# United States Patent

[11] 3,580,022


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[54] **ROLLING MILL INCLUDING GAUGE CONTROL**
**10 Claims, 8 Drawing Figs.**


[52] **U.S. Cl.** ..... **72/8**, 72/21
[51] **Int. Cl.** ..... **B21b 37/08**
[50] **Field of Search** ..... 72/8, 10, 11, 16, 21



[56] **References Cited**

UNITED STATES PATENTS

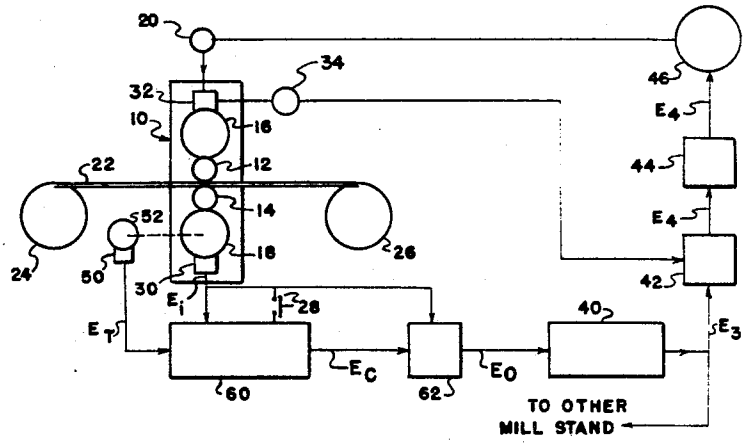
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**ABSTRACT:** In combination with a rolling mill and control means for controlling the spacing between a set of work rolls thereof, the method and means for producing an electrical control signal for said control means which is free of a component which varies cyclically with the rotation of the rolls, e.g., the eccentricity of the rolls.

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Fig. 1

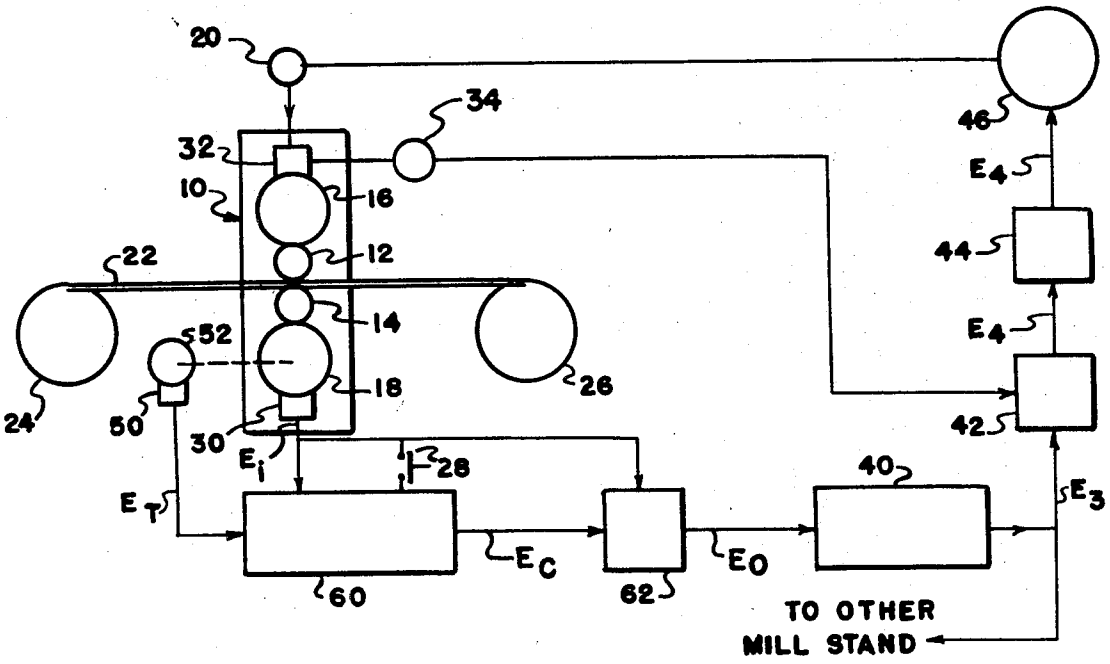



Fig. 2

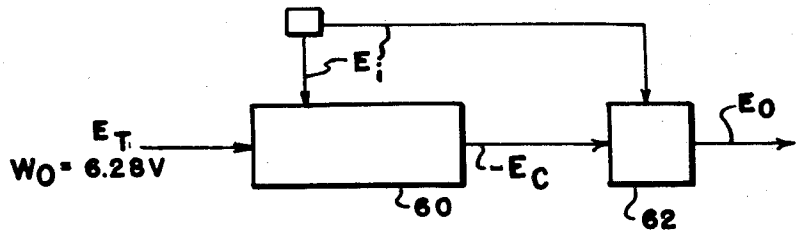
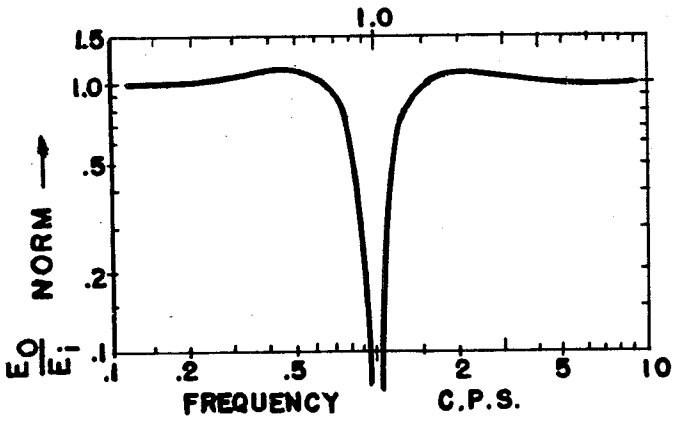



Fig. 3




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Fig.5

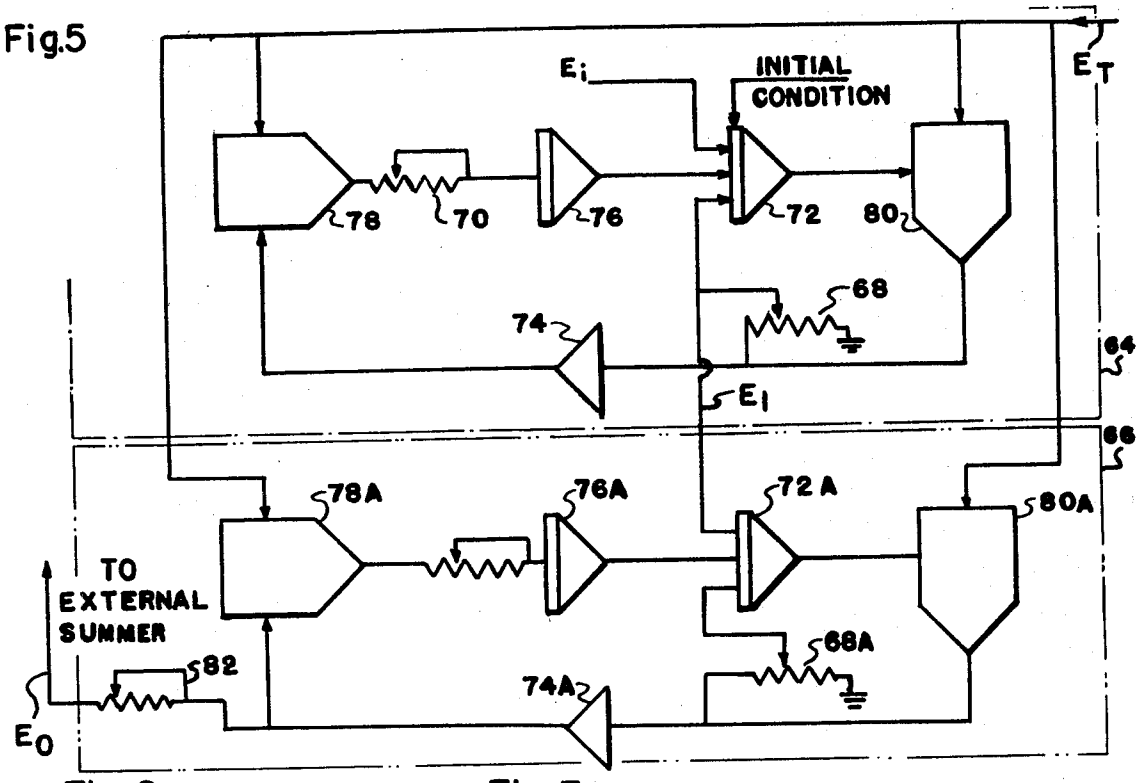



Fig. 6

PRIOR ART

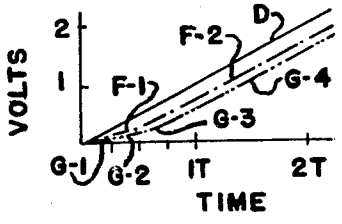



Fig. 7

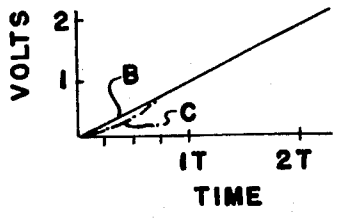



Fig. 4

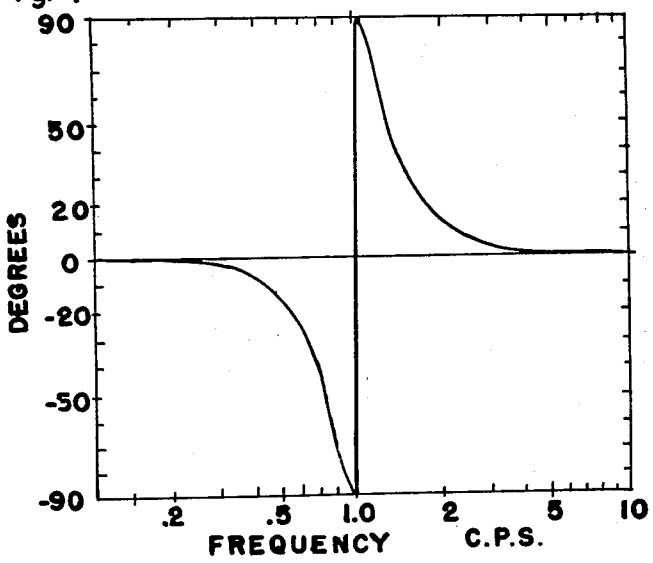
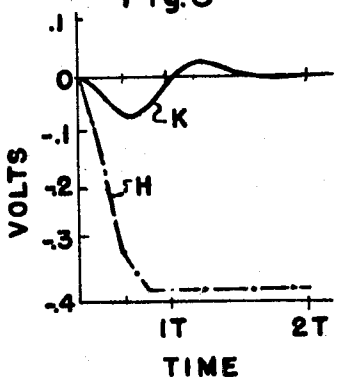



Fig.8




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# ROLLING MILL INCLUDING GAUGE CONTROL

## BACKGROUND OF THE INVENTION

This invention relates generally to rolling mills, such as strip mills, and particularly to the control of the spacing between the work rolls through the use of a screwdown device operated by a signal generated by a variation from a preselected value corresponding to roll separation necessary to produce the desired gauge.

Some of the features of this invention are particularly adapted for use as automatic gauge controls (AGC) for controlling the gauge of strip produced on a continuous strip line. However, these features may also be employed in conjunction with and as part of reversing mills.

In AGC systems, it is common to use load cells to sense the force between the work rolls of a rolling stand. The load cell generates a voltage signal which is generally indicative of this force. This signal is used to control the spacing between the face of work rolls or one or more stands. In the processing of steel slabs into strip, it is customary to reheat the slabs in a furnace having skid rails, along which the slabs are advanced. Those slab areas in contact with the rails (skid marks) are generally of lower temperature than those areas which are not in contact. These skid marks usually produce hardness variations. The AGC system attempts to properly adjust the spacing between the work rolls to compensate for these and other hardness variations and provide means whereby a product of uniform gauge may be produced.

Included in the load cell voltage signal is a component which is cyclically produced in accordance with the rotation of the mill rolls, e.g. that component due to eccentricity of the rolls or their shaft journals. The cyclic occurrence of such component may be more frequent than the occurrence of the hardness variations. Such component may also be of a value which represents a variation greater than the gauge tolerances. The inclusion of this component as part of the final control signal to the screwdown device can produce undesirable effects, such as "hunting" or continuous cycling, where the AGC system is constantly adjusting the screwdown device and never reaches a steady state. This rapid and repetitive screw motion results in short screw life, poor systems performance, and rapid deterioration of the mechanical portion of the equipment.

Others in the art have recognized that eccentricity variations in rolling mills produce erratic operation and increase stability problems, as exemplified by the disclosure in U.S. Pat. No. 3,194,035 to J. P. Smith. They have concluded that, under certain circumstances, it is impossible to increase the gain of the control system in order to increase overall performance and have attempted to reduce the effects of the problem by providing a circuit which partly removes the variations in gauge error signal resulting from roll eccentricity. The gauge error signal is applied to a delay circuit, which delays the signal by a fraction of a period and then the gauge error signal and the delayed signal are added. Such delay circuits usually include mechanical switching devices with commutators and a great number of brushes.

## OBJECTS AND SUMMARY OF THE INVENTION

It is an object of this invention to provide method and apparatus for improving automatic gauge control in a rolling mill.

It is another object of this invention to provide an improved rolling mill and method of controlling the operation which obviates the undesirable effects of cyclic variations.

A further object of this invention is to provide, in combination with a rolling mill and thickness control means, an improved control signal system capable of tracking a ramp-type input signal with less error than heretofore.

A still further object of this invention is to provide rolling mill method and apparatus including control method and system which is substantially electrical in operation, as distinguished from mechanical operation, and which requires little maintenance.



Briefly, the objects are attained by providing a control system in combination with a rolling mill having adjustment means for varying the roll spacing, which means is responsive to a control signal of said control system, and a load cell, which load cell produces a signal, including a cyclic component which varies cyclically with the rotation of the mill rolls, which system embodies: means for obviating the effect of said component and for freeing said control signal from said component. Preferably, electrical method and means are provided for filtering certain components of the load cell signal and generating a new signal which is free of said cyclic component. In a more preferred embodiment, the signal control system comprises: means for generating a first signal, which first signal is indicative of the variation between a preselected value, corresponding to the desired roll separation, and the actual roll separation, said first signal including a component which varies cyclically with the rotation of the roller elements of the rolling mill; means for producing a second signal indicative of, but with inverted order polarity of said component; and means for summarizing said first and second signals to produce what may be termed a third or control signal, and whereby said control signal is free of said component.

## DESCRIPTION OF THE DRAWING

The invention will be more fully understood and further objects and advantages thereof will become apparent when reference is made to the following detailed description and to the accompanying drawing, in which:

FIG. **1** is a diagram schematically illustrating a rolling mill stand and its controls, including a circuit filter section, in accordance with this invention;

FIG. **2** is a diagram illustrating the circuit established to determine the amplitude and phase characteristics of the filter section of the circuit;

FIG. **3** is a curve illustrating the experimental $E_o/E_i$ amplitude vs frequency response of the voltage tunable filter section illustrated in FIG. **2**;

FIG. **4** is a curve illustrating the phase response of the voltage tunable filter section illustrated in FIG. **2**;

FIG. **5** is a diagram schematically illustrating in more detail the filter section shown in FIG. **1**;

FIG. **6** is a curve diagram illustrating the response or output signal to the ramp input signal of a prior art delay circuit system;

FIG. **7** is a curve diagram illustrating the response or output signal to the ramp input signal of the filter section of this invention; and

FIG. **8** illustrates graphically the tracking errors as expanded from the curves shown in FIGS. **6** & **7**.

In a representative embodiment of this invention as schematically illustrated in FIG. **1**, a typical rolling mill stand **10** comprises a pair of working rolls **12** & **14** and respective backup rolls **16** & **18**. A screwdown motor control device **20** provides means for selectively adjusting the spacing between the work rolls **12** & **14**. Usually, the upper rolls **12** & **16** are adjustable while the bottom rolls **14** & **18** are stationary.

The strip stock **22** to be processed is fed from a first roller element **24**, which may be designated as an unwind roll, threaded between the rolls **12** & **14** of one or more sets of working rolls and then onto a coiler roll **26**.

A load cell **30** is provided to measure the rolling force exerted between the working rolls **12** & **14** on the strip **22**. A position indicating device **32** is also provided in cooperative arrangement with the screwdown device **20**, together with a position signal transmitter **34**, which may be in the form of a Selsyn motor.

An electrical signal $E_i$ generated by the load cell **30** is transmitted to a set point circuit **40** where the signal $E_i$ is compared with a selected setting. The setting is selected to correspond to that force which occurs immediately after the strip has en-

tered the mill. Any deviation from the set point will be reflected in a signal $E_3$ being transmitted to the summer circuit **42**. The summer circuit **42** also receives any signal transmitted by the transmitter **34**. The circuit **42** then applies a new signal $E_4$ (or modified error signal) to the motor control device **20**, through amplifier **44** and generator **46**, for making appropriate adjustments in the spacing between the work rolls **12** & **14**.

In the case of multiple stand rolling mills, the signal $E_3$ from a first set of work rolls may be employed to adjust or modify the setting between the rolls of another work roll set through which the work is to subsequently pass.

The output signal of the load cell **30** includes a component which varies cyclically with the rotation of the roller elements **12, 14, 16, 18**, e.g. the component due to the eccentricity of the backup rolls. Others in the art have recognized the problem of eccentricity of backup rolls and have attempted to reduce the effect by adding a delayed signal. The present invention obviates the effect of any fundamental harmonic component (e.g. eccentricity variation) which varies cyclically with the rotation of the roller elements by the provision of a control input signal which is free of such component.

Means is provided for producing a signal $E_T$ indicative of the rotation cycle of the mill rolls, which means is illustrated in the form of a tachometer **50** operative with the mill drive motor **52**. This signal $E_T$ is received by a tunable filter circuit **60**, which forms an important feature of this invention. The tachometer signal $E_T$ may be suitably employed to adjust the selection frequency of the filter circuit **60** to be equal to the fundamental cyclic component frequency. The filter circuit **60** also receives the signal $E_i$ from the load cell **30** and forms means for selecting and inverting the fundamental portion of the signal cyclic component and in turn transmits only the cyclic component $E_c$ to summer circuit **62**. In essence, the filter circuit **60** removes all portions from the signal $E_i$ but the cyclic component. The summer circuit **62** adds the load cell output signal $E_i$ and cyclic component signal from filter circuit **60**, which component signal is inverted, and produces an output signal $E_o$ which is free of the fundamental of cyclic component $E_c$ of original load cell signal $E_i$.

A preferred embodiment of the tunable filter circuit **60** is illustrated in FIG. **5**. The filter circuit **60**, in conjunction with the summer **62**, was designed to attenuate the regular cyclic component (roll eccentricity) of the load cell signal $E_i$ with a minimal effect of the remaining force signal. The load cell output signal $E_i$ was assumed to be a linear combination of the cyclic component (roll eccentricity) signal and the desired control signal. Thus, the filter was designed to select and invert, as a function of mill speed or roll frequency of rotation, that component of the load cell output signal which has a fundamental frequency corresponding to the roll frequency of rotation. In this case, the roll frequency was related directly to that of backup roll **18**. However, since the rotational frequency of the rolls are interrelated by means of common drive motor **52**, the selected roll frequency is also related to the rotational frequency of the other rolls.

The transfer function F(S) of the filter circuit **60** was selected as follows:

$$F(S)=\frac{E_o(S)}{E_i(S)}=\frac{-A^2W_o^2S^2}{(S^2+AW_oS+W_o^2)^2}$$

wherein:

$E_i$ = input voltage

$E_o$ = output voltage

$S$ = Laplace transform operator

$A$ = damping coefficient >0.2 and <1,

$W_o$ = natural frequency of filter circuit

The application of analog simulation techniques resulted in the electrical circuit schematically illustrated in FIG. **5**, which is comprised of two second order circuit sections, and with the output signal of the first section **64** being employed as the feed signal to the second section **66**. The elements of second section **66** corresponding to elements of first section **64** are designated by corresponding numerals, however the numerals of the second section include the letter "A" suffix. The purpose of providing multiple similar sections is to sharpen the attenuation of the component of the load cell output signal which has a fundamental frequency corresponding to the mill roll frequency. Consequently, it will be understood that additional or fewer sections may be provided. If additional sections are used, the output signal of the second section would be used as an input signal to the third section, etc.

The transfer function of the first section **64** may be expressed as:

$$F_i(S)=\frac{E_1}{E_i}=\frac{-AW_oS}{S^2+AW_oS+W_o^2}$$

where $E_1$ is the output voltage of potentiometer **68**.

The potentiometer **70** provides means for selectively adjusting the natural frequency ($W_o$) while potentiometer **68** provides means for selecting the desired damping coefficient $A$ of the transfer function in accordance with the equation shown above. The amplifier **74** serves as an inverter while amplifiers **72** and **76** serve as integrators. Multipliers **78** and **80** provide means of electrically varying the natural frequency $W_o$ with the external tachometer signal $E_T$.

The operation of filter section **66** is substantially the same as that of section **64**. However, an additional potentiometer **82** is provided to serve as means for adjusting the level of the filter circuit output $E_o$ to external summer **62**.

Optionally, an initial input condition phase, as represented by contact switch **28**, may be imposed on the filter circuit **60** to minimize oscillation, due to step changes in $E_i$. The switch **28** is normally closed but opens immediately after the work stock **22** passes between the rolls **12** and **14**.

For the sake of convenience, the circuit was scaled such that a 6.28 volt input, as $E_T$, corresponds directly to 6.28 radians/sec., as $W_o$(6.28 radians = 1 revolution). The scaling was accomplished experimentally by setting up the circuit as illustrated in FIG. **2**. A separate but controlled voltage source of 6.28 V. was employed to simulate the desired voltage signal $E_T$, then potentiometer **70** was adjusted until the phase shift between $E_1$ and $E_i$ was 180° with a 1 cycle per second signal applied as $E_i$. The damping coefficient $A$ is preferably selected so that the response of the filter circuit **60** to a step input contains only one cycle of damped oscillation. This may be done by applying a low frequency square wave to the input of the filter circuit **60** and adjusting the potentiometer **68** until the desired output $E_1$ is observed.

The normalized frequency response $E_o/E_i$ of the filter circuit **60** and summer **62** is illustrated in FIG. **3**. The almost infinite extent to which the nominal selected frequency of 1 cycle/sec. (c.p.s.) is attenuated may also be observed. It will also be observed that the amplitudes of the nonselected frequencies are not substantially affected.

In FIG. **4** the phase characteristics, in degrees, versus the filter circuit frequency, c.p.s., may be observed. At a frequency of 0.5 times the nominal selected frequency of 1 c.p.s., less than a 12° phase lag occurs. The low phase lag characteristic is of particular advantage in a control system as shown in FIG. **1**.

One of the significant advantages of the rolling mill control system of this invention is its ability to track a ramp-type input signal. The typical load cell signals produced while rolling can be closely approximated by a series of ramp signals. However, if a control circuit is unable to accurately track a ramp input, it cannot accurately track mill roll load changes from the load cell.

FIG. **6** graphically illustrates the ability of the modifying error section, which corresponds to the delay circuit, of the commutator-type control device disclosed in U.S. Pat. No. 3,194,035 to track a ramp or input signal of unity. Curve D represents the input; curve F, comprised of sections **F–1** and **F–2**, represents the output with only an odd harmonic correction; and, curve G, comprised of sections **G–1, G–2, G–3**, and **G–4**, represents the output with both even and odd harmonic corrections. The slopes of the curve sections are as follows:

| Section | Slope |
|---|---|
| F–1 | 1 to 2 |
| F–2 | 1 to 1 |
| G–1 | 1 to 4 |
| G–2 | 1 to 2 |
| G–3 | 3 to 4 |
| G–4 | 1 to 1 |

In contrast to the decaying error of less than 0.025 units in the modifying circuit of the device of this invention, the delay circuit of U.S. Pat. No. 3,194,035 appears to have a constant error of 0.375 units after 0.75T.

FIG. 7 graphically illustrates the ability of the modifying section of the control circuit of the present invention to respond to a ramp or input signal of unity. Curve B represents the input and curve C represents the output.

In FIG. 8, the tracking errors of the devices of this invention and that of a prior art device are shown as expanded from FIG. 6 & 7. Curve K in FIG. 8 corresponds to the tracking error of the device of this invention as exemplified by curve C in FIG. 7, and Curve H corresponds to the tracking error exemplified by curve G of a prior art device. As may be seen in FIG. 8, the maximum error which occurs at approximately 0.5T secs. (I = period of the fundamental cyclical components of the error signal), is in the order of 0.08 units. This error decays to less than 0.025 units after 0.75T secs. and continues to rapidly decay to a zero value.

A further advantage of the modifying unit of the rolling mill control system of this invention is that it requires no mechanical parts such as commutators, brushes, contacts, etc., and hence may be constructed of static and solid state devices. This feature is particularly beneficial in steel mill applications where dirt is likely to cause contamination problems.

Although the rolling mill and controls of this invention have been described in detail as to the component parts of preferred embodiments, it will be apparent that various changes and modifications may suggest themselves to one skilled in the art, which fall within the scope of the invention as defined by the subjoined claims.

What We claim is:

1. The combination of:
   a. a rolling mill, including a pair of roller elements operative with a moving product for reducing the thickness of said product;
   b. control means operative with at least one of said roller elements, in response to a control signal, for controlling the spacing between said roller elements; and
   c. a system for producing a first signal, which is generally indicative of the variation between a preselected value corresponding to the desired spacing between said roller elements and the actual spacing therebetween, and which includes a fundamental component which varies cyclically with the rotation of said elements, said system including tunable electrical means for acting on said first signal and producing a component signal corresponding to said fundamental component, and means for combining said first signal and said component signal and for producing an output signal free of said component for said control means.

2. In the combination of:
   a. a strip rolling mill, including a pair of roller elements operative with a moving strip for reducing the thickness of said strip;
   b. control means operative with at least one of said roller elements for controlling the spacing between said roller elements in response to a control signal; and
   c. a system for producing a control signal generally indicative of the variation between a preselected value, corresponding to the desired spacing between said roller elements and the actual spacing therebetween; the improvement wherein said system comprises:
      1. means for producing a first signal, indicative of said variation, said first signal including the fundamental component which varies cyclically with the rotation of said elements;
      2. means for producing a second signal, indicative of but in inverted polarity of said component; and
      3. means for summarizing said first and second signals to produce a control signal free of said component.

3. In rolling mill apparatus, the combination comprising:
   a. a screwdown motor for selectively adjusting the spacing between the faces of a pair of work rolls of the mill;
   b. a drive motor for driving said work rolls;
   c. a tachometer device for producing a tachometer electrical signal indicative of the rotation frequency of said work rolls;
   d. a load cell device for sensing the load force between said work rolls and providing a load force electrical signal indicative of said force;
   e. a filter circuit for receiving said tachometer electrical signal and said load force electrical signal, and for selecting and inverting, as a function of said tachometer electrical signal, the component of said load force electrical signal which has a fundamental frequency corresponding to said rotation frequency and thereby provide an inverted component signal;
   f. first summarizing means, for receiving and summarizing a load force electrical signal from said load cell device and said inverted component signal, and for providing a summarized signal, which may be designated as a first summarized signal;
   g. set point circuit means for receiving said first summarized signal, comparing it with a selected value, and providing a differential signal which is indicative of the difference between said selected value and the value of said first summarized signal;
   h. means for providing a screwdown position signal indicative of the relative spacing between said faces of said work rolls; and
   i. second summarizing means, for receiving and summarizing said differential signal and said screwdown position signal, and providing a control signal for said screwdown motor in accordance with the roll spacing necessary to provide the desired thickness of the product being processed.

4. Electrical control means, adapted for use in controlling the spacing between the work rolls of rolling mill apparatus, which includes a screwdown motor comprising:
   a. a filter circuit for receiving a first signal, indicative of the rotation frequency of the work rolls of a rolling mill, and a second signal, indicative of the spacing between said work rolls, said filter circuit including means for selecting and inverting a component of said second signal, which component has a fundamental frequency corresponding to the frequency of said first signal; and
   b. means for summarizing said second signal and said inverted component and providing a summarized signal free of said component for controlling the operation of said screwdown motor.

5. A method of controlling the operation of the screwdown device of a rolling mill, comprising:
   a. applying a load force to the work product passing a work roll of said mill;
   b. sensing said applied load force and generating a load force signal indicative of the discrepancy between a predetermined load force and said applied load force;
   c. selecting from said load force signal that component which has a fundamental frequency corresponding to the roll frequency of rotation, and producing a corresponding component signal; and
   d. combining said load force signal and said component signal and transmitting a summarized control signal to said screwdown device, which control signal is free of said component.

6. A method as described in claim 5, which comprises the step of:
   imparting an initial condition signal, indicative of the force between the work rolls immediately after the work

product is initially threaded therebetween, for minimizing oscillation of said second signal, which oscillation is due to step changes in said first signal.

7. The method as described in claim 5, wherein:

said load force signal is a ramp-type signal and is tracked with an output signal in an electrical filter circuit.

8. The method as described in claim 7, wherein:

said ramp-type signal is tracked with an error of less than 0.025 units after 0.75 T seconds, where T equals the period of said fundamental frequency.

9. Control means, adapted for use in controlling the operation of the work rolls of rolling mill apparatus, comprising:

a. a tunable electric filter circuit for receiving a first signal, indicative of the rotation frequency of said work rolls, and a second signal, indicative of the load force between said rolls, said filter circuit including means for selecting a component of said signal, which component has a fundamental frequency corresponding to the frequency of said first signal and providing a third signal corresponding to said component; and

b. summarizing means for receiving a signal corresponding to said second signal and for receiving said third signal, and providing a summarized signal, free of said fundamental component for controlling said operation.

10. Control means, adapted for use in controlling the spacing between the work rolls of rolling mill apparatus, comprising:

a. load force means for sensing the load force between said rolls and providing a load force signal indicative of said force, which load force signal includes a component which has a fundamental frequency corresponding to the rotation frequency of said rolls;

b. tunable electrical filter signal means for receiving said load force signal and providing a tuned filtered signal corresponding to said component; and

c. means for simultaneously receiving said load force signal and said filter signal and for providing a summarized signal free of said component.