

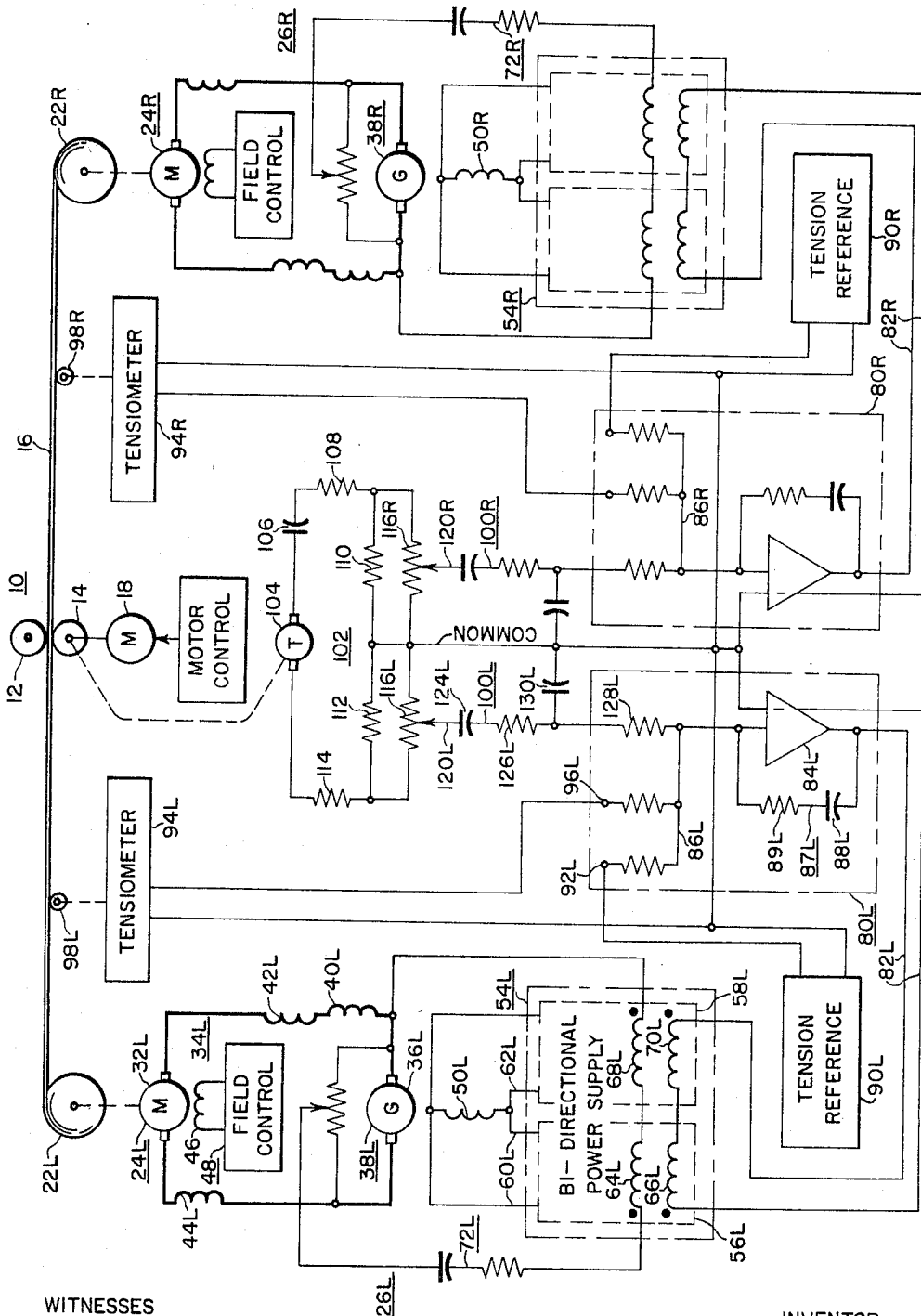
Nov. 1, 1966

S. J. ASSEO

3,283,228

PLURAL STAND, PLURAL MOTOR TENSION REGULATING APPARATUS

Filed June 28, 1963



1

3,283,228

PLURAL STAND, PLURAL MOTOR TENSION REGULATING APPARATUS

Sabi J. Asseo, Buffalo, N.Y., assignor to Westinghouse
Electric Corporation, Pittsburgh, Pa., a corporation of
Pennsylvania

Filed June 28, 1963, Ser. No. 291,553

3 Claims. (Cl. 318-7)

This invention relates to apparatus for regulating the tension of traveling elongate material, and more particularly to apparatus for controlling the tension between a transmitting station and a receiving station.

The transmitting station may for example be a payout reel, or a station for operating on the elongate material. The receiving station may for example be a pickup reel, or a station for operating on the elongate material. An operating station may for example be a mill stand in a metal strip rolling mill. Depending on circumstances and apparatus configuration one of the transmitting and receiving stations is a driving station which drives the strip, while the other station applies tension to the strip by means of a dynamo-electric machine located at the latter station.

The present invention is especially useful in connection with rolling mills for reducing strip made of steel, tin or other material. In the operation of mills of this general type, the material being worked or rolled, usually in the form of long thin strip, is passed back and forth through the rolls, while being wound on one reel and unwound from another on opposite sides of the roll stand. In order to obtain a uniform product it is necessary to maintain substantially constant tension on the material at all times on both sides of the roll stand. This is especially important during periods of acceleration and deceleration of the strip.

Heretofore, solely proportional systems were employed to regulate strip tension in steel rolling mills. In such a system the speed of a reel motor is regulated in accordance with a signal responsive to and proportional only to the tension error. While such systems provide useful tension regulation to a degree, their response and reaction is too sluggish to maintain uniform tension during acceleration and deceleration of the strip travel. In contrast the present invention is a proportional-plus-integral control system.

It is an object of the present invention to provide novel apparatus for regulating the tension of elongate material traveling between stations.

Another object of the invention is to provide novel apparatus for regulating the tension of elongate material being processed in a metal rolling mill or the like.

Another object is to maintain uniform tension at all times on traveling strip material being operated on.

A further object is to maintain uniform tension on traveling elongate material while it is being accelerated or decelerated.

In accordance with one embodiment of the invention, the above objects and other described advantages are attained in a metal rolling mill wherein the tension on strip material traveling between a roll stand and a reel is regulated by a torque producing dynamoelectric machine coupled to the reel and controlled in response to the tension error, the integral of tension error and the acceleration and acceleration rate of the strip travel.

In the specific example described, control is effected by

2

applying to the summing input, to a proportional-plus-integral controller, signals representing tension error and the acceleration rate of the strip, and employing the output of the controller to control the dynamoelectric machine. A "proportional-plus-integral controller" is an apparatus whose output is proportional to its input plus the integral with respect to time of the input. For convenience such apparatus will hereinafter be referred to as a "proportional integrator." All integrals hereinafter referred to in the specification and claims are with respect to time.

A useful aspect of the invention is the use of tension error plus integral of tension error, which may be obtained by supplying respective actual and desired tension signals to the summing input to a proportional integrator and utilizing the output of the integrator to control the dynamoelectric machine. However, the addition of acceleration and acceleration rate signal components multiplies the advantages many times and provides an extremely high degree of uniformity of tension.

Although the specific example of the invention disclosed is in connection with a metal rolling mill, it will be appreciated that the invention is useful in any system where precise control and regulation of the tension of elongate or strip material is desired, such as in the processing of metal, paper, textiles, etc.

Other useful objects and advantages of the invention will become apparent from the following description taken in connection with the drawing, wherein a combination block and schematic diagram illustrates a preferred form of the invention as embodied in a drive and control system of a rolling mill for reducing metal strip such as steel, tin, etc.

As seen in the drawing, the reversible rolling mill arrangement, disclosed by way of example, includes a mill stand 10 having upper and lower rollers 12 and 14 pressure biased toward each other to perform a reducing operation on a strip of metal 16 threaded between the rollers. The mill stand is driven in one or the other direction by a reversible motor 18 coupled to the lower roller 14 and controlled by a suitable motor control system 20. The mill arrangement further includes respective motor-driven left and right reels 22L and 22R. Depending on whether the mill stand is making a right or left pass, one of the reels performs as a payoff reel while the other reel acts as a takeup reel. When the mill is making a left pass, the left reel 22L operates as a takeup reel while the right reel 22R operates as a payout reel. On a right pass left reel 22L is the payout reel while the right reel 22R is the takeup reel.

The mill stand 10 is an operating station because it performs an operation on the strip 16. Actually, it performs two operations on the strip, reducing the driving respectively. On a left pass, left reel 22L is a receiving station with respect to the mill stand 10, which in that case is a feed station, the strip 16 feeding from the mill stand to the left reel. On the same pass, the mill stand 10 is a receiving station with respect to the right reel 22R, which in that case is the feed station, the strip 16 feeding from the right reel to the mill stand. It should be apparent that these relative positions are reversed on a right pass. In the latter case the right reel and the mill stand are respectively receiving station and feed station relative to each other, while the mill stand and left reel are respectively receiving station and feed station relative to each other.

Reels 22L and 22R are driven by motors 24L and 24R respectively, controlled by duplicate control systems 26L and 26R. Each of these control systems in response to tension error (difference between desired and actual tension) on its side (left or right of the mill stand) and acceleration rate (rate of rate of change of speed) of travel of strip 16, controls its associated reel motor in response to tension error, integral of tension error, acceleration and acceleration rate signal components produced by the control system.

Control systems 26L and 26R being alike, only one of the systems will be described in detail. Corresponding parts of both systems bear the same reference numeral modified however with either L or R depending on whether they are associated with the left or right reel motor. 26L is the left control system while 26R is the right control system.

Motor 24L, shown by way of example as a D.C. motor, has an armature 32L connected in a loop circuit 34L including the armature 36L of a D.C. generator 38L, whereby the generator supplies armature current to the motor. The loop circuit 34L may also include respective series and commutating fields 40L and 42L of the generator and a commutating field 44 for the motor. The motor 24L includes a shunt field 46L supplied from a suitable adjustable motor field control unit 48L.

The generator 38L has a shunt field 50L which is supplied with reversible D.C. power from the output lines of a bi-directional power supply circuit 54L, which may for example be a push-pull magnetic amplifier, a controllable converter employing semiconductor controlled rectifiers, or other. Amplifier 54L provides an output of one polarity in response to a net input excitation of one sense and an output of opposite polarity in response to a net input excitation of the opposite sense. Thus amplifier 54L is of the type which provides a reversible output having a polarity and magnitude dependent on the polarity and magnitude of the input to the amplifier. A suitable example of amplifier 54L is shown and described at 49 in a copending patent application Serial No. 253,801, entitled "Load Maneuvering Apparatus," filed January 25, 1963, by Edgar C. Fox and Richard L. Meyer, and assigned to the assignee of the present application.

The bi-directional power supply 54L may for example include two single ended channels 56L and 58L operating in push-pull, such as a reversible D.C. output magnetic amplifier, or a push-pull converter employing controlled rectifiers gated by magnetic amplifier controlled firing circuits. An example of the latter is disclosed and described in the aforesaid copending patent application Serial No. 253,801.

The output of channel 56L is at 60L, while the output of channel 58L is at 62L, both outputs being oppositely poled across the generator main field winding 50L. The input circuit of channel 56L includes magnetic amplifier feedback and control windings 64L and 66L, respectively. Likewise, the input circuit of channel 58L includes magnetic amplifier feedback and control windings 68L and 70L, respectively. Feedback windings 64L and 68L are connected in series opposition so that a given signal applied to the windings drives the channels 56L and 58L in opposite sense. Likewise, the main control windings 66L and 70L are connected in series opposition so that a given signal applied to these windings will provide oppositely related control effects on the channels 56L and 58L.

For damping, feedback windings 64L and 68L are provided with negative feedback in response to the rate of change of generator 38L output voltage through a rate feedback network 72L.

The bi-directional power supply 54L is controlled in response to the bi-directional output of a proportional integrator 80L. More specifically, the main control windings 66L and 70L are connected to the bi-directional output lines 82L of the proportional integrator 80L. Proportional integrator 80L provides an output proportional to its

input plus the integral of the input with respect to time. The "integral with respect to time of the input" may be referred to as the "time integral of the input."

The proportional integrator 80L for example includes a very high gain, drift-free, D.C. amplifier 84L with a summing junction 86L connected to its input, and a derivative or rate negative feedback network 87L around the amplifier. Thus, by way of example, the integrator 80L is an operational amplifier with a rate or derivative feedback therearound and a summing input. The feedback circuit 87L includes a capacitor 88L and a resistor 89L.

The input to the proportional integrator 80L is provided with input excitation proportional to the tension error on the left side of the mill stand 10, that is, proportional to the difference between desired and actual tension on that portion of the strip 16 between the reel 22L and mill stand 10. This tension error excitation is obtained by differentially summing a tension reference signal and a signal proportional to the actual tension in the summing circuit 86L. More specifically, a D.C. signal from an adjustable reference source 90L is applied to one summing input terminal 92L and the output signal of a tensiometer 94L is supplied to another summing input terminal 96L. Tensiometer 94L is coupled to a deflector roll 98L in contact with strip 16, which roll moves up and down in response to changes in tension of the strip. In response to the movement of the deflector roll 98L, tensiometer 94L produces an output, which when combined with the tension reference signal in the summing circuit 86L drives the proportional integrator 80L to produce an output which will alter the output of the power supply 54L to change the generator 38L output to reduce or increase the armature excitation of motor 24L as required to change the speed or drag of the motor 24L applied to the reel 22L to return the tension to normal. At a desired tension, the strip 16 is in a particular vertical position followed by the deflector roll 98L. Changes of tension change the vertical position of the strip 16, and the deflector roll 98L follows these changes to produce a corresponding output which so affects the input excitation of the proportional integrator 80L as to cause the power supply 54L to change the generator 38L output voltage to cause the reel motor 24L to so operate as to bring the tension back to its normal desired value.

Although the tension reference and tensiometer signal components are shown as being applied separately and mixed in the summing circuit 86L to provide a tension error signal component in the summing circuit, the tension reference and tensiometer signal components could alternatively be mixed externally of the summing circuit, and the resulting tension error signal component be then applied to the summing circuit. Either case results in a tension error signal being supplied to the summing circuit and consequently to the input of the proportional integrator.

A suitable example of a tensiometer is disclosed and described in a copending patent application Serial No. 113,938, entitled "Tensionless IR Compensation," filed on May 31, 1961 by Donald E. Abell, and assigned to the same assignee as the present application.

The tensiometer 94L provides a D.C. output signal which is a function of the deflection of roll 98L. Since the deflector roll responds to the tension of the strip 16, the output of tensiometer 94L is a function of the tension on that portion of the strip 16 between the reel 22L and the mill stand 10. In like manner, a tensiometer 94R provides an output which is a function of the tension on that portion of strip 16 between the mill stand and the right reel 22R. The tension signal from tensiometer 94L and the tension reference signal from the reference source 90L are applied to the summing circuit of the proportional integrator in opposite polarity.

In order to apply proper tension on the strip 16 for a given set of circumstances, the motor 24L will require a

particular magnitude and polarity of excitation from generator 38L, which in turn is provided by proper magnitude and polarity of the generator field excitation in response to a particular magnitude and polarity of signal supplied to the input of the amplifier 54L from the output 82L of the proportional integrator 80L. For this set of circumstances the output of the proportional integrator 80L will remain at that value as long as actual tension is exactly matched to tension reference. Should a small error occur between the actual tension (tensiometer) and tension reference signals, the amplifier 80L output will vary in such magnitude and polarity as to cause the control system to wipe out the difference and thus regulate for zero error. As a result of the input excitation which is a function of tension error provided in the input to the proportional integrator 80L, the proportional integrator provides an output proportional to tension error plus the integral (with respect to time) of tension error. Thus the proportional integrator provides output signal components proportional to tension error and to the time integral of tension error.

In a particular example and under a given set of conditions, the apparatus thus far described was subject to 1000 pound tension swings during acceleration and deceleration. This is better than a solely proportional system. However this was reduced to swings of 50 to 100 pounds by supplying to the input of the proportional integrator 80L an excitation component that is a function of the acceleration rate (rate of rate of change of speed) of the travel of strip 16, thus causing the proportional integrator 80L to produce an output proportional to

$$\text{tension error} + \text{acceleration rate} + \int (\text{tension error} + \text{acceleration rate}) dt$$

thus to provide output signal components proportional to acceleration and acceleration rate of the strip 16 travel in addition to the signal components proportional to tension error and the integral of tension error. The above mathematical representation ignores the constants of proportionality and other constants.

In the specific example shown, the acceleration rate signal is derived through cascaded rate networks 100L and 102 from a tachometer generator 104 driven by the mill roll 14 or the shaft of motor 18. The tachometer 104 produces a D.C. output voltage proportional to the driven travel speed of the strip 16 as imparted to the strip by the mill roll 14.

Rate network 102 comprises a first differentiator circuit including a capacitor 105 and resistors 108, 110, 112 and 114 and potentiometers 116L and 116R. The voltages across potentiometers 116L and 116R are proportional to the first derivative (acceleration) of the driven speed of strip 16. Thus the voltage at the potentiometer arm 120L with respect to common is proportional to the rate of change of speed of the strip 16.

The voltage on 120L is applied through the second differentiator circuit 100L to the summing circuit 86L. Differentiator circuit 100L is formed by a capacitor 124L and resistors 126L and 128L. Resistors 126L and 128L and a capacitor 130L form a noise filter to filter out noise picked up in the differentiator circuits.

It should be apparent from the circuit configuration of the cascaded first and second differentiators 104 and 100L that the summing junction 86L and the amplifier 80L have applied thereto a signal or excitation component which is a function of the second derivative or rate of rate of change of speed (acceleration rate) of the strip 16. The acceleration rate signal is applied to the summing network 86L in such polarity that it will aid the tension error excitation component to so control the regulator 26L as to wipe out the tension error, i.e. the difference between desired and actual tension of the strip 16 on the left side of the mill stand 10.

For example, when the tension error signal compo-

nent (resultant of tension reference and tensiometer signals) supplied to the summing circuit 86L is positive, then the acceleration rate signal component supplied to the summing circuit should also be positive. Likewise, if the tension error signal to the summing junction is negative, then the acceleration rate component should be negative. Thus the acceleration rate and tension error signal components are applied to the input of the proportional integrator 54L in a mutually aiding direction.

Since the control circuit 26R is a duplicate of control circuit 26L, it will be apparent that proportional integrator 80R has applied to its summing input circuit 86R a signal component which is a function of the second derivative of speed of travel of strip 16 and a signal component which is a function of the tension error relative to the tension on that portion of strip 16 between the mill stand 10 and the right reel 22R. Thus the output of amplifier 80R is proportional to tension error (right side), plus the integral of tension error (right side), plus acceleration plus acceleration rate of the travel of strip 16. These signal components are applied to the input of bidirectional amplifier 54R whose push-pull output is applied across the main field 50R of generator 38R. In turn the generator 38R supplies power to the armature of motor 24R which operates the right reel 22R.

When the mill stand is making a right pass, motor 24R operates as a motor to drive the right reel 22R as a takeup reel. On the same pass the motor 24L operates as a generator to apply drag to the left reel 22L which under the circumstances is the payoff reel. On a left pass the functions of motors 24L and 24R are reversed, motor 24R becoming the "brake" on reel 22R, while motor 24L becomes the driving motor for the left reel 22L.

Because of the circuit symmetry the voltage at 120L is positive with respect to common when the voltage at 120R is negative with respect to common. Thus the second derivative of speed signals (acceleration rate) are applied in opposite polarity to the amplifiers 80L and 80R.

In considering the operation of the apparatus, let it be assumed that the mill is making a right pass. Motor 24R is operating as a motor, driving reel 22R to windup the strip 16, while motor 24L is operating as a generator to apply a drag to reel 22L as the strip 16 unwinds from this reel. Suppose the mill is up to running speed, and with the tension and tension reference signals balanced, in other words with the strip running with desired tension on the left and right sides of the mill stand. Under these circumstances the regulating systems 26L and 26R will be supplying the correct magnitude and polarity of armature voltages to the motors 24L and 24R so that motor 24L applies just the correct amount of drag to the strip while motor 24R drives ahead to maintain just the correct amount of tension on the strip 16 between the mill stand 10 and the reel 22R.

Now suppose for some reason the speed of roll 14 is accelerated, thereby accelerating the travel of strip 16. This will result in a sudden drop of tension on the right side of the mill stand and an increase of tension on the left side of the mill stand. Tensiometers 94L and 94R will reflect these changes in tension. The outputs of tensiometers 94L and 94R change in opposite directions. The output signals from tensiometers 94L and 94R are applied to the respective summing junctions 86L and 86R where they are compared with the respective tension reference signals 90L and 90R thus providing tension error signals to the respective inputs of the amplifiers 80L and 80R. Acceleration rate signals from networks 100L and 100R are applied to the inputs of the proportional integrators 80L and 80R in such polarities and magnitude as to aid the action of the tension error signal on the output of the proportional integrators.

The amplifier outputs 82L and 82R will vary in such magnitude and polarity as to cause the regulating systems

26L and 26R to wipe out the error and thus regulate for zero error. More specifically, the output of amplifier 80R will cause the bidirectional power supply 54R to increase the power supplied to the generator main field 50R thus increasing the voltage output of generator 38R thereby to speed up motor 24R and the reel 22R to take up the slack in strip 16. At the same time amplifier 80L causes the power supply 54L to supply the proper magnitude and polarity of power to the generator field 50L thereby to cause generator 38L to change the power it supplies to motor 24L in a direction to reduce the generating action of motor 24L thereby to reduce the drag of reel 22L on strip 16. These reactions continue until equilibrium is reached. In the meantime acceleration rate signals generated in the rate networks 102 and 100L and 100R in response to the acceleration of the mill stand, are applied to the inputs of amplifiers 80L and 80R in the proper direction to aid in wiping out the error. The acceleration rate signals are applied in opposite polarity to the regulators 26L and 26R, thus to simultaneously compensate for tension variations at the payoff and takeup reels (opposite sides of mill stand).

Similar reactions take place when the mill stand is suddenly decelerated. In this case since tension increases on the right side of mill stand 10, the regulating action slows down motor 24R to return the right side tension to normal, and increases the generator action on motor 24L to increase the drag of the left reel 22L on strip 16 to normal. Acceleration rate signals are likewise generated in response to the deceleration of the strip and help in speeding up the regulating action to wipe out the error in a minimum of time.

It will be appreciated that control apparatus for a mill will customarily include inertia compensation circuits and also current regulator circuits for the power supply circuit of the generator. These are not necessary to an explanation of the invention and are not shown in order to avoid complexity and to simplify the illustration.

The invention is not limited to the particular apparatus and components thereof shown by way of example. Thus it is to be understood that the herein described arrangements are simply illustrative of the principles of the invention, and other embodiments and fabrications are within the spirit and scope of the invention.

I claim as my invention:

1. In a control system for apparatus operating on elongate material wherein the material passes from a feed station through an operating station to a receiving station, and wherein said operating station has operating means which drives the material so that it is drawn from the feed station and forced toward the receiving station, and wherein each of the feed and receiving stations includes controllable dynamoelectric machine means for applying tension between that station and the operating station, means for regulating the tension of the material on both sides of the operating station comprising a network responsive to the drive speed imparted to the material by the operating station, means responsive to said network for deriving first and second oppositely sensed signals proportional to the rate of rate of change of said speed, first and second proportional integrator means, each having input means and output means, means including means responsive to the tension on the material between said feed station and said operating station for supplying to the input means of said first proportional integrating means a first input excitation component which is a function of the difference between actual and desired tension on the material between the feed and operating stations, means for applying said first signal to the input means of said first proportional integrating means in a sense to aid said first excitation component, means including means responsive to the tension on the material between the operating station and the receiving station for applying to the input means of said second

proportional integrating means a second input excitation component that is a function of the difference between actual and desired tension on the material between the operating and receiving stations, means for applying said second signal to the input means of said second proportional integrating means in a sense to aid said second excitation component, means for controlling said feed station dynamoelectric machine means in response to the output of said first proportional integrating means, and means for controlling said receiving station dynamoelectric machine means in response to the output of said second proportional integrating means.

2. In a control system for a rolling mill operating on a strip of material wherein the strip passes from a payoff reel through a mill stand to a takeup reel, and wherein said mill stand has operating means which drives the material so that it is drawn from the payoff reel and forced toward the takeup reel, and wherein a controllable dynamoelectric machine is coupled to each of said reels for applying torque thereto, means for regulating the tension of the strip on both sides of the mill stand comprising first means responsive to the drive speed imparted to the strip by the mill stand for providing an output that is a function of the rate of change of said speed, means responsive to said first means for deriving first and second oppositely sensed signals that are a function of the rate of rate of change of said speed, first and second proportional integrator means, each having input means and output means, means including means responsive to the tension on the strip between said payoff reel and said mill stand for supplying to the input means of said first proportional integrating means a first input excitation component which is a function of the difference between actual and desired tension on the strip between the payoff reel and the mill stand, means for applying said first signal to the input means of said first proportional integrating means in a sense to aid said first excitation component, means including means responsive to the tension on the material between the mill stand and the takeup reel for applying to the input means of said second proportional integrating means a second input excitation component that is a function of the difference between actual and desired tension on the strip between the mill stand and the takeup reel, means for applying said second signal to the input means of said second proportional integrating means in a sense to aid said second excitation component, means for controlling said payoff reel dynamoelectric machine in response to the output of said first proportional integrating means, and means for controlling said takeup reel dynamoelectric machine in response to the output of said second proportional integrating means.

3. In a control system for apparatus operating on elongate material wherein the material passes from a feed station through an operating station to a receiving station, and wherein said operating station has operating means which drives the material so that it is drawn from the feed station and forced toward the receiving station, and wherein each of the feed and receiving stations includes controllable dynamoelectric machine means for applying tension between that station and the operating station, means for regulating the tension of the material on both sides of the operating station comprising means responsive to the drive speed imparted to the material by the operating station for deriving first and second oppositely sensed signals proportional to the rate of rate of change of said speed, first and second summing means, each having input means and output means, means including means responsive to the tension on the material between said feed station and said operating station for supplying to the input means of said first summing means a first input excitation component which is a function of the difference between actual and desired tension on the material between the feed and operating stations, means for applying said first signal to the input means of said first summing means in a

9

sense to aid said first excitation component, means including means responsive to the tension on the material between the operating station and the receiving station for applying to the input means of said second summing means a second input excitation component that is a function of the difference between actual and desired tension on the material between the operating and receiving stations, means for applying said second signal to the input means of said second summing means in a sense to aid said second excitation component, means for controlling said feed station dynamoelectric machine means in response to the output of said first summing means, and means for controlling said receiving station dynamoelectric machine means in response to the output of said second summing means.

5

10

15

10

References Cited by the Examiner

UNITED STATES PATENTS

3,187,243	6/1965	Long	318—6
3,188,841	6/1965	Wallace.	
3,189,804	6/1965	Dolphin	318—6

References Cited by the Applicant

UNITED STATES PATENTS

2,858,493	10/1958	Hull et al.	
2,972,269	2/1961	Wallace et al.	

ORIS L. RADER, *Primary Examiner.*

T. LYNCH, *Assistant Examiner.*