

[54] **MOTOR DRIVE SYSTEM FOR
ROLLING MILL**

[72] Inventor: **Howard Nesbit Cox**, Boxford, Mass.

[73] Assignee: **General Electric Company**

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[52] U.S. Cl.72/8, 72/21, 72/29

[51] Int. Cl.B21b 37/00

[58] Field of Search.....72/8, 19, 21, 29, 249

[56] **References Cited**

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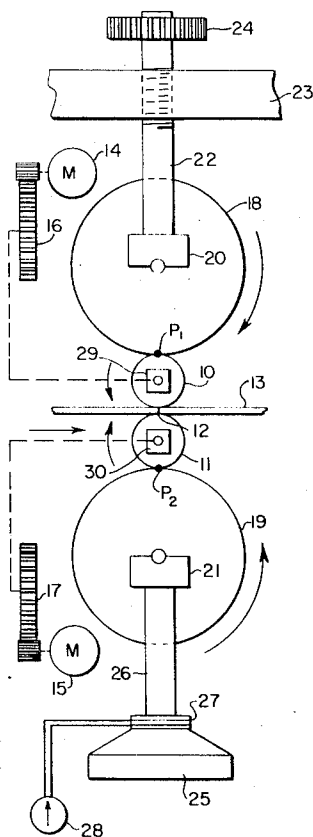
Primary Examiner—Milton S. Mehr

Attorney—James C. Davis, John J. Kissane, Frank L. Neuhauser, Oscar B. Waddell and Joseph B. Forman

[57] **ABSTRACT**

In a four high rolling mill having two powered working rolls and a pair of backup rolls, the backup rolls are synchronized by controlling the drive motors to force differential slippage between the working rolls and the strip being processed through the mill. Angular position comparison means senses and lack of synchronism of the backup rolls and produces a control signal which differentially adjusts the torques produced by the drive motors. Synchronization of the backup rolls reduces roll force variations caused by eccentricity of rolls.

10 Claims, 4 Drawing Figures



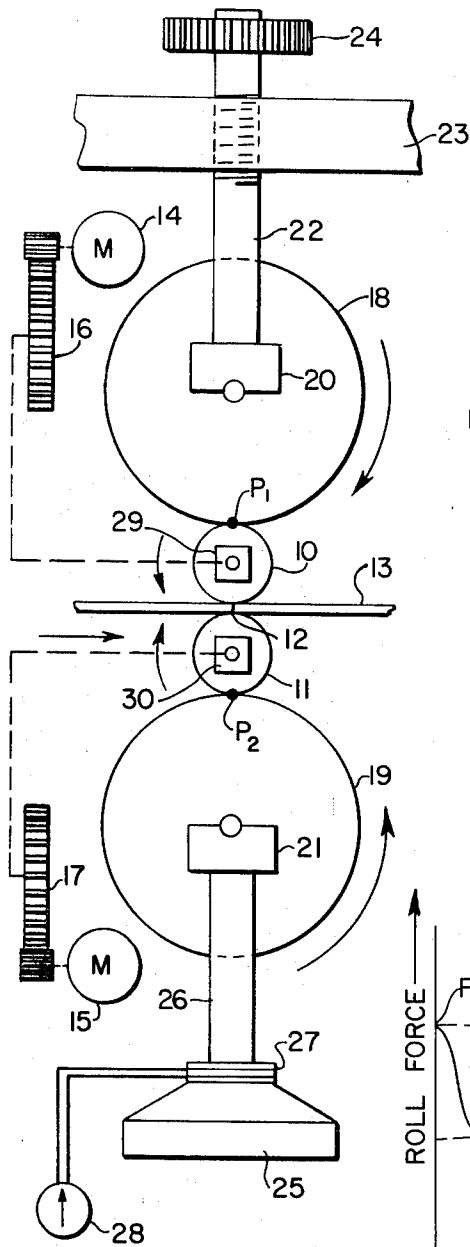


FIG. 1

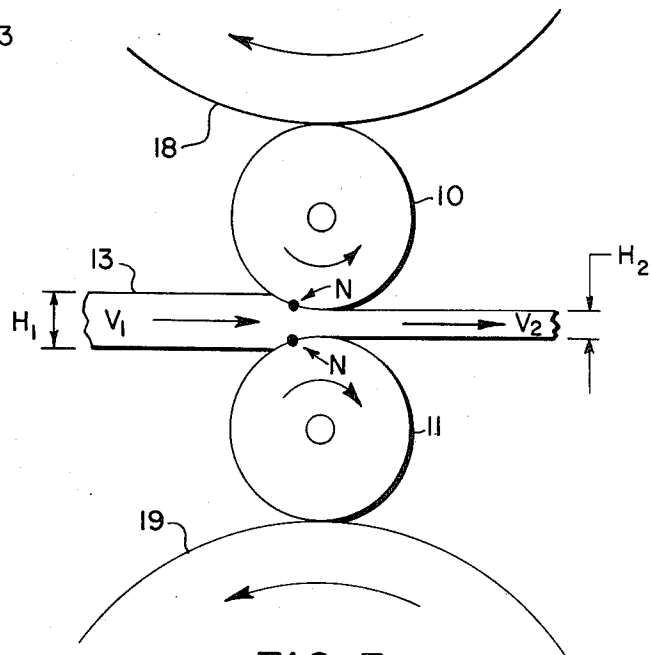


FIG. 3

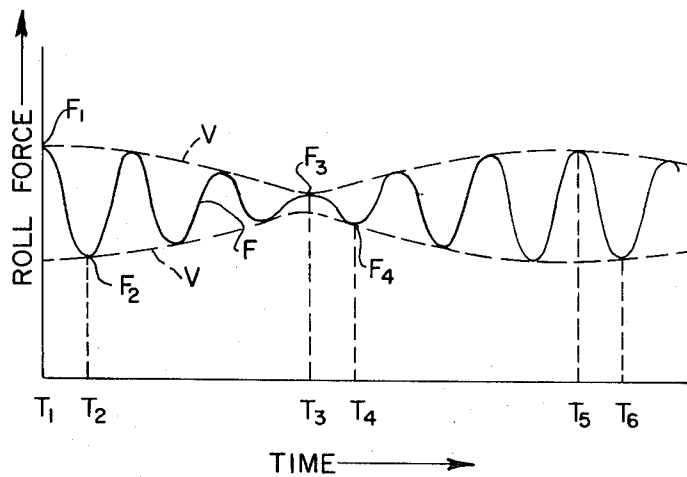


FIG. 2

INVENTOR
HOWARD N. COX

MOTOR DRIVE SYSTEM FOR ROLLING MILL

BACKGROUND OF THE INVENTION

This invention relates to a motor drive system for rolling mills of the type used to reduce the thickness of strip material passing through the mill.

Rolling mills of the so-called four high type are widely used. Typically, the mill comprises a pair of juxtaposed working rolls between which the strip to be processed passes, the working rolls being driven in opposite directions by powerful electric motors coupled to the rolls through a gear reduction drive system. To resist the large forces tending to separate the working rolls massive backup rolls are rotatably mounted in a mill frame so as to bear against the working rolls on opposite sides of the work rolls where the strip reduction takes place. The backup rolls are forced into engagement with the working rolls by screw-down apparatus and rotate with the working rolls.

A major problem in successful operation of a rolling mill is to maintain the processed strip material at a relatively constant thickness or gage. One cause of thickness variation is eccentricity of the backup rolls which results in roll force variations with corresponding changes in strip thickness. This roll force variation is random in nature because of lack of synchronism of the backup rolls during operation of the mill. This lack of synchronism is caused by differential slippage between the working rolls and the processed strip. It is also caused by the backup rolls having slightly different diameters resulting from regrinding of the rolls made necessary by wear. Because of the random nature of the roll force variation caused by roll eccentricity it is difficult to detect and control. Attempts have been made to compensate for roll eccentricity by continuous sensing of the roll force and adjustment of the screw-down apparatus to compensate for roll force variations. However, such control systems are costly to build and expensive to maintain.

Accordingly, it is an object of this invention to provide an improved system for driving and controlling a rolling mill that reduces and essentially eliminates roll force variations and resulting thickness variations of the processed strip caused by eccentricity of the backup rolls.

Another object of the invention is to provide a drive system for a rolling mill which reduces the effect of roll eccentricity by automatically and continuously synchronizing the backup rolls during the operation of the mill.

Further objects and advantages of the invention will become apparent as the following description proceeds.

SUMMARY

In accordance with the invention the backup rolls of a rolling mill are continuously synchronized by differentially adjusting the torques applied by the drive motors to the working rolls. This produces a differential slippage between the work rolls and the processed strip in a direction to synchronize the backup rolls. A position comparator continuously compares the instantaneous angular positions of the backup rolls and produces an output signal indicative of any

departure of the back rolls from a predetermined relative angular position that produces minimum roll force variation due to eccentricity of the backup rolls. The comparator output signal differentially adjusts the drive motor torques in any suitable manner as by coaction with the motor field current regulators. Position comparison of the backup rolls is performed by selsyns or other known types of angular position comparison devices.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic illustration of a rolling mill to which the drive system of the present invention may be applied.

FIG. 2 is a graphical representation showing the manner in which roll force variation occurs in the mill of FIG. 1 due to eccentricity of the backup rolls.

FIG. 3 is a geometrical diagram illustrating how slippage occurs between the rolled strip and the working rolls of a mill, and

FIG. 4 shows, in schematic form, a motor drive and control system for the mill of FIG. 1 which embodies the present invention.

DESCRIPTION OF THE ILLUSTRATED EMBODIMENT

Referring now to FIG. 1 of the drawing there is illustrated in schematic form a 4 high rolling mill to which a motor drive system embodying the present invention may be applied. As shown the mill comprises a pair of juxtaposed working rolls 10 and 11 having therebetween an interface 12 through which a strip 13 to be rolled passes. The working rolls 10 and 11 are separately driven in opposite directions by electric drive motors 14 and 15 through suitable gear reductions 16 and 17.

Bearing against the working rolls on opposite sides of the interface 12 are upper and lower backup rolls 18 and 19 the journals of which are supported in bearing blocks 20 and 21. Downward pressure exerted on upper backup roll 18 is adjusted by screw-down apparatus comprising a threaded screw 22 in the threaded engagement with a stationary frame member 23. The screw 22 terminates in a gear 24 driven by a reversible screwdown motor (not shown) providing a means for adjusting rolling force exerted by the mill.

The lower bearing block 21 is supported on a base 25 through a supporting member 26. Interposed between support 26 and base 25 is a load cell 27 of known construction providing a means for measuring mill rolling force on a suitable instrument 28.

The journals of the working rolls 10 and 11 are supported in bearing blocks 29 and 30 which are slidably supported to permit limited vertical adjustment of the working rolls. The bearing blocks 20 and 21 of the backup rolls are relatively fixed and because of this any eccentricity in the backup rolls causes substantial variation in the rolling force. For example, a relative vertical movement of the contact points P_1 and P_2 where the backup rolls engage the working rolls of 0.001 inch will cause a change in the roll force of 15 tons in a typical mill.

The backup rolls 18 and 19 are usually slightly eccentric due to manufacturing inaccuracies. Eccentricity may also be caused by bending of the roll journals

due to excessive transient roll force. If the high points on the backup rolls reach the contact points P_1 and P_2 simultaneously the roll force will be a maximum. After 180° of rotation the low points on the backup roll reach the contact points P_1 and P_2 simultaneously and the roll force will be at a minimum value. For this condition the difference between the maximum and minimum roll forces for a complete revolution of the backup rolls will be at a maximum. On the other hand if the angular relation of the backup rolls is such that the high point of one roll reaches one of the contact points at the same time that the low point on the other roll reaches the other contact point the difference between the maximum and minimum roll forces for a complete revolution of the backup rolls will be a minimum. For conditions where the angular relationships of the backup rolls are between the maximum and minimum conditions described above, the difference between the maximum and minimum roll forces during a complete revolution of the backup rolls will have some intermediate value.

During operation of a conventional four high rolling mill of the type shown in FIG. 1 the upper and lower backup rolls are likely to rotate at different speeds because the backup rolls have different diameters. This condition may, for example, be the result of different amounts of regrinding of the rolls to remove surface irregularities. Different speeds and angular relationships of the upper and lower backup rolls may also be caused by differential slippage between the working rolls and the strip being rolled. Because of the speed differential and slippage the angular relationship of the backup rolls continuously changes. As a result of the lack of synchronization of the backup rolls the roll force variations occurring during each rotation of the backup rolls continuously changes in a random and unpredictable manner.

Referring to FIG. 2 the roll force variation caused by eccentricity and continuously varying angular relationships of the backup rolls is graphically illustrated. Such roll force variation is indicated, for example, by the reading of instrument 28 at different times T . During the time interval T_1 , T_2 the roll force variation will have a maximum oscillation or range $F_1 - F_2$ which occurs when the high points of the backup rolls contact the working rolls at the same time. As the relative angular positions of the backup rolls change due to slippage at the work roll interface or because of different backup roll diameters an interval T_3 , T_4 will be reached when the roll force oscillation will have a minimum value $F_3 - F_4$. This occurs when the high point of one backup roll and the low point of the other backup roll contact the working rolls at the same time. As the relative angular positions of the backup rolls continue to change the roll force will reach another maximum oscillation during the time interval T_5 , T_6 .

The dotted lines V forming the envelope of roll force curve F show the cyclic manner in which the amplitude of the roll force oscillations varies as the relative angular position of the backup rolls continuously changes due to lack of synchronism of the rolls during operation of the mill. In actual practice the number of oscillations of the roll force curve F between maximum and minimum points will likely be considerably greater than the number shown which has been reduced for clarity and ease of illustration.

According to the invention the backup rolls 18 and 19 are synchronized and locked in a relative angular position which produces a minimum roll force variation caused by eccentricity of the backup rolls. This minimizes changes in thickness or gage of the rolled strip caused by such roll force variations resulting in a better product and less scrap loss of off-gage material exceeding permissible thickness variations. This is accomplished in a manner now to be described by causing differential slippage to occur between the work rolls and the rolled strip during operation of the mill.

The invention makes use of the fact that slippage necessarily occurs between the working rolls 10 and 11 and the rolled strip 13. The nature of this slippage is illustrated in FIG. 3. As the strip 13 passes through the working rolls 10 and 11 its thickness is reduced from H_1 to H_2 . Because of extrusion effects accompanying the thickness reduction the velocity V_2 of the strip after it passes through the rolls is necessarily greater than the entering velocity V_1 for constant mass flow through the mill. At neutral points N on the interface of the working rolls the peripheral velocity of the rolls equals the strip velocity after leaving the mill. At points of contact between the strip and the rolls beyond points N the strip velocity exceeds the peripheral velocity of the rolls so that there is slippage therebetween. At points of contact ahead of points N the strip velocity is less than the peripheral velocity of the rolls so that there is slippage therebetween in the reverse direction. Thus slippage continuously occurs between the working rolls and the rolled strip. According to the invention, this slippage is differentially adjusted by varying the torques exerted on the working rolls by their associated drive motors. This differential slippage is made to occur in a direction to restore the backup rolls to the synchronized position producing minimum roll force variation in response to a departure of the backup rolls from that position. This automatic controlling action is incorporated into the motor drive system of the working rolls. An illustrative way in which this control action may be accomplished will now be described.

Referring now to FIG. 4, the drive motors 14 and 15 for the working rolls 10 and 11 are shown as D.C. motors having armatures energized from a common bus 31 connected by a circuit breaker 32 to a D.C. power supply such as a generator 33.

The motors 14 and 15 have field windings 34 and 35 supplied with direct current by associated field current regulators 36 and 37. The field current regulators, which are shown schematically, are self-saturating magnetic amplifiers commonly referred to as amplistats. Such amplifiers are shown, for example, in U.S. Pat. No. 3,132,293 — Marrs, issued May 5, 1964, to which reference may be made for construction details. The amplifier-regulators are energized from A.C. power sources 38 and 39 and have D.C. output circuits 40 and 41 in which the output current is controlled in accordance with the net D.C. magnetic control flux supplied by control windings. As shown, the regulator 36 has three control windings 42, 43 and 44 and the regulator 37 has three control windings 45, 46 and 47. The motor field windings 34 and 35 are connected to the output circuits 40 and 41 of regulators 36 and 37 and the D.C. current supplied to these field windings is controlled by adjustment of D.C. current supplied to the control windings. To permit simultaneous adjust-

ment of the field currents of the motors 14 and 15 the control windings 43 and 46 are connected in series, as shown, and energized from the output of a rheostat 48. The rheostat is driven between predetermined stable operating limits by a reversible motor 49 which is manually operated by suitable controls (not shown) to adjust the operating speeds of the working rolls 10 and 11.

The control windings 42 and 45 of the field current regulators are energized in accordance with the output currents in their output circuits, as shown, and in this manner a feedback action occurs by which the motor field currents are maintained at values preset by the outputs of the other control windings. The control windings 44 and 47 are provided to permit a differential adjustment of the field currents and hence torque outputs of the drive motors 14 and 15 by means of which the backup rolls 18 and 19 are continuously synchronized as will be more fully described.

During operation of the mill any lack of synchronism of the backup rolls is detected by angular comparator apparatus which, in the form illustrated, is a differential selsyn system. The system comprises two selsyns 50 and 51 and a differential selsyn 52. Selsyn 50 has a rotor 53 mechanically coupled to the journal of the upper backup roll 18, the connection being indicated by the dash line 55. Similarly, the selsyn 51 has a rotor 54 mechanically coupled to the journal of the lower backup roll 19, the connection being indicated by the dash line 56. The selsyns 50 and 51 have rotor windings 57 and 58 and stator windings 59 and 60, the rotor windings being energized from a common A.C. power source 61. With this arrangement, the electrical outputs of the selsyn stator windings are indicative of the angular positions of the back rolls 18 and 19.

The differential selsyn 52 has a rotor 62 with a rotor winding 63 and a stator winding 64. As shown, the stator winding 59 of selsyn 50 is connected to the stator winding 64 of the differential selsyn, and the stator winding 60 of selsyn 51 is connected to the rotor winding 63 of the differential selsyn. The connections and polarities are chosen so that when the backup rolls are driven by the motors 14 and 15 through the working rolls 10 and 11, the magnetic fields in the rotor and stator windings of the differential selsyn rotate in the same direction, assumed for purposes of explanation to be clockwise. Thus, when the backup rolls rotate at the same speed the rotor 62 of the differential selsyn remains stationary. However, if the backup rolls begin to rotate at different speeds the rotor 62 of the differential selsyn will rotate in a direction dependent on whether one of the backup rolls leads or lags the other backup roll. Thus, the mechanical output of the differential selsyn rotor provides an output signal indicative of lack of synchronism of the backup rolls during operation of the mill. By coupling the output of the differential system to the differential field current control windings 44 and 47 of the regulators 36 and 37 the drive motor torques and the slippage between the working rolls 10 and 11 and the rolled strip 13 are controlled so as to correct continuously any lack of synchronism of the backup rolls. The coupling system by which this is accomplished will now be described.

The mechanical output of the differential selsyn 52 is first converted to a D.C. control signal the magnitude

and polarity of which is indicative of the direction and amount of displacement of the differential selsyn rotor from a null position. For this purpose there is provided a potentiometer 65 comprising a fixed resistance element 66 and a rotatable wiper 67. The ends of the resistance 66 are connected to plus and minus terminals of a suitable D.C. power supply with a midpoint 68 grounded so as to be at zero potential. The wiper 67 is biased by a spring 69 so that it normally occupies the zero or null output position shown but can be forcibly displaced in either direction to produce plus and minus output signals. These signals are fed by lead 70 to the input of an amplifier 71 the output of which is connected by lead 72 to the serially connected differential control windings 44 and 47 of the field current regulators 36 and 37. The amplifier input and output circuits are bridged by a capacitor 73 so that the amplifier performs an integrating function. With this arrangement the amplifier D.C. output and the current supplied to windings 44 and 47 is increased or decreased depending on the direction of displacement of potentiometer wiper 67 from the null position. Also, the rate of change of amplifier output varies with the degree of displacement of the potentiometer wiper from the null position. It will be noted that the polarities of windings 44 and 47 are chosen so that current flowing therethrough produces opposite effects on the current output of field current regulators 36 and 37. Thus a current flowing in circuit 72 from the amplifier in one direction will increase the output of field current regulator 36 and decrease the output of regulator 37 and vice versa. Since the torque produced by the drive motors 14 and 15 depends on the field currents supplied thereto in the normal motor operating speed range, it will now be clear that by controlling the direction and magnitude of the current in circuit 72 the motor torques may be differentially adjusted in either direction and to the desired amount, this action being accomplished by movement of the wiper 67 of potentiometer 65 in either direction from the null position.

To complete the control system loop the potentiometer wiper 67 is coupled to the rotor 62 of the differential selsyn 52 through a clutch 74 the interconnection being represented by dash lines 75 and 76. The clutch 74 may be electrically operated to permit engagement by closure of a control switch 77. With the clutch disengaged the differential selsyn rotor 62 is free to rotate and biasing spring 69 maintains potentiometer wiper 67 at the null position. When the clutch is engaged rotor 62 will drive wiper 67 off null in either direction to effect a differential adjustment of the output torques of the drive motors 14 and 15. Under certain operating conditions, the excursions of the control system and the motor speeds may exceed normal operating limits. Under such conditions, it may be desirable momentarily to zero the output of amplifier 71. For this purpose a shunting circuit controlled by a switch 78 is provided. The switch 78 may be operated manually or automatically.

OPERATION

The operation of the drive system to maintain synchronism of the backup rolls 18 and 19 in a position producing minimum roll force variation may now be described.

Initially, switch 77 is opened to disable the automatic motor differential field control. Backup rolls 18 and 19 are then positioned to have the relative angular relationship which produces minimum roll force variation caused by eccentricity of the backup rolls. One way to determine this predetermined relative angular position is to energize drive motors 14 and 15 as by closing circuit breaker 32 to rotate the mill rolls. Because the backup rolls usually have different diameters the angular relationship between the backup rolls will continuously change. By observing instrument 28 the point of minimum roll force variation can be determined at which point switch 77 is closed to activate the differential field control system. Use of a recording type of instrument facilitates this operation by producing a roll force amplitude curve similar to that shown in FIG. 2. After switch 77 is closed the drive system automatically acts to maintain synchronism of the backup rolls in the desired relative angular relationship in the following manner.

Referring to FIG. 4, it will be assumed for purposes of further explanation that the upper backup roll 18 has a high spot H whose instantaneous angular position with reference to a fixed point is located at angle θ_1 and that the lower backup roll 19 has a low point L located at an angle θ_2 as shown on the drawing. If angles θ_1 and θ_2 are equal and the backup roll speeds are equal the high and low points H and L will reach the points of contact with the working rolls at the same instant. This, then, is the desired angular relationship between the backup rolls for minimum roll force variation due to eccentricity of the rolls as explained in connection with FIG. 2.

During operation of the mill this desired angular relationship will tend to change due to different backup roll diameters or differential slippage between the working rolls and the rolled strip 13 or a combination of these two effects. For example, assume that backup roll 18 moves ahead of backup roll 19 so that angle $\theta_1 > \theta_2$. Differential selsyn rotor 62 and potentiometer wiper 67 will then rotate clockwise an amount equal to $\theta_1 - \theta_2$. Potentiometer wiper 67 is moved off the null position and current flows through circuit 72 and windings 44 and 47 of the field current regulators to produce a control flux in the direction of the arrows. In the case of regulator 36 this is in a direction to aid the flux produced by speed control winding 43 thereby increasing the field current and back EMF of drive motor 14. This decreases the motor current and output torque. On the other hand, in regulator 37 the flux produced by coil 47 opposes the flux produced by speed control winding 46 thereby decreasing the field current and back EMF of drive motor 15. This increases the motor current and output torque. As a result of these motor torque changes in opposite directions more slipping between working roll 11 and strip 13 occurs than the slippage between working roll 10 and strip 13. This causes backup roll 19 to rotate faster than backup roll 18 until the angles θ_1 and θ_2 are again equal. At this point differential selsyn rotor 62 will have rotated back to its original position for zero output of potentiometer 65. If backup roll 19 tends to move ahead of roll 18 angle θ_2 becomes larger than θ_1 . The reverse action then takes place in response to counterclockwise movement of differential selsyn rotor 62.

It will be noted that due to the integrating action of amplifier 71 the control system will stabilize, i.e., the potentiometer 65 will be at the null point with current flowing in circuit 72 in either direction. This is accomplished by combining the proportioning action of potentiometer 65 with the integrating action of amplifier 71.

It will be understood that the control principles of the present invention may be applied to other types of motor control systems without departing from the invention. For example, the relative torque outputs of drive motors 14 and 15 may be controlled by differential adjustment of their armature voltages rather than field currents and adjustable speed A.C. motors may be used as will be readily apparent to those skilled in the art. Also, other types of known angular comparison systems, both analog and digital, may be used instead of the selsyn system illustrated to control the drive motor torque differential.

The motor drive and control system embodying the present invention has been illustrated as applied to a rolling mill wherein the backup rolls are rotatably driven by the work rolls. It may also be applied to a mill where the backup rolls are directly driven by the drive motors and the working rolls are driven by the backup rolls.

While there has been shown what is presently considered to be a preferred embodiment of the invention, it will be apparent to those skilled in the art that various changes and modifications may be made therein without departing from the spirit and scope of the invention.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A drive system for a rolling mill comprising a pair of engaging working rolls having an interface through which a strip to be rolled passes, and a pair of backup rolls, each backup roll engaging its associated working roll on opposite sides of said interface and being rotatably driven with the working roll, said system comprising:

- a. a pair of motors for driving the working and backup rolls, each motor being separately connected to drive its associated working and backup rolls,
- b. control means for differentially adjusting the torques applied to the working rolls by the drive motors,
- c. comparator means arranged continuously to compare the instantaneous angular positions of the backup rolls and produce an output signal variable in accordance with deviation of the relative angular positions of the backup rolls from a predetermined position, and
- d. coupling means activating said control means in accordance with the output signal from said comparator means whereby the relative magnitudes of the torques applied to the working rolls are adjusted to cause differential slip to occur between the working rolls at said interface to maintain the backup rolls in said predetermined relative angular position during operation of the mill.

2. A drive system as set forth in claim 1 wherein the motors have fields supplied with adjustable current and the control means comprises means for differentially

adjusting the field currents supplied to the drive motors.

3. A drive system as set forth in claim 1 wherein the comparator means is a selsyn system comprising a differential selsyn having stator and rotor windings energized by selsyn generators coupled to the backup rolls, the mechanical deflection of the differential selsyn rotor constituting the output signal.

4. A drive system as set forth in claim 1 including disconnect means for disabling the control means until the backup rolls acquire said predetermined relative angular position during rotation thereof by the drive motors.

5. A drive system as set forth in claim 3 including a clutch interposed between the mechanical output of the differential selsyn and the control means.

6. A drive system as set forth in claim 1 wherein each drive motor has a separate field current regulator and the control means comprises means for differentially adjusting the outputs of the field current regulators.

7. A drive system as set forth in claim 6 wherein the means for differentially adjusting the output of the field current regulators includes a circuit energized from the output of an integrating amplifier controlled by said comparator means.

8. A drive system as set forth in claim 7 including means for supplying the integrating amplifier with an input signal the magnitude and polarity of which is varied in accordance with the direction and magnitude of the output signal from the comparator means.

9. A drive system as set forth in claim 8 wherein the comparator means is a selsyn system comprising a differential selsyn having rotor and stator windings energized by selsyn generators coupled to the backup rolls, the mechanical deflection of the differential selsyn rotor constituting the comparator output signal.

10. A drive system as set forth in claim 9 including a clutch interposed between the differential selsyn and the control means.

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