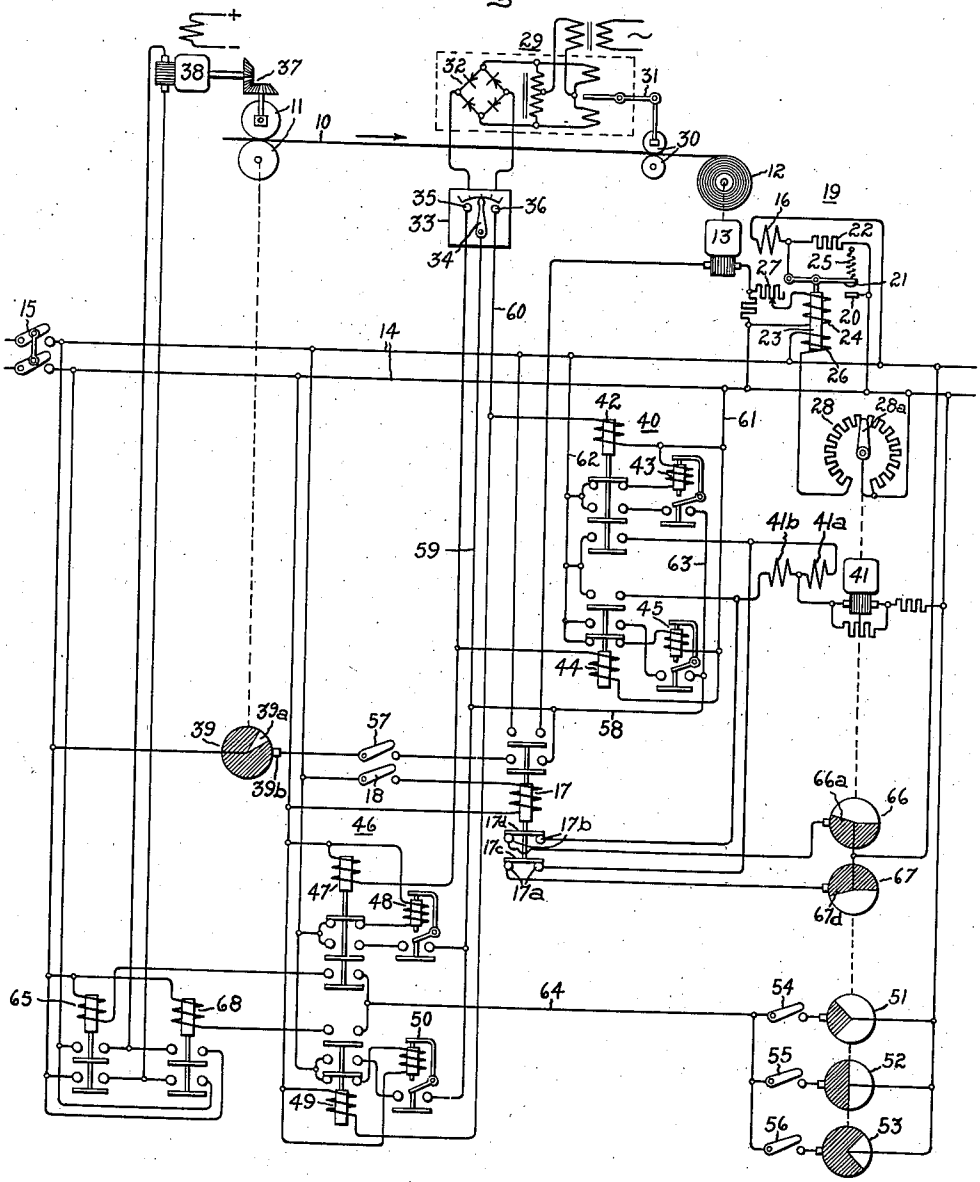
Nov. 25, 1941. F. MOHLER 2,264,096

CONTROL SYSTEM

Filed Aug. 11, 1938 4 Sheets-Sheet 1

Fig. 1.



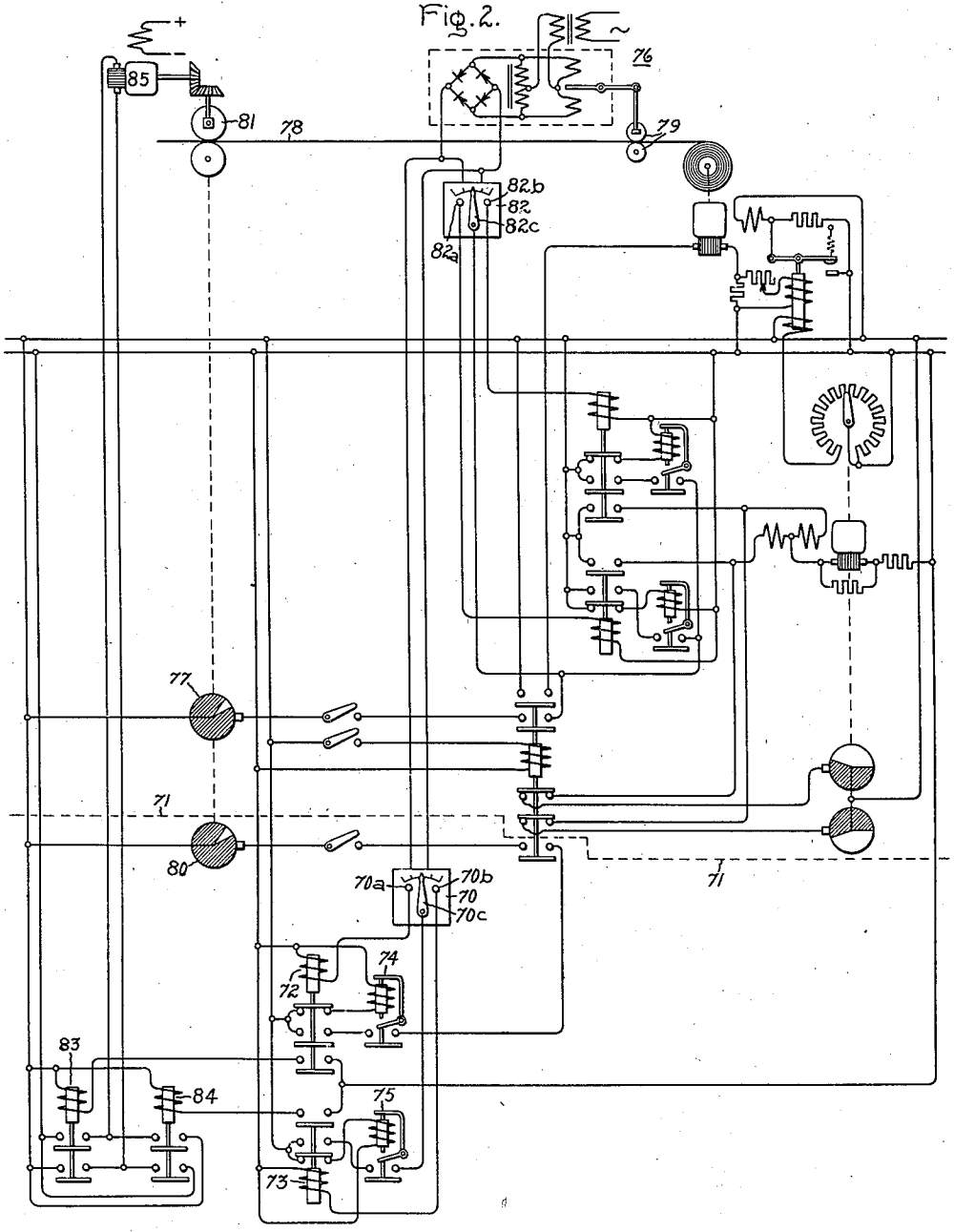
Inventor:
Francis Mohler,
by Harry C. Dunham
His Attorney.

Nov. 25, 1941. F. MOHLER 2,264,096

CONTROL SYSTEM

Filed Aug. 11, 1938 4 Sheets-Sheet 2

Fig. 2.



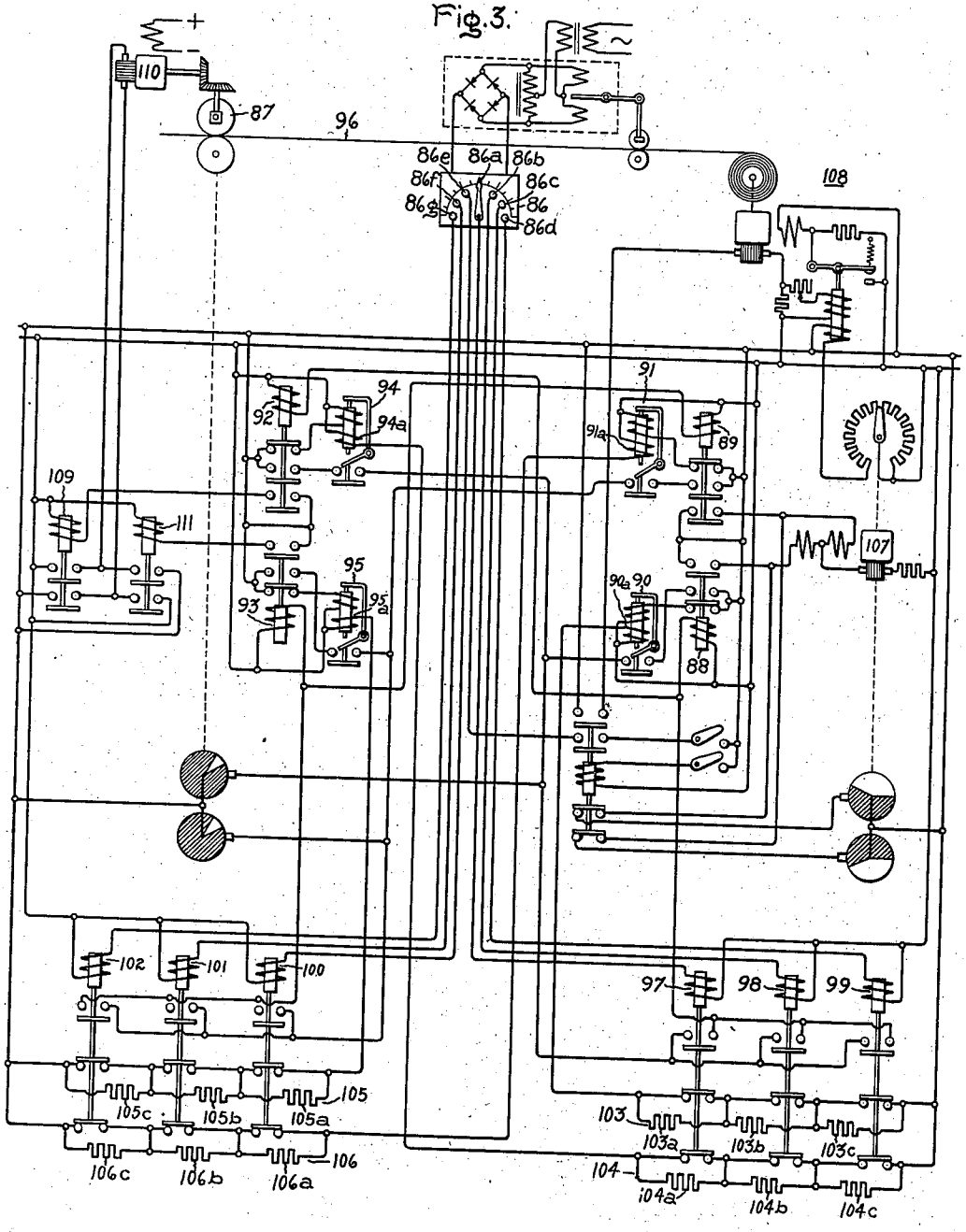
Inventor:
Francis Mohler,
by Harry E. Dunham
His Attorney.

Nov. 25, 1941. F. MOHLER 2,264,096

CONTROL SYSTEM

Filed Aug. 11, 1938 4 Sheets-Sheet 3

Fig. 3.



Inventor:
Francis Mohler,
by Harry E. Dunham
His Attorney.

Nov. 25, 1941. F. MOHLER 2,264,096

CONTROL SYSTEM

Filed Aug. 11, 1938 4 Sheets-Sheet 4

Fig. 4.

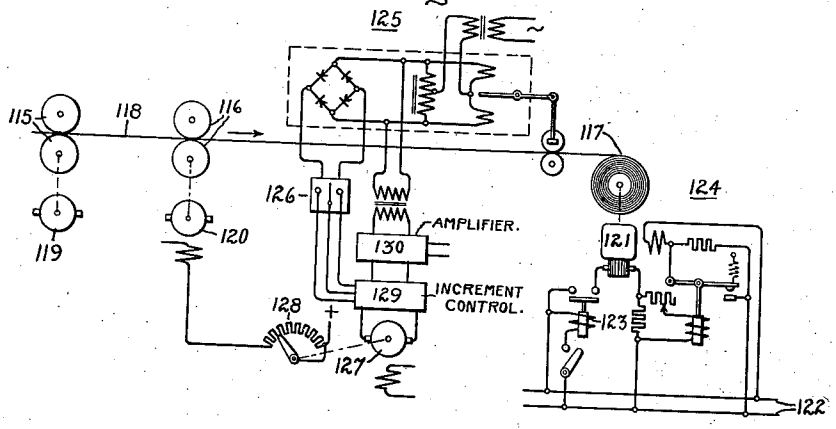


Fig. 5.

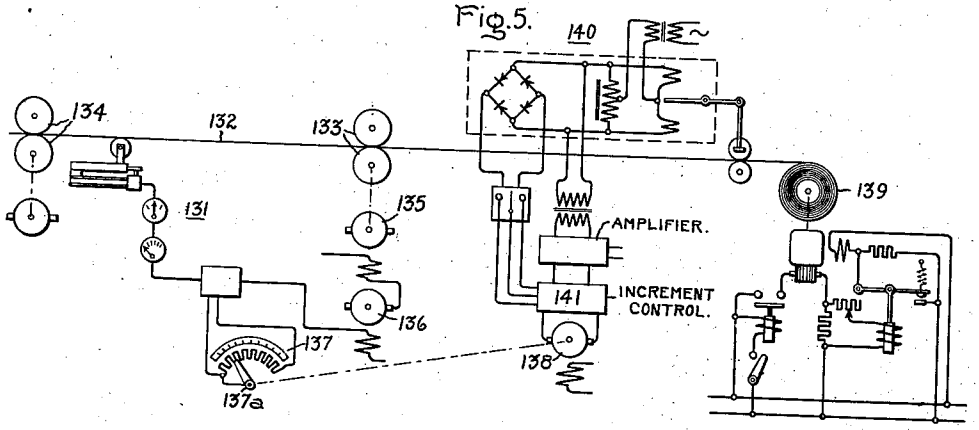
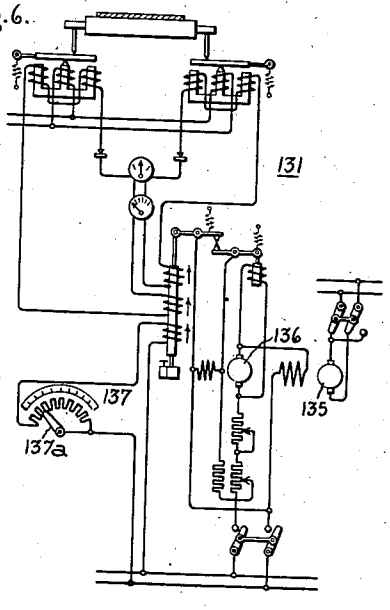


Fig. 6.



Inventor:
Francis Mohler,
by Harry E. Dunham
His Attorney.

Patented Nov. 25, 1941

2,264,096

UNITED STATES PATENT OFFICE

2,264,096

CONTROL SYSTEM

Francis Mohler, Schenectady, N. Y., assignor to General Electric Company, a corporation of New York

Application August 11, 1938, Serial No. 224,316

7 Claims. (Cl. 80—32)

This invention relates to control systems, more particularly to systems for controlling apparatus having an element for performing an operation on a length of material under tension, and it has for an object the provision of a simple, reliable, and improved system of this character.

This application is a continuation-in-part of earlier filed application Ser. No. 116,656, filed December 18, 1936, and assigned to the same assignee.

More specifically the invention relates to rolling mill apparatus and the like having means for reducing the gauge or thickness of a length of material and an element for maintaining the material under tension while its gauge is being reduced, and a more specific object of the invention is the provision of improved means for maintaining the gauge of the worked material substantially constant.

In the practice of rolling cold strip material for example, it is highly desirable to maintain a constant thickness of the rolled strip as nearly as possible or, in other words, constant gauge is of extreme importance. The trade is becoming very rigid in the allowable tolerances or variations in gauge. Even with the present precision mills which are equipped with very accurate continuous gauges for measuring the strip thickness at all times, all of the sheets must be sorted and a fairly high percentage is either thicker or thinner than the allowed tolerance.

These mills are equipped with screw-down mechanism for raising and lowering the top rolls and are equipped with tension devices for maintaining substantially constant tension in the strip as it is wound up on drums or reels after emerging from the mill. Some of the mills are of the continuous type utilizing a plurality of stands followed by a reel, and some are of the reversing type utilizing a reel on either side of the mill for winding up and unwinding the strip respectively, and vice versa. The type of mill, however, is immaterial, since the invention is applicable to all types.

In carrying the invention into effect in one form thereof, means are provided for responding to variations in the gauge of material being worked under tension to vary the tension so as to maintain the gauge substantially constant. More specifically, as applied to apparatus having an element for reducing the gauge of a length of material and a device for tensioning the material, a dynamo electric machine is mechanically coupled to the tensioning device, and a current regulator is provided for maintaining the current of the dynamo-electric machine substantially constant at a set value together with means responsive to variations in the gauge of the worked material for varying the setting of the regulator thereby to maintain the gauge of the material within the predetermined tolerance.

In the case of a rolling mill having screwdowns for varying the opening between the rolls, means are also provided for controlling the screw-down mechanism as well as the tension varying means in response to variations in the gauge of the worked material.

In illustrating the invention in one form thereof, it is illustrated as embodied in a control system for a rolling mill having a pair of rolls for reducing the gauge of a strip of material, a take-up reel, and driving means for the reel so controlled as to maintain the strip under tension between the rolls and the reel. For a better and more complete understanding of the invention, reference should now be had to the following specification and to the accompanying drawings in which Fig. 1 is a simple diagrammatical sketch of an embodiment of the invention, Figs. 2, 3, 4 and 5 modifications and Fig. 6 is a detail of the apparatus of Fig. 5.

Referring now to the drawings, the thickness of a length of material 10 is being reduced by suitable means illustrated as comprising a pair of rolls 11. Rolls 11 are driven by any suitable driving means such, for example, as an electric motor (not shown). The length of material 10 is delivered from the rolls 11 in the direction of the arrow and is wound upon a reel 12 driven by suitable means illustrated as a direct current electric motor 13.

Motor 13 is supplied from a pair of buses 14 which are connected to a suitable source when a switch 15 is moved to its closed position. As shown, motor 13 is provided with a field winding 16 which is also connected to the bus 14. Suitable starting means are provided for connecting the motor 13 to the source and for accelerating the motor to full speed. Motor starters used in actual practice are often quite complicated. They may be of the rheostatic type with a number of sections of resistance and a plurality of accelerating contactors for short circuiting the resistance sections, or they may be of the adjustable voltage type, in which case the voltage of a generator is controlled so as to start and stop the reel motor. However, since the specific structure of the starting means constitutes no part of the present invention, it is illustrated simply as comprising an electromagnetic con-

tactor 17 and a switching device, preferably a manually operated pushbutton type switch 18, for controlling its energization. For the purpose of maintaining the tension in the strip between the rolls 11 and the reel 12 substantially constant at a predetermined value, means illustrated as a constant current regulator 19 are provided for controlling the input to the reel motor 13. Since it is desirable to maintain the strip speed substantially constant it is necessary for the speed of the motor 13 to decrease as the diameter of the coiled strip increases, in order to maintain the strip tension between the mill rolls and the reels substantially constant at constant strip speed, it is necessary gradually to increase the excitation of the motor 13 so as to maintain the armature current constant. This is accomplished by the regulator 19. Although regulator 19 may be of any suitable type it is shown as a vibratory contact type regulator. Briefly, regulator 19 comprises stationary contact 20 and a movable contact 21 arranged for alternately short circuiting and removing the short circuit from a resistance 22 included in the field circuit of reel motor 13. A core member 23 is pivotally connected to the arm which carries the movable contact 21 and is arranged within the turns of a solenoid 24 which in turn is connected so as to be responsive to the current flowing in the armature circuit of reel motor 13. A spring 25 is attached to the movable contact arm so that its pull opposes the pull of the solenoid on the core. A second coil 26, referred to as a bias winding, is also provided and arranged to act on the core 23. The operation of the regulator is briefly as follows: With the machine 13 operating as a motor, an increase in the armature current of the motor 13 above the predetermined value causes the contacts 21, 20 to close against the tension of the spring 25 and thereby to short circuit the resistance 22. This increases the excitation of the motor 13 and causes its speed to decrease until the armature current becomes less than the predetermined value at which time the pull of the spring 25 overpowers the pull of the solenoid and separates the contacts 20, 21 to remove the short circuit about resistance 22. Reinsertion of the resistance 22 in the field circuit of motor 13 decreases the excitation of the motor and causes its speed and armature current to increase. The reel motor armature current continues to increase until it exceeds the predetermined value and again causes the contacts 20, 21 to close and short circuit the resistance 22. The foregoing operation is repeated at a very rapid rate and thus the regulator tends to vibrate to hold a fixed or constant current in the reel motor armature. A tension adjusting rheostat 27 is included in the circuit of the current winding. If this rheostat is adjusted to increase the resistance in series with the winding, more current in the reel motor armature will be necessary to obtain the required current in the current winding and therefore the actual current maintained in the reel motor armature can be increased and decreased by varying the resistance in series with the current winding. For all values of tension, however, the current in the current winding remains at a fixed value.

The purpose of the bias winding 26 is to provide for changing the setting of the regulator a fixed percentage of the tension being maintained for a predetermined increment adjustment of a controlling rheostat 28. As shown, this controlling rheostat 28 is included in circuit with the bias winding 26 across the buses 14. Winding 26 is wound so that it assists the winding 23 in opposing the pull of the spring 25. Since the pull of the two coils is in the same direction, the pull required from the current winding 23 is decreased by the amount of the pull supplied by the bias winding. Thus, if the bias winding supplied 10% of the pull, only 90% of the pull will be required from the current winding in order to balance the spring and, in turn, only 90% of the current will be required through the reel motor armature to produce this 90% pull. This is true irrespective of the actual value of the tension for which the tension adjusting rheostat 27 is set because, as stated in the foregoing, the current in the current winding remains fixed at a substantially constant value, irrespective of the tension being maintained. Thus if the tension adjusting rheostats 27 is set for 20,000 lbs. tension, and the bias winding supplies 10% of the pull, the actual tension maintained by the regulator will be 18,000 lbs. On the other hand, if the tension adjusting rheostat is set to hold 10,000 lbs. tension, and 10% of the pull on the regulator is supplied by the bias winding, the actual tension maintained will be 9,000 lbs.

If the control rheostat 28 is sufficient to vary the pull of bias winding 26 from practically zero to a substantial value such, for example, as 50% of the pull required for the regulator, equal increment adjustment of this rheostat will always represent the same percentage change of the tension being maintained, irrespective of the setting of the tension adjusting rheostat. This feature is desirable because if the strip is thick and a high tension is being maintained, the increment adjustment of the tension should also be relatively high as compared with the case when the strip is thin and relatively low tensions are being maintained.

For the purpose of continuously measuring and indicating the thickness of the material 10, a suitable gauge 29 is provided. Although several types of gauges and other devices satisfactory for this purpose are available on the market, it is preferred to employ a variable air gap transformer type gauge. This type of gauge has a pair of contact rolls 30, one above and one below the strip. One of these rolls, preferably the lower roll, is fixedly mounted, and the other roll is mounted for movement with respect to the first roll in response to changes in the gauge of the strip. These rolls press on the strip at all times, and the movement of one with respect to the other is a measurement of variations in the thickness of the strip. This movement is transmitted to the movable magnetic vane member 31 of an air gap transformer type gauge head and, by means of a power unit which includes the necessary rectifying means 32, an indication of the strip thickness is given on a microammeter 33 which is calibrated in any convenient unit of strip thickness. This type of gauge is well known to the trade, and since its specific internal structural details constitute no part of the present invention, a more detailed description is omitted.

The electric gauge indicating instrument 33 is preferably equipped with a zero-center movable contact member 34 and two stationary contacts 35 and 36. In practice, these two stationary contacts preferably take the form of mercury cup contacts, the positions of which are adjustable with respect to the central position of the movable contact member 34. The movable contact member makes contact with the mercury cup on

either side of the zero position and this circuit closing feature is utilized for actuating the control. The gauge is provided with means for initial adjustment so that the movable contact member 34 will be in the zero position when the contact rolls 30 are separated a distance equal to the desired thickness of the strip. Oversize calibrations are on one side of the zero position, preferably the right side, and the undersize calibrations are on the left side. Thus, if the strip is running at the correct gauge, the instrument will indicate zero, but if it runs oversize, the movable contact member will swing to the right in proportion to the amount of the oversize, and conversely, if the strip is running undersize, the movable contact member will swing to the left. The mercury cup contacts can be adjusted in position so that they may contact with the movable contact member at any desired point. In other words, if the total scale deflection to the right represents .005 inch the mercury cup can be adjusted so that it will make contact when the instrument indicates .005 inch, or any other desired point such as .002 inch. Thus the setting of the mercury cup depends upon the tolerance which is to be allowed.

Various mechanisms are available for operating the screws so as to raise and lower the top rolls. For the purpose of illustration, a simple screw gearing 37 and a direct-current motor 38 for driving the screw are indicated in the drawings.

In this specification the term "increment" is to be understood as the length of time, or amount that the screws are raised or lowered or, when referring to tension, "increment" is to be understood as the length of time or amount the tension is increased or decreased upon each automatic adjustment.

When an indication for correction is given, a second correction should not be made until the effect of the first correction is measured. The time required for the correction to be measured depends upon the distance between the mill rolls and the gauge as well as the time required for making the adjustment. Since the distance between the gauge and the rolls remains fixed, this part of the interval always represents a constant length of strip. That part of the interval which is dependent upon the time required to make the increment adjustment is variable in terms of the length of strip. Therefore, if the increment adjustment requires .25 second irrespective of the speed of the mill, more strip will pass through the mill when operating at maximum strip speed than when operating at minimum strip speed. Thus, if the intervals are measured as a function of length of strip, the length which passes through the mill during the longest increment adjustment and at the maximum speed must be taken into account.

For determining the intervals, a limit switch 39 is provided. This limit switch is connected either directly or through gearing to the mill rolls in such a manner that one revolution of the limit switch represents the length of strip which must pass through the mill between successive increment adjustments. Relay means 40 controlled by the gauge contacts 34, 35, 36 serve to control a pilot motor 41 which rotates the movable contact arm 28_a of the rheostat 28 in the circuit of the biasing coil 26 of the tension regulator. This relay apparatus comprises a switching device 42 and its timing device 43, for controlling the rotation of the motor 41 in such a direction as to increase the tension setting of the regulator, and a switching device 44 and its timing device 45 for effecting rotation of the motor 41 in the opposite direction to decrease the tension setting of the regulator. Switching devices 42 and 44 are illustrated as electromagnetic contactors, and timing devices 43 and 45 are illustrated as inductive time delay relays, or magnetic timing type relays. These relays have means for adjusting the time interval in their operation.

Similar relay apparatus 46 is provided for controlling the energization and direction of rotation of the screw-down motor 38. As shown, apparatus 46 comprises an electromagnetic contactor 47 and its timing relay 48 for effecting rotation of the screw-down motor 38 in a direction to increase the opening between the mill rolls 11 and an electromagnetic contactor 49 and its timing relay 50 for effecting operation of the screw-down motor 38 in a direction to lower the top roll and thereby to decrease the opening between the mill rolls.

Means, illustrated as comprising limit switches 51, 52, and 53, and corresponding selector switches 54, 55, and 56, are provided for maintaining the screw actuating mechanism inactive in response to variations in the gauge of the material until the tension regulating mechanism has varied the tension a preselectable percentage of the value the tension regulator is set to hold.

With the foregoing understanding of the elements and their organization in the complete control system, the operation of the system itself will readily be understood from the following detailed description: The system is placed in condition for operation by closing the line switch 15 to energize the buses 14. This completes an energizing circuit for the timing relays 43, 45, 48 and 50. The energizing circuit for timing relay 43 is traced from the upper bus 14 through the upper contact of contactor 42, through coil of relay 43 to the lower bus 14. Similar energizing circuits for timing relays 45, 48 and 50 are obvious. In response to energization, timing relays 43, 45, 48 and 50 close their contacts.

The reel motor 13 is started by depressing the start button switch 18 to close its contacts and thereby to complete an energizing circuit for the operating coil of starting contactor 17. In response to energization, contactor 17 closes its upper main contacts to complete a supply circuit for the armature of reel motor 13 that is traced from the upper bus 14, through upper contacts of contactor 17, armature of motor 13 to lower bus 14. As a result, motor 13 is energized and the regulator 19 functions in the manner described in the foregoing to maintain constant current input to the armature of reel motor 13. Switch 57 is closed to place the system in condition for automatic operation.

As long as the gauge of the strip remains within the predetermined tolerances for which the gauge 29 is set, the bridge circuit in the head of the gauge 29 remains balanced and no voltage is supplied to the contact-making microammeter 33. However, if the strip 10 should begin to run oversize, the movable contact member 34 will swing to the right and make contact with the stationary contact 36 partially to complete an energizing circuit for the contactor 42. This circuit is completed when the conducting segment 39_a of the limit switch makes contact with the brush 39_b. The circuit is traced from the upper bus 14 through the limit switch 39, switch 57, second contact, from the top of contactor 17, conductors 58 and 59, movable contact member

34, stationary contact member 36, conductor 60, operating coil of contactor 42, and thence by conductor 61 to the lower bus 14. Contactor 42 closes in response to energization, and its closing completes a circuit through the armature of thermostat motor 41 and its series split field winding 41_a. This circuit is traced from the upper bus 14 through conductor 62, lower contact of contactor 42, split field winding 41_a, armature of motor 41 to the lower bus 14. Motor 41 thereupon rotates the movable contact arm 28_a in such a direction as to increase the tension setting of the tension regulator 19. In closing, contactor 42 completes a holding circuit for itself independently of the limit switch 39 so that the contactor remains closed after the conducting portion 39_a of the limit switch has rotated out of contact with the brush 39_b. This holding circuit is traced from the upper bus 14 through conductor 62, intermediate contact of contactor 42, contacts of time delay relay 43, conductor 63, conductors 58 and 59, contacts 34 and 36, conductor 60, operating coil of contactor 42 and conductor 61 to the lower bus 14. Contactor 42 in closing interrupts the energizing circuit for the time delay relay 43 and after an interval of time determined by the adjustment of the time delay relay 43, this relay opens its contacts to interrupt the holding circuit for the contactor 42 which thereupon opens its lower contacts to interrupt the armature circuit of the rheostat motor 41. Movable contact arm 28_a of the rheostat comes to rest after having increased the resistance in circuit with the bias winding of the regulator. The result is that a larger current must flow in the armature circuit of the reel motor in order to produce sufficient current in the current winding 23 of the regulator to balance the pull of the spring 25. This increased armature current also increases the tension in the strip between the mill rolls 11 and the reel 12 and the effect of this increased tension is to reduce the gauge of the strip.

After an interval of time sufficient for a point on the strip to pass from the mill rolls 11 to the gauge contact rolls 30 has elapsed, conducting segment 39_a of the limit switch again rotates into engagement with the brush 39_b and if the increased tension in the strip has not reduced the thickness to within the required tolerance the foregoing operation is repeated.

If, on the other hand, the increment adjustments of tension were sufficient to bring the material down to the proper gauge, the mercury cup contacts 34, 36 will be separated and the contactor 42 will not reclose the next time the conducting segment 39_a of the limit switch 39 rotates into engagement with the stationary bus 39_b, and no further increment adjustment in the tension of the strip will be made.

If the strip runs undersize, the movable contact member 34 will make contact with the left-hand mercury cup contact and this will cause the contactor 44 and timing relay 45 to function in a manner similar to that described for contactors 42 and 43, to energize the rheostat motor 41 for rotation in a direction to decrease the amount of resistance in the bias winding of the regulator and thereby to decrease the tension in the strip between the rolls 11 and the reel 12. This decreased tension will cause the gauge of the strip to increase, and the operation of the contactor 44 and the timing relay 45 under the control of the limit switch 39 and the gauge will be repeated until the thickness of the strip is within the required tolerance.

During the time that the contactor 42 and its timing relay 43 are functioning to increase the tension in the strip the screw lowering contactor 49 and its time relay 50 are also functioning in a similar manner. However, this contactor and its relay cannot energize the screw-down motor 38, unless one of the selector switches 54, 55, 56, is closed and the conducting segment of one of the corresponding limit switches 51, 52, or 53 is in engagement with its cooperating stationary brush. For example, assume that the switch 55 is selected and closed by the operator. When the motor operated rheostat 28 has rotated the contact arm 28_a through an arc of 90° in the "increase" direction, an energizing circuit for the "down" contactor 68 will be established from the lower bus 14 through the limit switch 52 on selector switch 55, conductor 64, upper contact of contactor 49, operating coil of down contactor 68 to the upper bus 14. Contactor 68 will close in response to energization and connect the screw-down motor 38 to the supply source for rotation in a direction to lower the top roll 11 and thereby to decrease the opening between the rolls. After a predetermined interval of time determined by the setting of the time delay relay 50, the relay 50 functions in a manner similar to the relay 43 to deenergize the contactor 49 which thereupon opens its contacts to deenergize the coil of the down contactor 68, and contactor 68 in turn opens its contacts to disconnect the screw-down motor 38 from the supply source. If the correction so made is insufficient to restore the thickness of the strip to the required tolerance this action is repeated each time the conducting segment of the limit switch 39 rotates into engagement with the stationary brush 39_b.

If the thickness of the strip should be less than the required tolerance the contactor 47 and its timing relay 48 will function in a similar manner to energize the "up" contactor 65 to close its contacts and connect the screwdown motor 38 to the source for rotation in a direction to raise the top roll 11 to increase the distance between the rolls. After an interval of time determined by the setting of the time delay relay 48, the contactors 47 and 65 will be deenergized and the screw-down motor 38 disconnected from the supply source. It will, of course, be understood that the operation of the contactor 47 and its timing relay 48 is analogous to that of the contactor 49 and its timing relay 50. That is to say, contactor 47 will not energize the up contactor 65 until the tension in the strip has been decreased a predetermined amount and the limit switch 52 has been rotated through an arc of 90° from the position in which it is shown in the drawing.

If, on the other hand, selector switch 56 is closed the motor operated rheostat 28 would have to turn through an arc of 135° either in the tension increase or tension decrease direction, before the screw-down motor 38 could be energized to raise or lower the rolls.

Thus, means are established for first increasing or decreasing the tension in the strip up to a certain preselectable percentage of the value which the tension regulator is set to hold, and then lowering or raising the top mill roll in preselectable increments.

At the completion of the rolling of the strip or at the completion of a pass, it is desirable to return the motor operated rheostat 28 to its first

position so that the basic adjustment of the tension by the main tension adjusting rheostat 27 is always the same. This is accomplished by means of limit switches 66 and 67 connected to the shaft of the motor operated rheostat. It will be noted that as soon as the reel motor is stopped by opening the switch 18, and the consequent opening of the reel motor line contactor 17, stationary contacts 17a and 17b are bridged by movable contacts 17c and 17d respectively, thereby energizing the motor 41 to rotate in one direction or the other until the insulated segments 66a and 67a of the limit switches 66 and 67 are both in engagement with their cooperating brushes. When this condition obtains, the rheostat motor 41 is brought to rest with the movable rheostat arm 28a in the central position in which it is shown and the limit switches 51, 52 and 53 in the positions in which they are shown in the drawings.

An obvious modification of the scheme shown in Fig. 1 is to stop the increment adjustments of tension as soon as the increment adjustments of the screwdown are started.

For small variations in gauge, corrections can usually be made by varying the tension alone. However, upon greater variations it is necessary to adjust the screws as well as to vary the tension of the strip. In the modification of Fig. 2, means are provided for making corrections in the tension alone when the variations in the gauge are relatively small, and additional means are provided for simultaneously energizing the screwdown mechanism to raise or lower the top roll, when the variations in the gauge are relatively large. The arrangement disclosed in the modification of Fig. 2 is substantially identical with the arrangement disclosed in Fig. 1, but differs from it primarily in that the contactors and relays which control the screw-down motor are controlled by means of a second microammeter 79 supplied from the gauge head instead of being controlled by a plurality of limit switches operated by the rheostat motor cooperating with the indicating microammeter which controls the tension adjusting mechanism. Thus it will be noted that that portion of the modification disclosed in Fig. 2 of the drawings which is above the dotted line 71 is identical with a corresponding portion of the modification of Fig. 1. In the portion of the modification of Fig. 2 below the dotted line 71, limit switch mechanisms corresponding to limit switches 51, 52 and 53 are omitted and contactors 72 and 73 corresponding to contactors 47 and 49 of Fig. 1 and timing relays 74 and 75 corresponding to relays 48 and 50 of Fig. 1 are directly controlled from the microammeter 79 supplied from the power unit in the head of the gauge 76. In addition to a limit switch 77 for preventing repeated increment adjustment operation of the tension adjusting mechanism until a predetermined length of strip 78 has passed the contact rolls 79 of the gauge after an increment adjustment has been made, an additional limit switch 80 mounted on the shaft of the limit switch 77 is provided for preventing a repeated actuation of the screw-down mechanism until a predetermined length of strip has passed the contact rolls 79 of the gauge after an increment adjustment has been made in the position of the top roll 81.

The contact making microammeter 70 is provided with adjustable position mercury cup contacts 70a and 70b and with a movable zero center contact 70c. Similarly, the contact making microammeter 82 is provided with stationary adjustable position mercury cup contacts 82a and 82b and with a movable contact member 82c. The mercury cup contacts 82a and 82b are adjusted so that the movable contact member 82c will make contact with one or the other of the mercury cup contacts upon small variations in the gauge of the strip. The gauge 76 then controls the tension increment adjustment in a manner identical with that described in connection with the modification of Fig. 1. However, the mercury cup contacts 70a and 70b of the second contact making microammeter 70 are adjusted so as to make contact on greater variations in gauge. This in turn controls the increment adjusting contactors 83 and 84 for the screw-down motor 85 in a manner similar to that described for the tension increment adjustment.

Thus, if the variation is great, no time is wasted in making several tension increment adjustments before making an adjustment in the position of the top roll. On the contrary, an adjustment of the top roll is made immediately and simultaneously with the increment adjustment in tension of the strip. As soon as the large variations have been corrected, the small variations will be corrected by tension alone. Otherwise, the operation of the modified system of Fig. 2 is identical with the operation of the system of Fig. 1.

The modified system of Fig. 3 is similar to the systems disclosed in Figs. 1 and 2 but differs from these systems primarily in that the contact making microammeter 86 is provided with a plurality of stationary contacts on each side of the central zero position of the movable contacts 86a for the purpose of producing increment adjustments of the tension of the strips and the position of the top roll 87 more nearly proportional to the amount of adjustment required. Thus, if the variation in strip thickness is slight, the time setting for the increment adjustment will be rather short. If the variations strip thickness are somewhat greater, the time setting for the increment adjustment will be proportionally increased. The contact making microammeter is illustrated as provided with three stationary contact members 86b, 86c and 86d to provide three degrees or amounts of increasing increment adjustments, and three stationary contacts 86e, 86f and 86g to provide three degrees or amounts of decreasing increment adjustments.

The means for controlling the tension increment adjustments comprises contactors 88 and 89 and their timing relays 90 and 91 respectively. The means for effecting increment adjustments in the position of the top roll 87 comprises contactors 92, 93 and their respective timing relays 94 and 95. Contactors 88, 89 and 92, 93 correspond in structure and in function with the contactors 42, 44 and 49, 47 respectively of Fig. 1. Similarly, timing relays 90, 91 and 94, 95 correspond with timing relays 43, 45 and 50, 48 respectively of Fig. 1. The timing relays 90, 91 and 94, 95 are different from the timing relays of Fig. 1, however, in that means are provided for changing the time constants of these relays. These means are illustrated as bucking coils 90a, 91a, 94a and 95a. Additional means are provided for varying the change of the time constants of these timing relays in accordance with the amount of variation in the thickness of the strip 96. These means comprise contactors 97, 98, 99, 100, 101 and 102, and resistances 103, 104, 105 and 106 controlled thereby. The resistance 103

is divided into three sections 103a, 103b and 103c of progressively increasing ohmic values. Similarly, the resistances 104, 105 and 106 are divided into correspondingly numbered sections of progressively decreasing ohmic value.

Resistances 103, 104, 105 and 106 are connected in the circuits of bucking coils 90a, 94a, 95a and 91a respectively.

When the variation in the thickness of the strip from the desired thickness is sufficient merely to cause the movable contact member 86a of the contact making microammeter to move into engagement with stationary contact 86c, an energizing circuit is established for the operating coil of contactor 97, and this contactor responds to close its upper main contacts and to open its intermediate and lower contacts. The upper contacts in closing complete an energizing circuit for the operating coil of contactor 88 and as a result of this energization, contactor 88 and its timing relay 90 function to energize the rheostat motor 107 and thereby to change the tension setting of the tension regulator 108 and to effect an increment adjustment in the tension of the strip 96. Simultaneously, the upper contacts of contactor 97 complete an energizing circuit for the operating coil of contactor 92 and as a result of its energization, this contactor and its cooperating timing relay 94 function through contactor 109 to energize the screw-down motor 110 for rotation in a direction to lower the top roll 87.

Intermediate and lower contacts of contactor 97 in opening insert resistance section 103a in the bucking coil 90a of timing relay 90 and lower contact in opening inserts resistance section 104a in the bucking coil 94a of timing relay 94. The result is that the time constants of timing relays 90 and 94 are varied to correspond with the amount of variation of the strip thickness from the desired gauge, thereby to produce increment adjustments in the strip tension and in the position of the top roll 87 dependent upon the variation.

If the variations of the strip thickness from the desired gauge are sufficiently large to cause the movable contact member 86a of the contact making microammeter to rotate into engagement with one of the stationary contacts 86c or 86d, the contactor 98 or 99, as the case may be, will operate to insert resistance sections 103b or 103c in the circuit of bucking coil 90a, and resistance section 104b or 104c in the circuit of bucking coil 94a, thereby to vary the time constants of these relays in accordance with the amount of the variation of the strip thickness from the desired gauge.

If the strip thickness runs less than the desired gauge, the movable contact member 86a rotates in the opposite direction to engage the stationary contact members 86e, 86f and 86g and thereby to energize one or the other of contactors 100, 101, or 102. These contactors in turn function in a manner similar to that already described for contactors 97, 98 and 99, to insert varying amounts of resistance in the bucking coils 95a and 91a of timing relays 95 and 91 respectively to change the time constants of these relays in accordance with the variations in the thickness of the strip from the desired gauge. They also function to energize contactor 89 which in turn controls the motor 107 to rotate in the opposite direction thereby to effect a decrease in the setting of the regulator 108 and a corresponding increment adjustment in the strip tension; and these relays further function to effect energization of the contactor 92 which acts through contactor 111 to produce rotation of the screw-down motor 110 in such a direction as to raise the top roll 87.

Throughout the foregoing specification it is to be understood that increasing of tension in the strip and reducing the opening between the rolls have the same effect; namely, to decrease the gauge of the strip. Decreasing the tension in the strip and increasing the opening between the mill rolls has the opposite effect.

The apparatus of Fig. 4 differs from the apparatus of Figs. 1, 2, and 3 primarily in that the means responsive to variations in the thickness of the moving material is utilized to control the tension of the material at a preceding point in its travel instead of at a succeeding point. In this modification the invention is shown as embodied in a control system for a continuous strip rolling mill having a plurality of elements 115, 116, and 117 operating on the moving length of material 118. The elements 115 and 116 are illustrated as pairs of rolls for reducing the thickness of the material 118, and the element 117 is illustrated as a take-up reel for winding the material 118 to form a coil after it has passed through the reducing rolls 115, 116. For the purpose of simplicity, only two stands of reducing rolls are illustrated in the drawings. In actual practice a continuous rolling mill may have and frequently does have as many as five or more stands of rolls successively operating on a length of moving material.

Dynamo-electric machines 119, 120, and 121 are mechanically coupled to the pairs of rolls 115 and 116 and to the reel 117 respectively. Under normal operating conditions, the dynamo-electric machines 119, 120, and 121 operate as motors to drive the reducing rolls 115 and 116 and the take-up reel 117. Under certain operating conditions, one or more of these dynamo-electric machines may operate as a generator.

Dynamo-electric machine 121 is supplied from a suitable source represented by the supply lines 122 to which its armature terminals may be connected by means of the switching device 123 when the contacts of the switching device are closed. Dynamo-electric machines 119 and 120 are similarly supplied from a suitable source which may be and preferably is the same source as that represented by the lines 122.

Suitable current regulating means 124 are provided for maintaining the current input to the motor 121 substantially constant. Regulating means 124 are identical with regulating means 108 of Fig. 3 with the exception that the bias coil on the movable core member of regulating means 108 is omitted.

Suitable means 125 are provided for measuring variations in the thickness of the material 118 between the rolls 116 and the take-up reel 117 and for varying the tension of the material 118 so as to decrease the variations in thickness. These thickness variation responsive means are identical with the electric gauge illustrated in Fig. 3, and a repetition of the description of these means is accordingly omitted.

A contact-making microammeter 126 is connected to the output circuit of the electric gauge 125 and this contact-making microammeter controls the operation of a pilot motor 127, the shaft of which is connected to the movable arm of a rheostat 128 connected in the field circuit of motor 120. An increment control means 129 is included in the connections between the micro-

ammeter 126 and the motor 127. This increment control means may be substantially the same as the increment control means 88, 89, 90, 91 of Fig. 3 and for this reason it is shown merely conventionally in Fig. 4. In the modification of Fig. 3 the contact-making microammeter 86 is provided with a multiplicity of contacts which control contactors 97, 98, 99, 100, 101, and 102 which in turn control resistors 103_a, 103_b, 103_c, 106_a, 106_b, 103_c to supply variable voltages to the coils 90_a, 91_a to vary the time setting of the time element means 90, 91 of the increment control means. Instead of this arrangement, a variable voltage is obtained from the output circuit of the electric gauge 125 and supplied through a conventional tube amplifier 130 to the increment control means 129.

The operation is as follows: The regulating means 124 operates to maintain the current input to the motor 121 substantially constant by increasing its field strength as the diameter of the coil increases. As explained in the foregoing, this results in maintaining the tension in the material 118 substantially constant between the rolls 116 and the reel 117.

If the thickness of the material 118 becomes greater than the desired value, the gauge means 125 and the contact-making microammeter 126 controlled thereby cause the pilot motor 127 to rotate in such a direction as to rotate the movable arm of the rheostat 128 in a clockwise direction to weaken the field strength of motor 120. This causes the speed of motor 120 to increase which, in turn, increases the tension of the material between the preceding pair of rolls 115 and the rolls 116. The increasing tension in the material between the rolls 115 and 116 decreases the thickness of the material. This operation takes place by increments the magnitude of which is controlled by the increment control means 129 in the manner set forth in the description of the operation of the apparatus of Fig. 3.

When the variations in the thickness of the material 118 have been decreased so that the thickness of the material is again within the allowed tolerances, the gauge means 125 is balanced and the motor 127 is deenergized and stopped.

If the thickness of the material becomes less than the desired value which the gauge is set to hold, the motor 127 will be caused to rotate in the reverse direction to strengthen the field of driving motor 120 and thereby decrease its speed. This results in decreasing the tension of the material between the rolls 115 and 116, and this decreasing tension increases the thickness of the material. This operation likewise takes place in a series of increments of a magnitude depending upon the magnitude of the variations in the thickness of the material.

In the modification illustrated in Fig. 5, the apparatus is identical with the apparatus shown in Fig. 4 with the exception that a tensiometer mechanism 131 responsive to variations in the tension of the material 132 between the pair of rolls 133 and the preceding pair of rolls 134 is provided for controlling the driving motor 135 for the rolls 133 to decrease the variations in tension and thereby to maintain the tension substantially constant. This tensiometer mechanism 131 does not directly control the excitation of motor 135 but on the contrary, controls the excitation of a "buck-boost" exciter 136, the armature of which is connected in the field circuit of motor 135.

The structural details of the tensiometer mechanism 131 and its operation are fully described in United States Patent No. 2,100,653, L. A. Umansky, dated November 30, 1937, and a detailed description is accordingly omitted from this specification. It is sufficient to understand that the tensiometer mechanism is provided with means 137 illustrated as a calibrated rheostat for setting the value of the tension that it is desired to hold in the material, and that the tensiometer controls the "buck-boost" exciter 136 to vary the excitation of motor 135 so as to maintain the tension of the material 132 substantially constant at the value set upon the calibrated rheostat. This calibrated rheostat corresponds in structure and in function to the calibrated rheostat 38 shown in the Umansky patent. As shown, it is provided with a movable contact arm 137_a which is connected to the shaft of the motor 138. Since the remainder of the apparatus is identical with that of Fig. 4, it will be clear that if the thickness of the material 132 between the rolls 133 and the reel 139 becomes greater than the value the gauge 140 is set to hold, the motor 138 will rotate in a direction, e. g. the clockwise direction, to increase the tension setting of the tensiometer 131. The tensiometer 131 operates through the "buck-boost" exciter 136 to weaken the field strength of the motor 135 and thereby increase its speed and that of the rolls 133 driven thereby. This increased speed increases the tension of the material between rolls 133 and the preceding pair of rolls 134 and thereby decreases the thickness of the material. This operation of increasing the tension of the material 132 takes place in a series of increments under the control of the increment control mechanism 141 and as explained in the description of Figs. 3 and 4, the magnitude of these increments is proportional to the magnitude of the variations in the thickness of the material from the set value.

If the thickness of the material becomes less than the value the gauge 140 is set to hold, the motor 138 will rotate in the reverse direction and as a result the tension of the material 132 between the pairs of rolls 133 and 134 will be decreased in a series of increments of variable magnitude. The remaining features of the operation are identical with corresponding features explained in the description of Fig. 4.

Although in accordance with the provisions of the patent statutes this invention is described as embodied in concrete form, it will be understood that the specific elements, apparatus and their arrangement and connection in the various modifications are merely illustrative and that the invention is not limited thereto, since alterations and modifications will readily suggest themselves to persons skilled in the art without departing from the true spirit of this invention or from the scope of the annexed claims.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A control system for rolling mills and the like having a pair of rolls for reducing the thickness of a length of moving material and a reel for the material comprising in combination, a dynamo-electric machine mechanically coupled to drive said rolls, a second dynamo-electric machine mechanically coupled to said reel, and means responsive to variations in the thickness of said material for controlling the excitation of one of said machines to vary the tension of said material so as to decrease the variations in thickness of said material.

2. A control system for rolling mill apparatus and the like having a pair of rolls for reducing the thickness of a length of moving material, a reel for said material and separate dynamo-electric machines mechanically coupled to said rolls and said reel comprising in combination, a regulator for maintaining the current input to one of said machines and the tension of said material substantially constant, and gauging means responsive to variations in the thickness of said material for varying the setting of said regulator thereby to vary the tension of said material so as to decrease the variations in thickness of the material.

3. A control system for rolling mill apparatus and the like having an element operating on a length of moving material and a dynamo-electric machine mechanically coupled to said element comprising in combination, means responsive to variations in the thickness of said material for controlling said dynamo-electric machine to vary the tension of said material by increments to decrease the variations in thickness of said material, and means responsive to the magnitude of said thickness variations for controlling the magnitude of said increments.

4. A control system for rolling mill apparatus and the like having an element operating on a length of moving material and an electric motor mechanically coupled to said element comprising in combination, an electric gauge responsive to variations in the thickness of said material and means controlled thereby for varying the speed of said motor to vary the tension of the material by increments so as to decrease the variations in thickness of the material, and means controlled by said gauge for varying the magnitude of said increments in proportion to the magnitude of said thickness variations.

5. A control system for material modifying apparatus or the like having a pair of elements operating successively on a length of material and individual dynamo-electric machines mechanically coupled to said elements comprising in combination, a current regulator for maintaining the armature current of one of said machines substantially constant, and means responsive to variations in the thickness of said material for controlling the other of said dynamo-electric machines to vary the tension of said material to decrease the thickness variations of said material.

6. A control system for rolling mill apparatus and the like having a plurality of elements for successively operating on a length of moving material, and an electric motor for driving one of said elements and a second electric motor for driving another of said elements comprising in combination, a current regulator for maintaining the current input to one of said motors substantially constant, and means responsive to variations in the thickness of said material for controlling the speed of the other of said motors to vary the tension of said material to decrease the thickness variations of said material.

7. A control system for rolling mill apparatus and the like having an element operating on a length of moving material and a dynamo-electric machine mechanically coupled to said element comprising in combination, an electric gauge responsive to variations in the thickness of said material for producing control voltages proportional to said variations, means responsive to said voltage for controlling said machine to vary the tension of said material by increments to decrease the variations in thickness of said material, and means responsive to said voltages for varying the amount of said increments in proportion to the amount of said thickness variations.

FRANCIS MOHLER.