United States Patent [19]

Daab

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[54] **METHOD AND APPARATUS FOR MOVING A SHAFT INTO A PREDETERMINED ANGULAR POSITION**

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[30] **Foreign Application Priority Data**

Nov. 5, 1970 Germany .... P 20 54 501.1

[52] **U.S. Cl.** .... **318/467,** 318/369, 318/372, 112/219 A

[51] **Int. Cl.** **H02p 3/00**

[58] **Field of Search** .... 318/467, 265–267, 318/369, 372; 112/219 A

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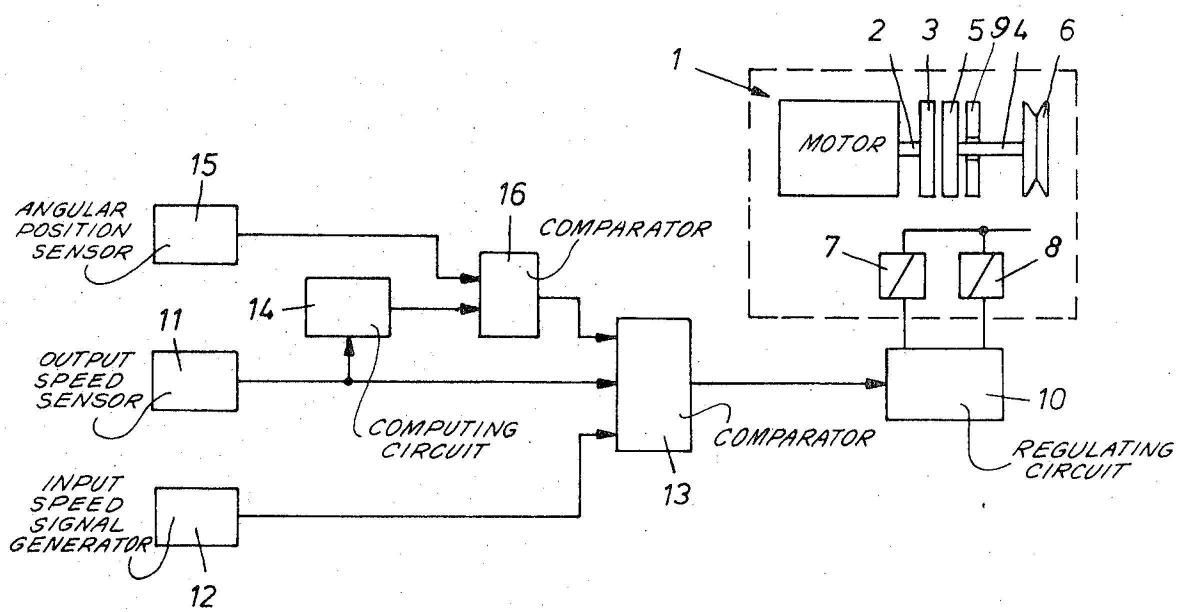
[57] **ABSTRACT**

A method and apparatus through which a moving shaft is stopped in a predetermined angular position. The shaft is driven at a maximum speed through an electrically driven motor. When the shaft is to be stopped at the predetermined angular position, the shaft is decoupled from the motor and an electromagnetic brake is applied. A regulating circuit controls the braking action so that it is dependent on a comparison of the actual output speed of the shaft and a desired input speed, as well as the comparison of a computed braking angle and the predetermined angular position to which the shaft is to be rotated. Position and speed sensors connected to the shaft provide signals representing the instantaneous output position and speed of the shaft.

27 Claims, 14 Drawing Figures



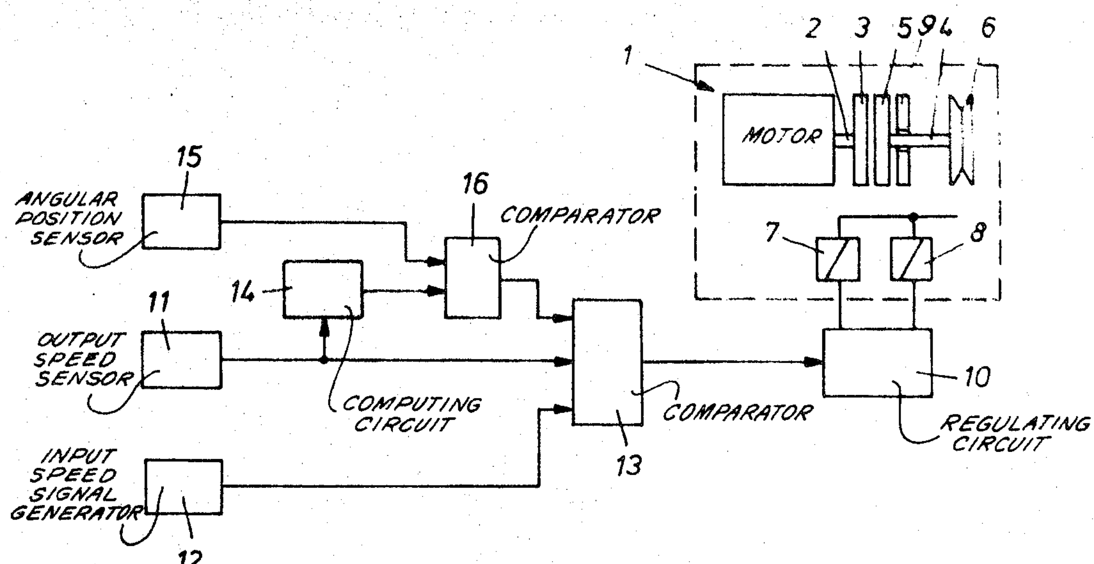


FIG. 1

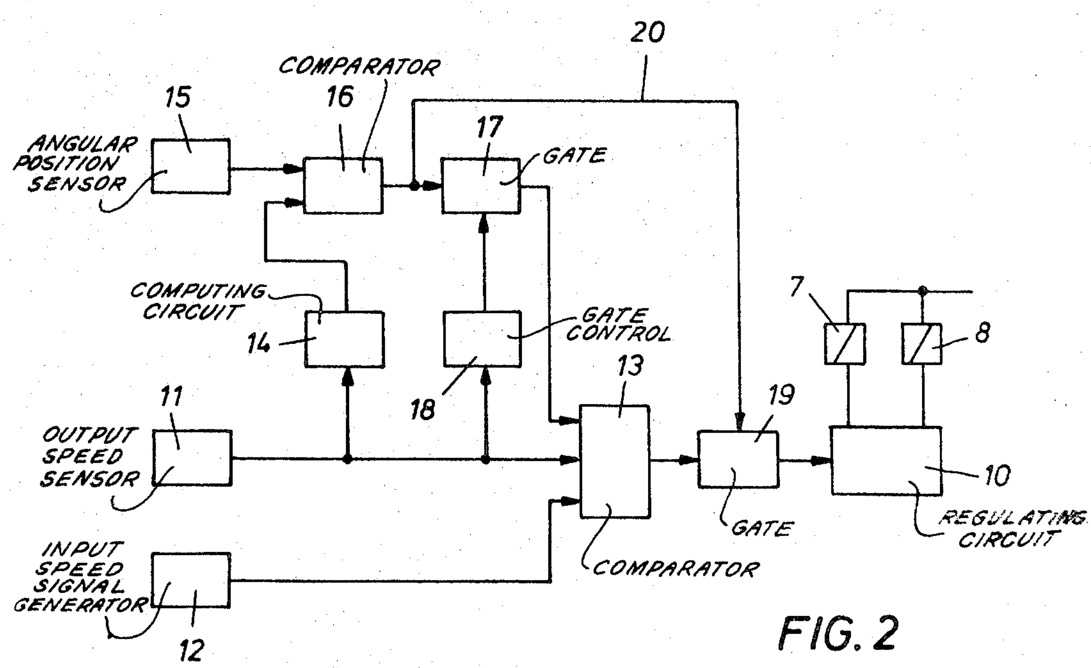


FIG. 2

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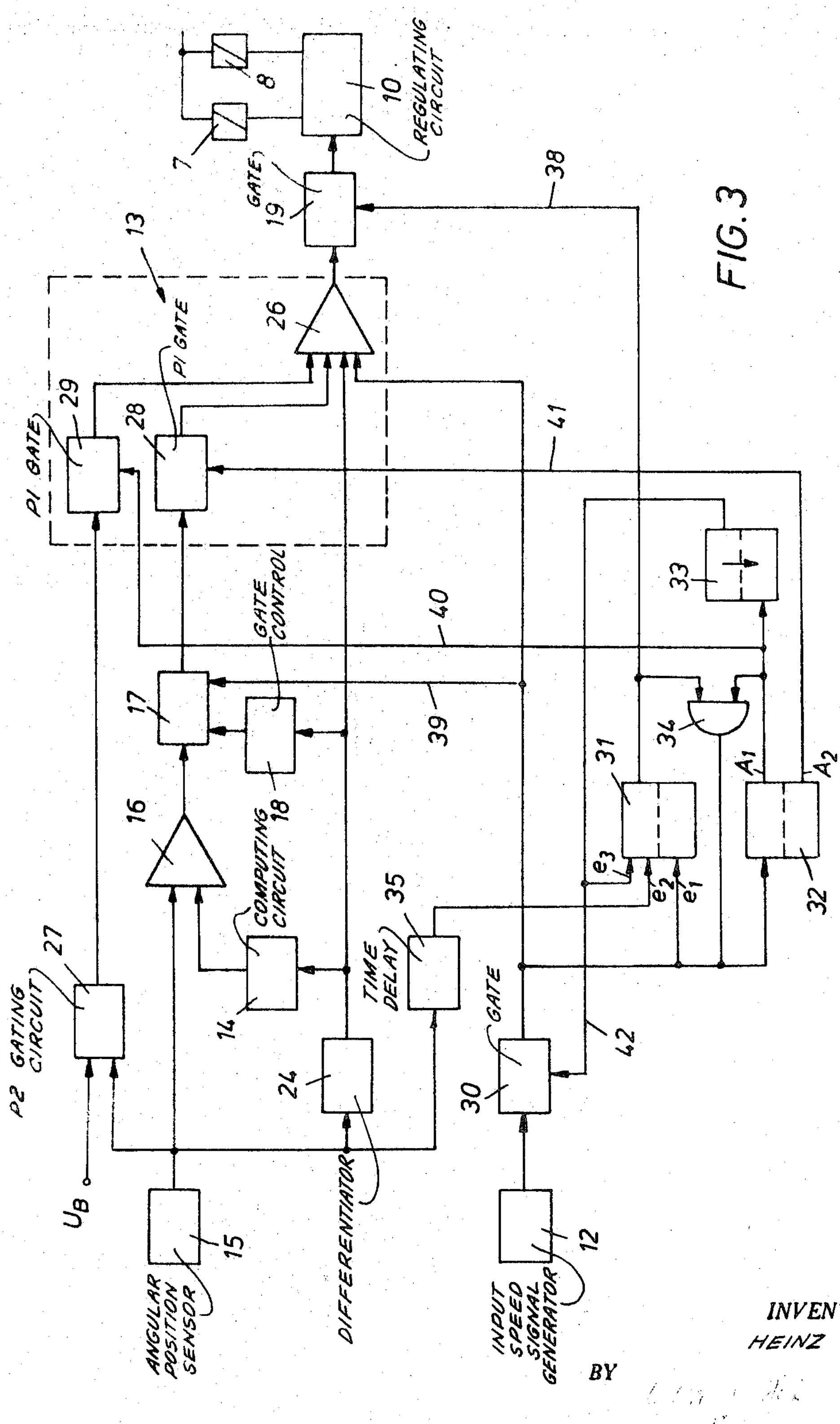

FIG. 3

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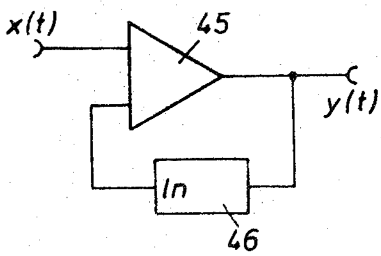

FIG. 4

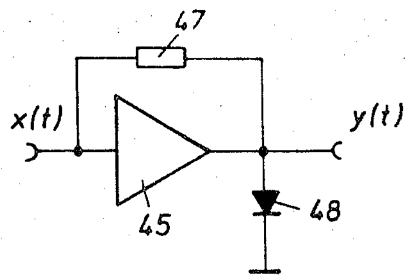

FIG. 5

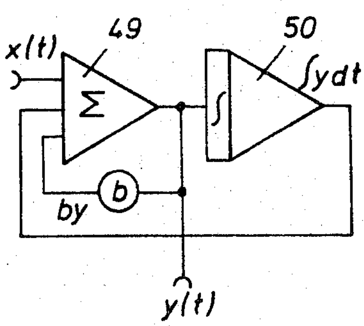

FIG. 6

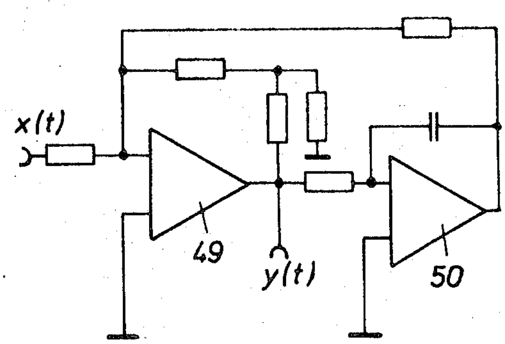

FIG. 7

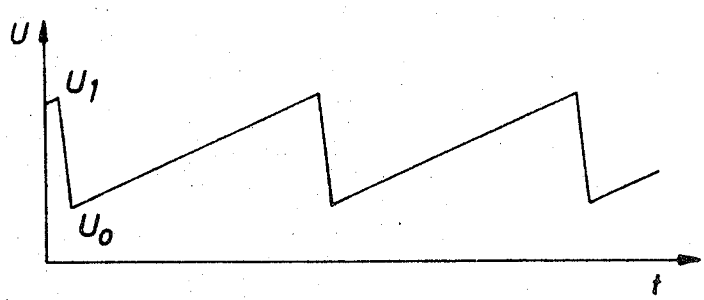

FIG. 13

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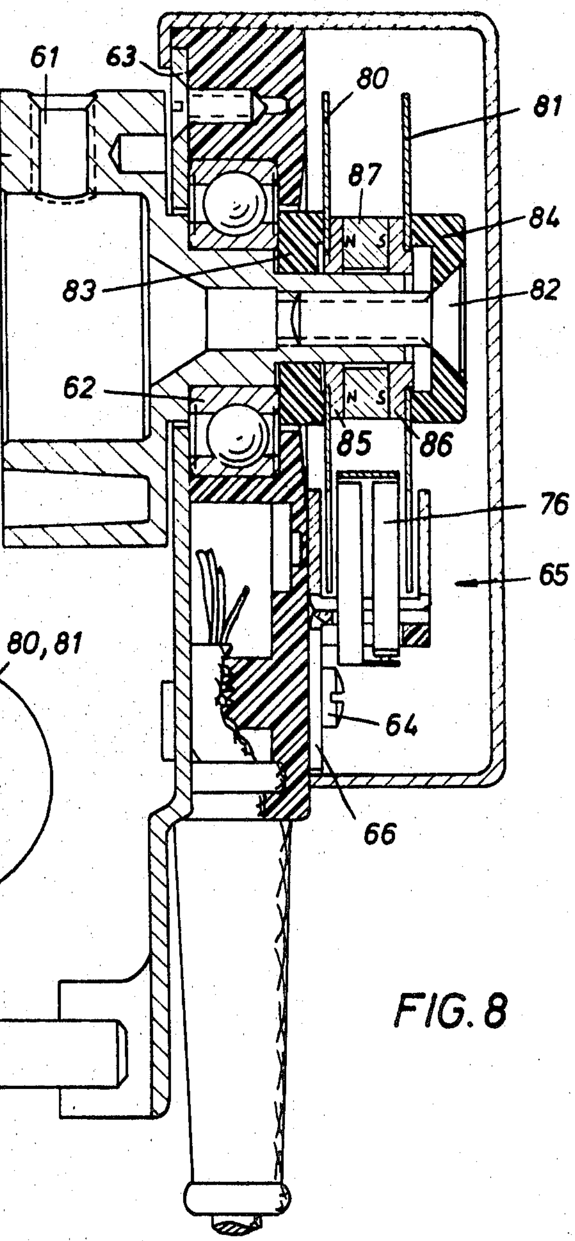

FIG. 8

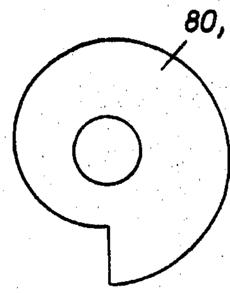

FIG. 9

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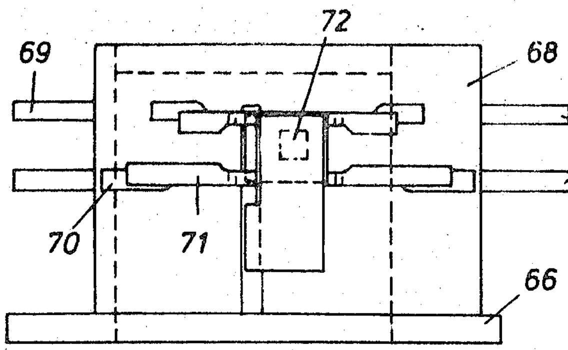

FIG. 12

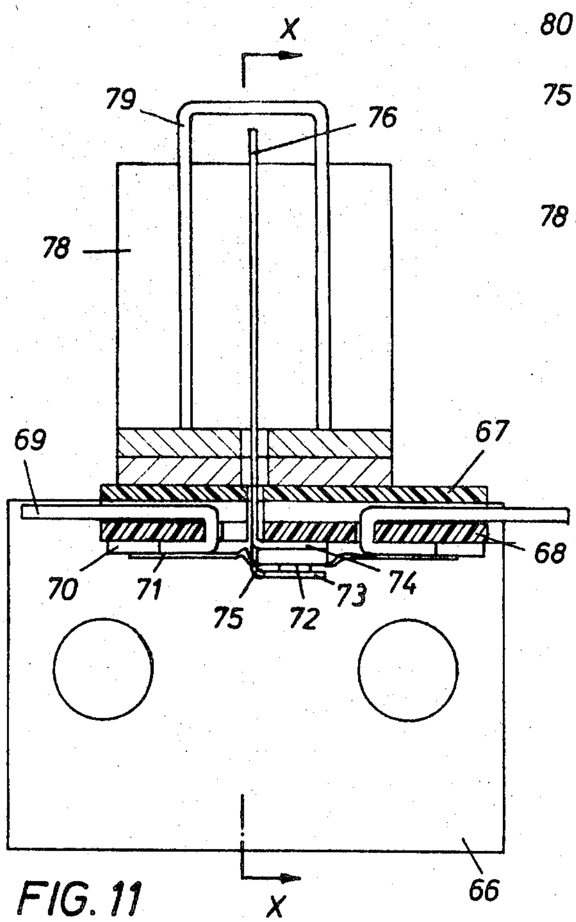

FIG. 11

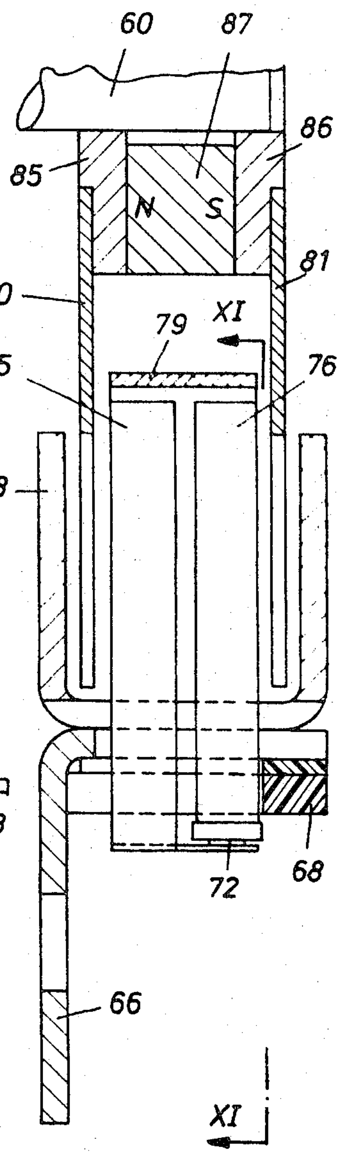

FIG. 10

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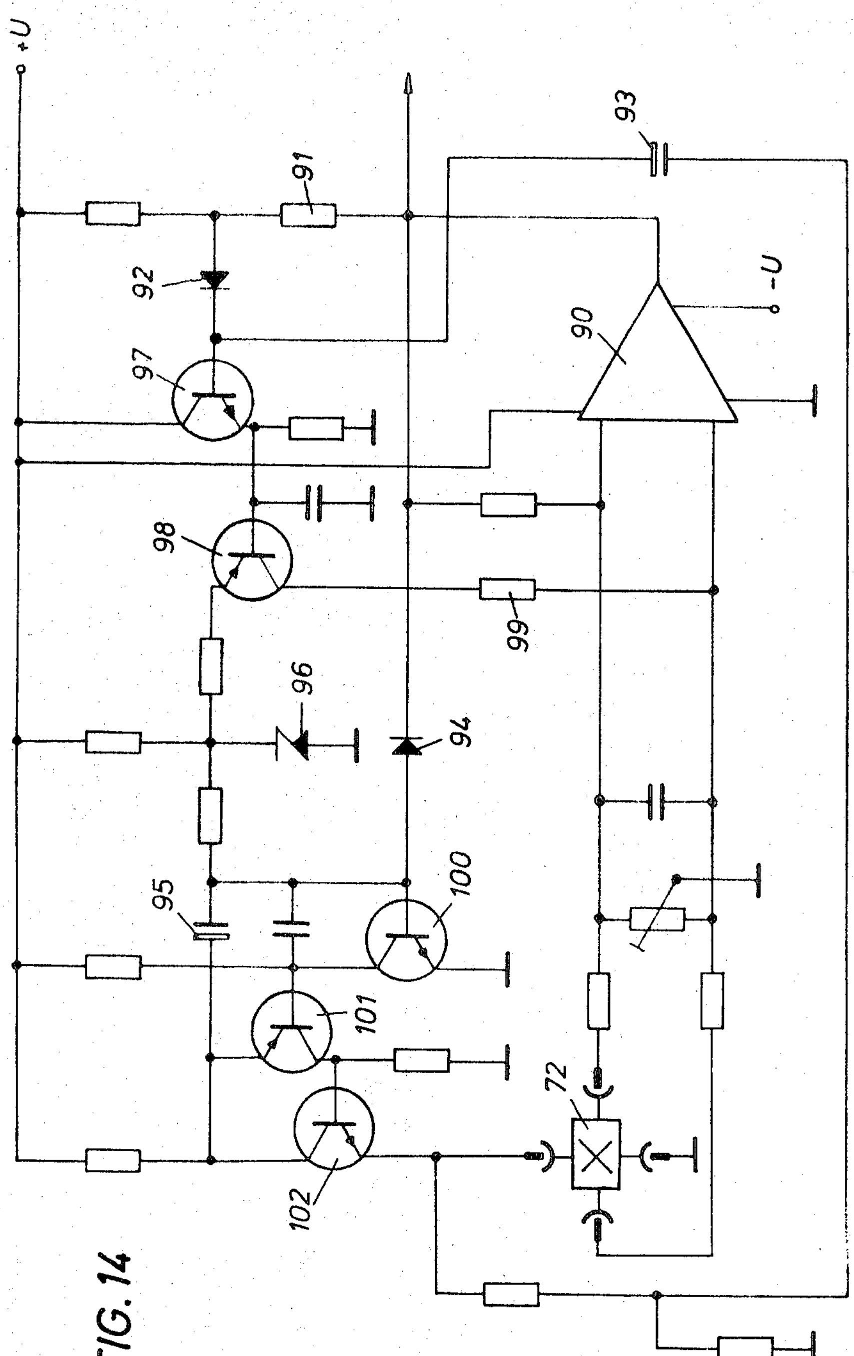

FIG. 14

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METHOD AND APPARATUS FOR MOVING A SHAFT INTO A PREDETERMINED ANGULAR POSITION

BACKGROUND OF THE INVENTION

The present invention relates to a method and apparatus for positioning a shaft into a predetermined angular location by using an electrical motor with an electrically-operated coupling. The coupling connects the shaft to be positioned with the motor for purposes of imparting to the shaft a predetermined operating speed. The coupling, as well as a brake winding through which the shaft is braked into the desired end position, are energized and controlled through a regulating circuit.

Conventional position control arrangements of the preceding species operate, in general on the basis that when the shaft is to be positioned, it is first braked to a lower speed from its higher operating speed and then a regulator maintains the lower speed of the shaft until a synchronizer becomes actuated or becomes operative for applying the final braking action to bring the shaft to a stop position, whereby the speed is then reduced to zero. The stopping process for the shaft under this conventional method, is not a continuous process. Instead, the conventional procedure is a stepwise control with intermediate delay periods in the lower operating speed portion of the cycle. The time interval during which the shaft to be positioned, operates at the lower braked speed, is dependent upon the angular position which the operating shaft is to assume upon reaching the lower braked speed, and thus this time interval can be greater or smaller. This time interval can, in fact, attain a value which corresponds to a full revolution of the operating shaft when rotating at the lower braked speed.

In many applications, as for example, in driving of industrial sewing machines, it is essential to position the shaft not only with high accuracy and precision, but also to carry out the positioning procedure within the shortest possible time. This requirement may be understood when taking into account the condition that industrial sewing machines are switched daily approximately ten thousand times. Accordingly, even a slight shortening of the period of time during which the shaft is stopped in a desired position, will have a considerable influence upon the productivity of the machine.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a positioning arrangement in which a rotatable shaft is positioned to a predetermined angular position within a substantially short time.

It is also an object of the present invention to position a rotatable shaft, as set forth, with substantial accuracy and precision.

It is a still further object of the present invention to provide a positioning arrangement of the foregoing character which is simple in design and may be readily fabricated.

Another object of the present invention is to provide a shaft positioning arrangement which has a long operating life and may be readily maintained.

The objects of the present invention are achieved by providing a method under which the actual output speed of the shaft to be positioned is continuously measured. A braking torque is applied which is lower than the maximum applicable braking torque, as computed in correspondence to a required braking angle which is related to the actual output position of the shaft. The actual output position of the shaft is measured instantaneously and compared with the computed braking angle. The signal obtained from the comparison of the angular positions, as applied to the regulator which also is controlled through a speed comparison which compares a desired input speed of the shaft with the actual output speed of the shaft. The regulator then provides signals by which the shaft is positioned into the desired angular location. In accordance with the method of the present invention, the time interval delay incurred with the lower braking speed used in the conventional methods is avoided. The operating shaft is braked, in accordance with the present invention to zero velocity in one predetermined procedural step which applies a predetermined braking function. The halting procedure of the shaft is regulated and this is also not found in the conventional methods. In the latter, there is no regulation after braking to the lower speed and allowing the synchronizer to become operative. In conjunction with shortening the time interval by which the shaft is positioned, therefore, the shaft is also positioned with considerably greater accuracy and precision, in accordance with the present invention, and therefore considerable improvement is obtained over the prior art.

In a further embodiment of the present invention the brake can be fully applied when the procedure for stopping the shaft is initiated. The brake can then be partially applied until the desired braking angle is attained. The braking action, in such case, is applied with full force in order to obtain a speed versus angle function which passes through zero, whereby no time is spent during an intermediate speed in correspondence to the conventional lower speed interval. If the function during the regulated braking interval is denoted by $w = f_2(n)$, and if the equation describing the functional operation for the unregulated part of the process is denoted by $w = f_1(n)$, then the switching from an uncontrolled procedure to the controlled procedure takes place preferably at the intersection of these two functions, where w is the braking angle dependent upon the predetermined angular shaft position, and n is the actual output shaft speed.

The actual output shaft speed can be obtained from variations in the speed of the angle measuring sensor. It is also possible, instead, to derive the value for the angular position from the actual speed parameter. For this purpose, pulses from a speed measurement may be summed from a speed output generator.

The output signal of the comparator which compares the braking function angle with the actual position of the shaft is preferably connected to a regulator which also takes into account the actual output shaft speed and the desired input shaft speed for the purpose of generating a regulating signal for purposes of bringing the shaft to the desired stationary position. For the rapid initial braking mentioned above, which is applied prior to carrying out regulation as a function of angular position, a gate is connected to the sensor which determines the actual output speed of the shaft for inhibiting the transmission of the output from the computing device for as long as the actual shaft output speed is above a predetermined value. Until this value is obtained, the braking action takes place exclusively on the basis of a comparison of the actual output speed of the shaft with a desired input speed.

While operating with a desired input speed generator which has a preset operating speed, it is possible to prevent undesired positioning of the shaft through the use of a gate connected to this generator for applying a desired input speed to the shaft. This gate causes to prevent transmission from the output of the computer which computes the braking function and applies it to a comparator for comparing against the actual output angular position of the shaft. The gate serves to block the output of this comparator for as long as the preset desired input speed is different from zero. First when the desired input speed generator is set to zero for the purpose of retaining the operating shaft in a predetermined angular position, does the gate permit the transmission of the output from the comparator which has the computing function as one input and the actual position of the shaft as the second input.

The regulator can have connected before it a control stage which causes the control windings for the motor coupling to be deenergized as a function of reaching the desired input position for the shaft. With this arrangement, the operating shaft becomes then freely rotatable after having reached its desired, predetermined angular position, and can then, as desired, be rotated by, for example, hand.

When braking as a function of angular position, in accordance with the present invention, it is particularly important to obtain precisely the instantaneous angular output position of the shaft until substantially very low speeds for the shaft are obtained. In order to meet these conditions, an angular measuring device with a hall generator is used. The latter becomes influenced through a magnetic disc coupled to the operating shaft. This magnetic disc has a continously decreasing radius from a maximum value to a minimum value. A sudden step takes place from the transition of the minimum value to the maximum value, Such an angular measuring sensor or device ir independent of frequency and speed. As a result, angular positions can be precisely reproduced and measured even at low speeds for the shaft. In addition, this angular position sensor, in accordance with the present invention, has no contacts, and this results in substantially high operating reliability and long operating life of the unit. The sudden step in the magnetic disc profile can be used, in a simple manner, for marking the desired input angle of the operating shaft. In this manner, the angular position sensor fulfills the function of a sensor for determining the actual output shaft angular position and as a generator for providing the desired input angle.

In place of the actual speed sensor for determining the output shaft speed, it is possible to use basically any of the conventional sensing devices, as for example, a tachogenerator which provides a voltage as a function of speed, or a pulse train which has a pulse frequency dependent upon the shaft speed. In accordance with a further embodiment of the present invention, the hall generator for measuring angular position can also be used for providing speed measurements. In such an arrangement, the actual output shaft speed is provided through a computing device which computes the speed from the measured angular position. Since the speed is the time derivative of angular position, the actual output speed can be obtained basically from the actual output angle, through the computing device which may

be designed in the form of a differentiating stage. Such a differentiating stage is well known in the art and can be of varied construction. A direct differentiation, however, can lead to instabilities in the regulating system. Such instabilities may be avoided when, in accordance with a further embodiment of the present invention, the actual shaft output speed and the actual shaft angular position from which the speed is determined through a computing device, are connected to two operational amplifiers. The first of these operational amplifiers is in the form of a summing amplifier, whereas the second amplifier is constructed in the form of an integrator with feedback coupling so that when an input voltage of $x(t)$ is applied, the output of the summing amplifier provides a voltage in the form of $y(t) = x + by - \int y\, dt$. In this relationship, b is different from one, and the integrator becomes reset at the completion of each revolution.

The computing dwvice for the braking function is provided preferably with an operational amplifier having a feedback network, so that when an input voltage $x(t)$ is applied to the amplifier, the latter provides an output voltage of the form $y(t) = e^x + C$.

The comparator for comparing the braking function with the actual output shaft angle, as well as the second comparator can be advantageously designed in the form of summing amplifiers. Operational amplifiers of such design can be constructed from low cost miniature components having high precision.

In practice, it is often necessary to move the operating shaft into a second desired position after having held it in a first desired position. The second position of the shaft may be separated by less than 360° from the first stopping position. The present invention provides for this feature by providing a control device which is influenced by the input angle position generator, whereby the regulator receives a control signal after the operating shaft has been stopped in the first desired position. This control signal then causes the operating shaft to further rotate into a second position. For this arrangement, it is desirable to alternatingly block the transmission of the output of the comparator for the brake function and actual shaft angular position, as well as the output for the control circuit associated with the second stopping position of the shaft. Programming stages are preferably provided through which the components used in the preceding arrangement can be controlled, so that the stopping of the shaft in the second desired position is always preceded by a braking of the shaft to the first desired position.

The transfer from the first position to the second shaft position can be carried out through any desired one of a number of possible circuits. A particularly simple operating circuit is made possible by providing that by means of the desired input speed generator, the command signal for the transfer from the first position to the second position is also obtained. In such a case, it is advantageous to provide a gate between the desired input speed generator and the regulator. The gate prevents the influence of the regulator through the output signal from the desired input speed generator during rotation of the operating shaft from the first position into the second desired position.

The precision of angular measurement carried out through the use of the aforementioned hall generator can be considerably increased through the use of comparator stages which compare the minimum and maximum values from the hall generator with reference voltages. In conjunction with this arrangement relating elements are provided which apply regulating functions in dependent on the reference values as a function of the comparison made with the minimum and maximum hall voltages.

The novel features which are considered as characteristic for the invention are set forth in particular in the appended claims. The invention itself, however, both as to its construction and its method of operation, together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is a block diagram and shows the controlling arrangement for positioning a shaft, in accordance with the present invention;

FIG. **2** is a block diagram of a second embodiment of the arrangement of FIG. **1**;

FIG. **3** is a schematic diagram of a third embodiment of the present invention;

FIG. **4** is a schematic diagram of a computing circuit for computing a braking function used in conjunction with the arrangement of the present invention;

FIG. **5** is a circuit diagram for a preferred embodiment of the computing curcuit of FIG. **4**;

FIG. **6** is a functional schematic diagram of an arrangement for deriving a speed signal from an angular position signal to be used in conjunction with the arrangement of the present invention;

FIG. **7** is a circuit diagram for the arrangement of FIG. **6**;

FIG. **8** is a sectional elevational view of a preferred angular position sensor, in accordance with the present invention;

FIG. **9** is a plan view of a magnetic element used in the sensor of FIG. **8**;

FIG. **10** is an enlarged sectional view of an angular measuring device taken along line X—X in FIG. **11**;

FIG. **11** is a partial sectional view taken along line XI—XI in FIG. **10**;

FIG. **12** is an enlarged view of the measuring head used in the angular measuring device illustrated in FIGS. **8** to **11**, when viewed from below;

FIG. **13** is a graphical representation of the waveform of the signal provided by the angular measuring device used in FIGS. **8** to **12** for measuring an actual shaft position; and

FIG. **14** is a circuit diagram for stabilizing the arrangement using the angular measuring device shown in FIGS. **8** to **12**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to the drawing, the brake characteristics of a motorized or motor-driven coupling are generally known in the art, or they may be determined empirically in a simple manner. In general, motor-driven coupling arrangements operate in a manner that when a constant voltage is applied to the brake winding of the coupling, a constant braking torque is applied to the driven shaft.

If the angular rotation of the driven shaft is denoted by w, and the rotational speed of a shaft is denoted by n, then for the mass m of the shaft the braking torque is given by

$$M = m\,(d^2\,w)/dt^2 = m\,dn/dt \qquad (1)$$

Since the mass m is constant, then for a constant braking torque M

$$dn/dt = \text{const.} \qquad (2)$$

Since, moreover

$$w = \int n\,dt = \int \frac{n}{\frac{dn}{dt}}\,dn \qquad (3)$$

It follows from a combination of equations 2 and 3 that

$$w \sim n^2 \qquad (4)$$

Equation 4 illustrates that a quadratic relationship prevails between the angular rotation of the brake shaft and the speed of the shaft when the applied braking torque is constant. Consequently, provided that the braking torque remains constant, then a predetermined angle of rotation of the brake shaft can be associated for each value of shaft speed, through the quadratic relationship.

It will be understood, of course, that a relationship can also be derived when the applied braking torque is not constant. For purposes of simplicity, however, it will be assumed that the braking torque is constant in the following analysis and application. This assumption simplifies the analysis.

The principle of the present invention involves the use of a computing element which takes into account the known braking characteristics of a motor driven coupling, and computes the braking angle or rotational angle of the shaft for the corresponding speed of the shaft. After having computed the angular rotation of the driven shaft to be braked, this computed angle is compared with an instantaneously measured position of the shaft, and the comparison is used to generate a regulating signal or parameter by which the braking coils for the shaft and/or coupling windings are energized, in order to produce the desired end results. Such end result is achieved by forcing the braked shaft to become stopped in an angular position which corresponds to the angle computed by the computing element. The movement of the shaft towards this desired computed angle is continuously monitored until the shaft has obtained this predetermined computed position. As a result, of the use of this arrangement, it is theoretically possible to obtain unlimited high precision for positioning the shaft. In practice, the precision for positioning a shaft, in this manner, is only limited through the component parts which are used, particularly the angle transducer which is the element that senses the instantaneous angular position of the shaft to be braked. The design of the computing element for the braking function is not to be based upon the maximum applicable braking torque. Instead, the design is to be based on a braking torque which permits regulation with an applied torque which is also below that of the maximum applicable torque. In carrying out the braking process, furthermore, no regulating deviations are to prevail which will require an instantaneous increase in the applied braking torque.

FIG. 1 shows in schematic form, a positioning arrangement, in accordance with the present invention. The motor 1 which drives the coupling has a continuous maximum rotational speed applied to its rotating shaft 2, which, in turn, carries a driving disc 3. A driven shaft 4 carries a coupling disc 5 and a driving pulley 6. By actuating a coupling winding 7, the coupling disc 5 can be made to move into contact with the driving disc 3. When energizing the braking winding 8, on the other hand, the coupling disc 5 is brought to bear or press against a braking member 9. Motorized drives of this type of construction are also known in the art, which have a subdivided coupling disc. Such subdivided coupling disc makes it possible to simultaneously engage the driven shaft with the driving disc and the braking member with more or less pressure. The windings 7 and 8 are controlled through a regulating circuit 10.

A rotational speed sensing device 11 determines continuously the instantaneous rotational speed of the driven shaft 4. Through the application of an input speed signal generator 12, the desired input speed of the driven shaft 4 may be adjusted or set. The signals from the speed sensor 11 and the input speed signal generator 12 are compared in a comparator 13. The difference between the two signals being compared, is applied in signal form to the regulating circuit 10. The arrangement described up to this point, is known in the art, and operates in the manner so that the regulating circuit 10 provides regulation whereby the driven shaft is caused to operate at a speed corresponding to the input speed determined by the generator 12.

In accordance with the present invention, the output speed sensing device 11 is connected to a computing circuit 14, which computes the braking angle or angle of rotation of the shaft corresponding to the instantaneous speed of the shaft, as measured by the sensor 11. This braking angle or angle of rotation of the shaft represents the angle through which the shaft will rotate to become stationary upon the application of a torque which is less than the required maximum braking torque. The computing circuit 14 can be designed, for example, so that the applied braking torque corresponds to a predetermined level of excitation of the braking winding 8. The output signal from the computing circuit 14 is applied to a comparator 16 which has also a second input derived from an angle transducer 15. This angle transducer measures angular position of a shaft or change in that position. The angular position sensor 15 measures continuously the angle which the driven shaft must pass through in order to attain the desired position at which the shaft is to be stopped. This measured output angular position derived from the sensor 15 is compared with the desired input angle as computed by the circuit 14. The computing circuit 14 provides the desired input or positioning the shaft, in accordance with the required braking angle corresponding to the prevailing rotational speed of the shaft to be positioned. The output signal from the comparator 16 is also applied to an input of the comparator 13.

In operation of the circuit arrangement of FIG. 1, the input speed signal generator 12 is set to zero, when the shaft is in the desired position. The circuit elements 14, 15 and 16 are simultaneously set into operation. For this purpose a gate, not shown, can be connected between the output of the comparator 16 and the corresponding input to the comparator 13, so as to gate as desired, the signal from the comparator 16 to the comparator 13. The deviation of the input speed signal generator from the output speed sensor is adjusted so as to become zero. The regulator 10 has then a signal applied to it by the comparator 13, so as to energize the brake winding 8. As a result of this action, strong braking of the driven shaft 4 results, as well as of any shaft connected to this driven shaft. The closer the instantaneous measured speed of the shaft is to the desired and set input speed, and this set input speed is zero, the stronger is the influence of the output signal on the comparator 16 on the regulator 10. As a result, the drive shaft is brought to the position computed by the circuit 14, and the shaft is braked by the regulator 10 in correspondence with a predetermined braking function. Such braking action applied by the regulating circuit 10 takes place until the output signals from the circuit 11, 12 and those from the elements 14, 15 are all equal, whereby the output from the comparator 13 is zero.

FIG. 2 shows in schematic form another embodiment of the arrangement of FIG. 1. From the viewpoint of simplifying the diagram, only the windings 7 and 8 are shown for the motor-driven arrangement. Thus, the motor 1 and the mechanically coupled parts thereto are omitted from the embodiment of FIG. 2 in order to maintain this diagram in simple form. In addition to the components used in FIG. 1, FIG. 2 provides for a gate circuit 17 connected between the output of the comparator 16 and the corresponding input of the comparator 13. Connected to the output of the input speed sensor 11, furthermore, is a control circuit 18 for switching the gate 17 on and off. Another gate 19 is connected in series with the signal line leading from the output of the comparator 13 to the input of the regulating circuit 10. This gate 19 is controlled through a line 20 in dependence on the output signal from the comparator 16.

Once normal operating speed of the driven shaft, the gate 17 blockes the transmission of the output signal from the comparator 16, to the corresponding or respective input of the comparator 13. The gate 17 becomes opened by the control circuit 18 first when the signal from the sensor 11 has dropped below a predetermined value during the process in stopping the driven shaft. The gate 17 in combination with the control circuit 18 makes it possible to fully energize the brake winding 8 during a first portion of the shaft stopping process. During this first portion of a stopping process, the difference between the output signals from the sensors 11 and generator 12 is substantially large, and the brake winding 8 is thereby to be energized independent of the output signal from the comparator 16. Only after the instantaneous measured speed of the driven shaft has dropped below a predetermined value, does the control circuit 18 switch on the gate 17, whereby further braking action becomes regulated in dependence on the speed comparison as well as the comparison between the desired or computed brake angle and the instantaneously measured angle. The duration of time interval during which the stopping procedure for the shaft is carried out is, thereby, reduced without incurring reductions in the precision for the positioning of the shaft.

During the stopping process for the shaft, the gate 19 is controlled so that the output signal from the comparator 13 can be applied to the regulating circuit 10. As soon as the instantaneously measured angle of the shaft position agrees with the computed brake angle, so that the shaft has arrived at the desired angular position, then the blocking signal applied by line 20 to the gate 19 is such that the gate 19 is switched to its blocking state. Thus, upon removal of the signal from the line 20, the gate 19 will not transmit. The regulating circuit 10 becomes, thereby, switched off, and the two windings 7 and 8 are deenergized. The driven shaft 4 is, as a result, disengaged from the driving disc 3, as well as from the brake member 9, — a situation which is often advantageous. If, for example, the drive of the present invention is used in conjunction with industrial sewing machines, then the sewing machine shaft is released in the desired stop position and can then be further adjusted or positioned manually as desired.

In the positioning of shafts in accordance with the species under consideration, it is often required to move the shaft into a second position after it was stopped in a first position. This second position may be spaced from the first position by an angular amount which is less than 360°. Thus, if the arrangement is used in conjunction again with industrial sewing machines, and the shaft is to be stopped when the needle is in its lowermost position, then it may be desirable to move afterwards the needle to its uppermost position, or vice versa. In such an operating requirement, the driven shaft, in this case, the sewing machine shaft, is to be moved to an angle of 180° after it has attained its first position where it is stopped through braking action. The second position thereby, is a 180° displaced from the first position. An arrangement for carrying out such a positioning operation, is schematically shown in FIG. 3. In the arrangement of FIG. 3, there are groups of elements and components which are used in the arrangement of FIG. 2, with the exception that no speed measuring device corresponding to the speed sensor 11 is provided in conjunction with the angular position sensor 15. Instead, the instantaneous speed of the shaft is obtained through a differentiating stage 24 connected to the output signal from the angular position sensor 15. Thus, as a result of differentiating the displacement signal from the sensor 15, the speed parameter is obtained. The comparator 13 has a summing amplifier 26, in this arrangement of FIG. 3. A gate circuit 27, furthermore, is provided, which is associated with the second position or positions P2. Further gate stages 28 and 29 are associated with the first position of the shaft or position P1. The output of the signal generator 12 is connected to a blocking stage or gate 30, the output of which is, in turn, connected to flip-flops 31 and 32. A monostable multivibrator circuit 33 is connected to one output of the flip-flop 33, and an AND gate 34 is interconnected with the elements 30, 31, 32 and 33. A time delay circuit 35 is, furthermore, provided in the circuit diagram of FIG. 3.

The angular position sensor 15 provides a saw-tooth voltage signal, the amplitude of which commences to rise from an angular position corresponding to the position 1 of the shaft to be controlled. After the shaft executes a a rotation of 360°, the saw tooth signal drops back from a maximum amplitude level to its initial value. The function of this saw tooth signal is represented in FIG. 13. A particularly advantageous design for such an angular position sensor is shown in further detail in FIGS. 8 to 14. The input speed signal generator 12 provides a signal for the desired input speed of the driven shaft, in the form of an analogue DC voltage of predetermined polarity. With the use of the input speed signal generator 12, it is possible to transmit simultaneously the command for the transition from position 1 to the position 2 for the shaft. Such a command for this purpose is in the form of, for example, a DC voltage of opposite polarity when the position to be taken into account is position 2. Thus, one polarity is associated with position 1 and another polarity is associated with position 2.

In operation of the arrangement of FIG. 3, assumed that the shaft be driven and then stopped in a particular position, is initially in a stationary position. If, now, the input speed signal generator 12 is set in a direction so that the signal output has one predetermined polarity, then this signal will be a DC voltage having a magnitude or level which determines the desired input speed for the driven shaft. This input speed signal from the generator 12 is transmitted through gate 30 to the input el of the flip-flop 31. The gate 30 transmits the signal in this phase of operation. The flip-flop 31 becomes set to the application of this signal to the input el, and transmits, thereby, a signal through line 38, to the gate 19 so as to switch this gate 19 for transmitting the output from the summing amplifier 26 to the regulating circuit 10. Ths flip-flop 32 has also applied to it the signal output from the gate 30, and provides, in turn, an output signal through the line 40, for switching gate 29 whereby this gate 29 will not transmit. As a result, no signal can be transmitted to the summing amplifier 26, from the circuit or gate 27 corresponding to position P2 of the shaft. The gate 28 associated with the first position of the shaft or P1 is free to transmit as a result of the signal on the line 41, but this has no effect upon the functional operation, since gate 17 is inhibited from transmitting its signal input.

The input speed signal from the device 12 is applied, furthermore, through the summing amplifier 26. Since the shaft, to be positioned, is still stationary, the instantaneous speed signal as derived from the differentiating network 24, and applied to the summing amplifier 26, is zero. The resultant output signal from the summing amplifier 26 is applied, through the gate 19, to the regulating circuit 10 and influences the latter whereby the coupling winding 7 is energized. The driven shaft 4 becomes, thereby, coupled to the shaft 2 of the motor, and the driven shaft 4 is, consequently, accelerated.

The input speed signal from the device 12 furthermore, inhibits the transmission of gate 17, simultaneously through the application of a signal to line 39, whereby the output signal from the comparator 16 is prevented from reaching the comparator 13. The comparator 16 is also constructed in the form of a summing amplifier.

For every revolution of the driven shaft 4, the angular position sensor 15 provides a linearly increasing voltage from a minimum value to a maximum value. The slope of this linear function or the rate of increase in value of this function is, determined through differentiation by the differentiating stage 24 and the output signal from this stage 24 represents the actual instantaneous output speed of the shaft 4. This actual output speed of the shaft 4 is compared with the desired input speed in the summing amplifier 26. As soon as the output signal from the summing amplifier **26** indicates that the difference between the actual output speed and the desired input speed is zero, then the desired input speed is obtained and the regulating circuit **10** will de-energize the winding **7**. The summing amplifier **26** causes the regulating circuit **10** to maintain the driven shaft **4** at the desired input speed. In the case that the input speed signal generator **12** is set to the new input speed value, then the summing amplifier **26** and regulator **10** combine to operate so as to adjust the speed of the driven shaft **4** to the new value.

The positioning of the driven shaft at the position P1, or the first position, is attained by setting the input speed signal generator **12** to zero. With this setting, the blocking signal applied to the line **39** is removed. The gate **17**, however, remains still in an untransmitting state, temporarily, as a result of the infuence of the gate control circuit **18**. Thus, the signal from the amplifier **16** is still blocked from being transmitted by the gate **17**, as a result of the control circuit **18**. As a result, the summing amplifier **26** receives only the relatively high signal indicating the output instantaneous speed of the shaft **4**, whereas the input speed signal is zero. The regulator circuit **10**, thereby applies full energization to the brake winding **8**. Consequently, the driven shaft becomes subjected to maximum braking moment, independent of the output signal from the comparator **16**, so that the driven shaft **4** becomes strongly braked. When the output instantaneous speed of the shaft corresponds to the predetermined level, the control circuit **18** becomes switched and as a result, the gate **17** is permitted to transmit the signal from the comparator **16**.

Through the gate **28** associated with the first stop position of the shaft **4**, the difference signal from the comparator **16** is transmitted to the summing amplifier **26**. As a result, the difference signal between the desired input angular position and the actual instantaneous output shaft position is superimposed upon the speed signals for the input and output shaft speeds, and this superimposing of the position signals upon the speed signals in this manner, causes attenuation or decrease in the excitation of the braking winding. Further braking action, thereby, is applied in a regulated manner as a function of angular position, in accordance with the computed braking function provided by the circuit **14**. As soon as the output speed signal and the output signal from the comparator **16** are both zero, then the position P1 for the driven shaft **4** is attained, and the shaft is held stationary.

The circuit **35** is designed so that it provides an output signal when its input corresponds to the instantaneous actual angular position of the shaft which is greater than that for a predetermined time interval. This time interval is determined so that the circuit **35** will not become activated when the position P1 is passed through during rotation of the shaft **4** while under speed, as well as during braking. However, after the shaft has become stationary in the position P1, then the circuit **35** becomes actuated. With actuation of this circuit **35**, a signal is transmitted from the circuit to the input e2 of the flip-flop **31**. This causes the flip-flop **31** to be reset, whereby the gate **19** is inhibited from transmitting through the line **38**. The regulating circuit **10** becomes, thereby, disconnected from the comparator **13**. As a result, the coupling and brake windings **7, 8** are de-energized. The driven shaft **4** can, thereafter, be manually rotated as desired.

If the speed signal generator **12** is set to the opposite direction, a signal of opposite polarity is applied to the flip-flop **32**, by way of the gate **30**. The flip-flop **32** becomes thereby switched, and actuates the monostable multivibrator circuit **33** with the signal applied from the output A1 of the flip-flop **32**. With the consequent switching of the monostable multivibrator circuit **33**, the latter provides an output signal for a time interval which is larger than the time duration which is required for moving the driven shaft **4** from position **1** into position **2**. This output signal from the multivibrator **33** is applied to the flip-flop **31** at input e3, and the gate **19** is permitted to transmit, as a result of the signal upon line **38**. At the same time, the gate **30** is switched so as to prevent transmitting of its signal from the device **12**, as a result of the line **42**, so that no signal from the speed generator **12** can reach the comparator **13**. The signal from the output A1 of the flip-flop **32** permits the gate **29** associated with position P2, to transmit as a result of this signal on line **40**. The transmitting state of the gate **28** associated with position P1 is continued. The summing amplifier cannot receive any signal from the comparator **16** thereby.

The circuit gate **27** associated with position P2, compares the instantaneous output angular position of the shaft **4**, as indicated by the sensor **15**, with a reference voltage U_B. As long as the actual position of the shaft **4** as represented by the signal from the sensor **15**, is smaller than this reference voltage, the comparator **13** receives a signal by which the coupling winding **7** becomes energized. The driven shaft **4** commences, thereby to rotate anew. As soon as the angular position signal from the sensor **15** becomes equal to the value of the reference voltage U_B, this gate circuit **27** transmits, through the gate **29**, to the summing amplifier **26** a signal which when transmitted through gate **19** applies a braking commence signal to the regulator **10**. As a result, the shaft **4** becomes braked and is held stationary in position P2.

As soon as the monostable multivibrator circuit **33** is returned to its stable state, the flip-flop **31** becomes reset. The gate **19** becomes, thereby switched to the state where it does not transmit, and the regulating circuit **10** is disconnected from the output of the summing amplifier **26**. Consequently, both windings **7** and **8** are de-energized. To prepare for a new operating cycle, the signal inhibiting states of the gates **28** and **30** must be discontinued so that these two gates are free to transmit. The gate **29** associated with position P2, becomes again switched so that it will not transmit or it is in the inhibiting state.

The AND gate **34** makes certain that the flip-flop **32** becomes switched first after the shaft **4** is held stationary in the position P1. Through this condition, it is achieved that the positioning of the shaft into a position P2 must always be preceded by a positioning of the shaft into a position P1.

As illustrated by equations **1** to **4** above, a quadratic relationship prevails between the brake angle and the speed of the shaft when constant braking torque is applied. This quadratic relationship, however, is relatively complicated from the circuit point of view. Thus, it is relatively involved to mechanize this equation in circuit **4**. The quadratic function

$$w \sim n^2 \qquad (4)$$

can be approximated through

$$w \sim e^{n} + C \tag{5}$$

The preceding equation 5 can be reproduced in circuit form through the use of an operational amplifier **45** with feedback, as shown in FIG. **4**. A germanium diode when driven in the conductive state, has an output function which is proportional to the logarithm of the current through the diode, minus the logarithm of the saturation current. By makinguse of this characteristic of the diode, the feedback network **46**, shown in FIG. **4** can be constructed in accordance with making use design illustrated in FIG. **5**. Thus, the feedback circuit **46** can consist of a resistor **48** connected between the output and input of the operational amplifier **45**, and a germanium diode **48** connected between the output of the amplifier and ground potential.

The differentiation process carried out by the circuit **24** for differentiating the actual output angular position of the shaft **4**, can also be approximated in an advantageous manner. Direct differentiation can easily lead to instabilities in the regulating circuit. Thus, it can be easily shown that the equation

$$y(t) = dx/dt \tag{6}$$

can be expressed in the form of

$$y = x + by - \int y\,dt \tag{7}$$

when b is not equal to 1. Equation 7 can be produced through two operational amplifiers in accordance with the arrangement of FIG. **6**. The first amplifier **49** in FIG. **6**, is arranged as a summing amplifier, whereas the second amplifier **50** is designed as an integrator. The schematic arrangement of FIG. **6** may be obtained through the detailed description of the circuit diagram of FIG. **7**.

For reliable operation of the circuit arrangements of FIGS. **1**, **2** and **3**, it is particularly important to obtain precisely the actual output position of the shaft **4**. As a result, the angular position sensor **15** has a particularly important part in the arrangement. From the viewpoint of operating reliability and high operating life, it is desirable that the angular position sensor be of the contactless type. Such a device **15**, furthermore, should be capable of providing a precisely and reproducable analogue voltage for each possible angular position of the shaft, independent of the prevailing speed of the shaft. An angular position sensor of this type which meets these requirements, is shown in FIGS. **8** to **12**. The sensor has a rotational member or body **60** which is mounted on one end of the shaft **4**, not shown in FIG. **8**. The rotational member **60** is held to the shaft **4** through a set screw which is threaded in a bore **61** of the member **60**. A ball bearing **62** is mounted upon a portion of the body **60** which has a smaller diameter, and is located towards the right in the drawing of FIG. **8**. The outer ring of the ball bearing **62** is seated in a stationary part of a housing **63**. A measuring head **65**, furthermore, is secured by means of screws **64** to the housing portion **62**.

The measuring head **65** has an angled element **66** which is connected with insulating plates **67**, **68**. Two hook-shaped contacts **69** are located between the plates **67** and **68**. The short ends **70** reaching around an opening through the plate **68**, contact the terminals **71** of a hall generator **72**. The ends **70** are soldered to the terminal **71**. The hall generator **72** is held between the end portions **73**, **74** of two magnetic conductive measuring strips **75**, **76**. These measuring strips **75**, **76** are mounted adjacent to each other in a radial manner relative to the axis of the shaft **4** or the rotational member **60**. The angled element or bracket **66** carries a U-shaped outer screening member **78**, as well as an oppositely-lying U-shaped interior screening member **79**. The interior screening member is oriented with respect to the outer scanning member **78** by the amount of 90°. The width of the interior screening member **70** corresponds essentially to the oppositely lined outer edges of the measuring strips **75**, **76**.

In the space between the ends of the outer screening **78**, on the one hand, as well as the ends of the inner screening **79** and the measuring strips **75**, **76**, on the other hand, are two pole pieces or elements **80**, **81**. These pole pieces are clamped, through a screw **82**, between an insulating element **83** or **84** and a magnetically conductive ring **85** or **86**. These pole pieces, furthermore, rotate together with the rotational member **60** and thereby together with the shaft **4** to be regulated in movement. Between the rings **85**, **86** is a ring-shaped permanent magnet **87** which is axially polarized. The pole pieces **80**, **81** are of this shaft illustrated in FIG. **9**. Their outer edge, as shown in that FIG. **9** form a spiral which satisfies the condition that

$$dw/dr = \text{const.}$$

where r is the radius of the spiral.

The rings **85**, **86** form an enclosure for the magnet **87**, which prevents that the pole pieces **80**, **81** become saturated. These rings **85**, **86**, furthermore, reduce strongly the stray magnetic flux and determine the field strength or field intensity at the pole pieces through their defined magnetic reluctance. Through the use of the hall generator **72** and the measuring strips **75**, **76** the magnetic flux is measured between the pole pieces **80**, **81** within the region of the measuring strips **75**, **76**. In view of the shape of the pole pieces, as shown in FIG. **9**, this magnetic flux and thereby the voltage provided by the hall generator **72**, are proportional to the angular rotation of the shaft **4** which is transmitted directly to the rotational member **60**. At the output of the hall generator, therefore, a voltage is available as shown in FIG. **13**. It may be seen, thereby that by adjusting the angular position of the rotational member **60** in relation to the shaft **4**, the desired input angle (which corresponds to position P1 in accordance with FIG. **3**) may be obtained in a predetermined and simple manner.

The input speed signal generator **13** can be designed directly on the basis of the arrangement described above in conjuntion with the angular position sensor **15**, with the exception that the rotational member **60** is not connected to the driven shaft **4**. In this case, the rotational member **60** is instead to be connected to a positioning member or element which is actuated or adjusted manually by being set either by hand or by foot. A further input speed signal generator for the device 12 is also well known in the art in the form of a device which operates on the contactless principle.

FIG. 14 shows the hall generator for measuring angular position through the sensor 15, when connected with a stabilizing circuit which improves particularly upon the desired angular input position signalling, within the frame of the present invention. In this arrangement, the sensor 15 is in the form of the construction illustrated by FIGS. 8 to 12.

As already mentioned above, the angular position sensor 15 provides a linearly increasing saw-tooth voltage from a lowest level U_0 to a maximum level U_1. Through the circuit arrangement shown in FIG. 14, the voltage values corresponding to U_0 and U_1 as, for example, zero volts and +6 volts, respectively, are held constant. Values between these two extreme limits are also thereby precisely determined. For this purpose of maintaining constant the limit voltages, the output signal from the operational amplifier 90 is applied to integrators with substantially large time constants. These integrators consist essentially of a resistor 91, a diode 92, and a capacitor 93 for one network, and a diode 94 and capacitor 95 for another network. The output voltages from the integrators are compared wth reference voltages of which one consist of ground potential and the other is determined by a Zener diode 96. Through the regulated variation of the voltage value of U_1, the operational amplifier 90 becomes correspondingly influenced through the transistors 97, 98 and a resistor 99. The operational amplifier becomes influenced by a corresponding variation of the operating point of the amplifier. The regulated variation of the voltage value U_0 varies the hall generator current, through transistors 100, 101 and 102. If, for example, a positive voltage appears across the diode 94 during a longer time interval, then this implies that the amplification is too low. As a result, the hall generator current is increased by way of the three transistors 100, 101, 102. The arrangement in accordance with FIG. 14 allows the elimination of all temperature and component manufacturing variations.

In accordance with a modified embodiment of the the present invention, the actual output speed of the shaft 4 can also be determined through the use of a speed measuring tachometer. Such a tachometer, for example, has a permanent magnetic disc connected to the driven shaft 4. The permanent magnetic disc has a peripheral surface of an alternating sequence of magnetic North and South poles. A magnetic coil is located in proximity of the permanent manetic disc and has induced within it a voltage, the amplitude and frequency of which, are essentially proportional to the rotational speed of the driven shaft 4.

In such a case, the actual ouput angular position of the shaft can be derived from the measured speed through the tachometer, or tachogenerator, by applying the speed signal to an integrator or integrating stage. Such an integrating stage sums the pulses from the tachogenerator. The integrator becomes reset through a synchronizer during each rotation of the shaft 4, in correspondence to a predetermined, desired stopped position of the shaft 4. The synchronizer, for this purpose is well known in the art. The advantage of a speed tachometer or tachogenerator resides on the basis that a substantially high output voltage can be derived without noise effects, which can be applied directly as the actual output value, to the regulator circuit 10. Through the use of a synchronizer in accordance with the conventional design, a reproducable voltage signal can be obtained from the hall generator for the desired input position for the shaft, for each revolution of the shaft.

It will be understood that each of the elements described above, or two or more together, may also find a useful application in other types of methods and means for positioning angular shafts, differing from the types described above.

While the invention has been illustrated and described as embodied in a method and means for positioning angular shafts, it is not intended to be limited to the details shown, since various modifications and structural changes may be made without departing in any way from the spirit of the present invention.

Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can, by applying current knowledge readily adapt it for various applications without omitting features that, from the standpoint of prior art, fairly constitute essential characteristics of the generic or specific aspects of this invention and, therefore, such adaptations should and are intended to be comprehended within the meaning and range of equivalence of the following claims.

What is claimed as new and desired to be protected by Letters Patent is set forth in the appended claims.

I claim:

1. A method for moving a shaft to a predetermined angular position, comprising the steps of: applying a source of rotary motion to said shaft for rotating said shaft at an angular speed corresponding to the speed of said source; measuring the instantaneous angular speed of said shaft; computing from the instantaneous speed of said saft a braking angle throughout which said shaft is to be braked to stop said shaft at said predetermined angular position, said braking angle being dependent on said instantaneous speed; removing said source of rotary motion from said shaft and permitting said shaft to continue rotating without continued application of said source; comparing the instantaneous angular position of said shaft with said braking angle; comparing said instantaneous speed of said shaft with a predetermined desired speed; and braking said shaft dependent on said comparing steps so that said shaft becomes stopped at said predetermined angular position.

2. The method as defined in claim 1, wherein said braking of said shaft is fully applied initially and is applied partially thereafter for bringing said shaft to a stopped position at said predetermined angular position.

3. The method as defined in claim 2, wherein the braking interval during which braking is fully applied is expressed as $w=f_1(n)$, the interval during which partial braking is applied being expressed by $w = f_2(n)$, wherein w is the angular shaft position relative to said predetermined angular position and n is said instantaneous angular speed of said shaft, the instant of changing from fully applied braking to partial braking corresponding to the intersection of $f_1(n)$ and $f_2(n)$.

4. The method as defined in claim 1, wherein said instantaneous angular speed of said shaft is derived from the instantaneous angular position of said shaft.

5. The method as defined in claim 1, wherein the instantaneous angular position of said shaft is derived from said instantaneous angular speed of said shaft, said instantaneous angular speed of said shaft being defined by a sequence of pulses, said instantaneous angu-

lar position of said shaft being defined by a summation of said pulses.

6. The method as defined in claim 1, including the step of removing said braking from said shaft when said shaft has attained said predetermined angular position.

7. An arrangement for carrying out the method of claim 1 for moving a shaft to a predetermined angular position, comprising, in combination, a source of rotational motion for rotating said shaft at an angular speed corresponding to the speed of said source; coupling means between said source and said shaft; braking means connectable to said shaft for braking said shaft and decreasing the speed of said shaft, said braking means being applied to said shaft when said shaft is decoupled from said source; speed measuring means connected to said shaft for measuring the instantaneous speed of said shaft; first comparator means connected to said speed measuring means for comparing said instantaneous speed with a desired input speed of said shaft; computing means connected to said speed measuring meas for computing a braking angle function; second comparator means connected to said computing means for comparing a braking angle function with said predetermined angular function; and regulating means connected to said comparator means for regulating said braking means in dependency on said braking angle function, whereby said shaft is braked so that said shaft is stopped at said predetermined angular position.

8. The arrangement as defined in claim 7, wherein the output of said second comparator means is connected to one input of said first comparator means.

9. The arrangement as defined in claim 8, including signal gating means connected in series with the output of said second comparator means; gate control means connected to said gating means and said speed measuring means for controlling the transmission of said gating means so that the output of said second comparator means is not transmitted to said first comparator means when said instantaneous speed of said shaft exceeds a predetemined value.

10. The arrangement as defined in claim 8, including speed input means for applying a desired input speed to said first comparator means; signal gating means connected in series with the output of said second comparator means, said gating means being controlled by said input speed means so that the output of said second comparator means is not transmitted to said first comparator means when the input speed applied by said input speed means is different from zero.

11. The arrangement as defined in claim 7, including gating means connected in series with the input to said regulating means for disconnecting said coupling means and said braking means from said shaft in dependency on the arrival of said shaft at said predetermined angular position.

12. The arrangement as defined in claim 7, including a hall generator for measuring the instantaneous position of said shaft, said hall generator having a magnetic disc coupled to said shaft, said magnetic disc having a varying radius from a predetermined minimum radius to a predetermined maximum radius, the transition between said minimum radius and said maximum radius being a step function.

13. The arrangement as defined in claim 7, wherein said speed measuring means comprises speed computing means for computing the instantaneous speed of said shaft from the angular position of said shaft.

14. The arrangement as defined in claim 13, wherein said speed computing means for computing said instantaneous speed of said shaft comprises two operational amplifiers connected in series, one of said operational amplifiers being a summing amplifier and the other one of said amplifiers being an integrating amplifier, said two amplifiers being further connected so that when applying an input signal of the form $x(t)$ to said summing amplifier the output signal of said summing amplifier is of the form of $y(t) = x + by - \int\ y\,dt$.

15. The arrangement as defined in claim 7, wherein said computing means comprises an operational amplifier with feedback network interconnected to said operational amplifier so that upon applying an input signal of the form of $x(t)$ to the input of said operational amplifier, an output signal from said amplifier is obtained in the form of $y(t) = e^x + C$.

16. The arrangement as defined in claim 7, wherein said second comparator means comprises an operational amplifier with feedback network whereby said operational amplifier functions as a summing amplifier.

17. The arrangement as defined in claim 7, wherein said first comparator means comprises an operational amplifier with feedback network interconnected to said operational amplifier, whereby said operational amplifier functions as a summing amplifier.

18. The arrangement as defined in claim 7, including angular position sensing means for sensing the instantaneous angular position of said shaft; control means connected to said angular position sensing means and to said regulating means for moving said shaft to a second predetermined angular position after having attained said first mentioned predetermined angular shaft position.

19. The arrangement as defined in claim 18, including gating means connected to said control means and output of said second comparator means for alternatingly blocking and transmitting the signal outputs of said control means and said second comparator means.

20. The arrangement as defined in claim 19, including programming means connected to said gating means for controlling said gating means so that the positioning of said shaft to a second predetermined angular position is always preceded by braking said shaft to said first-mentioned predetermined angular position.

21. The arrangement as defined in claim 18, including input speed applying means for applying said desired input speed of said shaft, the signal output from said input speed applying means signalling also the transition from said first mentioned predetermined angular to a second predetermined angular position.

22. The arrangement as defined in claim 21, including gating means connected between said input speed applying means and said regulating means for inhibiting the transmission of the output signal from said input speed applying means to said regulating means during the interval when said shaft moves from said first-mentioned predetermined angular position to said second predetermined angular position.

23. The arrangement as defined in claim 12, including a source of reference voltages for comparing the minimum and maximum output voltage values from said hall generator means; and auxiliary regulating means connected to said hall generator means for regulating said minimum and maximum output voltages

from said hall generator means in dependence on said reference voltages.

24. The method as defined in claim **1,** including the step of applying a braking torque to said shaft while braking said shaft, said braking torque being below the maximum braking torque applicable to said shaft when braking said shaft in dependence on said braking angle.

25. The arrangement as defined in claim **7,** wherein said source of rotational motion is an electrically driven motor.

26. The arrangement as defined in claim **7,** wherein said coupling means comprises an electromagnetic coupling having an actuating winding energized by said regulating means.

27. The arrangement as defined in claim **7,** wherein said braking means comprises an electromagnetic brake having a winding energized by said regulating means.

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