Aug. 3, 1965 R. P. FREEDMAN ET AL 3,197,986

CONTROL SYSTEM FOR ROLLING MILLS

Filed Nov. 7, 1961 4 Sheets-Sheet 1

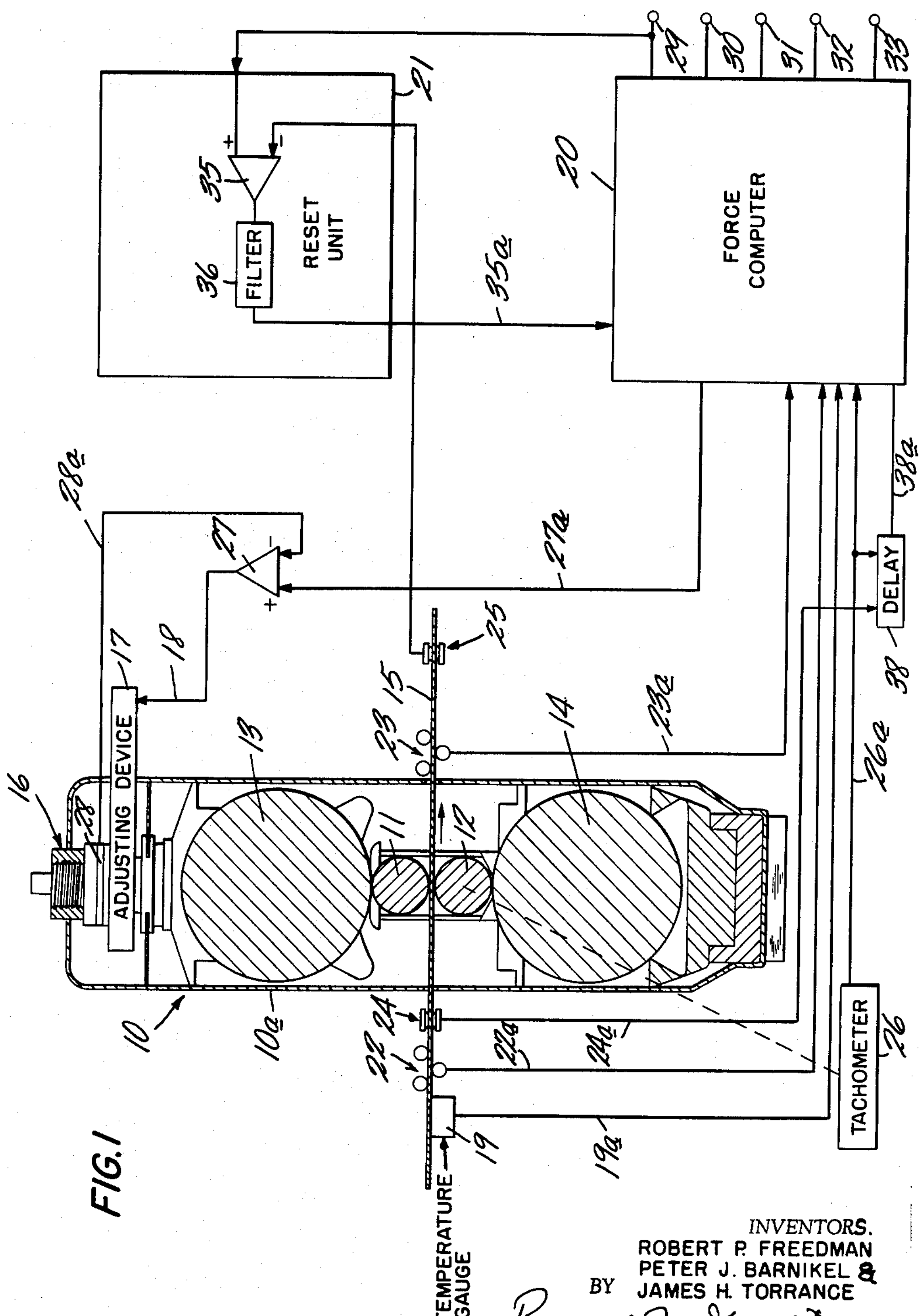

FIG. 1

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CONTROL SYSTEM FOR ROLLING MILLS

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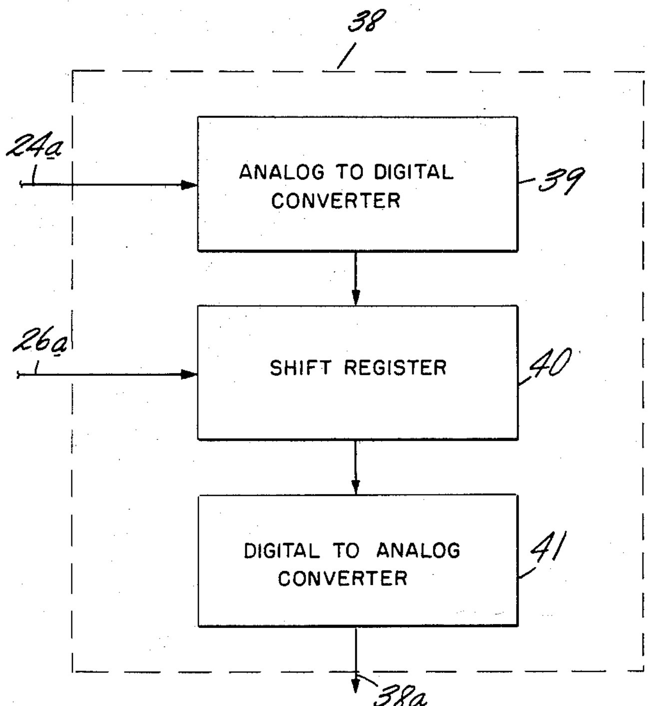
FIG. 2



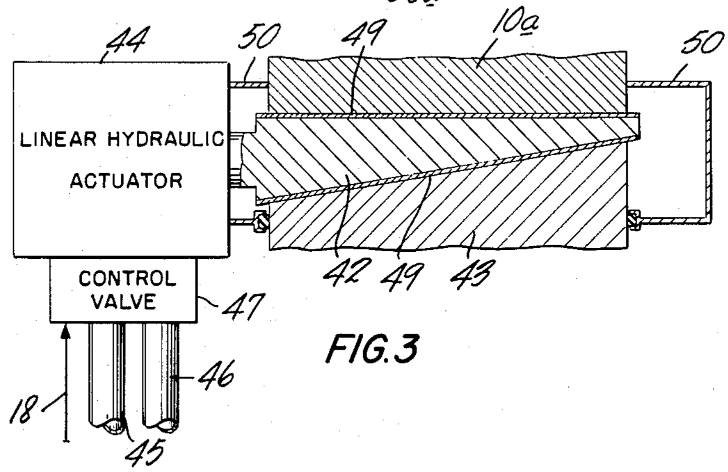


FIG. 3

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CONTROL SYSTEM FOR ROLLING MILLS

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FIG.4

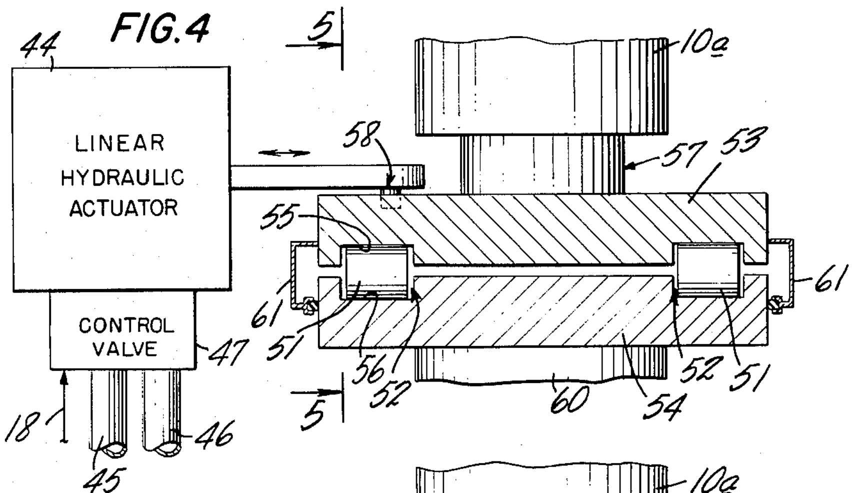


FIG.5

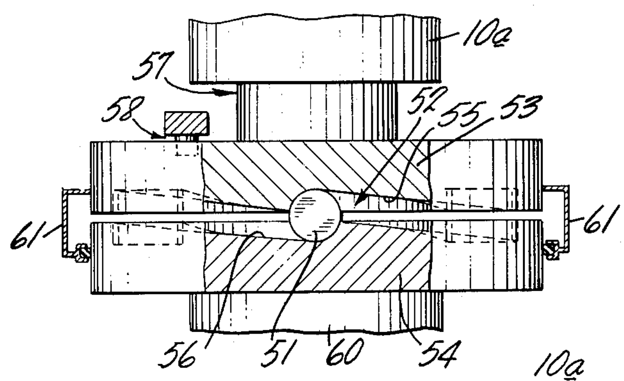
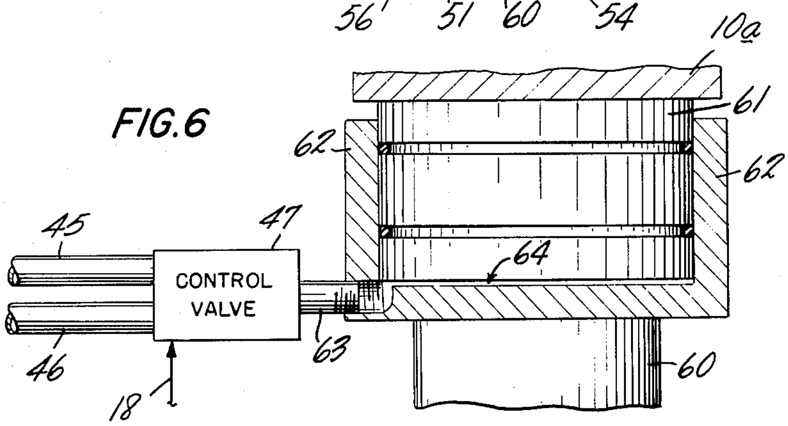


FIG.6



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CONTROL SYSTEM FOR ROLLING MILLS

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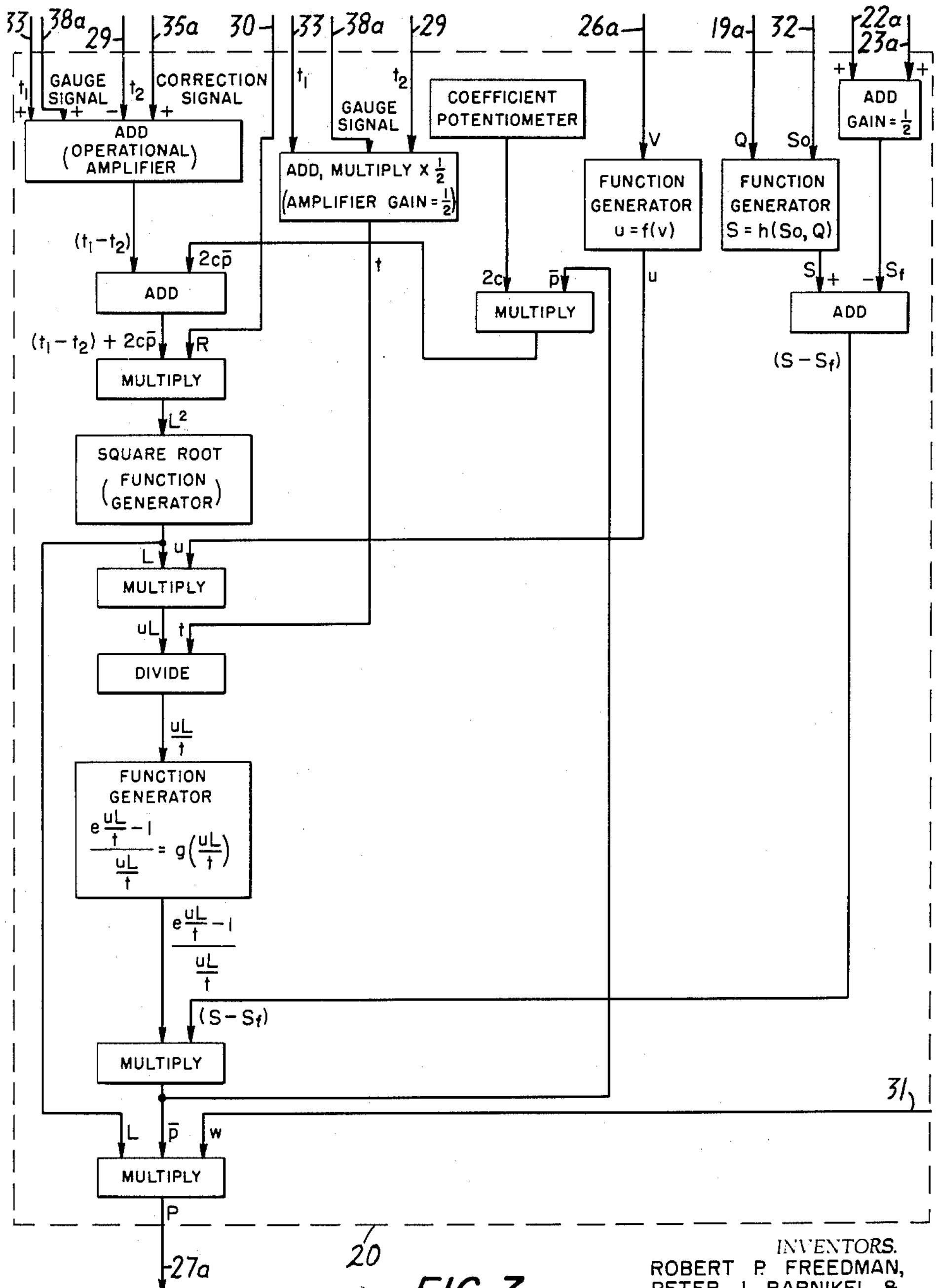

FIG. 7

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CONTROL SYSTEM FOR ROLLING MILLS

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Filed Nov. 7, 1961, Ser. No. 150,738
17 Claims. (Cl. 72—9)

This invention relates to systems for controlling the rolling of materials such as metal sheet, strip, or tube to produce material having a desired thickness and, more particularly, to a new and improved control system providing greater accuracy of the thickness of a rolled product.

Conventional systems for controlling the thickness of a material such as steel strip being processed in a rolling mill utilize a screw-down device interposed between the frame of the rolling stand and one of the backup rolls and a drive motor for rotating the screwdown device to adjust the spacing between the two working rolls of the stand. Because very high compressive forces are applied to the material through the screw-down device the frictional resistance to rotation, and particularly the starting friction of the device, is extremely high and for this reason the drive motor must be quite large. Consequently, the conventional adjusting system has a large inertia and necessarily responds relatively slowly to a control signal indicating a desired change with the result that the linear speed of the material passing through the mill must be kept relatively low if the thickness control is to be at all effective.

Moreover, in most conventional system control of the screwdown is usually based on thickness measurements made after the material has been rolled so that only long term trends are detected and compensated and no correction can be made for noncontinuous thickness variations such as welds. Even in those conventional control systems wherein a thickness measurement is made on the material before it is rolled, accurate thickness control is not possible because any adjustments which are made in advantage are based solely on the thickness measurement and do not take into account the many other variables which can affect the thickness of the rolled material. Consequently, in these systems primary reliance must be placed on the thickness measurement made on the material after it has been rolled to determine whether an indicated correction has been effected.

Accordingly, it is an object of the present invention to provide a new and improved system for controlling the thickness of the material being rolled in a rolling mill.

An additional object of the invention is to provide an adjusting device for a rolling stand which is capable of much faster response than has been possible heretofore.

A further object of the invention is to provide a new and improved control system for rolling operations capable of predicting accurately the force which must be applied to produce material having a desired thickness and making any necessary changes in the force rapidly.

These and other objects of the invention are accomplished by providing, in a rolling stand having a pair of adjacent compressing or working rolls supported in a frame, fluid-actuated rapid response adjusting means interposed between the frame of the stand and one of the rolls adapted to vary the distance between that roll and the frame of the stand so as to vary the pressure applied to a material passing between the rolls, and means for determining in advance the pressure necessary to accomplish a desired reduction in the thickness of the material and controlling the adjusting means to produce a force on the roll corresponding to the necessary pressure. In order to determine the necessary force the system includes

a detector for measuring the thickness of the material entering the stand, tension gauges for measuring the tension of the material entering and leaving the stand, and a force computer responsive to these measurements to apply a signal representing a desired force to the adjusting means. Moreover, to assure exact control of the pressure applied to the material the system preferably includes a gauge for detecting the force applied between the frame and the rolls and a device for comparing the applied force with the desired force and varying the condition of the adjusting means to eliminate any difference between them.

Preferably, to provide the fastest possible response to an indicated change in the necessary pressure the adjusting means comprises wedge means located between the stand frame and one of the working rolls and linear fluid actuating means such as a hydraulic ram connected to drive the wedge and thereby adjust the pressure. In a preferred form the wedge means includes a permanent layer of antifriction material such as "Teflon" fabric while, in another embodiment, rollers are held captive in wedge tracks or races having inclined surfaces in two adjacent members, one of which is movable relative to the other.

Further objects and advantages of the invention will be apparent from a reading of the following description in conjunction with the accompanying drawings in which:

FIG. 1 is a schematic diagram illustrating the arrangement of a typical control system according to the invention;

FIG. 2 is a block diagram showing one form of delay device suitable for use in the system shown in FIG. 1;

FIG. 3 is a partial sectional view illustrating a preferred form of adjusting device for use in the system of FIG. 1;

FIG. 4 is a sectional view illustrating another form of rapid response adjusting device;

FIG. 5 is a sectional view taken along the line **5—5** of FIG. 4 and looking in the direction of the arrows;

FIG. 6 is a partial sectional view showing another form of rapid response adjusting device; and

FIG. 7 is a schematic block diagram illustrating the arrangement and mode of operation of the force computer.

In the representative embodiment of the invention shown in FIG. 1, a generally conventional steel mill rolling stand **10**, shown partly in section, includes a pair of working rolls **11** and **12** and corresponding backup rolls **13** and **14**, the lower support roll **14** being mounted in a fixed location in the frame **10***a* of the stand and the upper support roll **13** being capable of vertical motion in the stand frame. As in conventional stands, a strip or sheet **15** of steel or the like which is to be rolled passes between the working rolls **11** and **12** and an adjustable screw-down device **16** is provided to force the upper backup roll **13** and working roll **11** toward the lower rolls so that the nominal separation between the working rolls can be set before rolling. Although the invention is described herein with reference to rolling of strip or sheet material, it will be understood that the invention is equally applicable to the rolling of other shapes such as tubes, I-bars and the like to reduce the thickness of the material, and that the rolling of any material capable of permanent deformation under pressure can be controlled according to the invention.

In accordance with the present invention, the stand **10** also includes a fluid-actuated rapid response adjusting device **17**, which is described in detail hereinafter for varying the pressure applied by the rolls promptly in accordance with a force control signal supplied through a line **27***a*. Although only one adjusting device is shown in the drawings it will be understood that this system preferably includes two such adjusting devices, one at each end of the roll, and that both of these are controlled by signals on the line 27*a*.

In order to calculate the force to be applied to the rolls to produce a given change in the thickness of the strip 15 automatically and supply a control signal to the adjusting device 17 through the line 27*a*, the control system includes a force computer 20 and a reset unit 21 which make the necessary computations in the manner described below based on information received from a temperature gauge 19, two conventional tension gauges 22 and 23 which measure the tension of the strip entering and leaving the stand, respectively, and two thickness gauges 24 and 25 positioned to measure the thickness of the incoming and outgoing portions of the strip, respectively, each of the latter being, for example, a beta or X-ray gauge of any well-known type. Also a tachometer 26 is connected to one of the rolls or strip 15 to detect the velocity of the strip 15 passing through the stand.

The force computer 20, illustrated schematically in FIG. 7, is arranged in any well-known manner to calculate the amount of force which must be applied between the working rolls 11 and 12 to produce a pressure on the strip which will reduce the strip thickness from that entering the stand to the desired thickness. These calculations are based on the following equations:

$$R'=R\left(1+\frac{2c\bar{P}}{t_1-t_2}\right) \tag{1}$$

and

$$P=(S_0-S_f)wL\frac{(e^{\frac{uL}{t}}-1)}{\frac{uL}{t}} \tag{2}$$

and the following relations involving the variables therein:

$$L^2=(t_1-t_2)R' \tag{3}$$

and

$$u=f(v) \tag{4}$$

where:

R=radius of work roll
R'=flattened radius of work roll
c=constant
$\bar{P}$=average pressure under contact
S_0=constrained yield stress
S_f=average of tensions in incoming and outgoing portions of the strip
w=width of strip
L=length of contact of work roll with strip
u=coefficient of friction

$$t=\frac{t_1+t_2}{2}$$

where

t_1=thickness before rolling
t_2=thickness after rolling
P=force necessary to obtain desired reduction in thickness
e=base of natural logarithms

Equation 1 has been taken from the article "Theory of Rolling" by Ford in Metallurgic Reviews, vol. 2, No. 1, p. 1 (1957) while Equation 2 is derived by Stone in the article "The Rolling of Thin Strip" in the Iron and Steel Engineer Yearbook, 1953, p. 115. Part II of the latter article appears at page 981 of the 1956 Iron and Steel Engineer Yearbook. By solving these two equations simultaneously, the iteration process, which would be necessary if Equation 2 were used by itself, is avoided. Relation 3 and the manner of determining the function "*f*" of Relation 4 for a particular set of conditions also appear in the 1953 Stone article at page 118.

In order to supply the information necessary for the solution of these equations to the computer 20, the strip temperature is transmitted from the gauge 19 through the line 19*a* to determine S_o, the two tension gauges 22 and 23 provide tension data to determine S_f to the computer through two corresponding lines 22*a* and 23*a*, and the incoming thickness gauge 24 and the tachometer 26 transmit information to a delay device 38 through lines 24*a* and 26*a*, the delay device being connected to the computer by the line 38*a*. For cold rolling operations a temperature gauge 19 may be omitted since S_o will then be constant for the particular material being rolled. The output signal from the computer representing the force necessary to produce a desired reduction in thickness is transmitted to a difference amplifier 27 through a line 27*a* for comparison with the actual force applied between the stand and the working roll which is detected by a conventional force gauge 28 and represented by a signal on a line 28*a*. One type of gauge suitable for this purpose is the ASEA "Presductor" force transducer. The closed loop control thus provided assures that the actual pressing force in the stand is at all times equal to the necesary force as determined by the computer despite the existence of uncontrollable factors which may affect the force, such as eccentricity of the backup and working rolls, for example.

To complete the information necessary to solve Equations 1 and 2, five input terminals 29, 30, 31, 32, and 33 are connected to the computer so that an operator can enter those factors which do not change during the rolling operation. One of these input terminals indicated by the numeral 29, receives a signal corresponding to the desired strip thickness after rolling (t_2) while the signals applied to the other terminals correspond to the work roll radius (R), the strip width (W), the constrained yield stress (S_o) of the material being rolled at a given temperature, and the nominal thickness of the incoming strip (t_1). In hot rolling, the yield stress is a function of the material being rolled and its temperature, for non-ferrous as well as ferrous metals. Larke, in The Rolling of Strip, Sheet and Plate; (Chapman & Hall Limited, London, England, 1957). FIGURE 9.21 shows the variation of yield stress, or resistance to deformation as a function of temperature. As previously mentioned, the value of (S_f) is determined by taking the average of the outgoing and incoming tensions, as indicated by the gauges 23 and 22, and it should be readily apparent that if the stand 10 is the first of the series and a strip with no tension is supplied to the stand, the gauge 22 can be omitted since the tension of the outgoing strip is then equal to ($2S_f$).

Inasmuch as the computer may be of either the analog or the digital type and the specific arrangement of the computer will be readily apparent to those skilled in the art from a consideration of the following calculations which are to be made, a description of the structure and operation of a specific computer is unnecessary and it will be sufficient to describe the mathematical steps to be performed which are illustrated in the diagram of FIG. 7.

First, the flattened radius R′ of the work roll is calculated from Equation 1, the constant *c* being built into the computer and having a value dependent on the material of which the working rolls are made. Then, from the equation $L^2=(t_1-t_2)R'$, the length of contact L of the roll with the strip can be determined. The coefficient of friction *u* is a known function *f* of the velocity *v* of the strip, as determined by the tachometer 26, so that it can be calculated from the equation $u=f(v)$, the particular function "*f*" being determined in the manner set forth in the 1953 Stone article.

The next step is to form

$$\frac{uL}{t}$$

and then calculate the value of

$$\frac{e^{\frac{uL}{t}}-1}{\frac{uL}{t}}$$

This expression is multiplied by the difference between the constrained yield stress S_o and the average tension S_f

to obtain the average pressure in the strip under contact with the rolls $\overline{P}$ which will cause the desired reduction in thickness. Finally, the force P necessary to produce this pressure and thereby obtain the desired reduction in thickness is obtained by solving the equation $P=w\ L\ \overline{P}$.

As previously mentioned, the computer output signal representing the necessary force is transmitted by a line **27a** to the difference amplifier **27** for comparison with the actual force, as measured by the gauge **28**. Any deviation of the actual force from the computed force detected in this manner actuates the rapid response adjusting device **17** to equalize the actual force with the desired force, thereby assuring that the proper pressure is applied to the strip **15** of material at all times without any delay in response to variations in the actual incoming and outgoing thickness and tension.

In this regard, the computer also includes a conventional device (not shown) for comparing the actual incoming strip thickness as measured by the gauge **24** with the nominal thickness represented by the signal at the input terminal **29** and making an appropriate correction for any difference between them in the output signal representing the required force. It will be apparent that, if desired, the computer **20** may be set to overcompensate for relatively large indicated thickness reductions, thus reducing the tendency of variations in thickness to "grow back" in subsequent rolling stands because of the increased hardness of the material caused by the larger reduction in thickness. Inasmuch as the gauge **24** is located a few feet in front of the work rolls, a time delay dependent upon the velocity of the strip is introduced by the delay device **38** into the signal supplied by this gauge so that any necessary correction in applied force will take place at the time the thickness irregularity passes between the rolls.

In order to control the application of force in the stand into the strip **15** at exactly the right time to correct a thickness variation measured by the gauge **24**, the delay device **38** must be highly accurate. One form of suitable delay device is shown in FIG. 2 wherein the thickness information from the line **24a** is converted from analog to digital form by an analog to digital converter **39**. Digital information from this unit is carried through a shift register **40** comprising a plurality of information storage units, the number of which correspond to the distance between the gauge **24** and the line between the centers of the working rolls **11** and **12**. The rate of transfer of the information through the shift register is controlled according to the velocity of the rolls **11** and **12**, as measured by the tachometer and indicated on the line **26a**, the response time of the system being taken into account, and the delayed information is then reconverted to analog form, if necessary, by a converter **41** for transmission to the computer on the line **38a**.

To monitor the operation of the system, the output thickness, as measured by the gauge **25**, is supplied through a line **25a** to a difference amplifier **35** in the reset unit **21** where it is compared with the desired output thickness, as represented at the terminal **29**, and an error signal is transmitted to the computer on a line **35a** to correct the computation of the required force. It will be readily apparent that the reset unit error signal is effective to compensate for any and all types of inaccuracies in the computer, the tension gauges, the incoming thickness gauge, the tachometer, and the force gauge, as well as any inaccuracies in the signals applied to the terminals **30–33**. Preferably, a filter **36** is included in the line **35a** to smooth out rapid changes in the error signals so that the reset unit provides relatively long term correction of the force signal.

In operation, with the strip **15** being drawn between the working rolls **11** and **12** signals representing the desired thickness and the nonvariable factors are applied to the input terminals **29–33**. Based on this information and the data supplied by a temperature gauge **19**, the tension gauges **22** and **23**, the input thickness gauge **24**, and the tachometer **26**, the computer determines the force required to reduce the thickness of the strip to the desired value in the manner described above and transmits a signal representing this force to the difference amplifier **27**. To correct for deflections in the stand and other unknown factors which may influence the thickness reduction of the strip, the actual force in the stand is, as previously mentioned, detected by the gauge **28** and compared with the desired force and a control signal on the line **18** is transmitted to the adjusting device **17**. Also, the actual outgoing strip thickness is detected by the gauge **25** and compared with the desired output thickness in the reset unit **21** to produce an error signal which revises the force calculation in the computer **20**.

In the preferred form of fluid actuated rapid response adjusting device **17**, which is of the type described and claimed in the copending application of Peter J. Barnikel and Robert P. Freedman, Serial No. 182,062, filed March 23, 1962, for "Actuating Device" and is illustrated in FIG. 3, a tapered wedge **42** is interposed between the frame **10a** of the stand and a support block **43** for the upper backup roll. This wedge is connected to a linear hydraulic actuator **44** which may comprise, for example, a hydraulic ram receiving hydraulic fluid under pressure from two conduits **45** and **46** through a conventional electrohydraulic servo control valve **47** arranged to regulate the position of the linear hydraulic actuator **44** in accordance with the control signal received from the line **18**.

In order to facilitate sliding of the wedge **42** between the frame **10a** and the backup roll support **43**, a permanent layer **49** of antifriction material is mounted on each of the working surfaces of the wedge. The best material presently known for this purpose is a fabric made of fibers of "Teflon" interwoven with fibers of cotton or glass or other bondable material. This fabric is preferably made so that only the "Teflon" fibers appear at the outer surfaces and the cotton fibers are adjacent to the body of the wedge and are bonded thereto by a conventional adhesive such as a phenolformaldehyde resin, thereby holding the fabric in place on the wedge surface. Another advantage of this fabric arrangement is that the greater tensile strength of "Teflon" fibers as compared with "Teflon" resin is utilized, the latter material being subject to cold flow under high loads.

Because of the very low coefficients of standing and sliding friction obtained at high loads with this arrangement and also by reason of the relatively low mass necessary for the hydraulic ram and the wedge, as compared with that of a screw-down device and drive motor, the wedge can be accelerated rapidly in either direction without requiring excessive hydraulic flow rates even when the strip **15** is under extremely high pressure. For example, with a total load force of two million pounds acting on a bearing area of about two hundred square inches so as to produce a compressive stress on the wedge of about 10,000 p.s.i., a wedge having a taper of 0.060 inch per inch can be accelerated at a rate of about five inches per second per second by a ram supplied with hydraulic fluid at a pressure of 3,300 p.s.i. and a flow rate of approximately 29 gallons per minute. This acceleration is sufficient to move one of the working rolls a distance 0.010 inch from a standing condition in one-quarter of a second. Consequently, it will be readily apparent that the thickness control system of the present invention can respond promptly to correct substantially all variations in the thickness of the incoming strip **15** including discontinuities such as welds, whereas the slow response of conventional screw-down devices prevents correction of many of these variations even if the thickness of the incoming strip is measured in advance, resulting in a considerable proportion of off-gauge material in the rolled strip. Moreover, the frequency response of this adjusting device is very high, approximately one cycle per second, thereby permitting variations in the working roll separation rapid enough to correct for eccentricities in the working roll which, otherwise would produce a wavy pattern in the rolled material.

While the preferred form of adjusting device utilizes the "Teflon" surfaced wedge shown in FIG. 3 because it provides the most rapid response for a given set of hydraulic ram requirements, other forms of rapid response adjusting devices may also be used with the control system of the invention if a hydraulic actuator of increased capacity is provided. In the embodiments shown in FIGS. 4 and 5, for example, a wedge system comprising a series of rolling members movable on adjacent inclined planes is illustrated. In this case, a plurality of hardened rollers **51** is held captive in a corresponding plurality of races **52** formed in two adjacent relatively rotatable cage members **53** and **54**, the bearing surfaces **55** and **56** of the races being inclined with respect to the plane of relative motion of the members. The upper cage member **53** is rotatably connected to the frame **10***a* of the stand, preferably through a bearing **57**, and is linked to the linear hydraulic actuator **44** through a peripheral pivotable attachment **58**, while the lower case member **54** is affixed to a support block **60** for the upper backup roll **13**. As in the previously described embodiment, this wedge arrangement may be enclosed in a housing **61** which is filled with a liquid lubricant to further reduce the frictional resistance of the system.

A different form of adjusting device which does not include any wedge arrangement is shown in FIG. 6 wherein a piston **61**, affixed to the stand frame **10***a*, is slidably received in a cylinder **62** mounted on the support member **60** for the upper back-up roll. Hydraulic fluid from the control valve **47** is supplied to or withdrawn from a chamber **64** located between the piston and cylinder through a conduit **63**, in response to signals on the line **18** calling for a change in the working roll separation. If desired, a separate bleed line may be provided in the cylinder **62** to withdraw hydraulic fluid from the chamber **64**.

It will be readily apparent from the foregoing that the control system of the present invention responds with greater rapidity to correct thickness variations than has been possible with other control systems, while at the same time producing at high speed a strip having a closely regulated thickness. In a particular instance, it is possible by utilizing the present control system to maintain the thickness of a rolled strip within the range of accuracy of presently available measuring devices.

Although the invention has been described herein with reference to specific embodiments many modifications and variations therein will readily occur to those skilled in the art. If desired, for example, the position of the movable member in the adjusting device **17** may be detected and the screw-down device **16** automatically controlled in accordance therewith so that the adjusting device is normally maintained at the center of its range of operation. Moreover, where the entire range of desired adjustment of the stand is within the range provided by the adjusting device, the screw-down device **16** may be omitted. Accordingly, all such variations and modifications are included within the intended scope of the invention as defined by the following claims.

We claim:

1. Control apparatus for a rolling mill wherein a piece of material is passed between a pair of working rolls supported in a frame to reduce its thickness to a desired value comprising fluid-actuated rapid response adjusting means interposed between the frame and one of the working rolls to vary the separation of the rolls in response to a control signal, and means operatively positioned in advance of the pair of working rolls for determining the force necessary to accomplish a desired reduction in the thickness of the piece and transmitting to the adjusting means a control signal to actuate the adjusting means to produce the necessary force at the time the piece passes between the working rolls.

2. Control apparatus according to claim **1** including force gauge means interposed between the frame and the working rolls for detecting the force applied to the working rolls, comparing means responsive to the force gauge means and the means for determining the necessary force for comparing the detected force with the necessary force and modifying the control signal in accordance with any difference between them.

3. Control apparatus according to claim **1** wherein the means for determining the necessary force comprises thickness gauge means for detecting the thickness of the piece of material as it enters the stand, tension gauge means for detecting the tension in the piece of material, and computer means responsive to the thickness and tension gauges to solve a function of the necessary force in terms of the thickness and tension of the piece.

4. Control apparatus according to claim **3** wherein the means for determining the force necessary to accomplish a desired reduction in thickness includes tachometer means for measuring the velocity of the piece through the stand, and delay means responsive to the thickness gauge means and the teachometer means for delaying the transmission of thickness information to the computer means so that the resulting actuation of the adjusting means takes place at the time the detected thickness of the piece of material passes between the working rolls.

5. Control apparatus according to claim **3** including output thickness gauge means for measuring the actual thickness of the piece of material after rolling and reset means for comparing the actual thickness with a desired thickness and transmitting an error signal to the computer means.

6. Control appaartus according to claim **5** including filter means in the reset means to smooth out rapid variations in the error signal so that the corrections made by the computer as a result of the error signal are relatively long term corrections.

7. Control apparatus according to claim **3** wherein the computer means includes means for solving simultaneously two different functions of the necessary force in terms of the thickness of the piece of material.

8. Control apparatus according to claim **1** wherein the adjusting means comprises wedge means interposed between the frame and the working roll and hydraulic drive means for driving the wedge means to vary the distance between the frame and the roll in response to a control signal.

9. Control apparatus according to claim **8** wherein the wedge means comprises a wedge-shaped member and including means forming surfaces cooperating with the surfaces of the wedge means and a permanent layer of antifriction material affixed to at least one of the cooperating surfaces.

10. Control apparatus according to claim **9** wherein the antifriction material comprises "Teflon" fabric.

11. Control apparatus according to claim **8** wherein the wedge means comprises a pair of relatively rotatable adjacent members formed with a plurality of races having inclined surfaces, and rolling means positioned within each of the races.

12. Control apparatus according to claim **1** wherein the adjusting means comprises hydraulic piston and cylinder means interposed between the frame and one of the working rolls and control valve means connected to a source of hydraulic fluid under pressure and responsive to the control signal to supply hydraulic fluid under pressure to the piston and cylinder means.

13. In control apparatus for a rolling mill wherein a piece of material is passed between a pair of working rolls supported in a frame to reduce its thickness to a desired value in accordance with a force applied between the frame and the working rolls, rapid response adjusting means for varying the force comprising wedge means interposed between the frame and one of the rolls, fluid actuated linear drive means for driving the wedge means, and control valve means for controlling the application of fluid to the linear drive means in response to a control signal representing a desired force.

14. Control apparatus according to claim **13** wherein the wedge means comprises a wedge-shaped member having relatively inclined surfaces interposed between the frame and one of the working rolls, means forming corresponding surfaces for cooperation with the wedge means for varying the force applied to the rolls in response to motion of the wedge-shaped member, and a permanent layer of antifriction material affixed to at least one of the surfaces.

15. Control apparatus according to claim **14** wherein the antifriction material is a fabric made of "Teflon" fibers.

16. Control apparatus according to claim **13** wherein the wedge means comprises a pair of relatively rotatable adjacent members formed with a plurality of races having inclined surfaces, and rolling means positioned within each of the races.

17. Control apparatus for a rolling stand wherein a piece of material is passed between a pair of working rolls supported in a frame to reduce its thickness to a desired value comprising a wedge-shaped member having relatively inclined surfaces supported for sliding motion between the stand frame and one of the working rolls, means forming corresponding surfaces for cooperation with the wedge means to vary the separation of the rolls in response to motion of the wedge-shaped member, a permanent coating of antifriction material on at least one of the surfaces, hydraulic ram means connected to a wedge-shaped member to drive it in response to a control signal, gauge means in the stand for detecting the force applied to the working rolls, comparing means for comparing the detected force with a desired force and modifying the control signal in accordance with any difference between them, thickness gauge means for measuring the thickness of the piece before rolling, computer means responsive to the thickness gauge means for determining the force required to produce a desired reduction in the thickness of the piece to the stand and providing a control signal to the comparing means, a control valve means for the hydraulic ram means responsive to a control signal from the comparing means for controlling the ram means to drive the wedge-shaped member in the direction to reduce the difference between the detected force and the desired force, output thickness gauge means for measuring the thickness of the piece after rolling, and reset means for comparing the rolled thickness with the desired thickness and transmitting an error signal to the computer means.

References Cited by the Examiner

UNITED STATES PATENTS

1,092,084	3/14	Stuting	80—56.3
2,040,755	5/36	Meyer	80—56.3
2,525,687	10/50	Kritscher	80—56
2,575,590	11/51	Goulding	18—2
2,998,397	8/61	Riesing	252—12
3,015,974	1/62	Orbom et al.	80—56.1

FOREIGN PATENTS

508,186	1/52	Belgium.

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