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CONTROL FOR ROLLING MILLS

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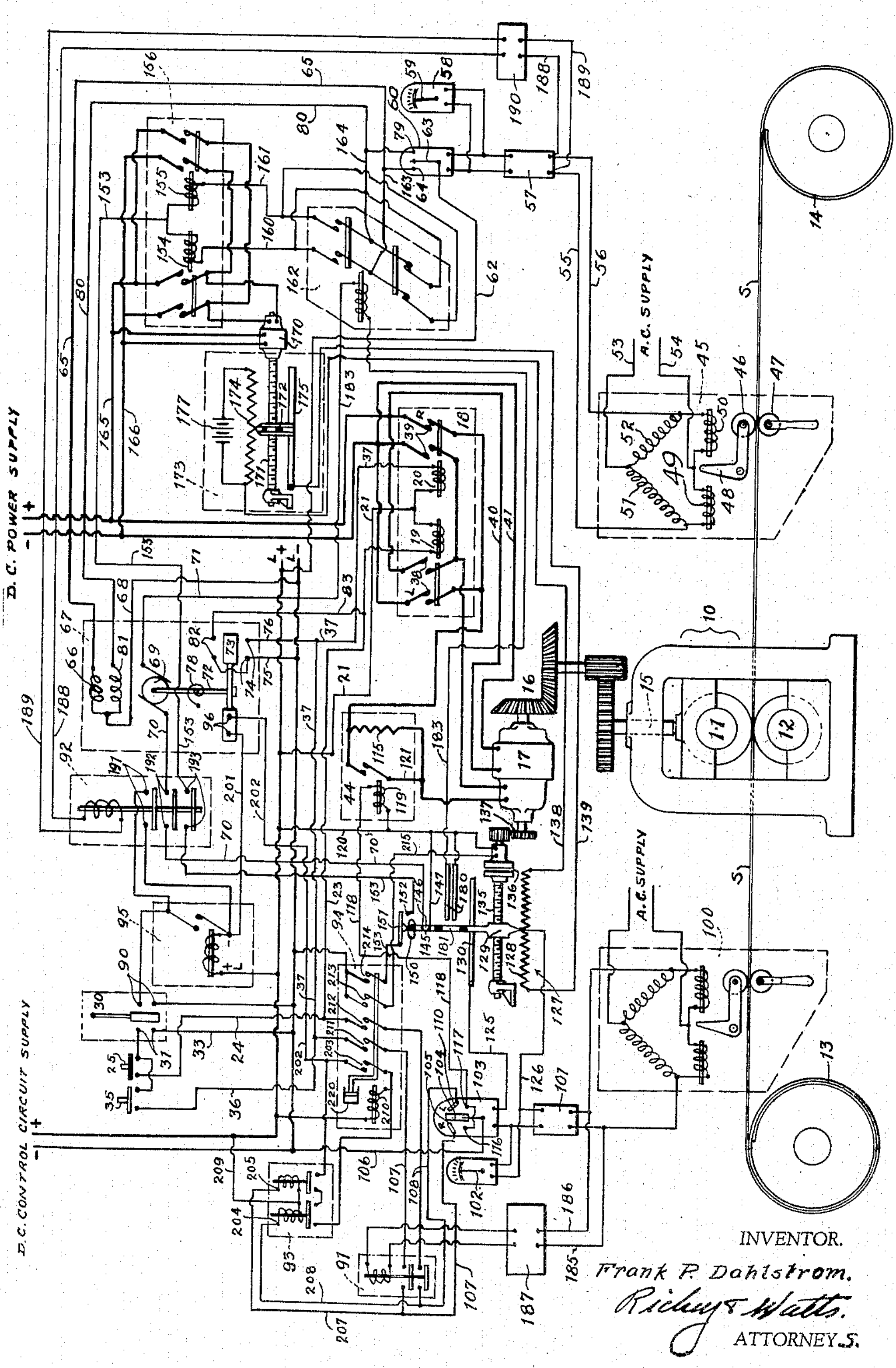

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CONTROL FOR ROLLING MILLS

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This invention relates to rolling mills such as are employed for rolling strips or sheets of steel, although it will be understood that the invention may be employed in conjunction with mills adapted to operate on other materials. More particularly the invention relates to a method and apparatus for automatically controlling the setting of the rolls of rolling mills in such a manner as to produce a strip or sheet of material of substantially uniform thickness.

In modern strip mills used in the production of steel sheets and strips, the material is passed between the rolls at high speed in long lengths. The operator attempts to produce material of uniform thickness by raising and lowering the screw-downs of the mill in accordance with variations in the thickness in the finished product. Frequently in modern mills, a continuously reading micrometer disposed in engagement with the strip after the strip leaves the mill is provided. By watching the changes in gage of the strip, as indicated by the micrometer, the operator attempts to correct the setting of the mill rolls to produce a strip of substantially uniform thickness. Necessarily, he is unable to even attempt to correct the setting until after some material of incorrect thickness has passed through the mill. In modern mills operating at speeds of say 500 or 600 feet per minute, even the most skilled operator with the best equipment must produce a considerable proportion of material which varies noticeably from the standard gage desired.

Many of these variations are caused by variations in the thickness of the strip entering the mill. Because of the elasticity of the mill, a thick strip entering the mill will result in the production of finished material above the standard gage unless the mill setting is adjusted before the thickened portion reaches the mill, and similarly if the strip being fed has a portion thinner than standard the finished strip will be rolled to a thinner gage than desired. In accordance with the present methods of operation wherein the operator adjusts the screw-downs in accordance with the indications on a gage disposed on the strip after the strip leaves the mill, it frequently may occur that the changes in thickness in the entering strip will be so closely spaced as to make it impossible for the operator to adjust the roll setting in time to produce strip of correct thickness, and in fact the changes may occur in such a manner that the operator's actions will accentuate the differences in thickness in the finished strip. One reason for this is that the large present day mills require powerful motors for operating screw-downs and an appreciable length of time elapses between the time when the operator presses the button to start the screw-down motor and the time when the motor gets up to speed and is able appreciably to move the screw-down mechanism. Furthermore, the operator himself can not act instantaneously but must note the kind and extent of error occurring in the finished strip and decide how to correct it, and then proceed with making the correction in the roll setting. Thus in the ordinary operation of mills, there are three cumulative delays between the time the error occurs and the time when the mill setting is corrected to compensate for the error. The first is due to the fact that the strip is not gaged until it has passed through the mill, the second is occasioned by the time required for the operator to note the error and take steps to correct it, and the third is caused by the relatively slow response of the screw-down mechanism of the mill. While the total delay may be very small, nevertheless the mills are operated at such speeds that a considerable quantity of material may pass through the mill before the error is corrected.

According to a preferred form of my invention, I eliminate the delays noted above and automatically and accurately correct the setting of the mill to insure the production of material of substantially uniform thickness by automatically adjusting the mill in accordance with variations in thickness of the material entering the mill. My mechanism is preferably controlled by gages engaging the strip before it passes through the mill as well as after it has passed through the mill. I thus provide an anticipating control which detects variations in thickness of material entering the mill and corrects the setting of the mill rolls as the material of changed thickness reaches the roll stand so as to insure the delivery of material of proper gage. Further, I preferably provide in conjunction with the anticipating control apparatus a gaging and contolling mechanism actuated by a gage measuring the thickness of the strip after it leaves the roll stand automatically to adjust or calibrate the anticipating control mechanism to insure the production of material of correct thickness and to correct the mill setting to compensate for variations in thickness of the finished strip which may occur even though no substantial changes in the thickness of the entering strip have taken place. In combination with the foregoing mechanism I preferably provide manual controls for operating the screw-downs, apparatus whereby the mechanism automatically sets itself when a new strip is entered in the mill, and means for preventing the mechanism from operating when there is no strip in the mill.

It is among the objects of my invention to provide a method and apparatus for controlling the setting of the rolls of a rolling mill to insure the production of material of substantially uniform thickness throughout its length. It is a further object of my invention to provide a method and apparatus for varying the percentage of reduction taken in a rolling mill in accordance with variations in thickness of material entering the mill. It is a further object to provide such a method and apparatus in which the gage of the finished product is employed to calibrate the mechanism to compensate for any errors which may occur in the finished thickness of the strip and which have not been compensated for by the anticipating control mechanism. Another object is to provide an apparatus which will adjust a rolling mill to compensate for whatever variations in thickness of finished strip may occur even though the thickness of the strip entering the mill remains constant. It is another object to provide apparatus of simple and sturdy construction which can be constructed at relatively low cost and which can be readily adapted to existing mills. A further object is to provide an apparatus which will automatically make a correct initial setting of the mill in accordance with the thickness of the finished strip and thereafter maintain the production of strip of correct thickness by means actuated in response to changes in thickness of the entering strip. Further objects and advantages of my invention will become apparent from the following description of a preferred form thereof, reference being made to the accompanying drawing which diagrammatically illustrates a preferred form of my control mechanism as applied to a rolling mill of conventional construction.

In the drawing, apparatus is shown as applied to an ordinary two-high mill indicated generally at **10** and having rolls **11** and **12** adapted to act upon the strip S which may be fed to the mill from a coil **13** and delivered to a coil **14**, although it will be obvious that the invention may be applied to mills of different types such as four-high mills or tandem mills embodying a plurality of roll stands.

The rolling pressure exerted by the mill may be controlled by a conventional screw-down mechanism **15** operated through the gear train indicated generally at **16** by means of a motor **17**. All of the parts described above are conventional and require no further description here.

Manual controls.—To control the operation of the screw-down motor **17** I may employ a reversing controller **18** which controls the current supplied to the armature of the motor **17**. The controller includes solenoids **19** and **20** which may be energized through the common conductor **21** leading to the control voltage supply line L+. When the master control switch **30** is swung to its manual control position (to the left in the drawing) to close the contacts **31** operation of the push button **25** will complete the circuit through the conductor **33**, the contacts **31**, and conductors **24** and **23** to energize coil **19**. Similarly the operation of the push button **35** will close the circuit from the negative side of the control circuit line through conductor **33**, contacts **31** and conductors **36** and **37** to energize solenoid **20**. Energization of solenoid **19** closes contacts **38** completing the circuit from the power supply lines to the armature of the motor **17**, through the accelerating contactor **44** to be described below, the connections being such that the motor operates to lower the screw-downs. Energizing of solenoid **20** closes contacts **39** to reverse the connections to the armature of motor **17** and thus to operate the motor to raise the screw-downs. The field current may be supplied to the motor through conductors **40** and **41** leading to the power supply lines.

By means of the above described controls the setting of the mill rolls can be manually controlled in the conventional manner. To provide automatic control of the setting of the mill rolls I preferably employ the instrumentalities about to be described all of which function in response to changes in the thickness of the material being operated upon by the mill to control the screw-down motor through the reversing controller **18** by energizing the solenoids **19** or **20** as the case may be to lower or raise the screw-down mechanism.

Control of screw-down in response to variations in thickness of finished strip.—To provide principally for automatic initial setting of the screw-downs I preferably employ mechanism responsive to variations in thickness of the finished strip and including continuous gaging device **45** which engages the strip immediately after it has passed through the mill rolls. Preferably the gage is of the type manufactured by the Pratt & Whitney Company, of Hartford, Connecticut, and marketed by them under the name "Electro-Limit" continuous gage. Briefly, this type of gage comprises rollers **46** and **47** engaging opposite sides of the strip, variations in distance between the rollers being reflected by movement of the armature **48** between the coils **49** and **50** which constitute part of an inductive bridge completed by the coils **51** and **52**. The bridge is supplied with alternating current through the conductors **53** and **54**. Movements of the armature **48** between the coils **49** and **50** result in variations in the impedance of these coils which will be reflected by variations in the voltage delivered by the conductors **55** and **56**. The voltage is rectified by a rectifier indicated at **57** and changes in the output are indicated by a D. C. micro-ammeter **58**, the circuits ordinarily being arranged so that an increase in the spacing between the rolls results in an increase in current flowing through the micro-ammeter.

The gage is constructed so that for any setting, the needle **59** of the micro-ammeter remains in the center when strip of the standard thickness for which the gage is set is passing between the rolls **46** and **47**. That is, the output voltage of the bridge circuit is constant and the instrument is calibrated so that the output of the gage maintains the needle in a central position so long as the rolls are spaced apart a distance equal to the standard thickness for which the gage is set. Variations in strip thickness above and below standard result in increases and decreases in output of the gage, which are indicated by movement of the micro-ammeter needle to the right and left, respectively. Movement of the needle along the scale is substantially in proportion to variations in thickness, and the instrument is sensitive to variations of less than one-ten thousandths of an inch. This type of gaging apparatus is well known in the art and will not be described further herein as the gage per se forms no part of the present invention.

To utilize the gage for controlling the screw-down motor, I connect in parallel with the micro-ammeter 58 a contact-making micro-ammeter or relay 60, which is arranged to operate the screw-down motor to reduce the pressure on the mill rolls upon decrease in thickness of the strip passing between the rollers of the gage 45 and to increase the rolling pressure upon increase of thickness of the strip passing through the gage 45. This operation is carried out through the electrical circuits shown, wherein the relay is supplied with a control current through the conductor 62, movement of the contactor 63 of the relay to the left, for example, into engagement with contact 64 in response to a reduction in the output voltage of the gage caused by reduction in thickness of the material by an amount exceeding the established tolerances, resulting in closing the circuit between the conductors 62 and 65, thereby energizing field coil 66 of oscillating relay 67, which is connected to the other side of the control circuit through conductor 68.

Assuming that the armature 69 of the oscillating relay 67 is energized through conductors 70 and 71 and connections to be described in detail below then the energization of field coil 66 will cause the armature 69 to rotate (in a clockwise direction in the embodiment shown) the shaft 72 to move the contactor 73 of the relay into engagement with contacts 74 thus completing the circuit through conductors 75 and 76 and energizing the solenoid 20 of the reversing controller 18 and causing the screw-down motor 17 to operate in a direction to raise the screw-down and reduce the rolling pressure applied to the strip until the strip passing between the rolls of the gage 45 becomes of the standard thickness for which the gage is set, at which time the contactor 63 will move back to its central position thus de-energizing field coil 66 of the oscillating relay and permitting the spring 78 to rotate shaft 72 back to its neutral position, breaking the circuit between the contacts 74 and stopping the screw-down motor.

Similarly an increase in thickness of the material passing through the gage 45 by an amount exceeding the established tolerances will cause the contactor 63 of the relay 60 to swing to the right into engagement with contact 79 and completing the circuit between conductors 62 and 80 thereby energizing field coil 81 of the oscillating relay, which is wound oppositely to coil 66, and causing the armature 69 to rotate in a direction to move the contactor 73 into engagement with contacts 82, closing the circuit between conductors 75 and 83, thus energizing solenoid 19 to close the contacts 38 and thereby supplying current to the screw-down motor 17 to cause the motor to operate in a direction to increase the rolling pressure applied to the strip. By this means the screw-downs may be automatically operated to insure production of strip of the thickness for which the gage 45 is set. This mode of operation, however, is preferably only employed in the initial operation of the mill when the strip is first fed therethrough or to take care of changes in thickness or finished strip which may occur due to changes in the operating conditions of the mill or changes in the character of material passing through the mill when no substantial change takes place in the thickness of the material entering the mill.

Anticipating control mechanism.—It will be understood by those skilled in the art that if a strip of uniform thickness and uniform physical characteristics is fed to a mill having a given roll setting and operating under uniform conditions, a definite and uniform percentage of reduction of thickness in the strip will take place. Thus the thickness of the rolled product will be uniform. However, any changes in any of the factors listed above will result in a variation in the thickness of the finished product unless the mill is adjusted to compensate for such variations. It has been my observation that most of the variations in thickness of the finished product are caused by non-uniform thickness of the entering strip. In order to eliminate errors in finished strip thickness due to such non-uniformity I preferably employ an anticipating control mechanism the principal elements of which will now be described.

For convenience in description it will be assumed that the master control 30 is swung to the right to close contacts 90 to set the device for automatic operation, that the circuits are completed through the lockout relays 91 and 92, the automatic control contactor 94, and the holding contactor 95, and that the finished strip passing through the gage 45 is of substantially standard thickness so that the oscillating relay 67 is in its neutral position thus completing the circuit between contacts 96. The operation of these various instrumentalities will be described below it being necessary that the circuits be arranged as just pointed out in order for the anticipating control to be placed in operation.

The anticipating control mechanism comprises a continuous gaging device 100 which may be similar in all material respects to the gage 45 heretofore described. The output of the gage is passed through a rectifier 101, and thence to an indicating micro-ammeter 102 and a contact making micro-ammeter or relay 103. The gage is set by the operator for the average standard thickness of the entering strip and so long as the strip entering the mill does not vary from the standard thickness by an amount exceeding the established tolerance, the contactor 104 of the relay 103 will remain in the center and there will be no change in the operation of the mill. However, should the strip thickness decrease by an amount exceeding the tolerance then the contactor 104 will swing to the left into engagement with contact 105 thus completing the circuit from the control circuit supply through conductors 106 and 107, the relay 91 and contactor 94 to the conductor 37 which completes the circuit through coil 20 of reversing controller 18 thus energizing the armature of the screw-down motor 17 and causing the motor to operate in a direction to raise the screw-down to reduce the rolling pressure applied to the strip, thus reducing the percentage of reduction taken by the mill and compensating for the reduction in thickness of the entering strip.

Similarly, an increase in the thickness of the entering strip exceeding the established tolerance will cause the contact 104 to swing to the right engaging contact 110 and completing the circuit through conductors 106 and 108, relay 91 and contactor 94 to conductor 23 thus energizing solenoid 19 of reversing controller 18 and closing contacts 38 to supply power to the motor 17 to operate in the opposite direction to increase the rolling pressure exerted on the strip, thus increasing the percentage of reduction taken by the mill and compensating for the increase in the thickness of the entering strip.

Variable speed control of screw-down.—Under some circumstances it may be desirable to provide for different speeds of operation of the screw-down motor so that the mill may be adjusted more rapidly in response to relatively great changes in thickness of the entering strip. To accomplish this, the acceleration device 45 may be employed. This may comprise a resistance 115 in the armature circuit of motor 17, an additional control circuit being employed to cut out the resistance in the event of a relatively large change in the thickness of the material passing through the gage. This operation is effected by relay 103, which is provided with additional contact points 116 and 117. A wide swing of the contactor 104 in either direction will complete the circuit between the conductor 106 and conductor 118 to which both contact points 116 and 117 are connected. Completing this circuit results in the energization of the magnetic switch 119 which is connected to the control line through conductor 120, thereby placing the conductor 121 in parallel with the resistance 115 and thus increasing the speed of the motor 17 regardless of the direction of its rotation.

Balancing circuit.—To prevent hunting and to insure that the screw-down motor will operate just sufficiently to correct the setting of the mill, I preferably employ a compensating or balancing circuit in conjunction with the relay 103 which functions to maintain the contactor of the relay in its central or off position whenever the screw-down has operated just sufficiently to compensate for the variations in thickness of the material entering the mill. This is accomplished by applying to the relay 103 a balancing electro-motive force controlled in accordance with the position of the screw-down and in accordance with the thickness of the material delivered by the mill. The main balancing circuit is connected in series with the relay by the conductors 125 and 126. The circuit includes the compensating or balancing potentiometer indicated generally at 127 and comprising a suitable resistance 128 connected at its center to conductor 126, and a sliding contactor 129 which engages the resistance 128 and makes contact through the slide 130 with the conductor 125.

The sliding contactor 129 may be moved either to the right or to the left of its neutral position by a worm 135 driven by the screw-down motor 17 through magnetic clutch 136 and gears 137. Thus, whenever the clutch is engaged, the position of the contactor 129 is controlled by and varies with the position of the screw-down mechanism, the contactor remaining in neutral position so long as the strip entering the mill is of standard thickness. As the ends of resistance 128 are connected to a source of electromotive force through conductors 138 and 139 the polarity and intensity of the balancing voltage applied to relay 103 is varied by movement of sliding contactor 129; the balancing voltage increasing as the contactor is moved from its neutral position and the polarity being reversed as the contactor moves from one side of the neutral position to the other.

As long as the thickness of the strip entering the mill remains within the predetermined limits, the contactor of relay 103 will not swing far enough from its neutral position to close the control circuits and the control mechanism will not operate. However, assuming for example that the strip thickness becomes greater than standard by an amount exceeding the established tolerance, then the gage 100 will operate to increase the current flowing through the relay 103 causing the contactor to swing to the right and operating the reversing switch 18 to start the screw-down motor in a direction to increase the pressure applied to the strip. This operation of the screw-down motor also drives the worm 135 which controls the output of the compensating potentiometer 127, moving the sliding contact 129 away from its central or neutral position in a direction (to the left, in the apparatus shown) tending to apply a balancing or compensating voltage to the relay 103 through the conductors 125 and 126 opposing the output voltage of the gage and thus tending to restore the contactor of the relay to its central or off position. The restoring effect increases in proportion to the distance the contact 129 is moved from its central position, and thus the restoring effect increases in proportion to the movement of the screw-down. When the screw-down has operated sufficiently to compensate for the increase in thickness in the strip, the balancing voltage will be sufficient to move the contactor of relay 103 to its central or off position, the screw-down motor will stop and will not operate again until a further change in conditions occurs.

If a reduction in thickness of the strip passing through the mill occurs, the operation of the gage 100 will result in a decrease in the current flowing through the relay 103 thus causing the contactor to swing to the left and operating the reversing controller 18 to start the screw-down motor in a direction to decrease the pressure applied to the strip. This operation will result in the movement of the contactor 129 of the balancing potentiometer towards the right, thus decreasing the opposing balancing voltage applied to the relay 103, if the contactor 76 was in a position to the left of center when the reduction in thickness occurred; or applying a balancing voltage of the same polarity as the output voltage of the gage if the contactor moves to the right of its neutral position. As before, the change in balancing voltage tends to restore the contactor of the relay to its central or off position. As before, the restoring effect increases in proportion to the distance the contactor 129 has been moved and because of this mode of operation all possibility of hunting is eliminated.

Calibrating control.—The balancing potentiometer can be arranged so that for a given set of operating conditions and for operations carried out on material having uniform physical characteristics the screw-downs will be operated the correct amount for each variation in thickness of material entering the mill. The amount of operation of the screw-downs for a given variation in thickness can be readily adjusted by varying the voltage applied to the compensating potentiometer through the conductors 138 and 139. Thus if the screw-downs should be over-correcting, then the electromotive force applied to the potentiometer should be increased so that a smaller movement of the contactor 129 would result in a greater change in the balancing voltage applied to the relay 103, and if the screw-downs are under-correcting the applied electromotive force should be reduced. The voltage supplied to the compensating potentiometer may be adjusted manually but preferably I adjust the voltage automatically in accordance with variations in the thickness of the finished strip in order automatically to calibrate the anticipating control mechanism to prevent error from occurring by reason of changes in the operating conditions of the mill or changes in the physical characteristics of the material being rolled, thereby insuring the production of finished material of substantially uniform thickness.

The control of the applied voltage is carried out by mechanism including gage 45, and the contact making micro-ammeter or relay 60 previously described in connection with the control of the screw-down in accordance with variations in thickness of the finished strip. Preferably the circuits from relay 60 are arranged so that whenever the contactor or slider 129 moves from neutral position by more than a predetermined amount, relay 60 operates to control the balancing voltage supplied to the balancing potentiometer 127 by conductors 138 and 139 instead of controlling the screw-down motor through oscillating relay 67. Thus so long as contacts 145 in conductor 70 are bridged by contactor 146 mounted on but insulated from sliding contactor 129, current can flow from the control voltage supply line through conductors 120 and 147, conductor 70 and relay 92 to energize the armature 69 of oscillating relay 67. Whenever sliding contactor 129 is moved away from its central position, contactor 146 is disengaged from contacts 145 and thus armature 69 is de-energized and the oscillating relay 67 is rendered inoperative.

Movement of sliding contactor 129 away from center also disengages the cam 150 from contactor 151 which then moves into engagement with contact 152 to close the circuit from the control current supply line through automatic control contactor 94, conductors 153 and lockout relay 92 to magnetic switches 154 and 155 of the calibrating control contactor 156. The circuits leading back to the control supply lines from switches 154 and 155 are completed by conductors 160 and 161, the reversing switch 162 and conductors 163 and 164 extending to contacts 64 and 79 of relay 60, and thence through contactor 63 and conductor 62 back to the line. The switches 154 and 155 are connected to the main power supply by lines 165 and 166, and control the small motor 170 which drives the screw 171 to move the sliding contactor 172 of the potentiometer 173. A suitable electromotive force may be supplied thereto as by the battery 177.

The output of the potentiometer 173 is connected to the ends of the resistance 128 of the balancing potentiometer 127 through the conductors 138 and 139. Thus the operation of the motor 170 and movement of the sliding contactor 172 along the resistance 174 and sliding contact 175 varies the output of potentiometer 173 and the voltage applied to the balancing potentiometer, thereby changing the effect of the balancing potentiometer and varying the balancing or restoring voltage applied to the anticipating control relay 103.

Assume, for example, that strip of greater thickness than standard is being fed to the mill and that the controls actuated by gage 100 do not operate the screw-down mechanism sufficiently to produce material of proper gage, but instead the mill produces material which is thicker than standard. Then the contactor 63 of the relay 60 will move to the right, energizing the magnetic switch 154 to close the circuit to the motor 170 which drives the worm 171 moving the contactor 172 in a direction (to the left in the apparatus illustrated) to decrease the voltage applied to the balancing potentiometer 127, thereby reducing the balancing voltage applied to the relay 103 and causing the relay to close the circuit through contact 104 until such time as the motor 17 operates the screw-down sufficiently to insure the production of strip of proper gage, and rotates the worm 135 sufficiently to move the sliding contactor 129 away from its central position an additional amount sufficient to offset the decrease in the applied voltage, thus again increasing the balancing voltage and bringing the relay 103 back into balance and to its "off" position.

Similarly, if the entering strip is thicker than standard but the product is thinner than standard, then the relay 60 will actuate the the switch 155 to operate the motor 170 in the opposite direction, moving the contact 175 to increase the voltage applied to the compensating potentiometer, thus throwing the relay 103 out of balance again but in the opposite direction and causing the relay to operate the switches necessary to raise the screw-down until strip of proper thickness is produced and the relay is again balanced.

If the entering strip is too thin instead of too thick, the effect of the relay 60 must be reversed in order to insure production of strip of the proper thickness. This is accomplished by the contact bars 180 which are arranged so that the circuit between them is closed by the supplementary sliding contactor 181 mounted on but insulated from the contactor 129, when the motor 17 raises the screw-downs from normal position and moves the contactor 129 to the right of its central position. Closing this circuit operates reversing switch 162 which reverses the connections between the relay 60 and the magnetic switches 154 and 155. The control circuit for switch 162 is completed through conductors 120 and 183.

Assuming that a strip of thickness less than normal is being fed to the mill, then the motor 17 will operate to raise the screw-downs, moving the contactor 129 to the right. If the compensating potentiometer reaches a position where the relay 103 is balanced before the screw-down has operated sufficiently to produce strip of proper thickness, so that the finished strip is too thin, then the relay 60, through the reversing switch 162, will close the magnetic switch 154 to operate the motor 170 to move the contactor 172 to decrease the voltage applied to the compensating potentiometer, thus causing the motor 17 to further raise the screw-downs until a balance is reached and material of the proper gage is being delivered.

If the entering strip is too thin but the strip leaving the mill is too thick, the relay 60 will close the circuit to the magnetic switch 155, thereby operating the motor 170 in the direction to increase the voltage applied to the compensating potentiometer, causing the relay 103 to close the circuit through conductor 108 and operating the motor 17 to lower the screw-downs thereby moving the contact 129 toward the center of the compensating potentiometer which reduces its output, thus cancelling the effect of the increased input voltage and thereby restoring the relay 103 to balance.

Control of sequence of operations.—As those skilled in the art will appreciate, it is desirable that the various controls heretofore described function at different times and under different conditions of the mill. Thus gages 45 and 100 should both be ineffective to actuate the screw-downs when there is no material between the rollers of the gages. During the initial operation of the mill, when a strip is first introduced therein, it is desirable that the screw-downs be initially adjusted by operation of the gage 45. After an initial setting has been made it is preferable that the screw-downs be controlled by the anticipating mechanism in conjunction with gage 100. Under some circumstances variations in thickness of the finished product may occur without variations in thickness of the entering strip. If such variations occur when the entering strip is of standard thickness, the anticipating control will be ineffective to properly correct the setting of the mill, for when the contactor 129 of the balancing potentiometer 127 is at or near its neutral position, a change in the voltage applied to the balancing potentiometer will have no appreciable effect on its output voltage. Under such circumstances adjustment of the potentiometer 173 will be ineffective and accordingly, under such circumstances it is preferable that the screw-down motor be controlled in response to variations in thickness of the finished strip.

The several relays and switches for changing the mode of operation of the apparatus in accordance with the various conditions noted above are described in the following paragraphs.

Lockout relays.—To prevent operation of the control mechanism by either gage 45 or 100 when there is no material between the rolls of the gages, I preferably employ lockout relays 91 and 92. Lockout relay 91 is energized by the gage 100 through conductors 185 and 186 and vacuum tube relay 187. The output of the gage 100 is reduced as the rolls approach each other and the circuits are arranged so that relay 91 will open the circuits including conductors 107 and 108 when the rolls of the gage are in engagement with each other. Thus unless strip is passing through the gage 100 the controls leading from the relay 103 will be interrupted and ineffective to operate the screw-down motor.

In a similar manner, relay 92 is controlled by gage 45, through conductors 188 and 189 and vacuum tube relay 190. Contacts 191, 192 and 193 of relay 92 are closed only when strip is disposed between rolls 46 and 47 of gage 45. Contacts 191 control the circuit to the holding contactor 95, contacts 192 control the energization of the armature 69 of the oscillating relay 67 and contacts 193 control the circuit through conductor 153 to the coils 154 and 155 of the control contactor 156.

Anticipating control starting relay and automatic control contactor.—In starting the apparatus the operator, in addition to setting gage 45 to the standard finished thickness, sets the sliding contactor 129 of the balancing potentiometer 127 at its central position and sets the anticipating control gage 100 for the average thickness of the entering strip. The anticipating control preferably becomes effective when the mill is producing strip of correct finished thickness and when the material entering the mill is of the thickness set on the gage 100. To complete the anticipating control circuit I preferably employ relay 93 and contactor 94 in conjunction with contacts 96 which are closed whenever the oscillating relay 67 is in its neutral position thus completing the circuit from the holding contactor 95 through conductors 201 and 202 to contacts 203 of the contactor 94 and also to the starting relay 93. The coils 204 and 205 of the starting relay are connected to the control supply line through conductor 209 and are energized through conductors 107 and 207 or 108 and 208 whenever the contactor of the relay 103 is swung to either side of its central position into engagement with contact 105 or contact 110. Thus coils 204 and 205 of relay 93 are energized, opening the circuit through the relay, whenever strip which is not of standard gage is passing through gage 100. The circuit through the relay, however, is closed whenever contactor 104 is in its central position, and if this occurs at a time when oscillating relay 67 is in its neutral position thus closing contacts 96, then solenoid 210 of the automatic control contactor 94 will be energized, closing the circuits through contacts 203, 211, 212, 213 and 214. This action can take place only when the thickness of the strip entering the mill corresponds to the setting of gage 100 and the thickness of the strip produced by the mill corresponds to the setting of gage 45.

Closing of contact 203 in contactor 94 completes a holding circuit through coil 210 so that after the contact has once been made it will remain closed so long as contacts 96 are closed even though the circuit through relay 93 is open. Contacts 211 and 212 close the circuits between conductors 107 and 37, and 108 and 23, respectively, leading to the screw-down motor reversing controller 18. Closing contact 213 completes the circuit through conductors 215 and 120 to energize magnetic clutch 136, thus coupling the screw 135 to the screw-down motor 117. Closing contacts 214 completes the circuit through conductors 153, contact 152 and contactor 151 to coils 154 and 155 of the calibrating control contactor 156.

Anticipating control cut-out.—When the sliding contactor 129 of the balancing potentiometer is in its central position the contacts 151 and 152 are opened by cam 150, and the contacts 145 are closed by contactor 146. Under these circumstances the circuit leading to the calibrating control contactor 156 is open while the circuit leading to the armature 69 of the oscillating relay 67 is closed. Thus the screw-down motor will be controlled by gage 45 through relay 64 and oscillating relay 67 in response to variations in the thickness of the finished strip.

Movement of the armature of oscillating relay 67 in response to variations in thickness of the finished strip will break the circuit between contacts 96 thus de-energizing the holding coil 210 of the automatic control contactor 94 and opening contacts 203, 211, 212, 213 and 214. Preferably the contactor 94 is provided with a time delay device such as the dash-pot 220 so that the circuit will not be broken unless strip of incorrect thickness is being produced by the mill for an appreciable period of time, for example 1 or 2 seconds. When contactor 94 opens the circuits therethrough the anticipating control mechanism is rendered ineffective by opening contacts 211 and 212, the magnetic clutch 136 is de-energized by opening contacts 213, while the opening of contacts 214 opens the circuit through conductors 153 to the coils 154 and 155 of the reversing contactor 156. Under these circumstances the screw-down motor will be controlled solely by the thickness of the finished strip and this mode of operation will continue until the finished strip thickness is corrected and the thickness of the entering strip simultaneously corresponds to the setting of gage 100, whereupon the anticipating control mechanism will be started again by the closing of contacts 96 and the de-energization of the automatic control starting relay 93, resulting in the closing of contactor 94.

Summary of operation.—The mill may be controlled manually in the usual manner by swinging the master control switch 30 to the left to close contacts 31 whereupon the screw-down motor can be controlled through push buttons 25 and 35 respectively to lower and raise the screw-downs, the push buttons controlling the operation of the screw-down motor through the contactor 18.

To initiate automatic operation the operator sets the gage 45 for the thickness desired, adjusts the gage 100 for the average thickness of the entering strip, and sets sliding contactor 129 of the balancing potentiometer to the central position. Also, the mill may be adjusted to approximately the correct setting by the push button control although this operation is not necessary as the automatic control will take care of setting the mill rolls.

The master controller is then set to the automatic position to close contacts 90 and the strip is fed through the mill. Passing the strip between rollers of the gage 100 energizes the lock-out relay 91 and when the strip passes between the rollers of the gage 45 the lock-out relay 92 will be energized. Thus the apparatus is set for automatic operation. Inasmuch as the slider 129 of the balancing potentiometer is in its central position thus cutting out the anticipating control, the screw-downs will be adjusted to produce strip of correct finished thickness by the gage 45 acting through the contact making microammeter 60 and the oscillating relay 67 to control reversing controller 18, the circuit to the armature of the oscillating relay 67 being completed through contacts 192 of the lock-out relay 92 and the contacts 145 engaged by contactor 146 on the slider 129. Under these conditions the automatic control contactor 94 is not energized and the anticipating control is ineffective until such time as the finished thickness of the strip corresponds to the setting of gage 45 so that the armature of the oscillating relay 67 is in its neutral position thus closing contacts 96, and simultaneously the contactor 104 of the relay 103 is in its neutral position, indicating that strip of correct thickness is being fed to the mill, thus de-energizing the coils 204 and 205 of the automatic control starting relay 93.

When these two conditions occur simultaneously the coil 210 of the contactor 94 is energized thus closing contacts 203, 211, 212, 213 and 214 and permitting control of the screw-down motor by the anticipating gage 100 through relay 103 and the contactor 18. At the same time closing of the contact 213 energizes clutch 136 thus coupling the screw 135 of the balancing potentiometer to the screw-down motor and placing the anticipating control mechanism in operation. The gage 45 and relay 60 will not operate the screw-down motor under these circumstances as the contacts 74 and 82 of oscillating relay 67 are open. The screw-down will be operated in response to variations in thickness of the entering strip by the gage 100 and relay 103 to correct the setting of the mill for any change in thickness of the strip, the distance between the gage 100 and the mill preferably being correlated with the speed of the strip and the speed of operation of the screw-down motor so that the mill setting will be substantially corrected by the time that portion of the strip of greater or lesser thickness reaches the mill. Balancing voltages are applied to restore relay 103 to its neutral position by the balancing potentiometer 127, the magnitude of the balancing voltage applied for a given travel of the screw-down being determined by the setting of the potentiometer 173 which in turn is controlled automatically by gage 45 through relay 60, contactor 156, and motor 170 in response to variations in thickness of the finished strip.

When the trailing end of the strip passes through gage 100 lock-out relay 91 is de-energized thus opening the circuit from relay 103 to contactor 18 and preventing operation of the anticipating control. When the trailing end of the strip passes through gage 45 lock-out relay 92 is de-energized thus opening contacts 191, 192 and 193. Opening of contact 192 breaks the circuit leading to armature 69 of the oscillating relay 67 thereby preventing it from rotating so that the screw-down can not be operated by gage 45 after the strip has left the mill, and opening of contact 193 de-energizes coils 154 and 155 of contactor 156 so that the motor 170 can not be operated after the strip leaves the mill. When the next strip is entered in the mill the lock-out relays 91 and 92 will be energized as the strip passes between the rollers of gages 100 and 45 respectively and the normal sequence of operations again takes place.

From the foregoing description of a preferred form of my invention it will be seen that I have provided a method and apparatus for controlling rolling mills which is completely automatic in that the mill is adjusted automatically to produce strip of the correct gage. Under normal operating conditions, after the apparatus has adjusted itself to produce strip of the correct thickness, the mill will be controlled in response to variations in thickness of the entering strip. By the reason of the balancing potentiometer all possibility of hunting is eliminated and the mill setting will be adjusted only sufficiently to produce a strip of correct thickness. The anticipating control mechanism is continuously calibrated by the action of the gage 45 controlling the potentiometer 172 and is thus corrected to compensate for changes in the operating conditions of the mill or in the physical characteristics of the material being rolled. The mechanism is arranged automatically to compensate for errors in finished thickness which occur without any error in the thickness of the material entering the mill and, by reason of the lock-out relays, the control mechanism will not operate when there is no strip passing through the gages. Thus the mechanism is substantially fool-proof and will operate to produce rolled material in which the thickness is maintained much more accurately than has heretofore been possible.

The various gages, relays and contactors employed in my apparatus may be of standard construction and all of the instrumentalities are sturdy and will operate accurately over long periods of time. The mechanism can be adapted readily to existing mills without any expensive changes in the mill set-up being required.

In the foregoing specification I have described a preferred embodiment of my invention as applied to an ordinary two-high mill adapted for rolling sheet steel, and in which the percentage of reduction is controlled by adjusting the setting of the mill rolls. It will be apparent to those skilled in the art that various changes in conditions may be made in the apparatus without departing from the spirit and scope of my invention and further that the method and apparatus can be adapted to different types of mills, to mills embodying different methods or devices for controlling the percentage of reduction, and to the rolling of different materials all without departing from the spirit and scope of my invention. Therefore it is to be understood that my patent is not limited to the preferred form of my invention described herein or in any manner other than by the scope of the appended claims.

I claim:

1. In combination with a rolling mill, means positioned in advance of the mill for measuring the thickness of the material entering the mill, means controlled by said measuring means for adjusting the reduction effected by the mill in response to variations in thickness of material entering the mill, a second measuring means positioned beyond the mill for measuring the thickness of the material delivered by the mill and connections operable in the event that the adjustment effected by said first measuring means fails to adjust the mill to produce material of correct thickness whereby said second measuring means modifies the amount of adjustment effected by said first measuring means thereby to produce finished material of the desired thickness.

2. In combination with a rolling mill, means positioned in advance of the mill for measuring the thickness of the material entering the mill, means for adjusting the reduction effected by the mill, control means for said adjusting means actuated by said measuring means, a second measuring means positioned beyond the mill for measuring the thickness of the material delivered by the mill, and means controlled by said second measuring means for calibrating said first control means to insure the production of finished material of the desired thickness.

3. In combination with a rolling mill, means positioned in advance of the mill for measuring the thickness of the material entering the mill, means for adjusting the reduction effected by the mill controlled by said measuring means when the thickness of the entering material varies from a predetermined standard, a second measuring means positioned beyond the mill for measuring the thickness of the material delivered by the mill, and connections whereby said second measuring means controls said adjusting means in the event that variations in thickness of the material delivered by the mill occur in the absence of variations in the thickness of the material delivered to the mill.

4. Means for controlling a rolling mill having a power operated screw-down mechanism, comprising a gage adapted continuously to measure the thickness of the material entering the mill, said gage producing a voltage which varies in accordance with variations in thickness of the material, a relay automatically operable in response to variations in said voltage for operating said screw-down mechanism to increase the rolling pressure applied by the mill in the event of an increase in thickness of the material entering the mill and to decrease the rolling pressure applied by the mill in the event of a decrease in thickness of the material entering the mill, and means controlled by the movement of said screw-down mechanism for applying a balancing voltage to said relay tending to restore said relay to its neutral position and thereby to stop operation of said screw-down mechanism after said mechanism has operated sufficiently to compensate for the variation in thickness of the material entering the mill.

5. Means for controlling a rolling mill having a power operated screw-down mechanism comprising a gage adapted continuously to measure the thickness of the material being rolled before it enters the mill, said gage producing a voltage which varies in accordance with variations in thickness of the material, a relay automatically operable in response to variations in said voltage for operating said screw-down mechanism to increase the rolling pressure applied by the mill in the event of an increase in thickness of the material entering the mill and to decrease the rolling pressure applied by the mill in the event of a decrease in thickness of the material entering the mill, means controlled by the movement of said screw-down mechanism for applying a balancing voltage to said relay tending to bring said relay back to a neutral position thereby to stop operation of said screw-down mechanism after said mechanism has moved sufficiently to compensate for the variation in thickness of the material entering the mill, and means controlled in response to variations in the thickness of the strip leaving the mill for varying the amount said balancing voltage is changed in response to a given movement of the screw-down mechanism.

6. Means for controlling a rolling mill having a power operated screw-down mechanism, comprising a gage adapted continuously to measure the thickness of the material being rolled before it enters the mill, said gage delivering an electric current which varies in accordance with variations in thickness of the material, a relay automatically operable in response to variations in said current for operating said screw-down mechanism to increase the rolling pressure applied by the mill in the event of an increase in thickness of the material entering the mill and to decrease the rolling pressure applied by the mill in the event of a decrease in thickness of the material entering the mill, a balancing potentiometer controlled by the movement of said screw-down mechanism for applying a balancing voltage to said relay tending to bring said relay back to a neutral position and to stop operation of said screw-down mechanism, and means for controlling the input voltage supplied to said potentiometer, thereby to control the amount of change in the balancing voltage applied to said relay in response to a given movement of said screw-down mechanism.

7. Means for controlling a rolling mill having a power operated screw-down mechanism, comprising a gage adapted continuously to measure the thickness of the material being rolled before it enters the mill, said gage delivering an electric current which varies in accordance with variations in thickness of the material, a relay automatically operable in response to variations in said current for operating said screw-down mechanism to increase the rolling pressure applied by the mill in the event of an increase in thickness of the material entering the mill and to decrease the rolling pressure applied by the mill in the event of a decrease in thickness of the material entering the mill, a balancing po-

tentiometer controlled by the movement of said screw-down mechanism for applying a balancing voltage to said relay tending to bring said relay back to a neutral position, a second gage adapted to measure the thickness of the material after it leaves the mill, and a second potentiometer controlled by said second gage in response to variations in the thickness of the strip leaving the mill for varying the input voltage supplied to said balancing potentiometer thereby varying the amount said balancing voltage is changed in response to a given movement of the screw-down mechanism, the connection being such that the balancing voltage restores the relay to neutral position, thereby stopping operation of the screw-down mechanism, substantially as soon as said mechanism has operated sufficiently to compensate for a variation in thickness of material entering the mill.

8. Means for controlling a rolling mill having a power operated screw-down mechanism, comprising a gage adapted continuously to measure the thickness of the material being rolled before it enters the mill, said gage delivering an electric current which varies in accordance with variations in thickness of the material, a relay automatically operable in response to variations in said current for operating said screw-down mechanism to increase the rolling pressure applied by the mill in the event of an increase in thickness of the material entering the mill and to decrease the rolling pressure applied by the mill in the event of a decrease in thickness of the material entering the mill, means controlled by the movement of said screw-down mechanism for applying a balancing voltage to said relay tending to bring said relay back to a neutral position thereby to stop operation of said screw-down mechanism after said mechanism has moved sufficiently to compensate for the variation in thickness of the material entering the mill, a second gage adapted to measure the thickness of the material after it leaves the mill, means controlled by said second gage in response to variations in the thickness of the strip leaving the mill for varying the amount said balancing voltage is changed in response to a given movement of the screw-down mechanism, and lockout relays in conjunction with both said gages for preventing the respective control mechanism associated with said gages from operating when there is no material passing through said gages.

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