

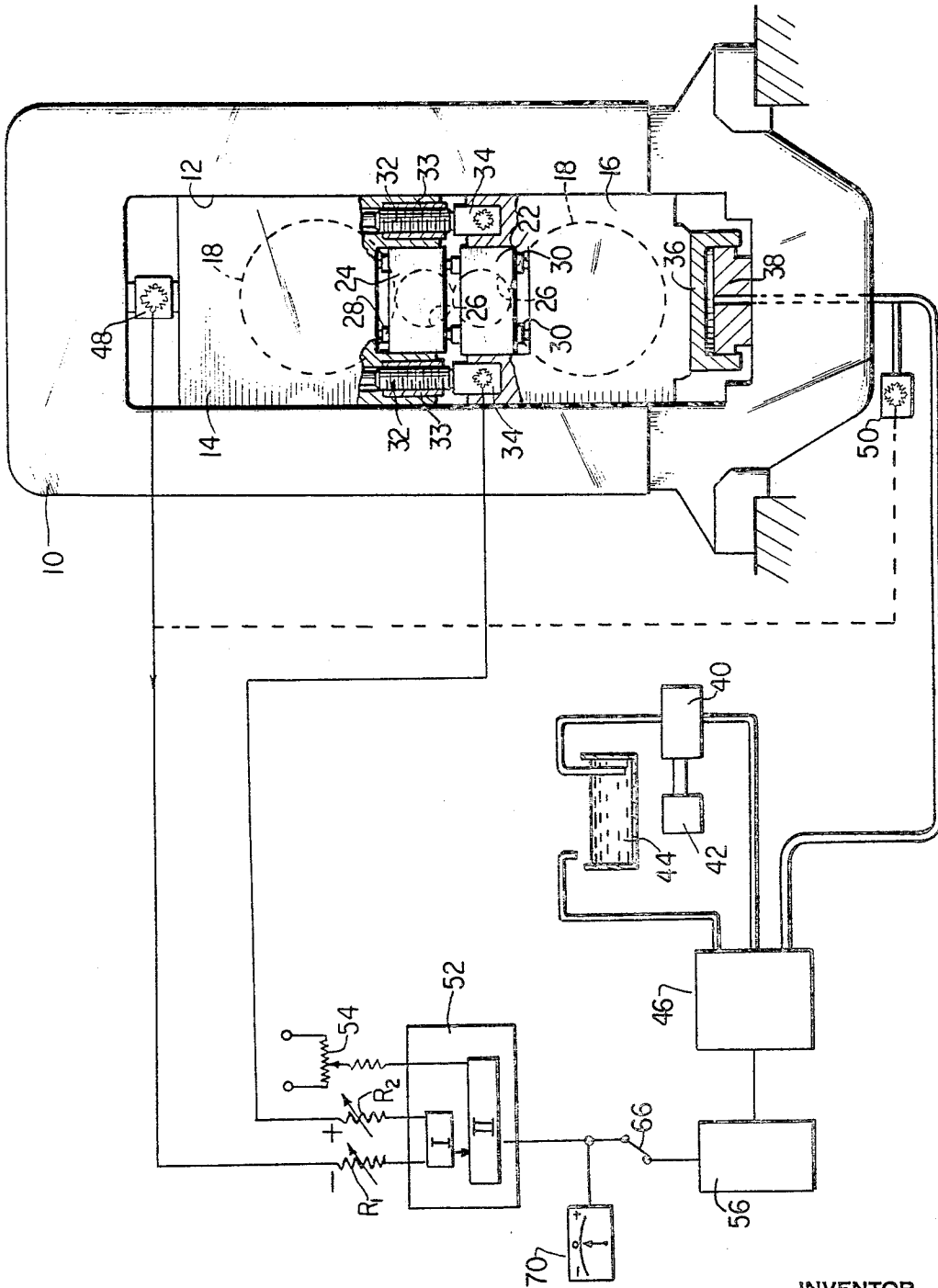
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CONTROL OF PRESTRESSED ROLLING MILLS

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CONTROL OF PRESTRESSED ROLLING MILLS

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ABSTRACT OF THE DISCLOSURE

A method and apparatus for controlling the operation of a prestressed rolling mill by continuously controlling the prestressing force so that the opening between the working rolls is maintained at its desired distance irrespective of any changes in the roll separating force during rolling signals representing the prestressing force and the load in the spacing means are continuously measured and are multiplied by a factor which includes the coefficients of chock spring and roll spring so as to eliminate the effect of this elasticity upon the roll opening.

This invention relates to a method and means for controlling the operation of a prestressed rolling mill by continuously controlling the opening between the working rolls of the mill so as to maintain this opening at a constant value, with the aim of obtaining a rolled article or product whose thickness remains constant throughout a rolling operation.

As is well-known, the forces which act in a rolling mill during its operation cause parts of the mill to expand or to contract, including those parts which support the working rolls of the mill in its housings, whereby the relative position of these rolls, and thereby the size of the opening between them, changes. This leads to corresponding changes in the thickness of the rolled articles, which, small as these changes are, may often be critical in the case of thin, flat material, such as strip, foil or sheet stock.

This invention is applicable in particular to a type of prestressed rolling mill in which the distance between the roll axes, and hence the opening between the rolls, is set by spacing means acting directly on the bearing chocks of the rolls. These spacing means may be mounted in the chocks of one roll and abut against the chocks of the other roll, so that the distance between the rolls can be varied by displacing the spacing means relative to the chocks of the first roll while retaining their abutting relationship with the chocks of the other roll. In rolling mills equipped with backing rolls for the working rolls, the aforesaid spacing means may act on the bearing chocks of the backing rolls.

The spacing means may consist of spindles mounted in the chocks of one roll so as to be longitudinally displaceable in those chocks, while their ends abut on the chocks of the other roll or on parts supported on the last-mentioned chocks.

During a rolling operation, a force is developed which tends to separate from each other the rolls which by their distance from each other define the roll opening. In prestressed rolling mills of the above type, any difference between the prestressing and the separating forces is taken by the spacing means and will be referred to in the following as the "spacing load." In practice, the prestressing force will always be set at a value greater than the maximum separating force which, under normal conditions, can be expected during rolling operations in order to insure that the spacing load is never reduced to zero. The spacing load causes a compressive strain to occur in the spacing means and the bearing chocks, and leads to a reduction in height both of the spacing means

and the chocks, whereby the distance between the centres of the chocks, and thereby also the distance between the axes of the rolls supported in those chocks, are diminished. The decrease of this distance and thus of the size of the roll opening is proportional per unit load to the elasticity or "springiness" of the chocks and the spacing means, which will be referred to in the following as "chock spring."

During the rolling of an article, the separating force is apt to vary frequently, such variations being caused by changes in the thickness, hardness, temperature or other physical properties of the rolled material. Hence, the spacing load, and consequently the roll opening, vary as well, and the rolled article will not be of uniform gauge.

In British Patent No. 955,164 there is described a control system for the operation of rolling mills in which any change in the separating force produces automatically an equivalent change in the prestressing force. This cancels out variations in the spacing load which would otherwise occur. Thus, some of the changes of the distance between the chock centres and thereby of the size of the roll opening are obviated, and the gauge of the rolled material is rendered more uniform.

However, the control method described is incomplete, insofar as it does not take into account those changes of the size of the roll opening which are the result of the deflection of the rolls and of their bearings in the chocks, and of the flattening of the rolls under load. These changes are proportional per unit load to changes in the elasticity or "springiness" of the rolls which will be referred to in the following as "roll spring." Roll spring and chock spring are frequently of the same order and it is therefore desirable that roll spring should be taken into account as well.

It is relatively easy to measure directly the spacing load and thereby also the changes in the roll opening which result from the chock spring of a rolling mill. These measurements can be effected by means of load cells placed between the chocks of one roll and the spacing means mounted in the chocks of the other roll, as described in British Patent No. 955,164. It is, however, difficult to measure those changes in the roll opening which are the result of roll spring, especially while the mill is in operation and the rolls rotate.

It is an object of the present invention to provide a method for controlling the operation of a prestressed rolling mill by continuously controlling the prestressing force in such a manner that the opening between the working rolls of the rolling mill is maintained at its pre-set value irrespective of any changes in the separating force during rolling.

It is another object of the present invention to provide a method for controlling the opening between the working rolls of a rolling mill during its operation in such a manner that this opening remains during rolling unaffected by variations both of chock spring and roll spring.

Still another and more specific object of the invention is to improve the method and means described in British Patent No. 955,164 by compensating additionally those changes of a roll opening which are the result of variations of roll spring.

According to the present invention, a method for controlling the operation of a prestressed rolling mill having spacing means for setting the roll opening, said spacing means being mounted in the bearing chocks of one roll and acting on those of the other roll, comprises the steps of measuring continuously during rolling the load in said spacing means and the prestressing force, transforming these measurements into electric signals, establishing a predetermined ratio between two signals representing simultaneous measurements of the prestressing force and

the spacing load by multiplying at least one of these signals by a factor which includes co-efficients representing both chock spring and roll spring, and obtaining a signal for controlling the prestressing force by comparing the two first-mentioned signals, after multiplication, with each other, the prestressing force being so controlled that the influence of chock spring and roll spring on the roll opening is eliminated.

The signals representing the load in the spacing means and the prestressing force may be compared, after multiplication, with a third signal which represents the desired thickness of the rolled material, and which acts as a reference signal; in this way, the required controlling signal for the prestressing force is obtained. The reference signal may represent the roll opening which produces rolled material of a given thickness.

The signals representing the load in the spacing means and the pre-stressing force may be compared with each other, after multiplication, in a first step to form an intermediate signal, and the intermediate signal may be compared in a second step with the afore-mentioned third or reference signal to form the controlling signal for the prestressing force.

The intermediate signal may be obtained by subtracting from each other the signals representing the spacing load and the prestressing force respectively. Similarly, the controlling signal for the prestressing force may be obtained by subtracting from each other the intermediate and the reference signals.

In the case of a rolling mill in which the prestressing force is produced by hydraulic means, the controlling signal may be fed into a circuit of a servo valve which controls the fluid pressure in the hydraulic means.

The predetermined ratio which is established between signals representing simultaneous measurement of the prestressing force and the spacing load is preferably equal, or substantially equal, to

$$\frac{1+m}{m}$$

wherein m is equal to k_2/k_1 , k_1 and k_2 being constant coefficients representing the chock spring and roll spring respectively and determined by the design of the rolling mill.

Optimum results are obtained when this ratio is equal to

$$\frac{1+m}{m}$$

but sufficiently satisfactory results can also be obtained for ratios which are slightly above or below this value.

The significance of the term

$$\frac{1+m}{m}$$

for the cancelling out of the influence of both chock spring and roll spring on the size of the roll opening between the working rolls is evident from the following.

Let:

R =the separating force

P =the prestressing force

S =the spacing load

then

$$P=R+S \quad (1)$$

as stated above.

Assuming P to be constant, then an increase of the separating force by r would result, without intervention of the automatic control according to British Patent No. 955,164, in

$$P=(R+r)+(S-r) \quad (2)$$

i.e., the load S would be reduced by r , and consequently the compression of the chocks and spacing reduced by $k_1 r$

which would increase the distance between the centres of the chocks and thereby the size of the roll opening by the same amount. This increase is cancelled out by the control method and means described in British Patent No. 955,164, by which the prestressing force P is automatically increased by r upon any increase of the separating force R by r . Equation 2 becomes:

$$P+r=(R+r)+S \quad (3)$$

Equilibrium between the forces is established again, and the spacing load S resumes its initial value. Therefore, the distance between the chock centers and hence the roll axes is also the same as before. Thus, the effect of an increase of the separating force on the size of the roll opening is cancelled out, but only in so far as it is the result of chock spring. (Any decrease of the separating force would be dealt with by the control means in a similar way.)

However, any changes of the size of the roll opening which are the result of roll spring have so far not been taken into account. For an increase of the separating force by r , the roll opening is increased as a result of roll spring by $k_2 r$. Hence, the increase of the roll opening resulting from both chock spring and roll spring is $k_1 r + k_2 r$, or $r k_1 (1+m)$ wherein

$$m = \frac{k_2}{k_1}$$

as stated before. This increase in the roll opening can be cancelled out by reducing the distance between the chock centers by $k_1 (1+m)$. This reduction is brought about by increasing the prestressing force by $r(1+m)$. If this is done, Equation 3 becomes:

$$P+r(1+m)=(R+r)+(S+mr) \quad (4)$$

This means that, for an increase of the prestressing force by $r(1+m)$, equilibrium between the forces is established if the spacing load is increased at the same time by mr , or for the full cancellation of the influence of both chock spring and roll spring on the roll opening, the ratio between the increase dP of the prestressing force and the increases dS of the spacing load must be:

$$\frac{dP}{dS} = r \frac{(1+m)}{rm} = \frac{1+m}{m}$$

which is a constant and the term mentioned before.

While it is preferred to make the ratio between the changes of the prestressing force and the spacing load equal to

$$\frac{1+m}{m}$$

acceptable results may be obtained when employing ratios which are slightly above or below this value.

The method according to the invention therefore involves the simultaneous measurement of the prestressing force and of the spacing load which is preferably done by separate instruments. The roll-spacing load may be measured by load cells which are placed in the path of the roll-spacing load, and the prestressing force may be measured by load cells placed in the path of the prestressing force. In the case of the prestressing means being of the hydraulic type, the prestressing force may alternatively be measured by a pressure transducer connected to the fluid pressure chamber or chambers of the prestressing means, for instance, to a cylinder in which a hydraulic ram is movable. Instead of employing load cells for the measurement of the spacing load, a distance-measuring transducer may be employed which measures the changes, caused by that load, of the distance between the centers of the chocks of one roll and those of the chocks of another roll.

An embodiment of the invention will now be described by way of example with reference to the accompanying drawing, which shows diagrammatically a rolling mill

equipped with a control system according to the present invention.

The rolling mill shown is designed for the rolling of flat articles such as sheet, strip or foil stock, and is of the four-high type. The mill has housings 10, of which only one is visible in the drawing. Each housing has a window 12 in which are accommodated an upper bearing chock 14 and a lower bearing chock 16 for two back-up rolls 18. Upper and lower bearing chocks 22 and 24 for the working rolls 26 are mounted in recesses of the chocks 14 and 16. Hydraulic cylinder-and-piston units 28 and 30 are provided in the chocks 22 and 24 for supporting the latter in the chocks 14 and 16.

Screw spindles 32 are mounted in the chocks 14 and abut against load cells 34 received in recesses of the chocks 16. These spindles act as spacing means for the working rolls 26, determining the size of the opening between them. The spindles 32 can be advanced or retracted relative to the chocks 14 by being rotated in fixed nuts 33 by motors (not shown) whereby the opening between the rolls 26 is set and adjusted. The load cells 34 measure the spacing load S in the spindles 32.

Each housing 10 is prestressed by hydraulic means comprising a cylinder 36 and a ram 38 placed between the bottom of the housings 10 and the chocks 16. Pressure fluid in the cylinders 36 is supplied from a pump 40, driven by a motor 42, the hydraulic circuit of the pump including further a reservoir 44 and a servo control valve 46.

The prestressing force P in the housings 10 is measured by one or more load cells 48 positioned either between the top of the housings and the chocks 14, as shown, or between the rams 38 and the bottom of the housings. Alternatively, pressure transducers 50 connected to the space inside the cylinders 36 may be used.

The load cells 34, 48 and the pressure transducers 50 may be of any suitable and known design and need not be described here. They register their measurements as electrical signals which are fed into a control circuit. This circuit includes a two-stage electrical comparator 52 to which signals emanating from load cells 48 (or from the transducers 50) are fed through a variable resistor R_1 , and signals emanating from the load cells 34 through a variable resistor R_2 . In stage I of the comparator, an intermediate signal si is produced by subtracting from each other simultaneously-arriving signals from the load cells 34 and from the load cells 48 (or from the transducer 50). This signal is fed into stage II of the comparator 52, together with a constant reference signal sr obtained from an adjustable potentiometer 54. This reference signal represents the size of the roll opening which is required to produce a rolled article of the required dimensions. By subtracting the reference signal sr from the intermediate signal si , a controlling or error signal $e=si-sr$ is obtained which is fed into a power amplifier 56. This amplifier feeds its output into the electro-hydraulic servo control valve 46 which operates in such a manner that an increase or decrease in the output of the amplifier 56 results in a change of pressure in the pump 40 and therefore also in the cylinders 36 of the hydraulic prestressing means. The servo control valve 46 may be of any suitable and known type.

Prior to the starting of a rolling operation, the opening between the working rolls 26 is set by means of the spindles 32 for the desired thickness of the rolled article. The cylinders 36 are filled with pressure fluid, producing a prestressing force P which exceeds the maximum separating force R to be expected under normal operating conditions. The difference $P-R=S$ will thus always be positive.

Rolling is started with the automatic control system switched off by a switch 66. The load meters 34 produce a signal representing the spacing load S in the spindles 32 and in the chocks 14 and 16, and the load meters 48 (or the pressure transducers 50) produce a signal rep-

resenting the prestressing force P in the housings 10. These signals are multiplied by the resistors R_1 and R_2 or by potentiometers, the factor of multiplication being (k_2) and (k_1+k_2) respectively. The multiplied signals are fed into stage I of the comparator 52 and produce therein an intermediate signal $si=k_2P-(k_1+k_2)S$. This signal is fed into stage II of the comparator 52 and compared therein with the reference signal sr from the adjustable potentiometer 54, whereby the controlling or error signal $e=si-sr$ is obtained. The signal e can be read on indicator 70. The potentiometer is then so adjusted that e becomes zero, whereupon the automatic control system is switched on at 66. From then onwards, any changes in the separating force R due to changes in a physical property of the rolled material are reflected in corresponding changes of the signal si and lead, owing to the operation of the automatic control system, to changes in the prestressing force P by dP , and of the spacing load S by dS , so that the intermediate signal si becomes:

$$si=k_2(P\mp dP)-(k_1+k_2)(S\mp dS)$$

the plus and minus signs in the brackets corresponding to increases or decreases of the separating force R . The error signal e which has been reduced to zero will now be:

$$e'=si-sr$$

which can be resolved into:

$$e'=k_2dP-(k_1+k_2)dS$$

The electrical control system reduces the error signal e' again to zero, so that:

$$k_2dP=(k_1+k_2)dS$$

$$dP=dS\left(\frac{1}{m}+1\right)$$

$$\frac{dP}{dS}=\frac{1+m}{m}$$

This has been shown above to be the condition for eliminating any changes in the size of the opening between the rolls 26, whether caused by chock spring or by roll spring. In this way, close tolerances of the rolled material can be maintained throughout a rolling operation independently of any changes in the physical properties of the rolled material.

The indicator 70 makes it possible to observe continuously the operation of the control system and in particular the reduction of the errors in signal e to zero. Thus, the correct operation of the system can be constantly checked.

At least one of the resistors R_1 , R_2 is preferably adjusted for initial calibration and for taking into account any subsequent variations of the co-efficient m which may occur from time to time due to wear of the rolls or other causes.

The invention is capable of variations in detail. It is, for instance possible to multiply only one of the signals from which the intermediate signal is produced. In this case, the multiplying factor is changed into

$$\frac{k_1+k_2}{k_2}$$

and the intermediate signal then becomes:

$$P-\frac{(k_1+k_2)}{k_2}S$$

In the embodiment, two load cells 34 are shown, one for each spindle 32. As usually the spacing loads in the two spindles are equal, one of the load cells may be dispensed with. It is also possible to provide only one side of the rolling mill with instruments for measuring the spacing load and the prestressing force if it can be assumed that the loads on both sides of the mill are equal.

I claim:

1. A method for controlling the operation of a prestressed rolling mill having spacing means for setting the roll opening, said spacing means being mounted in the bearing chocks of one roll and acting on the bearing chocks of the other roll, comprising the steps of measuring continuously during rolling, the load in said spacing means and the prestressing force, transforming these measurements into electric signals, establishing a predetermined ratio between two signals representing simultaneous measurements of the prestressing force and the spacing load by multiplying at least one of these signals by a factor which includes co-efficients representing both chock spring and roll spring and obtaining a signal for controlling the prestressing force by comparing the two first-mentioned signals, after said multiplication, with each other, and with a reference signal representing the desired thickness of the rolled material, and controlling the prestressing force in accordance with the indication of said controlling signal, the prestressing force being so controlled that the influence of chock spring and roll spring on the roll opening is eliminated.

2. A method for operating a prestressed rolling mill according to claim 1, in which the reference signal represents the roll opening which produces rolled material of a given thickness.

3. A method for operating a prestressed rolling mill according to claim 1, in which the signal controlling the prestressing force is obtained in two steps in such a manner that in the first step the signals representing the load in the spacing means and the prestressing force are compared with each other, after multiplication, to form an intermediate signal, and that in the second step the intermediate signal is compared with the third or reference signal which represents the desired thickness of the rolled article, to form the controlling signal for the prestressing force.

4. A method for operating a prestressed rolling mill according to claim 3, in which the intermediate signal is obtained by subtracting from each other the signals representing the spacing load and the prestressing force respectively.

5. A method for operating a prestressed rolling mill according to claim 3, in which the controlling signal for the prestressing force is obtained by subtracting from each other the intermediate and the reference signals.

6. A method for operating a prestressed rolling mill having rolls and chocks subject to elastic springing, two of said rolls comprising work rolls between which material to be rolled is passed, spacing means for setting the opening between said work rolls, and means for applying a prestressing force, said method comprising the steps of measuring the spacing load and the prestressing force continuously during rolling, transforming said measurements into a pair of electrical signals, establishing a predetermined ratio between simultaneous values of said pair of signals which ratio includes coefficients representing chock spring and roll spring, comparing one signal of said pair with the other signal of said pair after said ratio has been established, and using the compared signal for controlling the prestressing force so that the influence of both chock spring and roll spring on the opening between the working rolls is canceled out.

7. A method for operating a prestressed rolling mill

according to claim 1, in which the predetermined ratio between the pair of signals representing simultaneous measurements of the prestressing force and of the spacing load is equal or substantially equal to

$$\frac{1+m}{m}$$

wherein m is a constant and equal to k_2/k_1 , k_1 and k_2 being constant co-efficients of the chock spring and roll spring respectively.

8. A rolling mill having housings with superposed rolls between which a separating force is established during a rolling operation, bearing chocks supporting said rolls in said housings, means for setting the distance between two super-posed chocks, prestressing means for applying a prestressing force to said chocks and said housings, means for measuring the load in said setting means, means for measuring the prestressing force and means for controlling the prestressing force so that the difference between the prestressing force and the roll-separating force is kept constant during a rolling operation.

9. A rolling mill according to claim 8, in which said control means comprise means for developing a first signal representing the load in said setting means, means for developing a second signal representing the prestressing force, and means for comparing the first and second signals with each other and developing a third signal, said third signal being utilized for controlling the prestressing force so that the difference between the prestressing force and the load in said setting means is kept constant during a rolling operation.

10. A rolling mill according to claim 9 comprising means for developing a fourth signal, said fourth signal representing the desired thickness of the rolled material, and means for comparing said third and fourth signals with each other so as to obtain an error signal for controlling the prestressing force so that the difference between the prestressing force and the load in said setting means is kept constant during a rolling operation.

11. Rolling mill according to claim 8 in which the load in said setting means is measured by load cells and the prestressing force is measured by load cells.

12. Rolling mill according to claim 11 in which the prestressing means is of the hydraulic type and a pressure transducer is used to measure the prestressing force.

13. Rolling mill according to claim 8 in which the load between said bearing chocks is measured by distance-measuring transducers.

14. Rolling mill according to claim 8 in which the prestressing means is of the hydraulic type and a servo-valve is used to control the hydraulic pressure in said prestressing means.

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