

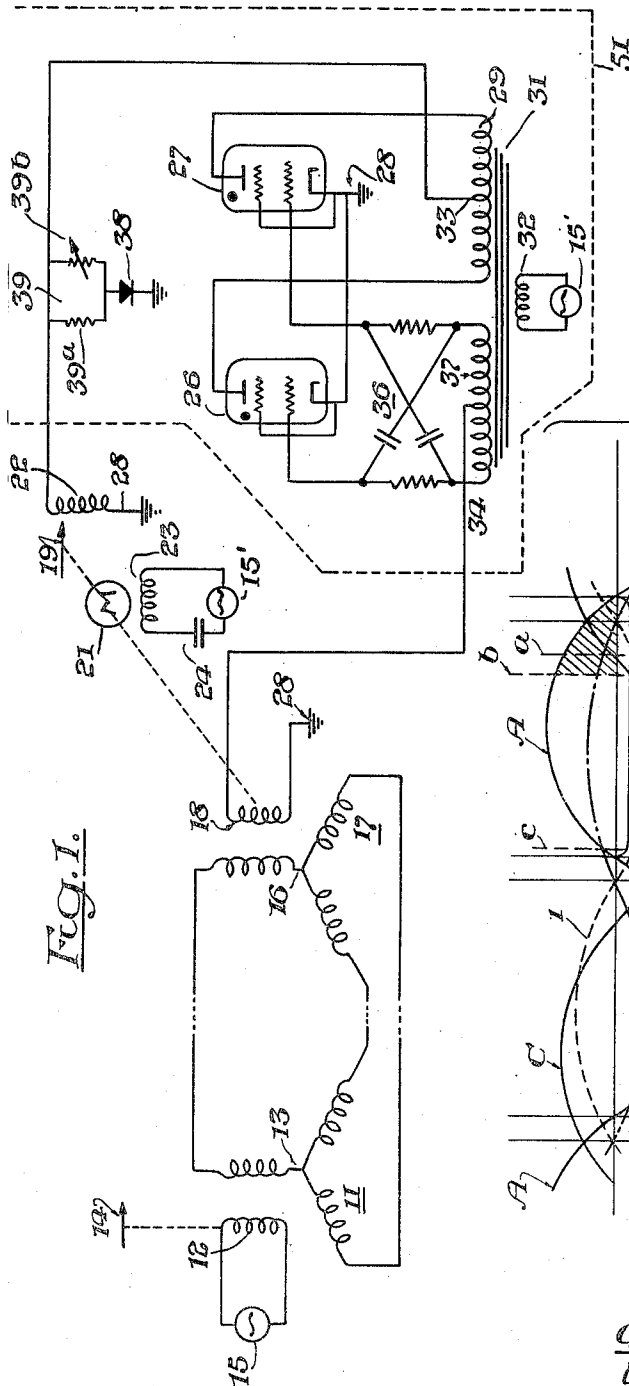
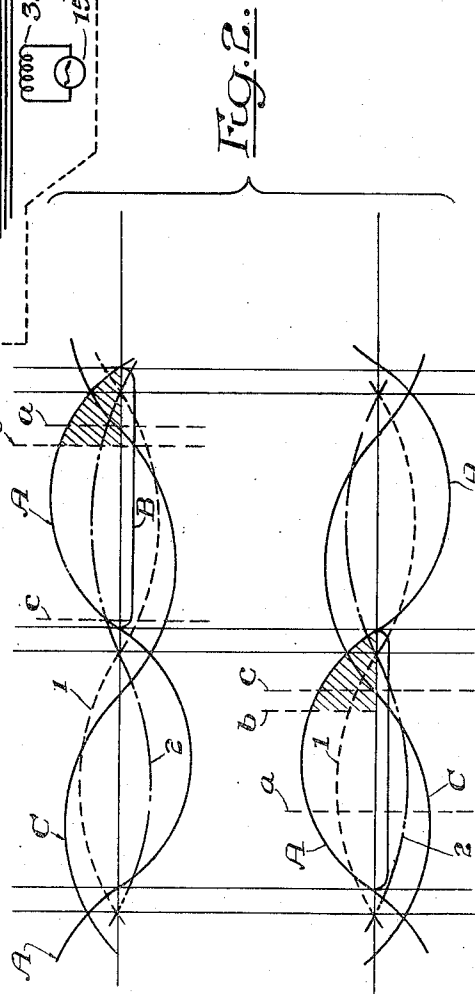
Oct. 7, 1952

G. L. TAWNEY
CONTROL CIRCUITS

2,613,341

Filed Aug. 8, 1951

2 SHEETS—SHEET 1



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2 SHEETS—SHEET 2

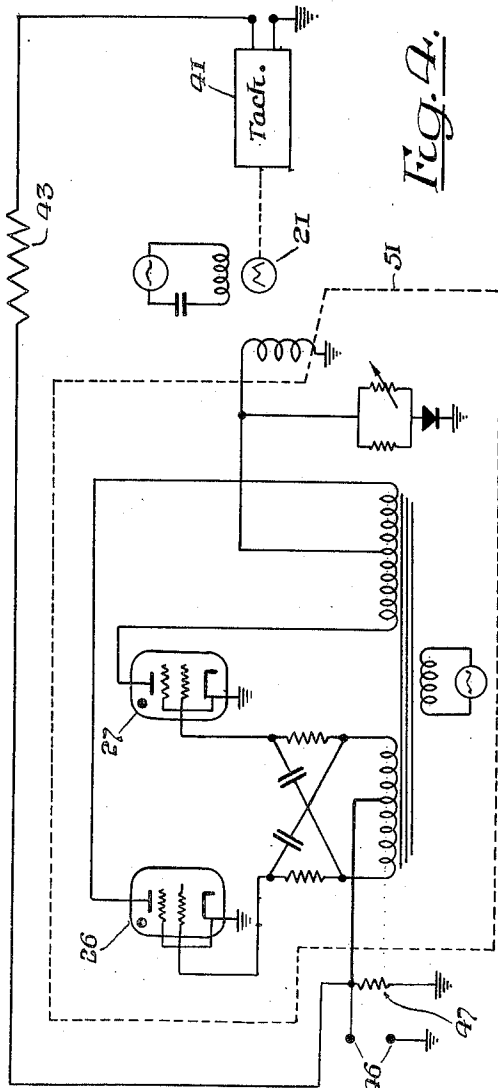


Fig. 4.

Fig. 5.

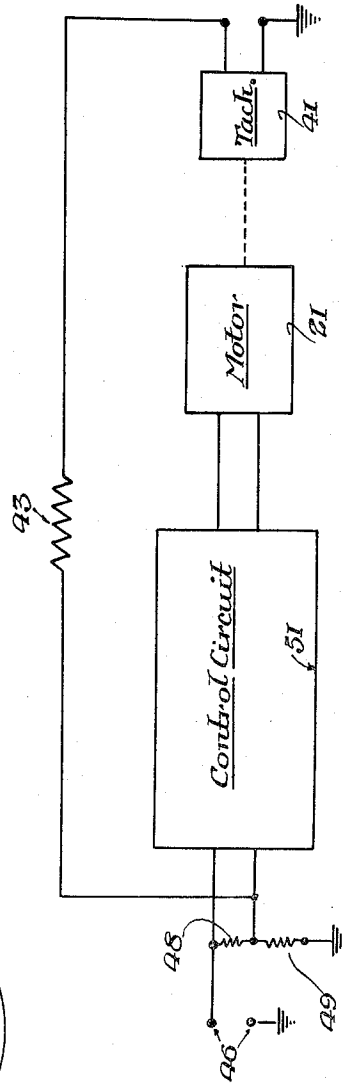
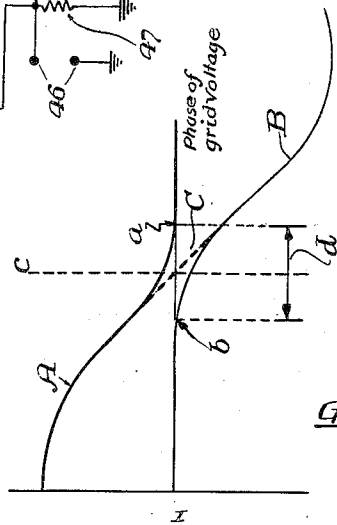


Fig. 3.



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CONTROL CIRCUITS

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8 Claims. (Cl. 318-30)

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The present invention relates to the art concerning control circuits such as are used in positional control systems, follow-up systems, servo systems, integrating systems and the like.

In systems for controlling the position or movement of a controlled object in correspondence with the position or movement of a local object or in response to an electrical signal, the use of motor-controlled circuits employing gas discharge tubes such as those known as thyratrons is widespread. However, known systems using such gas discharge tubes have suffered from a number of defects and disadvantages implicit in the characteristics of the gas discharge tube.

As is well known, a gas discharge tube such as of the thyatron type becomes conductive when its anode voltage is positive and when its grid voltage exceeds a predetermined critical firing value. In alternating current systems where such tubes are most frequently used, the control of the point of initiation of discharge or firing point of the tube has conventionally been determined by the phase of the alternating grid voltage relative to the phase of the anode voltage and to secure variable control it has been necessary to devise phase shifting circuits. Such circuits have proved uneconomical and cumbersome, especially where a wide range of variable control is desired.

In general, such gas discharge tube control circuits find considerable utility in controlling the operation of motors in response to control signals which may be derived from or correspond to the position or movement of a local member under whose control it is desired to actuate a remote object, or may be independently produced. In such systems thyratrons are useful because they can handle considerable amounts of power and thereby directly control an output motor without requiring excessive amounts of input power. However, in such systems the control signals normally are of fixed phase and vary in amplitude in accordance with the magnitude of the control effect desired, while the control of thyatron tubes circuits normally requires a variable phase signal. To adapt such circuits for control by variable amplitude signals has often required the use of extra tubes or circuit elements introducing further complexity and expense in the system. By the present invention however, these disadvantages are overcome and a thyatron type servo circuit is provided which is directly controlled by a variable amplitude fixed phase signal, with simplification in the operation and construction, and reduction in cost of such a circuit.

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A further disadvantage in the use of gas discharge tubes is that their control action is essentially nonlinear, since the output current varies in non-linear fashion with changes in the phase of the grid voltage. In addition, such gas tube circuits tend to be least sensitive under the conditions where control voltage is small, whereas in servo systems it is usually important that the greatest sensitivity occur exactly at the position of zero output, since it is at this position that the controlled object requires greatest response to changes in controlling action, to maintain it in the desired condition. These disadvantages of the conventional gas discharge tube circuits are also overcome by the present system in which the output is made substantially linear with respect to the input over a relatively wide range of control action and the sensitivity at or near zero output is increased.

Another feature of the present invention resides in the use of a simple alternating current motor, preferably of the two-phase type, in a thyatron circuit, rather than relatively more complex direct current motors. This is made possible in the present case by reliance upon the sum of the currents passing through two thyratrons in a balanced connection, and rendering the motor responsive to the alternating current components of those currents, to yield a properly reversing type of control action.

Also, according to another feature of the present invention, an improved damping circuit is provided for preventing or reducing hunting or overshoot of the controlled object.

Accordingly, it is an object of the present invention to provide simplified gas discharge tube circuits which require a minimum number of parts, which have low cost, which provide substantially linear control action over a wide range of input values, which are directly responsive to variations of amplitude of an input control signal, which have increased sensitivity near the zero point, and which have improved motor damping.

The circuit of the present invention is also useful in a speed-control system, which may be used as an integrating means. According to another feature of the present invention, a motor output shaft is controlled in response to an input variable magnitude reversible-phase alternating current signal so that the velocity of the motor output is linearly proportional to the control signal amplitude with a direction of rotation corresponding to the phase-sense of the control signal. The system also eliminates any non-linearity which may be caused by the gas dis-

charge tube or circuit. In this way, the angle through which the motor output shaft is rotated is the time integral of the control signal.

These and other advantages and objects of the present invention will become more readily apparent from a consideration of the following detailed description of illustrative embodiments of the present invention, taken in conjunction with the appended drawings wherein

Fig. 1 is a schematic circuit diagram of a positional control system embodying aspects of the present invention;

Figs. 2 and 3 are curves illustrating the principles of operation and advantages of the present invention;

Fig. 4 is a schematic circuit diagram of a modified form of the present invention including shunt-coupled anti-hunting feedback;

Fig. 5 is similar diagram with series-type feedback.

Referring to Figure 1 there is schematically shown a transmitter selsyn 11 having a rotor 12 and a stator 13, the rotor 12 being suitably positioned or rotated by a controlling member 14. The rotor 12 is excited from a suitable source of alternating current 15, while the stator 13 is coupled to the stator 16 of a receiver selsyn 17 having a rotor 18. The arrangement thus described produces an alternating signal in the receiver rotor 18 corresponding in amplitude and phase sense (polarity) to the magnitude and direction of deviation of the position of the controlling member 14 with respect to the position of the rotor 18. It will be understood that this system as thus far described represents merely one example of a source of control signal adapted to actuate the remainder of the circuit to produce the positioning of a controlled object 19 in correspondence with such signal, and any other type of control signal source may be used.

The controlled object 19 (for example, an indicator or an antenna) is mechanically coupled to the receiver selsyn rotor 18 and to an A. C. motor 21 of the two-phase type, such as an induction motor, having windings 22 and 23. Winding 23 is energized from a source of alternating current 15' (which is preferably the same source as source 15, or may be an independent source of the same frequency as and fixed in phase relative to source 15) through a phasing condenser 24. The other motor winding 22 is excited under the control of the alternating signal output of receiver rotor 18 by means of the circuit to be described, to actuate the motor 21 and hence the controlled object 19 to a position providing zero signal output from the rotor 18, whereby the controlled member 19 is positioned in correspondence with the signal and hence in correspondence with the controlling member 14. Phasing condenser 24 assures phase quadrature between the currents in the two windings 22, 23.

The control circuit is designed to require a minimum number of tubes and circuit components, and as shown comprises a pair of thyatron or other gas discharge tubes 26, 27. The cathodes of tubes 26, 27 are grounded at 28. The anodes are supplied with alternating potentials of opposite phase from the secondary 29 of a transformer 31 whose primary 32 is supplied from source 15'. As seen, each anode is coupled to a respective end of the secondary winding 29 of transformer 31 whose center tap 33 is connected through motor winding 22 to ground at 28. It will thus be apparent that the anode-to-cathode voltages of the tubes 26 and 27 are of opposite

phase and equal amplitude. The control grids of the tubes 26 and 27 are similarly supplied with equal alternating bias potentials of opposite phase by a further secondary winding 34 of transformer 31, to whose opposite ends the respective control grids are connected through a phase shifting network 36. The center tap 37 of winding 34 is connected through selsyn receiver rotor 18 to ground at 28. It will be obvious that secondary windings 29 and 34 could be provided by other transformer means, such as on separate transformers with separate primary windings excited from the same source.

The operation of the gas discharge tubes 26, 27 and the design of the circuit will be more clearly understood from consideration of Figures 2 and 3. In Figure 2 (a), the characteristics of one tube such as 26, are shown, while Fig. 2 (b) shows the characteristics of the other tube, such as 27. Considering one of these tubes, such as 26, as illustrated in Fig. 2 (a), a curve A shows the time graph of its anode voltage. As is well known, such a tube conducts only while its anode voltage is positive. At the same time, it will not conduct unless its grid voltage is more positive than a certain critical or firing voltage illustrated by curve B. Thus the tube will become conductive at a certain instant when, for its particular anode voltage, its grid voltage at the same instant is more positive than the corresponding ordinate of the grid firing voltage curve B. However, once the conduction starts in the tube, it will terminate only when the anode voltage diminishes to zero or reverses in polarity. Thus, the current conducted by the tube is in pulse form, each pulse occurring for an interval during the positive anode half cycle between the instant of firing and the instant the anode voltage drops to zero. If the grid voltage is as shown in curve C, the current pulse will occur during the cross-hatched interval shown.

This fundamental control action of gas discharge tubes is conventionally employed for control purposes by controlling the point at which conduction commences in such a tube, by shifting the phase of the grid voltage relative to the anode voltage. By thus controlling the phase of the grid voltage the portion of the positive half cycle of the anode voltage during which the tube is conductive may be readily controlled, thereby correspondingly controlling the average current passing through the tube, and this variable average tube current is employed for control purposes, as by controlling the operation of electric motors in response thereto. However, circuits for shifting the phase of such a grid voltage in response to the variation of the amplitude of a fixed phase alternating signal, such as the signal derived from receiver rotor 18, have been quite complex. The present invention provides an extremely simple circuit directly responsive to the variation in amplitude of the fixed phase alternating signal from rotor 18, as will be shown below.

Furthermore, as also shown below, the present invention does not rely upon the average tube current, which would require a D. C. motor, but instead utilizes the alternating component of the tube current. As will readily be appreciated, a pulse current such as this is effectively a constant direct current upon which is superposed an alternating current having the same fundamental frequency as the anode and grid voltages. It is this alternating current component which is utilized in the present system, as shown below.

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It will be understood that the operation of the other tube, such as 27 is similar. However, its anode voltage A (Fig. 2 (b)) is in phase opposition to that of tube 26. Hence if the grid voltage is as at C in Fig. 2 (b), which is in phase opposition to that of tube 26 as shown in Fig. 2 (a), the conductive period for tube 27 will be the cross-hatched area in Fig. 2 (b), which is exactly 180 electrical degrees displaced from the corresponding period for tube 26 shown in Fig. 2 (a). Hence the fundamental alternating current component of the tube 27 current will be in phase opposition to that for tube 26, which phenomenon is also utilized in the present system.

By means of the phase-shifting network 36, the voltages impressed on the grids of tubes 26 and 27 from the transformer winding 34 are shifted in phase relative to the corresponding anode voltage of each tube. These grid bias voltages are shown in curves C of Figures 2 (a) and 2 (b). The phase shift network 36 is a particularly simple and inexpensive way of assuring equal phase shift between grid and anode voltages of the two tubes.

The phase shift produced by network 36 is so chosen that, in the absence of any signal from rotor 18, each of tubes 26 and 27 will conduct for brief and equal portions of the cycle. These periods of conduction at zero signal (shown cross-hatched in Figures 2 (a) and 2 (b), may be of the order of 10 to 60 electrical degrees out of the total of 360 electrical degrees per cycle or 180 electrical degrees per half cycle of positive anode voltage.

The purpose of this zero signal conduction is to improve the linearity of response of the control circuit, especially at the neighborhood of the zero signal point. This is illustrated in Figure 3, which shows in solid line at A a curve of current passing through a gas discharge tube as a function of the phase of its grid voltage. Near the zero conduction point *a* it will be seen that the characteristic curve is far from linear. Curve B shows the same characteristic for the other tube. It too has a non-linear form near its zero conduction point *b*. Curve C is below the axis since, as indicated above, the fundamental frequency alternating component of current through tube 27 is of opposite phase from that for tube 26.

The effect of these non-linearities is overcome according to the present invention by arranging the system so that the zero control signal point is not the same as the zero conduction point. Rather, the zero signal point is chosen at *c*, at approximately the center of the lower non-linear portions of both curves A and B, at which the currents from the two tubes are equal. Being of opposite phase, these currents cancel so far as their effect on motor 21 is concerned. The resultant current characteristic (which is the motor winding current) will then be as shown by the heavy dotted line C, which merges into the essentially linear portions of curves A and B, to provide wide range linear control.

To obtain this desired characteristic, phase shift network 36 is designed to produce equal current through tubes 26 and 27 at zero control signal. This requires a phase shift for the grid bias voltage of from 10 to 60 degrees leading with respect to the reversed anode voltage. This is the same as lagging the actual anode voltage by 170 to 120 degrees. A suitable value has been attained by using resistance R equal to 1.5 megohms and capacitance C of .0047 microfarad, in network 36, when using type 2D21 thyratron tubes 26 and

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27 at a line frequency of 60 cycles per second, producing a phase shift of 45 degrees relative to the reversed anode voltage. This is shown approximately by curves C in Figs. 2 (a) and 2 (b).

The control signal derived from rotor 18 is now added to the bias voltage represented by curves C of Figure 2. It will be seen that this control signal is superposed in like phase upon the oppositely phased bias voltages, so that it renders one control grid more positive during the period of positive anode voltage on that tube while it renders the other control grid more negative during positive voltage periods of its anode. The control signal is made to have a phase leading the reversed anode voltage by from zero degree to a value equal to a portion of the bias voltage phase angle, as shown by curves 1 and 2 of Figures 2 (a) and 2 (b), which represent different control signals corresponding to different relative positions of the controlled and controlling members 19 and 14. As seen in Figure 2, these signals have fixed phase, but variable amplitude and reversing polarity. In one example, the bias voltage phase was 45 degrees leading, and the control signal phase was 14 degrees leading, with respect to the reversed anode voltage. Under these conditions the zero signal conduction angle was 48° and linearity was excellent.

Considering first the control signal shown in curve 1, which is cophasally applied to both tubes, as shown in Figs. 2 (a) and 2 (b), at the point of the cycle where the amplitude of the control signal is equal to the difference between the grid bias amplitude and the grid firing voltage, the tube will begin to conduct. This is shown at the vertical dotted lines *a*. In Fig. 2 (b), the tube conducts for a major portion of its positive anode half cycle. For the tube of Fig. 2 (a), conduction is a very small part of its period, thereby yielding a larger net current from the Fig. 2 (b) tube. If the control signal amplitude is increased, the Fig. 2 (b) tube will begin to conduct even earlier, and the Fig. 2 (a) tube later, causing a greater net current. As the control signal amplitude decreases, the reverse takes place until, for zero control signal, the two tubes begin conducting at lines *b*, yielding equal and opposite currents. As the control signal reverses polarity and increases in amplitude, the Fig. 2 (a) tube conducts earlier and the Fig. 2 (b) tube later, as shown by curve 2 and lines *c*. By choosing the phase shift between the control signal and the anode voltage (as by use of a phase shifting network where desired) and retaining equal and opposite currents at zero control signal, the relationship between the total output current and the control signal can be determined so as to yield an essentially linear characteristic such as shown in curve *c* of Figure 3.

As a result, the fundamental current component flowing in the winding 22 of motor 21 will have an amplitude substantially linearly related to the control signal derived from rotor 18 and of a polarity corresponding to the polarity (or phase-sense) of the control signal. As is well known, such a current in one winding 22 of a two-phase motor 21 having a substantially quadrature-phase current in the other winding will produce rotation of the motor in a direction corresponding to the polarity of the signal supplied to winding 22 and with a velocity substantially proportional to the magnitude of that signal. Motor 21 is coupled to rotor 18 to rotate rotor 18 in a direction reducing the control signal derived from rotor 18.

Motor 21 will therefore stop at the point where winding 22 has zero signal supplied to it. At this point motor 21 and controlled object 19 will be positioned in exact correspondence with the controlling member 14 and the signal from rotor 18 as is desired.

For providing a simple type of highly useful damping for motor 21, use is made of the direct current component of the tube currents, and the circuit is arranged to provide a desired amount of direct current component in the motor winding. In Figure 1 this is done by rectifier 38 connected in series with a variable resistance 39 across the winding 22. The resistance 39 is formed by a fixed resistor 39a in parallel with a variable resistor 39b to obtain sensitive adjustment control, and is adjusted to provide the desired degree of damping. Rectifier 38 is poled so that it will not conduct current flowing through tubes 26 and 27, which current is fed entirely to the motor winding 22. However, when the tube 26 or 27 cuts off, the induced electromotive force in winding 22 is then of the proper polarity to pass current through rectifier 38. The flow of direct current in winding 22 is still the same, however, so that rectifier 38 serves to maintain direct current flow in the motor winding even during the tube cut-off periods. This direct current provides a magnetic field drag on the armature of motor 21 proportional to the armature velocity and thereby has the same effect as viscous damping.

Figure 4 illustrates a circuit similar to that of Figure 1, but adapted to produce an output speed linearly proportional to an input control voltage, independent of the amplifier characteristics. In Fig. 4, a control voltage is supplied to terminals 46, to which is connected a circuit 51 identical with the circuit of Fig. 1, and including tubes 26 and 27 and their associated circuit elements. The output of circuit 51 is coupled to motor winding 22, as in Fig. 1. In addition, mechanically coupled to the motor 21 is a tachometer 41 of conventional type having an output 42 at which is produced an alternating voltage of an amplitude proportional to the speed of rotation of motor 21 and of the line frequency. The phase of the tachometer output is preferably chosen as cophasal with the control signal. This output is supplied over a resistor 43 to the input 46 of the control circuit. Thus, the control signal, which may be the output from a selsyn or may be any other signal, is applied to terminals 46, across which is an input resistor 47 to whose high potential end is applied the feedback signal from resistor 43. In this circuit, the feedback signal is in shunt with the control signal, and is coupled degeneratively thereto. Resistor 43 is selected or adjusted to provide the desired amplitude of feedback signal to give the desired feedback, such as for minimizing hunting or jitter of motor 21 or any object connected therewith.

The manner in which this circuit eliminates non-linearity due to the circuit will now be shown. If the ratio of the output speed to the total input to circuit 51 is designated as u , and the ratio of the feedback voltage appearing at 47 to the output speed is designated by B , then in accordance with well known feedback circuit theory, the overall gain or ratio of output speed to the input control signal at 46 is given by

$$\frac{u}{1+uB}$$

By making uB much larger than unity, this becomes

$$\frac{1}{B}$$

But B is a characteristic of the tachometer alone, and such tachometers are available which are accurately linear in their speed-output characteristics. Hence the overall gain, or output speed vs. input control voltage is made linear by depending solely on the tachometer for linearity, and by eliminating the circuit as a distorting factor.

Since the speed of the motor is thus linearly proportional to the control signal, it will be apparent that the angle through which the motor turns is thus proportional to the time integral of the control signal, and the system of Fig. 4 can be used as an integrating means.

It will be understood that the system of Fig. 4 can also be used to position the motor in correspondence with the control signal, by providing repeat-back means for reducing the control signal as the motor turns, until a stable condition is reached with the control signal reduced to zero. One example of such a means is shown in Fig. 1, although many others are also known. In such case the tachometer aids in preventing hunting or over-shooting.

Fig. 5 shows a further circuit, here using series degenerative feedback from tachometer 41. In this case, connected across control signal input terminals 46 are two resistors 48 and 49 in series. The control circuit 51 is coupled across resistor 48, while the feedback signal is placed in series therewith by being coupled across resistor 49. Otherwise Fig. 5 is the same as Fig. 4.

While the present invention has been described illustratively with respect to a control signal derived from a selsyn system, it will be understood that it is not limited thereto, but may be used with any source of alternating control signal of fixed reversible phase and variable magnitude.

Since many other apparently widely differing embodiments of the invention are possible without departing from the spirit thereof, the above description is to be considered as illustrative only, and is not to be construed as limiting the invention, which is defined solely by the appended claims.

What is claimed as the invention is:

1. A control circuit for actuating a two-phase motor having a pair of windings in correspondence with a reversible-phase variable magnitude alternating control signal, comprising a pair of gas discharge tubes each having an anode, a cathode and a control grid, the cathodes being interconnected, a source of fixed-magnitude alternating voltage, transformer means excited by said fixed voltage source and having a first secondary winding having a center tap, the outer terminals of said secondary winding being directly connected to said anodes to apply respectively equal antiphasal voltages thereto, said transformer means having a second secondary winding having a center tap, a phase-shifting network coupling the outer terminals of said second secondary winding to said control grids to apply equal antiphasal bias voltages to said grids respectively leading said anode voltages reversed by a phase angle of between 10 and 60 electrical degrees and of a magnitude producing equal currents through said tubes in the absence of any other grid voltages applied

thereto, one winding of said motor being coupled between said first secondary winding center tap and the cathodes of said tubes, the other of said motor windings being excited from said fixed source substantially in phase quadrature to the excitation of said first winding, and said control signal being adapted to be applied between said second secondary winding center tap and said cathodes with a phase angle leading one of said reversed anode voltages by less than the phase angle of said leading bias voltages relative to their reversed anode voltage.

2. A control circuit as in claim 1 further including means responsive to rotation of said motor for reducing the magnitude of said control signal whereby said motor assumes a position corresponding to the value of said control signal before reduction thereof.

3. A control circuit for actuating a two-phase motor having a pair of windings in correspondence with a reversible-phase variable-magnitude alternating control signal, comprising a source of fixed alternating voltage coupled to one of said windings, a pair of gas discharge tubes each having an anode and a control grid, transformer means excited by said source of fixed alternating voltage and having a secondary winding with a center tap, the outside terminals of said secondary winding being coupled respectively to said control grids to provide bias voltages therefor, said reversible-phase variable-magnitude control signal being fed to said center tap, said transformer means having a second secondary winding with a center tap, the outside terminals of said second secondary winding being coupled respectively directly to said anodes, and the other winding of said motor being coupled to said second center tap, whereby said two tubes are excited cophasally by said control signal and said motor is controlled by the sum of the currents through said tubes.

4. A control circuit as in claim 3, further including means comprising a phase-shifting network for causing each of said bias voltages to lead its respective anode voltage reversed by respective phase angles producing equal currents through said tubes in the absence of said control signal.

5. A control circuit as in claim 4 wherein said control signal has a phase-angle leading one of said reversed anode voltages by between zero degree and a value less than the lead angles of said bias voltages.

6. A motor control circuit, comprising a two-phase motor having a pair of windings, one of said windings having fixed excitation, a pair of gas discharge tubes having input and output electrodes, means exciting said input electrodes cophasally with a control signal, means exciting said same input electrodes anti-phasally by biasing voltages, means exciting said output electrodes

anti-phasally, the other of said windings being coupled to said tubes in a parallel circuit arrangement to be excited by the sum of the currents in said tubes, said bias voltages having phases respectively leading said output electrode voltages reversed, said control signal having a phase leading one of said reversed output electrode voltages, and being of reversible-phase and variable magnitude.

7. A control circuit for actuating a motor having a variably excitable winding in correspondence with a reversible-phase variable-magnitude control signal, comprising a pair of gas discharge devices having input electrodes and output electrodes, means for exciting said output electrodes with respectively equal fixed antiphasal alternating voltages, means for exciting said input electrodes by respectively equal fixed antiphasal bias voltages adapted to produce equal currents through said gas discharge tubes having fundamental frequency alternating components of opposite phase, means coupling said motor winding to said tubes to be excited by the sum of said current components through said tubes, and means for exciting said same input electrodes cophasally by said control signal, said control signal being phase-displaced with respect to one of said anode voltages.

8. A control circuit for a two-phase motor having a pair of windings comprising a source of alternating voltage coupled to one of said windings, a pair of gas discharge tubes each having an anode and a grid, a transformer having a primary winding excited from said source and a secondary winding having a center tap, said anodes being directly coupled to respective ends of said secondary winding, and said second motor winding being coupled to said center tap to be excited by the sum of the currents through said tubes, means for applying equal alternating bias voltages anti-phasally to said grids, and means for applying a control signal cophasally to said same grids.

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