Nov. 28, 1944. T. B. MONTGOMERY 2,363,684

CONTROL SYSTEM

Filed Nov. 17, 1941 2 Sheets-Sheet 1

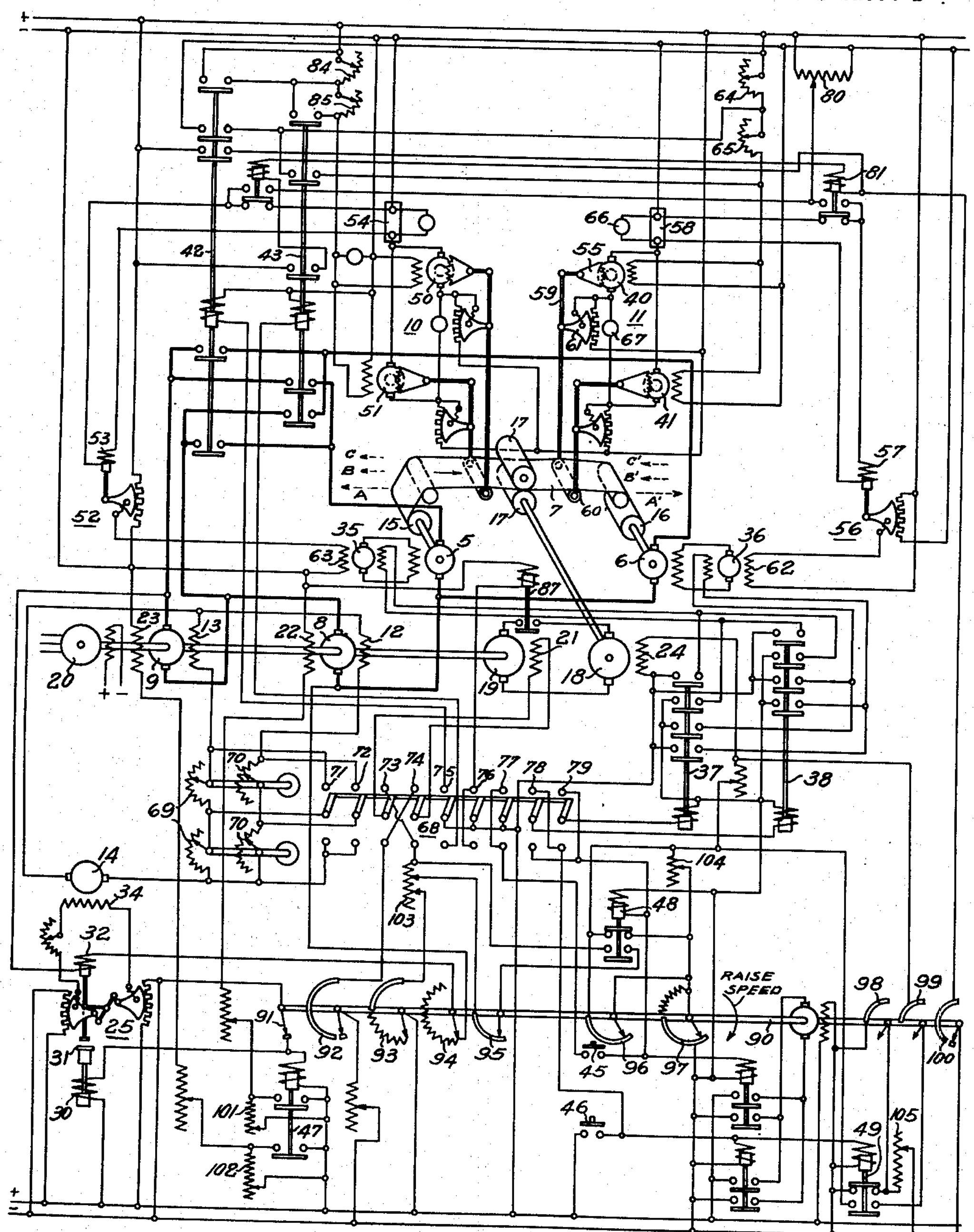

Fig. 1

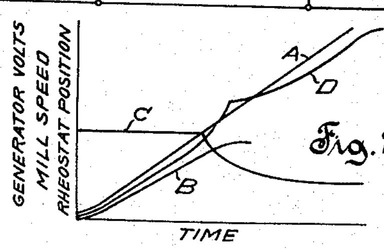

Fig. 2

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Filed Nov. 17, 1941 2 Sheets-Sheet 2

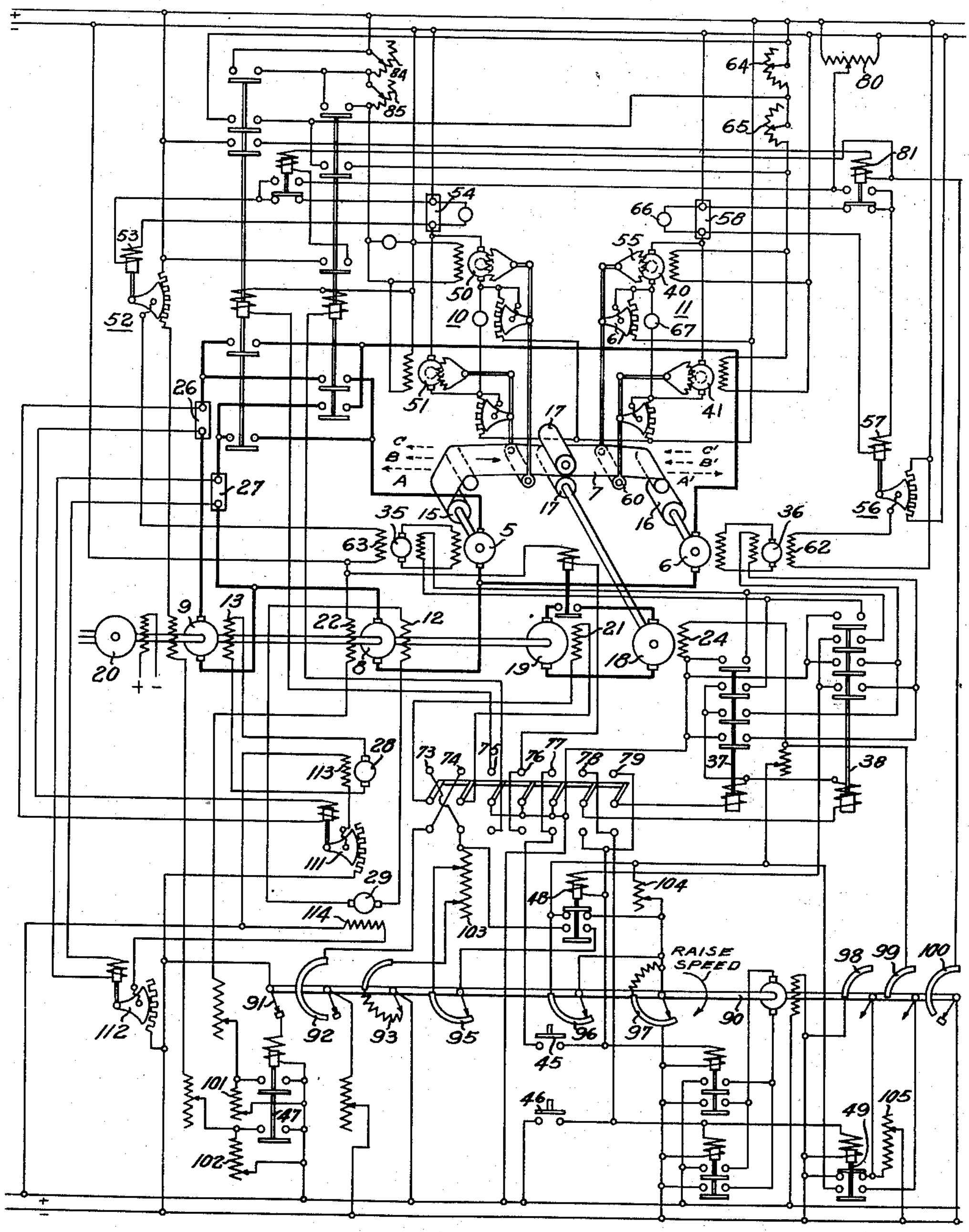

Fig. 3

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CONTROL SYSTEM

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14 Claims. (Cl. 80—32)

This invention relates in general to a control system for controlling the operation being performed on a strip of material while being unwound from a reel and wound upon another reel. This invention is particularly applicable to a control for a strip rolling mill of the type in which a metal strip is run through reducing rolls while being wound and unwound from reels and for automatically tensioning this strip while the mill is at standstill, while the mill is accelerating or decelerating and while running at mill speed.

In prior art rolling mill installations of the type utilizing tensioning control systems for steel or other metal strip, operating disadvantages have existed by reason of application of improper tension to the steel or the like strip during acceleration and deceleration of the mill, with the result that during such periods of acceleration and deceleration the thickness of the strip has not been uniform and of a predetermined gauge. As the off-gauge material is scrap, the present invention attempts to cut down the percentage of the scrap in a given pass, by shortening the time required for acceleration and deceleration.

The tension controlling systems of the prior art have attempted to provide a constant tension in the strip by attempting to maintain a constant kilowatt power consumption in the reel tensioning machines, which power consumption was compensated for the reel build-up and build-down as the material increases or decreases on the reel. Regulation of the reel machine has been utilized to effect this tension control. The regulators of these reel machines have been further compensated in an attempt to anticipate the various factors whereby other than a constant power consumption in the reel machine is necessary to maintain a constant tension. These included compensations for inertia of the mill machine, the reel machine and the inertia in the steel or like strip being wound and unwound from the reels. Failure to properly compensate for all variable factors introduced error in the tension provided.

In the early prior art control systems an attempt to maintain a constant tension or slack in a strip between two sets of rolls was made by controlling the speed of one machine connected to one set of rolls relative to the speed of the machine connected to the other set of rolls.

It is therefore an object of this invention to provide an improved control system avoiding the above disadvantages.

It is also an object of the present invention to provide a control system in which the mill can be accelerated to mill speed in a very short time and a constant tension maintained during such acceleration.

It is also an object of the present invention to provide a means for measuring the difference between the tensions on both sides of the strip.

Objects and advantages other than those above set forth will become apparent with the following description taken in conjunction with the drawings, in which:

Fig. 1 is a schematic diagram illustrating the invention;

Fig. 2 illustrates the operation of the tensiometers of Fig. 1; and

Fig. 3 is a schematic diagram of a modification of the invention shown in Fig. 1.

In Fig. 1, a strip of material 7, which may be considered as steel strip, is shown being unwound from an unwinding or entry reel 15 and passing between the main rolls 17, which are operating upon the strip, and being wound upon the winding or delivery reel 16. The main rolls 17 are operated by a motor 18 which is the main mill motor. This main mill motor 18 obtains its power from the main generator 19 which may be operated by an alternating current motor 20 as shown. The speed of the mill is varied over the lower half of the speed range by variation of the field 21 of the main generator 19. The upper half of the speed range variation is obtained by controlling the field 24 of the main mill motor 18. The mill is shown as being run in the arrow direction or from left to right as viewed in the drawings.

The strip of material 7 is tensioned on both sides of the main roll by the entry and delivery reel machines 5 and 6 connected to the entry and delivery reels 15 and 16. The reel machines 5 and 6 are connected across a reel generator 8 with an auxiliary generator 9 or booster connected in circuit with the winding or delivery reel machine 6. The reel generator 8 and auxiliary generator 9 may be driven by the same alternating current motor 20 driving the main generator 19. In other words, the entry or unwinding reel machine 5 is connected directly across the terminals of reel generator 8 and the delivery or winding reel machine 6 is connected across the reel generator 8 and auxiliary generator 9 in series.

The tension on the entry and delivery reel machines 5 and 6 is maintained and controlled both by tensiometers, shown generally at 10 and 11, controlling the field excitation of the reel machines and also by control of the energization of the field excitation of the reel and auxiliary generators 8 and 9.

In order to tension the strip 7 while the mill is at a standstill, the main fields 12 and 13 of the reel and auxiliary generators 8 and 9 are excited in parallel from a pilot exciter 14. For this "stall" tension, full load current through the reel machines 5 and 6 is necessary. The reel generator fields 12 and 22 are energized so as to apply a voltage to the entry reel machine 5 which will tend to rotate the same in the reverse or winding direction with full load current through this machine.

In this energization the differential field 22 is sufficiently strong to overbalance the main field 12 to provide this voltage which we will assume to be twenty volts. Pilot exciter 14 is regulated by a regulator 25 in the field circuit thereof. A pickup coil 30 on this regulator 25 has a stop 31 holding the regulator in a position to energize the field 34 of pilot exciter 14 sufficiently to energize the main field 13 of the auxiliary generator 9 so that it applies a voltage of forty volts in a direction opposite to the voltage of the reel generator 8. The forty volts of the auxiliary generator 9 minus the twenty volts of the reel generator 8, appears as twenty volts across the terminals of the delivery reel machine 6 which, with full load current in the delivery reel machine 6, applies full stall tension thereto.

By adjusting the differential fields 22 and 23 of the reel and auxiliary generators 8 and 9, the amount of current at standstill in the entry and reel machines 5 and 6 is adjusted.

Stall tension is also dependent upon the field strength of the reel machines 5 and 6. The field strength of the delivery reel machine 6 is controlled through pilot exciter 36 by the delivery reel regulator 56 whose main coil 57 is connected across a shunt 58 measuring the current in the torque motors 40 and 41 of the tensiometer 11. The torque motor 40 has a pinion on its shaft connected to a gear section 55 pivoted on an arm 59 connected to one end of a roll 60 on which the strip 7 runs. The torque motor 41 is similarly connected to the other end of the roll 60.

The torque motors 40 and 41 are connected in parallel across a constant source of direct current voltage, and tends to drive their gear sectors in a direction to pull the tension measuring roll 60 in an upward direction. As the roll 60 is pulled upward by the torque motor 40, a regulator sector 61, also connected to the arm 59 connecting the gear sector 55 and the roll 60, moves to insert more resistance in circuit with the armature of torque motor 40 which reduces the pull of the torque motor 40 on the roll 60 and hence reduces the pull of the roll 60 on the strip 7.

The regulator 56 increases the voltage on the field 62 of pilot exciter 36 when the current in the regulator coil 57 is increased. This regulator 56 is set to balance when there is full load current in the torque motor 40 as measured by the shunt 58 across which the coil 57 is connected. It will be noted that tensiometer roll 60 operates at approximately the same position independently of the amount of tension applied to the strip 7. This permits the angle of the strip 7 at the rolls 17 to be that which gives the best position for rolling.

When the standstill or stall tension is first applied, the tensiometer roll 60 is at its top position thereby providing less than full load current on the torque motors 40 and 41. As the regulator 56 balances at full load current in the torque motors, it will be in its lowermost position against a stop (not shown) thereby providing full field on the delivery reel machine 6. When stall tension current is applied to the delivery reel motor 6 by energization of the reel and auxiliary generators 8 and 9, the delivery reel motor 6 rotates in a winding direction to take up the slack in strip 7.

If the strip 7 in between the main rolls 17 and the delivery reel 16 were inflexible, the stopping of the motor 6 as the strip becomes taut would project suddenly into the strip the full torque of the motor 6 plus its stopping inertia torque. However since the torque motors 40 and 41 are pulling upwardly on the roll 60 at the top position thereof with only about twenty-five percent of full load current therein, the shock of the motor 6 is taken up as the roll 60 pulls from its stop position to operating position. This follows as the roll 60 in its downward movement gradually increases the current in the torque motors 40 and 41 from twenty-five percent to a hundred percent. As soon as the roll 60 reaches its operating position, which is about three-quarters of an inch above the pass line, the regulator 56 balances and adjusts the field 62 of the delivery reel motor 6 until the delivery reel torque is at a value corresponding to the pull on the strip exerted by the torque motors 40 and 41 at the setting of its field adjusting rheostat 64 or 65.

To consider the operation of the tensiometer 11 in controlling the energization of the delivery reel motor 6 to maintain a predetermined tension, the operation following a change in predetermined tension will be described. Assuming that the adjusting rheostat 64 in the field circuit of the torque motors 40 and 41 is set for a hundred percent tension and is changed to a setting for fifty percent tension. Such change will reduce the field current in the torque motors 40 and 41 and will reduce their torque, thereby permitting the tensiometer roll 60 to be moved downward by the existing tension in the strip 7. Movement of the tensiometer roll 60 and the arm 59 connected thereto, moves the tensiometer regulator sector 61 so as to increase the current in the armature of the torque motors 40 and 41 above one hundred percent and thereby above the balance point of the regulator 56. The increase in current through the torque motor armature current shunt 58, increases the energization of the coil 57 of the regulator 56.

This increase in regulator coil current moves the regulator 56 so as to decrease the energization of the reel motor field 62 which decreases the tension applied by the delivery reel motor 6 to a value at which the roll 60 moves back to operating position corresponding to one hundred percent current through shunt 58. Only one position of the torque motor regulator section 61 and, hence, only one position of the tensiometer roll 60, gives one hundred percent armature current through the torque motors 40 and 41 and balances the regulator 56.

As shown in Fig. 1, there are two tensiometers, one on each end of the tensiometer roll 60, thus making four regulators on the two rolls. One side of the armature of each of torque motors 40 and 41 is connected through its corresponding gear sector regulator resistance to one side of the constant voltage bus. The other sides of each of the armatures of these torque motors are connected together and the total current thereof moves through the shunt 58 which energizes the coil 57 of the regulator 56. A voltmeter 67, connected across the armatures of the torque motors as shown, will measure the differential tension between the two sides of the strip. This is important in measuring a difference in gauge or thickness of the material at each edge of the strip. The total tension in the strip is measured by an ammeter 66 connected across the shunt 58.

Stall tension current is applied by closing the main switch 68 in either the upper position if running to the right or in the lower position if running to the left. Assuming that it is desired to run to the right or in the arrow direction shown, the switch 68 is thrown to the upward position. Movement of the switch 68 in the upward direction transfers the controls, which are duplicated on both entry and delivery sides of the mill, to the sides of the mill toward which the mill is running. For example, when the mill is run to the right the operator stands at the right side of the mill or at the delivery side of the mill, where he is available to watch the finished steel.

Contact 71 on the switch 68 short circuits the upper of the two booster voltage adjusting rheostats 69, which is the one operable from the left side or entry side of the mill. Contact 72 on the knife switch short circuits one of the two rheostats 70 in the main field 12 of the reel generator 8, thereby transferring control of reduction compensation to the right side or delivery side of the mill. Contacts 73 and 74 connect the main generator field 21 in a direction so as to run the mill the the right. Contact 75 closes contactor 42 to connect the right reel motor 6 to the auxiliary generator 9 and reel generator 8 in series and connects the left or entry reel machine to the reel generator 8 only.

A third contact on the relay 42 short circuits the back tension adjusting rheostat 84 of tensiometers 10 on the left side of the mill transferring this control to the right side of the mill. A fourth contact of relay 42 similarly transfers the control to the adjusting rheostat 65 of the torque motors 40 and 41. A fifth contact of the relay 42 prepares a circuit for a relay 81 which circuit becomes effective when closed through contact 100 on the main mill motor operated rheostat 90. When 81 is energized, upon operation of the main mill rheostat to start movement of the mill, the control of the coil 57 of regulator 56 is transferred from the voltage of the shunt 58 to control by a constant voltage (across the left hand part of resistor 86) minus the voltage of the shunt 58.

Contact 76 of the main switch 68 connects the main generator 19 to the main motor 18 by relay 87, however the main generator 19 is without field voltage as the field circuit thereof set up through the main switch contacts 73 and 74 is incomplete until the contact 92 of the main mill rheostat 90 is closed. Contact 77 of the main switch 68 closes the circuit to the raise push button 45 so that speed can be raised. This prevents the mill speed from being raised by the mill motor rheostat 90 until connections for stall tension are made in proper direction and the control connections for tension are made operative on the proper side of the mill. Connections (not shown) may be made for running the mill motor separately if desirable in order to set up the mill and thread the strip, for polishing the rolls and similar functions.

In order to reduce the amount of off-gauge or scrap material rolled during the acceleration period, the time of accelerating the mill to full mill speed is greatly shortened and a constant tension maintained on the strip during the acceleration period. At standstill the forces present in the strip may be represented by the vectors (shown in dotted lines in Fig. 1) of which A and A′ represent the front and back stall tension applied to the strip by the delivery and entry reel machines. At the instant that the main mill rheostat 90 effects starting of the mill and acceleration is started, two other forces acting on the strip are present. One force is the friction in all the rotating parts which must be overcome and this force is represented by the vectors C and C′ which, as shown, act in a back direction at both ends of the mill. Another force acting on the strip is the force of inertia or WR^2 and this force is indicated by the vectors B and B′ and also act in a backward direction at both ends of the mill.

In other words, the vectors B and C add to the vector A on the entry reel side of the strip and the vectors B′ and C′ subtract from the vector A′ on the delivery reel side of the strip. Therefore, if torque is maintained on the motors when rotation begins of the same value as at standstill, excessive tension will be effected on the strip on the entry side of the mill, which is likely to cause breakage, and too small a tension will be exerted on the delivery reel side of the strip thereby permitting looping.

It is therefore necessary to break away or start rotation on all three motors at exactly the same instant. It is necessary to start the mill under varying conditions of mill load and varying conditions of WR^2 for inertia value. The mill may be started with all the steel on the entry reel or, if the mill has been stopped during a pass, the mill may be started with various percentages of the steel on the entry and delivery reels. This will, of course, give varying WR^2 values or in other words the vectors B and B′ may vary with respect to each other.

Therefore at the instant sufficient current is applied to the main motor 18 to start rotation, an additonal torque sufficient to overcome friction and WR^2 must be added to the delivery reel motor 6 in addition to the stall tension. Similarly an additional torque sufficient to overcome friction and WR^2 must be subtracted from the torque supplied to provide tension by the entry reel machine 5. If the torque overcoming friction and inertia of the entry reel machine 5 is greater than the stall tension, the action of the entry reel machine 5 is reversed and at the start of acceleration the entry reel machine actually rotates as a motor tending to push the strip toward the main roll.

When the main motor rheostat 90 is operated to raise the speed of the mill, which is effected by movement in the arrow or clockwise direction as viewed in the drawings, a circuit for the relay 47 is opened at contact 91 on the main mill rheostat 90. Relay 47 opens the circuit of the differential fields 23 and 22 of the auxiliary generator 9 and the reel generator 8. Opening of the reel generator differential field 22 reduces the voltage thereof (in the reverse direction) to a value determined by the setting of resistor 101. If the friction and WR^2 represent a torque corresponding to one-half full load motor current, resistor 101 will be adjusted to reduce the voltage of reel generator 8 to one-half the stall tension value. This reduces the current in the entry reel machine 5 to one-half, thereby reducing by one-half the torque supplied by the entry reel machine 5 to the strip.

Opening of the lower contact of relay 47 connects the differential field 23 of the auxiliary generator 9 through the resistance 102, however this reduction has little appreciable effect on the delivery reel motor 6. This is because the reel generator 8 and auxiliary generator 9 are connected in series across the delivery reel motor 6. Therefore, a reduction in the reel generator voltage (which opposes the voltage of the auxiliary generator 9 at standstill) causes an increase in voltage across the delivery reel motor 6 thus increasing its current and torque to overcome friction and WR^2. However, the differential field 23 of the auxiliary generator 9 may be reduced to zero, or reconnected in a reverse direction when necessary, so that the voltage of the reel generator 8 is additive to the voltage of the auxiliary generator 9 to give a voltage increase and therefore increase the current in the delivery reel machine 6 independently of the entry reel machine 5.

When the main mill rheostat 90 is moved in a clockwise direction to initiate acceleration of the mill, the main generator field 21 is connected through sectors 92 and 93 to start raising the voltage on the main mill motor 18. At the same time the reel motor currents are changing to compensate for friction and WR^2, the main generator voltage rises to a value determined by the setting of resistor 103 to supply enough current to the main mill motor 18 to cause the mill to start rotating.

When the main rheostat 90 is moved to start raising speed of the mill, the pickup coil 30 of regulator 25 for pilot exciter 14 is deenergized, thereby permitting this regulator to come under the control of its main coil 32 which is connected in series with sector 94 of the main mill rheostat 90 across the armature of the auxiliary generator 9. The drive for this mill is essentially a constant torque drive, which requires that the horsepower of the main mill motor 18 be increased in proportion to the increase in mill speed. Movement of rheostat 90 in a clockwise direction will increase the speed of the mill by increasing the main generator voltage up to a position of full generator voltage which is equal to half mill speed. After full generator voltage is reached further speed increase is obtained by weakening the field 24 of the main motor 18. The rheostat sectors 93 in series with the main generator field 21 and rheostat section 97 in circuit with the main motor field 24 are so stepped as to give equal R. P. M. change per step.

By driving the mill with full field on the main motor 18, maximum torque is provided to break away the mill against mill load and friction. For example, with a main motor 18 of a two to one speed range, twice the full load torque at top speed is available for break away with full load current. In order that the horsepower delivered by the main mill motor 18 will increase with speed in the reel machine circuits as well as in the main motor circuit, the main coil 32 of regulator 25 is connected to the rheostat sector 94 on the main mill rheostat 90. As the rheostat 94 is stepped with equal resistance per step, this regulator causes an increased voltage across the delivery reel motor 6 in proportion to speed increase. To further insure that the horsepower increase is in proportion to the speed increase, an essentially constant speed motor is used to drive the main mill rheostat 90.

The horsepower is made to increase with speed in the reel circuit by equal stepping of the rheostat sector 94 and for accurate results the speed of the main motor must follow the rheostat position. Although sectors 97 and 93 are stepped in equal R. P. M. per step, due to the time lag in the main motor and generator fields, speed will actually lag behind the rheostat position unless compensation is provided. To insure that the mill speed changes in proportion to rheostat position the main generator field 21 and motor field 24 are forced.

When the raise push button 45 is operated, it also picks up relay 48 which has a contact which short circuits an adjustable section of resistance 103 to increase the generator voltage an amount to overcome this lag. Thus the generator field increases exactly as fast as the rheostat sector 93 moves. Another contact of relay 48 inserts resistor 104 in the circuit of main mill motor field 24 and in a similar manner decreases the motor field sufficiently to make up for the lag. The operation of the field forcing on the main motor is made effective by the ring 96 of rheostat 90, also short circuiting resistor 104, operable only after full generator voltage has been reached.

The operation of the field forcing is shown in Fig. 2 in which the curve A shows the positions of motor operated rheostat 90 with respect to time. As this is a constant speed motor, the curve A is a straight line. The curve B shows the generator voltage rise as it would be if the speed is raised without field forcing, and it can be seen that this voltage rise would lag the regulator position. With field forcing as above described the generator voltage can be made to follow the lower half of the curve D, thereby arriving at full generator voltage at substantially the same time or a little ahead of the rheostat 90. As the mill speed is further increased along the line D, the forcing of the main mill motor field keeps this mill speed curve substantially along the line A. The curve C shows the motor torque as being full torque at the moment the mill starts. Curve C also shows that as the speed reduces from full mill speed, the torque of motor 18 increases.

The operation of the tensiometers 10, to control the tension by acting on the regulator 52 to control pilot exciter 35 and the field strength of the entry reel machine 5, to regulate the entry mill tension, is the same at standstill as while the mill is running. However, the operation of the tensiometers 11 for controlling the current of the delivery reel motor 6 must be changed under running condition from that at standstill.

When the delivery reel motor 6 is standing still, tension is increased by increasing the field strength of the motor. However when the motor 6 is running, tension is increased by decreasing the counter E. M. F. of the motor and thus allowing more current to flow in the armature circuit thereof. Consequently, when the delivery reel motor 6 starts to rotate, the regulator 56 must change so as to decrease the field current in the reel motor 6, rather than increase such field current, when an increase in tension is desired and called for by the tensiometer regulator.

This change of regulation is obtained upon rotation of the mill by making the main coil 57 of regulator 56 responsive not to the voltage of the shunt 58 but to the voltage of a constant voltage minus the voltage of the shunt 58. This change is effected by contact 100 of the main mill rheostat 90 as was previously explained. The energization of relay 81 is effected when the mill is started running to the right. A contact of relay 81 disconnects one side of main coil 57 from the shunt 58 and reconnects the regulator coil 57 to measure the difference between the voltage across the shunt 58 in series with a fixed voltage across a portion of resistance 80. The voltage across resistor 80 is adjusted to be twice one hundred percent voltage across the shunt 58.

Therefore, if the current through the torque motor 40 increases above one hundred percent, showing too much tension in the strip, the voltage of resistor 80 minus the voltage of the shunt 58 will be less than one hundred percent shunt voltage at which the regulator balances. This permits the elements of regulator 56 to be moved downward by gravity due to the lower energization of its main coil 57. Such action of the regulator 56 increases the field current and therefore the counter E. M. F. of the delivery reel motor 6 until the delivery reel motor current is reduced sufficiently to restore tension which will give one hundred percent full load current in the torque motor 40.

Conversely with too small a tension, the voltage of the resistance 81 minus the shunt voltage will be more than one hundred percent balance voltage of the regulator 56 and the regulator 56 will act to decrease the field strength and counter E. M. F. of motor 6, thereby increasing the armature current thereof until tension is raised back to normal. In the above manner the delivery reel regulator 56 is changed from generator to motor regulation as soon as acceleration begins.

Acceleration is continued until the desired speed is reached. When the speed of the mill is raised above a very low value, the added torque necessary to take care of the inertia and friction are taken care of by the tensiometer control without further change in the field current to the differential fields of the reel generator and auxiliary generator.

When the mill is decelerated from full speed, the fields 21 and 24 of the main generator and main motor are forced to avoid lag in their action. The sectors 98 and 99 on rheostat 90 are at the topmost position thereof. When the lower speed button 46 is pressed, relay 49 picks up which short circuits ring 98 to force the motor field 24 by increasing the field current sufficiently to overcome the lag therein. This forcing continues until full motor field is reached at which time the motor field forcing is removed by opening of the forcing circuit at ring 98.

Relay 49 also opens a contact paralleling the resistance 105, however, 105 is still short circuited during field weakening of the main mill motor because of the short circuit maintained by ring 98 on rheostat 90. Upon further movement of rheostat 90 to decelerate the mill by lowering the generator voltage, ring 98 opens thereby inserting resistor 105 to force the reduction of the generator field so as to overcome the lag therein, thereby lowering the generator voltage at the same rate that the rheostat ring 93 moves.

As explained above when a change in speed is required it is necessary to add sufficient torque to the delivery reel motor and subtract sufficient torque from the entry reel motor to compensate for WR^2 or inertia. The required change in torque necessary to compensate for the inertia of the machine is proportional to the rate of speed change and is therefore constant for a constant rate of change. The main mill rheostat 90 is, as explained above, operated to produce a constant rate of acceleration and deceleration.

Therefore if the field excitation of the entry reel and delivery reel machines are changed by predetermined values of the proper magnitude and direction, accurate compensation will be provided for WR^2 or inertia of these machines. The tensiometer regulator on each reel machine measures the tension in the strip and regulates the fields to keep this measured value constant both during speed change and at any given speed. The tensiometer regulator will therefore compensate for inertia or WR^2.

However, compensation by the tensiometer control must of necessity occur at some time after such compensation is needed, due to the time it takes the tensiometer regulator to act plus the time it takes for the regulator 56 to act, plus the time lag of the reel motor field when such change is made. The need for WR^2 compensation is present at the instant speed begins to change. With constant acceleration, a constant change in reel machine field flux is required to compensate for inertia, and if a given change is made directly in the motor field flux sufficient to overcome inertia at the instant the speed change is initiated, no movement of the regulators will be required. Also with the machine fields changed in this manner, over-shooting of the regulator will be eliminated and the compensation can be applied and taken off at exactly the proper instant.

To accomplish this compensation, for example, when the speed is raised, two contacts of relay 37 energize the auxiliary field of pilot exciter 35 (when running to the right) to decrease the flux of the entry reel motor machine 5. Two other contacts of relay 37 increase the field flux of the delivery reel motor 6 by an amount sufficient to overcome inertia. Upon deceleration relay 38 is closed which adds a compensated torque to the entry reel machine 5 and subtracts an equivalent torque from the delivery reel motor 6. When the mill is running to the left the reverse action takes place, that is, relay 38 is energized upon acceleration and relay 37 is energized upon deceleration.

The operation and functioning of the above control system has been described for the condition where the mill is running in the arrow direction from left to right. To reverse the mill the main switch is moved to its lower position, which reverses all the controls to give the same operation with machine 6 as the entry reel machine and machine 5 as the delivery reel machine.

In Fig. 1 the compensation for reduction in the strip is provided for by manual setting of the particular resistors 69 and 70 functioning when the mill is being run in the given direction. Control of resistors 69 and 70 controls the field strength of main fields 13 and 12 of the booster 9 and reel generator 8. For example, with a 50% reduction in the strip, the delivery reel machine 6 must run at twice the speed of the entry reel machine 5. Setting of the resistors 69 and 70 provides for this difference in speed by providing differences in full load currents of machines 5 and 6.

In Fig. 3, a control system generally similar to that shown in Fig. 1 is shown, except that the compensation for reduction is effected automatically. The fields 12 and 13 of the reel generator 8 and auxiliary generator 9 are energized respectively from pilot exciters 29 and 28. These pilot exciters 29 and 28 have fields 114 and 113 which are controlled by regulators 112 and 111. The regulators 112 and 111 are energized in accordance with the currents flowing in the reel machines 5 and 6 by having the main coil of the regulators connected to shunts 27 and 26.

If during a mill pass the reduction should be suddenly changed from 50% to 25%, the current in the entry reel machine 5 would be automatically changed by a change in the generator field 12 to have the corrected current value due to relative action of regulators 111 and 112. Thus, the setting of the relative field strengths of the reel generator 8 and the auxiliary generator 9 due to reduction of the strip is automatically accomplished.

While but two embodiments of the invention have been illustrated and described it will be apparent to those skilled in the art that various changes and modifications may be made therein without departing from the spirit of the invention or from the scope of the appended claims.

It is claimed and desired to secure by Letters Patent:

1. In a rolling mill, winding and unwinding reels for handling strip material rolled by said mill, dynamo electric machines connected to said reels, a power source, an auxiliary power source, and means for connecting said unwinding reel dynamo electric machine directly across said power source and for connecting said winding reel dynamo electric machine and said auxiliary power source in series across said power source, whereby said auxiliary power source is operable to supply the difference in voltages between said dynamo electric machines.

2. In a rolling mill, winding and unwinding reels for handling strip material rolled by said mill, dynamo electric machines connected to said reels, a power source, an auxiliary power source, means for connecting said unwinding reel dynamo electric machine directly across said power source and for connecting said winding reel dynamo electric machine and said auxiliary power source in series across said power source, and means directly responsive to change in tension of said strip material for controlling the energization of said dynamo electric machines.

3. In a rolling mill, reducing rolls operating on a strip of material, an unwinding and a winding reel for said strip of material, dynamo electric machines connected to said reels, a power source, an auxiliary power source, means for connecting said dynamo electric machine connected to said unwinding reel directly across said power source and for connecting said other of said dynamo electric machines to said power source and said auxiliary source in series, and means responsive to a change in reduction of said strip for varying the relative voltages of said power source and said auxiliary power source.

4. In a control system for a strip of material operated upon by rolls while unwinding from an unwinding reel and winding upon a winding reel, dynamo electric machines connected to said winding and unwinding reels, a motor for driving said rolls operating upon said strip, a generator for energizing said motor, and means for energizing said dynamo electric machines connected to said reels in a circuit separate from said main motor and main generator, said means including a second generator connected across said unwinding reel machine and an auxiliary generator connected in series with said second generator across said winding reel machine.

5. In a control system, for a strip of material operated upon by rolls while unwinding from an unwinding reel and winding upon a winding reel, dynamo electric machines connected to said winding and unwinding reels, a motor for driving said rolls operating upon said strip, a generator for energizing said main motor, means for energizing said dynamo electric machines connected to said reels in a circuit separate from said main motor and main generator, said means including a second generator connected across said unwinding reel machine and an auxiliary generator connected in series with said second generator across said winding reel machine, means for regulating the energization of said winding and unwinding machines, and means for reversing the action of said regulator on said winding machine when said machine begins to rotate.

6. In a tension control system, a reel for strip material, a dynamo electric machine connected to said reel to tension said strip, means for regulating the energization of said dynamo electric machine in accordance with the tension in said strip, said means comprising a torque motor mechanically connected to said strip so that the torque of said motor is a measure of said tension, and means operatively responsive to operative movement of said torque motor to regulate said dynamo electric machine and control the current through said torque motor.

7. In a tension control system, a reel for strip material, a dynamo electric machine connected to said reel to tension said strip, a plurality of means for regulating the energization of said dynamo electric machine in accordance with the tension in each edge of said strip, said means comprising a plurality of torque motors mechanically connected to said strip so that the torque of said motors is a measure of said tension, means operatively responsive to operative movement of said torque motors for controlling the currents therethrough, and means for measuring the difference in said tensions.

8. In a tension control system, a reel for strip material, a dynamo electric machine connected to said reel to tension said strip, means for regulating the energization of said dynamo electric machine in accordance with the tension in said strip, said means comprising a torque motor mechanically connected to said strip by a tensioning roll so that the torque of said motor is a measure of said tension, and means including a regulator operable in accordance with movement of said tensioning roll and connected to control the torque of said torque motor, whereby said tensioning roll operates at substantially the same position independently of the amount of said tension.

9. In a rolling mill control system, power rolls for performing an operation on a strip of material, winding and unwinding reels for handling said strip material, a motor for driving said power rolls, dynamo electric machines connected to said reels, means for controlling the energization of said dynamo electric machines to maintain a predetermined tension at zero speed of said strip, and means for simultaneously energizing said motor and varying the energization of said dynamo electric machines, whereby said ener-

gization of said winding dynamo electric machine is increased proportionally to the friction thereof and the inertia of strip wound on said winding reel, and whereby said energization of said unwinding dynamo electric machine is decreased proportionally to the friction thereof and the inertia of strip on said unwinding reel.

10. In a tension control system, a reel for winding strip material, a dynamo electric machine connected to said reel to tension said strip, means for regulating the energization of said dynamo electric machine in accordance with the tension in said strip, said means comprising a torque motor mechanically connected to said strip so that the torque of said motor is a measure of said tension, said means further comprising means for regulating the energization of said dynamo-electric machine in accordance with current in said torque motor at zero speed of said strip and for regulating the energization of said dynamo-electric machine in accordance with a constant value minus the current in said torque motor at other speeds of said strip.

11. In a control system for a strip of material operated upon by rolls while unwinding from an unwinding reel and winding upon a winding reel, dynamo electric machines connected to said winding and unwinding reels, a motor for driving said rolls operating upon said strip, a generator for energizing said motor, means for energizing said dynamo electric machines connected to said reels in a circuit separate from said main motor and main generator, said means including a second generator connected across said unwinding reel machine and an auxiliary generator connected in series with said second generator across said winding reel machine, and means for varying the speed of said operating rolls, said means comprising a constant speed motor operated rheostat.

12. In a control system for a strip of material operated upon by rolls while unwinding from an unwinding reel and winding upon a winding reel, dynamo electric machines connected to said winding and unwinding reels, a motor for driving said rolls operating upon said strip, a generator for energizing said motor, means for energizing said dynamo electric machines connected to said reels in a circuit separate from said main motor and main generator, said means including a second generator connected across said unwinding reel machine and an auxiliary generator connected in series with said second generator across said winding reel machine, and means for varying the speed of said operating rolls, said means comprising a constant speed motor operated rheostat, and further comprising means for forcing the energization of said generator so that it changes during said mill speed variation in accordance with said speed of said rheostat.

13. In a control system for a strip of material operated upon by rolls while unwinding from an unwinding reel and winding upon a winding reel, dynamo electric machines connected to said winding and unwinding reels, a motor for driving said rolls operating upon said strip, a generator for energizing said motor, means for energizing said dynamo electric machines connected to said reels in a circuit separate from said main motor and main generator, said means including a second generator connected across said unwinding reel machine and an auxiliary generator connected in series with said second generator across said winding reel machine, and means for varying the speed of said operating rolls, said means comprising a constant speed motor operated rheostat, and further comprising means for forcing the energization of said motor so that it changes during said mill speed variation in accordance with said speed of said rheostat.

14. In a rolling mill control system, power rolls for operating on a strip of material, a motor for operating said rolls, a generator for supplying said motor, means for varying the speed of said motor from zero speed to base speed by variation of the field of said generator, means for varying the speed of said motor from base speed to full speed by controlling the field of said motor whereby the torque of said motor varies inversely with speed from said base speed to said full speed, and means for forcing the fields of said motor and generator to obtain a constant rate of acceleration, thereby permitting substantially constant compensation of said motor for the inertia of said mill.

TERRYL B. MONTGOMERY.