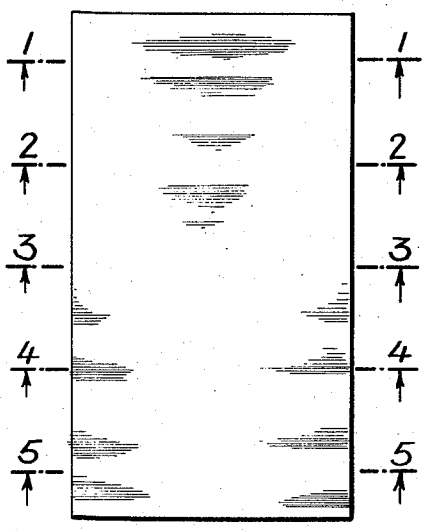
Sept. 15, 1959 R. M. REICHL 2,903,926

METHOD AND APPARATUS FOR CONTROLLING THE CONTOUR OF ROLLS IN A ROLLING MILL

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Fig. 6.



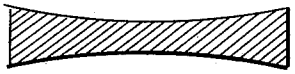



Fig. 1

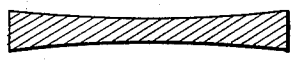


Fig. 2



Fig. 3



Fig. 4.



Fig. 5.

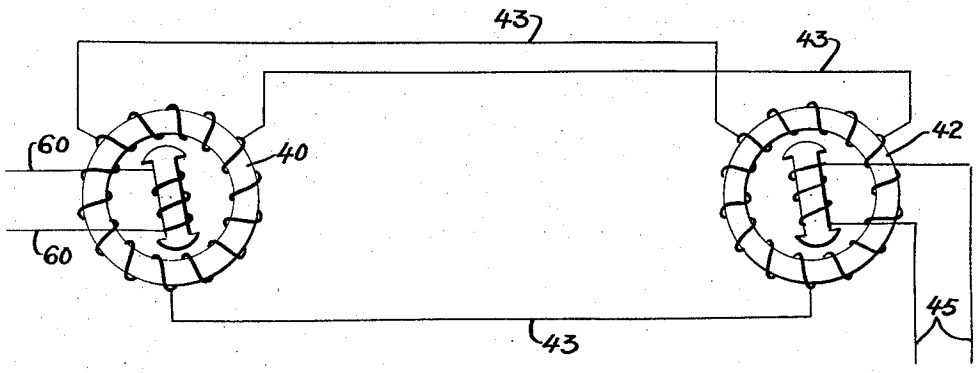



Fig. 9.

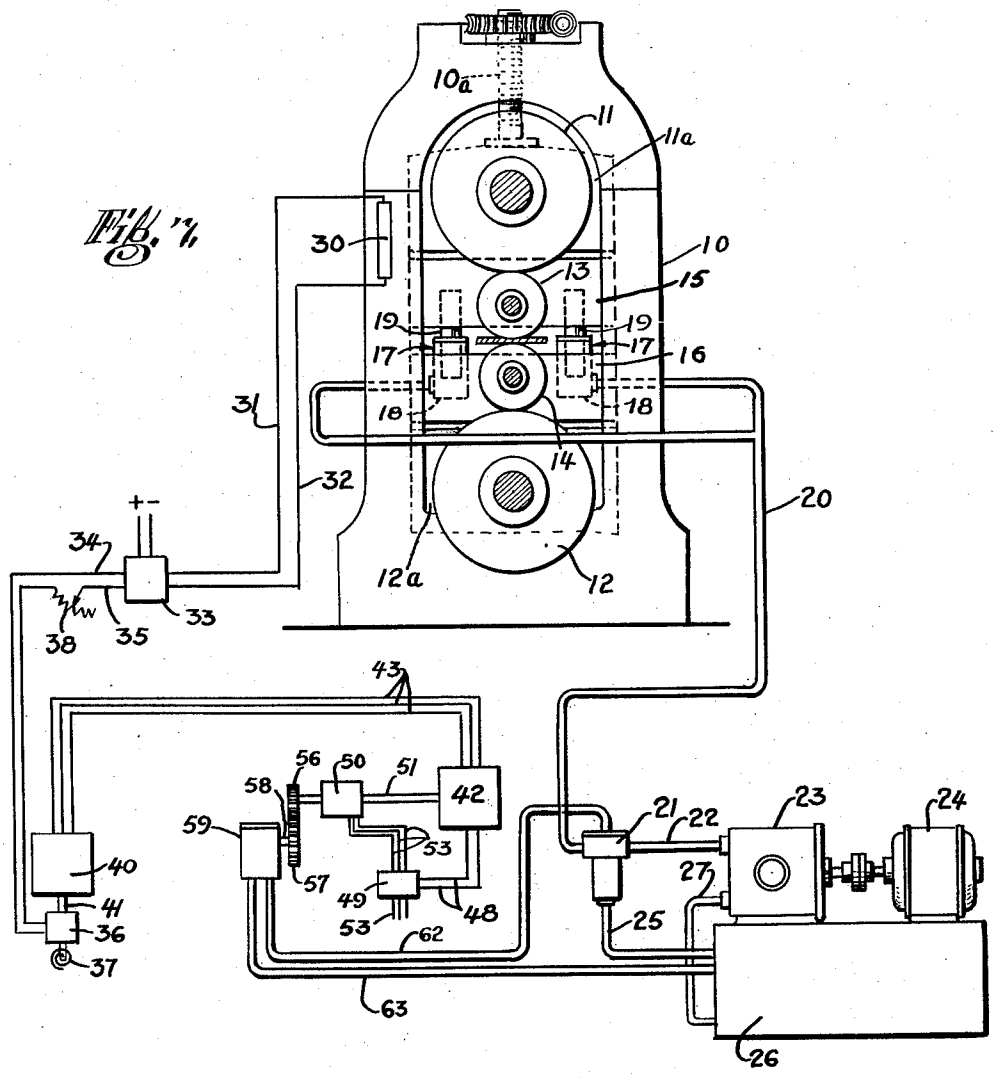
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METHOD AND APPARATUS FOR CONTROLLING THE CONTOUR OF ROLLS IN A ROLLING MILL

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Fig. 1




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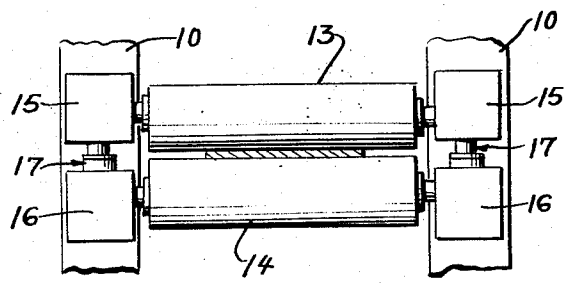



Fig. 8.

Fig. 12.

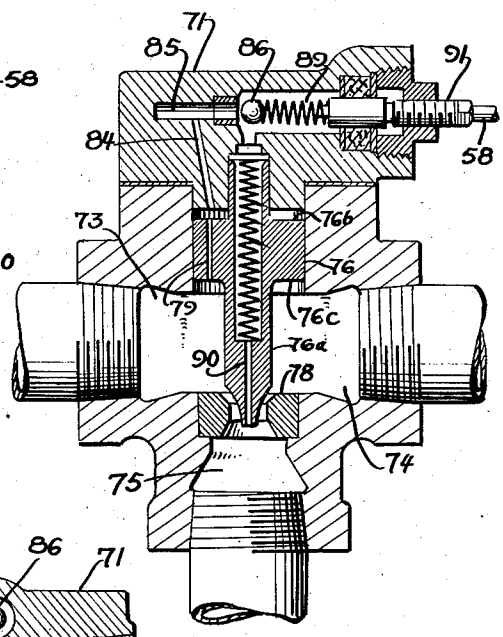
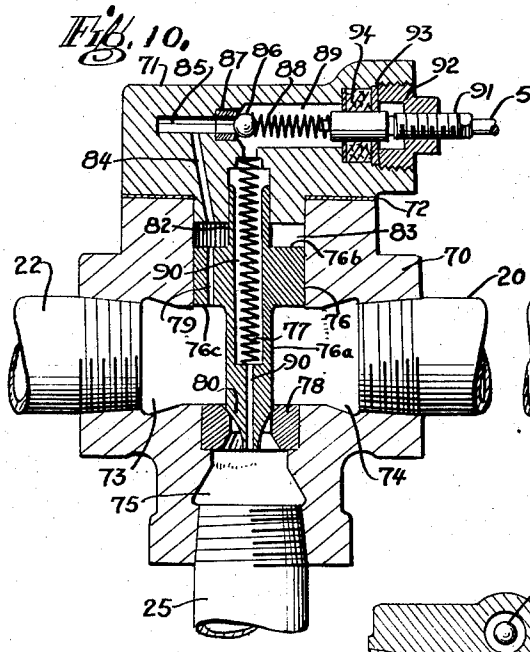



Fig. 10.



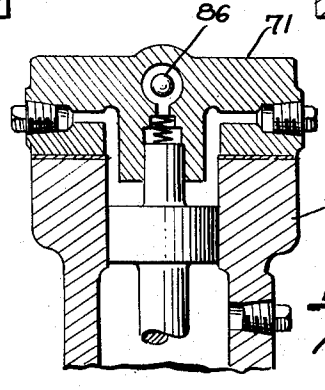




Fig. 11.

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United States Patent Office 2,903,926 Patented Sept. 15, 1959



2,903,926

# METHOD AND APPARATUS FOR CONTROLLING THE CONTOUR OF ROLLS IN A ROLLING MILL

Reymond M. Reichl, Forest Hills, N.Y., assignor to Baldwin-Lima-Hamilton Corporation, Philadelphia, Pa., a corporation of Pennsylvania

Application January 11, 1956, Serial No. 558,516

5 Claims. (Cl. 80—56)

This invention relates to a method and to apparatus for controlling the contour of the working rolls of a rolling mill to compensate for changes in the conditions under which they are working.

During both hot and cold rolling, the working rolls tend to expand due to increases in their temperature and to deflect with the roll pressure. The resulting change in the contour of the roll is normally the greatest near its mid-point. In order to compensate for these changes, the working faces of the rolls are ground to a predetermined contour which is non-cylindrical and usually convex.

In the rolling of sheets of uniform thickness, the rolls are normally set at a given spacing and to exert a given pressure on the slab, ingot or other stock being rolled to effect reduction to the desired thickness. If, however, a slab or ingot of greater or lesser thickness enters between the rolls, or if hard or soft spots are encountered in a slab or ingot, or, in hot rolling, if the temperature of the slab or ingot or a portion thereof varies materially from the desired temperature, the rolls will move closer together or farther apart as less or greater resistance is encountered, and variations in the sheet will inevitably result.

It is known that such variations in the thickness of a sheet can be avoided within certain limits by changing the pressure applied by the working rolls of the mill to compensate for the changes in the resistance of the metal being rolled. Methods and apparatus have heretofore been developed by which the roll pressure is automatically adjusted to compensate for variations in the resistance of the metal being rolled. One such method and apparatus is described in the co-pending application Serial No. 444,106, filed July 19, 1954, by Reymond M. Reichl and George N. Landis. However, the changing pressure applied by the rolls, or conversely, the changing separation resistance of the metal between the rolls, causes a changing deflection of the rolls, which itself may introduce non-uniformity in the thickness of the sheet.

In the rolling of tapered metal sheets the difficulties arising from the deflection of the working rolls are even greater than in rolling sheets of uniform thickness. In such taper rolling, the pressure under which the rolls work is continuously changing during each pass. The separating pressure between the rolls may, for example, have a certain value at the beginning of a pass and increase two or three fold during the pass. This changing separation pressure causes a continuous change in the deflection of the rolls, the extent of which depends upon the degree of taper being imparted to the sheet. The continuous change in the deflection of the rolls, in turn, causes waves and non-uniformity in the rolled sheet which cannot be removed by stretching, leveling or the like.

It is known that roll contour can be corrected, for example, in a four high rolling mill which has convexly ground work rolls by positioning a hydraulic cylinder between the chocks of the upper and lower work rolls. The hydraulic cylinders may, for example, be located in



the chocks of the lower work-roll, with their rams bearing against the chocks of the upper work-roll. This arrangement permits an operator to alter the contour of the work rolls by changing the hydraulic pressure applied to the rams.

The use of hydraulic cylinders in this manner does not prevent non-uniformity in the thickness of a rolled sheet arising from deflections in the working rolls, since the operator can compensate for the changes in the contour of the rolls only after defects in the sheet have appeared. This is particularly true in the rapid rolling of tapered sheets in which very strong increases or decreases in the pressure on the rolls occur in a single pass. It has not been possible according to prior art practice to apply suitable correction for the deflection of the working rolls particularly in taper rolling operations and this deflection has led to unsatisfactory products, particularly in the case of tapered sheets.

It is an object of this invention to provide means for continuously correcting the contour of the working rolls of a rolling mill in accordance with changes in roll pressure during the rolling operation.

Another object of this invention is to provide means for continuously adjusting the contour of the working rolls of a rolling mill in accordance with the increases or decreases in the pressure on the rolls which take place during a taper rolling operation.

A further object is to provide means for continuously and automatically adjusting and correcting the contour of the working rolls of a rolling mill in accordance with changes in roll pressure in synchrony with said changes in pressure with no perceptible time-lag between the changes in the roll pressure and the synchronized correction.

Various other objects and advantages of the invention will appear in the detailed description of a preferred embodiment of my invention which follows.

In the practice of my invention, a slab, ingot or sheet or other work-piece is passed between two opposed working rolls of a rolling mill which carries at least one back-up roll for each of the working rolls, while exerting a pressure between the adjacent chocks of the working rolls which is in a direct ratio to the pressure exerted by the working rolls on the sheet passing between them. The pressure exerted between the adjacent chocks of the working rolls may be applied by hydraulic rams, positioned between each pair of adjacent chocks, each of which has a hydraulic cylinder which may, for example, form a part of one of the chocks, and have its ram-head bearing against the adjacent chock of the other working roll. The pressure exerted by the working rolls on the sheet passing between them may be conveniently measured in terms of the strain placed upon the stand or housing of the rolling mill which carries the chocks of the rolls, for example, by a strain gauge affixed to the mill housing.

The control system in accordance with my invention, comprises essentially a means for measuring the strain placed upon the housing of a rolling mill having two working rolls and at least two backing rolls, hydraulic rams positioned between the adjacent chocks of the upper and lower working rolls, a hydraulic system for supplying a liquid under pressure to the cylinders of the said rams, and a control system which regulates the pressure at which the liquid is supplied to the hydraulic rams to maintain such pressure at all times at a level which is in direct proportion to the strain or stretch on the housing of the rolling mill. The strain on the housing or roll stand is created by the pressure exerted by the working rolls on the sheet being rolled so that a strain gauge, in effect, measures the pressure exerted by those rolls. In place of the usual strain gauge and electrical control system the separation between the upper and

lower work rolls may be measured mechanically and a mechanical hydraulic control system used to control the increase or decrease of pressure on the rams separating the chocks of the working rolls.

Referring now to the drawings, in which certain figures illustrate a preferred embodiment of my invention, and in which like reference characters are used to designate like parts wherever they occur:

Figures 1 to 5, inclusive, illustrate exaggerated cross-sections of a tapered sheet taken along section lines **1—1**, **2—2**, **3—3**, **4—4** and **5—5**, respectively, of Figure 6,

Figure 6 is a plan view of a taper rolled sheet produced without correction of the contours of the working rolls of the rolling mill,

Figure 7 is a schematic illustration of an embodiment of means, in accordance with this invention, for continuously correcting the contours of the working rolls of a rolling mill during a rolling operation,

Figure 8 is a front view of the working rolls of the rolling mill shown in side view by Figure 7, illustrating diagrammatically the location of the hydraulic pressure jacks in relation to the roll chocks of the working rolls,

Figure 9 is a diagram of a portion of the electrical wiring of an electrical synchro control system schematically illustrated by Figure 7, which may be used in the practice of this invention,

Figure 10 is a cross-sectional view of a pressure relief valve which I may use as an alternative to the combination of a main pressure relief valve and a pilot pressure relief valve shown by Figure 7, illustrating the position of its parts when it is in closed position,

Figure 11 is a fragmentary, cross-sectional view of the valve illustrated by Figure 10, taken in a plane at right angles to the plane of the cross-section of Figure 10, and

Figure 12 is a cross-sectional view of the valve illustrated by Figures 10 and 11, identical with the view of Figure 10, except that its parts are shown in open position.

In rolling a tapered sheet with working rolls having convexly ground faces, the original convex contour of the rolls is well maintained in the beginning of the rolling operation when the pressure applied by the rolls is relatively light. Figure 1 illustrates an exaggerated cross-section of the resulting sheet, taken near its thicker end. As illustrated by this figure, the convexity of the rolls causes the surfaces of the sheet to have a corresponding, mirror image concavity.

As the rolling progresses the pressure on the working rolls is continuously increased, causing a progressive deflection of the rolls. Figures 2 to 5, inclusive, illustrate in an exaggerated manner the effect of this progressive deflection on the cross-section of the tapered sheet. Referring to Figure 2, it will be noted that by the time the rolling has reached the illustrated cross-section, the roll pressure has risen and the convexity of the rolls has been considerably reduced with a corresponding reduction in the concavity of the surfaces of this sheet at that cross-section.

At a certain point in the taper rolling operation represented, for example, by the cross-section, illustrated by Figure 3, the roll pressure is such that the deflection of the rolls has substantially equalled the original convex contour of the rolls and a substantially flat sheet of uniform cross-sectional thickness is being rolled. As the rolling progresses still further in going from a thick to a thin cross-section in a taper rolling operation, the rolls deflect still more, if no correction is applied, and as illustrated by Figures 4 and 5, the rolling pressure may become so great that the deflection at the center of the rolls causes a slight convexity in the rolled sheet.

Figure 6 illustrates the appearance of the surface of a tapered sheet rolled without correction for the changing roll pressure. Along the sections **1—1** and **2—2** near the thick end of the sheet, it has been elongated more in the middle than near its edges, with the result that trough-shaped waves appear in the middle of the sheet. These troughs disappear gradually toward section **3—3** where the surface of the sheet is flat. From section **3—3** toward the thin end of the sheet, the sheet is elongated more near its edges than in its mid-portion, which results in waviness near the edges. A sheet of this kind has no usefulness and cannot be made useable by corrective operations such as stretching, leveling and the like.

In order to overcome the difficulties arising from the deflection of the working rolls with changes in rolling pressure, I provide for automatically correcting the roll contour with the increase or decrease in the rolling pressure. This automatic correction is particularly useful in the rolling of tapered sheets in which strong increases or decreases in pressure occur from end to end of the sheet being rolled. It may, however, also be used in rolling of tapered sheets in which strong increases or decreases in pressure occur from end to end of the sheet being rolled. It may, however, also be used in rolling sheets intended to be of uniform thickness from end to end.

Referring specifically to Figures 7 and 8, a pair of rolling mill stands or housings **10** carries backup rolls **11** and **12** and working rolls **13** and **14**. The trunnions of the back-up rolls **11** and **12** are mounted in roll chocks **11***a* and **12***a*, and a screwdown mechanism, such as well known in the industry and illustrated diagrammatically at **10***a*, extends through the top of the frames of each of the mill housings **10** and bears upon the upper back-up roll chocks **11***a* to control the pressure applied to the back-up rolls. When the rolling mill is used for rolling tapered sheets the screw-down mechanism is operated to progressively increase or decrease the pressure on the sheet to produce the desired taper, as described in said copending application of Reymond M. Reichl and George N. Landis, Serial No. 444,106, filed July 19, 1954. The trunnions of the working rolls **13** and **14** are mounted in roll chocks **15**, **15** and **16**, **16** respectively which are movable in housings **10**. Two hydraulic jacks **17**, **17** consisting of the hydraulic cylinders **18**, **18** and pistons **19**, **19** are positioned between each adjacent pair of roll chocks **15**, **16**. Upon the application of suitable hydraulic pressure in the cylinders **18**, **18**, **18**, **18**, the chocks **15**, **15** and **16**, **16** may be moved apart or permitted to move closer together depending upon the pressure applied in the cylinders. This movement of the chocks **15** and **16** corrects the contour of the working rolls **13** and **14** by pushing the trunnions of the working rolls apart or permitting them to come closer together to vary the bending movements acting upon the working rolls, the back-up rolls **11** and **12** continuing to exert pressure on the working rolls **13** and **14** during this correction.

The hydraulic cylinders **18**, **18**, **18**, **18** are connected by a branched conduit **20** carrying a hydraulic fluid such as, for example, a hydrocarbon oil, from a main pressure relief valve **21** to the cylinders **18**. The main pressure relief valve **21** is in turn connected by the conduit **22** to a pump **23** driven by a motor **24**. The pump **23** is capable of supplying an excess of the hydraulic fluid to the conduit **22** running to the main pressure release valve **21** at a pressure in excess of that required to apply the necessary correction to the work rolls **13** and **14**, for example, a pressure of three thousand pounds per square inch. A by-pass conduit **25** connects the main pressure relief valve **21** to the reservoir **26** for the hydraulic fluid. The intake side of the pump **22** is, in turn, connected to the reservoir **26**, by conduit **27**.

A pilot valve indicated at **59**, and controlled by an electrical circuit operated from a strain gauge **30** on one of the mill housings **10**, is connected to the main pressure relief valve **21** by the pipe **62** and to the tank **26** by the pipe **63**. Operation of the pilot valve **59** controls the amount of oil bypassed through the main pres-

sure valve 21 and hence controls the pressure of the oil to the cylinders 18, 18 in a manner hereafter described.

The pressure on the hydraulic fluid in conduit 20 and in the hydraulic cylinders 18, 18, 18, 18 is determined by the extent to which the pump pressure is relieved by the action of the main pressure relief valve 21, controlled by the pilot valve 59, in by-passing hydraulic fluid through the conduit 25 back to the reservoir 26. An excess of the fluid is normally supplied to the main relief valve 21 and a portion of the hydraulic fluid supplied to the main relief valve 21 is continually by-passed to the reservoir 26. The setting of the main relief valve 21 is automatically controlled through the strain gauge 30 and pilot valve 59, by the pressure under which the rolls 13 and 14 are working, and this, in turn, controls the quantity of the hydraulic fluid by-passed to the reservoir 26 and automatically controls the pressure applied by the hydraulic jacks 17, 17 between each of the adjacent pairs of roll chocks 15, 15 and 16, 16.

When the working rolls 13 and 14 and the back-up rolls 11 and 12 deflect under the resistance of the metal being rolled, hydraulic pressure on the pistons 19, 19 causing the chocks to separate, will deflect the ends of the rolls 13 and 14 to compensate for the working deflections in the opposite direction. By a suitable adjustment of the hydraulic pressure by the action of the main relief valve 21, a deflection of the rolls is obtained which exactly compensates for this working deflection and a uniform gap between the working rolls 13 and 14 is thereby maintained, even in the case of a substantial variation in the rolling pressure.

This hydraulic deflection of the working rolls 13 and 14 to compensate for their working deflection is caused to take place automatically by the action of the resistance strain gauge 30 mounted on one of the rolling mill housings 10 in such a position as to register increases or decreases of strain on the housing produced by increases or decreases in the pressure under which the rolls 13 and 14 are working during the rolling operation. Strain gauges of this type are described, for example, in the book entitled "Resistance Strain Gauges," by J. Yarnel, published August 1951, by Electronic Engineering, 28 Essex Street, Strand, London W.C. 2, England, or in United States Patent No. 2,292,549, granted August 11, 1952, however, other electrical or mechanical strain measuring devices may be used.

When the pressure on the working rolls 13 and 14 is increased or decreased, this change in pressure is transmitted to the back-up rolls 11 and 12, or to a back-up roll train and through the screwdown mechanisms 10*a* to the mill housings 10. The mill housings 10 will hence register the degree of increase or decrease in pressure on the working rolls, as strain on the housings which is reflected in the strain gauge 30 mounted on the housing 10.

The electrical resistance of the strain gauge 30 increases or decreases with increases or decreases in the strain on the mill housing during a taper or other rolling operation. This changing electrical resistance in the strain gauge 30 is used to control the changes in setting of the main pressure relief valve 21 through the pilot relief valve 59 by means of a servo system consisting of a synchro electrical control system and a hydraulic control system. Synchro electrical control systems of the general type which I utilize are described in the Electronic Control Handbook by Ralph R. Batcher and William Moulic, published in 1946 by Caldwell-Clements, Inc., 480 Lexington Avenue, New York 17, N.Y., on pages 233 to 237, inclusive, and can be purchased from manufacturers of this type of equipment.

Referring specifically to Figures 7 and 9, which illustrate diagrammatically an electrical and hydraulic control system suitable for the practice of my invention, the strain gauge 30 is connected with the electrical conductors 31 and 32 through which an electrical current of low amperage flows from the amplifier 33. The changes in the resistance of the strain gauge 30, created by changes in the working pressure of rolls 13 and 14, change the voltage of the current flowing through it. The strain gauge current is electronically amplified by the amplifier 33 and the higher voltage output of the amplifier is fed through electrical connections 34 and 35 to a torque motor 36 which is balanced against a spring 37. One of the electrical connections 34 or 35, illustrated as conductor 35, passes through a rheostat 38 by which the voltage of the electric current supplied by the amplifier 33 to the torque motor 36 can be readily adjusted. The angular deviation of the torque motor 36, produced by the varying voltage of its current supply, is directly proportional to the strain on the mill housing 10, as measured by changes in the resistance of the strain gauge 30.

The rotor of synchro generator 40 of an electrical synchro system is mechanically connected to the torque motor 36 by a shaft 41. There is no electrical connection between the torque motor 36 and the synchro control combination which I utilize. The control transmitted by the torque motor 36 to the synchro system is solely in terms of the mechanical angular deviation of the shaft 41.

The stator of the synchro generator 40 is electrically connected to the stator of a synchro motor or rotatable position control transformer 42 by three electrical connections 43, 43, 43 as more clearly shown by Figure 9. The rotor of the position control transformer 42 is mechanically linked to the rotor of drive motor 50 by the shaft 51, and is electrically connected by conductors 48, 48 to an amplifier and motor control assembly 49 to control the power required to operate the drive motor 50. Power for the motor control assembly 49 and motor 50 is fed through a three wire electrical circuit 53. The drive motor 50 is, in turn, mechanically connected through the reducing gears 56 and 57, and shaft 58 to the pilot relief valve 59 to adjust a spring in the pilot relief valve 59 and thus control the degree of opening or closing of the valve 59 which, in turn, controls the amount of pressure applied to the cylinders 18, 18 through the main pressure relief valve 21. The rotor of the synchro generator 40 is connected to an alternating current source by the electrical connections 60, 60 (Fig. 9).

The synchro generator 40 receives information as to the angular deviation of the torque motor 36 through the shaft 41. This mechanical shaft angle information is converted into a combination of voltages which are transmitted through the electrical connections 43, 43 and 43 to the stator of position control transformer 42. The rotor of the position control transformer or synchro motor 42 produces an electrical voltage in lines 48 when its shaft is not in angular positional agreement with that of the rotor of the synchro generator 40. The current or so-called error signal produced by the rotor of the position control transformer 42 is introduced into the amplifier and motor control assembly 49 to cause rotation of the rotor of the drive motor 50 which, in turn, adjusts the pilot relief valve 59 to cause the pressure of the hydraulic fluid from the main relief valve 21 to increase or decrease in the pipe 20. The direction in which the shaft of the drive motor 50 turns and the extent of its rotation is determined by the direction and extent to which the rotor of the position control transformer 42 is not in angular positional agreement with the rotor of generator 40.

When the rotor of the synchro motor 42 is at exactly the same position as the rotor of the synchro generator 40, no current is generated in the stators of the motor and the generator, and hence, no current is supplied to the drive motor 50 by the stator of the position control transformer 42. On the other hand, such current is supplied as long as the rotor of the synchro motor 42 is not in the same angular position as the angular position of the rotor of the synchro generator 40.

As the motor 50 drives the gear train 56, 57 to adjust the pilot relief valve 59, it also moves the rotor of position control transformer 42 to which it is connected by shaft 51 to bring the rotor of transformer 42 into synchronous position with the rotor of generator 40 when the proper correction has been made, at which position no further current flows in transformer 42 and rotation of the motor 50 ceases. While these operations have been described in terms of a single change in the position of the pilot relief valve 59 to correspond to a change in strain on the mill housing, it will be understood that in a rolling operation the pressures on the mill stand are constantly changing and that the position of the pilot relief valve 59 is constantly being adjusted to change the pressure in the hydraulic cylinders 18, 18, 18, 18 to correct the working roll contours and that my invention provides in effect a constant floating correction of the pressure relief valve 59 to automatically and simultaneously change the working roll contour in accordance with changes of pressure in the rolling operation.

In this electrical control of the pilot relief valve 59, it will be noted that the strain gauge 30 controls the angular deviation of the torque motor 36, which, in turn, controls the angular position of the rotor of the synchro generator 40. On the other hand, the angular position of the rotor of the synchro motor 42 is restored by the mechanical linkage 51 between the drive motor 50 and the rotor of the control transformer 42. When at any time the angular deviation of the torque motor 36 changes the position of the rotor of the synchro generator 40, with respect to the position of the rotor of the synchro motor 42, the stators of the synchro generator 40 and synchro motor 42 provide current to furnish power to rotate the motor 50 to adjust the pilot relief valve 59, as required by the angular deviation of the torque motor 36 and at the same time to bring the rotors of the synchro system back into registry when the required correction has been made. By means of this system the strain gauge 30 produces a continual adjustment of the pilot relief valve 59, without over-adjustment.

The pilot relief valve 59 is connected by a conduit 62 to the main relief valve 21 and to the reservoir 26 by the conduit 63 for hydraulic fluid. The pilot relief valve 59 adjusts the setting of the main relief valve 21 by permitting hydraulic fluid to flow from the main relief valve 21 through conduit 62, through the pilot valve 59, itself, and finally through conduit 63 to the reservoir 26. As the position of the main relief valve 21 is changed it by-passes more or less oil through the conduit 25 back to the reservoir 26. By this means, the pilot relief valve 59 continually adjusts the setting of the main relief valve 21 in terms of its own setting and continuously adjusts the pressure in the line 20 leading to the cylinders 18, 18.

As an alternative to the use of the combination of a pilot relief valve 59 and a main relief valve 21, illustrated by Figure 7, I may utilize a single valve which performs the functions of both. While various forms of main relief valve 21 and pilot relief valve 59 may be used to control the pressure on the hydraulic fluid in the cylinders 18, 18, 18, 18, a combination valve which I have found particularly suitable for this purpose is illustrated by Figures 10, 11 and 12.

This valve provides a combination of main relief valve and pilot valve in one casing and may be used for the main relief valve 21 and the pilot relief valve 59 upon connection to the spring adjustment shaft 58 driven from the motor 50. The use of this valve eliminates the necessity for the conduits 62 and 63 for hydraulic fluid to and from the pilot relief valve 59 as shown in Figure 7, as well as for a separate pilot relief valve 59. In describing this valve with specific reference to Figures 10, 11 and 12, I shall indicate its connections in this alternative embodiment of my invention, with the parts already described with reference to Figure 7.

Referring specifically to Figures 10, 11 and 12, this valve consists of a body 70 to which a cover section 71 is attached, as for example, by stud bolts, with a sealing gasket 72 interposed between the two parts. The body 70 is provided with an inlet port 73 to which conduit 22 (Figure 7) is attached as by a threaded joint, an outlet port 74 to which conduit 20 (Figure 7) is attached and a by-pass port 75 to which conduit 25 (Figure 7) is attached.

The body 70 carries a piston 76 which is loaded by a spring 77 and at one end seats against a valve-seat 78. The piston 76 is cylindrical and is fitted within the valve body 70 with a substantially liquid-tight sliding fit, but has an orifice 79 extending through its body. The lower portion 76*a* of the piston 76 is slender so that it does not block the direct passage of a hydraulic fluid from the inlet port 73 to the outlet port 74. The end 80 of piston 76 is shaped to form a liquid-tight joint when forced into contact with the valve seat 78.

The upper portion 82 of the piston 76 is equal in diameter to the lower portion 76*a* and is fitted into a cylindrical opening in the cover 71, while leaving a chamber 83 between its main body section and the cover 71. The orifice 84 connects the chamber 83 with a chamber 85. The orifice 84 is larger in diameter than the orifice 79. This difference between these orifices is essential to the functioning of this valve as will be explained hereinafter.

A pressure control ball valve 86 fitted in a closely fitting seat 87 and held in position by an adjustable spring 88, closes the end of the chamber 85 and its connection with chamber 89. The chamber 89 is connected by orifice 90, extending through the piston 76, to the by-pass port 75 of the valve.

The end of the adjustable spring 88, opposite that which bears on the pressure control ball valve 86, bears on the end of the adjustment screw 91 which is threaded in a packing retainer 92. This retainer also holds in position a gasket 93 and packing 94 which makes this connection liquid-tight. The screw 91 is affixed to the end of the spring adjustment shaft 58 to permit its rotation by the drive motor 50 to move the screw 91 in and out and vary the pressure on the spring 88.

The functioning of this valve can best be understood by a comparison of Figures 10 and 12, which show the valve in its closed and open positions, respectively. The control of its operation as a pressure control mechanism is the tension or load which is placed on the spring 88 by the adjustment of the screw 91, the position of which is controlled by the shaft 58. The force with which the ball 86 is held against or near its seat 87 to keep the end of the chamber 85 closed or partially closed is controlled by the rotation of shaft 58.

Referring specifically to Figure 10, it will be noted that when the valve is in closed position, that hydraulic fluid entering through port 73 flows around the lower portion 76*a* of piston 76 and out through the port 74 and conduit 20 with none of the fluid passing out through the by-pass port 75. In this position the full hydraulic pressure in the line 22 will be transmitted to the cylinders 18, 18. A portion of the hydraulic fluid will pass through orifice 79 into chamber 83 and through orifice 84 and into chamber 85. The fluid cannot escape from chamber 85 into chamber 89 since the port between these chambers is sealed by the ball 86 which is held in position by the tension or load on the adjustment spring 88. In this condition the fluid pressures on the top surface 76*b* and the bottom surface 76*c* of piston 76 will be equal and the end 80 of the piston will remain on its seat 78.

When the pressure of the hydraulic fluid in chamber 85 becomes sufficiently high to overcome the resistance of the adjustment spring 88, or conversely, when the re-

sistance of the spring **88** is reduced by an adjustment of the screw **91**, the hydraulic fluid escapes from chamber **85** around the pressure control ball **86**. This escaping hydraulic fluid flows through chamber **89**, orifice **90** in the piston and out through the by-pass port **75**.

As the hydraulic fluid tends to flow in through the relatively small orifice **79** at a lesser rate than it tends to flow out of the larger passage **84**, the pressure of the fluid in chamber **83** is reduced more than the pressure on the bottom surface **76c** of the valve piston **76**. The reduction of the pressure in chamber **83** permits the piston **76** to rise against the pressure of spring **77** to displace the piston from its seat **78**, as illustrated by Figure 12, and permit a portion of the hydraulic fluid to flow directly from the inlet port **73** to the by-pass port **75**. This by-passing of a portion of the fluid reduces the pressure on the fluid at the outlet port **74** and, hence reduces the pressure in the cylinders **18**, **18** and permits the working roll chocks **15** and **16** to move closer together.

When the pressure on the fluid has been reduced to an extent substantially corresponding to the respective adjustment of spring **88**, the latter will cause ball **86** to contact or approach its seat **87**. The pressures on the fluid above and below piston **76** will now be equalized to a greater or lesser degree and spring **77** will cause piston **76** to move downwardly to close or partially close the passage to by-pass port **75**.

In the reverse operation of the main pressure relief valve, if the resistance of spring **88** is increased by an adjustment of screw **91**, the pump **23** which as mentioned hereinbefore supplies an excess of fluid to the main pressure relief valve **21** will build up pressure on the fluid to an increased degree. Unless there is an increase beyond the pressure corresponding to the setting of spring **88**, the ball valve **86** will remain closed. This will increase the pressure of the hydraulic fluid in the outlet port **74** and line **20** to thereby move the roll chocks **15** and **16** apart.

Referring again to Figures 10 and 12, it will be appreciated that in the operation of this alternative embodiment of this invention in which the valve there illustrated is used to replace both the main pressure relief valve **21** and the pilot valve **59**, that the orifice between chambers **85** and **89** of the valve **70** is seldom fully closed by the pressure control ball **86** and, hence that the lower end **80** of piston **76** is seldom fully seated, with the result that excess hydraulic fluid furnished by the pump **23** is being more or less continuously by-passed back to the oil reservoir **26**.

The resistance of the adjustment spring **88** to the passage of this excessive hydraulic fluid is practically continually altered by the action of the drive motor **50** in continually rotating the shaft **58** backward or forward to adjust the position of the screw **91** as required by the change of pressure in the mill stand as measured by the strain gauge **30** on the mill housing **10**. In a taper rolling operation, for example, the drive motor **50** more or less continually increases or decreases the pressure of the adjustment spring **88** on the ball **86**. It thereby increases or decreases the hydraulic pressure in the main hydraulic fluid conduit **20** and increases or decreases the force applied by the hydraulic jacks **17**, **17**, **17**, **17** to separate the chocks **15** and **16** of the working rolls as the rolling pressure and the strain on the mill stand **10** increases or decreases, giving a substantially constant floating control responsive to the pressure changes on the work rolls. This, in turn, continuously corrects for the deflection of the working rolls **13** and **14** caused by the variations of pressure under which they are working. In this manner unevenness in the rolled sheets, which occurs in ordinary taper rolling operations as described in connection with Figures 1 to 6, is overcome and smooth sheets of even taper are produced. As will be understood from the foregoing description, an important feature of my control system is to utilize the strain on the housing **10** to control the force exerted by the hydraulic jacks **17**, **17**. While an electrical strain gauge and servo control system of the type described is preferred, a mechanical measurement of the strain and a mechanical-hydraulic system for changing the pressure in the jacks **17**, **17** may be used.



The "strain" measured by the strain gauge is an elongation or contraction of the housing **10** of the rolling mill, within its elastic limits, resulting from the changes in the pressure under which rolls **13** and **14** operate on the sheet being rolled. The extent of this elongation or contraction of the housing is determined by the physical characteristics of the housing itself and by the pressures under which the rolls **13** and **14** are working. The physical characteristics of the housing of any given rolling mill are fixed, and the adjustment of the hydraulic pressure in the jacks **17**, **17** can be fixed within any desired range, in terms of the physical characteristics of the housing **10** and the overall range of working pressures of the rolls **13** and **14**, by the amplification characteristics of the amplifier **33**.

Any given rolling mill will be required to roll sheets which exert substantially different separation pressures on the rolls and, hence substantially different strain on the mill housings. This variation makes desirable an adjustment of the level of the responses of the control system used in accordance with this invention, within ranges determined by the characteristics of the metal being rolled, including the width thereof, and by extent of deformation of the metal required in any pass through the mills. The rheostat **38** provides a convenient means for adjusting the level of the responses of my control system. This rheostat provides a ready means for modifying the level of the voltage supplied by the amplifier **33** to the torque motor **36** to adjust the response range of the synchro system to the range required by the particular job being done by the rolling mill.

It will be readily apparent from the foreing description that the method of this invention provides instantaneous and continuous correction for the deflection of the working rolls of a rolling mill and that the method is equally applicable to the rolling of tapered sheets and sheets of uniform thickness. In the control system illustrated, the response of both the electrical system and the hydraulic system to changes in the pressure under which the rolling mill is operating is instantaneous. For this reason, the correction applied to the rolls is completely synchronized with the cause of their deflection. The result is that the difficulties which have heretofore been caused by roll deflection are entirely eliminated.

While preferred embodiments of this invention have been diagrammatically illustrated and described, and various parts of the rolling mill have been omitted for purposes of simplification, it will be understood by persons skilled in the art that various well known controls equivalent to those described and illustrated may be substituted, that multiple control circuits may be used and may be installed on other types of rolling mills than the one specifically illustrated and that various other modifications and changes from the illustrative embodiments shown may be made without departing from the spirit of my invention or the scope of the following claims.

I claim:

1. In a control system for automatically controlling the deflection of the working rolls in a rolling mill comprising a rolling mill stand, two working rolls carried by roll chocks which are free to move relative to the mill stand, and at least two back-up rolls, hydraulic jacks positioned to apply force to separate the chocks of the working rolls and connected through a valve to a source of hydraulic fluid under pressure in excess of the maximum pressure required for separation of the chocks of said working rolls, a strain gauge for registering increases and decreases in the strain on the rolling mill stand during the rolling operation produced by increases and de-

creases in the pressure under which its rolls are operating, an electrical circuit connected with said strain gauge, a motor and means in said circuit for controlling said motor, means operated by said motor for controlling the operation of the said valve to adjust the pressure on the hydraulic fluid in the said jacks in direct proportion with increases and decreases in the strain on the mill stand as measured by the said strain gauge, and means to adjust the level of response of said electrical circuit.

2. In a control system for automatically controlling the deflection of the working rolls in a rolling mill comprising a rolling mill stand, two working rolls carried by roll chocks which are free to move relative to the mill stand, and at least two back-up rolls, hydraulic jacks positioned to apply force to separate the chocks of the working rolls and connected through a by-pass valve to a source of hydraulic fluid under pressure in excess of the maximum pressure required for separating the chocks of said working rolls, a strain gauge for registering increases and decreases in the strain on the rolling mill stand during the rolling operation produced by increases and decreases in the pressure under which its rolls are operating, an electrical circuit connected with said strain gauge, a control motor and means in said circuit for controlling said control motor, means operated by said motor for controlling the operation of the said by-pass valve to adjust the pressure on the hydraulic fluid in the said jacks in direct proportion with increases and decreases in the strain on the mill stand as measured by the said strain gauge, a spring loaded torque motor in said electrical circuit which registers as angular deviation the changes in the electrical resistance of the strain gauge, a synchro electrical system to drive said control motor to adjust the said by-pass valve in terms of the angular deviation registered by the said torque motor, and means to adjust the level of response of said electrical circuit.

3. In a control system for automatically controlling the deflection of the working rolls in a rolling mill comprising a rolling mill stand, two working rolls carried by roll chocks which are free to move relative to the mill stand, and at least two back-up rolls, hydraulic jacks positioned to apply force to separate the chocks of the working rolls and connected through a by-pass valve to a source of hydraulic fluid under pressure in excess of the maximum pressure required for separating the chocks of said working rolls, a strain gauge for registering increases and decreases in the strain on the rolling mill stand during the rolling operation produced by increases and decreases in the pressure under which its rolls are operating, an electrical circuit connected with said strain gauge, a control motor operated by said circuit, means operated by said control motor for controlling the operation of the said by-pass valve to adjust the pressure on the hydraulic fluid in the said jacks in direct proportion with increases and decreases in the strain on the mill stand as measured by the said strain gauge, a spring loaded torque motor in said electrical circuit which registers as angular deviation the changes in the electrical resistance of the strain gauge, a combination of a synchro generator and a control transformer which generates an electric current when the angular deviation of the said torque motor changes to control said control motor, and means connecting the said control motor to said by-pass valve to adjust the said by-pass valve in terms of the polarity of the said current.

4. In a control system for automatically controlling the deflection of the working rolls in a rolling mill comprising a rolling mill stand, two working rolls carried by roll chocks which are free to move relative to the mill stand, and at least two back-up rolls, hydraulic jacks positioned to apply force to separate the chocks of the working rolls and connected through a by-pass valve to a source of hydraulic fluid under pressure in excess of the maximum pressure required for separating the chocks of said working rolls, a pilot hydraulic valve connected to and adapted for adjusting the said by-pass valve, a strain gauge for registering increases and decreases in the strain on the rolling mill stand during the rolling operation produced by increases and decreases in the pressure under which its rolls are operating, and an electrical circuit for controlling the operation of said pilot valve from said strain gauge to adjust the pressure on the hydraulic fluid in said jacks in direct proportion with increases and decreases in the strain on the mill stand as measured by said strain gauge, said electrical circuit including a spring loaded torque motor which registers as angular deviation the changes in the electrical resistance of the strain gauge, a combination of a synchro generator and a control transformer which generates an electric current when the angular deviation of the said torque motor changes, a drive motor controlled by said electrical circuit which is operated by the current generated by the control transformer, connections between the drive motor and said pilot valve to adjust the said pilot valve in terms of the polarity and amplitude of the said current, and means to adjust the level of response of said electrical circuit.

5. In a control system for automatically controlling the deflection of the working rolls in a rolling mill comprising a rolling mill stand, two working rolls carried by roll chocks which are free to move relative to the mill stand, and at least two back-up rolls, hydraulic jacks positioned to apply force to separate the chocks of the working rolls and connected through a floating control valve to a source of hydraulic fluid under pressure in excess of the maximum pressure required for separation of the chocks of said working rolls, a strain gauge for registering increases and decreases in the strain on the rolling mill stand during the rolling operation produced by increases and decreases in the pressure under which its rolls are operating, an electrical circuit connected with said strain gauge, a motor and means in said circuit for controlling said motor, means operated by said motor for controlling the operation of the said floating control valve to adjust the pressure on the hydraulic fluid in the said jacks in direct proportion with increases and decreases in the strain on the mill stand as measured by the said strain gauge, and means to adjust the level of response of said electrical circuit.

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UNITED STATES PATENT OFFICE

# CERTIFICATE OF CORRECTION

Patent No. 2,903,926 September 15, 1959

Reymond M. Reichl

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 4, lines 18 to 21, strike out "It may, however, also be used in rolling of tapered sheets in which strong increases or decreases in pressure occur from end to end of the sheet being rolled."; column 10, line 38, for "foreing" read -- foregoing --.

Signed and sealed this 9th day of August 1960.

(SEAL)
Attest:

KARL H. AXLINE
Attesting Officer

ROBERT C. WATSON
Commissioner of Patents