Fig. 2

ANALOG TO DIGITAL CONVERTER

SHIFT REGISTER

DIGITAL TO ANALOG CONVERTER

Fig. 3

LINEAR HYDRAULIC ACTUATOR

CONTROL VALVE
This invention relates to systems for controlling the rolling of materials such as metal sheet, strip, or foil 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 include 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 screw-down 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 a mill must be kept relatively low if the thickness control is to be at all effective.

Moreover, in most conventional control systems of the screw-down 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 advance 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 maintaining the desired thickness even if the control system has been heretofore inadvertent. 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 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 "Tufon" 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 16 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 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 response with a force control signal supplied through a line 27a. Although only one adjusting device is shown in the drawings it will be understood that this system prefer-
ably includes two such adjusting devices, one at each end of the roll, and that both of these are controlled by signals on the line 27α.

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 27α, 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:

\[ R^* = R \left(1 + \frac{2cP}{\Delta t - \Delta t_0}\right) \]  
\[ P = \left(S_o - S_i\right)wL(e^{\frac{\Delta t}{t}} - 1) \]

and the following relations involving the variables therein:

\[ L^2 = (t_1 - t_2)R^* \]
\[ w = f(v) \]

where:

\( R \) = radius of work roll
\( R^* \) = flattened radius of work roll
\( c \) = constant
\( P \) = average pressure under contact
\( S_o \) = constrained yield stress
\( S_i \) = 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

\( t_1 = t + \frac{t_2}{2} \)

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 19α to determine \( S_o \), the two tension gauges 22 and 23 provide tension data to determine \( S_i \) to the computer through two corresponding lines 22α and 23α, and the incoming thickness gauge 24 and the tachometer 26 transmit information to a delay device 35 through lines 24α and 26α, the delay device being connected to the computer by the line 35α. 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 27α 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 28α.

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 necessary 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 into 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 \( t_0 \) 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 \( t_0 \). 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 \( S_o \) is determined by taking the average of the outgoing and incoming tensions, as indicated by the gauges 22 and 23, 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 \( 2S_o \).

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 \( f \) 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 \( w = f(v) \), the particular function “f’ being determined in the manner set forth in the 1953 Stone article.

The next step is to form

\[ \frac{uL}{w} \]  
\[ \frac{uL}{w} \quad e^{\frac{\Delta t}{t}} - 1 \]

and then calculate the value

\[ \frac{uL}{w} \]  
\[ \frac{uL}{w} \]

This expression is multiplied by the difference between the constrained yield stress \( S_o \) and the average tension \( S_i \).
to obtain the average pressure in the strip under contact with the rolls $P$ 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 $P = \frac{N}{x}$, where $P$ is the desired force, $N$ is the load on the rolls, and $x$ is the thickness of the strip.

Previously mentioned, the computer output signal representing the necessary force is transmitted by a line 27 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. It is thereby ensured 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 thin 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 force 15, it is necessary to convert 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 by 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 32a 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 29-33. Preferably, a filter 43 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 input parameters 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 24 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 18 of the stand and a support block 43 for the upper backup roll. This wedge is connected to a linear hydraulic actuator 44 which, 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 18 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 are in contact with 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" 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, that is, 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 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 3,600 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 substantial variation 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. Consequently, 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. 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 10a 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 cage 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 10a, 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 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 1 wherein the means for determining the necessary force includes fachometer means for measuring the velocity of the piece through the stand, and delay means responsive to the thickness gauge means and the telemeter 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 apparatus 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.

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