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FOIL THICKNESS CONTROL APPARATUS

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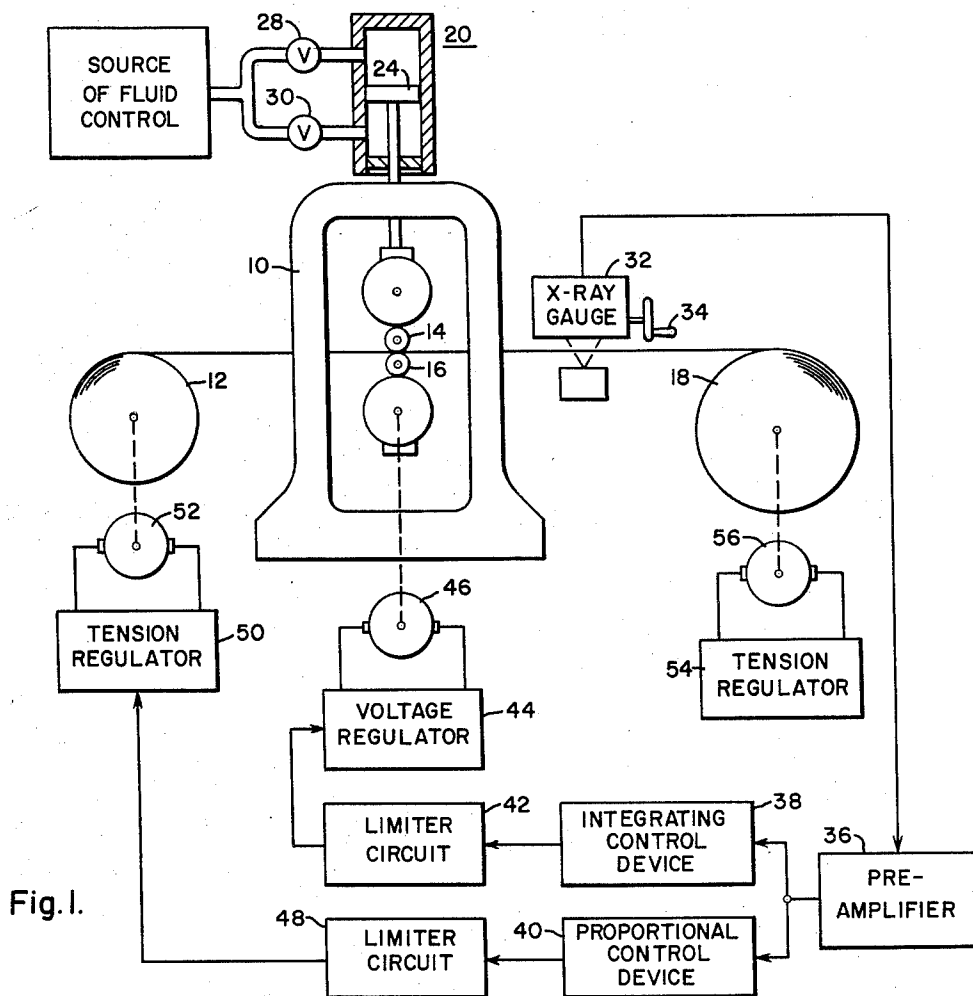


Fig. 1.

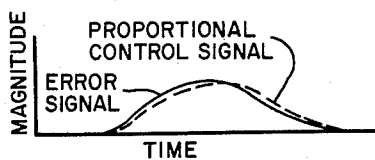


Fig. 2.

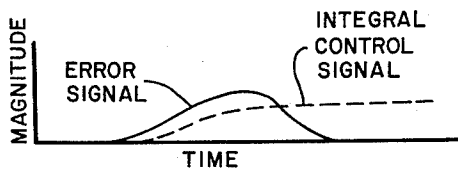


Fig. 3.

WITNESSES:

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FOIL THICKNESS CONTROL APPARATUS

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The present invention relates to metallic foil thickness control apparatus and more particularly to automatic thickness or gauge error correcting control apparatus for a metallic foil rolling mill.

The control of foil strip thickness is extremely critical for a foil rolling mill due to the thickness of the foil being only in the order of .004 of an inch thick and less. Thusly, the maintenance of accurate foil strip thickness or gauge without adversely affecting the rolling process is very difficult in that breakage and deformation of the foil strip is very likely to occur.

It is an object of the present invention to provide improved thickness control apparatus for a metallic foil rolling mill, wherein a more accurate control of the foil thickness or gauge is maintained relative to a predetermined reference or desired foil thickness.

It is an additional object of the present invention to provide an improved thickness control apparatus for a foil rolling mill, wherein an optimum control of the rolled foil thickness is provided with less resulting variation or error in the rolled thickness relative to a predetermined reference or desired foil thickness.

It is a further object of the present invention to provide an improved foil rolling mill thickness control apparatus that has a better error correction response characteristic and thereby gives a better and more even coil buildup on the rewind reel with less foil strip wander in the rolls of the rolling mill.

These and other objects and advantages of the present invention will become apparent in view of the following description taken in conjunction with the drawings, wherein

FIGURE 1 is a diagrammatic showing of the thickness control apparatus in accordance with the teachings of the present invention;

FIG. 2 is a curve illustrating the operation of the proportion control device shown in FIG. 1; and

FIG. 3 is a curve illustrating the operation of the integrating control device shown in FIG. 1.

In FIG. 1, there is shown a rolling mill stand 10 for the rolling of metallic foil strip 11 which has a thickness in the order of 0.004 inch. The foil is supplied from an unwind reel 12 along a travel path between the upper roller member 14 and lower roller member 16 of the foil rolling mill 10 to a rewind reel 18. The spacing between the roller members 14 and 16 is controlled by a suitable force member 20, which is illustrated as a cylinder 22 having a piston 24 therein which is connected to apply force pressure to control the spacing between the roller members 14 and 16. A source of high pressure control fluid 26 is operative through suitable control valves 28 and 30 for controlling the force applied to determine the spacing between the roller members 14 and 16. A well known X-ray gauge 32 is operative to measure the actual rolled thickness of the foil strip 11 leaving the rolling mill 10, and provides a control signal in accordance with any error or difference between the actual rolled foil thickness and a predetermined desired or reference foil thickness. The reference thickness may be manually set or determined by the setting of the X-ray gauge 32 by means of, for example, a manual control handle 34.

The error signal from the X-ray gauge 32 is supplied to a preamplifier 36 which amplifies the error signal

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and supplies it to each of an integrating control device 38 and a proportional control device 40. The integrating control device 38 is operative in the manner of a motor operated rheostat such that the output signal from the integrating control device 38 varies in accordance with the time integral of the error signal supplied by the X-ray gauge 32. A signal value limiter circuit 42 is connected between the integrating control device 38 and a voltage regulator 44 operative to control the operating speed of a motor 46 connected to the roller members 14 and 16.

The proportional control device 40 is operative to provide an output signal which varies proportional to and in accordance with the instantaneous variation of the error control signal received from the X-ray gauge 32. The output signal from the fast acting proportional control device 40 is supplied through a signal value limiter circuit 48 to a tension regulator 50 operative to control the speed of a motor 52 connected to the unwind reel 12. The voltage regulator 44 is operative with the mill motor 46 to control the operation of the mill at a substantially constant and predetermined speed. The tension regulator 50 is operative with the unwind reel 12 and its motor 52 to control their operation for a pre-set strip tension by suitable changes in the operation of the motor 52.

A suitable tension regulator 54 is operative with a motor 56 connected to the rewind reel 18 for providing a predetermined desired and substantially constant tension between the rolling mill 10 and the rewind reel 18 relative to the foil strip 11 which leaves the rolling mill 10 and is wound up as a coil on the rewind reel 18.

The curve of FIG. 2 illustrates the operation of the proportional control device 40 and is plotted in terms of signal magnitude as a function of time. It will be seen from the curve of FIG. 2 that the error signal is operative with the proportional control device 40 to provide a control signal which varies substantially in accordance with the instantaneous variation of the error signal.

In FIG. 3 the curve illustrates the operation of the integrating control device 38 such that the error signal which is plotted in terms of signal magnitude as a function of time is operative with the integrating control device 38 to provide a control signal which is the effective integral of the error signal.

Thusly, in the case of an error signal which is removed due to the correcting operation of the present control apparatus, the control signal supplied by the proportional control device would return to a zero value, whereas the integral control signal supplied by the integrating control device 38 would have a finite value in accordance with the effective integral of the error signal as a function of time.

In the operation of the control apparatus as shown in FIG. 1, the X-ray gauge 32 is operative to provide an error signal in accordance with any error or difference in the actual rolled foil thickness, as measured by the X-ray gauge 32 relative to a predetermined desired or reference foil thickness as determined by the setting of the manual handle 34. This error signal is supplied through the preamplifier 36 to each of the integrating control device 38 and the proportional control device 40.

The integrating control device 38 is operative as a slow responding and highly accurate integral control system that is operative as a zero error system and controls the operating speed of the mill, hence the friction of the mill, to maintain a very accurate average foil thickness. The proportional control device 40 is a fast responding proportional control device and operates into the unwind reel tension regulator to correct for fast changes in foil thickness or gauge to reduce the amplitude of the thickness or gauge deviation relative to the desired or reference thick-

ness. The limiter circuits 42 and 48 are operative to limit and thereby provide a maximum correction signal to the respective voltage regulator 44 and tension regulator 50.

The combination of the slow responding and highly accurate integral control device 38 with the fast responding proportional control device 40 provides an optimum control system for the control of rolled foil thickness or gauge. Thusly, the combination of the fast acting proportional control device 40 being operative only with the unwind reel 12 tension regulator provides a correction for fast changes in foil strip thickness or gauge to thereby reduce the amplitude of such errors or changes, and the slower acting integrating control device 38 is operative as a zero error device and corrects only the operating speed of the rolling mill 10 through the voltage regulator 44 and the mill motor 46. The integrating control device 38 works only on mill friction to maintain a very accurate average rolled coil thickness. Because the integrating control device 38 responds slowly enough that the tension regulator 54 for the rewind reel 18 can follow its corrections, there is no problem regarding the build-up of a good coil of foil strip on the rewind reel 18.

It is necessary that the thickness control operation is very closely coordinated with the operation of the rewind reel 18, since fast changes of the rolling mill speed will cause the foil strip to wander undesirably in the roll members 14 and 16 and further to result in an uneven build-up of the coil on the rewind reel 18. This uneven build-up is in the form of a mismatch between successive layers of the coil on the rewind reel 18. In actual practice, it is extremely difficult and not practical to precisely coordinate the speed of the rolling mill 10 and the operation of the rewind reel 18 well enough to obtain an advantage from fast control of the operating speed of the rolling mill 10 through fast or rapid controlling of the operating speed of the mill motor 46. However, the operation of the rolling mill 10 itself is less sensitive to fast changes in the operating speed of the unwind reel 12 due to fast correction of the operating speed of the motor 52 of the unwind reel 12, and such changes in the operation of the motor 52 connected to the unwind reel 12 do result in correcting the rolled thickness of the foil strip leaving the roller members 14 and 16. Further, fast changes in the operating speed of the motor 52 connected to the unwind reel 12, for example changes taking place in one second of time or less, do not cause undesirable wandering of the foil strip between the roller members 14 and 16, nor do such fast changes cause loss of desired tension between the rolling mill 10 and the rewind reel 18. Thusly, no coil layer telescoping or uneven buildup of the coil on the rewind reel 18 results. In this manner the tension between the unwind reel 12 and the rolling mill 10 can be changed quite rapidly to vary and correct the thickness or gauge of the rolled foil strip without adversely affecting the other factors in the rolling process.

A typical foil rolling mill includes a single stand such as the rolling mill 10 and it has been found in actual practice that a superior operation of a foil rolling mill results when the fast acting proportional control device 40 is operative to control the tension of the foil strip between the unwind reel 12 and the roller members 14 and 16 of the foil rolling mill 10, in combination with a slower acting integrating control device 38 operative to control the speed of the mill motor 46 connected to the roller members 14 and 16 of the foil rolling mill.

For a prior art teaching of each of the proportional control device and the integrating control device, reference may be made to a book entitled *Electronic Analog Computers* by Korn and Korn, 2nd Edition, published by the McGraw-Hill Book Co. in 1956, and particularly pages 175 to 184.

While one preferred embodiment of this thickness control apparatus is to have the proportional control device 40 be operative with the unwind reel 12 tension regulator 50 and to have the integrating control device 38 be

operative to control the speed of the rolling mill 10 through the voltage regulator 44, it is clearly within the scope of the present teachings to connect the integrating control device 38 to be operative for controlling either one of the strip tension through the tension regulator 50 for the reel motor 52 or the speed of the rolling mill 10 through the voltage regulator 44, and to connect the proportional control device 40 to be operative for controlling the other of said speed of the rolling mill 10 or said strip tension through the tension regulator 50, as may be desired.

Although the present invention has been described with a certain degree of particularity, it should be understood that the present disclosure has been made only by way of example and that numerous changes in the details of construction and the combination and arrangement of parts may be resorted to without departing from the scope and the spirit of the present invention.

I claim as my invention:

1. In control apparatus for a foil rolling mill having a roll member driven by a first motor and including a tension controlling device having a second motor, the combination of signal providing means operative with the foil leaving said mill for providing a thickness error signal in accordance with the actual foil thickness compared to a desired reference foil thickness, first thickness control means operative with only one of said first and second motors for varying the speed of said one motor as a substantially direct proportional function of said error signal, and second thickness control means operative with only the other of said first and second motors for controlling said other motor as a predetermined rate integral of said error signal.

2. In thickness control apparatus for a foil rolling mill including a mill speed controlling motor and a foil tension controlling motor, the combination of signal providing means operative with the foil at a predetermined location relative to said mill for providing a thickness error signal having a magnitude variation in accordance with the actual foil thickness relative to a desired reference foil thickness, first thickness control means operative with only said tension controlling motor for varying the operation of said tension controlling motor as a directly proportional function of the magnitude of said error signal, and second thickness control means operative only with said mill speed controlling motor for varying the operation of said mill speed controlling motor as a predetermined rate function of the variation of said error signal, with said first thickness control means being faster acting than said second thickness control means.

3. In thickness control apparatus operative with a metallic foil rolling mill having a roll member driven by a first motor and including a tension controlling reel member driven by a second motor, the combination of error signal means operative with said rolling mill for providing an error signal having a magnitude in accordance with the difference between the actual thickness of the foil leaving the rolling mill and a predetermined desired foil thickness, a first control device operative only with one of said first motor and said second motor and being responsive to said error signal for controlling the operation of said one motor as a substantially proportional function of the magnitude of said error signal, and a second control device operative only with the other of said first motor and said second motor and being responsive to said error signal for controlling the operation of said other motor as a predetermined integral of said error signal, with said second control device being slower acting than said first control device.

4. In thickness control apparatus for a foil rolling mill driven by a mill roll motor and including a tension controlling motor, the combination of signal providing means operative with the foil at a predetermined location relative to said mill for providing a thickness error signal

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having a magnitude variation in accordance with the actual foil thickness relative to a desired reference foil thickness, first thickness control means operative with only said tension controlling motor for varying the operation of said tension controlling motor as a directly proportional function of the magnitude of said error signal, and second thickness control means operative only with said mill motor for varying the operation of said mill motor as a predetermined rate function of the variation of said error signal.

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