A method for detecting an eccentricity and phase angle (an angle formed between a predetermined point of a roll and a point at which the maximum eccentricity occurs) of a working or backing roll in a rolling mill without use of detectors directly attached to the peripheral surface of the roll is provided. The rolling pressure is sampled, quantized and fed into an arithmetic unit for calculating the eccentricity and phase angle of the roll based upon the following relations:

\[ \Delta P = \frac{\Delta S}{K + M} \]

\[ \Delta S = A \cos (\omega t - \beta) \]

where \( \Delta P \) = variation in rolling pressure; \( \Delta S \) = eccentricity; \( K \) = mill constant; \( M \) = plastic deformation coefficient; \( A \) = eccentricity of a backing roll of for example a four-high rolling-mill stand; \( \omega \) = angular velocity of the roll; \( t \) = time and \( \beta \) = phase angle. The calculated eccentricity and phase angles may be converted into analog quantities which may be used as signals for correcting the variation in thickness of rolled stock.

4 Claims, 4 Drawing Figures
ROLLING PRESSURE MEASUREMENT

SAMPLING

A-D CONVERTER

MEMORY

ARITHMETIC UNIT
CALCULATION OF MEAN VALUES AND A AND B

HOLDING CIRCUIT

D-A CONVERTER

SIGNALS REPRESENTATIVE OF ROLL ECCENTRICITY

PULSES GENERATED IN RESPONSE TO ROTATION OF ROLLER

TIMING CIRCUIT

FIG. 4

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METHOD FOR DETECTING ECCENTRICITY AND PHASE ANGLE OF WORKING OR BACKING ROLL IN ROLLING MILL

DETAILED EXPLANATION OF THE INVENTION

The present invention relates to a method for detecting the eccentricity and phase of a roll from the rolling pressure of the roll in a rolling mill without employing a detector directly attached to the peripheral surface of the roll.

The accuracy of the thickness of the stock rolled by a rolling mill has been much improved, but there still remains an unsolved problem of the eccentricity of roll which adversely affects the accuracy of the thickness of rolled stock. A working roll in a two-high rolling-mill stand and backing rolls in a four-high rolling-mill stand present the problem of eccentricity. The eccentricity of the working roll or backing rolls will cause the variation in roll gap so that the thickness of the rolled stock varies as a function of rotation of the working or backing roll.

The speed at which the rolling pressure may be varied in response to various rolling factors has been much improved recently so that when the eccentricity of the working or backing roll is detected, the rolling pressure may be varied very quickly in response to this detected eccentricity, whereby the variation in thickness of the rolled stock may be effectively prevented.

It is therefore the primary object of the present invention to provide a method for detecting the eccentricity of a working or backing roll of a rolling mill without using a detector or detectors which are directly attached to the peripheral surface of the roll, so that the signals for correcting the variation in thickness of rolled stock may be generated.

In brief, the rolling pressure and rotational speed of a working or backing roll are measured, and the measured rolling pressure is sampled at a suitable time interval, quantized and fed into an arithmetic unit for calculation of the eccentricity and phase of the roll. The eccentricity and phase may be stored in a holding circuit and converted into analog quantities which may be used as the signals for correcting the variation in thickness of the rolled stock due to the eccentricity of the roll.

According to the method of the present invention, the detection of the eccentricity and phase of a working or backing roll may be made very quickly in a very simple manner so that the variation in thickness of the rolled stock may be immediately corrected.

The present invention will become more apparent from the following description of the preferred embodiment thereof taken in conjunction with the accompanying drawing.

FIGS. 1, 2 and 3 are graphs for explanation of the principle of the method for detecting the eccentricity and phase in accordance with the present invention; and

FIG. 4 is a block diagram illustrating the sequence of calculating the eccentricity of the roll from the measured rolling pressure.

The working principle of the present invention will be discussed first. The relationship between the roll eccentricity and the variation in rolling load (variation in rolling force) may be expressed as follows:

\[
\Delta P = \frac{\Delta S}{1 + \frac{1}{K + M}}
\]

where
\[
\Delta P = \text{variation in rolling pressure;}
\Delta S = \text{roll eccentricity;}
K = \text{mill constant of a rolling mill; and}
M = \text{plastic deformation coefficient which may be determined depending upon rolling conditions.}
\]

In case of a four-high rolling-mill stand, the fundamental cyclic period of the roll eccentricity coincides with the period of the backing rolls and, according to elementary mathematics, this cyclic phenomenon can be expressed as:

\[
\Delta S = A \cos (\omega t - \beta)
\]

where
\[
A = \text{eccentricity of backing roll;}
\omega = \text{angular velocity of backing roll;}
t = \text{time; and}
\beta = \text{a phase angle from a predetermined point upon a roll to a point where the roll eccentricity is the maximum.}
\]

Substituting Equation (1) for Equation (2), we have

\[
\Delta P = \frac{A \cos (\omega t - \beta)}{1 + \frac{1}{K + M}}
\]

Therefore, it is possible to detect both of A and \(\beta\) by measuring the value of \(\Delta P\) during one rotation of the backing roll. More particularly, the rolling pressure and the rotational speed of the roll are measured. The measured rolling pressure is sampled at a predetermined time interval, converted into a digital value which may be fed into an arithmetic unit so as to calculate the roll eccentricity and phase. The calculated roll eccentricity and phase may be stored and converted into analog quantities which may be used as signals for correcting the variation in thickness of rolled sheet due to the eccentricity of the working roll.

Next the preferred embodiment of the present invention will be described with reference to the accompanying drawing. The following description is assumed to consider a machine in the form of a conventional four-high rolling mill stand. According to the invention, the pressure and rotational speed of a backing roll of the rolling mill stand are first measured. The rolling pressure, for example the downward pressure in the machine, can be detected by a conventional method, for example, by means of a load cell installed between the backup roll, chuck and housing. Such arrangement is shown for example, in U.S. Pat. No. 3,100,410, Hulls, which issued on Aug. 13, 1963. The detection of the rotation of the rolls can also be detected by any conventional technique such as providing a pulse transmitter at the end of the axis of a backing roll to generate a pulse for each rotation of the roll over a given angular displacement that the rolling pressure \(P\) varies with respect to time \(t\) as shown by the curve a in FIG. 3. The rolling pressure \(P\) is sampled at a time interval of \(T/n\) where \(T\) is a time required for the working roll to make one rotation and \(n\) is an integer, and then quantized as shown in FIG. 2. Generally the rolling pressure \(P\), will not coincide with the rolling pressure
As shown in FIG. 1, a straight line shown by the chain line L is drawn so as to obtain the deviations from this straight line L. Assume that the deviations $\Delta P_1 - \Delta P_n$ are as shown in FIG. 3. From these deviations $\Delta P_1 - \Delta P_n$ and the following equations, the eccentricity $A$ of the backing roll and the phase angle between a predetermined point and a point at which the eccentricity is maximum are calculated.

\[ A = \left( \frac{1}{k} + \frac{1}{M} \right) \sqrt{B^2 + C^2} \]

where

\[ B = \frac{2}{n} \sum_{k=1}^{n} \Delta P_k \cos \left( \frac{2\pi k}{n} \right) \]

\[ C = \frac{2}{n} \sum_{k=1}^{n} \Delta P_k \sin \left( \frac{2\pi k}{n} \right) \]

\[ \beta = \tan^{-1} \left( \frac{C}{B} \right) \]

these formulas are known formulas for obtaining the constants of the first harmonic of the Fourier series of a function.

The mean values of $A$ and $\beta$ during a number of $m$ rotations of the backing rollers are obtained so as to use them as the signals representative of the eccentricity of the roll in the next $m$ rotations of the roller. The values of $A$ and $\beta$ in this next $m$ rotations are compared with the former values of $A$ and $\beta$ and the deviations or differences are added to the former values so as to generate the signals representative of the eccentricity which may be used in a second $m$ rotations of the roller.

The generated signals may be applied in conventional manner to suitable motors for adjusting the roll setting, or to hydraulic roll adjustment devices by way of amplifiers, in order to thus compensate for the effect of roll eccentricity. FIG. 4 is a block diagram illustrating the sequence of the above described steps. In case of a two-high rolling-mill stand, the values $A$ and $\beta$ may be obtained from a working roll in a similar manner as described above.

Referring now to the block diagram of FIG. 4, therein is illustrated a pulse generator 8 for generating pulses responsive to the degree of rotation of a roller. The pulse output of the generator 8 is applied to a timing circuit 9 which, responsive to the pulses received from the generator 8, generates time pulses for the operation of a sampling circuit to, a memory circuit 4, an arithmetic unit 5 and a holding circuit 6, so that the timing of the operations of these devices is responsive to the pulse output of the pulse generator 8.

The roll pressure load is measured by a roll pressure measurement detector 1, with the output of the detector being applied to a sampling circuit 2 which samples the signals in accordance with the timing output of the timing circuit 9 as above stated. The output of the sampling circuit is applied to an analog-to-digital converter 3 to provide a digital output for a memory circuit 4 and an arithmetic unit 5. The memory circuit 4, the output of which is also applied to the arithmetic unit 5, stores the sampled data from the converter 3 while the arithmetic unit 5 is performing other calculations. The arithmetic unit 5 calculates the value of the eccentricity $A$ of the backing roll and the phase angle $\beta$.

\[ \Delta P = \frac{A \cos (\omega t - \beta)}{K + \frac{1}{M}} \]

where $\Delta P$ is the variation in rolling pressure of said roll, $K$ is a mill constant, and $M$ is the plastic deformation coefficient.

3. The system of claim 2 wherein said means for providing said first signal comprises means for sampling the rolling pressure of said roll at a rate $T/n$ to provide said first signal, where $T$ is the time of one rotation of the roll and $n$ is an integer.

4. The system of claim 3 further comprising storage means, and means for applying said first signal to said arithmetic unit directly and by way of said storage means, and wherein said arithmetic unit comprises means for producing said output signals $A$ and $\beta$ according to the relationship:

\[ A = \left( \frac{1}{k} + \frac{1}{M} \right) \sqrt{B^2 + C^2} \]

where

\[ B = \frac{2}{n} \sum_{k=1}^{n} \Delta P_k \cos \left( \frac{2\pi k}{n} \right) \]

and

\[ C = \frac{2}{n} \sum_{k=1}^{n} \Delta P_k \sin \left( \frac{2\pi k}{n} \right) \]

\[ \beta = \tan^{-1} \left( \frac{C}{B} \right) \]