Feb. 2, 1932. R. H. WRIGHT 1,843,588

CONTROL SYSTEM

Filed Aug. 22, 1928

Fig. 1.

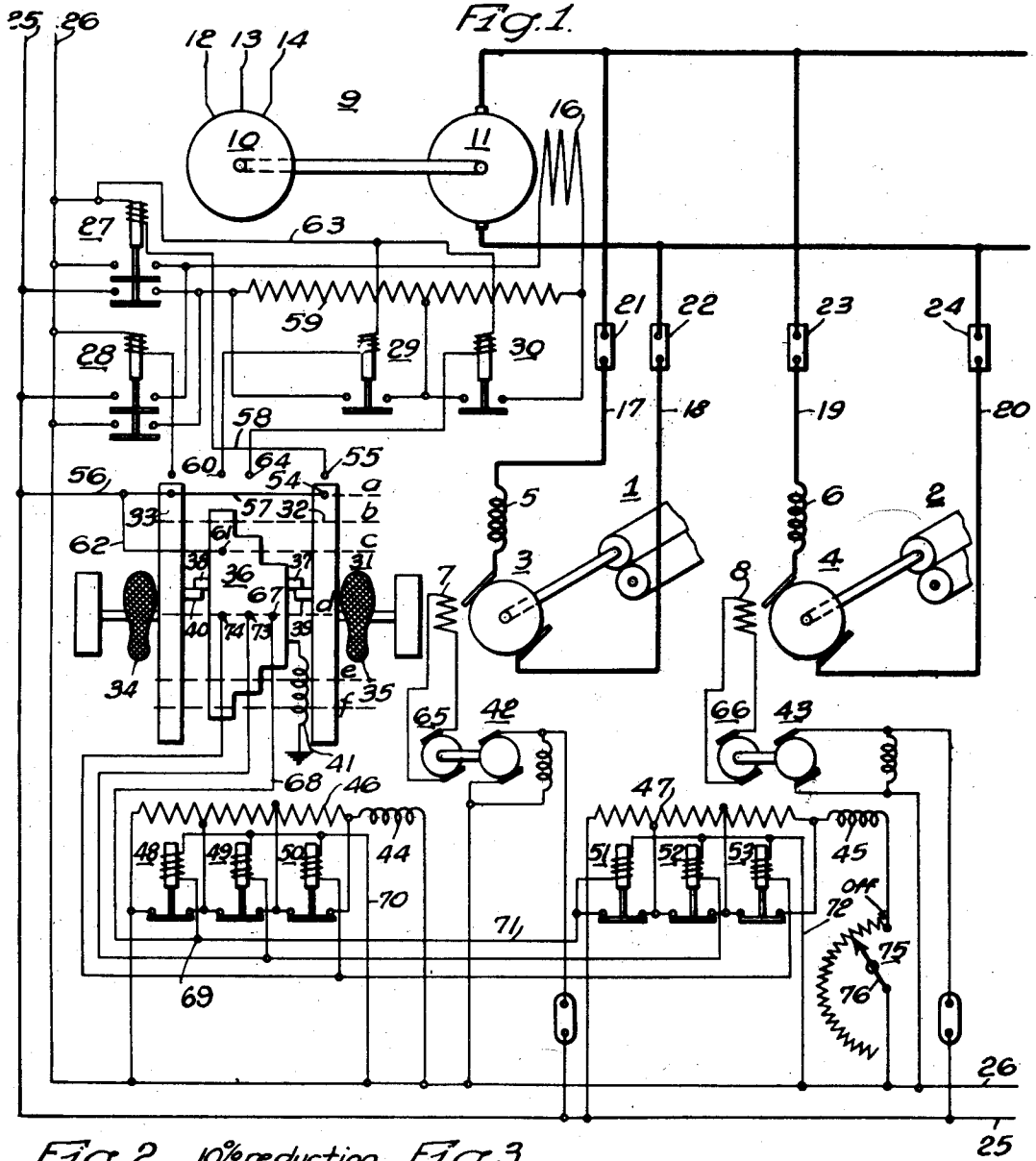


Fig. 2. 10% reduction.

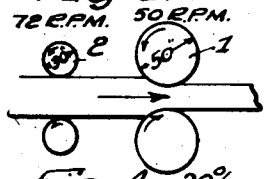


Fig. 3.

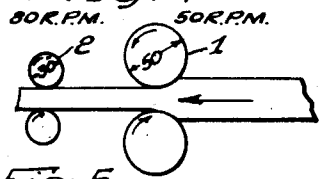


Fig. 4. 20% reduction.

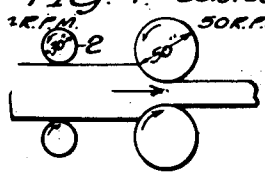
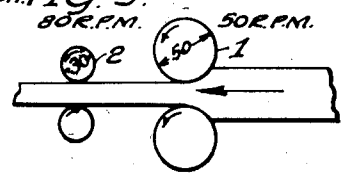


Fig. 5.



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UNITED STATES PATENT OFFICE

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CONTROL SYSTEM

Application filed August 22, 1928. Serial No. 301,290.

My invention relates generally to control systems for rolling mills and more particularly to control systems for tandem mill drives of the reversing type.

In the operation of rolling mills of the tandem reversing type where the metal stock is worked between two or more sets of rolls, simultaneously, each set of rolls is usually provided with a separate driving motor of the reversing type. Since the rolls are usually of different diameters, they must be operated at different speeds. In one direction of rotation of the rolls, the motor speeds are determined entirely by the roll diameters, the speed being inversely proportional thereto. When the rolls are rotating in the opposite direction, the speed of one motor must be adjusted to compensate for the reduction of or draft on the metal stock. Therefore, the speed of one motor may be the same for both directions of rotation, while the speed of the other may vary depending upon the direction of rotation.

Since the metal stock is engaged by both sets of rolls at the same time during the accelerating and decelerating periods of the motors, it is highly important that the driving motors change their speeds in the desired ratio or percentage from a normal or base speed to a maximum speed within the same time interval in order to prevent the buckling or stretching of the metal which extends between the sets of rolls.

Furthermore, since the motors are both energized simultaneously from a common generator, being connected in parallel relation thereto, it is desirable that their deceleration to a minimum or base speed occur simultaneously in order to prevent the circulation of large amounts of current between the two machines, which would cause serious circuit disturbance, opening of the main circuit-breakers in the motor feed conductors and, consequently, the shutting down of the mill before a pass has been completed. Heretofore, the usual practice has been to secure speed control of the roll motors by varying their applied voltage to a certain point which determines their minimum, or base speed, and from the base speed upwards to a maximum speed by varying their field excitation.

In operating rolling mill drives of this type, field-control is satisfactory only when the excitation of the field windings may be varied without changing the electrical characteristics of the field windings, which govern the building-up and dying-out of the field flux, i. e., the ratio of inductance to resistance or the time-constants of the respective field windings must be maintained substantially constant. It is evident that if the ratio of the maximum speeds is varied, by varying the resistance of the field circuits in the usual way, the time-constant of the windings will be changed to such an extent, as to affect the inherent operating characteristics of the motors. This practice results in changing the time interval required for the field flux to build-up, or die out, during the periods of acceleration and deceleration, and, consequently, the motors do not accelerate to their predetermined maximum speed or decelerate to their base speed, simultaneously.

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

A more specific object of my invention is to provide for operating a plurality of motors in tandem, whereby the relative maximum speeds of the motors may be varied without changing the time-interval required for the motors to accelerate or decelerate, to and from, any predetermined maximum speed within their operating range.

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 rolling mill drive arranged in accordance with my invention, and

Figs. 2 to 5, inclusive, are diagrammatic views of tandem-driven rolls illustrating the various roll speeds which must be maintained for different percentage reductions of

the metal stock when passing through the mill, in either direction.

Reference may now be had to Figure 1 of the drawings, in which a complete drive for a tandem-driven mill having two sets of rolls, is shown.

The roll-sets 1 and 2, which are arranged to operate upon the metal stock simultaneously, are disposed to be driven by motors, 3 and 4, respectively. In this embodiment of the invention, the motors 3 and 4 are illustrated as direct-current, compound motors, direct-connected to the rolls as shown, and provided with series field windings 5 and 6, and separately-excited field windings 7 and 8.

Since it is desirable to control the operation of the roll motors 3 and 4, as a single unit, a motor-generator set 9, comprising a driving-motor 10 direct-connected to a direct-current generator 11, is provided as a source of variable-voltage power. The motor 10 may be operated from any suitable source of power which, in this instance, is illustrated by line conductors 12, 13 and 14.

The generator 11 is provided with a shunt filed winding 16, and is connected directly to the roll-motors by means of power conductors 17, 18 and 19, 20, through any suitable type of circuit breakers 21 to 24, inclusive.

In order to control the amount and direction of voltage developed by the main generator 11, its shunt field winding may be separately excited from any suitable source of direct-current power, which, in this instance, is illustrated as line conductors 25 and 26. Directional switches, 27 and 28 are provided for determining the polarity of the generator field winding, and switches 29 and 30 for controlling the degree of energization of the field winding.

In order to control the operation of the roll-motors 3 and 4, a master switch 31 is provided. Any suitable type of switch may be utilized for this purpose, therefore, in this embodiment of the invention, a foot-actuated master switch is provided. As shown, the switch 31 comprises two movable segments, 32 and 33, disposed to control the operation of the field directional switches, 27 and 28, and are provided with foot rests 34 and 35, for effecting the operation of the switch.

The master switch 31 also comprises a third segment 36, disposed to control the speed of the roll motors when operated in either direction and is, therefore, disposed to be operated in conjunction with either of the foot-actuated segments 32 and 33. As shown, the segment 36 is provided with lugs 37 and 38, which are disposed to engage with the lugs 39 and 40, provided on the foot-actuated segments 32 and 33. A biasing-spring 41 is also provided for actuating the segment 36 to the "off" position as shown in the drawings, when released by the operator.

In order to control the excitation of the roll-motors 3, and 4, in a manner to be hereinafter described in detail, a plurality of exciter sets 42 and 43 are provided. As shown (the exciter sets are provided with separately-excited field windings 44 and 45, respectively, which are connected to the direct-current power source comprising line conductors 25 and 26, through circuits comprising resistors 46 and 47, which are disposed to be varied to change the resistance of the exciter circuits by the operation of a plurality of shunting switches 48 to 53, inclusive. The shunting switches are disposed to be controlled by the foot master switch 31 as will hereinafter be described in detail.

In order to set forth the features of the invention in greater detail, the operation of the drive will now be described.

Assuming that the motor generator set 9 is in operation, the roll motors 3 and 4 may be energized for operation in one direction by actuating the segment 32 of the master switch 31 into its first operating position *a*, thereby bridging the fixed contact-fingers 54 and 55. Accordingly, an operating circuit for the switch 27 is established from the line conductor 25, through conductors 56 and 57, contact-fingers 54 and 55, conductor 58 and operating coil of the switch 27, to the line conductor 26. Upon the closure of the switch 27, the shunt field winding 16, of the generator 11, is energized through a circuit extending from the line conductors 25 and 26 and comprising the field resistor 59, as shown. This causes the generator 11 to develop a predetermined voltage, thereby effecting the operation of the roll motors 3 and 4, at reduced speed.

In order to accelerate the roll motors to their base-speeds, the master-switch 31 is actuated to the second and third positions, *b* and *c*, respectively. In the second position *b*, the contact-fingers 60 and 61 are bridged by the segment 36 to establish an operating circuit for the resistor short-circuiting switch 29, extending from the line conductor 25, through conductors 56 and 62, contact fingers 60 and 61, operating coil of the switch 29, and conductor 63 to the line conductor 26. In the third position *c*, of the master switch, the contact-finger 64 is engaged by the movable segment 36 to establish an operating circuit for the switch 30, thereby short-circuiting the field resistor 59, and causing the generator 11 to develop full voltage.

It will be readily understood that little difficulty is encountered in effecting the simultaneous acceleration of the two motors to their base speeds by means of the variable-voltage control, since their field excitation need not be varied, and, therefore, the time

constants of the field windings remain fixed.

In order to effect the simultaneous change in the speeds of the two motors in whatever ratio desired, at speeds above the base speed, it is necessary to provide separately excited field windings for the roll motors 3 and 4, which inherently have the same time constants, thus determining the time-interval required for the field-flux to change from one value to another. Therefore, it will be apparent that when field control of the roll motors 3 and 4 is utilized for effecting an increase in speed from their base speeds, which is determined by the variable-voltage control with fixed excitation on the roll motors 3 and 4, the resistance of the energizing circuits for the separately-excited field windings 7 and 8, cannot be changed without changing the time-constants of the field windings of the respective motors.

In order to provide for varying the excitation of the shunt-field windings 7 and 8, without changing the time-constants of the field circuits, the exciting-generators 65 and 66, of the exciter sets 42 and 43, respectively, are direct-connected to the field windings 7 and 8 in a closed-circuit, which has predetermined and fixed electrical characteristics.

It will, therefore, be readily understood that the relative values of exciting current in the field windings 7 and 8, may be varied by controlling the voltage developed by the excited generators 65 and 66, which, by reason of the fixed time-constants of both the motor field windings, causes the roll motors 3 and 4 to always accelerate to a predetermined maximum speed or decelerate to the base speed, in exactly the same time interval.

In order to effect further acceleration of the roll motors by means of field control, the master switch 31 may be actuated to its fourth position *d*, thereby effecting the disengagement of the contact finger 67 from the segment 36.

It will be observed that upon the disengagement of the contact finger 67, an energizing circuit is interrupted which extends from line conductor 25, through conductors 56 and 62, contact fingers 61 and 67, bridged by the segment 36, and conductor 68 to junction-point 69, where the circuit divides, one branch extending through the operating coil of the short-circuiting switch 48, and conductor 70 to the line conductor 26, and the other branch extending through conductor 71, operating coil of the short-circuiting switch 51, and conductor 72, to the line conductor 26. The deenergization of this circuit causes the normally closed short-circuiting switches 48 and 51 to open, thereby inserting the first step of resistance in the excitation circuits of the exciter field windings 44 and 45. Accordingly, the exciting-current flowing in the exciter field circuits is reduced a predetermined amount, thereby effecting a reduction in the voltage developed by the exciter and, consequently, a weakening of the field fluxes of the roll motors 3 and 4.

Further, acceleration of the motors may be obtained by actuating the master switch 31 to the fifth, and sixth positions, *e* and *f*, respectively, to effect the disengagement of the contact fingers, 73 and 74, respectively. This operation effects the interruption of the operating circuits for the remaining short-circuiting switches 49, 50, 52 and 53 in exactly the same manner as described hereinbefore in connection with the switches 48 and 51.

Upon the opening of all the short-circuiting switches 48 to 53, inclusive, the full amount of the resistors 46 and 47, is connected in the exciter field circuits, causing the exciter voltages to become a minimum; and, consequently, the speeds of the roll motors 3 and 4 are increased to their maximum value, the motors operating under weakened field conditions.

Referring to Figs. 2 and 3, it will be observed that the maximum speed of the roll motor 4, which drives the roll-set 2, must be varied depending upon the direction which the metal is passed through the rolls. Referring to Fig. 3, it is evident that since the reduction is being made by the roll-set 1, the relative speeds of the rolls is determined only by their respective diameters. However, in Fig. 2, the stock is fed to the roll-set 2 before a reduction has been made by the roll-set 1 and, therefore, the relative speeds are determined by their respective diameters and also by the percentage reduction. That is, in making a pass as illustrated by Fig. 2, the speed of the motor driving the roll-set 2 must be decreased by approximately the same percentage as the percentage reduction of the metal, in order to compensate for the reduction of the metal in roll-set 1. Likewise, as shown in Figs. 4 and 5, the speed range of the roll motor 4 varies from 64 to 80 revolutions per minute in order to take care of a 20% reduction in the metal.

In order to provide for adjusting the speed of the roll motor 4, in accordance with each reversal of the rolls as hereinbefore described, a variable-resistor 75 is utilized for further controlling the excitation of the shunt field winding 45. Any suitable type of variable-resistor may be utilized and operated in conjunction with the master switch 31 by any suitable means, or the variable resistor may be controlled through manual operation by the same operator who operates the foot master switch. In this embodiment of the invention, there is illustrated a simple form of variable-resistor adapted for manual control.

It will be readily understood that when the movable contact arm 76 of the variable resistor 75 is set in the position designated as "off", the voltage developed by the exciter

generator 66 is such as to cause the roll motor 4 to operate at a predetermined speed above the base speed, and that by actuating the movable contact arm 76 in a counter-clockwise direction, the maximum speed above base speed may be changed to any point desired. It is, therefore, evident that the resistor 75 may be calibrated and definite points determined, on which the movable contact arm 76 must be set for each direction of pass and for any percentage of reduction in the metal.

Furthermore, it is evident that the operation of the variable-resistor unit 75 to change the ratio of the maximum speeds of the two motors, in no way affects their acceleration and deceleration periods, since the excitation circuits for the field windings 7 and 8 of the motors 3 and 4, respectively, maintain their electrical characteristics; that is, there is no change of resistance or inductance of the circuit and when these values have once been determined and the circuits so regulated that the ratio of $\frac{L}{R}$ in each circuit is equal, they remain equal regardless of any changes or variations which may be made in the field excitation circuits of the exciter-generators.

Since the resistance of the excitation-circuits for the field windings 44 and 45 is varied, there will be a difference in the time-interval required for their field fluxes to build-up and die-out. However, in this instance, the exciter field windings 44 and 45 are designed with a low time-constant providing what is termed as a "fast field", in which the current can be built up from zero to full field value in a fraction of a second. To build up the field current of the main motors 3 and 4 may require 15 or 20 seconds. It is evident that with the excitation arrangement shown, the total time for any percentage of change in the main motor field current is the sum of the time period required in each field winding for this percentage change. Since the time to change the excitation of the exciter field winding is a very small part of the total time required to vary the excitation of the roll motor, the variation in the time-constant of the exciter field circuits is of little consequence, and, therefore, the desired operation of the roll-motors is unaffected.

Since the exciter arrangement for the roll motors 3 and 4 as hereinbefore described in detail, provides also for causing the motors to decelerate to their base speeds from whatever maximum speed at which they may be operating, at practically the same instant, there is no tendency for one motor to act as generator and cause a heavy circulating current to flow through the circuit to the other motor. Since this circulating current might, in many cases, exceed the normal overload current of the motors, any of the main circuit-breakers 21 to 24, inclusive, might be opened to stop one or both of the motors and thus shut down the mill before the pass was completed, thereby resulting in a loss of time, and increased operating expenses.

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 modifications of the same may be made without departing from the spirit and scope of the invention as defined by the appended claims.

I claim as my invention:

1. In a drive for rolling mills provided with rolls of different diameters, parallel connected motors for driving the rolls, said motors having field windings of similar time constants, an exciter for each motor, a closed circuit comprising one field winding and the armature of the exciter for energizing the field winding, a source of variable-voltage power for varying the speed of the motors between zero speed and a predetermined ratio of base speeds simultaneously, and means for varying the exciter voltage to effect the acceleration of the motors from a predetermined ratio of base speeds to a different predetermined ratio of maximum speeds in accordance with the current-time characteristic of the field windings to cause the rolls to reach the same peripheral speed at the same time.

2. In a drive for steel mills provided with rolls of different diameters, a plurality of parallel connected motors for driving the rolls, said motors being provided with field windings having similar electrical characteristics, a source of power for the motors, means for exciting said field windings comprising a motor-generator set for each field winding having the armature of the generator connected in series-circuit relation with said field winding to provide excitation circuits of unvarying electrical characteristics, and means disposed to effect a simultaneous variation of the excitation voltages developed by the generators to change the speeds of the motors in different amounts, within the same time interval, as determined by the common electrical characteristic of their field windings.

3. In a drive for steel rolling mills provided with a plurality of roll sets of different diameters, in combination, a source of power, a plurality of roll motors disposed for tandem operation and connected in parallel relation to the source of power, said motors being provided with field windings having the same time-constants, means for varying the excitation of the field windings without changing the time-constant of the windings, said means comprising a variable-voltage generator connected to each motor-field winding, and means for varying the excitation of the generators in a predetermined ratio to effect predetermined percentage variations in the

speeds of all the motors during a predetermined time interval, as determined by the common time constant of the field windings.

4. In a drive for steel rolling mills provided with a plurality of sets of rolls of different diameters, in combination, a source of power, a main motor having a field winding with a predetermined time-constant for operating one set of rolls, an auxiliary motor for operating another set of rolls disposed to operate at predetermined speeds relative to the speed of the rolls driven by the main motor, said auxiliary motor being provided with a field winding having the same time constant, said main and auxiliary motors being individually connected to the power source and means including a plurality of variable-voltage exciter sets for simultaneously varying the excitation of the field windings without effecting a change in their respective time-constants, thereby to effect different changes in speed of the motors within equal predetermined time intervals.

5. In a drive for rolling mills provided with a plurality of sets of roll members of different diameters, in combination, a plurality of drive motors provided with field windings for operating the roll sets at different speeds, a source of power for the motors, said power source comprising a motor-generator set, the motors being connected independently to the generator and means for varying the generator voltage to vary the speeds of the motors to and from a predetermined base speed simultaneously, said motor field windings having the same time-constant and being disposed under normal excitation to provide a predetermined ratio of speeds between the motors, means for effecting an increase in the excitation of one motor thereby to change the speed ratio between the drive motors from the normal value, an exciter for each field winding connected in a closed circuit therewith, and means for simultaneously varying the voltage of the exciters to change the excitation of the motor field windings without changing their respective time-constants, thereby to cause all the motors to attain their maximum predetermined speed simultaneously.

6. In a drive for rolling mills provided with separate groups of roll members which cooperate in the rolling of a single piece of metal, in combination, a motor provided with a field winding for operating each group of rolls, said field windings of each motor having similar time-constant characteristics, a source of variable-voltage power for the motors, the motors being connected in parallel-circuit relation to the power source, a separate exciter for each motor, said exciters being disposed to vary the excitation of the field, windings without changing the time constant of the field circuit, and means for controlling the voltage of the exciters to control the speed of the motors in accordance with the time-constants of their fields, thereby to cause the motors to accelerate and decelerate throughout unequal speed ranges within the same time interval.

7. In a drive for steel-rolling mills provided with a plurality of independent roll sets having rolls of different diameters, in combination, a source of power, parallel-connected motors for actuating the roll sets, said motors having field windings of equal ratios of resistance and inductance to provide equal time-delay periods for the establishment and decay of the field flux, a master switch operable to effect the starting and stopping of the motors, an exciter for each of the motors, said exciters being provided with separately-excited field windings and armatures connected in closed-circuit relation with the field windings of the respective motors, separate means for driving the exciters at substantially constant speed, and means disposed to be controlled by the master switch for varying the excitation of the exciter field windings to vary the excitation of the roll motors, thereby to effect a change in speed of all the motors in a predetermined manner within the same time interval.

8. In a drive for rolling mills provided with a plurality of sets of rolls of different diameters, a plurality of motors for driving the roll sets at different speeds, said motors being provided with field windings having the same time-constants to cause the field flux to change in any desired ratio in all of the motors within a predetermined time interval, a source of power, said motors being connected in parallel-circuit relation to the power source, means for varying the voltage of the power source to change the speed of all the motors from zero to a predetermined base speed, and means comprising an exciter connected solidly to each motor field winding for further controlling the speed of the motors above the base speed, said means being operable to cause the motors to accelerate as a group from the base speed to different maximum speeds and reach said maximum speeds at the same instant and to decelerate therefrom to the base speed in a similar manner.

9. In a drive for rolling mills provided with a plurality of roll sets having rolls of different diameters, in combination, a source of power, a plurality of drive motors independently connected to the power source provided with field windings, said field windings having the same time-constant, a variable-voltage exciter for each field winding, said exciters being direct-connected to the field windings to provide exciting circuits of unvarying electrical characteristics to provide for varying the excitation of the motor-field windings without changing the value of the time-constants, means for pre-selecting the ratio of speeds between the motors, and electro-responsive means for controlling the

field excitation of each exciter, and a master switch operable to effect the simultaneous operation of the electro-responsive excitation-controlling means for the exciters to cause the motors to attain different speed conditions at the same time.

10. In a drive for rolling mills provided with a plurality of roll stands having more than one roll member, a plurality of motors for operating the rolls of the stands at different speeds, a source of power for the motors, said motors bing connected in parallel-circuit relation to the source of power, field windings for each motor, said field windings having similar current-time characteristics, a separately-driven exciter for each field winding, means for varying the voltage of the power source to control the speed of the motors over a portion of their speed range, and means for controlling the voltage of the exciters for further controlling the speed of the motors by varying their separate excitations in any desired ratio to cause their field flux to vary in accordance with the current-time characteristics of the field windings whereby all the motors may be caused to change their speeds simultaneously and reach the desired new speed condition at substantially the same instant.

11. In an electric drive for rolling mills provided with a plurality of sets of rolls of different diameters, in combination, a plurality of motors provided with field windings disposed to operate the individual roll sets at different speeds, a generator for supplying power to the motors, said motors being connected in parallel-circuit relation to the generator, means for varying the excitation of the generator to cause said generator to supply variable-voltage power to the motors, said field windings of the motors having the same time-constant characteristics, a separately driven exciter connected in series with each field winding to provide field circuits for each motor of fixed resistance and reactance to maintain the time constants of the field windings at a fixed value, and a master controller operable over a predetermined range to control the means for varying the excitation of the generator to initially vary the speed of all the motors simultaneously, and subsequently operable to vary the voltage of the exciters in any desired ratio to cause said roll motors to change from one speed ratio to any other desired speed ratio within the same period of time.

In testimony whereof, I have hereunto subscribed my name this 13th day of August, 1928.

RALPH H. WRIGHT.