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Peterson

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[45] **Oct. 30, 1973**

[54] **INTERSTAND TENSION REGULATOR FOR A MULTISTAND ROLLING MILL**

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[73] Assignee: **Westinghouse Electric Corporation**, Pittsburgh, Pa.

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[52] **U.S. Cl.** **72/9**, 72/11

[51] **Int. Cl.** **B21b 37/12**

[58] **Field of Search** 72/8, 9, 10, 11, 72/12, 16

[56] **References Cited**

UNITED STATES PATENTS

3,049,036	8/1962	Wallace et al.	72/9
3,440,846	4/1969	Scott	72/11
3,566,639	3/1971	Dornbusch	72/8
3,613,419	10/1971	Silva	72/8
3,045,517	7/1962	Wallace et al.	72/9

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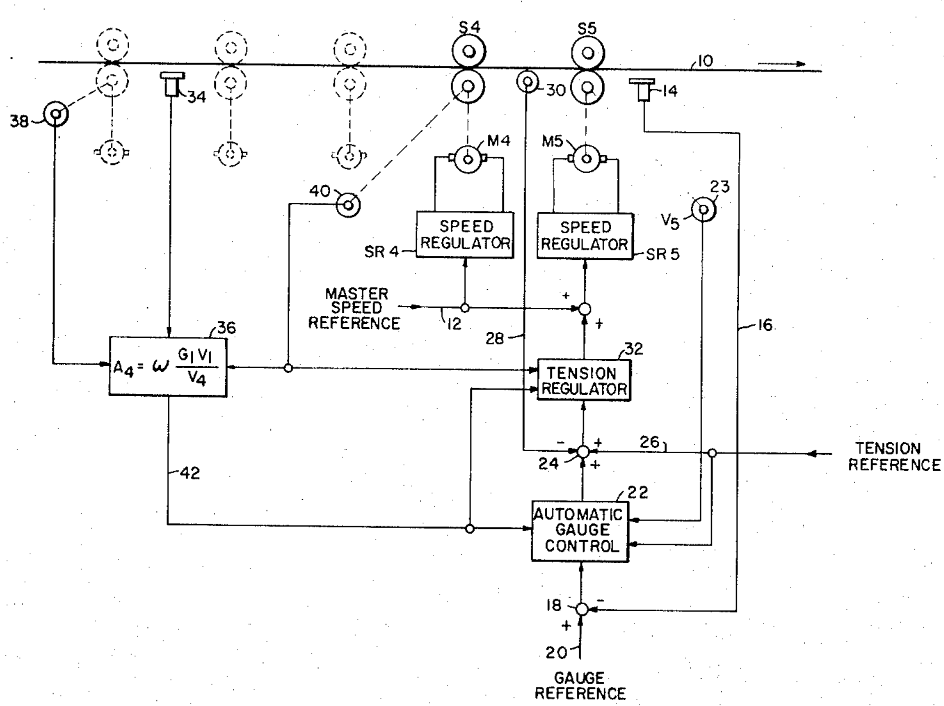
[57] **ABSTRACT**

An interstand tension regulator for tandem rolling mills wherein the gain coefficient of the regulator is varied to maintain a fast constant tension loop response regardless of mill speed, the cross-sectional area of the product being rolled, and its modulus of elasticity.

11 Claims, 3 Drawing Figures



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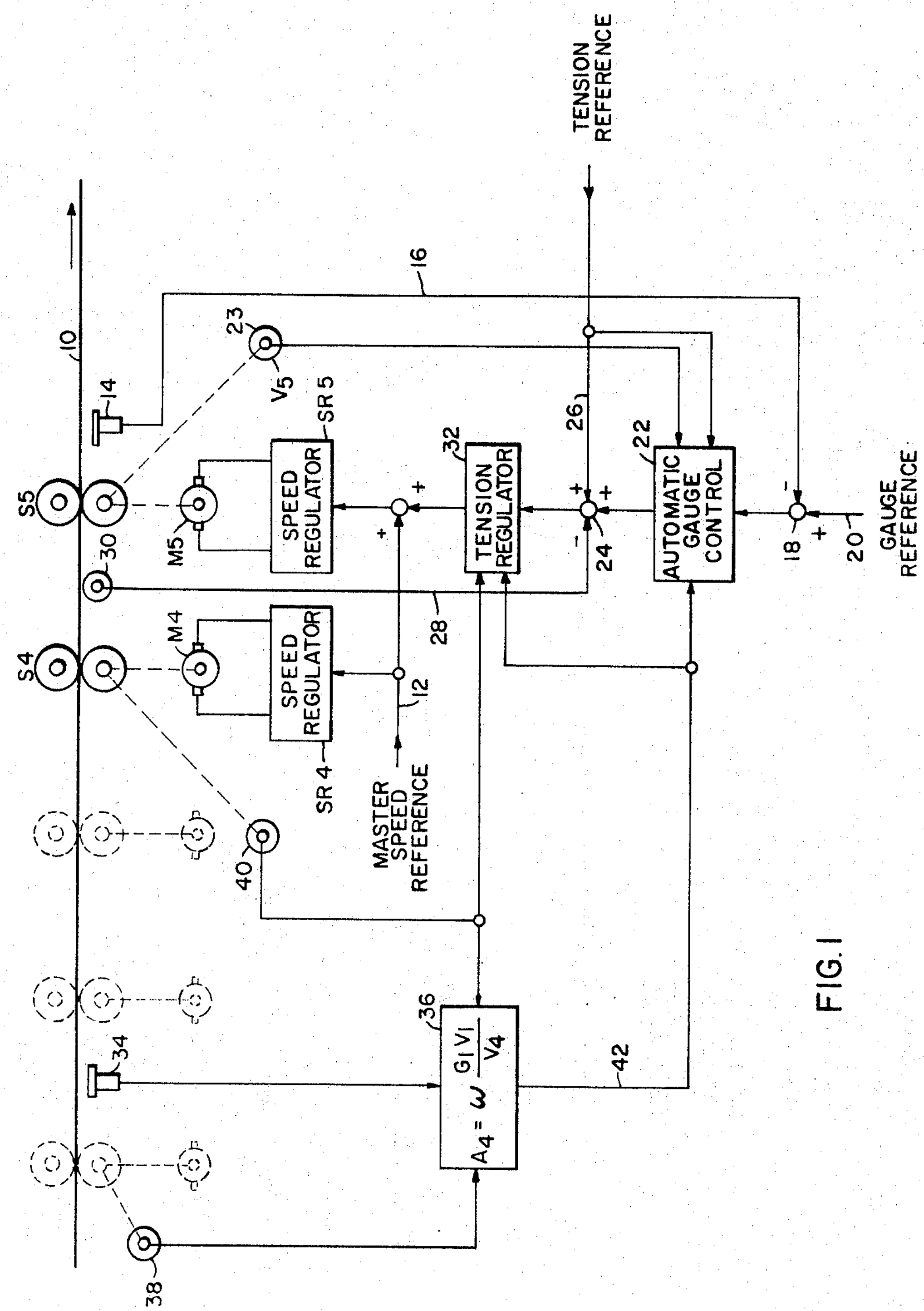

FIG. 1

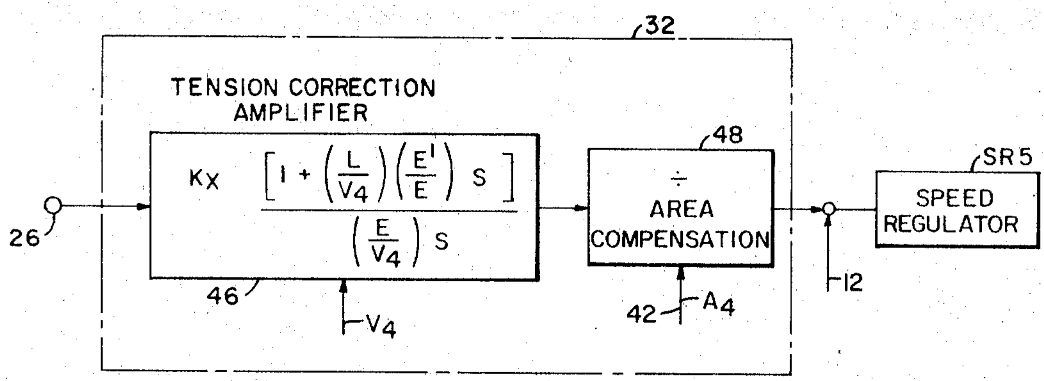
32
TENSION CORRECTION
AMPLIFIER
48
SR5
KX
$\left[1+\left(\frac{L}{V_4}\right)\left(\frac{E^1}{E}\right)S\right]$
$\left(\frac{E}{V_4}\right)S$
÷
AREA
COMPENSATION
SPEED
REGULATOR
26
46
V4
42
A4
12

FIG.2

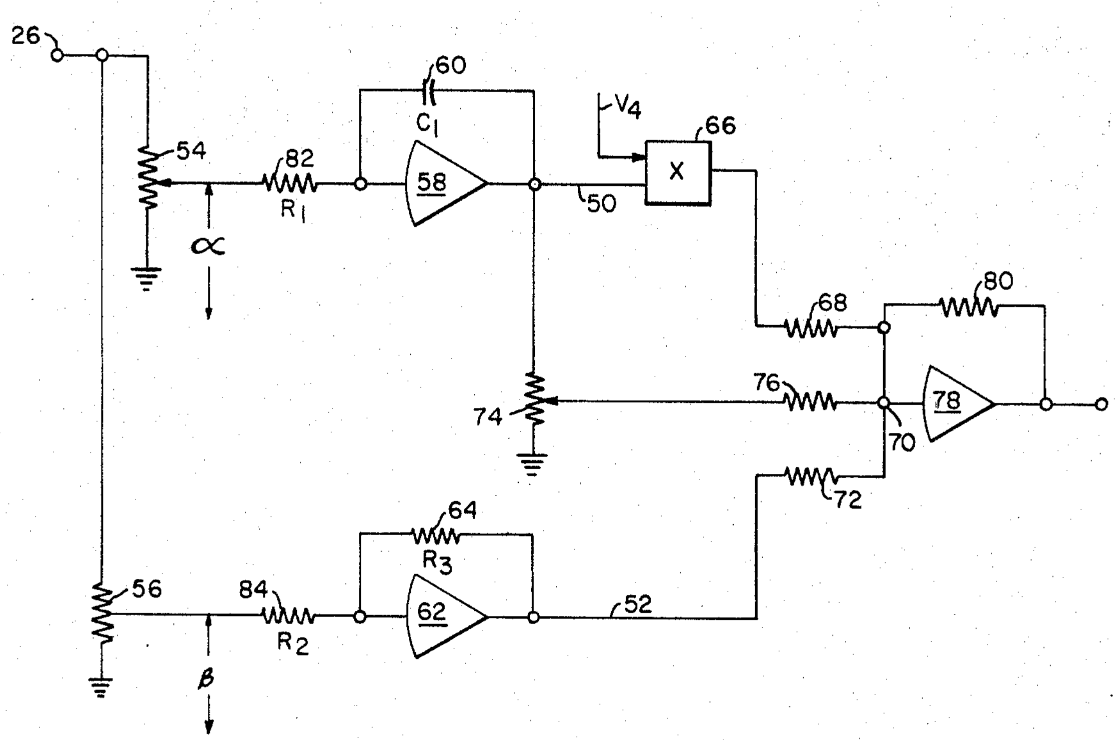
26
60
C1
V4
66
54
82
R1
58
X
50
∝
68
80
74
76
78
70
72
64
R3
56
84
62
52
R2
β

FIG.3

INTERSTAND TENSION REGULATOR FOR A MULTISTAND ROLLING MILL

CROSS REFERENCES TO RELATED APPLICATIONS

Application Ser. No. 230,298 and Application Ser. No. 230,299, both filed concurrently herewith.

BACKGROUND OF THE INVENTION

In the past, attempts have been made to control interstand tension in tandem rolling mills by simply comparing an actual tension signal with a desired tension signal and by varying the speed of one of the two stands with an error signal derived by comparison of the desired and actual tension signals. However, controlling interstand tension by controlling stand speed has been difficult, if not impossible. The reason for this is that the product being rolled will vary; and this variation affects the dynamics of the fixed plant of the tension loop.

SUMMARY OF THE INVENTION

In accordance with the present invention, a method and apparatus are provided for controlling the gauge of strip material issuing from a tandem rolling mill by varying tension in the strip material between any two stands in the mill through control of one of the stand's speed. Tension between any two stands of the mill can be increased by decreasing the speed of the front stand or by increasing the speed of the rear stand. While the embodiment of the invention shown herein varies tension between the last two stands with the tension regulator operating on the last stand speed, it should be understood that the tension regulator shown herein can be used on any stand to vary tension between it and either a preceding or succeeding stand. It has been found that the transfer function relating interstand tension between the last two stands to the operating speeds of the last two stands is dependent upon the cross-sectional area of the strip between the last two stands. Consequently, means are provided for compensating for this variation in the transfer function as the cross-sectional area of the strip varies, as well as the speed of the next to the last stand varies.

Specifically, the method of the invention contemplates generating an electrical signal proportional to actual tension between the last two stands, generating an electrical signal proportional to desired tension between the last two stands, comparing the actual and desired signals to derive an error signal for varying the speed of the last stand, and modifying the error signal as a function of the cross-sectional area of the strip between the last two stands and the speed of the next to the last stand to compensate for changes in the aforesaid transfer function.

The above and other objects and features of the invention will become apparent from the following detailed description taken in connection with the accompanying drawings which form a part of this specification, and in which:

FIG. 1 is an overall schematic diagram of the rolling mill gauge control system of the invention;

FIG. 2 is a block diagram of the tension regulator shown in FIG. 1; and

FIG. 3 is a schematic circuit diagram of the tension correction amplifier utilized in the system of FIG. 2.

With reference now to the drawings, and particularly to FIG. 1, a five-stand tandem rolling mill is shown including five stands S1, S2, S3, S4 and S5, only the rolls for stands S4 and S5 being shown in full lines since these are the only stands with which the tension regulating system shown herein is concerned, although the regulator of the invention can be used between any two stands. Strip material **10** to be rolled passes between the rolls of the successive stands S1–S5 and is progressively reduced in gauge while the speed of the strip material increases at the output of each stand. The rolls for each of the stands are provided with drive motors, only motors M4 and M5 being shown in FIG. **1.** Motors M4 and M5 are controlled by speed regulators SR4 and SR5, respectively, which receive a master speed reference signal on lead **12** from a master mill speed controller, not shown.

The gauge of the strip material issuing from the last stand S5 is measured by an X-ray gauge **14** or the like which produces a signal on lead **16** proportional to actual gauge. The signal from X-ray gauge **14** is compared at summing point **18** with a gauge reference signal on lead **20** determined by the operator of the mill, or possibly by a computer, this gauge reference signal being proportional to the desired output gauge. If the desired output gauge signal on lead **20** is not equal to the actual gauge signal on lead **16,** an error signal is developed which is applied to an automatic gauge control circuit **22,** the details of which may be had by reference to copending application Ser. No. 230,299, filed concurrently herewith and assigned to the Assignee of the present application.

Also applied to the automatic gauge control circuit **22** is a signal derived from a tachometer or pulse generator **23.** This signal is proportional to the circumferential speed of the last stand S5 and, hence, the speed of the strip material issuing from the mill. The output signal from the automatic gauge control circuit **22** is then summed at summing point **24** with a tension references signal on lead **26** and with an actual tension signal on lead **28** derived from a tensiometer **30** in engagement with the strip material **10** between the last stands S4 and S5. The signal from the gauge control circuit **22** and the tension reference signal **26** are summed and compared in subtractive relationship at point **24** with the actual tension signal from tensiometer **30.** The resulting signal is then applied as an error signal to the tension regulator **32** of the present invention.

As was explained above, it is necessary in accordance with the present invention to control the gain of the tension regulator **32** as a function of the cross-sectional area of the strip material being rolled. Accordingly, means must be provided for determining the cross-sectional area of the strip material **10** between the last two stands. In the embodiment of the invention shown in FIG. **1,** the gauge of the strip material between stands S1 and S2 is measured by X-ray gauge **34** and applied to circuit **36** along with signals from tachometer generators or pulse generators **38** and **40.** Tachometer generator **38** is connected to the rolls of stand S1 and hence, produces an output signal proportional to the speed of stand S1; whereas tachometer generator **40** is connected to the rolls of stand S4 and produces an output signal proportional to the speed of stand S4. X-ray gauge **34,** of course, produces a signal proportional to the thickness of the strip material between the first and second stands.

It is known that the width of the strip material being rolled does not vary materially in passing from one stand to the next. Furthermore, it is known in accordance with the constant volume principle that the volume of material entering the bite of the rolls of a rolling mill is equal to the volume of material leaving. That is,

$$G_1V_1W = G_2V_2W$$

where:

G_1 and G_2 = the gauges of the strip material entering and leaving the second stand S2;

V_1 and V_2 = the velocities of the strip material entering and leaving the second stand S2; and

W = the width of the strip material.

Consequently, by knowing the gauge of the strip material between the first and second stands, the speed of the first stand, and the speed of the fourth stand, the area A_4 of the strip material between the fourth and fifth stands S4 and S5 can be determined from the equation:

$$A_4 = W(G_1V_1/V_4)$$

Circuit **36**, therefore, performs this computation and derives a signal on lead **42** proportional to $A_4$the area of the strip material between stands S4 and S5. This signal on lead **42** is applied to the tension regulator **32** of the present invention as shown in FIG. **1**.

An analysis made of the cold mill shown in FIG. **1** results in a linear transfer function relating interstand tension in pounds between stands S4 and S5 to the operating speeds of these two stands. This linear transfer function can be expressed as follows:

$$T = [(AE'/V_4)/1 + [(L/V_4)\ (E'/E)]\ S]\ (V_5 - V_4) \qquad (1)$$

where:

T = interstand tension in pounds;

L = distance between stands S4 and S5 in feet;

A = strip cross-sectional area between stands S4 and S5 in square inches;

V_4 = stand S4 speed in feet per second;

V_5 = stand S5 speed in feet per second;

E = strip modulus of elasticity in pounds per square inch (30,000 for steel);

E' = apparent modulus of elasticity in pounds per square inch; and

S = Laplace operator, 1/sec.

From Equation (1) given above, it can be observed that the tension loop dynamics parameters which vary with product being rolled are strip cross-sectional area A between the two stands in question, and also the strip velocity between these two stands, V_4. The apparent modulus of elasticity E' will also vary somewhat between the different types of steel being rolled and the amount of reduction is taken in stand S5; but it has been found that the variation in E' is small and can be neglected on steel mill applications. On the other hand, it may have to be considered for other metals, such as aluminum, where this can be a factor.

The tension regulator **32** controls the interstand tension between stands S4 and S5 by controlling stand S5 speed as shown in the block diagram of FIG. **1**. However, it is important that the dynamics of stand S5 speed do not change throughout the operating speed range. In this connection, and in accordance with the present invention, the tension error signal from summing point **24** is caused to pass through circuitry having a transfer function which is the inverse of that given by Equation (1) above, whereby the gain of the loop will not be altered for changes in strip cross-sectional area and mill speed.

This circuitry is shown in block diagram form in FIG. **2** where the tension regulator **32** is enclosed by broken lines and includes a tension correction amplifier **46** and an area compensation circuit **48**, comprising a divider. As can be seen from FIG. **2**, the transfer function of the tension correction amplifier **46** is the inverse of that given by Equation (1) above, neglecting the cross-sectional area A. Thus, circuit **46** has a transfer function:

$$K_x\ [1 + [(L/V_4)\ (E'/E)]\ S/(E/V_4)\ S] \qquad (2)$$

where:

K_x is an adjustable gain which determines the crossover frequency or loop gain of the tension loop.

Consequently, it can be seen that after passing through the tension correction amplifier **46** and after having been divided by the Area A_4 in area compensation circuit **48**, the variation in loop gain due to the transfer function given by Equation (1) above is compensated for at all speeds and cross-sectional areas.

An examination of Equation (2) given above shows that the integral gain of the tension correction amplifier **46** must vary proportionally to stand speed V_4 and inversely proportional to strip apparent modulus of elasticity E'. The apparent modulus of elasticity of steel E' varies with steel composition and stand S5 reduction. Hence, it will have to be incorporated into the amplifier **46** as a gain change via a potentiometer initiated by the mill operator or digital computer. This can be accomplished by a potentiometer in cascade with the integral part of the tension correction amplifier; however, the potentiometer is not shown herein since it is usually not required. The proportional gain is a function of the distance L between stands S4 and S5 and the steel modulus of elasticity, which does not vary.

The details of the tension correction amplifier **46** are shown in FIG. **3**. It will be noted that it includes two signal channels **50** and **52**, both connected through potentiometers **54** and **56**, respectively, to the tension error signal at summing point **24**. Channel **52** includes an integrating operational amplifier **58** having a feedback path including capacitor **60**. Channel **52** includes a proportional operational amplifier **62** having a resistor **64** in its feedback path. The output of integrating operational amplifier **58** in channel **50** is applied to multiplier **66** along with the signal V_4 proportional to stand S4 speed. The output signal from multiplier **66** is applied through resistor **68** to summing point **70**. Similarly, the output of operational amplifier **62** is applied through resistor **72** to the summing point **70**; while a movable tap on potentiometer **74**, connected between the output of amplifier **58** and ground, is connected through resistor **76** to summing point **70**. The summing point **70** is then connected to the input of proportional operational amplifier **78** having a resistor **80** in its feedback path.

The channel **52** is necessary since it will be observed from Equation (2) given above that the integral gain of the tension controller integral amplifier **58** disappears at low speeds (e.g., threading speeds) since stand S4 speed V_4 is very small at this time. This means that the tension loop response at low speeds must be adjusted by varying the gain B of the proportional amplifier **62** via potentiometer **56**. This low speed adjustment fixes the gain of the proportional amplifier **62** in channel **52**, leaving the high speed gain to be adjusted by varying the gain α of the integral operational amplifier **58** via potentiometer **54** to obtain the desired tension response at mill speeds. Because of the inaccuracy of the static multiplier **66** used at low voltage operation (i.e., low mill speeds), some permanent integral gain by potentiometer **74** is also used in the tension loop. This gives better tension loop response to mill disturbances during rolling operations. The permanent integral gain set by potentiometer **74**, however, is very small.

If it is assumed that the resistance of resistor **82** connecting potentiometer **54** to amplifier **58** is R_1; that the resistance of resistor **84** connecting potentiometer **56** to amplifier **62** is R_2; that the resistance of resistor **64** is R_3 and that the capacitance of capacitor **60** is C_1, it can be shown that the transfer function of the circuit of FIG. **3** is:

$$\alpha[1 + (B/\alpha)\ (R_3R_1C_1/R_2V_4)\ S/(R_1C_1/V_4)\ S] \quad (3)$$

which is the necessary transfer function as explained above. Thereafter, by dividing the output of amplifier **46** and area compensation circuit **48** by the area A_4, the inverse of the transfer function given in Equation (1) is derived.

While the cross-sectional area A_4 is shown herein as being derived in circuit **36**, it should be understood that it can be derived in other ways. That is, if the tension reference is programmed to have a constant strip tension in pounds per square inch, the tension reference signal is a representation of schedule cross-sectional are and the loop gain can be divided by tension reference to compensate for cross-sectional area variation. If the variation of strip tension in pounds with cross-sectional area is known, the cross-sectional area can be calculated by an analog computer and used. Another method is to use an analog or digital computer to calculate cross-sectional area directly. To divide the tension loop gain by cross-sectional area requires an analog divider.

Although the invention has been shown in connection with certain specific embodiments, it will be readily apparent to those skilled in the art that various changes in form and arrangement of parts may be made to suit requirements without departing from the spirit and scope of the invention.

I claim as my invention:

1. In the method for controlling the gauge of strip material issuing from a tandem rolling mill by varying tension in the strip material between two stands of the mill through control of the speed of one of said two stands and wherein the transfer function relating interstand tension between said two stands to the operating speeds of the two stands is dependent upon the cross-sectional area of the strip between the two stands and the speed of the first of said two stands in the tandem mill, the steps of:
   - generating a first electrical signal proportional to actual tension between said two stands,
   - generating a second electrical signal proportional to desired tension between said two stands,
   - generating a third electrical signal which varies as a function of the gauge of the strip material at the output of the last of said two stands in the tandem mill,

   - comparing said first, second and third signals to derive an error signal for varying the speed of one of said stands, and
   - modifying said error signal as a function of the cross-sectional area of the strip between said two stands and the speed of said first of the two stands to compensate for changes in said transfer function.

2. The method of claim **1** wherein said error signal is modified by steps including multiplying the error signal by the speed of the first of said two stands and dividing the product thus derived by the cross-sectional area of the strip material between said two stands.

3. The method of claim **1** including the step of controlling tension in the strip material between said two stands of the mill at low speed without materially modifying said error signal.

4. The method of claim **1** wherein said two stands comprise the last two stands in the tandem rolling mill, said first of the two stands comprising the next to the last stand in the tandem rolling mill.

5. In the method for controlling the gauge of strip material issuing from a tandem rolling mill by varying tension in the strip material between two stands of the mill through control of the speed of one of the two stands and wherein the transfer function relating interstand tension between said two stands to the operating speeds of said two stands is:

$$T = [(AE'/V_4)/1 + [(L/V_4)\ (E'/E)]\ S]\ (V_5 - V_4)$$

where T is interstand tension between said two stands, L is the distance between said two stands, A is the strip cross-sectional area between said two stands, V_4 is the speed of the first of said two stands in the tandem rolling mill, V_5 is the speed of the last of said two stands in the tandem rolling mill, E is the strip modulus of elasticity of the strip material, E' is the apparent modulus of elasticity, and S is the Laplace operator, the steps of:
   - generating an electrical signal proportional to actual tension between said two stands,
   - generating an electrical signal proportional to desired tension between said two stands,
   - comparing said actual and desired signals to derive an error signal for varying the speed of the last of said two stands, and
   - modifying said error signal in accordance with the transfer function:

$$K_x\ [1 + [(L/V_4)\ (E'/E)]\ S/[A(E/V_4)]\ S\ ]$$

where K_x is a constant.

6. The method of claim **5** wherein said error signal is modified in circuitry having said transfer function, and including the steps of generating electrical signals proportional to A and V_4 and applying said signals to said circuitry.

7. In apparatus for controlling the gauge of strip material issuing from a tandem rolling mill by varying tension in the strip material between two stands of the mill through control of the speed of one of said two stands and wherein the transfer function relating interstand tension between said two stands to the operating speeds of said two stands is represented by:

$$T = [(AE'/V_4)/1 + [(L/V_4)\ (E'/E)]\ S]\ (V_5 - V_4)$$

where T is the interstand tension between said two stands, L is the distance between said two stands, A is the strip cross-sectional area between said two stands, V_4 is the speed of the first of said two stands in the tandem rolling mill, V_5 is the speed of the last of said two stands in the tandem rolling mill, E is the apparent modulus of elasticity, and S is the Laplace operation, the combination of

means for generating an electrical signal proportional to actual tension between said two stands,

means for generating an electrical signal proportional to desired tension between said two stands,

means for comparing said actual and desired signals to derive an error signal for varying the speed of one of said two stands,

means for controlling the speed of said last of the two stands, and

circuitry for applying said error signal to said speed controlling means, said circuitry having the transfer function:

$$K_x [1 + [(L/V_4) (E'/E)] S/[A (E/V_4)] S]$$

where K_x is a constant.

8. The apparatus of claim **7** including means for generating an electrical signal proportional to V_4, means for generating an electrical signal proportional to A, said circuitry incroporating means for multiplying said error signal by said signal proportional to V_4, and means for dividing the product derived by multiplication by said signal proportional to A.

9. The apparatus of claim **8** wherein said means for multiplying is included in a signal channel including an integrating operational amplifier for applying said error signal to the input of said multiplying means.

10. The apparatus of claim **9** including a second channel in shunt with said first channel, the second channel including a proportional operational amplifier, the outputs of said channels being summed and applied to said means for dividing by a signal proportional to A.

11. The apparatus of claim **10** including a signal channel in shunt with said multiplying means whereby a portion of the signal at the output of said integrating operational amplifier is applied directly to said summing point.

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