

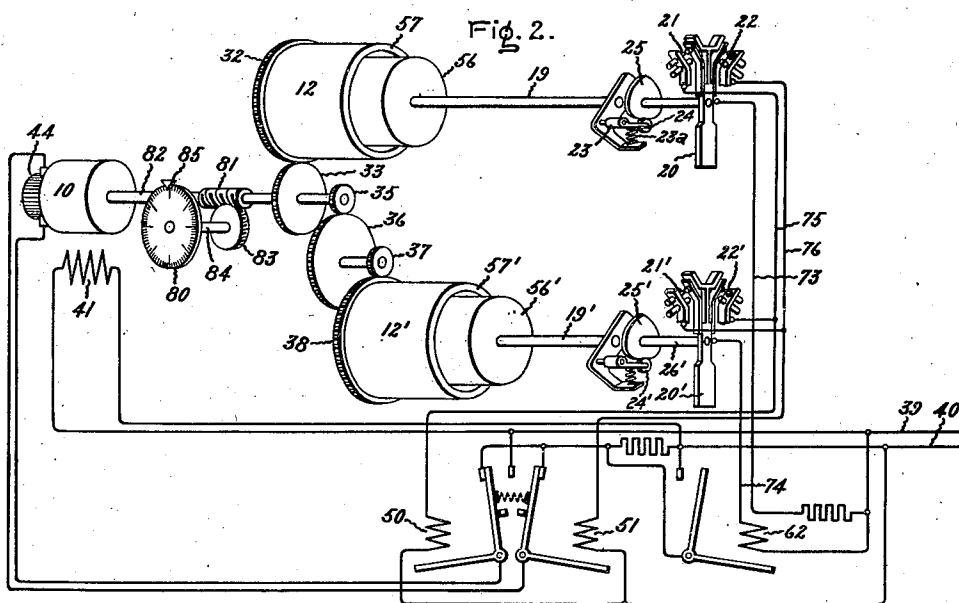
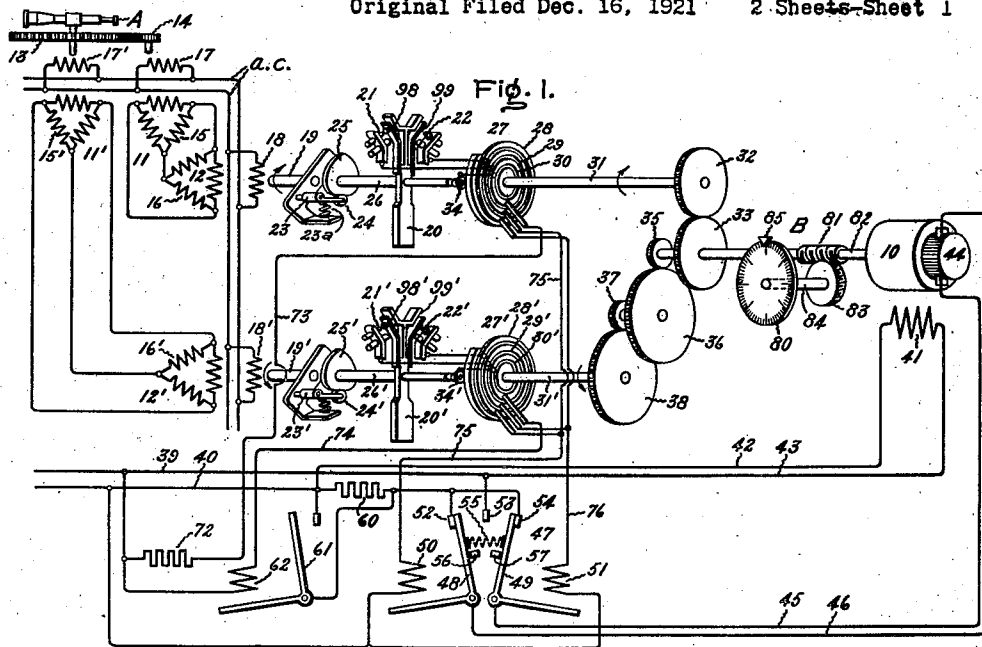
Oct. 27, 1925.

1,559,525

E. J. MURPHY ET AL

MEANS FOR REPRODUCING POSITION

Original Filed Dec. 16, 1921 2 Sheets-Sheet 1



Inventors:
Edwin J. Murphy,
Leonard P. Hutt,
by *Allen S. Davis*
Their Attorney.

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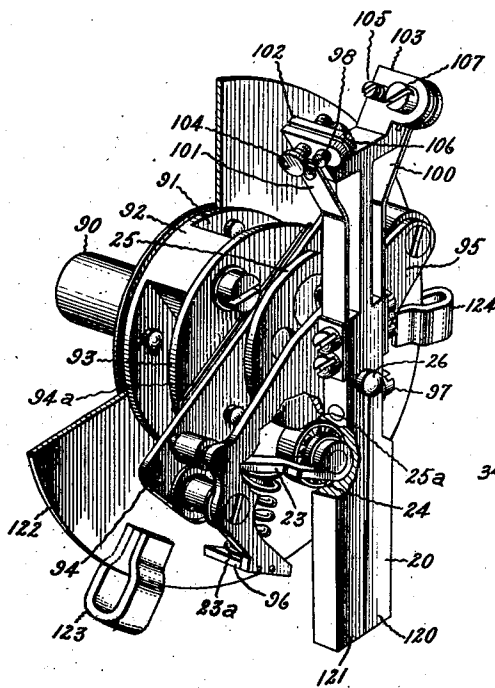


Fig. 3.

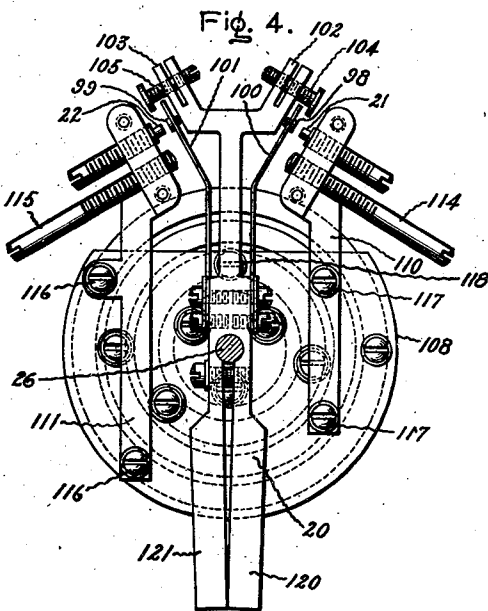
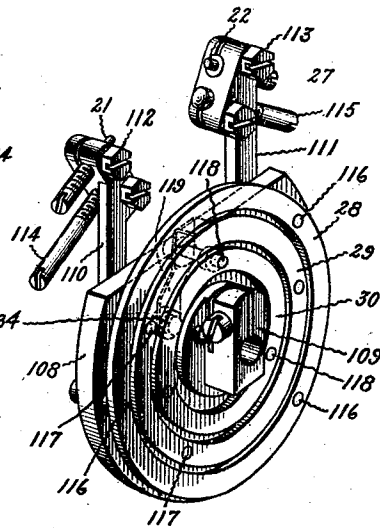
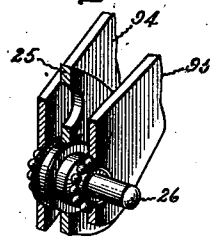


Fig. 5.



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UNITED STATES PATENT OFFICE.

EDWIN J. MURPHY AND LEONARD P. HUTT, OF SCHENECTADY, NEW YORK, ASSIGNORS
TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

MEANS FOR REPRODUCING POSITION.

Application filed December 16, 1921, Serial No. 522,946. Renewed July 27, 1925.

To all whom it may concern:

Be it known that we, EDWIN J. MURPHY, a citizen of the United States, and LEONARD P. HUTT, a subject of the British Empire, residing at Schenectady, county of Schenectady, State of New York, have invented certain new and useful Improvements in Means for Reproducing Position, of which the following is a specification.

This invention relates to means for reproducing position and has for its object the provision of improved means for driving an object in response to movement of another object.

More specifically this invention relates to systems for driving an object in response to movement of a controlling object, in which the driven object is actuated by an electric motor controlled in response to movement of the controlling object by means of one or more reproducers of angular movement responsive to movement of the controlling object. Although it has various applications whether the movement of the objects be that of translation or of rotation, our invention is particularly applicable in the driving of devices for indicating at some remote point the angular position of an object, such as a telescope.

Various systems of this type have been devised in which the reproducer has been restrained by the control means from moving freely into agreement with its transmitting device. Such arrangements produce excessive heating of the reproducer and inaccuracies in its operation. It is also impossible to operate in parallel with such a reproducer another reproducer having a free rotor element.

In carrying out our invention we have provided control means which in its operation places but a slight burden on the reproducer and means whereby the reproducer is movable without appreciable restraint independently of the control means. In one embodiment of our invention we have provided a contact arm actuated by the reproducer between two spaced contacts for the control of the servo motor, the contact arm being operatively connected to the reproducer by means of a yieldable coupling which we have shown in the form of a heart-shaped cam having a spring-pressed roller cooperating therewith. The roller tends to seek a definite position on the heart cam

thus biasing the contact arm in a predetermined relation with the reproducer. This coupling permits any amount of independent movement of the reproducer and contact arm, but reverses the contact arm every half revolution of such independent movement, thus controlling the motor to drive the driven object by the shortest path into agreement with the controlling object. The servo motor as it drives the driven object, moves the spaced contacts so as to break its own circuit when the driven object comes into agreement with the controlling object, or in a modification of our invention the servo motor drives the stator of the reproducer to open its own circuit, the spaced contacts being stationary. The yieldable coupling is particularly advantageous when both coarse and fine reproducers are used, since it permits any amount of motion between the rotor and contact arm of the fine reproducer as the servo motor operates under the control of the coarse reproducer.

For a more complete understanding of our invention reference should be had to the accompanying drawings in which Fig. 1 shows in diagrammatic fashion a system for the reproduction of angular movement embodying our invention; Fig. 2 shows in diagrammatic fashion a modified form of our invention; Fig. 3 is a view in perspective of the control mechanism for the motor with the cooperating contact devices thereof in spaced relation; Fig. 4 is an elevation view partially in section showing the relation of the contact devices; while Fig. 5 is a perspective view partially in section showing the support for the heart cam.

Referring to Fig. 1 of the drawings, in one form of our invention the electric motor 10, hereinafter referred to as a "servo" motor, is controlled in response to angular movement of a remote telescope A so as to drive an indicator B into angular agreement with the telescope. Movement of the telescope is transmitted for the control of the motor by means of coarse and fine self-synchronous or selsyn systems for the transmission of angular movement. The fine system consists of a selsyn transmitting generator 11 and a selsyn receiving motor or reproducer 12 connected thereto, while the coarse system consists of a selsyn transmitting generator 11' and a selsyn receiving motor or reproducer 12' connected thereto.

Selsyn generator 11 is connected to be driven by the telescope at a suitable high speed ratio, such as 72:1, by means of a spur gear 13 secured to the telescope and meshing with spur gear 14 secured to the rotor shaft of the generator. The selsyn generator 11' is operatively connected to the telescope so as to be driven at a suitable low speed ratio, such as 1:1.

The selsyn generators 11 and 11' and the motors 12 and 12' are similar in construction. They are shown as being provided with three phase armature windings 15, 15', 16, and 16' on their stators and single phase field windings 17, 17', 18, and 18' on their rotors. Like points of the armature windings 15 and 16 are electrically interconnected, and also like points of armature windings 15' and 16' are interconnected. The field windings are energized from a suitable source of alternating current supply.

In the operation of systems of this general character, voltages are induced in the three phase stator windings of the generators and motors by the single phase field windings on the associated rotors. When the rotors of the generator and motor in each system are in corresponding angular positions with relation to their stators, the induced voltages in the interconnected armature windings are equal and opposite, and consequently no current is set up in the armature windings. If the rotor of the generator is turned and held in its new position, the voltages no longer counterbalance, whereby equalizing currents are caused to flow in the armature windings. The equalizing currents exert a torque on the rotor of the motor causing it to take up a position corresponding to the position of the generator rotor. Movement imparted to the generator is therefore repeated synchronously by the receiving motor connected thereto. The receiving motors in systems of this character turn into angular agreement with their transmitting generators by the shortest path. That is to say, if the receiving motor rotor lags slightly more than 180 degrees, its torque will reverse causing it to move in the opposite direction through the lesser angle into agreement with the transmitting generator.

The receiving motor 12 has a shaft 19 operatively connected to actuate a contact arm 20 between two spaced contacts 21 and 22. The contact arm is connected to the receiving motor through a yieldable coupling comprising a spring-pressed arm 23 carrying a roller 24 and a heart-shaped cam member 25 on which the roller bears. The roller and spring-pressed arm are carried on the end of the receiving motor shaft 19, while the heart-shaped cam is carried on a shaft 26 to which the contact arm 20 is secured. The contacts 21 and 22 are carried by a collecting device 27 having three insulated slip rings

28, 29, and 30. This collecting device is mounted on a shaft 31 which is actuated through spur gears 32 and 33 by the servo motor 10. A contact 34 is carried by the collecting device in position to cooperate with the end of shaft 26. Contacts 22, 21, and 34 are electrically connected to slip rings 28, 29, and 30, respectively. A similar control device is associated with receiving motor 12', like parts of which are indicated by prime reference numerals for a clearer understanding. The collecting device 27' of this control device is actuated by servo motor 10 through a reduction gear train comprising gears 35, 36, 37, and 38. The gear ratio between the two collecting devices is equal to the speed ratio between receiving motors 12 and 12'.

The servo motor 10, which is of the direct current shunt type, is supplied from mains 39 and 40, leading from a suitable source of electrical supply, the field 41 of the servo motor having a permanent connection to the supply mains through conductors 42 and 43. The armature 44 of the servo motor is supplied by conductors 45 and 46 through a control relay 47. Relay 47 consists of two pivoted contact arms 48 and 49, actuated by electromagnetic coils 50 and 51, respectively. The contact arms are adapted to cooperate with three spaced stationary contacts 52, 53, and 54 and, as shown in the drawing, are held when the electromagnetic coils are deenergized in engagement with contacts 52 and 54 by an insulated spiral spring 55. Insulated projections 56 and 57, forming interlocks, are provided on adjacent sides of the contact arms. These projections are of such length that they engage with each other when either contact arm is moved into engagement with contact 53, thus effectively locking the other contact arm against movement in the event that its operating coil is energized. Contacts 52 and 54 are electrically connected to supply main 40, while contact 53 is electrically connected to supply main 39. The object of relay 47 is to control under guidance of contact arms 20 and 20' the direction of the current supply to the armature of the servo motor so as to control the direction of rotation thereof, and with coils 50 and 51 deenergized, as shown in the drawing, to short circuit the armature, thus dynamically braking the servo motor. A resistance 60 is included in the armature circuit of the servo motor. This resistance is controlled by a pivoted relay arm 61 actuated by an electromagnetic coil 62. The function of resistance 60 is to control the speed of the servo motor.

Operating coil 62 and coils 50 and 51 of relay 47 are controlled by contact arms 20 and 20' to control the servo motor, the control circuits for the coils being supplied from mains 39 and 40. Supply main 39 is con-

5 nected through a resistance 72 by way of
conductor 73 to collector ring 30 and
through electromagnetic coil 62 by way of
conductor 74 to collector ring 30'. Supply
10 main 40 is connected through electromag-
netic coil 50 by way of conductor 75 to col-
lector rings 28' and 29 and through elec-
tromagnetic coil 51 by way of conductor 76
to collector rings 29' and 28. The connec-
15 tions with the collector rings are made
through suitable brushes, as shown in the
drawings.

The moving element of indicator B con-
sists of a dial 80 which is actuated by the
15 servo motor through a worm 81, secured to
the shaft 82 of the servo motor, which
meshes with a worm gear 83 attached to a
shaft 84 carrying the dial. A stationary
index pointer 85 cooperates with the dial 80.
20 The dial is suitably calibrated, for example
in degrees and minutes of arc. Preferably
the driving gear ratio for the dial is such
that the dial is given an angular movement
which is the same as that imparted to the
25 telescope A, and therefore the dial gives
an accurate indication at all times of the
angular position of the telescope.

Referring to Figs. 3, 4, and 5 showing
the details of a control device for the servo
30 motor; this mechanism will be described in
connection with receiving motor 12, although
it will be understood that receiving motor
12' is arranged in a similar manner. Se-
cured to sleeve 90, which is adapted to be at-
35 tached to shaft 19 of receiving motor 12
in any suitable manner, is a metallic disc
91 having a diametrical rib 92 to which
is secured a second disc 93. An elongated
plate 94 is secured to disc 93 and insulated
40 therefrom by a layer of insulating material
94^a. A second plate 95 is attached by means
of suitable screws and spacing members to
plate 94 in parallel and spaced relation there-
with. The parallel plates 94 and 95 form
45 a support for the heart cam 25, which is
secured to shaft 26 carried on suitable ball
bearings in plates 94 and 95 in such position
that its longitudinal axis is coincident with
the axis of sleeve 90. The arm 23 is pivot-
50 ally secured at one end to the plates 94 and
95 and carries on its other end on ball bear-
ings the roller 24, which is yieldably held
in engagement with the heart cam 25 by
means of a spiral spring 23^a and normally
55 rests in a recess 25^a at the base of the heart.
The spring 23^a is held between the arm 23
and a supporting plate 96 secured at right
angles to plate 95. On the outer end of shaft
26 is secured the contact arm 20 by means of
60 a clamping screw 97. The heart cam is
generated with relation to its supporting
shaft 26 so that roller 24 always tends to
seek a position of rest in the recess 25^a, thus
biasing the contact arm in a predetermined
65 angular relation with the receiving motor.

The heart cam is also generated so that but
a very slight torque is necessary to move the
roller out of this stable position. The re-
ceiving motor and contact arm are therefore
independently movable without appreciable
70 restraint. Upon displacement of the receiv-
ing motor and contact arm through more
than 180 degrees so that the roller moves
past the point of the heart, it will be ob-
served that the bias on the contact arm re-
75 verses causing the contact arm to engage
the other contact and reverse the servo
motor.

Adjacent opposite sides of the upper end
of contact arm 20 are two contacts 98 and
99, which are carried on flexible spring arms
100 and 101, respectively. These springs
are made of a suitable magnetic material,
such as steel. The contacts are secured near
the upper ends of the arms, the lower ends
85 of which are attached to contact arm 20.
The upper end of the contact arm adjacent
the contacts is provided with two oppositely
extending arms 102 and 103, which carry
screws 104 and 105 having their heads in
90 position to limit the lateral movement of the
free ends of flexible arms 100 and 101.
Arms 102 and 103 extend at a slight angle
with contact arm 20, and the upper ends of
arms 100 and 101 are bent outward to con-
95 form thereto. The upper ends of arms 102
and 103 are divided into two portions by
means of transverse slots intersecting the
holes for screws 104 and 105, whereby the
screws may be locked by means of clamping
100 screws 106 and 107.

As shown in Fig. 4, contact arm 20 is nor-
mally in such position with relation to col-
lecting device 27 that contacts 98 and 99 are
in position to cooperate with contacts 21 and
22, respectively, carried by the collecting de-
vice 27. The collecting device consists of a
disc 108 made of suitable insulating mate-
rial, such as hard rubber, to which are se-
cured in spaced and insulated relation with
each other the collecting rings 28, 29 and 30.
A small segment of the disc at the top is
cut away. At the center of the insulating
disc is secured a metallic clamping member
109 having an aperture and clamping screw
115 whereby the collecting device may be at-
tached rigidly to its shaft 31 (Fig. 1). The
axis of shaft 31 is coincident with the axis of
shaft 26. The collecting rings 28, 29 and 30
are preferably secured in spaced relation with
120 the insulating disc 108 by means of suitable
washers. Secured to the opposite side of
disc 108 are two spaced metallic arms 110
and 111 which carry near their upper ends
the contacts 21 and 22. The upper ends of
125 the arms extend outwardly at an angle to
conform with arms 102 and 103. The con-
tacts 21 and 22 are preferably carried on the
ends of suitable screws so that their posi-
tion with respect to their supporting arms
130

may be adjusted as desired. The contacts can be secured in any adjusted position by means of clamping screws 112 and 113, the ends of the arms having transverse slots intersecting the holes for the contacts. Slightly below contact 21 on supporting arm 110 is a permanent magnet rod 114, which is threaded and extends through a tapped hole in the supporting arm. A similar magnet rod 115 is supported in arm 111 in like relation to contact 22. The magnets 114 and 115 are provided for the purpose of effecting a positive make and break between the respective cooperating contacts. Since the contacts 98 and 99 are mounted on flexible spring arms, it will be observed that when either one is brought within a certain distance from its respective cooperating contact 21 or 22, it will be pulled quickly into contact by the effect of magnet 114 or 115, as the case may be. Likewise when arm 20 is being moved to break contact, the magnets will retain the flexible spring arms in closed circuit position until a certain force is exerted or until the heads of screws 104 and 105 are engaged, when the spring arms will be pulled away from the magnets to effect a quick break. By means of screws 104 and 105 the limit of possible outward movement of contacts 98 and 99 can be adjusted as desired, the screws being turned until their heads will be engaged by the free ends of the spring arms 100 and 101. The magnets thus prevent the touching and consequent burning of the contacts, which would otherwise result from the constant vibration inherent in the alternating current receiving motor or from vibration of the support.

Collector ring 28 is electrically connected to arm 111 through screws 116, while collector ring 29 is electrically connected to arm 110 by screws 117. Collector ring 30 is electrically connected by screw 118 to contact 34, which is held on the end of a resilient arm 119 secured to insulating disc 108. Contact 34 engages the end of shaft 26 when contact arm 20 is in operative position with the collecting device 27, as shown in Fig. 4, thus electrically connecting contacts 98 and 99 through contact arm 20 and shaft 26 to collector ring 30. Preferably the lower end of the contact arm 20 is provided with weights 120, 121, which are designed to counterbalance the upper end of the contact arm. A metallic disc 122 is also secured to sleeve 90. Cooperating with the disc are stationary permanent magnets 123 and 124. The disc 122 and magnets 123 and 124 provide a damping device of well known form for the selsyn motor. Should the selsyn motor tend to run at high speed as a synchronous or induction motor, a braking effect will be exerted on disc 122 due to the generation of eddy currents therein.

As thus constructed and arranged and with the contact arms intermediate their contacts and the servo motor at rest, as shown in the drawing, the operation of our invention is as follows: Assuming that the receiving motors 12 and 12' are electrically connected to transmitting generators 11 and 11', through suitable switching mechanism (not shown), when the indicator is considerably out of angular agreement with the telescope, the receiving motors snap quickly into angular agreement with their transmitting generators, moving contacts arms 20 and 20' into engagement with one or the other of their cooperating contacts. The heart cam couplings yield, permitting movement of the receiving motors independently of the contact arms. Contact arm 20' is usually moved to make contact ahead of contact arm 20. In case the angle of disagreement between the telescope and indicator is such that upon connecting the receiving motors to the generators, shafts 19 and 19' rotate as indicated by the arrows, a control circuit is usually established through operating coil 51 by the engagement of contact 98' with contact 21'. This circuit leads from supply main 39 through coil 62 and conductor 74 to collector ring 30', thence to contact 34', and through contact arm 20' to contacts 98' and 21', and thence to collector ring 29', and through conductor 76 and operating coil 51 to supply main 40. The energization of coil 51 picks up arm 49 of relay 47, thus closing a circuit for the armature 44 of servo motor 10 from supply main 39 through switch arm 49, conductor 45, armature 44, conductor 46, switch arm 48 of relay 47, and resistance 60 to supply main 40. The field 41 of the servo motor is energized through conductors 42 and 43. The energization of coil 62 picks up relay arm 61, which closes a short circuit around resistance 60, thus causing the motor to operate at high speed. The direction of rotation of the servo motor, determined by the energization of operating coil 51, is such that the motor drives collecting devices 27 and 27' in directions to follow contact arms 20 and 20', and consequently dial 80 in the direction to take the shortest path into angular agreement with the telescope due to the fact that the receiving motors take the shortest path into angular agreement with their transmitting generators. As collecting device 27' moves, contact arm 20' moves with it due to the bias caused by roller 24' on heart cam 25', the roller approaching its stable position in the depression at the base of the heart, contact 98' being maintained meanwhile in engagement with contact 21'. Collecting device 27 is meanwhile actuated to reproduce the movement previously given to generator 11 independently of receiving motor 12, receiving motor 12 remain-

ing in fixed relation with the generator. When the initial angular disagreement between receiving motor 12 and generator 11 includes a number of whole revolutions of generator 11, collecting device 27 will be actuated by the servo motor to make a corresponding number of whole revolutions, and contact arm 20 will consequently vibrate between its contacts due to the effect of the heart cam coupling. This relative movement between the contact arm and the receiving motor may include any number of revolutions, but it will be observed that the contact arm is always biased through the shortest path to a definite angular relation with the receiving motor in any revolution. The interlocking projections 56 and 57 on the control relay 47 prevent the opening of the servo motor control circuit by the energization of coil 50 upon the reversal of contact arm 20. Operating coil 62 is prevented by resistance 72 in parallel with it from being short circuited by the reversal of contact arm 20. The servo motor now operates at high speed for the coarse adjustment, driving the indicator and collecting devices 27 and 27'.

When the servo motor has driven collecting device 27' to bring contact arm 20' at some point, determined by the accuracy of the coarse system, within $2\frac{1}{2}$ degrees of its correct angular position with relation to its receiving motor 12', roller 24' reaches its stable position on heart cam 25' bringing contact arm 20' to rest. Immediately thereafter, as the collecting device 27' continues to move, contacts 98' and 21' are separated, whereby the control of the servo motor is turned over to contact arm 20 for the fine adjustment. The control circuit for coil 51 is maintained by contact arm 20 through contacts 99 and 22, which are now in engagement. This control circuit leads from supply main 39 through resistance 72 and conductor 73 to collector ring 30, thence to contact 34, and through contact arm 20 to contacts 99 and 22, and thence to collector ring 28, and through conductor 76 and coil 51 to supply main 40. The servo motor therefore continues to operate in the same direction. Operating coil 62 is not included in this control circuit, however, and consequently relay arm 61 drops out inserting resistance 60 in the armature circuit of the servo motor. The servo motor is thus caused to operate at slow speed for the final accurate adjustment. When the servo motor has been controlled to move dial 80 into positional agreement with the telescope so that pointer 85 indicates thereon the angular position of the telescope, roller 24 seats in the depression in the base of heart cam 25 bringing contact arm 20 to rest. Immediately thereafter contact 22 moves away from contact 99 breaking the control circuit for

the servo motor, whereby coil 51 is deenergized. Arm 49 is immediately forced by spring 55 into engagement with stationary contact 54. A short circuit for armature 44 of the servo motor is thus closed through conductors 45 and 46 and relay 47, whereby the servo motor is dynamically braked to bring it quickly to rest.

For certain angular differences in position between the telescope and indicator, contact arm 20 may move to close its control circuit slightly ahead of contact arm 20'. Contact arm 20 is in such case only temporarily in control, however, since contact arm 20' immediately thereafter establishes its control circuit, short-circuiting resistance 60 for high speed operation of the servo motor.

In case the angular difference between the indicator and the telescope is such that the receiving motors 12 and 12' rotate in directions opposite to the directions indicated by the arrows when switched on their generators, a control circuit for operating coil 50 may be first temporarily closed by the engagement of contact 98 with contact 21. In such case the control is immediately taken over, however, by contact arm 20' by the engagement of contact 99' with contact 22'. Contacts 99' and 22' establish a control circuit which leads from supply main 39 through operating coil 62 and conductor 74 to collector ring 30', thence to contact 34', through contacts 99' and 22', and thence to collector ring 28', and through conductor 75 and operating coil 50 to supply main 40. The energization of operating coil 50 picks up switch arm 48 into engagement with contact 53, thus closing the circuit through the armature of servo motor 10 in the reverse direction from supply main 39 through switch arm 48, conductor 46, armature 44, conductor 45 and switch arm 49 back to supply main 40. The servo motor is now controlled to move the indicator into angular agreement with the telescope, the final accurate adjustment being made under the direction of contact arm 20, as will be understood from the previous description.

Due to the fact that receiving motors 12 and 12' always turn in directions to take the shortest paths into angular agreement with the transmitting generators, it will be observed that for certain angular differences between the indicator and the telescope, contact arm 20 may initially assume control ahead of contact arm 20' to operate the servo motor in the wrong direction. In such case contact arm 20' will be prevented from taking control by the interlocking projections 56 and 57 on relay 47. The servo motor will therefore be operated in the wrong direction under the control of contact arm 20 until roller 24 seats in the depression in the base of heart cam 25 bringing the contact arm to rest. Immediately

thereafter, as the servo motor continues to drive collecting device 27, the control circuit of contact arm 20 is broken and contact arm 20' takes control, reversing the servo motor. The servo motor is now controlled successively by the contact arms for the coarse and fine adjustments of the indicator, as previously described. Since receiving motor 12 operates at high speed, the indicator will be moved through only a very small angle in the wrong direction before contact arm 20' takes control. The adjustment of the indicator is therefore not appreciably delayed should contact arm 20 initially take control in the wrong direction.

After the receiving motors have been electrically connected to the generators, any subsequent movement of the telescope is immediately reproduced by indicator B. Assuming that the indicator is in agreement with the telescope and the servo motor at rest, as shown in the drawing, any movement of the telescope is immediately reproduced by receiving motors 12 and 12' in their respective ratios, whereby contact arms 20 and 20' are actuated to close the control circuit for the servo motor, the heart cam couplings yielding to permit the receiving motors to turn at once to their stable position. Due to the greater speed ratio of receiving motor 12, contact arm 20 makes contact first. In case the telescope is moved slowly or through only a small angle, contact arm 20' may not be moved sufficiently with relation to its contacts to close the control circuit for the servo motor at all, the servo motor then being controlled entirely by contact arm 20. When a considerable movement is given rapidly to the telescope, a temporary control circuit is initially established by contact arm 20, the control is immediately thereafter taken over by contact arm 20' for the coarse adjustment and subsequently by contact arm 20 for the fine adjustment, as will be understood from the previous description. When operating at high speed, the servo motor is adapted to move the indicator at a higher speed than it is possible to move the telescope, and therefore the indicator will not lag appreciably behind the telescope. Should, however, for any reason whatever, receiving motor 12' be displaced more than 180 degrees with relation to contact arm 20', so that roller 24' is moved past the point of heart 25', then the contact arm would be biased in the opposite direction and moved into engagement with the other cooperating contact, whereby the servo motor would be reversed to drive the indicator through the lesser angle into agreement with the telescope.

In Fig. 2 we have shown a modification of our invention in which the stators of the receiving motors 12 and 12' are rotatably

mounted. By means of this arrangement we are enabled to eliminate the collecting devices 27 and 27'. The contacts 21 and 22 are mounted on a suitable stationary support, as are also contacts 21' and 22'. The conductors 73, 74, 75 and 76 are connected permanently to the various contacts in the same relation as described in connection with Fig. 1, but without the interposition of the collecting devices 27 and 27'. The effect of the heart cams 25 and 25' is the same as disclosed in connection with Fig. 1 to allow the rotors 56 and 56' of the receiving motors to turn at once to their stable positions. Instead of being geared to drive collecting devices 27 and 27' as shown in Fig. 1, the servo motor is geared to the stators 57 and 57' of the receiving motors. The servo motor is connected to stator 57 by means of a spur gear 32 on the stator meshing with the spur gear 33 on the shaft 82 of the servo motor, and to stator 57' by a gear train 35, 36, 37, and 38. The gear ratio between the stators is the same as the speed ratio between the rotors. The connections of the stator and rotor windings of receiving motors 12 and 12' are the same as disclosed in connection with Fig. 1.

Upon connecting receiving motors 12 and 12' to their generators, the receiving motor rotors snap quickly into angular positions with relation to their stators which correspond with the angular positions of the generator rotors with relation to their stators. Contact arms 20 and 20' are thus moved to close the control circuit of the servo motor, as disclosed in connection with Fig. 1. As the servo motor operates, moving the indicator into angular agreement with the telescope, it rotates the stators of the receiving motors in directions opposite to the previous movement of the rotors of the receiving motors. As the stators of the receiving motors are rotated, their respective rotors are maintained in a predetermined angular relation therewith, assuming the telescope to be at rest, and hence are rotated with the stators in directions opposite to their previous movements with relation to their stators. The rollers on the heart cam couplings are at the same time moved toward the depressions in their respective heart cams. When rotor 56' of receiving motor 12' has been rotated to some point within 21½ degrees of its predetermined angular relation with contact arm 20', roller 24' seats in the depression on heart cam 25', and upon a slight continued movement of rotor 56' contact arm 20' is moved to open the control circuit for the servo motor, the control of the servo motor being then taken over by contact arm 20 for the accurate adjustment. Upon subsequent angular movement of the telescope the servo motor is controlled by the contact arms to drive the indicator into

angular agreement with the telescope. The details of the operation of this modification of our invention will be understood with reference to the description of Fig. 1.

5 It will be observed that in this modification of our invention the rotors of the receiving motors are maintained substantially in predetermined angular positions in space. When the receiving motors are electrically
10 connected to their respective generators with the telescope and indicator considerably out of angular agreement, the rotors of the receiving motors snap quickly into positions with relation to their respective stators corresponding to the relative position of the
15 respective generator rotors and stators, but are subsequently carried back to their predetermined angular positions in space upon rotation of their stators by the servo motor.
20 When the telescope is being moved, the stators of the receiving motors are rotated by the servo motor at practically the same speed as the rotors of the generators are rotated, the rotors of the receiving motors
25 moving angularly in space only through the very small angle necessary to control the servo motor.

It will be observed that in both forms of our invention receiving motor 12' controls
30 the servo motor independently of receiving motor 12. The control of the servo motor by receiving motor 12 is dependent, however, upon the initial coarse adjustment of the servo motor under the control of receiving motor 12'.
35

Obviously, various objects may be driven by the servo motor, and a servo motor may be chosen so as to amplify the power of the reproducers to any desired degree as required to drive the driven object.
40

In accordance with the provisions of the patent statutes, we have described the principle of operation of our invention, together with the apparatus which we now consider
45 to represent the best embodiment thereof; but we desire to have it understood that the apparatus shown is only illustrative, and that the invention can be carried out by other means.

50 What we claim as new and desire to secure by Letters Patent of the United States, is:

1. Means for reproducing position comprising in combination with a controlling
55 object and a driven object, of an electric motor for driving said driven object, a contact device for controlling said motor operated upon a slight movement of the controlling object in either direction to close
60 a circuit for movement of the driven object in either of two directions, and an operating connection between said controlling object and said contact device for controlling said contact device to cause the driven ob-
65 ject to assume any position of the control-

ling object by the shortest path thereto regardless of the course of the controlling object.

2. Means for reproducing position comprising in combination with a controlling
70 object and a driven object, of an electric motor for driving said driven object, control means for said motor, a reproducer of angular movement responsive to movement
75 of said controlling object for operating said control means so as to cause the motor to drive the driven object into agreement with the controlling object, and an operating connection between said reproducer and said
80 control means for controlling said control means to cause the driven object to assume any position of the controlling object by the shortest path thereto regardless of the course of the controlling object.

3. Means for reproducing position comprising in combination with a controlling
85 object and a driven object, of an electric motor for driving said driven object, a contact device for controlling said motor, a reproducer of angular movement responsive to movement of said controlling object for operating
90 said contact device upon movement of the controlling object in either direction to close a circuit for movement of the driven object in either of two directions, and an operating connection between said
95 reproducer and said contact device for controlling said contact device to cause the driven object to assume any position of the controlling object by the shortest path thereto regardless of the course of the controlling
100 object.

4. Means for reproducing position comprising in combination with a controlling
105 object and a driven object, of an electric motor for driving said driven object, a contact device for controlling said motor operated upon a slight movement of the controlling object in either direction to close
110 a circuit for movement of the driven object in either of two directions, and an operating connection between said controlling object and said contact device permitting independent movement thereof but causing said
115 contact device to reverse said motor every half revolution of such independent movement.

5. Means for reproducing position comprising in combination with a controlling
120 object and a driven object, of an electric motor for driving said driven object, control means for said motor, a reproducer of angular movement responsive to movement of said controlling object for operating said
125 control means so as to cause the motor to drive the driven object into agreement with the controlling object, and an operating connection between said reproducer and said control means permitting independent move-
130 ment thereof but causing said control means

to reverse said motor every half revolution of such independent movement and being adapted to maintain said control means in open circuit position at one of the points of reversal.

6. Means for reproducing position comprising in combination with a controlling object and a driven object, of an electric motor for driving said driven object, a pair of spaced contacts, a contact arm cooperating with said spaced contacts, a reproducer of angular movement responsive to movement of said controlling object for actuating said contact arm between said contacts to cause the motor to drive the driven object into agreement with the controlling object, and an operating connection between said reproducer and said contact arm permitting independent movement thereof but reversing said contact arm at every half revolution of such independent movement and being adapted to maintain said contact arm in open circuit position at one of the points of reversal.

7. Means for reproducing position comprising in combination with a controlling object and a driven object, of an electric motor for driving said driven object, a contact device for controlling said motor operated upon a slight movement of the controlling object in either direction to close the circuit for movement of the driven object in either of two directions, and a yieldable operating connection between said controlling object and said contact device having cooperating parts independently rotatable but biased in a predetermined angular relation in any particular revolution.

8. Means for reproducing position comprising in combination with a controlling object and a driven object, of an electric motor for driving said driven object, a contact arm for controlling the circuit of said motor, a reproducer of angular movement responsive to movement of said controlling object for actuating said contact arm so as to cause the motor to drive the driven object into agreement with the controlling object, and a yieldable operating connection biasing said reproducer and said contact arm in a predetermined angular relation but reversing its bias every half revolution of independent movement thereof.

9. Means for reproducing position comprising in combination with a controlling object and a driven object, of an electric motor for driving said driven object, a contact device for controlling said motor operated upon a slight movement of the controlling object to close a circuit for movement of the driven object in either of two directions; and a yieldable operating connection between said reproducer and said contact device comprising a heart shaped cam and a yieldable member cooperating therewith whereby said

reproducer and said control means are biased in a predetermined angular relation.

10. Means for reproducing position comprising in combination with a controlling object and a driven object, of an electric motor for driving said driven object, control means for said motor, a reproducer of angular movement responsive to movement of said controlling object for operating said control means so as to cause the motor to drive the driven object into agreement with the controlling object, and a yieldable operating connection between said reproducer and said control means comprising a heart shaped cam and a spring pressed roller cooperating therewith, said heart cam being characterized by the fact that the roller is caused to seek a definite position thereon whereby said reproducer and said control means are biased in a predetermined relation.

11. Means for reproducing position comprising in combination with a controlling object and a driven object, of an electric motor for driving said driven object, control means for said motor, a reproducer of angular movement responsive to movement of said controlling object for operating said control means to close the circuit of said motor, a yieldable operating connection between said reproducer and said control means permitting independent movement thereof but reversing said motor each half revolution of such movement, and an operating connection between said motor and said control means whereby the circuit of the motor is opened when the driven object assumes the position of the controlling object.

12. Means for reproducing position comprising in combination with a controlling object and a driven object, of an electric motor for driving said driven object, a reproducer of angular movement responsive to movement of said controlling object, a rotatably mounted stator for said reproducer, control means actuated by the moving element of said reproducer to close the circuit of said motor upon a slight movement of the controlling object, and an operating connection between the motor and said stator whereby the moving element of said reproducer is actuated jointly with said stator to open the circuit of said motor when the driven object assumes positional agreement with the controlling object.

13. Means for reproducing position comprising in combination with a controlling object and a driven object, of an electric motor for driving said driven object, a reproducer of angular movement responsive to movement of the controlling object, a rotatably mounted stator for said reproducer, a pair of spaced contacts, a contact arm actuated by the moving element of said re-

producer between said contacts to close the circuit of said motor upon a slight movement of the controlling object, and an operating connection between the motor and said stator whereby the moving element of said reproducer is actuated jointly with said stator to cause said contact arm to open the circuit of said motor when the driven object is moved into positional agreement with the controlling object.

14. Means for reproducing position comprising in combination with a controlling object and a driven object, of an electric motor for driving said driven object, a reproducer of angular movement responsive to movement of the controlling object, a rotatably mounted stator for said reproducer, a pair of spaced contacts, a contact arm actuated by the moving element of said reproducer between said contacts to close the circuit of said motor upon a slight movement of the controlling object, an operating connection between the motor and said stator whereby the moving element of said reproducer is actuated jointly with said stator to cause said contact arm to open the circuit of said motor when the driven object assumes positional agreement with the controlling object, and a yieldable operating connection between said contact arm and the moving element of said reproducer, permitting independent movement thereof but reversing said contact arm every half revolution of such independent movement.

15. Means for reproducing position comprising in combination with a controlling object and a driven object, of an electric motor for driving said driven object, control means for said motor, coarse and fine reproducers of angular movement responsive to movement of said controlling object for operating said control means so as to cause the motor to drive the driven object into positional agreement with the controlling object, and yieldable operating connections between said reproducers and said control means.

16. Means for reproducing position comprising in combination with a controlling object and a driven object, of an electric motor for driving said driven object, control means for said motor, coarse and fine reproducers of angular movement responsive to movement of said controlling object for operating said control means so as to cause the motor to drive the driven object into positional agreement with the controlling object, and operating connections between said reproducers and said control means for causing the driven object to assume any position of the controlling object by the shortest path thereto regardless of the course of the controlling object.

17. Means for reproducing position comprising in combination with a controlling

object and a driven object, of an electric motor for driving said driven object, control means for said motor, coarse and fine reproducers of angular movement responsive to movement of said controlling object for operating successively said control means so as to cause the motor to drive the driven object into positional agreement with the controlling object, and operating connections between said reproducers and said control means permitting independent movement thereof but reversing said control means every half revolution of such independent movement.

18. Means for reproducing position comprising in combination with a controlling object and a driven object, of an electric motor for driving said driven object, control means for said motor, coarse and fine reproducers of angular movement responsive to movement of said controlling object for operating said control means successively so as to cause the motor to drive the driven object into agreement with the controlling object, and operating connections between said reproducers and said control means permitting independent rotation of said reproducers and said control means but biasing them in a predetermined angular relation in any particular revolution.

19. Means for reproducing position comprising in combination with a controlling object and a driven object, of an electric motor for driving said driven object, control means for said motor, coarse and fine reproducers of angular movement responsive to movement of said controlling object for operating said control means successively so as to cause the motor to drive the driven object into positional agreement with the controlling object, and yieldable operating connections between said reproducers and said control means each comprising a heart shaped cam and a yieldable member cooperating therewith whereby said reproducers and said control means are biased in a predetermined angular relation.

20. Means for reproducing position comprising in combination with a controlling object and a driven object, of an electric motor for driving said driven object, control means for said motor, coarse and fine reproducers of angular movement responsive to movement of said controlling object for operating said control means successively so as to cause the motor to drive the driven object into agreement with the controlling object, and yieldable operating connections between said reproducers and said control means each comprising a heart shaped cam and a spring pressed roller cooperating therewith, said heart cams being characterized by the fact that the rollers are caused to seek definite positions thereon whereby said reproducers and said control

means are biased in a predetermined angular relation.

21. Means for reproducing position comprising in combination with a controlling object and a driven object, of an electric motor for driving said driven object, coarse and fine reproducers of angular movement responsive to the movement of said controlling object, rotatably mounted stators for said reproducers, control means actuated by the moving elements of said reproducers to close the circuit of said motor, and operating connections between said motor and said stators whereby the moving elements of said reproducers are actuated jointly with said stators to open the circuit of said motor when the driven object comes into positional agreement with the controlling object.

22. Means for reproducing position comprising in combination with a controlling object and a driven object, of an electric motor for driving said driven object, coarse and fine reproducers of angular movement

responsive to the movement of said controlling object, rotatably mounted stators for said reproducers, pairs of spaced contacts, contact arms actuated by the moving elements of said reproducers to close the circuit of said motor upon a slight movement of the controlling object, an operating connection between the motor and said stator whereby the moving element of said reproducer is actuated jointly with said stator to cause said contact arm to open the circuit of said motor when the driven object comes into positional agreement with the controlling object, yieldable operating connections between said contact arms and the moving elements of the reproducers permitting independent movement thereof but reversing said contact arms every half revolution of such independent movement.

In witness whereof, we have hereunto set our hands this 14th day of December, 1921.

E. J. MURPHY.
LEONARD P. HUTT.