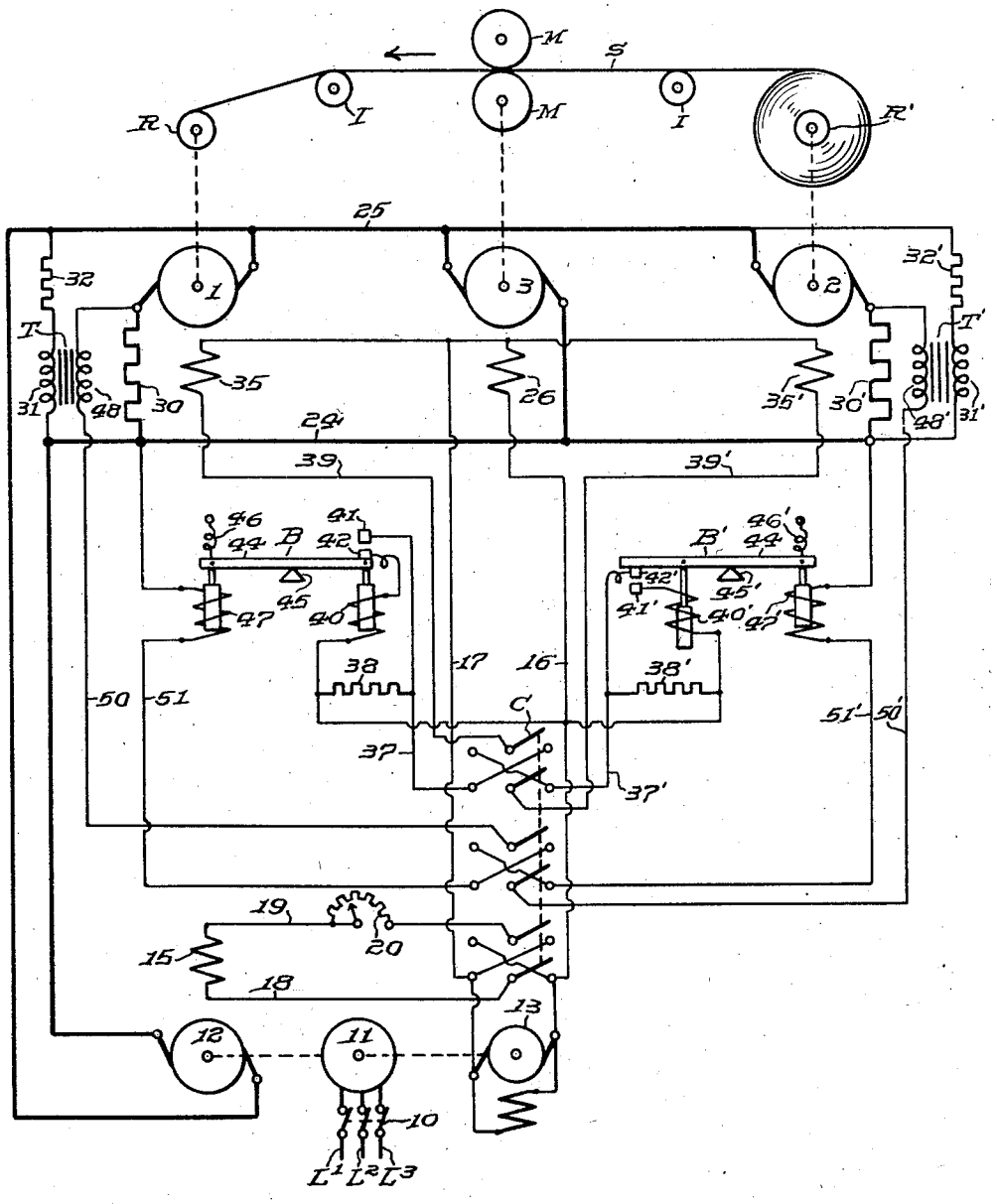
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CONTROL SYSTEM FOR ELECTRIC MOTORS

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CONTROL SYSTEM FOR ELECTRIC MOTORS

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The present invention relates to a control system for maintaining the relative torques of a plurality of motors at predetermined proportional values during their concurrent accelcration and deceleration, and is of particular advantage when employed for controlling the motors of a strip mill at the beginning and end of each pass as the strip is directed between its rolls.

Such mill usually comprises a pair of spaced reels, each with a driving motor, and rolls interposed between the reels and also provided with a driving motor, so that a strip of metal to be rolled may be wound on one reel, one end thereof led between the rolls and attached to the other reel and the entire strip then rolled and wound on the latter reel as it is unwound from the first reel. By reversing the direction of movement of the reels and rolls, the strip may be wound back and forth between the reels in this manner any number of times and operated upon by the rolls at each pass until a desired thickness and length are attained. Thus, during the reduction of each strip, the reels and the rolls are repeatedly reversed in direction of rotation, and for most satisfactory results it is desirable that tension be maintained on the strip continuously from initiation to completion of the rolling operation.

It will also be understood by those skilled in the art that the speed of rolling is customarily varied through wide limits in accordance, inter alia, with the strip speed, its thickness and other well-known factors. Thus, when the strip is relatively thin it may be rolled at high speed, but a considerable amount of strip then passes between the rolls during acceleration and deceleration of the mill and it is desirable that uniform tension be maintained on the strip during these periods, irrespective of the rate of speed change or the time consumed thereby.

It is therefore a principal object of our invention to provide a control system particularly adapted for association with a strip mill of the aforesaid character which is effective to control the operation of the mill motors in such way as to maintain predetermined relationships between their respective torques, so that a tension suitably proportioned to rolling conditions may be maintained on the strip during acceleration and deceleration of the mill motors while the strip is being rolled.

A further object of the invention is the provision of a control system for three electric motors, of which one is driven mechanically from one of the others, operative to maintain a predetermined relation between the torque of the driven motor and an opposing torque of the driving motor, as well as between the torques of both these motors and that of the third motor.

Another object is the provision of means for controlling the torque of one motor relatively to that of another in predetermined ratio to the rates of acceleration and deceleration to which said motors are subjected.

Another object is the provision of a commercially practicable strip mill control system of the character aforesaid comprising electrical and mechanical instrumentalities well known in the art suitably interconnected to properly perform their several interrelated functions uniformly and reliably and to afford substantially automatic regulation of the strip tension.

A still further object of the invention is to provide a control system for a strip mill which is well adapted to meet the needs of commercial operation and which by permitting more rapid acceleration and deceleration of the mill and reducing strip breakage and other causes of delay frequently arising during these periods, facilitates the rolling of a strip in a minimum of time.

Another object is to provide a control system utilizing relatively inexpensive instrumentalities which may be of such type and so arranged as to occupy but a relatively small space, while affording adequate and reliable automatic control of the strip tension during acceleration and deceleration of the mill without the expenditure of large quantities of power and therefore without material expense for operation or maintenance.

Other objects, purposes and advantages of the invention will hereinafter more fully appear or will be understood from the following description of one embodiment thereof illustrated in the accompanying drawing.

The said drawing is a simple diagrammatic representation of the principal electrical elements and connections employed in the system with certain mechanical elements of a strip mill of a usual type associated therewith and indicated by conventional symbols.

The mill comprises a pair of reels R, R' between which a strip S, passing over suitable idlers I and between mill rolls M is arranged for winding alternately upon either reel. The reels R, R' are respectively driven by variable speed driving motors 1, 2 and the rolls by another variable speed motor 3, usually through suitable reducing gears or the like (not shown). The motors 1, 2, and 3 are preferably separately excited direct current motors and therefore adapted to operate with substantially equal efficiency in either direc-

tion and at any speed within usual limits, and our control system is interconnected with the motors through their respective armature and field windings to control their torques under operating conditions.

The strip S is shown as wound on reel R' with one end extending therefrom over idlers I, between rolls M and attached to roll R and thus in position to be unwound from reel R', operated upon by rolls M and wound upon reel R, and the control mechanism will be therefore considered first as in condition for controlling the mill during this operation. For operating the mill in this direction a reversing switch C, hereinafter more fully described, is closed on the right hand side as shown.

The basic energizing force for the control system and for the mill is derived from any convenient source of current through leads L1, L2, L3 controlled by a switch 10 to drive a motor 11; the latter is preferably an alternating current motor as current suitable therefor is usually readily obtainable. In the drawing switch 10 is indicated as open, but it will be understood it is normally closed throughout the rolling operation.

The motor 11 is mechanically connected to drive a separately excited direct current generator 12 and a self-excited direct current generator 13. The exciting current for field 15 of generator 12 is derived from output leads 16, 17 of generator 13 through leads 18, 19, and a suitable rheostat 20 is interposed in the latter so that the excitation of field 15 and hence the voltage output of generator 12 may be controlled by the operator, while interconnection of two poles of reversing switch C in these leads permits reversal of the field and hence the direction of rolling.

The armature of roll motor 3 is directly connected through leads 24, 25 to generator 12 while the field 26 of this motor is directly connected with output leads 16, 17 of generator 13. Thus, when the excitation of field 15 of generator 12 is varied by operation of its field rheostat 20, the voltage supplied to the armature of motor 3 is proportionally varied and a roll driving torque is developed in the motor to drive it at a speed proportional to the voltage output of generator 12 as determined by the adjustment of rheostat 20.

The armature of reel motor 1 driving reel R is connected through a resistor 30 with the generator output leads 24, 25, and is therefore correspondingly supplied with driving current from generator 12 under the conditions of operation assumed, while the primary winding 31 of a transformer T in series with a resistor 32 is also connected to the same output leads.

The field 35 of motor 1 is excited from generator 13, and the exciting current passes from the latter through lead 17, field 35, lead 39, the top pole of reversing switch C, lead 37, resistor 38, and lead 16 back to the other side of generator 13. A low resistance actuating solenoid 40 in series with contacts 41, 42 of a vibrating relay B is shunted across resistor 38 so that when the contacts are closed the effect of the resistor on the current in field 35 is removed but is restored when the contacts are opened. Arm 44 of relay B is arranged for oscillation on a fulcrum 45 and is controlled by a spring 46 and an opposing solenoid 47 in such manner that the force exerted by solenoid 47 approximately balances the tension of spring 46 when the solenoid current is at a minimum. When this current is increased the spring is overbalanced and the ratio of the time contacts 41, 42 are closed to the time they are open is also increased, and when the current is reduced this ratio is correspondingly decreased.

Solenoid 47 is connected in series with the secondary winding 48 of transformer T by means of reversing switch C and leads 50, 51, and this series circuit is connected across resistor 30; the strength of the current in solenoid 47 is thus modified by the voltage induced in the secondary winding of transformer T.

This voltage when induced as a result of an increase in the generator voltage subtracts from the voltage drop across resistor 30, so that the current in solenoid 47 is momentarily reduced, thereby decreasing the ratio of the time contacts 41, 42 are closed to the time they are open; this in turn results in a corresponding decrease of current in field 35 of motor 1, which causes an added increase of current in the motor armature and resistor 30 until the current in solenoid 47 is restored to almost its original value. Conversely, when the secondary voltage is induced by a decrease in that of the generator and thus is produced in the opposite direction, it adds to the voltage drop across resistor 30 and the current in solenoid 47 is momentarily increased, thereby increasing the ratio of the time contacts 41, 42 are closed to the time they are open; this in turn results in a corresponding increase of the current in field 35 of motor 1, which causes an added decrease of current in the motor armature and resistor 30 until the current in solenoid 47 is restored to almost its original value. The relay B in this manner controls the average excitation of field 35 so as to maintain practically constant voltage across solenoid 47. When the voltage of generator 12 remains constant there is no voltage induced in the secondary winding 48 of transformer T and consequently, since the voltage across solenoid 47 is practically equal to the voltage drop across resistor 30, the relay B will regulate the excitation of field 35 so as to maintain virtually constant current through the armature of motor 1 and resistor 30.

Thus, when rheostat 20 is operated to start the mill by increasing the excitation of field 15 of generator 12 and hence its voltage output, the armatures of motors 1 and 3 are energized to drive reel R and rolls M in the proper direction to draw the strip S from reel R', roll it and wind it on reel R. The voltage across the armature of motor 1 is thus progressively increased as the mill is brought to rolling speed, the rate of increase being determined in accordance with the rate of acceleration desired. During this period the voltage across solenoid 47 is maintained practically constant by the action of relay B on the current in field 35 as just explained, and since the voltage induced in coil 48 of transformer T is proportional to the rate of acceleration of motor 3, the current in motor 1 and resistor 30 is increased by an additional amount proportional to the rate of acceleration of motor 3. This amount of increase of current in motor 1 can be adjusted to any desired value for a predetermined rate of acceleration by varying the amount of resistance in resistor 32 and when this adjustment is properly made, the current in motor 1 increases just enough relatively to the increase of that in motor 3 during acceleration to provide the additional torque required to accelerate the moving parts of motor 1 and reel R in the desired ratio to the acceleration of motor 3 and rolls M. The current in motor 1 may thus be regulated in such manner as to maintain constant tension on the

strip S between rolls M and reel R during the acceleration period, regardless of the rate of acceleration.

During the acceleration period the desired tension on the strip between unwinding reel R' and the rolls is also maintained by mechanism and circuits now to be described. Thus, the armature of motor 2 which is mechanically geared to reel R' is connected in series with resistor 30' to leads 24 and 25 of generator 12, while the field 35' of this motor is excited through resistor 38' and reversing switch C from generator 13. Motor 2 is thus so connected with the generator circuits as to be driven in the same direction as motor 1, but field 35' is so controlled by mechanism (not shown) which bears no specific relation to the present invention, that strip S when being drawn from reel R' tends to drive the motor faster than the speed at which it would operate under no load, and its counter electro-motive force is therefore greater than the voltage supplied to it and in the opposite direction; it thus exerts a regenerative braking effect on reel R' and hence a tension on the strip. In order to control this tension during the acceleration period, a transformer T' is shunted across leads 24, 25 with a resistor 32' in series with its primary winding 31'; the secondary winding 48' of this transformer T' is connected through reversing switch C in series with solenoid 47' of vibrating relay B' and this series circuit is shunted across resistor 30', so that when the voltage of generator 12 is increased to accelerate the mill, the induced voltage in the secondary coil 48' adds to the voltage drop across resistor 30', and since the relay B' regulates the current in field 35' so as to reduce the regenerative current in motor 2 and resistor 30' until the current in solenoid 47' is maintained practically constant, the amount of decrease of current in motor 2 will be proportional to the rate of acceleration of the mill. By proper adjustment of resistor 32' this amount of decrease of regenerative current in motor 2, when the mill is being accelerated, can be adjusted so as to reduce the regenerative torque by an amount equal to the torque required to accelerate motor 2 and reel R'. The current in motor 2 is thus regulated in such manner as to maintain constant tension in the strip between rolls M and reel R' during the acceleration period regardless of the rate of acceleration.

Relay B' is in certain respects similar to relay B heretofore described but its solenoid 40' is arranged to act upon arm 44' in the opposite direction; in other words, in opposition to spring 46' and hence in the same direction as solenoid 47' rather than in opposition thereto, and contacts 41', 42' are so arranged that the circuit of solenoid 40' is broken when the arm is operated by energization of this solenoid; the ratio between the time they are closed and the time they are open thus varies through a wide range for a small change of the current in the regulating solenoid 47'. If preferred, however, a relay like relay B but with its actuating solenoid and spring connected to the arm on the opposite side of the fulcrum may be employed in place of relay B' as shown.

When the mill has been brought up to speed, the strip is rolled in the usual manner until the point is reached at which deceleration is to begin when rheostat 20 is operated in the opposite direction to reduce the excitation of the field of generator 12 and consequently decrease its output. The voltage supplied to motors 1 and 2 from generator 12 is therefore reduced, and voltages are induced in the opposite directions in secondary windings 48, 48' in transformers T, T'. These currents therefore have the opposite effects on the respective armature currents from those created during acceleration of the mill while the excitation of solenoids 47, 47' of vibrating relays B, B' is also varied in accordance with the rate of change of the respective armature voltages; the armature current of motor 1 is therefore decreased and that of motor 2 increased substantially in proportion to the rate of decrease of the voltage output of generator 12. The desired tension on the strip is thus maintained on both sides of rolls M during deceleration as well as during acceleration when the strip is being rolled in the direction of the arrow in Fig. 1.

Reversing of the mill has been incidentally mentioned and will now be more fully described with particular reference to the six-pole double throw reversing switch C which, as diagrammatically shown in the drawing, may be employed for selectively connecting relay B and resistor 38 in circuit with field and the armature respectively of either motor 1 or 2, for connecting relay B' and resistor 38' in circuit with the field and the armature respectively of the other motor, and also for reversing field 15 of generator 12 when the strip is to be rolled in the opposite direction.

It is common practice to make motors 1 and 2 as nearly identical as possible and consequently when reversing switch C is thrown to the left hand side motor 1 operates as a generator to exert a regenerative braking effect on the strip and is controlled by relay B', resistor 38' and solenoid 47' of this relay now in circuit across resistor 30, while motor 2, now driving reel R' to wind the strip thereon, is controlled by relay B, resistor 38 and solenoid 47 of the latter relay in circuit across resistor 30'.

While we have herein described our invention with considerable particularity and made extensive reference to specific circuits and arrangements of parts and connections which we deem preferable for controlling a strip mill, it will be understood that we do not thereby desire or intend to limit or confine ourselves specifically thereto or to any apparatus particularly referred to as adapted for the performance of the several functions of the instrumentalities we employ, as changes and modifications therein will readily occur to those skilled in the art and may be made if desired without departing from the spirit and scope of the invention as defined in the appended claims.

Having thus described our invention, we claim and desire to protect by Letters Patent of the United States:

1. In a control system for an electric motor, a resistor in the motor field circuit, means for intermittently shunting out said resistor, and means for controlling said shunting out means in accordance with the rate of armature voltage change.

2. In a control system for an electric motor, a resistor in the motor armature circuit and a transformer having its primary winding connected in said circuit across the armature and its secondary winding connected therein across the resistor whereby the current induced in said secondary winding by fluctuations in the primary

winding circuit modifies the normal effect of the resistor in the armature circuit.

3. In a control system for an electric motor, a resistor in the armature circuit, a transformer having its primary and secondary windings connected in said circuit, means for regulating the field excitation of the motor, and means in series with said secondary winding adapted to control the operation of the regulating means in accordance with variations in the voltage induced in the secondary winding.

4. In a control system for an electric motor, a resistor in the motor field circuit, means for intermittently shunting out said resistor, and means for controlling said shunting out means in accordance with the rate of armature voltage change comprising a transformer having its primary winding connected across the motor armature and its secondary winding connected across another portion of the armature circuit, and a solenoid in series with said secondary winding adapted to modify the operation of the shunting out means in accordance with the voltage induced in the secondary winding.

5. Electric motor field excitation regulating means comprising an oscillatory arm, means in the motor field circuit for oscillating the arm comprising a solenoid and make-and-break contacts in circuit therewith operated by said arm, yielding means tending to move the arm in one direction, a regulating solenoid operative to exert on the arm in opposition to the yielding means a force proportional to the voltage supplied to the regulating solenoid, and a transformer having its secondary winding in series with said solenoid and its primary winding connected in the motor armature circuit.

6. In a control system for an electric motor, a transformer having its primary winding connected in the motor armature circuit and its secondary winding connected in another portion thereof operative to modify the armature voltage in accordance with voltage induced in said secondary winding by changes in the voltage in the primary winding.

7. In a control system for an electric motor, a resistor in the motor armature circuit and a transformer having its primary winding energized from said circuit and its secondary winding connected in said circuit across the resistor to thereby modify the voltage drop thereacross in accordance with the induced secondary voltage of the transformer.

8. In a control system for a plurality of electric motors mechanically interconnected to drive one from another and a current source interconnected with the respective motor armatures, a resistor in each armature circuit, transformers having their primary windings respectively connected across the armatures of the motors and their secondary windings respectively connected across said resistors, and means comprising electrically actuated elements respectively in series with said secondary windings operative to regulate the field excitation of the respective motors in accordance with changes in their respective armature voltages.

9. In combination with a pair of electric motors and means for mechanically driving one motor from the other, a source of current for both motors, control means for varying the field excitation of the respective motors, and means responsive to changes in the armature voltage of each motor for regulating said control means to thereby vary the torque of each motor in accordance with the motor speeds.

10. In combination with a pair of motors, means for driving one from the other and means for supplying armature and field currents thereto, control means comprising means for modifying the motor armature voltages, and means responsive to changes in said voltages for regulating the control means.

11. In combination with an electric motor, a source of current supply therefor and a regulator operable to control the field excitation of the motor, means for controlling the operation of said regulator comprising current responsive means, and current inducing means interconnected with said current responsive means and said current source whereby current is supplied to said current responsive means in accordance with changes in the power input of said current source to the motor.

12. In combination with a strip mill comprising a pair of motors, sources of current respectively for their armatures and fields, and a strip connected with each motor and operative to drive one motor from the other, strip tension regulating means comprising means respectively controlling the motor field circuits, and means operable in accordance with changes in the voltage of the armature currents for regulating said controlling means.

13. In a control system for a pair of electric motors, a source of current interconnected with the armatures of both motors and means interconnecting the motors to drive one mechanically while the other is being driven electrically, a resistor interposed in the armature circuit of each motor, and transformers having their primary windings respectively connected across the motor armatures and their secondary windings respectively connected across the resistors whereby voltage induced in the secondary winding of the transformer having its primary winding connected across the armature of the electrically driven motor in response to an increase in the voltage in said primary winding subtracts from the voltage drop across the corresponding resistor and during such increase the voltage induced in the secondary winding of the other transformer adds to voltage drop across the other resistor.

14. In a control system for a pair of electric motors, a source of current interconnected with the armatures of both motors and means interconnecting the motors to drive one mechanically while the other is being driven electrically, a resistor interposed in the armature circuit of each motor, and transformers having their primary windings respectively connected across the motor armatures and their secondary windings respectively connected across the resistors whereby voltage induced in the secondary winding of the transformer having its primary winding connected across the armature of the electrically driven motor in response to a decrease in the voltage of said primary winding adds to the voltage drop across the corresponding resistor and during such decrease the voltage induced in the secondary winding of the other transformer subtracts from the voltage drop across the other resistor, the resulting modifications of the voltage drop across the resistors being thereby maintained at predetermined proportionate ratios to the rate of change of the respective armature voltages.

15. In a control system for an electric motor, a

source of armature current therefor, a resistor in the armature circuit, a transformer having its primary winding connected across the motor armature and its secondary winding connected across the resistor whereby voltage induced in the secondary winding in response to a change in the primary winding voltage modifies the voltage drop across the resistor in correspondence with the nature of such change and in predetermined ratio to the rate thereof.

16. In a control system for a pair of electric motors, sources of armature and field currents therefor, and means interconnecting the motors to drive one mechanically while the other is being driven electrically, resistors respectively interposed in the motor field circuits, alternating relays respectively operative to intermittently short circuit the resistors, electrically actuated means for controlling each relay to thereby regulate the ratio between the time each resistor is short circuited and the time it is not short circuited by the relay, and transformers having their primary windings respectively connected to the motor armature circuits to derive energizing voltage therefrom proportional to the armature voltage and their secondary windings interconnected with said controlling means whereby the average field excitation of the electrically driven motor is modified in inverse ratio to the rate of change of the voltage in its armature circuit and the average field excitation of the mechanically driven motor is modified in direct ratio with the rate of change of the voltage in its armature circuit.

17. In combination with a strip mill comprising a pair of motors, sources of current respectively for their armatures and fields, and a strip connected with each motor and operative to drive one motor from the other, control and regulating means responsive to change in speed of the driving motor operative to effect corresponding change of power input to and speed of the driven motor.

18. In combination with a pair of mechanically interconnected motors and a source of current therefor, control and regulating means responsive to changes in speed of one of the motors operative to cause corresponding changes in the power input to both motors.

19. In combination, a pair of mechanically interconnected motors, means for supplying energizing current to the motor armatures and exciting current to the motor fields, and control and regulating means for said armature and field currents operative in response to any change of speed in one motor to change the power input to the other motor in predetermined ratio to the rate of said speed change.

20. In combination, a motor, means for supplying current thereto, an electrically operated regulator for the motor field current, and inductive means supplied with energizing current from the motor armature circuit supplying induced voltage to the regulator whereby any change in the voltage applied to the motor armature will provide induced voltage in the regulator to thereby correspondingly change the power input to said motor.

21. In a strip mill comprising a pair of reels, a strip extending between the reels, and a motor mechanically interconnected with each reel, means for supplying current to the motors, and control and regulating means for the motor circuits responsive to any change in the speed of one of the motors to change the speed of the other motor in predetermined ratio to the change of speed of the first motor to thereby maintain a predetermined and definite strip tension.

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