Sept. 28, 1965 | L. R. HULLS ETAL | 3,208,251

ROLLING MILL CONTROL SYSTEM

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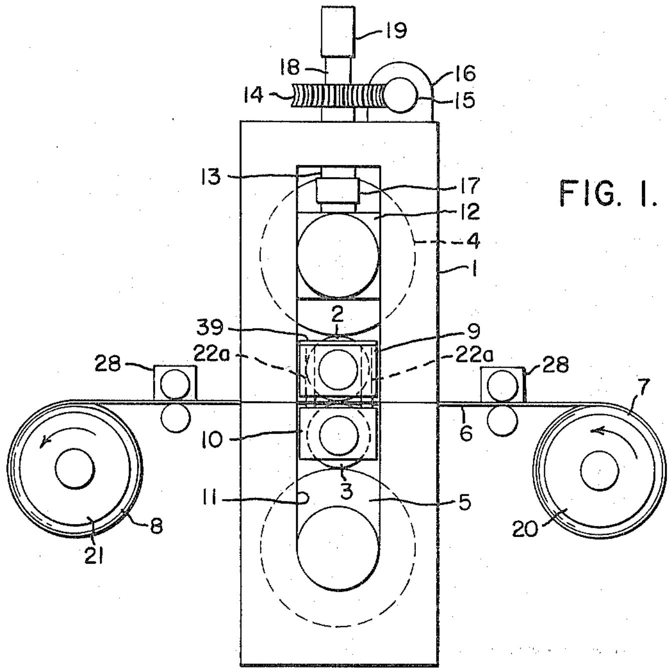

FIG. 1.

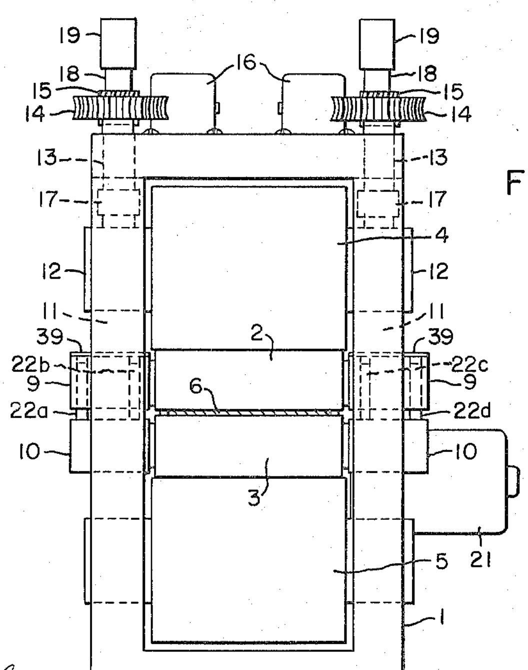

FIG. 2.

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ROLLING MILL CONTROL SYSTEM

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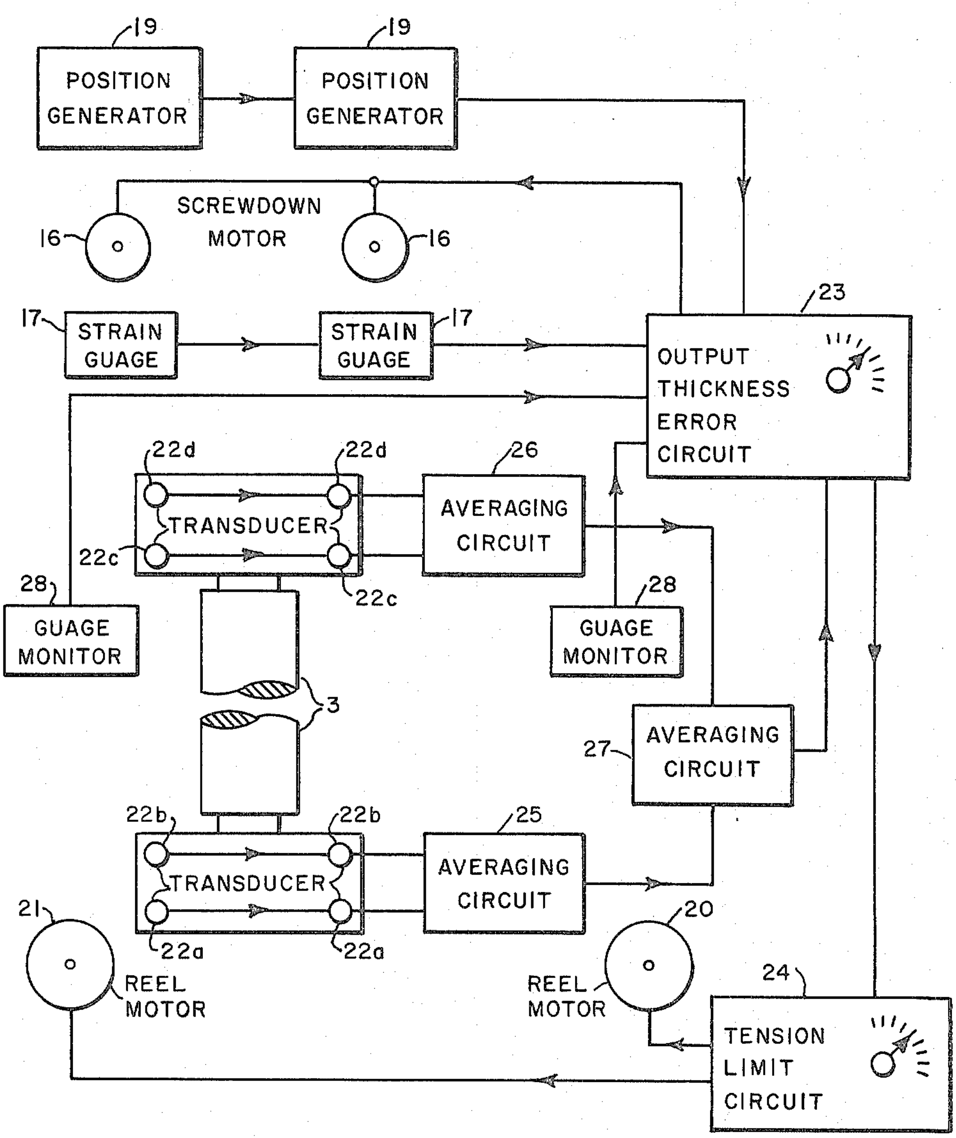

Fig. 3

ROLLING MILL CONTROL SYSTEM

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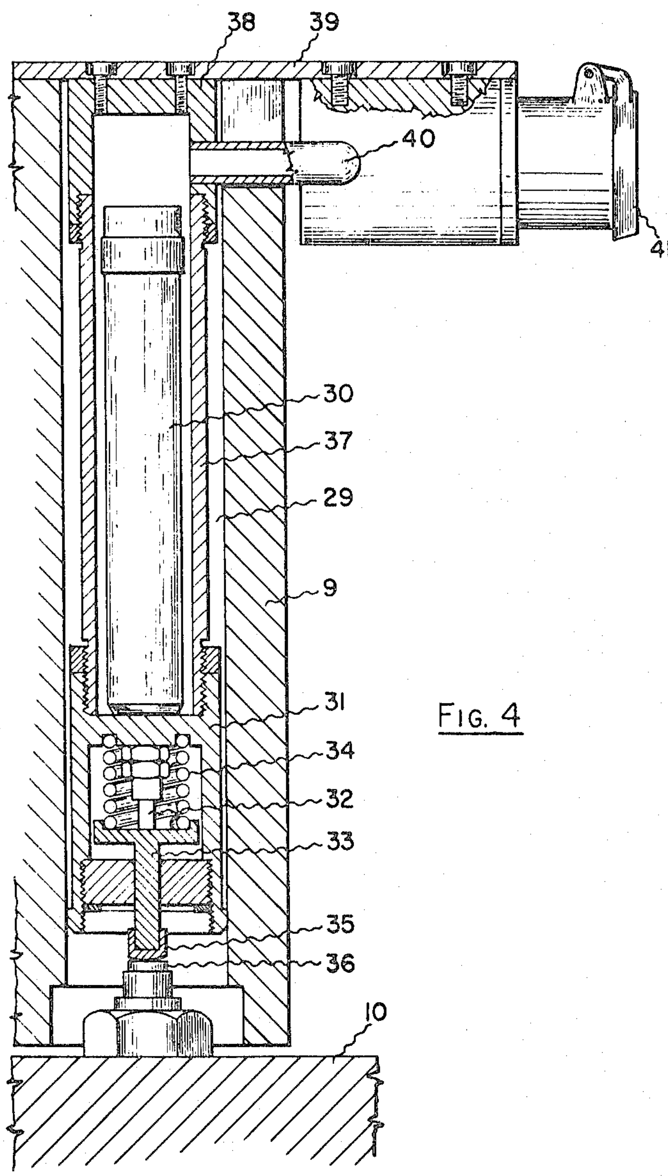

FIG. 4

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3,208,251

ROLLING MILL CONTROL SYSTEM

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11 Claims. (Cl. 72—11)

The present invention is concerned with improvements in or relating to control systems for rolling mills.

Material entering a rolling mill may vary in thickness, hardness and other properties along its length and it is customary to try to compensate for these variations of the ingoing material so that the outgoing material will be of as constant thickness as possible.

Accordingly, various control systems have been proposed in which the thickness of the outgoing material is measured continuously and the spacing of the mill rolls, and/or the tension on the material being rolled are adjusted so as to maintain the outgoing thickness as constant as possible. In recent years the users of the rolled material have required that the material be rolled to within closer and closer limits, owing to the advantages obtained in their own use of the material.

With the increasing speed of mills and this requirement for added accuracy of rolling, it has become more and more necessary to provide a fast response in the mill control system. In order to obtain such fast response, and also to reduce the errors incurred in measurement, a number of proposals have been made hitherto whereby the outgoing thickness is measured at the nip of the work rolls. This measurement can be made directly or indirectly.

An application in the United State Patent Office, S.N. 761,495, now U.S. Patent No. 3,062,078, by Leonard Hulls filed September 17, 1958 discloses a method in which the measurement is made indirectly, the specification describing a system that makes use of the fact that a mill obeys Hooke's Law, and that therefore during its operation the spacing between the rolls is equal to their spacing when unloaded plus an additional spacing proportional to the strain of the mill. An electric signal representing the unloaded position of the rolls is added to a signal representing the correct proportion of the total strain between the rolls, the resulting signal being compared with a reference signal and the difference between the two signals giving an error signal representing the amount by which the actual outgoing thickness of the material differs from the desired outgoing thickness. This error signal is used to control the tension of the material passing between the rolls and the spacing at which the rolls are set.

British patent specification No. 743,233 discloses a direct method of measurement, the specification describing apparatus for maintaining the axial distances between the lower and upper work rolls of the rolling mill at a preset value during the rolling period, the apparatus including measuring devices which are disposed between specially provided extensions of the rolls. The measuring devices are responsive to divergence of the actual distance of these bearing extensions from the preset value and causes operation of control means to move the upper roll so as to return the said axial distance to the preset value. In the specific embodiment described each measuring device consists of an air gauge which actuates a differential pressure relay in known manner.

It is an object of the present invention to provide a rolling mill control system of new form.

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It is another object of the present invention to provide a rolling mill control system of new form that is inherently more capable of accurate rolling than comparable systems provided hitherto.

According to the present invention there is provided a control system for a rolling mill, the mill comprising a pair of work rolls between which passes the material to be rolled, the system comprising means for making a measurement that is effectively a direct measurement of the distance between the axes of rotation of the work rolls and for producing a first electric signal representative thereof, means for producing a second signal representative of the separating force produced between the rolls with the material passing between them, means utilizing the said first and second signals in the production of a third signal representative of the output thickness of material that has passed between the rolls, and means utilizing the said third signal for controlling the rolling of the mill.

A specific embodiment of the invention will now be described, by way of example, with reference to the accompanying diagrammatic drawings, wherein:

FIGURE 1 is a side elevation of the mill;

FIGURE 2 is an elevation of the mill taken on the line 2—2 of FIGURE 1;

FIGURE 3 is a schematic representation of a control system for the mill of FIGURES 1 and 2; and

FIGURE 4 is a longitudinal section showing a specific form of transducer for use in the control system of FIGURE 3 and mounted in a roll chock of the mill.

The mill illustrated is a reversing rolling mill comprisa mill frame 1 in which are rotatably mounted a pair of working rolls 2 and 3 and respective co-operating back-up rolls 4 and 5. A strip 6 of material that is to be reduced in thickness passes between the work rolls 2 and 3 from a right-hand side unwind reel 7 to a left-hand take-up reel 8. The work rolls 2 and 3 are mounted for rotation with their necks in respective work roll chocks 9 and 10, which are mounted for sliding movement in slots 11 of the frame 1. The upper back-up roll 4 is mounted for rotation by plummer blocks 12, which also slide vertically in the respective slots 11.

The postions of the blocks 12, and thus the spacing of the rolls 2 and 3, are established by screws 13 which pass through corresponding screw-threaded bores in the frame 1, so that rotation of the respective pinions 14 mounted on the upper ends of the screws cause them to move vertically through the frame. The pinions 14 are rotated by means of respective worm gears 15 mounted on the shafts of their motors 16. A strain gauge 17 is interposed between the end of each screw 13 and its point of contact with the respective plummer block 12, the gauge measuring the force of each screw 13 on its block 12 due to the separating force produced between the rolls 2 and 3 by the strip 6. An extension shaft 18 is mounted on the upper surface of each pinion 14 and drives a position generator 19 which produces an electric signal representative of the rotation and displacement of the screws 13 relative to the frame 1, and hence representative of the height of the gap between the rolls 2 and 3 when no material is present between them.

For reasons which will be described below a mill in accordance with this invention will generally be provided either with the strain gauges 17 or with the position generators 19, both being shown together in the embodiment illustrated to avoid undue repetition of the description.

The reels 7 and 8 are driven by respective electric motor/generators 20 and 21, the construction of the motor/generators being such that they can be used alternatively as motors or as drag generators. In this embodiment the reel 7 is the unwind reel and therefore the motor/generator 20 is operating as a drag generator, the condition of operation being reversed when the direction of travel of the strip **6** is reversed.

Each pair of work roll chocks **9** and **10** is provided with four electric transducers **22** arranged in pairs **22***a*, **22***b*, **22***c* and **22***d* (reading from left to right in FIGURE 2). Each transducer produces an electric signal representative of the respective distance between the work-roll chocks **9** and **10** as measured by the transducer. These electric signals will therefore also be representative of the distance, as measured by the respective transducer, between the axes of rotation of the work rolls **2** and **3** as measured at the roll necks, these measurements including appreciable errors owing to a reduction in the effective diameters of the work rolls under the influence of the pressure on the rolls by the strip **6**.

The operation of the control system is as follows:

The mill operator sets an output thickness gauge, represented herein by a dial on a circuit block **23**, to indicate the thickness required for the reduced strip, and at the same time set a tension signal setting gauge, represented herein by a dial on a circuit block **24**, to give the proper range of tension as dictated by the operator's experience for the material to be rolled, so that the strip will be coiled neatly and tightly on the reel **8** without danger of breaking. The mill is then put in motion.

The two transducers **22***a* are connected so that the signals they produce are combined to give an average signal and this combined signal is fed together with the combined signal from the two transducers **22***b* to an averaging circuit **25**. Similarly, the combined signals from the transducers **22***c* and **22***d* are fed together to an averaging circuit **26** in which they are combined. The outputs from the circuits **25** and **26** are supplied to a further averaging circuit **27**, the output of which in turn is fed to the circuit **23**. Thus, the signal received by the circuit **23** from the transducers is the average of all eight transducers and is an accurate representation of the distance between the axes of rotation of the work roll necks. The presence of the errors mentioned above prevents this signal from being also an accurate representation of the height of the roll gap and the output thickness of the strip **6**. The circuit **23** produces a signal that is an accurate representation of the output thickness in a manner described below, and this is compared with the reference set by the output thickness gauge. If the two signals do not correspond, showing that the output thickness does not correspond to the preset thickness, then the circuit **23** produces a control signal which is used to actuate the tension control **24** and/or the screw down motors **16** in order to bring the output thickness to the desired value.

A suitable and well known averaging circuit for this application can be an operational amplifier employing negative capacitive feedback and operative as an electrical integrating element or even a conventional motor driven potentiometer or the like. The circuit **23** can be a signal summing amplifier such as shown on page 14 of the book Electronic Analog Computers by G. A. Korn and T. Korn, McGraw-Hill Book Company (1952).

An additional gauge monitor **28** is provided on each side of the mill in order to check the correct operation of the control system, and also to give indication of any long term changes in the system due, for example, to temperature changes, or aging or malfunction of any of the system components. In the embodiment illustrated these gauge monitors comprise flying micrometers disposed one on each side of the mill, the signals provided by the monitors **28** being fed to the circuit **23**. These monitor signals are employed in checking that the system is functioning correctly, but do not directly control the mill operation because of the long time delay involved in their production.

If the signal from the monitors **28** is compared with the signal from the circuit **27** significant differences are found between the two. As stated above, this difference is due to the flattening of the work rolls under the effect of the pressure applied to them by the material passing between the rolls, and this flattening varies appreciably with changes in the properties of the strip and changes in the setting of the mill. It is proposed, in accordance with this invention, to compensate for these errors by providing a signal which is a suitable measure of the amount of flattening encountered. This signal can be provided by two methods which are alternatives of each other. In the first method the force is measured directly by means of the strain gauges **17**. In the second method the force is measured indirectly by determining the difference between the preset roll spacing (which may be negative, i.e. the rolls are being forced together) as indicated by the position generators **19**, and the roll spacing as measured by the transducers **22**.

The output thickness G of the material **6** can be represented by the equation

$$G=\frac{F}{M}+So \tag{1}$$

where F is the force as measured by the strain gauges, M is the elastic coefficient of the mill and S*o* is the preset spacing of the rolls, as indicated by the position generators **10**. The output thickness G can also be represented by the equation

$$G=\frac{F}{W}+Sw \tag{2}$$

where W is the elastic coefficient of the work rolls **2** and **3** and S*w* is the actual spacing as measured by the transducers **22**, the component F/W being the correction required to take account of the above described roll flattening.

The operation of the control apparatus of Canadian patent specification No. 571,793 is in accordance with Equation 1 above and, despite the undoubted advantages of such apparatus, as compared with the apparatus known prior to the invention which is the subject of British patent specification No. 571,793, the operation of the apparatus with the required degree of accuracy requires the measurement of and compensation for parameters which are not shown in the equation. The operation of the apparatus in accordance with this invention is in accordance with Equation 2 above and it can be shown that the parameters affecting the measurements of Equation 1 are with the Equation 2 of the second order, so that the required order of accuracy can be obtained without the need to measure them. The equations also show that the force F of Equation 2 can be replaced by suitable substitution of M and S*o* of Equation 1.

In one particular form of the invention therefore the strain gauges **17** are provided and produce a second signal which is combined in the required proportions with the signal from the circuit **27**, the resultant signal being compared with reference signal and a control signal being produced which is supplied by the circuit **23** to control the strip tension and the screw motors **16**, as described above. In the other particular form of the invention the position generators **19** are provided and the signal they produce is compared with the average signal supplied by the circuit **27**, a proportion of the resultant signal being used to modify the signal from the circuit **27**. The modified signal is then compared with the reference and a control signal produced which again is used in controlling the strip tension and/or the screw motors **16**.

Referring now to FIGURE 4, a particular preferred form of the transducer **22** will now be described. The major portion of the transducer is accommodated in a bore **29** in the chock **9**, so that it is housed completely within the body of the chock and is thereby protected against the deleterious effects of oil, dirt and mechanical shock and damage. The transducer proper consists of a differential transformer **30** which is mounted in a housing **31** with its operating plunger **32** protruding and engaging a slide **33**. The plunger **32** is biased for movement (in a downward direction as seen in FIGURE 4) by a spring (not shown) mounted in the body of the transducer, while the slide **33** is biased by a spring **34** for downward movement relative to the housing **31**, so that a projecting end **35** thereof engages a reference anvil **36** which is screwed to the upper surface of the lower work roll chock **10**. Thus, the spring **34** maintains the elements **35** and **36** in close contact with one another, while the internal spring of the transducer maintains the plunger **32** in close contact with the slide **33**. The housing **31** is supported by a tube **37** to which it is screw-threaded, the tube **37** being in turn screw-threaded to another housing **38** that is bolted to a mounting plate **39** supporting conduit **40** and connecting plug **41**. The mounting plate **39** is removably fastened to the upper face of the upper roll chock **9** (see also FIGURES 1 and 2) and all the tranducers are fastened to it, so that the removal of the plate **39** will also remove all the transducers together as a unitary structure, e.g. when the rolls and their chocks are to be replaced.

Although a particular form of transducer has been described, it will be apparent that any other form of electrical transducer producing a voltage which varies in dependence upon the distance apart of two of its elements can be used. In some embodiments the transducer may not produce an electric signal, but instead may produce a mechanical displacement which is applied to control a member of the circuit **23**, although a signal-producing transducer will usually be desired. Moreover, although in the embodiment described the transducers employed are accommodated in respective ones of the work roll chocks, in other embodiments they may be mounted on the sides or the ends of the chocks and protected by suitable shields.

We claim as our invention:

1. A control system for a rolling mill, comprising a pair of work rolls between which passes the material to be rolled, the system comprising means for making a measurement that is effectively a direct measurement of the distance between the axes of rotation of the work rolls and for producing a first electric signal representative thereof, means for producing a second signal representative of the separating force produced between the rolls with the material passing between them, means utilizing the said first and second signals in the production of a third signal representative of the output thickness of material that has passed between the rolls, and means utilizing the said third signal for controlling the operation of said work rolls of the mill.

2. A control system for a rolling mill, the mill comprising a pair of work rolls mounted by their necks for rotation about their axes of rotation and between which rolls passes the material to be rolled, the system comprising means for making a measurement between the roll necks that is effectively a direct measurement of the distance between the axes of rotation of the work rolls and for producing a first electric signal representative thereof, means for producing a second signal representative of the separating force produced between the rolls with the material passing between them, means utilizing the said first and second signals in the production of a third signal representative of the output thickness of material that has passed between the rolls, and means utilizing the said third signal for controlling the operation of said work rolls of the mill.

3. A control system as claimed in claim **1**, wherein the said means for producing a second signal comprise means for measuring the separating force produced between the work rolls by the material passing between them.

4. A control system as claimed in claim **1**, wherein the said means for producing a second signal include strain gauges interposed between the work rolls and the mill frame.

5. A control system as claimed in claim **1**, wherein the said means for making a measurement comprise two pairs of transducers, each pair being disposed at a different one of the two ends of each roll, the two transducers of each pair being disposed on opposite sides of a plane passing through the axes of rotation of the work rolls.

6. A control system as claimed in claim **1**, wherein the said means utilizing the third signal compare the third signal with a reference to produce an error signal and employ the error signal in controlling the tension of the material passing between the work rolls.

7. A control system as claimed in claim **1**, wherein the said means utilizing the third signal compare the third signal with a reference to produce an error signal and employ the error signal in controlling the separation setting of the work rolls.

8. A control system as claimed in claim **1**, wherein the said means utilizing the third signal compares the third signal with a reference to produce an error signal and employs the error signal in controlling the tension of the material passing between the work rolls and in controlling the separation setting of the work rolls.

9. A control system as claimed in claim **1**, wherein the said means for making a measurement comprise two pairs of differential transformers, each pair being disposed at a different one of the two ends of each roll, the two transducers of each pair being disposed on opposite sides of a plane passing through the axes of rotation of the work rolls, the differential transformers being so electrically connected that the said first signal is representative of the average of the measurements of all the transformers.

10. A control system for a rolling mill, the mill comprising a pair of work rolls mounted by their necks in roll chocks for rotation about their axes of rotation and between which rolls passes the material to be rolled, the system comprising distance measuring means for measuring the distances between the associated pairs of roll chocks, which distances are effectively a direct measurement of the distance between the axes of rotation of the work rolls and for producing a first electric signal representative thereof, means for producing a second signal representative of the separating force produced between the rolls with the material passing between them, means utilizing the said first and second signals in the production of a third signal representative of the output thickness of material that has passed between the rolls, and means utilizing the said third signal for controlling the operation of the work rolls of the mill.

11. A control system as claimed in claim **10**, wherein the said distance measuring means comprise transducers associated with each pair of work roll chocks and accommodated within one of the chocks of each pair thereof.

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