplifier being applied to the grids of said control tubes, the cathodes of said control tubes being connected together, thus providing a control potential between said cathodes and said center-tap.

11. The combination claimed in claim 10, including an induction motor having two windings, a phase-shifting capacitor connected in series with one of said windings to said source of alternating current, the other of said windings being connected between said center-tap and said control tube cathodes, and a resistor connected between one end of said center-tapped winding and said cathodes, whereby a nominal torque may be exerted by said motor windings when said higher frequency signal is at said desired frequency but is changed therefrom by variations in said higher frequency signal and by instantaneous values other than zero of said lower frequency signal.

12. Combination claimed in claim 11, said induction motor having a rotor comprising a disc and means therein for determining the frequency of both said signals.

13. Combination claimed in claim 12, wherein said frequency determining means comprises tracks of the light-varying type, and including a light source, a photocell, and a second amplifier, said photocell being adapted to receive light from said source as modulated by said tracks for the production of said signals, said amplifier acting to amplify said signals for transmission to said network.

14. Combination claimed in claim 13, wherein said second amplifier has two stages of amplilcation and includes a high-pass filter between said stages and a potentiometer coupled to the output of said first stage, a tap of said potentiometer being connected through a resistor to the input of the second stage, whereby said relatively low frequency signal does not reach the second stage except as fed thereto by said potentiometer for control of the amplitude of said variations.

15. Combination claimed in claim 13, including a light shutter between said light source and said photocell, whereby the light modulated by one

of said tracks may be intercepted at will so as to provide control of the extent of speed variation.

16. A speed-variation amplitude control circuit comprising a photoelectric generator producing a relatively high frequency speed-control and a relatively low frequency speed-variation control signal, a two-stage amplifier for said signals, a filter between said stages passing only said high frequency signal, and a voltage divider coupled to the output of the first stage, a tap of said divider being connected through a resistor to the input of the second stage, whereby said low frequency signal does not reach the second stage except as fed thereto from said divider.

17. A system responsive to the frequency of a control signal, comprising a network having two series resonant paths connected in parallel between two input terminals, the inductive element of one path being connected to one of the input terminals and the capacitive element of the other path being connected to the same input terminal, the resonant frequency of one of the paths being slightly above a reference frequency and the resonant frequency of the other path being slightly below the reference frequency and two conversion circuits respectively in connection with and receiving the potentials across the inductive element of one of said paths and the capacitive element of the other of said paths, said circuits producing at least one unidirectional potential, the magnitude of which is a function of the difference between the control signal frequency and the reference frequency.

18. A system responsive to the frequency of a control signal, comprising a network having two series resonant paths connected in parallel between two input terminals, the inductive element of one path being connected to one of the input terminals and the capacitive element of the other path being connected to the same input terminal, the resonant frequency of one of the paths being slightly above a reference frequency and the resonant frequency of the other path being slightly below the reference frequency and two conversion circuits respectively in connection with and receiving the potentials across the inductive element of one of said paths and the capacitive element of the other of said paths, wherein said conversion circuits produce a pair of unidirectional potentials whose algebraic difference is positive, negative or zero depending upon whether said control signal frequency is respectively above, below or equal to the reference frequency.

19. A system responsive to the frequency of a control signal, comprising a network having two series resonant paths connected in parallel between two input terminals, the inductive element of one path being connected to one of the input terminals and the capacitive element of the other path being connected to the same input terminal, the resonant frequency of one of the paths being slightly above a reference frequency and the resonant frequency of the other path being slightly below the reference frequency and two conversion circuits respectively in connection with and receiving the potentials across the inductive element of one of said paths and the capacitive element of the other of said paths, wherein said conversion circuits produce a pair of unidirectional potentials whose algebraic difference is positive, negative or zero depending upon whether said control signal frequency is respectively above, below or equal to the reference frequency, including a transformer with a center-tapped secondary winding and primary winding connected to a power source, a pair of electronic tubes having grids biased respectively by said pair of unidirectional potentials, having anodes respectively in connection with ends of said secondary winding and having cathodes with a common connection to a bias source, whereby control energy is available between the center tap of said winding and said common connection to said cathodes.

20. A system responsive to the frequency of a control signal, comprising a network having two series resonant paths connected in parallel between two input terminals, the inductive element of one path being connected to one of the input terminals and the capacitive element of the other path being connected to the same input terminal, the resonant frequency of one of the paths being slightly above a reference frequency and the resonant frequency of the other path being slightly below the reference frequency and two conversion circuits respectively in connection with and receiving the potentials across the inductive element of one of said paths and the capacitive element of the other of said paths, wherein said conversion circuits produce a pair of unidirectional potentials whose algebraic difference is positive, negative or zero depending upon whether said control signal frequency is respectively above, below or equal to the reference frequency, including a transformer with a center-tapped secondary winding and a primary winding connected to a power source, a pair of electronic tubes having grids biased respectively by said pair of unidirectional potentials, having anodes respectively in connection with ends of said secondary winding and having cathodes with a common connection to a bias source, whereby control energy is available between the center tap of said secondary winding and said common connection to said cathodes, including a resistor connected between one end of said winding and said common connection, motive means having at least two windings, one of said windings being connected between said center tap and said common cathode connection, the other of said windings being connected to said power source through phase-shifting means causing the potential on said second winding to be substantially 90° out of phase with the potential of said first winding.

21. A motive and speed control system for a pitch disc, comprising an annular armature mounted peripherally on said disc, a stator structure having an air gap through which some portion of said armature passes upon rotation of said pitch disc, two windings for said stator, signal producing means associated with said pitch disc, the frequency of the signal thereby produced being proportional to the speed of said disc, a discriminator circuit receiving said signal and operative to feed to one of said windings a speed error voltage proportonal to the difference between the actual speed of said disc and a desired speed, and circuit means connected to a source of alternating current, said circuit means supplying a fixed voltage to the other of said windings and a second voltage to the first winding at substantially 90° from said fixed voltage, said second voltage being of such magnitude so as together with said fixed voltage to cause said stator structure to exert a force on the said armature sufficient to drive the disc at approximately a desired speed, said speed-error voltage being of the same or opposite phase as said second voltage depending upon whether said disc is rotating at a speed below or above said desired speed, whereby departures in speed of said disc from said desired speed are corrected.

22. A process of controlling the movement of a moving member having a drive to produce variations of movement about a fixed mean, which comprises causing the moving member to generate electrical oscillations of two diverse frequencies, feeding the higher frequency oscillations through a discriminator circuit to a control circuit for said drive whereby to fix said mean, and applying the lower frequency oscillations as such to said control circuit so as to make said drive responsive thereto.

23. In a speed regulating system, a motor having a control winding with two terminals, a center-tapped alternating current source, two control tubes having their respective anodes connected to said source, their respective grids connected to respective sources of unidirectional control potentials and their respective cathodes connected to a fixed potential source and to one terminal of said winding, the other terminal of said winding being connected to the center tap of said alternating current source, whereby the current through said winding is proportional to the algebraic difference between said potentials on said grids.

24. In a speed regulating system, a motor having a control winding with two terminals, a center-tapped alternating current source, two control tubes having their respective anodes connected to said source, their respective grids connected to respective sources of unidirectional control potentials and their respective cathodes connected to a fixed potential source and to one terminal of said winding, the other terminal of said winding being connected to the center tap of said alternating current source, whereby the current through said winding is proportional to the algebraic difference between said potentials on said grids, and including an impedance connected between one terminal of said alternating current source and one terminal of said winding to provide a nominal current through said winding.

25. The combination claimed in claim 6, wherein said system includes a frequency responsive circuit in connection with a control circuit for said motive means, said frequency responsive circuit and said control circuit operating to translate frequency variations in said control signal into corresponding variations in the power supplied to said motive means from said source.

26. The combination claimed in claim 25, said moving member comprising a disc having an electrically conductive rim, said motive means comprising a C-shaped core and an E-shaped core respectively, located on either side of said rim and a winding located on each core, at least one of said windings being connected in said electric system controlled by said track.

27. The system claimed in claim 21, including vibrato signal generating means associated with said pitch disc, the generated vibrato signal operating to cause periodic departures in the speed of said disc from said desired speed.

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