July 4, 1933. H. E. STOKES 1,916,447

POWER TRANSMISSION SYSTEM

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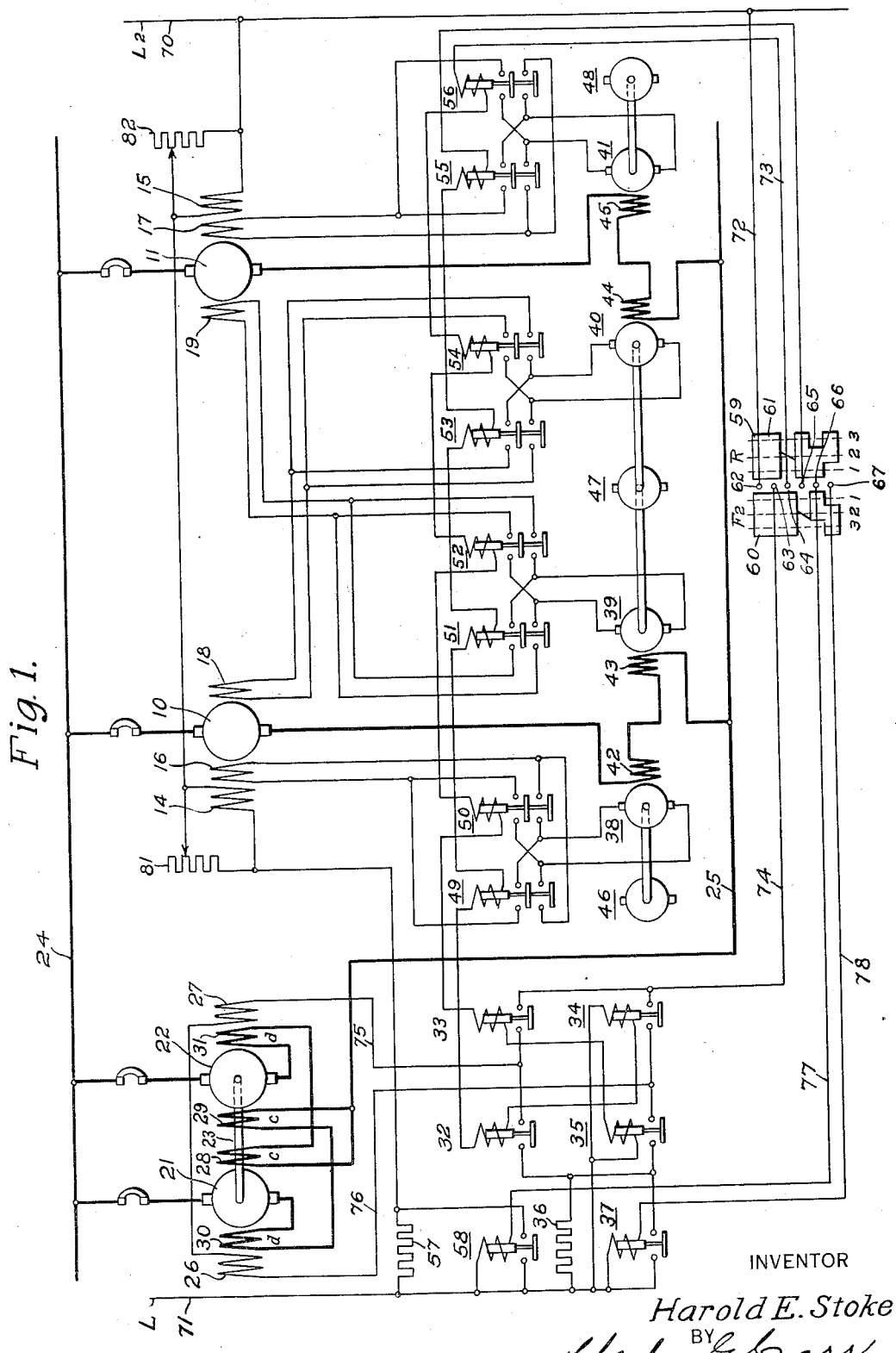


Fig. 1.

INVENTOR

Harold E. Stokes.

BY Chesley G. Carr

ATTORNEY

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Fig. 3.

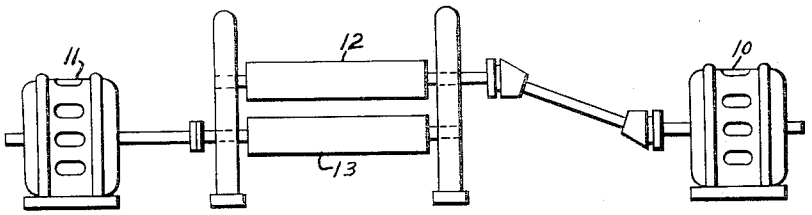
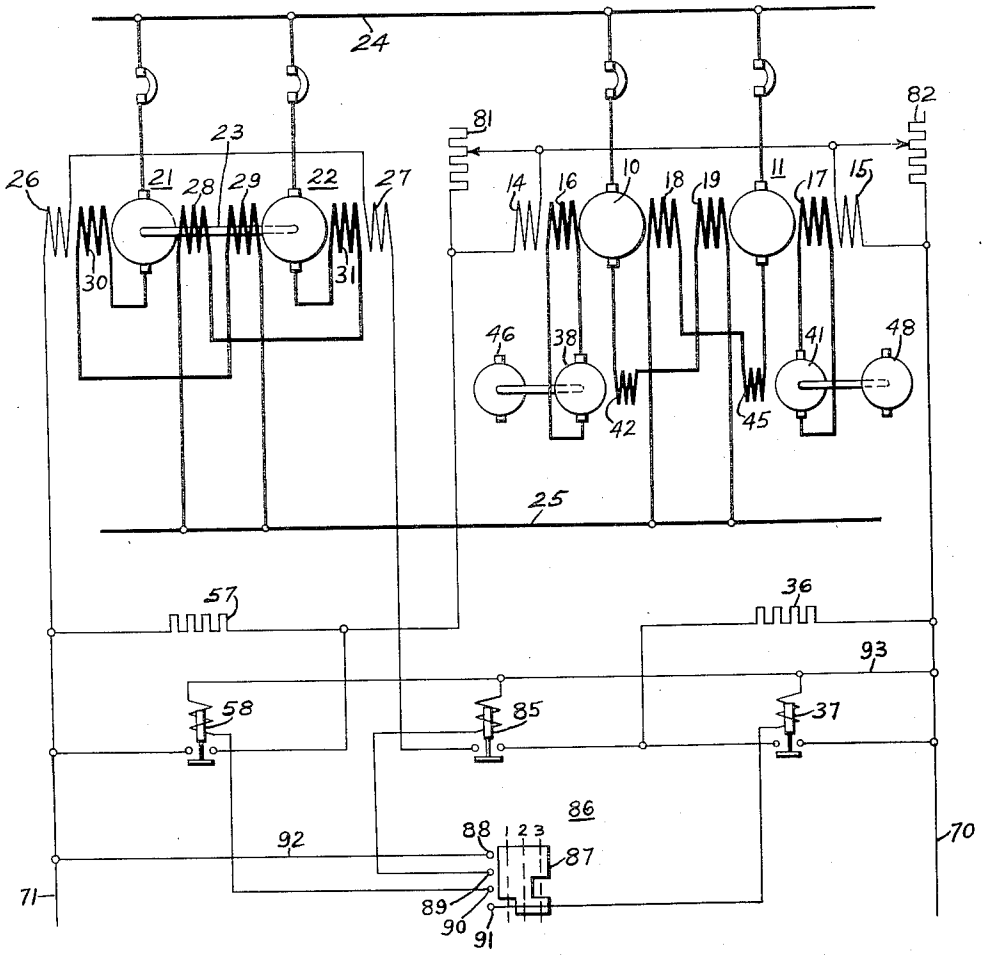


Fig. 2.



INVENTOR
Harold E. Stokes

BY
Wesley G. Carr
ATTORNEY

Patented July 4, 1933 1,916,447

UNITED STATES PATENT OFFICE

HAROLD E. STOKES, OF MURRYSVILLE, PENNSYLVANIA, ASSIGNOR TO WESTINGHOUSE ELECTRIC & MANUFACTURING COMPANY, A CORPORATION OF PENNSYLVANIA

POWER TRANSMISSION SYSTEM

Application filed June 22, 1929. Serial No. 372,843.

My invention relates generally to power-transmission systems and more particularly to power systems suitable for operating rolling mills and machines of similar nature wherein each roll or element of the mill or machine is driven by a separate motor.

In the operation of rolling mills, it is the usual practice to operate a pair of rolls, forming a single stand, by means of a single motor connected to both rolls through a suitable gear box having cooperating pinion members connected to the roll spindles. As a result of the increasing demand for more economical mill installations, the single-motor drive has proved unsatisfactory, since the initial cost of the installation, as well as the maintenance cost, is high.

The present day practice has extended rolling-mill operations to include many different rolling schedules. In order to meet these demands, the mill operator following the old practice must necessarily make a large investment to provide a sufficient number of mill rolls to maintain the required schedules. The reason for the great increase of rolls, with the increase of schedules, results, because the single-motor drive does not lend itself to relative speed variation of the rolls.

In other words, when a gear box having a fixed gear ratio is utilized, as in a single-motor drive, the speed of the individual rolls is fixed, and rolls of different diameters cannot be used interchangeably in order to reduce the number of roll sets required for the different schedules.

Furthermore, the natural tendency is for the mill rolls to wear, changing their respective diameters and, consequently, causing their peripheral speeds to become unequal, unless a corresponding change is made in their speed ratio. Since the rolls in a single-motor drive are mechanically connected through the gear box, which has a fixed gear ratio, there can be no readjustment of their relative speeds to maintain the peripheral speed of one roll exactly equal to that of the other unless a change be made in the gear ratio of the drive.

Another undesirable feature resulting from worn rolls is that the metal which is being rolled tends to cause the rolls to operate at equal peripheral speeds which do not conform to the fixed speeds at which the positively connected motor tends to drive them. When this condition occurs, stresses are set up in the rolls and in the pinions of the gear drive which generally result in damaged rolls, broken spindles, damaged gears and an improperly rolled product.

The object of my invention, generally stated, is to provide a power system for rolling mills which shall be simple and efficient in operation and readily and economically manufactured and installed.

A more specific object of my invention is to provide for maintaining a predetermined peripheral speed and load ratio between motors individually connected to the separate rolls of a rolling mill.

Another object of my invention is to provide for readily adjusting the relative speeds of the cooperating rolls of a mill driven by separate motors to maintain equal peripheral speeds, regardless of the diameters of the respective rolls.

Other objects of my invention will become evident from the following description, taken in conjunction with the drawings, in which

Figure 1 is a diagrammatic view of a power system suitable for application to rolling mills having individual-roll drive motors, embodying the principal features of my invention.

Fig. 2 is a diagrammatic view showing a modification of the power system of Fig. 1 which may be utilized for non-reversing mills, and

Fig. 3 is a simplified diagrammatic view of a rolling mill showing how individual-roll drive motors may be applied.

Referring now to the drawings, 10 and 11 designate, generally, direct-current motors of any suitable type which may be utilized for operating the rolls 12 and 13 of a rolling mill of a conventional type, as shown in Fig. 3.

While, in this disclosure of the invention, the power system is applied to rolling mill drives, it will become evident as the description proceeds that it may also be readily applied to other machines having similar operating characteristics.

In this embodiment of the invention, compound-wound motors are utilized for driving the rolls. The motors are provided with main or separately-excited field windings 14 and 15, cumulative compounding field windings 16 and 17 and differential compounding field windings 18 and 19. In this instance, the compounding-field windings function in the same manner as ordinary series wind-

ings. However, they are of different construction and the effect which they produce may be more readily controlled and varied, as will be pointed out hereinafter.

The roll motors 10 and 11 may be supplied with power from any suitable source of direct-current energy. However, in this instance, since it is desirable to control the speed and direction of operation of the motors by variable-voltage control, a plurality of direct-current generators 21 and 22 are utilized. As shown, the generators are mechanically connected by a shaft 23 and electrically connected in parallel-circuit relation to the bus bars 24 and 25, to which the control motors 10 and 11 are also connected in parallel-circuit relation.

The generator may be driven by a prime mover of any suitable type, which, in this instance, is not shown, since the construction and operation of motor-generator sets of this type are well known.

As shown, the generators 21 and 22 are provided with main or separately-excited field windings 26 and 27, cumulative series-field windings 28 and 29 and differential series-field windings 30 and 31. The series-field windings of the generators are cross connected in a well-known manner to obtain a predetermined load balance between the two machines. Since generator connections of this kind are well known, the function and operation of the series windings, when connected in this manner, will be described only generally. The main field, which determines the voltage of the generators, is developed by the main or separately excited field windings 26 and 27. The differential series-field windings are connected to establish a field flux in the opposite direction to the flux established by the main or separately-excited field windings, while cumulative series-field windings are connected to establish a field flux in the same direction as the main field. If the generators are of equal capacity, the main fields are regulated or adjusted to cause an equal division of load between the two machines or, if the machines are of unequal capacity, the relative excitation of the main field windings may be adjusted to divide the load in the desired ratio.

Since the cumulative series-field windings are cross connected, they may be caused to exactly balance and counteract the excitation produced by the differential fields when the loads on the generators are equal or when the total load is being divided in a predetermined ratio. When the load becomes unbalanced, the heavily-loaded generator decreases its main-field flux through the action of its differential series-field winding, which is in series with its armature, while the opposite effect is produced upon the main-field flux of the other machine, since its cumulative series-field is cross connected to the heavily loaded machine and, therefore, adds to the main-field excitation. It will be readily understood that the effect of this is to reduce the voltage of the heavily loaded machine, causing it to reduce its load and increase the voltage of the lightly loaded machine, causing it to assume a greater share of the load and thus establish the initial load balance.

In order to control the direction of the main field of the generators and, consequently, the voltage applied to the motors 10 and 11, a plurality of reversing switches 32 to 35, inclusive, are provided.

The speed of the roll motors 10 and 11 may be controlled by either varying the voltage of the generators or by varying the field excitation of the motors. In this instance, one point of speed control by each method is shown, although it is to be understood that as many points of speed control as desired may be obtained. As shown, a field resistor 36, and a bridging switch 37, are provided in the energizing circuit of the generator main field windings 26 and 27 to vary the field current in a one-step operation. The speed control obtained by varying the excitation of the motor fields will be described in detail, hereinafter.

In order to control the operation of the roll motors in accordance with the present invention, a plurality of series exciters 38 to 41, inclusive, are provided. The exciters are provided with field windings 42 to 45, inclusive, connected in series with the motor armatures, as shown.

In this embodiment of the invention, one of the main functions of the series exciters is to provide an energizing voltage for the compounding-field windings on the motors which shall vary in direct proportion to the load currents flowing in their respective circuits. Accordingly, the exciters are driven at substantially constant speed and operated on the lower portion of their saturation curve in order that a change in field excitation shall cause a corresponding change of terminal voltage. Constant-speed motors of any suitable type may be utilized for driving the exciters and, in this instance, motors designated, generally, by the numerals 46, 47 and 48 are provided.

In order to control the direction of flow of current in the exciter circuits, a plurality of reversing switches 49 to 56, inclusive, are provided. As shown, a pair of switches are utilized in each exciter circuit, the function and operation of which will be described in detail hereinafter.

As described hereinbefore, the second step of speed control is obtained by varying the field excitation of the motors. Therefore, in order to vary the excitation of the main field windings 14 and 15, a field resistor 57 and a bridging switch 58 are provided. In this

instance also, a plurality of points of speed control may be obtained by simply providing a plurality of bridging switches for the resistor.

The operation of the system may be controlled in any suitable manner. However, in this embodiment of the invention, a manually-operated master switch 59, provided with drum segments 60 and 61 and stationary contact fingers 62 to 67, inclusive, is utilized.

In order that a full and complete understanding of my invention may be obtained, the operation of the system, as it is applied to a rolling mill having individual roll drive motors, will now be described in detail.

Assuming that the generators 21 and 22 are being driven by a prime mover (not shown), then a voltage for energizing the bus bars 24 and 25 may be developed. As shown, a master switch 59 is provided for controlling the operation of the bridging switches 37 and 58, generator field reversing switches 32, 33, 34 and 35 and motor field reversing switches 49 to 56, inclusive.

If it is desired to operate the roll motors 10 and 11, in the forward direction, the drum segment 60 of the master switch 59 may be actuated to the first position into engagement with the contact fingers 62, 63, 64 and 66. An operating circuit is thereby established for actuating the proper motor and generator field-reversing switches which may be traced from the line conductor 70, through conductor 72, contact fingers 62 and 64—bridged by the segment 60—conductor 73, operating coils of the motor-field reversing switches 56, 54, 52, and 50 and the operating coils of the generator field-reversing switches 33 and 35, to the line conductor 71.

In response to the closing of switches 33 and 35, an energizing circuit for the generator main-field windings is established which extends from the line conductor 70, through conductor 72, contact fingers 62 and 63—bridged by the segment 60—conductor 74, switch 33, conductor 75, main field windings 27 and 26, conductor 76, switch 35 and field resistor 36, to the line conductor 71.

In order to provide a strong shunt-field excitation for the roll motors 10 and 11, during the starting operation, provision is made for bridging the field resistor 57 during the initial starting period. As shown, an actuating circuit for the bridging switch 58 may be established which extends from the energized contact finger 66 through conductor 77 and operating coil of the switch 58, to the line conductor 71. Therefore, the switch 58 is closed when the drum 59 is actuated to its first position.

The speed of the roll motors 10 and 11 may be further increased by actuating the master switch to the second position, thereby energizing the contact fingers 67 and establishing an operating circuit through the conductor 78 for the bridging switch 37, as shown. Upon the closure of the switch 37, the generator-field resistor 36 is bridged, and the main field excitation of the generators increased a predetermined amount. Further increase in speed of the roll motors may be obtained by actuating the master switch to the third position, thereby deenergizing the contact finger 66 which interrupts the operating circuit of the bridging switch 58. When the switch 58 opens its contact members the field resistor 57 is reinserted in the excitation circuit of the main field windings 14 and 15.

In performing rolling operations, it is desirable to rotate the rolls at the same peripheral speed, independently of their diameters. Therefore, it becomes necessary to provide for readily adjusting the initial speed of the roll motors in order to obtain equal peripheral speeds. Since the main fields predominate in controlling the operation of the motors, provision is made for separately varying the excitation of the main field windings 14 and 15. Field rheostats of any suitable type may be utilized for this purpose which, in this instance, are shown in diagrammatic form at 81 and 82.

It will be readily understood that, through the agency of the rheostats, the initial relative speeds of the motors 10 and 11 may be adjusted at will. Thus, if the diameter of one roll is one half that of the other, the speed of its motor may be doubled and that of the other may remain unaffected or any other desired speed adjustment may be made.

When the metal is engaged by the rolls, an entirely different problem of control presents itself. In order to perform a desirable rolling operation and to obtain a desirable product, it is necessary that each roll shall exert the same pulling or reducing force upon the metal during the rolling operation. This is necessary in order to roll a flat strip or a flat object of any kind since, if the rolls rotate at different peripheral speeds, the pulling forces, of reduction, applied by the rolls are unequal, and the reducing process will be unbalanced. When a condition of this kind exists, the reduction of one side of the metal will be carried on at a faster rate than on the other side, and, in leaving the rolls, it will naturally acquire a curved shape. Therefore, it is evident that the initial speeds of the roll motors 10 and 11, as determined by the adjustment of their shunt-field excitation, must be maintained; or, in other words, there must be a balancing force acting continuously throughout the rolling operation in order to maintain this operating characteristic.

In this particular embodiment of the invention, the balancing force for maintaining a predetermined load balance and speed ratio between the roll motors 10 and 11 is ob-

tained by cross connecting the differential-compounding-field windings 18 and 19 and maintaining balanced condition between the excitation produced by the compounding-field windings of each motor when the motors are dividing the total load in the desired ratio.

As shown, the cumulative-field winding 16 of the motor 10 is connected to the series exciter 38 and, therefore, the excitation of this field winding varies in direct proportion to the motor load. However, its differential-field winding 18 is cross-connected to the series exciter 40 of the motor 11 and, therefore, its excitation varies in direct proportion to the load on the motor 11. The same scheme is used for the field windings 17 and 19 of the motor 11. Therefore, it is evident that the load currents in the motor circuits must remain at the same relative value in order that a balanced condition may be maintained between the compounding fields of each motor.

In order that a more comprehensive understanding of the balancing operation may be obtained from the description which is to follow, the cause of load unbalance will first be explained.

In manufacturing motors and electrical machines of this character, it is difficult to produce motors which are exactly alike. There is always a slight variation in those parts which determine the operating characteristics of the motor, that is, the air gaps are unequal or the iron used in the magnetic circuit is not of the same quality or quantity.

It is evident that, when two motors differ in such respects, their operating characteristics are not the same and, consequently, a seemingly correct adjustment of their shunt-field currents does not cause them to divide the load in a predetermined ratio, when they operate in parallel-circuit relation and cooperate in carrying the same total load.

It will be readily understood that, if the motor 10, for example, becomes overloaded, for any reason, the current flowing through its armature circuit and the field windings 42 and 43 of the exciters 38 and 39 is increased. The exciter voltages are immediately increased, thereby increasing the cumulative field excitation of the motor 10 and the differential field excitation of the motor 11. The effect of this is to strengthen the effect of the cumulative field of the motor 10 and to weaken its effect in motor 11.

Since the cumulative field aids the main field, the total field flux in the motor 10 is increased, causing its counter E. M. F. to increase which opposes and decreases its load current to reduce the load.

The increased excitation of the differential-field winding 19 of the motor 11, however, produces exactly the opposite effect on this motor. Since its load does not change appreciably during the initiation of the balancing operation, the excitation of its cumulative-field winding 17 remains substantially constant. An increased excitation of the differential-field winding 19, however, interrupts the balanced-field condition in this motor, and, since the flux produced by the differential-field winding 19 is in opposition to that produced by the main field winding 15, the total excitation of the motor is reduced. When this condition exists, the counter electro-motive force of this motor is decreased and renders it more susceptible to assuming an increase in load current.

In view of the foregoing explanation, it is evident that the balancing force created by a load unbalance is doubly effective. In the first instance of the heavily loaded motor, a condition is established which causes this motor to reduce its load, while, in the second instance, a condition is established in the other motor which causes it to assume a greater load. It is evident that the heavily-loaded motor is not merely prevented from taking more load, but conditions are set up in the lightly-loaded motor which cause it to actually take a part of the load of the heavily loaded motor.

The double effect of the balancing force may be further illustrated by assuming that the load on the motor 10 is sufficient to enable it to produce, for example, +1500 ampere turns in its cumulative-field winding 16, which would cause the differential field winding 19 of the motor 11 to produce −1500 ampere turns, while the load on motor 11 produces +1000 ampere turns in its cumulative-field winding 17 and, therefore, −1000 ampere turns in the differential-field winding 18 of the motor 10. When this condition exists, the unbalance in the field excitation of the motor 10 is +500 ampere turns, while, in the motor 11, it is −500 ampere turns. Therefore, it is evident that the total unbalance between the fields of the two motors is 1000 ampere turns, which is double the amount which could be produced unless the fields of both motors were differentially varied by utilizing cross-connected differential-field windings.

It will be readily understood that the load ratio of the motors is automatically maintained in response to the continuous operation of the balancing force and its effect upon the motor speeds. The balancing force in the system is created by the load unbalance and, consequently, it appears and continues to exist to cause the motors to always divide the load, regardless of its total amount, in a predetermined ratio and, therefore, when the overloading of one motor tends to reduce its speed, it is immediately relieved of a portion of its load, which is assumed by the other motor. This division of load is obtained automatically by a slight adjustment of the

relative speeds of the motors through the operation of the balancing force.

The importance of maintaining a predetermined speed ratio between the motors is realized more fully when the effect of unbalanced counter electro-motive forces between the two motors is considered. Assuming that the excitation of the motors remains constant, their respective counter electro-motive forces vary in direct proportion to their speed, and, since they are not mechanically connected except by the metal between the rolls, there is a tendency for one motor to constantly run faster than the other. Since the loop circuit connecting the two motors is of very low resistance, a small unbalancing of the counter electro-motive forces causes an extremely high circulating current to flow between the motors. This condition may occur when motors of any capacity are connected and operated in this manner. However, the larger the motors the more serious the condition becomes, since only a small unbalance may cause the flow of several thousand amperes of circulating current.

As set forth hereinbefore, each exciter circuit is provided with a pair of reversing switches which, as described, are utilized to maintain the proper direction of flow of the exciting current in each of the compounding-field windings. As is well understood, when the motors 10 and 11 are reversed by reversing the applied voltage, a reversal of their armature current occurs. This causes the exciters to reverse their polarity and, consequently, the excitation of the compounding-field windings is reversed. Since the direction of the main field excitation is not changed, it is evident that the flux produced in the compounding-field windings must always be maintained in the same direction in order that the proper balancing effect may be obtained. The use of field-reversing switches in the exciter circuit is only necessary in case the roll motors are to be reversed, as would be the case for a reversing mill.

As described in detail hereinbefore, it is necessary to utilize crossed-field control in the system in order to obtain a load-balancing and speed-maintaining effect. Furthermore, if the mill is of the reversing type using Ward Leonard speed and direction control, it is necessary to reverse the excitation of the compounding-field windings in accordance with each reversal of the motors. It is evident that it would be practically impossible to reverse the excitation in this manner if series field windings of the ordinary type were utilized for the reason that they would carry the entire load current of the motor. This would require the use of high-capacity switches and a complicated control apparatus in order to effect their reversal.

However, it is evident that this function may be readily accomplished by utilizing the series-exciter scheme embodied in this invention. In this instance, the compounding-field windings produce the same effect as ordinary series windings by utilizing a small excitation current which is, at all times, proportional to the load current, due to the operation of the series exciters, and it is easily controlled by utilizing reversing switches in the exciter circuits.

In Fig. 2 of the drawings, is shown a power system embodying the same features of my invention suitable for application to a non-reversing mill. The operation of this system is practically the same as that described hereinbefore for the system shown in Fig. 1. The main field circuit of the generators is controlled by the single field switch 85 instead of the reversing switches 32 to 35, inclusive, in Fig. 1.

A master switch 86, having a drum segment 87 and contact fingers 88 to 91, inclusive, is provided for controlling the operation of the system. As shown, when the master switch is actuated to the first position, contact fingers 88 to 89 are bridged by the segment 87 to establish an operating circuit for the field switch 85 which extends from the line conductor 71, through conductor 92, contact fingers 88 and 89—bridged by the segment 87—operating coil of the switch 85 and conductor 93, to the line conductor 70. Upon the closure of the field switch 85, the excitation circuit of the generator main field windings 26 and 27 is established.

The contact finger 90 of the master switch 86 is also energized to establish an operating circuit for the switch 58, thereby bridging the motor-field resistor 57 to provide maximum field excitation for the roll motors 10 and 11 during their starting operation. The speed of the roll motors 10 and 11 may be further increased by actuating the master switch to the second position, thereby energizing the contact finger 91 and establishing an operating circuit for the switch 37 which, upon its closure, bridges the generator field resistor 36 and increases the main field excitation of the generators. The operation of the master switch to the third position interrupts the operating circuit of the bridging switch 58, thereby rendering the field resistor 57 effective to decrease the excitation of the motors to further increase their speed.

It will be readily understood that, since this system is intended only for non-reversing operation, it is unnecessary to provide for reversing the excitation of the compounding-field windings of the motors 10 and 11 in order to maintain the balancing effect in the system. As shown, the differential-field windings 18 and 19, in this instance, are in the form of regular series-field windings connected in the motor circuits in series with

the field windings 42 and 45 of the series exciters 38 and 41, respectively.

The method of connecting the compounding-field windings of the system in Fig. 2 may be exactly opposite that shown, if desired. That is, the cumulative-field windings 16 and 17, may be in the form of regular series windings, and the differential field produced by compounding-field windings excited from the exciters.

The latter method of excitation would be of particular advantage, in obtaining proper speed regulation of the motors, if it were desired to maintain a constant operating speed for tandem-mill application. In this event, the series fields would be designed to give the motors a drooping-speed characteristic, and the excitation of the differential-compounding field windings varied by means of suitable rheostats to give the desired operating speed for the load at which the motors were required to operate.

From the foregoing description, it is evident that the operation and the functions produced by the different elements of this system are exactly the same as those produced by the system shown in Fig. 1.

It may be stated in conclusion that, while the illustrated example constitutes a practical embodiment of my invention, I do not wish to limit myself strictly to the exact details herein illustrated, since other modifications may be made without departing from the spirit of the invention, as defined in the appended claims.

I claim as my invention:

1. In a power system, in combination, a plurality of motors and generators, said motors being connected in parallel-circuit relation to said generators, each motor being provided with a main field winding and cumulative and differential compounding field windings, and exciter means responsive to the load on any one motor for establishing an unbalance in the field excitation of the compounding field windings of all the motors, thereby to correct for a load unbalance between the motors, caused by a variation in their relative speeds.

2. In a power system, in combination, a plurality of motors each provided with a main field, cumulative compounding and differential compounding-field windings, means for individually energizing the differential-compounding windings of each motor in accordance with the current flowing in the other motor, and means for individually energizing the cumulative-field windings of each motor in accordance with the current flowing in that motor, to obtain balance of load.

3. In a power system for motors dividing their loads in a predetermined ratio, in combination, a plurality of motors each provided with separately-excited main field windings, differential-field and cumulative-field windings, and means for individually exciting the field windings of each motor, said exciting means being arranged to respond to the loads carried by the motors to cause an increase in the excitation of the cumulative-field winding of the motor exceeding its proportion of the load and an increase in the excitation of the differential-field winding of the other motor to reestablish the load ratio.

4. In a power system, in combination, a plurality of motors disposed to divide a common load in a predetermined ratio, the motors being provided with separately-excited main field windings which determine the load ratio and auxiliary-field windings, the auxiliary-field windings of each motor being differentially arranged to balance when there is proper division of load, and separate exciters for the auxiliary-field windings, means for driving the exciters at substantially constant speed, said exciters being disposed to respond to changes in the load current of the motors to vary the relative excitation of the auxiliary-field windings to correct changes in the load ratio.

5. In a power system, in combination, a plurality of motors disposed to divide a common load in a predetermined ratio, each motor being provided with separately-excited main and auxiliary-field windings, the auxiliary-field windings of each motor being differentially disposed, and current responsive means for exciting the auxiliary windings of the motors, said exciting means being disposed to effect a balance between the auxiliary windings of each motor when the motors divide the load in the predetermined ratio and to unbalance the auxiliary field windings to correct for a division of load which is not in accordance with said load ratio.

6. In a power system, in combination, a plurality of motors disposed to divide a common load in a predetermined ratio, the motors being provided with separately-excited main field windings and auxiliary-field windings, the auxiliary-field windings of each motor being differentially disposed, and electro-responsive means for individually exciting the auxiliary-field windings of the motors, said electro-responsive exciting means being disposed to effect a balance between the auxiliary-field windings of each motor when the motors divide the load in the predetermined ratio and to correct for a division of load which is not in accordance with said load ratio by effecting an unbalance between the auxiliary field windings of each motor.

7. In a power system for motors dividing the load in a predetermined ratio, in combination, a plurality of motors, each provided with main, differential compounding and cumulative compounding field windings, and separately-driven generator means for exciting the field windings of each motor,

said exciting means being disposed to respond to the loads carried by their respective motors to cause an increase in the excitation of the cumulative compounding-field and a decrease in the excitation of the differential compounding-field of a motor carrying a load greater than its predetermined proportion, and an increase in the excitation of the differential field and a decrease in the excitation of the cumulative field of the motor carrying a load less than its proportion to reestablish a predetermined ratio in the loading of the motors.

8. In a motor-control system, in combination, a plurality of motors provided with main and series-compounding field windings disposed to drive a common load, a source of power for the motors, said motors being connected in parallel-circuit relation to the power source, means for controlling the excitation of the main field windings to vary the relative motor speeds, and eletrical means associated with, and responsive to, the load current of each motor for separately controlling the relative excitation of the series-compounding field windings of each motor, thereby to automatically vary the strength of the total field flux produced by the main field and compounding-field windings to maintain any predetermined speed relation between the motors, as established by the initial main field excitation.

9. In a motor-control system, in combination, a plurality of motors provided with main and series compounding-field windings, a source of power for the motors, said motors being connected in parallel-circuit relation to the power source, manual means for varying the main field excitation of the motors to establish a predetermined speed relation between the motors, rotatable means associated with each motor to individually vary the excitation of the series-compounding-field windings in accordance with the loads on the respective motors to produce a total variation of the field flux of both motors in proportion to the variation in load, and means for driving said rotatable means at a substantially constant speed.

10. In a system for controlling the speed relation between a plurality of individual motors, in combination, a source of power for the motors, said motors being connected in parallel-circuit relation to the power source, each motor being provided with main field windings and cumulative and differential compounding-field windings, and separate means responsive to a change in load ratio for controlling the excitation of said compounding-field windings, to vary the field excitation differentially with respect to the loads thereby to correct for load unbalance.

11. In a power system, in combination, a plurality of motors, a source of power for the motors, said motors being connected in parallel-circuit relation to the power source, each motor having a main field winding and cumulative and differential compounding-field windings, means for varying the excitation of the main field winding to predetermine the load ratio of the motors, and means including separately-driven exciters responsive to the motor loads for controlling the relative excitation of the compounding-field windings to maintain the predetermined load ratio.

12. In an electric drive for rolling mills provided with a plurality of reducing rolls, in combination, a plurality of motors individually connected to the reducing rolls, a source of power for the motors, the motors being provided with separately-excited main field, cumulative and differential compounding field windings, means for controlling the relative excitation of the main field windings to establish a predetermined load ratio, a pair of exciters for each motor, one of each pair being connected to the cumulative compounding-field winding of its motor, the other to the differential compounding-field winding of another motor, said exciters being disposed to balance the excitation of the compounding-field windings of each motor when the load is dividing in said predetermined ratio and to act in response to changes in motor-load currents, thereby to unbalance the excitation of the motors in proportion to the unbalance in load to correct the unbalanced load condition.

13. In an electric drive for rolling mills provided with a plurality of reducing rolls, in combination, a plurality of motors individually connected to the reducing rolls, a source of power for the motors, the motors being provided with separately excited main field, cumulative and differential compounding-field windings, means for controlling the relative excitation of the main field windings to establish a predetermined load ratio, an exciter for each compounding-field winding, said exciters having field windings connected in series with the roll motors, each differential compounding-field winding being cross connected to an exciter of another motor to effect a balance of the fields produced by the compounding-field windings of each motor when the motors are properly dividing the load and to produce equal and opposite variations in the field excitation of the respective motors, thereby to produce a total corrective unbalance between the fields of the motors double in proportion to the load unbalance.

14. The combination with a rolling mill provided with a plurality of reducing rolls, of a plurality of motors for individually operating the rolls, a generator for supplying power to the motors, means including a master switch for controlling the direction and value of the generator voltage to con-

trol the speed and direction of operation of the motors, said motors being provided with separately-excited main field windings and cumulative and differential compounding field windings, a series exciter for each compounding field winding associated with each motor, one of the compounding field windings of each motor being connected to one of the exciters associated with the other motor to provide for maintaining a predetermined load ratio between the motors, and means responsive to the operation of the master switch for rendering the series exciters effective to maintain load division when the motors are operating in either direction.

15. In combination, a plurality of cooperating roll members, a motor connected to each roll member, each of said motors being provided with a main field winding and a pair of differentially-disposed auxiliary field windings, a source of excitation current for the main field windings, and separately-driven exciter means associated with each motor disposed to automatically vary the excitation of the auxiliary field windings in accordance with the loads carried by their respective motors.

16. In combination, a plurality of cooperating rolls, a motor for actuating each roll, said motors being provided with main field windings and cumulative and differential auxiliary field windings, a source of power for the motors, means for varying the excitation of the main field windings, means associated with each motor responsive to the load currents of the motors for simultaneously controlling the excitation of the auxiliary field windings of all the motors, and means operable to render said last named means effective regardless of the direction in which the motors are operated.

17. In combination, a plurality of roll members, a motor for actuating each roll, a source of power for the motors, means for manually controlling one component of excitation of the motors, and separately-driven generators associated with each motor for simultaneously controlling another component of excitation of their respective motors and of the other motors, said generators being disposed to function in accordance with the load currents of their respective motors thereby to provide for automatically maintaining a predetermined load ratio between the motors and a predetermined speed ratio between the rolls.

18. In combination, a plurality of roll members, a motor for actuating each roll, a source of power for the motors, means for manually controlling one component of excitation of the motors, a plurality of exciters associated with each motor, said exciters having field windings connected in series-circuit relation with the armatures of their respective motors, means for driving the exciters at a substantially constant speed, and means for rendering the exciters associated with each motor effective to automatically control another component of excitation of the motors thereby to maintain a predetermined speed ratio between the rolls.

19. In combination, a pair of cooperating roll members, a motor for actuating each roll member, each of said motors being provided with a separately-excited main field winding and cumulative and differential compounding field windings, a source of power for the motors, means for controlling the excitation of the main field windings, means for connecting one of the compounding field windings of each motor in series circuit relation with the armature of the other motor, and means associated with each motor disposed to develop a voltage proportional to the load current of their respective motors for controlling the excitation of the other compounding field windings.

20. In combination, a pair of cooperating roll members, a motor for actuating each roll member, each of said motors being provided with a separately-excited main field winding and cumulative and differential compounding field windings, a source of power for the motors, means for controlling the excitation of the main field windings, means for rendering the excitation of one compounding field winding of each motor dependent upon the load of the other motor, and a separately-driven exciter associated with each motor disposed to control the excitation of the other compounding field windings of their respective motors, said exciters having field windings disposed to be energized in accordance with the load currents of their respective motors.

21. In combination, a plurality of cooperating roll members, a plurality of motors having main, cumulative compounding and differential compounding field windings for individually actuating the roll members and dividing the total load in a predetermined ratio, a source of power for the motors, manually-operable means for controlling the excitation of the main field windings to control one component of the excitation of the motors, means associated with each motor disposed to develop voltages proportional to the load currents of the motors for controlling the excitation of the compounding field windings to automatically vary another component of the excitation of the motors to effect relative variations of the total excitation of the motors proportional to the degree of departure from a predetermined load ratio thereby to maintain predetermined speed and load ratios.

In testimony whereof, I have hereunto subscribed my name this 14th day of June 1929.

HAROLD E. STOKES.