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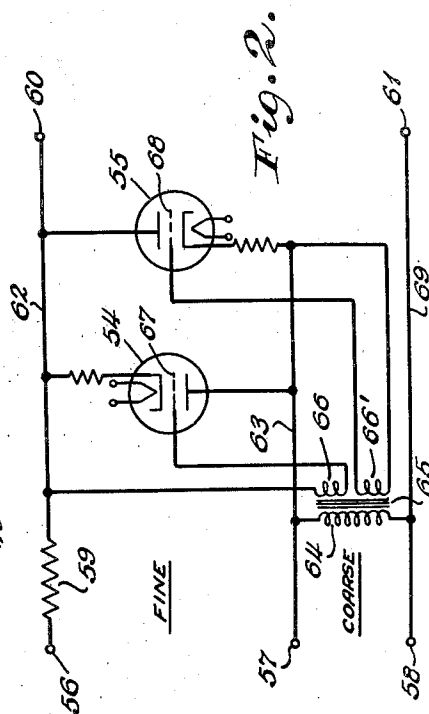
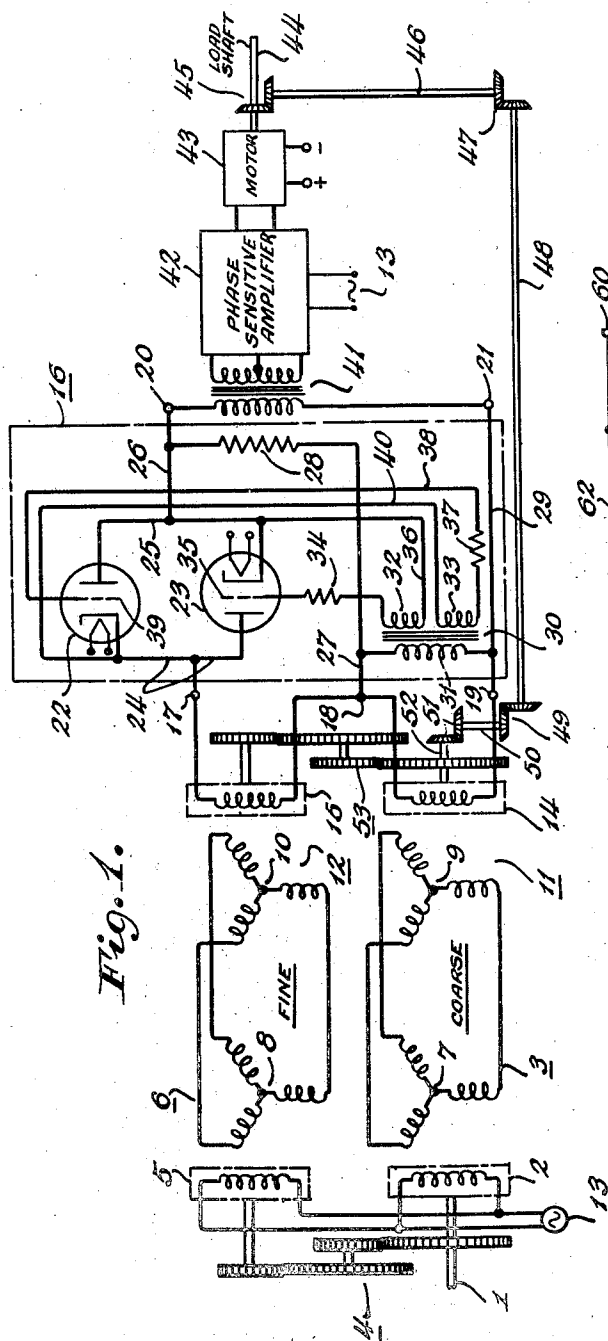
R. D. McCOY ET AL.

2,493,772

ELECTRONIC SIGNAL MIXING CIRCUIT

Filed April 17, 1945

2 Sheets-Sheet 1



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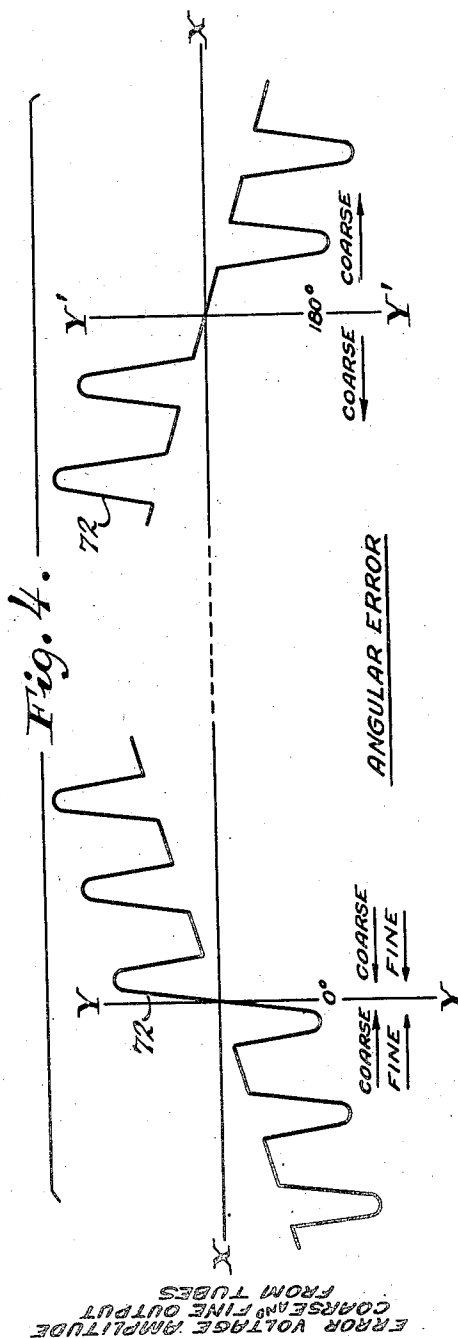
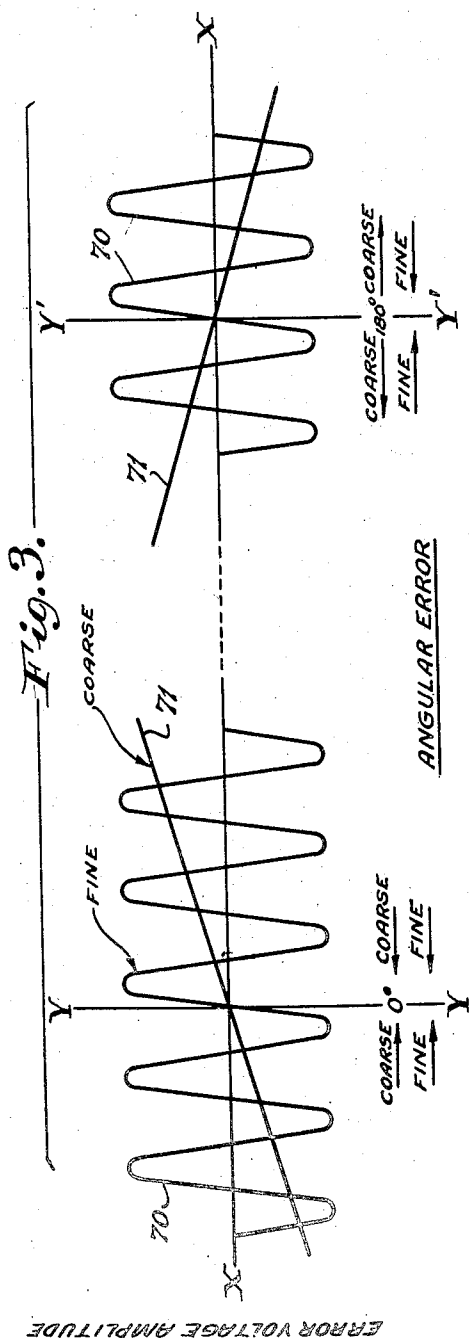
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2 Sheets-Sheet 2



UNITED STATES PATENT OFFICE

2,493,772

ELECTRONIC SIGNAL MIXING CIRCUIT

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1

Our invention particularly relates to a signal mixing circuit for use in a servomotor system wherein fine and coarse error signals are employed in the control of the servomotor. The mixing circuit of the present invention is primarily designed to mix the fine and coarse error signal voltages employed in controlling the servo and particularly to control at least the fine voltage.

Fine and coarse error signal systems are ordinarily employed in servomotor systems to provide a close and quite accurate control over the servomotor so that, for example, the load shaft or positionable object driven thereby will follow an input shaft or reference member with extremely small lag or lead therebetween. Ordinarily, fine and coarse error systems, such as those herein illustrated and hereinafter described, respectively include a signal transmitter and a signal receiver or transformer. The transmitter of the coarse system is ordinarily connected directly with the data input or with the reference member so that the rotor of the transmitter rotates in a 1:1 ratio with respect thereto. The rotor of the fine transmitter, on the other hand, is rotated in some fixed, higher ratio with respect thereto, such as for example, a 36:1 or in any other desired ratio with respect to the reference member or input shaft. The coarse signal error voltage derived from the coarse system will therefore vary in amplitude directly with rotation of the input shaft, or, more precisely the amplitude of the voltage envelope of the output voltage of the coarse system will vary in amplitude directly with rotation of the input shaft. The fine error voltage or the voltage envelope of the output voltage of the fine system will vary in amplitude in the adopted ratio as, for example, 36:1 with respect to rotation of the input shaft. These signal voltages are ordinarily supplied to an amplifier which is associated in controlling relationship with the servomotor or other controlled device.

Since fine and coarse error voltages are employed to provide close and accurate tracking of the positionable object, driven by the servo, with the reference member, a control must be exercised over these signal voltages in order that they may be fully utilized under those conditions where their presence is most needed for proper control, and may yet be modified or eliminated under those conditions where their presence would impair the operation of the servo or, even bring about a reversal of its direction of operation.

2

In the present case, it is assumed that the fine and coarse ratio of the signal systems is an even numbered ratio, such as 36:1, because, as will be evident as the description of the present invention proceeds, the mixing and control circuit of the present invention prevents synchronization where the units of the fine and coarse systems are displaced 180° with respect to each other, and this is accomplished without the use of any additional voltages or the incorporation of other means such as have been heretofore employed to prevent such synchronization where an even numbered ratio of fine to coarse has been employed.

It is the primary object of this invention to provide an electronic circuit in which the output voltage contains components proportional to the summation of two separate voltages of like phase, the presence of a component in the output proportional to one of said voltages being controlled by the other voltage through the electronic means.

Another object resides in providing a mixing and controlling circuit for fine and coarse signal voltages, comprising electronic means controlled by one of said signal voltages for controlling the presence of a voltage component in the output thereof which is proportional to the other signal voltage.

Still another object resides in providing a control circuit for fine and coarse error signal voltages, comprising a pair of electron tubes arranged back to back and so connected for energization or bias by both of said signal voltages that the presence of the voltage component in the output of the circuit which is proportional to one of said signal voltages will be controlled by the other of said signal voltages.

More particularly, it is an object of the present invention to provide a control circuit for a servomotor in which fine and coarse signal voltages are mixed and controlled, said circuit including a pair of electron tubes connected back to back with the plates and cathodes thereof energized by the fine signal voltage and the control grids energized by the coarse signal voltage and in out-of-phase relationship whereby the output of said circuit will comprise only voltage components proportional to the summation of like phase fine and coarse voltages.

Still another object of this invention resides in providing a control and mixing circuit of the foregoing character which is so constructed and arranged that synchronization of the system cannot occur when the 1:1 ratio synchro units or the

positionable object and reference member are 180° angularly displaced.

With the foregoing and still other objects in view, our invention includes the novel elements and the combinations and arrangements thereof described below and illustrated in the accompanying drawings, in which—

Fig. 1 schematically represents a positional control system, illustrated herein by way of example and embodying a preferred form of fine and coarse signal mixing and control circuit;

Fig. 2 is a wiring diagram of a modified form of signal voltage mixing and controlling circuit;

Fig. 3 represents the envelope of fine and coarse signal voltages; and

Fig. 4 illustrates the envelope of the voltage output of the circuits of the present invention.

Fig. 1 illustrates somewhat schematically a positional control system as illustrative of systems embodying the present invention. In Fig. 1, 1 indicates generally the input shaft with which a reference member may be connected and to which the rotor 2 of the transmitter 3 in the coarse signal system is directly coupled or so coupled thereto that the reference member or shaft 1 and the rotor 2 rotate together. The input shaft 1 is also coupled through a gear train, indicated generally at 4, with the rotor 5 of a transmitter 6 which is the transmitter in the fine signal system. The gear train 4 is designed, as herein assumed for descriptive purposes, to drive the rotor 5 in a ratio of 36:1 with respect to the input shaft or rotor 2 of the coarse transmitter.

The stator windings of the transmitters 3 and 6 as indicated generally at 7 and 8, respectively, are connected together in polycircuit fashion and with the correspondingly disposed and similarly connected stator windings 9 and 10 of the signal transformers 11 and 12. Selsyn or Autosyn type units may be employed as the transmitters and as the receivers or signal transformers in the above-described transmission systems, and it will be understood that where in the following description we may refer to Selsyns that we mean to include any suitable type unit which may be employed for the purposes herein specified.

The rotors of the transmitters 3 and 6 are connected across a source of suitable alternating current indicated generally at 13, while the rotors 14 and 15 of the receivers or signal transformers 11 and 12 are connected to supply signal voltages to the mixing and signal voltage control circuit included within the dot-dash line and indicated generally at 16. The output of the fine transmission system or rotor 15 of signal transformer 12 is connected across the input taps 17 and 18, while the output of the coarse transmission system or signal transformer 11 is connected across the input terminals 18 and 19.

The mixing and signal voltage control circuit 16, in accordance with the present invention, functions to mix the fine and coarse signals and to control the fine signal so that only like phase, voltage components of fine and coarse signal voltage appear in the output of the circuit, and is herein illustrated as comprising a pair of inputs and an output. The inputs are represented as respectively including the terminals 17—18 and 18—19 and the output terminals are indicated at 20 and 21.

In accordance with the preferred arrangement of the circuit 16 of the present invention, a pair of electron tubes 22 and 23 are connected together in back to back relation as shown and in

series between the fine signal voltage input and the output. By back to back relationship, we mean a connection wherein the plate of one tube is connected to the cathode of the other and the plate of the latter is connected to the cathode of the former. By arranging the tubes in this manner, they may be controlled to pass current in the circuit therethrough in one direction and also in the other, or to block the flow of current in both directions or in either direction. The input terminal 17 is connected through lead 24 to the plate of tube 23 and to the cathode of tube 22. The plate or anode of tube 22 is connected by lead 25 to the cathode of tube 23 and through lead 26 to one of the output taps 20. The input terminal 18 is also connected through lead 27 and through resistor 28 to output terminal 20. Therefore, a closed circuit may exist embodying the rotor winding 15 of signal transformer 12, tubes 22 and 23 and resistance 28. If both tubes 22 and 23 conduct, it will be obvious that a voltage will appear across resistor 28 or between the input terminal 18 and the output terminal 20 which is proportional to the fine error signal voltage. Also, a signal voltage will appear across the input terminal 18 and the output terminal 21 which is proportional to the coarse error signal voltage since the input terminal 19 is connected through lead 29 with output terminal 21 and the rotor winding 14 of the coarse signal transformer 11 is connected across the input terminals 18 and 19. Therefore, under the above assumed conditions, a signal voltage comprising components proportional to the fine and coarse error voltages will appear across the output taps 20 and 21 of the mixing circuit 16.

In accordance with the present invention, however, the presence of components in the output of circuit 16 which are proportional to or correspond to the fine signal voltages appearing in the output of the fine transmission system is controlled by the coarse error signals derived from the rotor winding 14 of the coarse signal transformer 11. In other words, the voltage output of signal transformer 11 is applied across the output terminals 20 and 21 of the mixing circuit and a component thereof is applied to the grids of tubes 22 and 23 to control the conductivity thereof.

In accordance with the preferred embodiment of our invention, the signal voltage components of coarse signal voltage are impressed on the grids of the tubes 22 and 23 by employing a transformer indicated generally at 30, the primary 31 of which is connected between the leads 27 and 29 or the input terminals 18 and 19. Transformer 30 preferably comprises a pair of secondary windings 32 and 33. Winding 32 is connected at one end through resistor 34 to the grid 35 of tube 23, and the other end of winding 32 is connected through lead 36 to the cathode of tube 23. Similarly, the other secondary winding 33 of the transformer is connected at one end through resistor 37 and lead 38 to the grid 39 of tube 22, and the other end of said winding is connected through lead 40 to the cathode of tube 22.

It will be noted, as shown in Fig. 1, that the secondary windings 32 and 33 are so arranged and connected with the grids of the tubes 22 and 23 that the voltage components appearing across these secondary windings will be applied in opposite phase sense to the grids. In other words, a component of coarse error voltage of positive sense will be applied to the grid of one of these tubes while simultaneously a component of coarse

5 signal voltage will be applied in a negative sense to the grid of the other tube, or, the control voltages applied to the grids of these tubes will be applied thereto in opposite phase relationship. Therefore, the output of tubes 22 and 23 under control of the coarse signal voltage will depend upon the phase relationship which exists between the fine and coarse error signals. More specifically, when the fine and coarse signal voltages are in phase or are of the same phase sense, the coarse signal voltage components will control the tubes to conduct and thereby provide a signal voltage component in the output of the mixing circuit which is dependent upon and proportional to the fine error signal. On the other hand, if the fine signal voltage changes in phase sense with respect to the coarse signal voltage, such that they have opposite phase senses, the tubes will be rendered non-conductive and no voltage corresponding to the fine signal voltage will appear in the output of the circuit.

The operation of the above-described circuit is briefly set forth as follows. Assuming that the signal and fine error signals derived from the signal transformers 11 and 12 are of like phase sense, it may be assumed that the anode or plate of tube 23 will become positive when its grid is driven positive by the secondary 32 of transformer 30 or is biased in a positive direction by a component of coarse error voltage. Under such a condition, tube 23 will conduct and a voltage will appear across resistor 28 corresponding to the fine error voltage. For the above assumed relationship of plate and grid voltages on tube 23, the voltage across resistor 28 will be additive with the voltage induced in the rotor winding 14 of the signal transformer 11, and therefore a voltage will appear across the output taps 20 and 21 which is proportional to the summation of these two voltages. When the phase of both the fine and coarse signal voltages reverses, the plate of tube 22 will become positive and likewise the grid 39 thereof will be driven positive from the secondary 33 of the transformer 30, thereby again providing a closed circuit to supply a voltage component proportional to the fine error voltage output of the signal transformer 12. Since the fine and coarse voltages have reversed in phase together, they will still appear in an additive sense across the output taps 20 and 21 of the circuit.

If, on the other hand, the phase of the fine voltage output from the signal transformer 12 were to change relative to the coarse signal voltage so as to be of opposite phase sense, it should be readily seen that the control voltages which are applied to the grids of the tubes 22 and 23 will drive the grids negative when the plates become positive and therefore no signal voltage will appear in the output of the circuit which corresponds to the fine signal voltage.

In the exemplary embodiment of my invention shown in Fig. 1, the output of the circuit 16 is connected across the primary of a coupling transformer 41, the center tapped secondary of which is connected to the input of a phase-sensitive amplifier 42. A source of alternating reference voltage is connected to the phase-sensitive amplifier, and this source may be the source 13 employed in exciting the transmitters of the fine and coarse transmission systems. Any conventional type of phase-sensitive amplifier may be employed, and, since the particular arrangement or construction thereof forms no part of the present invention, we have not herein illustrated or

described the amplifier in detail. The output of the amplifier is applied in controlling relation to a servomotor 43. Furthermore, in like manner, we have represented the motor 43 as any suitable type of servomotor.

To complete the servo system of Fig. 1 which has hereinbefore been indicated as a positional control system, we have shown the servomotor 43 as driving a load shaft 44 to which, it will be understood, is secured the positionable object to be positioned in agreement with the reference member associated with the input shaft 1. For repeat back purposes, we have shown the load shaft or motor 43 as driving the rotors of the signal transformers 11 and 12 through bevel gears 45, shaft 46, bevel gears 47, shaft 48, bevel gears 49, shaft 50 and bevel gears 51. The foregoing transmission is shown purely for illustrative purposes. One of the bevel gears 51 is illustrated as secured to the shaft 52 of the rotor 14 and to this shaft is also secured the first gear of a gear train indicated generally at 53 which corresponds in all material respects to the gear train 4 hereinbefore described in connection with the rotors of the transmitters 3 and 6. Therefore, the servomotor 43 will drive the load and the rotor 14 of signal transformer 11 together and in synchronism while, through the gear train 53, the rotor 15 of signal transformer 12 will be driven in the same ratio with respect to rotor 14 as the rotor 5 of transmitter 6 is driven through gear train 4 with respect to the rotor 2 of transmitter 3. By means of the repeat back, the error signal supplied in controlling relation to the servomotor is made primarily dependent upon the angular lag or lead of the positionable object or load shaft with respect to the reference member or input shaft 1.

In Fig. 2, we have shown a modified embodiment of the mixing and control circuit of the present invention wherein two tubes 54 and 55 which may be generally similar to tubes 22 and 23 are connected back to back and in shunt across the one pair of input terminals to which the fine error signal is applied. In this form of the invention, the tubes 54 and 55 are adapted and controlled to conduct and thereby shunt out of the output of the circuit voltage components which are proportional to the fine error signal voltage when the fine error voltage is of opposite phase sense to the coarse error voltage or when the two voltages are out of phase with respect to each other.

In the preferred form of circuit for functioning in the above described manner and which is illustrated in Fig. 2, one pair of input taps 56 and 57 are connected to opposite sides of the tubes 54 and 55. In other words, terminal 56 is connected through a suitable resistor 59 directly with one of the output terminals 60 of the output 60-61. The cathode of one tube and the plate of the other are connected with the lead 62 joining the resistor 59 with the output tap 60 while the plate of the first-mentioned tube and the cathode of the latter are connected together and through lead 63 to the input terminal 57. The fine signal voltage output from the fine signal transformer 12 is adapted to be connected across the input 56-57 and the coarse signal voltage derived from the coarse signal transformer 11 is connected across the input 57-58, while the output terminal 60-61, which corresponds to the output 20-21 of Fig. 1, may be connected through suitable coupling means with

a phase-sensitive amplifier as illustrated in Fig. 1.

The tubes 54 and 55 are controlled by the control grids thereof to conduct or may be biased to cut-off dependent upon the relationship which the phase of the fine and coarse signal voltages bear one to the other. The primary 64 of a transformer 65 is connected across the coarse error input 57—58. A first secondary winding 66 thereof is connected between the grid 67 of tube 54 and lead 62 or the cathode of this tube and, similarly, a second winding 67 of transformer 65 is connected between the grid 68 of tube 55 and its cathode. The input tap 58 is, of course, connected directly through lead 69 with output terminal 61.

The foregoing described circuit functions as follows. Assuming that the fine and coarse error voltages are not in phase, the plate of tube 54 will, it may be assumed, be driven positive with respect to its cathode by the fine error voltage which is applied thereacross when the grid 67 of this tube is driven positive by the coarse error voltage through the medium of transformer 65. Under these assumed conditions, the fine and coarse error voltages will be out of phase, tube 54 will conduct and thereby will shunt the fine error voltage out of the output of the circuit. When the voltages reverse in phase, the plate of tube 55 will become positive with respect to its cathode by virtue of the fine error signal which is applied thereacross and at the same time its grid 68 will be driven positive by the coarse error voltage. Therefore, tube 54 will conduct during one-half cycle and tube 55 will conduct during the next succeeding half cycle so that the alternating fine error voltage will be shunted across the lead 62 and 63 and will not appear in the output 60—61. However, under all of the above assumed conditions, the coarse error voltage will appear across the output 60—61.

As compared to the foregoing, when the fine and coarse error voltages appear in phase or in like phase relationship, the anode of each tube will be driven positive when the respective grids are driven negative and therefore the two tubes will not conduct during either half cycle, and the output of the circuit will comprise summation voltage components corresponding to the like phase, coarse and fine signal voltages, such summation components being applied to the signal voltage amplifier. For the circuit to operate as above described, it will be seen that the grids of the tubes 54 and 55 are energized in out-of-phase relationship.

In Figs. 3 and 4 we have illustrated curves representing the envelopes of the signal voltages which are derived from the fine and coarse signal transformers. For example, curve 70 which is generally of sine wave form represents the error voltage which will be derived from the signal transformer 12. The curve 71 represents the envelope of the signal voltage derived from the signal transformer 11 or represents the coarse error signal voltage. It will be seen that the fine error voltage as represented by curve 70 goes through many cycles for one cycle of the coarse voltage, and the ratio thereof will be the same as the ratio adopted between the fine and coarse signal transmission systems. In this case, we have assumed a 36:1 ratio and therefore it will be understood that 18 cycles of the fine error voltage will appear between the axis Y—Y and Y'—Y', the spacing of these axes representing 180° of angular displacement between the ref-

erence member and the positionable object. We have illustrated the two curves 70 and 71 as they appear in the zone of zero degrees on the coarse and fine transmission systems of zero actual error, and 180° therefrom on the coarse system.

If both signal voltages were to be applied in controlling relation to the servomotor, and realizing that values of signal voltage either fine or coarse above the axis will function to drive the servo in one direction, while corresponding values below the axis will drive in the opposite direction, it will be seen that at 0° of actual error both the coarse and fine voltages will serve to drive the servomotor into synchronizing position with the reference member as indicated by the arrows. At 180° displacement or actual error as represented by the curves to the right of Fig. 3, although the coarse error will function to drive the servo in a direction away from a 180° error synchronizing point, the fine error voltages which have a much steeper gradient adjacent the 180° or Y'—Y' axis tend to produce synchronism at this point.

Obviously, both signals as shown in Fig. 3 cannot be supplied in toto to control a servomotor since the fine error would reverse the direction of operation of the servo a short way out from zero error when the phase of the fine signal voltage reversed and became greater than the coarse signal voltage.

Heretofore, because of the fact that the system might synchronize with 180° of actual error for the reasons above briefly presented, an additional voltage component was introduced into the system so that both voltages did not reduce to zero at 180° of error or an odd ratio of fine to coarse signal was adopted. It is to be observed that with the mixing circuit of the present invention, as readily seen from the curves in Fig. 4, that the system cannot synchronize at 180° of error but will only synchronize when the error is reduced to zero.

Referring now to Fig. 4, curve 72 represents the voltage output appearing across the output of the signal mixing and control circuit 16 of Fig. 1 or the circuit of Fig. 2. As hereinabove pointed out, only signal voltage components of like phase will appear in the output of these circuits, and therefore those components of the fine signal voltage below the X—X axis of Fig. 3 do not appear and are not added to the coarse signal voltage because they are either blocked as in Fig. 1 or shunted as in Fig. 2. The output voltage of the circuits is a summation of the fine and coarse signal voltages of like phase and the envelope thereof is represented by the curve 72. It will be observed that around zero error the fine signal voltage greatly predominates although superimposed upon the coarse error voltage. This provides quite accurate and close control of the servo about the zero error position. At a point representing 180° of actual error as indicated in Fig. 4 by the Y'—Y' axis, it will be observed that only coarse error voltage appears in the output of the circuits of Figs. 1 and 2 because these circuits eliminate the components of fine error signal which are of opposite phase sense with respect to the coarse error voltage. Under these conditions, no fine error voltage around 180° of actual error is present to produce a false synchronizing point and the coarse error signal will drive the servo away from the 180° error and in a direction tending to zero the error.

The function of the fine and coarse voltages as they individually control the servomotor or as

the corresponding voltage components in the output of the circuits of the present invention control the servomotor is represented by the arrows. The legends indicate which voltage components cause the servo to drive in the direction represented by the associated arrow. Since, as shown in Fig. 4, only coarse error voltage is present in the output of the control circuits of the present invention adjacent the $Y'-Y$ axis, synchronization with 180° of actual error cannot result. Therefore, the circuits in the present invention may be employed with fine and coarse transmission systems having an even ratio therebetween and eliminate any necessity of employing additional means, added voltages and the like for preventing false synchronization of the system.

While we have described our invention in its preferred embodiments it is to be understood that the words which we have used are words of description rather than of limitation and that changes within the purview of the appended claims may be made without departing from the true scope and spirit of our invention in its broader aspects.

What is claimed is:

1. In a servo system of the character described, fine and coarse transmission systems, a servomotor connected for control by the voltage outputs of said fine and coarse systems, and a mixing circuit for mixing the fine and coarse error voltage outputs of said systems, said mixing circuit comprising a pair of electron tubes having space discharge paths and control elements therefor, said space discharge paths being connected together in back to back relation and in circuit with one of said error voltages, and both of said control elements being connected with the other error voltage whereby said signal voltages jointly function to control the conductivity of said tubes.

2. In a servo system of the character described, fine and coarse transmission systems, a servomotor connected for control by the voltage outputs of said fine and coarse systems, and a mixing circuit for mixing the fine and coarse error voltage outputs of said systems and for controlling at least the fine voltage, said mixing circuit comprising a pair of electron tubes each having a cathode, a plate and a grid, said cathode and plate being connected together in back to back relation and energized by said fine error voltage, and means for connecting the grids thereof for energization by said coarse error voltage in opposite phase relationship, whereby the error voltage output of said mixing circuit contains voltage components proportional to the summation only of like phase, coarse and fine error voltages.

3. In a servo system of the character described, fine and coarse transmission systems, a servomotor connected for control by the voltage outputs of said fine and coarse systems, and a mixing circuit for mixing the fine and coarse error voltage outputs of said systems and for controlling at least the fine voltage, said mixing circuit comprising a pair of inputs to which said fine and coarse transmission systems are respectively connected, an output, and a pair of electron tubes having space discharge paths and control grids therefor, said space discharge paths being connected together in back to back relation and in shunt with the input to which the fine error signal voltage is connected, whereby to function when conducting to shunt the fine error voltage and substantially eliminate it from the output of said circuit output, the grids of said tubes being connected to receive a component of coarse signal

voltage from the other of said inputs whereby the presence of a voltage component in the output of said circuit corresponding to the fine signal voltage supplied to said circuit is controlled by the coarse signal voltage.

4. In a servo system of the character described, fine and coarse transmission systems, a servomotor connected for control by the voltage outputs of said fine and coarse systems, and a mixing circuit for mixing the fine and coarse error voltage outputs of said systems and for controlling at least the fine voltage, said mixing circuit comprising a pair of inputs to which the voltage outputs of said fine and coarse systems are respectively connected, an output, and a pair of electron tubes each having a space discharge path and a control grid therefor, said space discharge paths being connected together in back to back relation and in a series circuit between one of the fine signal voltage inputs and the output, the grids of said tubes being connected for energization by a component of voltage from the coarse signal voltage input whereby the presence of voltage components in the output of said circuit which correspond to the fine signal voltage are controlled by the coarse signal voltage.

5. A servo system of the character recited in claim 3 in which the coarse error signal voltages are supplied to the grids of the tubes in opposite phase relationship.

6. A servo system of the character recited in claim 4 in which the coarse error signal voltages are supplied to the grids of the tubes in opposite phase relationship.

7. In a servo system of the character described, fine and coarse transmission systems, a servomotor connected for control by the voltage outputs of said fine and coarse systems and a mixing circuit for mixing the fine and coarse error voltage outputs of said systems, said mixing circuit comprising a pair of input terminals connected to receive said fine and coarse error voltages, a pair of electron tubes having space discharge paths and control elements therefor, said space discharge paths being connected back to back and in circuit with one of said inputs, and means for connecting the control elements of said tubes to the other of said inputs to receive voltages therefrom in opposite phase relationship, whereby said voltages function to control the conductivity of said tubes.

8. In a servo system of the character described, fine and coarse transmission systems, a servomotor connected for control by the voltage outputs of said fine and coarse systems and a mixing circuit for mixing the fine and coarse error voltage outputs of said systems, said mixing circuit comprising means for supplying two separately controlled variable amplitude, reversible polarity signal voltages having the same frequency, an electrical circuit including a pair of voltage inputs respectively connected to receive said signal voltages, a pair of electron tubes having space discharge paths and control elements therefor, said space discharge paths being connected back to back and in circuit with one of said inputs, both of said control elements being connected to the other of said inputs to receive voltages therefrom, whereby one of said signal voltages functions to control the operation of said tubes to thereby control the component of the signal voltage in the output corresponding to the other signal voltage.

9. In a servo system of the character described, fine and coarse transmission systems, a servo-

motor connected for control by the voltage outputs of said fine and coarse systems and a mixing circuit for mixing the fine and coarse error voltage outputs of said system, said mixing circuit comprising an electrical circuit including a pair of inputs having the same frequency and a pair of electron tubes having plates, cathodes, and grids, said plates and cathodes being connected back to back and in circuit with one of said inputs, the grids of said tubes being connected for energization from the other of said inputs, whereby the output of said tubes is controlled by both signal voltages.

10. In a servo system of the character described, fine and coarse transmission systems, a servomotor connected for control by the voltage outputs of said fine and coarse systems and a mixing circuit for mixing the fine and coarse error voltage outputs of said systems, said mixing circuit comprising an electrical circuit including a pair of inputs and a pair of electron tubes having plates, cathodes, and control grids therefor, said plates and cathodes being connected back to back and in circuit with one of said inputs, the grids of said tubes being connected for energization by the voltage supplied to the other of said inputs in opposite phase relationship, whereby one of said signal voltages functions to control the conductivity of said tubes to thereby control the component of the signal voltage output corresponding to the other signal voltage.

11. In a servo system of the character described, fine and coarse transmission systems, a servomotor connected for control by the voltage outputs of said fine and coarse systems and a mixing circuit for mixing the fine and coarse error voltage outputs of said systems, said mixing circuit comprising an electrical circuit having an output and a pair of voltage inputs, a pair of electron tubes having space discharge paths and control grids therefor, said space discharge paths being connected back to back and in shunt with a first of said inputs, whereby to shunt the voltage across said first input out of said output, and the grids of said tubes being connected to receive the signal voltage from the other of said inputs, whereby the presence with a voltage component in the output of said circuit which corresponds to one of said voltage inputs is controlled by the other voltage input.

12. In a servo system of the character described, fine and coarse transmission systems, a servomotor connected for control by the voltage outputs of said fine and coarse systems and a mixing circuit for mixing the fine and coarse error voltage outputs of said systems, said mixing circuit comprising an electrical circuit having an output and a pair of voltage inputs, a pair of electron tubes having space discharge paths and control grids therefor, said space discharge paths being connected back to back and in shunt with a first of said inputs, whereby to shunt the voltage across said first input out of said output, and the grids of said tubes being connected to receive the component of signal voltage from the other of said inputs in opposite phase relationship, whereby the presence of the voltage component in the output of said circuit which corresponds to one of said voltage inputs is controlled by the other voltage input.

13. In a servo system of the character described, fine and coarse transmission systems, a servomotor connected for control by the voltage outputs of said fine and coarse systems and a mixing circuit for mixing the fine and coarse error volt-

age outputs of said systems, said mixing circuit comprising an electrical circuit including an output and a pair of voltage inputs of the same frequency, a pair of electron tubes having space discharge paths and control grids therefor, said space discharge paths being connected back to back and in series circuit between one of said inputs and the output, the grids of said tubes being connected for energization from the other of said inputs, whereby the presence of voltage components in the output of said circuits which corresponds to one voltage is controlled by the other voltage.

14. In a servo system of the character described, fine and coarse transmission systems, a servomotor connected for control by the voltage outputs of said fine and coarse systems and a mixing circuit for mixing the fine and coarse error voltage outputs of said systems, said mixing circuit comprising an electrical circuit including an output and a pair of voltage inputs, a pair of electron tubes having space discharge paths and control grids therefor, said space discharge paths being connected back to back and in a series circuit between one of said inputs and the output, and the grids of said tubes being connected for energization from the other of said inputs in opposite phase relationship, whereby the presence of voltage components in the output of said circuit which correspond to one voltage are controlled by the other voltage.

15. In a servo system of the character described, fine and coarse transmission systems, a servomotor connected for control by the voltage outputs of said fine and coarse systems and a mixing circuit for mixing the fine and coarse error voltage outputs of said systems, said mixing circuit comprising means for supplying a pair of input voltages having the same frequency, one of said means providing an input voltage varying in amplitude in accordance with a quantity and the other of said means providing an input voltage varying in amplitude in accordance with a multiple of said quantity, a pair of electron tubes having space discharge paths and control elements therefor, said space discharge paths being connected in back to back relation and in circuit with one of said voltage inputs, and means for connecting the control elements of said tubes in opposite polarity sense to the other of said voltage inputs, whereby said signal voltages function jointly to control the conductivity of said tubes.

16. In a servo system of the character described, fine and coarse transmission systems, a servomotor connected for control by the voltage outputs of said fine and coarse systems and a mixing circuit for mixing the fine and coarse error voltage outputs of said systems, said mixing circuit comprising means for supplying a pair of input voltages having the same frequency and of like phase, but varying in amplitude in accordance with a predetermined ratio with respect to a measure of said error signal, a pair of electron tubes having plates, cathodes, and grids, said plates and cathodes being connected in back to back relation and in circuit with one of said input voltages, said grids being connected for energization from the other of said input voltages, whereby the output of said tubes is controlled by both signal voltages.

17. In a servo system of the character described, fine and coarse transmission systems, a servomotor connected for control by the voltage outputs of said fine and coarse systems and a mixing circuit for mixing the fine and coarse error voltage outputs of said systems, said mixing circuit

13

comprising an electrical circuit including a pair of voltage inputs and an output error signal source, said pair of input voltages having the same frequency, the amplitude of one of said inputs being arranged to vary with a measure of said error signal and the amplitude of the other of said inputs being arranged to vary with a whole multiple of said measure of said error signal, a pair of electron tubes having space discharge paths and control elements therefor, said space discharge paths being connected in back to back relation and in circuit between one of said inputs and said output, and said control elements being connected for energization from the other of said inputs in opposite phase relationship, whereby the presence of voltage components in the output of said circuit which correspond to one voltage are controlled by the other voltage.

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14

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,969,550	Evans -----	Aug. 7, 1934
1,985,981	Edwards -----	Jan. 1, 1935
2,057,485	Haller -----	Oct. 13, 1936
2,082,644	Lord -----	June 1, 1937
2,106,831	Dawson -----	Feb. 1, 1938

FOREIGN PATENTS

Number	Country	Date
373,253	Italy -----	July 22, 1939