Dec. 17, 1968 C. DEY ET AL 3,416,341

ROLLING MILL CONTROL SYSTEM

Filed Dec. 12, 1966 2 Sheets-Sheet 1

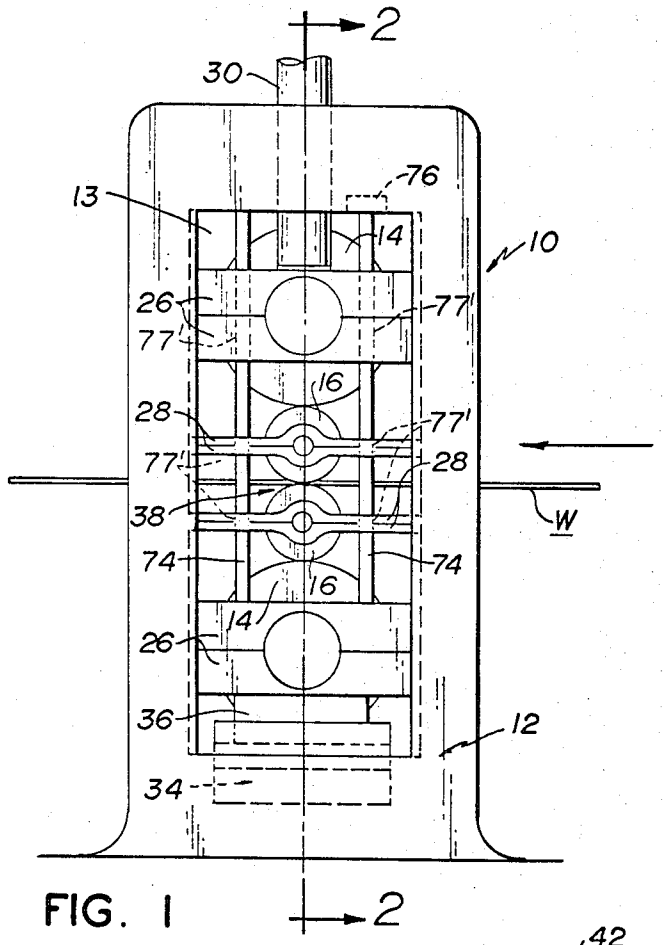


FIG. 1

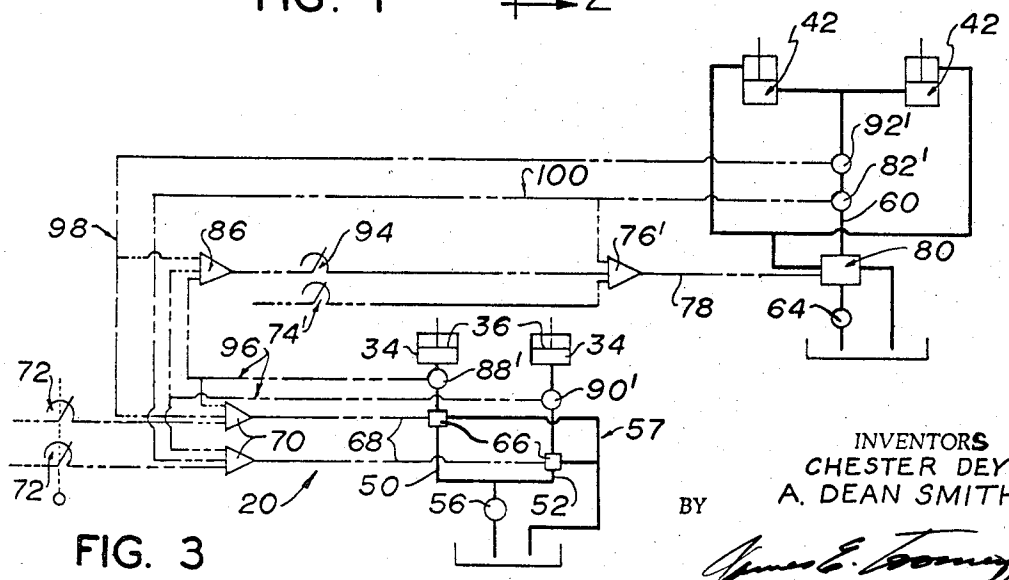


FIG. 3

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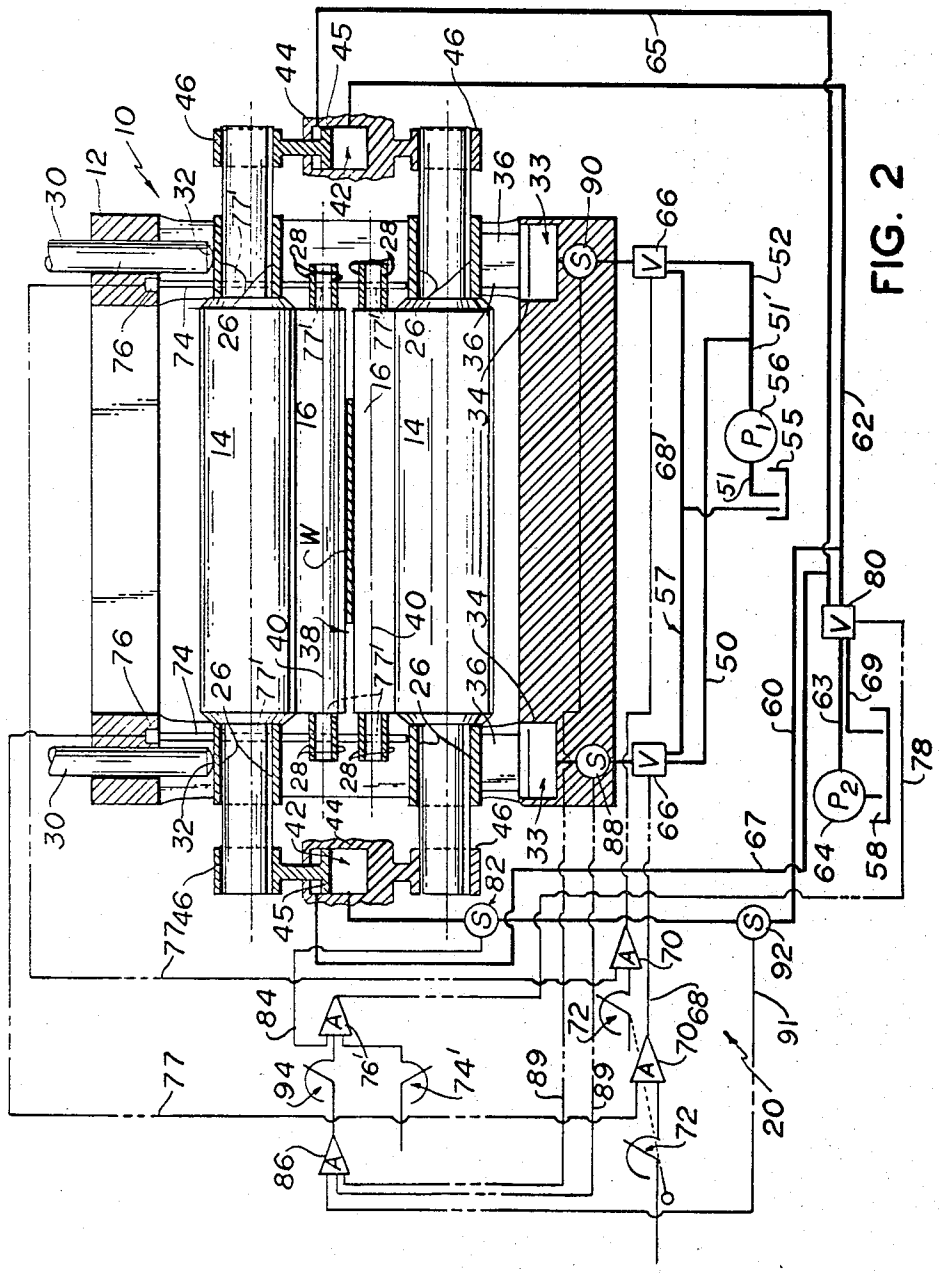


FIG. 2

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ROLLING MILL CONTROL SYSTEM

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17 Claims. (Cl. 72—20)

The invention relates to rolling mills and more particularly to an improved roll gap control system therefor wherein the functions of a rolling mill pushup control means and a rolling mill roll bending control means are both fully integrated with each other during operation of the rolling mill and wherein the pushup means are also operated in an improved fashion so that the material being rolled will maintain a substantially uniform gauge across its entire width irrespective of changes in various mill load conditions which occur during rolling.

In prior rolling mill practices, in order to maintain substantially uniform gauge across the entire width of the material being rolled, it has been customary to use work or backup roll bending devices and roll pushup devices. The bending devices apply bending loads to the work rolls to counter or compensate for deflection of certain portions of the rolls due, for example, to separating forces exerted upon the rolls by the workpiece, roll heat up, roll flattening, etc. Roll pushup devices, such as pushup cylinders, are used in addition to the normal roll screw down devices primarily to compensate for stretching of the mill housing or frame, which also normally occurs as a result of the separating forces exerted directly upon the work rolls and indirectly on the mill frame by the material, such as metal sheet, that is rolled. Despite all of these corrective measures, problems still exist because of the failures that have occurred to date in efficiently and reliably integrating the control system for the roll bending devices with the control system for the pushup devices whereby each control system will still perform its assigned function, as such, while at the same time taking into account and at the same time synchronizing its operations with those of its companion control system so that the desired optimum roll gap setting for the mill is constantly maintained throughout rolling.

Accordingly, it is a primary purpose of the instant invention to provide, among other things, an improved and highly reliable control arrangement for operating and integrating a mill roll bending device with a mill roll pushup device, whereby each device will efficiently perform its own assigned function, as such, while at the same time being fully synchronized with its companion device whereby one device will not only not adversely affect the operation of the other device, but instead will advantageously complement the workings of the other device in maintaining the desired optimum roll gap setting for a given rolling operation.

This and other purposes and advantages of the instant invention will become more apparent from a review of the following detailed description when taken in conjunction with the appended drawings, wherein:

FIG. 1 is a side elevational view of a typical rolling mill with certain parts removed and other parts broken away and incorporating the improved integrated control systems of the instant invention;

FIG. 2 is a sectional view generally taken along line 2—2 of FIG. 1 with parts of the mill being removed and with other parts being schematically shown for purposes of illustration and with the integrated mill control systems of the instant invention being schematically added to illustrate the novel details thereof; and

FIG. 3 is a diagrammatic view of a modified form of the integrated control systems of FIG. 2.

With further reference to the drawings and in particular FIGS. 1 and 2, a preferred form of apparatus that can be used in carrying out the teachings of the instant invention generally comprises a typical four-high rolling mill stand **10** used to roll ferrous or non-ferrous metals. Mill stand **10** includes a mill housing or framework **12**, a pair of backup rolls **14** and a pair of work rolls **16**. Although the forming surfaces of the work rolls **16** along their axial lengths are shown to have a uniform diameter, these surfaces can, if desired, be initially made to have an axial convex or concave shape in accordance with customary roll finishing practices. Rolls **14** and **16** are rotatably and adjustably mounted within the framework **12** by the journal or reduced ends of rolls **14** and **16** being appropriately mounted in their respective chock blocks **26** and **28** and these chock blocks **26** and **28** are then slidably mounted within vertically recessed track means in the window **13** of the housing **12** in the usual fashion as indicated by the dotted lines in FIG. 1. It is to be understood, of course, although not shown, that the customary jack rams such as those shown in United States Patent 2,903,926 to R. M. Reichl, issued Sept. 15, 1959, or other appropriate upper roll and upper chock block counterbalancing devices are used on the mill illustrated in order for the upper rolls and chock blocks to follow the upward movements of the upper screw downs and remain in contact therewith during adjustments thereto.

As indicated in FIGS. 1 and 2, in order to assist in establishing the proper setting of the roll gap **38** between the work rolls **16** in accordance with the desired gauge for the workpiece W to be rolled, a pair of conventional feed screws or screw down devices **30** are disposed within threaded openings in the upper portion of the framework **12**. The ends of the screws **30** are kept in abutting contact at **32** with the chock block elements **26** for the upper roll **14** and screws **30** are adjustable by conventional actuating means (not shown).

In the rolling mill illustrated, the chock blocks **26** associated with the ends of the lower backup roll **14** are interconnected to the lower portion of the framework **10** by conventional fluid actuators or pushup devices **33** which include pistons mounted in openings **34** and rod elements **36** directly connected to the chocks **26**. These fluid actuators **33** act primarily to compensate for the spreading apart of the rolls, changes in the preselected roll gap setting **38** between rolls **16** and mill housing stretch resulting from insertion of a workpiece W between the rolls and the consequent rolling loads applied to the rolls by a workpiece W during rolling. In their operation, devices **33** act in conjunction with the mill screws **30** to bring the rolls back to the desired roll gap setting.

Although other tying arrangements can be used, an advantageous embodiment of the invention contemplates that the ends of the backup rolls **14** in the apparatus illustrated be interconnected to each other by extensible fluid actuators **42**. The purpose of these actuators is to apply appropriate bending loads to the work rolls when needed at the same time that appropriate pushup loads are applied to the rolls by the actuators **33**.

The overall control circuit generally indicated at **20** in FIG. 2 for the fluid actuators **42** and **33** includes improved means for fully integrating and correlating all applied bending loads with the rolling loads applied by the workpiece W and counter-loads applied by the pushup actuators **33** at any given time in order to maintain the desired roll setting gap substantially uniform across the full length of the work rolls whereby the workpiece W will be rolled with the desired substantially uniform gauge across its full width.

The control circuit **20** in the embodiment of FIG. 2 includes an improved circuit component sensing means

comprised of a gauge rod **74** and a sensing device or load cell **76**. Load cell **76** can be a conventional sensing element of the type sold by Asea Electric, Inc., of San Francisco, Calif., under Model No. TGPUB–200 and under the trade name "Pressductor."

The load cell **76** is connected to a hydraulic circuit for selectively controlling the admittance of fluid under pressure to the fluid actuators or pushups **33** for expanding or collapsing the pushup devices in a manner to be described more fully hereinafter. The hydraulic circuit includes a pump **56** connected by a conduit **51** to a source of supply or reservoir **55**. Branch lines **50** and **52** lead from main line **51'** to the various actuators **33**. In the event of build-up of excess pressure fluid within the actuators **33** and conduits **50** and **52**, control valves **66**, connected to each conduit **50** and **52**, can be preset whereby they automatically function to exit the excess fluid through the line **57** to the reservoir **55**.

Also included in the overall control circuit **20** is a further hydraulic circuit for controlling the admittance of fluid under pressure to the fluid actuators **42** for applying the desired bending loads to the backup rolls **14** and in turn to the work rolls. Each fluid actuator **42** can include a fluid cylinder **44** within which a piston **45** is slidably disposed. The exposed end of the rod for piston **45** as well as one end of the cylinder **44** can be provided with apertured enlargements **46** within which the journal ends of the rolls **14** can be disposed as shown in FIG. 2. Thus, the cylinder **44** can be affixed to one backup roll and the piston **45** to the other backup roll. A pump **64** is used to supply fluid under pressure to opposite sides of the piston **45** disposed within the cylinder **44**. This pump supplies fluid under pressure from a source of supply or reservoir **58** through a main conduit **63** to an appropriate control valve **80**. Valve **80** operates to distribute fluid under pressure to either side of the pistons **45** disposed within the cylinders **44** by the interconnected branch conduits **60** and **62**, which lead to the free sides of the pistons **45** and by the other interconnected branch conduits **65** and **67** which lead to the rod sides of the pistons **45** in accordance with specific roll bending requirements. Control valve **80** can also be preset depending upon the requirements for fluid under pressure to either side of the pistons **45** within the cylinders **44** of the actuators **42**, to exit any excess fluid through the exhaust line **69** to the reservoir **58**.

Control valves **66** for actuators **33** operate in response to appropriate electrical signals transmitted through the lead lines **68** and generated by their respective separate summing amplifiers **70**. Suitably calibrated means such as an adjustable rheostat device **72** is connected to each of the amplifiers **70** for feeding the appropriate reference signal into the input side of an amplifier **70**.

Each set of electrical elements or electrically responsive elements **66**, **70** and **72** is separately connected to one of the fluid actuators **33**. If desired, the rheostat devices **72** of both sets of elements can be mechanically interlocked together, as schematically shown in dotted lines in FIGS. 2 and 3, whereby adjustment of one rheostat device **72** will automatically cause a corresponding adjustment of the other rheostat **72**.

A brief discussion is believed to be in order at this point of how the rheostats **72** act in conjunction with load cells **76** and pushups **33** along with screws **30** in the operational set up and working of the mill. In setting up the mill stand for normal operation and with the mill stand being empty of a workpiece, the fluid actuators **33** are first actuated whereby they will raise the lower work roll **16** and backup roll **14** to the point where the bottom tips of the rods **74** for the load cells **76** are brought into contact with the chock blocks **26** for the lower backup roll **14**. This may be referred to as the step of preloading the load cells **76**. This preloading of the load cells is, in the case of any given mill installation, determined by the rolling requirements for the mill and the particular load cell used. Thus, in the present instance a load cell **76** may, for example, require a 20,000 lb. load to be applied thereto in order to place it in the desired preloaded condition. At this time, rods **74** are in the desired physical and pressure contact with lower chocks **26**. This preloading of cells **76** is accomplished by the rheostats **72** which are calibrated in terms of pushup loads or load pounds, and once they have been set to the above 20,000 lb. load for the mill stand illustrated, they will for all practical purposes require no further attention. When fully set, rheostats transmit the proper reference signals to amplifiers **70** which operate valves **66** so that the actuators **33** are motivated to raise lower chocks **26** to the point where they are brought into proper pressure contact with rods **74** connected to load cells **76**. After preloading of the load cells **76**, the mill operator next adjusts screws **30** and the jack rams (not shown) to bring the upper backup and upper work rolls down until they are properly spaced the appropriate amounts from lower backup and lower work rolls to give the proper gap setting **38** for a given rolling condition, say .055".

When a workpiece is later inserted between the work rolls and the rolls are forced apart, it will be observed that the desired pressure contact will be lost between the load cell rods **74** and lower chock blocks **26** thereby causing the load cells **76** to become unloaded. As the cells become unloaded, they transmit appropriate feed back signals to amplifier **70** which then compares these signals with those from rheostats **72**. The difference in signals causes amplifiers **70** to signal valves **66** to actuate the pushups **33** and raise rolls **14** and **16** upwardly and lower chocks **26** back to the point where they are again in the proper pressure contact with rods **74** for the load cells **76**, thereby reestablishing the proper loading of the load cell **76** to the point (e.g. 20,000 lbs.) where cells **76** discontinue the feedback signals to amplifiers **70** and bring about a deactivation of actuators **33**.

Put another way, the normal operation of the load cell **76**, rheostats **72** and actuators **33** can be expressed in terms of a conventional rolling mill formula used when load cell devices **76** are incorporated in a mill stand. Normal pushup loads (P), i.e. the final loads to be applied by actuator devices **33** in compensating for the final rolling loads applied to the rolls including that of the workpiece that passes therethrough and spreads the rolls apart and for reestablishing the loading of the load cells **76**, is equal to the load cell load (LC) plus the final rolling load. Thus, $(P)=(LC)+(RL)$.

Thus, in the above formula, if a load cell **76** as manufactured and installed is set to operate at a load cell load (LC) of 20,000 lbs. and the rheostats **72** are set at the 20,000 lbs. and the rolling load (RL) including that applied by the workpiece to the rolls as it is introduced into the mill which results in roll separation equals 180,000 lbs., the final pushup loads that must be applied to restore the load cells **76** to their balanced or loaded condition and the roll gap **38** to say the above mentioned .055" would be 200,000 lbs.

In order to efficiently perform the aforesaid operations, the load cell sensing elements **76**, there being one of these elements on each side of the mill stand **10**, are connected to the vertically disposed and laterally spaced gauge rods **74** positioned within each window **13** of the framework **12** adjacent the journal ends of the rolls **14** and **16**. The upper ends of the gauge rods **74** are disposed preferably immediately adjacent the lower surface portion to the frame **12**, while their lower ends, which are preferably rounded off, rest upon and have the desired floating pressure contact with the upper surfaces of the chock blocks **26** associated with the lower backup roll **14**. To facilitate vertically free but laterally restrained movement of each gauge rod **74** and loading and unloading of the cells **76**, the rods **74** are passed through appropriate vertically disposed passageways in upper chock blocks

26 and 28 and lower chock block 28. These passageways are indicated by the dotted lines 77' in FIGS. 1 and 2. Due to this mounting arrangement, movements of the upper chocks 26 and 28 during initial screw down operations will have no effect on cells 76.

Although it is to be understood that a pair of active sensing devices 76 can be mounted on each side of the mill in the upper portion of the frame 12 for engagement with the upper ends of the rods 74 in each window 13, only one active sensing device 76 need be used for each side of the mill stand in actual practice.

In some instances, it may also be desirable to use a dummy or follower rod 74 in combination with a fully operative sensing rod 74 in each window and with one end of the dummy rod resting on the lower chock 26 and with its upper end contacting the undersurface of the frame 12. In such instances, the dummy or follower rods can act as vertical guides for the lower chock block 26 upon which the operative sensing rod 74 rests so that the lower block will be restrained and cannot take on simultaneous twisting movements about the axis of the rolls.

Each sensing element 76 is electrically connected to one of the amplifiers 70 by a line 77 (see FIG. 2) and operates in response to appropriate pressures exerted by contact with a lower chock 26 through its associated gauge rod 74 to transmit appropriate feed back signals to its associated amplifier 70 when deviations occur in the 20,000 lb. pushup loads as determined by the original reference signal being transmitted through rheostats 72, all as noted above. The signals transmitted by a sensing element 76 are opposite in polarity to the initial 20,000 lbs. reference signals transmitted from the rheostats 72 to the amplifiers 70. Whenever the feed back signals from cells 76 to the summing amplifiers 70 are in effect substantially cancelled out by the signals being transmitted to the amplifiers by the preset rheostats 72, either during the initial start up with no workpiece W between the rolls or during rolling when the gap 38 has exceeded the desired gauge setting, valves 66 will cease operating and stop the further flow of pressure fluid into the bottom sides of fluid actuators 33. This signal cancellation as noted above occurs at the time the pushup loads from the actuators 33 have loaded the cells 76 at the requisite (LC) load of 20,000 lbs. or at the time sensing rods 74 are in the appropriate pressure contact with the lower chocks 26.

By the contact pressure mounting of the sensing gauge rods 74 in the manner aforedescribed, the rods and in turn cells 76 are not adversely influenced in their operation by external loads imposed thereon, such as by the weight of rolls or the chock blocks or by any torque of the feed screws 30 whereby inaccurate or non-reliable feed back signals could be transmitted to the amplifiers 70 by the sensing elements 76. Thus, the sensing devices 76 perform their roll separation and rolling load detection functions through the medium of amplifiers 70, etc. in an extremely sensitive and highly reliable fashion and efficiently operate the compensating pushups 33.

The electrical components of circuit 20 used to operate and control the roll bending actuators will now be described. Main control valve 80 is electrically connected to a summing amplifier 76' by line 78 whereby, depending upon the type of signal received from the amplifier 76', the control valve operates to direct fluid under pressure from pump 64 through the proper branch conduits 65 and 67 or 60 and 62 to the various sides of the pistons 45 to effect bending of the backup rolls and in turn the work rolls in the fashion desired.

Excess fluid from the supply conduit 63 or fluid returned from the various sides of cylinders 44 by the conduits 60 and 62 or 65 and 67 as the case may be is at the same time directed by the valve 80 through the conduit 69 to the reservoir 58. An adjustable rheostat 74' calibrated in the appropriate roll bending load pounds is also connected to the input side of the summing amplifier 76' and is manipulated at the proper time by the mill stand operator to transmit the appropriate roll bending reference signal thereto. The amplifier 76' then continues the transmission of this signal through line 78 to the valve 80 and valve 80 operates to cause admittance of selected amounts of fluid under pressure to actuators 42 so as to apply the desired bending loads to the backup and work rolls 16.

The incorporation of bending rolls in the mill stand aggravates the problem of maintaining the desired roll gap 38 at say the above .055" across the length of the rolls since the application of the roll bending loads will increase the rolling loads (RL) and apply additional forces on the pushup actuators 33 which must be compensated for. This means then if the overall mill compensation is to be obtained, operation of the roll bending and pushup devices must also be fully correlated and synchronized with each other if the pushups are to continue to perform their proper function.

This correlation has been effected in the instant invention by way of a unique interlock or integration of the various pushup and bending roll components in the overall circuit 20. This component interlock involves use of an auxiliary summing amplifier 86 and suitable load feed back sensing devices 82, 88, 90 and 92, all of which can be of the type which translate or convert a given fluid pressure at any given time into an appropriate electrical signal. These sensing devices 82, 88, 90 and 92 can be of the type sold by Computer Instrument Corporation of New York under Model No. 3000. The sensing devices 88 and 90 are disposed within the branch conduits of the pushup actuator fluid circuit immediately adjacent the pushup devices 33 as shown in FIG. 1. The other sensing devices are both disposed within the branch conduit 60 of the roll bending fluid circuit for constantly sensing the fluid pressure within the roll bending actuators 42. Sensing devices 88 and 90 are both electrically connected by their separate output lines 89 to the input side of the auxiliary summing amplifier 86. Sensing device 92 is likewise connected by its output line 91 to the input side of amplifier 86 and output line 84 connects the remaining sensing device 82 to the input side of the summing amplifier 76'. A rheostat 94 is also electrically connected across the output of amplifier 86 to the input side of amplifier 76'.

When no workpiece W is in the mill and with the initial pushup load setting preset at 20,000 lbs. by initial adjustment of the rheostats 72 in the manner aforedescribed, the output signal from amplifier 76' can be such as to normally produce no actuation of valve 80 and no application of bending loads to the rolls 16 and 14. When, however, a workpiece is passed through the mill and a roll bending operation is required for any reason, such as roll heat up, etc. to reestablish the desired roll contour for rolling, the operator moves rheostat 74' to the proper roll bending load application position.

In the case of where a constant roll bending load is to be applied, the operator merely adjusts rheostat 74', leaving the other rheostat 94 in the circuit between amplifiers 86 and 76' in a zero or at rest position. By turning this roll bend pressure adjusting rheostat 74' to increase pressures in actuators 42, a positive signal is fed to the roll bending summing amplifier 76' and if no counter-signal is fed back from the roll bending pressure sensor 82 the signal to valve 80 will continue to be positive until valve 80 has fully operated to build up the necessary pressures in actuators 42. As the pressure builds up, the pressure sensor 82 will feed back negative signals to summing amplifier 76' or signals opposite in polarity to the signals set by rheostat 74'. When the signals from rheostat 74' are substantially equated with the signals from sensor 82, the signals from amplifier 76' to the valve 80 will cease and shut off valve 80 when the desired roll bending pressure is reached.

An increase in roll bending cylinder pressure, however, will also cause the additional application of pressure on the pushup cylinders thus, in effect, increasing the rolling load which will relieve the pressure on the load cells as contact is lost between rods **74** and the lower chock blocks **26**. This loss of pressure on the load cells will result in the unloading of the load cells and cause the signals from the load cells **76** to amplifiers **70** to be appropriately negative. The signals then emanating from amplifiers **70** as determined by the difference between load cell signals and rheostats **72** will cause whatever increase in the pushup cylinder pressure is needed to reload cells **76** and compensate for the roll bending pressure and the mill housing stretch due to the new increase in rolling load.

This additional pushup loading will, however, usually cause undesirable roll deflection from the bending deflection desired which will now be reflected by feed back signals from sensors **82** and **92** and, consequently, may require additional roll bending to compensate for the increase in pushup loading.

This is done automatically in the following fashion. It will be remembered that auxiliary summing amplifier **86** receives feed back signals both from pushup load sensors **88** and **90** and a roll bending load sensor **92**. The feed back signal in line **91** from sensor **92** is opposite in polarity to the signals from the pushup sensors in lines **89** and this feed back signal reflects the loss in the desired bending roll pressures as set by rheostat **74'**. All of these signals are now combined with one another at amplifier **86** and the algebraic sum of the two sets of signals, which are properly calibrated as regards each other in amplifier **86**, is used as a further signal that can be fed to amplifier **76'** and this further signal is superimposed upon the original signal transmitted through amplifier **76'** and as initially received from rheostat **74'**. It will also be remembered that roll bending sensor **82** continues to operate at the same time and when the feed back signals from line **84** coming from bending roll sensor **82**, which are opposite in polarity to the net input signals received by amplifier **76'** from rheostat **74'** and amplifier **86**, substantially reaches the value of the aforesaid net input signals activation of valve **80** will cease and the desired balance between bending roll actuators and pushup actuators will be reached. In the aforesaid operation of amplifier **86**, the algebraic sum of the signals from sensors **88** and **90** and **92** can be regarded as amounting to the final or overall rolling load, (i.e. bending load plus the superimposed workpiece load) plus the contant preset load cell pressure, which final rolling load is to be equated by the final pushup loads.

Thus, any increase in the overall rolling load will be followed instantly by the required pushup pressures and pushup loads. If further compensating bending loads are required they too are made readily available. In order to keep the aforesaid process from "cascading," since it must be remembered that load cells **76** are also functioning at the same time to maintain load cell pressure, until both the roll bend pressure and the pushup pressure are at the maximum, preferably not more than 50 percent of the differential pushup pressure signals from amplifier **86** are fed to the roll bending summing amplifier **76'**. This is accomplished by means of the rheostat **94** interposed in the circuit between amplifiers **86** and **76'**. Rheostat **94**, of course, can be adjusted to increase or even further decrease the signals from amplifier **86** or to make other minute adjustments in the feed to amplifier **76'**. These amplifiers **70**, **76'** and **86** can be of the type sold by Burr-Brown Research Corporation of Tucson, Ariz., as Model Nos. 1506 or 1507. Instead of rheostat **94**, a suitable function generating device can be employed, which can be made to vary the effect of amplifier **86** with relation to any desirable variable, such as rolling load, temperature of work rolls, etc.

In the modified form of the control circuit **57** of FIG. 3, in which parts corresponding to previously described parts are used and given the same reference numerals unless otherwise specified, it is contemplated that the gauge rods **74** and load cells **76** would be removed from the mill **10** of FIGS. 1 and 2. Thus, with the rolls **14** and **16** being so disposed relative to each other within the mill **10** whereby for all practical purposes there is no gap between the rolls **16** and prior to entrance of a workpiece therebetween, the modified circuit of FIG. 3 is adjusted in such a fashion by adjustments of rheostats **72** so as to apply a predetermined pushup load on the backup and work rolls in accordance with expected rolling load conditions and established rolling practices. This preselected pushup load setting can then be used as a main reference point for operation of the modified overall control circuit **57** of FIG. 3.

Thus, in the instance of control circuit **57**, the sensing devices **88'** and **90'**, which are similar to sensing devices **88** and **90** previously described, are used to constantly sense or monitor the fluid pressure of the pushup components in the overall circuit **57**. They are each advantageously connected in parallel by their separate lines **96** to the auxiliary summing amplifier **86** as before and in addition to different ones of the two summing amplifiers **70**. The sensing device **92'**, which is similar to device **92**, within the roll bending load component part of circuit **57** is not only connected by the line **98** to the amplifier **86** in the roll bending load part of the circuit as before, but it is also connected and interlocked in parallel to one of the summing amplifiers **70** in the pushup load portion of the circuit. The other sensing device **82'**, which is similar to previously described sensing device **82**, and is located within the bending load component part of the circuit, is not only electrically connected by the line **100** to an amplifier **76'** in the roll bending portion of the circuit as before, but it is also connected and interlocked by the same line **100** to the other summing amplifier **70** in the pushup load portion of the circuit. The electrical signals transmitted by the roll bend load feed back sensing devices **82'** and **92'** are normally of the same polarity as the initiating pushup signals received from the rheostat load setting devices **72** but opposite in polarity to the signals normally received from the feed back sensing devices **88'** and **90'** used in sensing the fluid pressures in the lines for the pushup actuators **33**.

By virtue of the aforesaid interlocking of the several sensing devices **88'**, **90'**, **82'** and **92'**, the signals from rheostats **72** are used as follows to set the pushup actuators to a given pressure position so that the desired roll gap will be established and maintained during a given rolling operation. When additional pushup pressures are needed to compensate for the rolling load applied to the rolls by a workpiece W, the feed back signals from sensors **88'** and **90'** transmitted to amplifiers **70** reflect this and amplifiers **70** will operate to produce the necessary actuation of valves **66** until the signals from sensors **88'** and **90'** are again substantially equated with the signals from rheostats **72**. If the aforesaid rolling load is further increased by operation of the roll bending actuators **42** so that a new overall rolling load exists, sensors **82'** and **92'** in addition to feeding back signals to the main roll bending load amplifier **76'** also feed back signals to the summing amplifiers **70** along with feed back signals from sensors **88'** and **90'** until the algebraic sum of the feed back signals of the sensors **88'**, **90'** and sensors **82'** and **92'** substantially equate the original signals fed to amplifiers by the presetting of amplifiers **70** by rheostats **72'** and thereby indirectly reestablish the desired roll gap setting as determined by the original presetting of rheostats **72**.

Conversely, if the pushup pressures at any time become so great whereby the signals to amplifier **76'** become unbalanced and applied roll bending loads and roll contour are adversely affected, the feed back signals from pushup sensors **88'** and **90'** to amplifier **86** are further compared

with the feed back signal from sensor 92' which reflects the change in roll bending pressure from that desired and being requested by rheostat 74. When the algebraic sum of the signals from sensors 88', 90' and 92' and as transmitted by amplifier 86 substantially equate the feed back signal from sensor 82' to amplifier 76', no differentiating signal will be transmitted to amplifier 76' from amplifier 86 for further operating valve 80 and the roll bending load will be retained at that established by the setting of rheostat 74'. Thus, sensors 92' and 82' in the circuit of FIG. 3 as in the case of sensors 92 and 82 in the circuit of FIG. 2 perform a dual function in that they act as feed back devices for the roll bending actuators and at the same time as a means for comparing pushup pressures with bending roll pressures whereby any increase in pushup pressure which is adverse to the desired bending roll pressures is compensated for by increasing the roll bending pressures untilthe desired balance or proper equilibrium is established between roll bending and pushup pressures.

Further, the various embodiments of the instant invention can be used to advantage with other rolling mill instrumentations, such as specially designed work flattening control devices, computers, etc., to obtain the very optimum overall rolling conditions such as where one mill stand equipped with the improvements of the instant invention is used alone and equipped with specially designed work flattening control devices or a series with other mill stands equipped with specially designed work flattening control devices. The invention is also applicable to mill stands comprised only of work rolls which have roll bending attachments and to mills used to roll other materials besides metal.

Advantageous embodiments of the invention have been shown and described. It is obvious to those skilled in the art that various changes and modifications may be made therein without departing from the spirit and scope thereof, as set forth in the appended claims, wherein:

What is claimed is:

1. In a rolling mill apparatus including a framework and a pair of rolls rotatably and slidably mounted within said framework; a mill roll gap control system for said apparatus comprised of a roll pushup means including a first actuator operatively connected to said frame work and one of the rolls for applying selected pushup loads to said rolls and a first fluid circuit for said first actuator; a roll bending means including a second actuator operatively connected to a roll for applying bending loads thereto and a second independent fluid circuit for said second actuator; a first control means for controlling said first fluid circuit and for operating the actuator of said roll pushup means; a second control means for controlling said second fluid circuit and for operating the actuator of said roll bending means; means including electro-load sensing means interlocking said first and second control means, said first and second fluid circuit and said first and second actuators in an interdependent relationship whereby a predetermined actuation of one of said actuators can produce a preselected actuation of the other actuator in order to reestablish and maintain an established roll gap setting.

2. The apparatus as set forth in claim 1, including means for presetting one of said control means in order to initially establish a predetermined roll gap setting for a given rolling operation.

3. A mill roll gap control system for use with a rolling mill apparatus comprised of a framework, a pair of rolls and chock block means for rotatably and slidably mounting said rolls within said framework; said mill roll gap control system being comprised of a pushup means including a first actuator operatively connected to said framework and one of said rolls for applying selected pushup loads to said rolls in a direction transverse to the normal axis of said rolls; a first electro-control means operatively connected to said first actuator and including electrical signal transmitting means for adjusting said first actuator in accordance with an initially established roll gap setting when roll separating forces generated by a workpiece being rolled are applied to said rolls so as to reestablish and maintain the initially established roll gap setting; roll bending means, and a second electro-control means for said roll bending means and including an electrical signal transmitting means for adjusting the roll bending means in accordance with a desired roll bending condition; and further electro-control means which operate in conjunction with said first and second electrical signal transmitting means of said first and second electro-control means to interlock said first and second electro-control means and to transmit electrical signals to said second actuator to effect adjustment in the roll bending means when the roll bending means is adversely affected by operation of said pushup means so as to maintain the initially established roll gap setting and thereby produce a final workpiece having a substantially uniform gauge across its entire width.

4. An integrated roll bending and roll pushup control system for a rolling mill apparatus comprised of a framework and a pair of rolls rotatably and slidably mounted within said framework; said control system comprising a roll pushup means including a first actuator operatively connected to said framework and one of the rolls for establishing and maintaining a predetermined pushup load upon said rolls and a first fluid circuit for said first actuator; a roll bending means including a second actuator operatively connected to a roll for applying bending loads thereto and a second independent fluid circuit for said second actuator; a first electro-control means for operating the fluid circuit for said pushup means; a second electro-control means for operating the fluid circuit for said roll bending means; means including electro-load sensing means interlocking said first and second electro-control means and said actuators in an interdependent relationship whereby whenever a predetermined actuation of one of said actuators adversely affects the operation of the other actuator said other actuator will be further operated so as to bring one actuator into full balance with the other actuator.

5. A control system as set forth in claim 4 including means for presetting said first control means in accordance with a predetermined pushup load.

6. A system as set forth in claim 4, wherein the first electro-control means of said system includes a gauge rod and a load cell sensing element operatively connected to said pushup means.

7. A system as set forth in claim 4, wherein chock blocks are provided for one of the rolls and the first electro-control means of said system includes a gauge rod and a load cell sensing element operatively connected to said pushup means, the free end of the gauge rod being mounted so as to rest upon and be in selected pressure contact with one of said roll chock blocks whereby it is sensitive to a movement of said roll chock block in a direction generally normal to the axis of said chock block.

8. A system as set forth in claim 4, wherein the rolling mill apparatus with which the system is associated includes backup and work rolls and said roll bending means is connected to the backup rolls.

9. A system as set forth in claim 4, wherein said electro-load sensing means includes a load feed back sensor for the first fluid circuit, a load feed back sensor for the second fluid circuit and an auxiliary summing amplifier connected to both of said load feed back sensors and to the actuator of said roll bending means.

10. A system as set forth in claim 4, wherein said electro-load sensing means includes an amplifier connected to said pushup means actuator, a load feed back sensor connected to said amplifier and to the roll bending means actuator, and a load feed back sensor also connected to said amplifier and said pushup means actuator.

11. A system as set forth in claim 4, wherein said electro-load sensing means includes a summing amplifier,

a load feed back sensor for the first fluid circuit, a load feed back sensor for the second fluid circuit and an auxiliary summing amplifier connected to both of said load sensors and to said summing amplifier.

12. A system as set forth in claim **4**, wherein said electro-load sensing means includes a first summing amplifier connected to said pushup means actuator and a second summing amplifier connected to said roll bending means actuator, a load feed back sensor connected to said first named actuator and both of said summing amplifiers and a second load feed back sensor connected to said second named actuator and both of said summing amplifiers.

13. A system as set forth in claim **10**, including means for transmitting an initial reference signal to said amplifier.

14. A system as set forth in claim **11** including means for transmitting an initial reference signal to said summing amplifier.

15. A rolling mill apparatus comprising a framework, a pair of rolls, chock blocks for rotatably and slidably mounting said rolls within said framework, pushup means including an actuator operatively connected to said framework and one of the chock blocks for applying pushup loads to one of said chock blocks and said rolls in a direction transverse to the normal axis of said rolls, control means operatively connected to said pushup means actuator and including a load cell for transmitting electrical signals to said pushup means actuator, a load cell rod connected to said load cell and having a free end adapted to rest upon and be in pressure contact with the top of the lowermost chock block of said chock blocks, said load cell rod also being mounted so as to be free of any pressure contact with another chock block, means for applying a predetermined pressure to said pushup means actuator and means interconnecting said load cell to said actuator pressure applying means whereby when a rolling load is applied to said mill apparatus by a workpiece and the load cell rods cease to be in pressure contact with the one chock block said load cell will operate to transmit a signal to the actuator pressure applying means of said pushup means actuator to move the said one chock block and return said one chock block into a selected pressure contact with the load cell rod.

16. An apparatus as set forth in claim **15** wherein said control means includes a summing amplifier for establishing a preselected load on said pushup means actuator and a feed back circuit from the load cell to the summing amplifier.

17. An apparatus as set forth in claim **15** wherein said control means includes a summing amplifier connected to said pushup means actuator, a rheostat for establishing a reference signal to said summing amplifier and a feed back circuit from the load cell to the summing amplifier.

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