July 26, 1960 W. R. PECK 2,946,942

THYRATRON CONTROL SYSTEM

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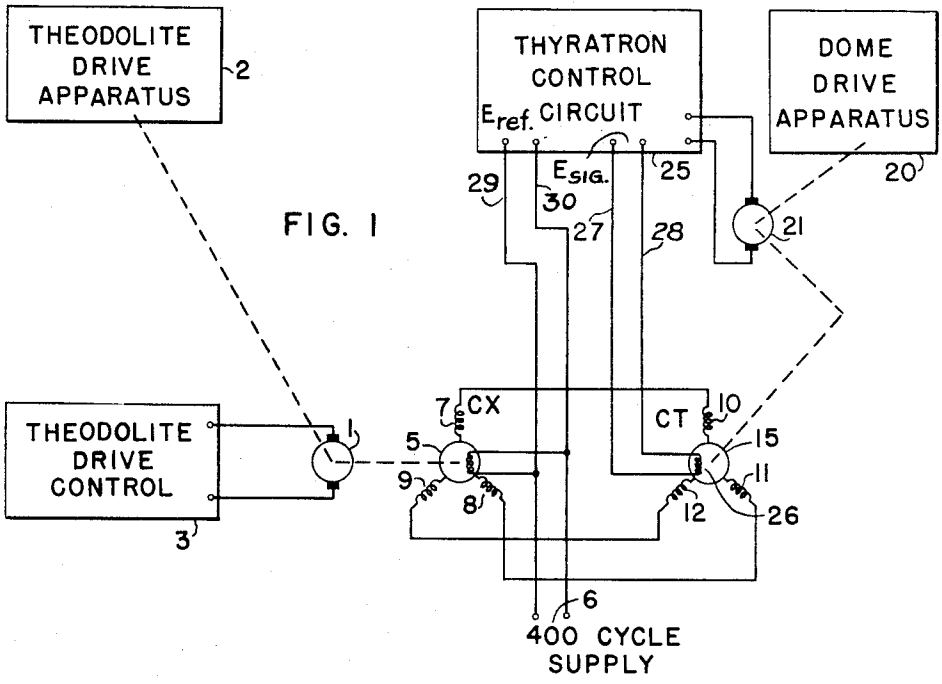


FIG. 1

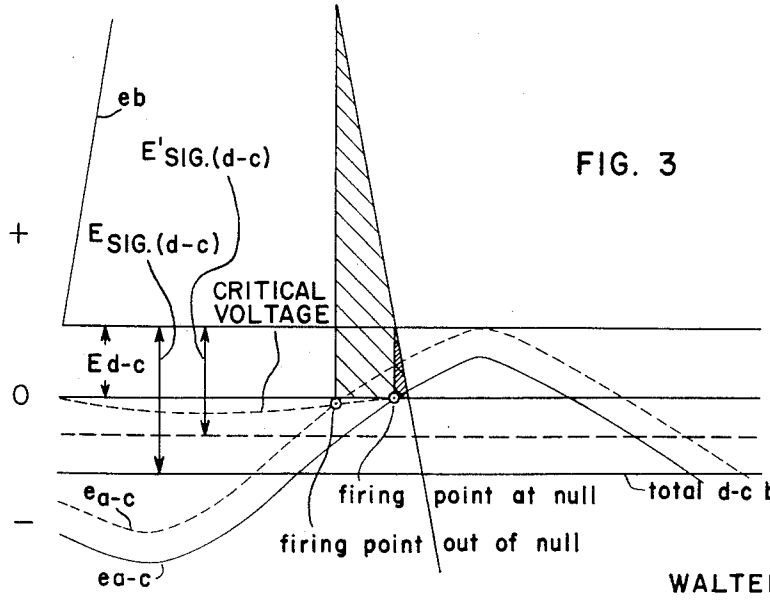


FIG. 3

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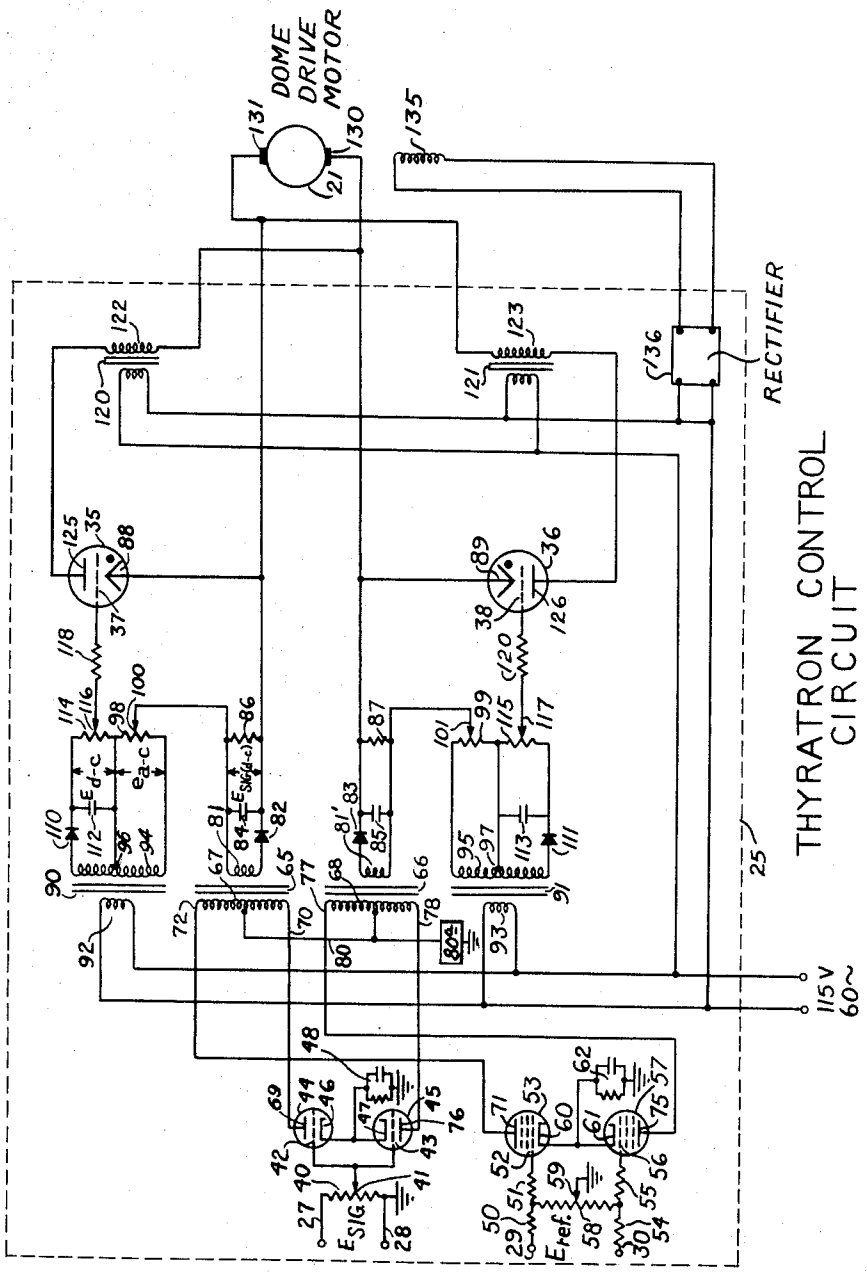
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FIG. 2



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THYRATRON CONTROL SYSTEM

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12 Claims. (Cl. 318—293)

This invention relates to a thyratron control system, and, more particularly, to a method and apparatus for controlling a thyratron circuit to vary the output current thereof.

Thyratron circuits have been extensively used in industrial electronic control, and have been particularly useful in conjunction with controlling the degree and direction of movement of motors. As is well known, a thyratron is a grid-controlled gas discharge tube which has the characteristics of "firing," or conducting current, only when its control grid voltage reaches a critical level, and of continuing conduction until its plate voltage decreases to substantially zero. As a result of this characteristic, the thyratron is subject to rather precise control, and the portion of a cycle of plate voltage within which the tube conducts can be varied from cycle to cycle.

One of the problems often met in design of thyratron control circuits is that the signal voltage which is to be used to control firing of the thyratron often is of a different frequency or phase from the frequency and phase of the plate voltage. For instance, when synchro systems or servo-mechanisms, are used to control the firing of thyratrons, the signal voltage of the synchro which is applied to the thyratron circuit is ordinarily of a different frequency than the supply mains voltage used as a source of plate voltage for the thyratron. In such a situation, if the control or signal voltage were applied directly to the thyratron grid, the conduction time would vary from cycle to cycle out of the control of the operator or of the controlling device. Since this is obviously disadvantageous, several solutions to the problem of making the signal voltage and the thyratron plate voltage of the same or of controllable phase relation, have been proposed. One of these solutions is to rectify the signal voltage, and then convert the resulting D.-C. voltage into an A.-C. voltage by use of a so-called "chopper," the latter being controlled by the same source of voltage which supplies the thyratron plate. This solution, and the others of which applicant is aware, require rather extensive and expensive additions to the thyratron control circuits. The present invention is designed to avoid following the solutions previously proposed, and to decrease the cost and complexity of the thyratron control circuit.

The method of the present invention includes the steps of obtaining an A.-C. signal voltage, comparing this A.-C. signal voltage with an A.-C. reference voltage having the same frequency as the signal voltage and of constant phase to obtain a comparison voltage, rectifying the comparison voltage to obtain a D.-C. signal voltage, and combining with the D.-C. signal voltage and A.-C. bias voltage of constant frequency and controllable phase relation with the A.-C. plate voltage of the thyratron, and also combining with the A.-C. bias and D.-C. signal voltages a D.-C. bias voltage to set the D.-C. bias of the thyratron grid at an appropriate level below the critical voltage. Thus, the only A.-C. voltage which is supplied to the grid of the thyratron is one which has a constant, or controlled phase relation with the plate voltage, yet it is not necessary to go through the complex procedure of, for instance, rectifying the signal voltage and then converting it back into an alternating current voltage of constant phase relation to the plate voltage.

The present invention is particularly useful in conjunction with an apparatus disclosed in a co-pending application filed by Edward L. Morgan, entitled "Protective Housing," and assigned to the same assignee as the present invention. The Morgan application has been given Serial Number 521,730, and was filed July 13, 1955, now Patent No. 2,846,962. The Morgan application discloses a protective housing or dome for a photo-theodolite. Reference is made to the Morgan application for a full understanding of the features of the protective housing, and suffice it to state herein that the Morgan apparatus includes a motor drive system which is designed to drive a pinion in mesh with a gear carried by the housing. The housing is caused thereby to rotate with the motor, and, through use of a circuit to be described specifically in this application, the motor for the housing is caused to track with the motor which drives the theodolite.

The method and apparatus of the present invention will now be more fully described in conjunction with a specific embodiment of the invention shown in the accompanying drawings.

In the drawings:

Fig. 1 is a schematic diagram, partly in block form, showing the relative connections between the theodolite drive apparatus, the thyratron control circuit, and the dome drive apparatus;

Fig. 2 is a schematic diagram of the elements of the thyratron control circuit of Fig. 1; and

Fig. 3 is a graphic representation of the control of one of the thyratrons of Fig. 2, showing the control grid voltage in comparison with the plate voltage of the thyratron.

In Fig. 1, a drive motor **1** rotates a theodolite drive apparatus **2** to cause movement of a photo-theodolite (not shown). Reference is made to an article titled "New Tracker Pinpoints Missiles," Aviation Week, September 13, 1954, for a disclosure of the essential characteristics of the photo-theodolite.

Drive motor **1** is controlled by a theodolite drive control circuit **3** which need not be specifically described in this application. Suffice it to state here that the drive control circuit **3** causes movement of the shaft of motor **1** to turn the theodolite drive apparatus and thereby rotate the theodolite. Since the viewing means and camera of the theodolite project through slots in the protective housing of the Morgan application, it is desired to rotate the housing in synchronism with rotation of the theodolite itself. A circuit to accomplish this effect will now be described.

The shaft of motor **1** drives the rotor of a control transmitter type synchro unit **5** identified with the letters CX in Fig. 1. The rotor coil of the synchro is supplied with 400 cycle voltage from a supply identified at **6** in Fig. 1. As a result of this supply and the driving connection, the three stator coils **7**, **8** and **9**, of the synchro develop voltages thereacross whose relative magnitudes and polarities uniquely define the angular position of the shaft of the synchro with respect to the stator thereof. Stator coils **7**, **8** and **9** are connected to corresponding stator coils **10**, **11** and **12**, of a control transformer type synchro **15**, identified as CT in Fig. 1.

The apparatus which it is desired to control in synchronism with the theodolite drive apparatus **2** is identified in block form at **20** in Fig. 1 and labelled "Dome

Drive Apparatus." This apparatus is driven by a motor 21 which may be a shunt-wound D.-C. motor whose rotational speed is controlled by the magnitude of the voltage applied across its armature leads, and whose direction is controlled by the direction of the current flowing between the armature leads. Control of the direction of rotation of the motor 21 and of the extent of movement thereof is had by use of a thyratron control circuit identified at 25 and shown in block form in Fig. 1. Motor 21 drives the control transformer synchro 15, thus causing a voltage to be developed across rotor coil 26 of the synchro which is proportional to the sine of the difference between the angle defined by the voltages supplied to its stator leads, and the angular position of the shaft of the synchro with respect to its stator. This voltage is supplied to the thyratron control circuit across leads marked 27 and 28, the voltage thereacross being labelled $E_{SIG.}$ in Fig. 1.

As will be explained hereinafter, as part of the procedure of controlling the thyratron control circuit 25 of Fig. 1, the signal voltage $E_{SIG.}$ is compared with a reference voltage $E_{ref.}$ having the same frequency as the signal voltage and of constant phase. This voltage is derived from the 400 cycle supply 6 of Fig. 1 and is connected to the thyratron control circuit by leads 29 and 30.

With the apparatus of Fig. 1, as long as the thyratron control circuit supplies an output current for the motor 21 which varies in value and in phase with the extent and direction of movement of motor 1, motor 21 will be driven in synchronism with motor 1.

Referring now to Fig. 2, the thyratron control circuit 25, more specifically, includes a pair of thyratrons 35 and 36. The circuit to supply an appropriate control voltage for the grids 37 and 38, respectively, of the thyratrons, will now be described. The A.-C. signal voltage of 400 cycles, $E_{SIG.}$, is supplied across leads 27 and 28, which are connected across a potentiometer 40 having a slider 41, and having the end connected to lead 28 grounded. Slider 41 is connected to the control grids 42 and 43 of a pair of vacuum triodes 44 and 45, respectively. Cathodes 46 and 47 of the triodes are connected together, and through an R–C D.-C. bias circuit 48, to ground. Consequently, a varying voltage proportional to the A.-C. signal voltage is developed between each of the plates of tubes 44 and 45 and the cathodes thereof.

As explained above, the 400 cycle reference voltage is conducted to the thyratron control circuit by a pair of leads 29 and 30. Lead 29 is connected through a pair of voltage-dropping resistances 50 and 51, to grid 52 of a pentode vacuum tube 53. Lead 30 is connected through a similar pair of voltage-dropping resistances 54 and 55 to the control grid 56 of another pentode 57. A potentiometer 58 is connected between the junction points of the pairs of voltage-dropping resistances, and the slider 59 of the potentiometer is connected to ground. The cathodes 60 and 61 of the pentodes are connected through the conventional R–C bias circuit 62 to ground. The screen and suppressor connections of the pentodes need not be more fully described, since they are of conventional type. As a result of these connections, a voltage of one phase varying in proportion with the A.-C. reference voltage is developed between plate and cathode of pentode 53, and a voltage of the opposite phase, likewise varying with the reference voltage, is developed between plate and cathode of pentode 57.

In order to permit comparison of the output voltages derived from triodes 44 and 45, and pentodes 53 and 57, a pair of transformers 65 and 66, having center tapped primary windings 67 and 68, respectively, is provided. Plate 69 of triode 44 is connected to one lead 70 of primarly 67, while plate 71 of pentode 53 is connected to the opposite lead 72 of the primary. Also, plate 75 of pentode 57, and plate 76 of triode 45, are connected to opposite leads, 77 and 78, respectively, of primary 68. The center taps of the two primaries are connected together by lead 80 and are connected to a suitable source of plate voltage source 80^a which source is, as usual, connected between plate and ground of each of the four vacuum tubes.

Each of transformers 65 and 66 has a secondary, 81 and 81', respectively, so that an A.-C. voltage proportional to the difference between the A.-C. signal voltage $E_{SIG.}$ and the A.-C. reference voltage $E_{ref.}$ of one phase is developed across secondary 81, while an A.-C. voltage proportional to the difference between $E_{SIG.}$ and $E_{ref.}$ of the opposite phase developed across secondary 81. These A.-C. comparison voltages are rectified and filtered by the combination of rectifiers 82 and 83, in series with the two secondaries 81 and 81', respectively, and by capacitors 84 and 85, connected across the series combination of the secondary coils and the rectifiers. The D.-C. voltages of these circuits are developed across a pair of resistors 86 and 87, thus furnishing a pair of voltages labelled $E_{SIG.(d-c)}$. The positive end of resistor 86 is connected to filament or cathode 88 of thyratron 35, while the positive end of resistor 87 is connected to filament or cathode 89 of thyratron 36.

In order to provide for appropriate control of the thyratron grid to cathode circuits, it remains to provide an A.-C. bias voltage, and a D.-C. bias voltage, for each circuit. To provide these voltages, a pair of transformers 90 and 91, having primaries 92 and 93, respectively, are connected to the usual power mains, which may conveniently supply 115 volts, 60 cycle power. The secondaries 94 and 95 of transformers 90 and 91 are center tapped at 96 and 97, respectively. A potentiometer 98 is connected directly across the lower half of secondary 94 of transformer 90, while a potentiometer 99 is connected directly across the upper half of secondary 95 of transformer 91. Consequently, A.-C. bias voltages are developed across these potentiometers, and the levels of bias voltage to be used in the grid-cathode circuits of the triodes are selected by sliders 100 and 101 of potentiometers 98 and 99, respectively. It will be noted that opposite halves of secondaries 94 and 95 are used to develop the A.-C. bias voltages, so that the two A.-C. voltages supplied to thyratrons 35 and 36 will be of opposite phase.

To provide the D.-C. bias voltage for each of the thyratrons, the other halves of secondaries 94 and 95 are provided with rectifying and filtering elements including rectifiers 110 and 111, respectively, and capacitors 112 and 113. The shunt-connected filter capacitors 112 and 113 are connected in parallel with potentiometers 114 and 115, respectively, thus developing a D.-C. voltage thereacross. The connections of rectifiers 110 and 111 are such that the sliders 116 and 117 of potentiometers 114 and 115, respectively, are negative with respect to the cathodes of the corresponding thyratrons. Potentiometer slider 116 is connected through an appropriate voltage dropping resistance 118 to control grid 37 of thyratron 35, and potentiometer slider 117 is connected through a similar resistor 120 to control grid 38 of thyratron 36.

As a result of these connections, the grids of thyratrons 35 and 36 are both driven in the negative direction by a D.-C. signal voltage, $E_{SIG.(d-c)}$, obtained by comparison of the A.-C. signal voltage and the A.-C. reference voltage and rectification of the difference voltage, and the grids are driven in the positive direction by a D.-C. bias voltage, E_{d-c}, to adjust the bias of the thyratrons to appropriate levels with respect to their critical voltages. The grids are further driven by A.-C. bias voltages, e_{a-c}, of opposite phase.

In order to provide plate voltage for thyratrons 35 and 36, a pair of transformers 120 and 121, having their primaries connected to the power mains source of 60 cycle voltage, are provided. The secondaries of transformers 120 and 121, 122 and 123, respectively, each have one of its ends connected to the corresponding plate

of the thyratrons and its opposite end connected to the cathode or filament thereof. The connections and windings are so arranged that plate **125** of thyratron **35** is positive with respect to its cathode when plate **126** of thyratron **36** is negative with respect to its cathode. The end of secondary **122** opposite the plate-connected end is connected to one brush **130** of the dome drive motor **21**, while the other brush **131** of the motor is connected to the cathode of thyratron **35**. Likewise, the end of secondary **123** opposite the plate-connected end is connected to brush **131**, while the cathode of thyratron **36** is connected to brush **130**.

The field-winding **135** of drive motor **21** may be supplied with a D.-C. voltage from a full-wave rectifier **136** connected to the power mains.

The operation of the method and apparatus of the above-described embodiment of the invention will now be discussed in conjunction with Fig. 3. In that figure, the plate voltage of thyratron **36** is represented by curve e_b, while the critical voltage curve of the thyratron, a curve determined by the design of the thyratron employed, is represented by the dashed-line labelled "critical voltage." As is well known, whenever the total voltage between grid and cathode crosses the critical voltage line in the negative-to-positive direction, the thyratron fires. For thyratron **36**, the voltage between potentiometer slider **117** and center tap **97** of secondary **95** is the D.-C. bias voltage, labelled E_{d-c} in Figs. 2 and 3. This voltage tends to drive the grid of thyratron **36** in a positive direction with respect to the cathode. However, the voltage across resistor **87**, labelled $E_{SIG.(d-c)}$ in Figs. 2 and 3, tends to drive the grid negative with respect to the cathode and is substantially larger than the D.-C. bias voltage, so that the static level about which the grid voltage varies, labelled "total d-c bias" in Fig. 3, is substantially below the zero level and is also below the critical voltage curve. The A.-C. bias voltage, derived between potentiometer slider **101** and center tap **97** of secondary **95**, is shown as e_{a-c} in Figs. 2 and 3, and is combined with the total D.-C. bias, so that e_{a-c} in Fig. 3 represents the total grid-cathode voltage. This voltage carries the voltage of the grid with respect to the cathode about the level determined by the algebraic sum of E_{d-c} and $E_{SIG.(d-c)}$. As is evident from Fig. 3, and in accordance with conventional practice, the A.-C. bias voltage is delayed with respect to the plate voltage e_b by between 135° and 140°. The magnitude of the D.-C. bias, the D.-C. signal, and the A.-C. bias voltages are such that, when motor **21** is in a position corresponding to that of theodolite drive motor **1**, the total grid voltage curve cuts the critical voltage curve for thyratron **36** very near the end of the half cycle of the positive plate voltage, so that tube **36** conducts current during only a small portion of the cycle, as indicated by cross-hatching in Fig. 3. The same is true for thyratron **35**, so that the net current flowing through motor **21** is zero, and no movement of the motor occurs. However, when the two drive motors are not in synchronism, the D.-C. signal voltage changes, as a result of change in the A.-C. signal voltage. If the A.-C. signal voltage increases in phase with the reference voltage, the D.-C. signal voltage is increased, while, if the A.-C. signal voltage increases out of phase with the reference voltage, the D.-C. signal voltage is decreased. The latter condition is shown in Fig. 3, where $E'_{SIG.(d-c)}$ is shown in dashed line as as being of lesser value than the steady-state or null condition of the D.-C. signal voltage. In such case, the total grid voltage increased, so that the voltage level e_{a-c}, shown in Fig. 3 as a dashed curve, cuts through the critical voltage curve at an advanced point in the cycle, labelled the "firing point out of null." Thyratron **36** then carries a large amount of current, as indicated by the shaded portion of Fig. 3. In contrast, at the same time, thyratron **35** would be driven more negative, so that it would not fire. The conduction of thyratron **36** would cause current to pass through the armature of the dome drive motor **21** in such direction as to rotate the motor to correspondence with the theodolite drive motor **1**.

It will be evident that I have described a method and apparatus which will maintain the dome drive motor **21** in synchronism with the theodolite drive motor **1**, through use of a thyratron control circuit which is positively controlled by a signal voltage independent in phase with respect to the thyratron plate voltage, yet without any extensive additions to convert the A.-C. signal voltage to be of constant phase with respect to the thyraton plate voltage. It will further be obvious that many minor changes could be made in the method and apparatus specifically described herein without departure from the scope of the present invention. Accordingly, the invention is not to be considered limited to the embodiment specifically disclosed, but rather only by the appended claims.

I claim:

1. A method of controlling firing of a thyratron which comprises supplying an A.-C. voltage between the plate and cathode of the thyratron, comparing an A.-C. signal voltage with an A.-C. reference voltage of identical frequency and of substantially constant phase and amplitude to obtain a comparison voltage, rectifying and filtering said comparison voltage to obtain a D.-C. signal voltage having an amplitude and polarity determined by the amplitude and phase of the A.-C. signal voltage as compared with the reference voltage, deriving from the source of said A.-C. plate voltage an A.-C. bias voltage having a constant phase delay of about 135°–140° with respect to the A.-C. plate voltage, deriving a D.-C. bias voltage, combining algebraically said D.-C. signal voltage, said A.-C. bias voltage, and said D.-C. bias voltage to obtain a control voltage, and supplying said control voltage between grid and cathode of said thyratron.

2. A method of synchronizing movement of one motor-driven device with another motor-driven device which comprises supplying an A.-C. signal voltage of amplitude and phase dependent upon the relative position of the motor of said other motor-driven device with respect to the position of the motor of said one motor driven device, comparing said A.-C. signal voltage with an A.-C. reference voltage of frequency identical with said signal voltage and of substantially constant amplitude and phase, to obtain a comparison voltage, rectifying said comparison voltage to obtain a D.-C. signal voltage of amplitude dependent upon the relative amplitudes and phases of said A.-C. signal and said A.-C. reference voltages, supplying the plates of a pair of thyratrons with an A.-C. plate voltage in such fashion that the plate voltages are substantially 180° out of phase with each other, deriving from the source of said plate voltage an A.-C. bias voltage having a phase delayed with respect to the plate voltage, combining algebraically said D.-C. signal voltage and said A.-C. bias voltage in one sense to obtain one composite voltage and in the opposite sense to obtain another composite voltage, applying said one composite voltage between grid and cathode of one thyratron and applying said other composite voltage between grid and cathode of the other thyratron, and supplying the plate currents of said thyratrons in opposite direction to said motor of said one motor-driven device.

3. The method of claim 2 including the steps of adding to each of said composite voltages a D.-C. bias voltage in such sense and of such amplitude to maintain the grid of each of the thyratrons negative with respect to the cathode, but within approximately the peak amplitude of the A.-C. bias voltage from the thyratron critical voltages.

4. A thyratron control system comprising means for supplying an A.-C. signal voltage, means for supplying an A.-C. reference voltage of the same frequency as the signal voltage and of substantially constant phase, means for adding said A.-C. signal voltage and said A.-C. reference voltage to obtain a composite voltage, means for rectifying said composite voltage to obtain a D.-C. signal

voltage, means for supplying a pulsating voltage between the plate and cathode of said thyratron, means for supplying a pulsating control voltage of the same frequency as and of controllable phase relation to the voltage supplied to said plate, and means for adding said D.-C. signal voltage and said pulsating control voltage algebraically for supply between grid and cathode of said thyratron.

5. A thyratron control system as defined in claim 4 including means for supplying a D.-C. bias voltage and for adding said D.-C. bias voltage algebraically with said pulsating control voltage and said D.-C. signal voltage between grid and cathode of said thyratron.

6. A thyratron control system comprising means for supplying an A.-C. signal voltage, means for supplying an A.-C. reference voltage having the same frequency as the A.-C. signal voltage, means for adding the A.-C. signal voltage and the A.-C. reference voltage of one phase to obtain one composite A.-C. voltage, means for adding the A.-C. signal voltage and the A.-C. reference voltage of the opposite phase to obtain another composite A.-C. voltage, means for rectifying both composite voltages to obtain one D.-C. signal voltage and another D.-C. signal voltage, a pair of thyratrons, means for supplying an A.-C. voltage of one phase between plate and cathode of one of said pair of thyratrons, means for supplying an A.-C. voltage of the same frequency and opposite phase between plate and cathode of the other of said pair of thyratrons, means for supplying an A.-C. bias voltage of constant frequency and phase relation to said A.-C. plate voltages, means for combining said one D.-C. signal voltage and said A.-C. bias voltage algebraically to obtain one control voltage and for supplying said one control voltage between grid and cathode of one thyratron, and means for combining said other D.-C. signal voltage and said A.-C. bias voltage to obtain another control voltage and for supplying said other control voltage between grid and cathode of said other thyratron.

7. A thyratron control system as defined in claim 6 including means for adding to each of said control voltages a D.-C. bias voltage.

8. An apparatus for causing the motor of one motor-driven device to track with the motor of another motor-driven device which comprises means for deriving an A.-C. signal voltage of phase and amplitude indicative of the difference in relative positions of said two devices, means for supplying an A.-C. reference voltage of the same frequency as the A.-C. signal voltage and of substantially constant amplitude and phase, means for comparing said A.-C. signal voltage with said A.-C. reference voltage of one phase to obtain one comparison voltage, means for comparing said A.-C. signal voltage with said A.-C. reference voltage of the opposite phase to obtain another comparison voltage, means for rectifying and filtering said one comparison voltage to obtain one D.-C. signal voltage, means for rectifying said other comparison voltage to obtain another D.-C. signal voltage, a source of A.-C. voltage of substantially constant phase and frequency, means for deriving from said source an A.-C. bias voltage, means for combining algebraically said A.-C. bias voltage of one phase and said one D.-C. signal voltage to obtain one control voltage, means for combining algebraically said A.-C. bias voltage of the opposite phase and said other D.-C. signal voltage to obtain another control voltage, a pair of thyratrons, means for supplying said one control voltage between grid and cathode of one of said thyratrons, means for supplying said other control voltage between grid and cathode of the other of said thyratrons, the grid-cathode circuits of the thyratrons being isolated from each other for D.-C. voltages, means for deriving from said source of A.-C. voltage a first A.-C. plate voltage of leading phase with respect to said one control voltage and for supplying said first plate voltage between plate and cathode of said one thyratron, means for deriving from said source of A.-C. voltage a second A.-C. plate voltage of opposite phase to said first A.-C. plate voltage and for supplying said second plate voltage between plate and cathode of said other thyratron, and means for supplying the difference of the plate currents of said pair of thyratrons to the motor of said one motor-driven device.

9. The apparatus of claim 8 including means for supplying a D.-C. bias voltage between grid and cathode of each of said thyratrons of such polarity and amplitude as, when added into said control voltages, to maintain the grid of each thyratron negative with respect to the cathode.

10. The apparatus of claim 9 in which both said comparing means comprise a first pair of grid-containing vacuum tubes, a second pair of grid-containing vacuum tubes, and a pair of transformers having center-tapped primary coils, said A.-C. signal voltage being applied between control grid and cathode of each of said first pair of vacuum tubes, said A.-C. reference voltage being applied in opposite phase between grid and cathode of the two of said second pair of vacuum tubes, the plate of one of said first pair and the plate of one of said second pair of vacuum tubes being connected to opposite ends of one primary of said pair of transformers, the plate of the other of said first pair and the plate of the other of said second pair of vacuum tubes being connected to the opposite ends of the other primary of said pair of transformers, and the center taps of said primaries being connected to the cathodes of all of said tubes through a source of plate voltage.

11. The apparatus of claim 8 which said means for deriving an A.-C. signal voltage comprises a control transmitter-type synchro having its rotor driven with the motor of said other motor driven device, said synchro having its rotor coil supplied with voltage from said means for supplying an A.-C. reference voltage, and a control transformer-type synchro having its rotor driven with the motor of said one motor-driven device, the respective stator coils of said two synchros being connected to each other and the rotor coil of said control transformer-type synchro thereby developing said A.-C. signal voltage across it.

12. A method of controlling firing of a gaseous discharge tube for which the signal voltage need not be of the same frequency and phase as the tube plate voltage which comprises comparing the signal voltage with an A.-C. reference voltage of identical frequency and of substantially constant phase and amplitude to obtain a comparison voltage, rectifying and filtering said comparison voltage to obtain a D.-C. signal voltage having an amplitude and polarity determined by the amplitude and phase of the A.-C. signal voltage as compared with the reference voltage, deriving from the source of tube plate voltage an A.-C. bias voltage of the same frequency as the plate voltage and having a controllable phase relation therewith, and applying the algebraic sum of the D.-C. signal voltage and the A.-C. bias voltage between the control electrode and cathode of the discharge tube.

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