

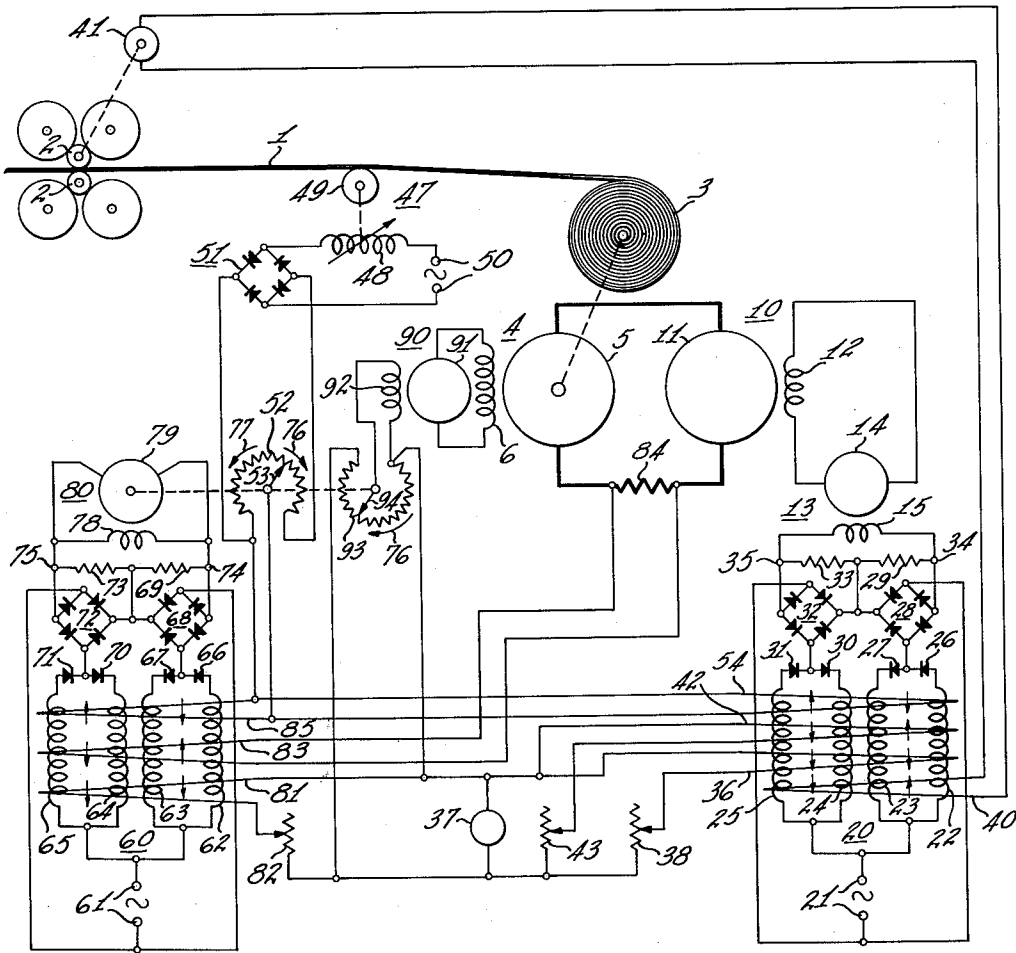
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TENSION MAINTAINING MOTOR CONTROL SYSTEM

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TENSION MAINTAINING MOTOR CONTROL SYSTEM

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This invention relates generally to motor control systems and in particular to those systems wherein a reel drive in a strip processing machine is used to maintain tension in the material being processed.

In a strip processing machine, such as a steel rolling mill, it is advantageous to the rolling operation to have the material under tension as it emerges from the work rolls. Since the reduction which is obtained during the rolling operation is partially a function of the tension on the material being rolled, it is desirable that a constant tension be maintained so that the product has a uniform gauge.

If the conditions remained constant during the entire operation, the tension control would be a relatively simple device and once set it would remain in adjustment throughout the rolling operation. However, such is not the case. Many conditions which affect tension vary during the operation and the tension control must be effective to compensate for these variations if the product is to be of uniform thickness. Where the windup reel is used to maintain tension, the windup reel motor control must compensate for the conditions which vary during the course of the rolling operation.

For example, as the material being reeled builds up upon the mandrel, the motor must exert a greater torque to maintain the same tension in the material being rolled. This is due to the increasing radius of the reel. At the same time, the reel must operate at a slower speed since the winding radius has increased and it takes fewer revolutions of the reel to wind a given length of material. When reels are wound to a large diameter, it is necessary to vary the speed of the reel motor over a considerable range to match the periphery of the reel to the speed of the material as it emerges from the work rolls. The speed range obtainable with the motor will therefore limit the maximum amount of material which can be placed upon one reel.

In general, when the strip speed is a constant, a constant tension may be maintained in the material being reeled if the reel motor delivers a constant horsepower. In practice the strip speed may vary over a considerable range and the motor horsepower output must be varied to correspond to the change in speed.

A constant horsepower regulator may incorporate a signal which is proportional to the strip speed to provide a system which maintains a constant tension in the material being reeled.

Some prior art systems use a constant horsepower control system and modify it by introducing a signal proportional to the speed of the work rolls since this signal approximates the speed of the strip being processed. This system introduces an error equal to the reduction made in the strip by the work rolls. In other words, since the material is being reduced in thickness the strip will have a higher speed as it emerges from the rolls than the speed at which it enters. Thus, it is not possible to obtain an accurate measure of the strip speed from the work rolls above.

If the draft remains relatively constant throughout a rolling operation, it is possible to take a speed measurement from the work rolls and modify this signal by a factor equal to the draft. This results in an output signal which approximates the speed of the strip. However, such a system necessitates the manual adjustment of a

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draft compensating rheostat every time the draft is altered or if the reduction changes due to changes in the mill. For these reasons, the foregoing system of compensating a signal proportional to the speed of the work rolls and obtain thereby a measure of the strip speed is not generally satisfactory for a tension maintaining reel drive.

Another method of measuring the strip speed is by the use of a deflector roll tachometer. This consists of a deflector roll which bears against the material being reeled and rotates at the same speed as the strip being processed. Connected to the roll is a tachometer generator which provides an output signal proportional to strip speed. However, at very low tensions, it has been found that the roll slips against the strip being processed and introduces an error since the output signal of the tachometer generator is somewhat lower than the actual speed of the strip being rolled. For this reason, a deflector roll tachometer is not entirely satisfactory as a means of obtaining a strip speed signal.

The disadvantages of the above mentioned systems are overcome in our invention by utilizing a deflection roll tensiometer to measure the strip tension. The output signal of the tensiometer is then used to regulate the output of the reel motor supporting generator and the motor field exciter to hold the strip tension constant. The tension regulator of our invention will hold the strip tension to the desired value under all conditions of rolling from a standstill to the top mill speed.

The ideal method of controlling strip tension is to use a reel motor supporting generator of sufficient capacity to allow regulation of the tension entirely by the generator. In such a system the motor field winding is excited from a constant potential source. The range of this system is very limited and where the rolling conditions vary widely, in particular where the diameter of the coil being rolled changes over a wide range, the current required to hold constant tension requires that the reel motor and generator be capable of handling more than normal current. Such a requirement necessitates the use of a motor and generator that are excessively large with respect to the average load imposed by the mill.

To avoid the necessity for an oversize generator and motor while retaining the advantages of tensiometer regulation, our invention provides means for appropriately varying the reel motor field in a manner to obtain constant tension with substantially constant motor current. This allows the most economical motor and generator to be used in the system. Such a regulator does away with the necessity for a manually adjusted draft compensating rheostat or a tachometer generator driven by the strip being processed both of which have undesirable characteristics.

In a regulator according to our invention, the motor field will be supplied through a motor driven rheostat energized from a constant potential source. The rheostat motor is responsive to the ratio of the signal from the tensiometer and the signal proportional to reel motor current. Adjustment of the regulator permits only one desired ratio between the current and the tension signals, the most desirable being that ratio established when minimum current from the motor will produce the desired tension. This usually is obtained when the reel diameter is at a minimum and the rolling operation is proceeding at the slowest speed.

When the balance between current and tension is upset, for example by the increased reel diameter as a result of the build-up of material, the motor operated rheostat moves to change the reel motor field excitation to rebalance the motor armature current and tension signals. This balancing continues until the range of the reel motor is exhausted. By constructing the motor field regulator in

a manner to provide a long time constant the instantaneous corrections in tension are achieved by variations of the generator output voltage but a sustained variation such as reel build-up will be compensated for by a change in the motor field excitation. Since the generator regulator has a relatively short time constant and the motor field regulator has a relatively long time constant, due to the rheostat, the tendency to interact will be diminished and instability avoided.

Since speed of the work rolls provides a good approximation for the voltage required from the generator the system may be improved by obtaining the basic generator excitation from a tachometer generator on the work rolls and modifying this with a signal responsive to strip tension. This eliminates the necessity for high gain amplifiers and their attendant difficulties such as instability and tendency to hunt.

It is therefore an object of our invention to provide an improved tension regulating system for a strip processing machine.

It is another object of our invention to eliminate the necessity for a deflector roll tachometer or a draft compensating rheostat in a tension regulating system.

It is still another object of our invention to provide a control system for a reel motor in which the basic excitation for the generator supplying the motor is obtained from a device which senses the tension in the strip being rolled.

Another object of our invention is to provide a control system for a windup reel motor in which the exciter for the motor field has a relatively long time constant and the exciter for the generator has a relatively short time constant.

A further object of our invention is to provide a windup reel control system in which the range of the reel motor is increased over that obtainable with conventional field weakening or alternate field and armature control.

Other objects and advantages of this invention will become apparent from the following description taken in connection with the accompanying drawings wherein are set forth by way of illustration and example certain embodiments of this invention.

A strip 1 of material such as steel is passed through a pair of work rolls 2 and wound upon a reel 3 driven by a direct current motor 4 having an armature winding 5 and a field winding 6. A generator 10 having an armature winding 11 and field winding 12 is connected to supply armature winding 5 of motor 4. Field winding 12 of generator 10 is energized by exciter 13 having an armature winding 14 and a field winding 15.

Exciter field winding 15 is energized by a reversible output magnetic amplifier 20. Alternating current source 21 energizes the pair of reactance windings 22 and 23 and the pair of reactance windings 24 and 25. Current through reactance windings 22 and 23 passes through rectifiers 26 and 27 to energize the alternating current bridge rectifier 28. The direct current output of bridge rectifier 28 appears across resistor 29. The current flowing through reactance windings 24 and 25 passes through rectifiers 30 and 31 to energize bridge rectifier 32. The direct current output of bridge rectifier 32 appears across resistor 33. It will be observed that the voltages produced across resistor 29 and resistor 33 are of opposite polarities. This means that when the voltage across resistor 29 predominates over the voltage across resistor 33 the current in the field winding 15 of exciter 13 will flow from terminal 34 to terminal 35 to increase the output of generator 10 and pull strip 1 under greater tension. When the reversed condition exists, for example when the voltage across resistor 33 predominates over the voltage across resistor 29, the current in the exciter field winding 15 will flow from terminal 34 to terminal 35. In this manner, it is possible to reverse the direct current output of magnetic amplifier 20, which in turn reverses the direct current output supplied by exciter 13 to the gen-

erator field winding 12, causing the reversal of the polarity of the output voltage of generator 10.

A bias winding 36 on magnetic amplifier 20 is energized from a direct current source 37 through an adjustable resistor 38. The current through this winding is polarized to reduce the output of the magnetic amplifier. Under normal conditions the resistor 38 will be adjusted to pass sufficient current through winding 36 to cut off the amplifier in the absence of current through the other control windings.

Tension in strip 1 is adjusted by means of resistor 43 in series with reference winding 42 and direct current source 37. The arrows associated with this winding indicate the effect of the control current. For example, the arrow points upward with reference to reactance windings 22 and 23 and downward relative to reactance windings 24 and 25. This means that the current of the indicated polarity flowing in winding 42 increases the output of windings 22 and 23 and decreases the output of windings 24 and 25. Or, putting it another way, the current output of generator 10 is raised by increasing the current through control winding 42. Since strip tension is responsive to the armature current the increased current through control winding 42 has the effect of increasing the tension.

A change in tension is reflected in the output of the tensiometer 47 which has a deflector roll 49 coupled to reactance winding 48 and spring biased so that the reactance of winding 48 is proportional to strip tension. Although this embodiment employs a deflector roll tensiometer, equivalent means for sensing tension could be used. These might include load cells, differential transformers or other well known devices.

Alternating current source 50 energizes bridge rectifier 51 through the reactance winding 48 to produce a direct current output which is proportional to the tension in strip 1.

The direct current output of rectifier 51 appears across rheostat 52 having a movable tap 53 which picks off a variable amount of the output to energize control winding 54 on magnetic amplifier 20.

This control winding acts in the opposite sense from winding 42 and has the effect of decreasing the current output of generator 10. In this manner, a balance is obtained between the ampere turns of control winding 42 and control winding 54 at the desired value of tension as determined by the setting of resistor 43.

If the tension decreases for some reason, the current in winding 54 drops off and the output of the magnetic amplifier reacts to increase the output current of generator 10 which restores the tension to the proper value and restores the condition of balance between the ampere turns of winding 54 and winding 42.

The action of the motor field regulator is somewhat more complex and consists of an exciter 90 having an armature winding 91 coupled to motor field 6. Field winding 92 of exciter 90 is energized by the voltage across the portion of rheostat 93 which is picked off by tap 94. A constant voltage direct current source 37 is connected to impress a voltage across rheostat 93.

The amount of current supplied to winding 92 will depend upon the position of tap 94 which is controlled by shunt wound motor 80 having a field winding 78 and an armature winding 79. The motor 80 is energized by the voltage output of magnetic amplifier 60.

In magnetic amplifier 60 the alternating current source 61 is connected to energize bridge rectifier 68 through self-saturating rectifiers 66 and 67 and reactance windings 62 and 63. Bridge rectifier 72 is energized from alternating current source 61 by the current passing through reactance windings 64 and 65 and self-saturating rectifiers 70 and 71.

The direct current output of the two bridge rectifiers 68 and 72 appears across resistors 69 and 73. Since motor 80 is connected to the terminals 74 and 75, the

motor will be energized by the difference between the pairs of reactance windings and thus can be made to revolve in either direction by changing the relative magnitude of the outputs of bridge rectifiers 68 and 72.

Control of magnetic amplifier 60 is accomplished by means of three control windings. The first of these, bias winding 81, is energized by direct current source 37 through the variable resistor 82. The action of this winding is to cut off the amplifier and prevent any current from passing through either pair of reactance windings to the bridge rectifiers. This is shown in the drawing by the arrows associated with winding 81. The arrows point down with respect to both pairs of reactance windings indicating that the effect of the winding is to reduce the output from these windings.

A second control winding 83 is energized by the voltage developed across a resistor 84 in series with the motor armature winding 5. This voltage is proportional to the motor armature current. From the arrows associated with winding 83 it may be seen that the current in this winding increases the output of reactance windings 62 and 63 and decreases the output of reactance windings 64 and 65. It follows that the voltage across resistor 69 will be greater than the voltage across resistor 73 and the motor responds to the voltage difference and revolves in direction 76. If the voltage difference is of the opposite polarity the motor will revolve in the direction of arrow 77.

A third control winding 85 is energized by the output of tensiometer 47 picked off rheostat 52 by tap 53 and acts in opposition to control winding 83 indicated by the arrows associated with these windings.

The following description of the operation neglects, for the moment, the tachometer generator 41 which energizes a control winding 40 on magnetic amplifier 20 and also the effect of the motor driven variable tap 53 on potentiometer 52.

At the beginning of a rolling operation the strip being processed is threaded through the work rolls 2 and fastened to the reel mandrel. At this point the stall tension may be applied by means of resistor 43 which adjusts the current in control winding 42. As was mentioned earlier, an increase in current in this control winding causes a corresponding increase in the output current of the generator 10.

The increased current in the motor armature 5 has the effect of increasing the tension in strip 1. The motor armature current and therefore also tension continues to build up until the output of the tensiometer 47 is fed to control winding 54 balances the ampere turns of control winding 42. At this point, the mill is not yet moving although full tension has been applied.

The current in the motor armature develops a voltage across resistor 84 which excites the control winding 83. This control winding acts upon magnetic amplifier 60 to cause the motor 80 to revolve in direction 76 and increase the current through motor field winding 6.

When the mill is in operation and motor 4 is revolving, an increase in the field current will tend to decrease armature current. Therefore, as the generator 10 changes the armature current to compensate for rapid variations in tension, a sustained variation which changes the voltage across resistor 84 will cause the relatively slower acting motor field regulator to alter the field current so that the balance between tension and motor current is restored.

In the event that the motor current rises to maintain the correct tension, the balance is upset between the control winding 85 responsive to tension and the control winding 83 responsive to motor armature current. Since the armature current has increased, the excess ampere turns of control winding 83 serve to unbalance the output to motor 80, causing the motor to revolve in the direction 76 to increase the current through motor field winding 6. The increased field current restores the motor armature current to the previous value and restores the

magnetic amplifier 60 to a condition of balance at which point the motor 80 will stop.

Operation of the basic systems described above may be further improved by introducing a signal responsive to the speed of the work rolls 2 into the generator regulator. Such a signal is provided by a tachometer 41 which is driven at the speed of the work rolls through an appropriate means.

The output of the tachometer generator 41 energizes control winding 40. The effect of this control winding as indicated by the arrows is to increase the excitation of generator 10 in response to an increasing mill speed.

Since the excitation of generator 10 will follow the speed of the work rolls, the task of the generator regulator may be eased by introducing into the generator regulator a signal proportional to the work roll speed. With the basic excitation derived directly from the mill speed the other control windings have only to exert a trimming action on the output of magnetic amplifier 20. This improvement provides a control which is more stable and easier to build than the basic system.

A further refinement allows the system to be used on mills where the physical layout of the mill prevents proper positioning of the deflector roll to obtain an output from the tensiometer which is directly proportional to strip tension.

If the angle of the strip varies relative to the deflector roll as the reel builds up, there will be a nonlinearity in the output of the tensiometer. In our invention, this nonlinearity is eliminated without modifying the mill simply by the use of a potentiometer driven by the motor 80 controlling the motor field rheostat 93. Since the field current is approximately equal to the strip build-up on the reel, it is possible to compensate the tensiometer signal according to the position of the motor field rheostat 93. By properly proportioning the value of the potentiometer 52, across which the output of the tensiometer 47 appears, a signal which is proportional to strip tension may be picked off by means of the variable tap 53 connected to be driven by motor 80.

Although the regulating system has been embodied in a reel motor drive, it will be obvious to a person skilled in the art that it may be used as well to control the motors driving the work rolls on a tandem mill.

What is claimed is:

1. In a tension regulating system for a reel, a motor driving said reel and having an armature winding and a field winding, a generator connected to supply said motor armature winding, voltage control means for said generator, means for developing a first signal proportional to the desired tension, tension measuring means for developing a second signal responsive to the tension of the material being reeled, means connecting said voltage control means to be responsive to said first and second signals, exciter means for said motor field winding, means for developing a third signal responsive to motor armature current, means connecting said motor field exciter to be responsive to said second and third signals to control said motor field to maintain said third signal constant with respect to said second signal.

2. In a tension regulating system for a reel, a motor driving said reel and having an armature winding and a field winding, a generator connected to supply said motor armature winding, voltage control means for said generator, means for developing a first signal proportional to the desired tension, tension measuring means for developing a second signal responsive to the tension of the material being reeled, means for developing a third signal responsive to the speed of the material being reeled, means connecting said voltage control means to be responsive to said first, second and third signals, means for developing a fourth signal responsive to the motor armature current, exciter means for said motor field winding, means connecting said motor field exciter to be responsive to the difference between said second

and fourth signals to minimize the difference between said second and fourth signals.

3. In a tension regulating system for a reel disposed to accommodate material passed between a pair of work rolls, a motor driving said reel and having an armature winding and a field winding, a generator connected to supply said motor armature winding, voltage control means for said generator, means for developing a first signal proportional to the desired tension, a tensiometer having a deflector roll and a variable reactance winding for developing a second signal responsive to the tension of the material being rolled, means connecting said voltage control means to be responsive to said first and second signals, means for developing a third signal responsive to the motor armature current, exciter means for said motor field winding, means connecting said motor field exciter to be responsive to said second and third signals in opposition to oppose changes in said third signal relative to said second signal.

4. In a tension regulating system for a reel disposed to accommodate material passed between a pair of work rolls, a motor driving said reel and having an armature winding and a field winding, a generator connected to supply said motor armature winding, voltage control means for said generator, means for developing a first signal responsive to the desired tension, a tensiometer of the deflector roll variable reactance type for producing a second signal responsive to the tension of the material being rolled, means connecting said voltage control means to be responsive to said first and second signals, means for producing a third signal responsive to the motor armature current, exciter means for said motor field winding, means connecting said motor field exciter to be responsive to said second and third signals, means integrating the difference between said second signal and said third signal to compensate for material build-up on said reel.

5. In combination with work rolls and a reel, a control system for holding a constant tension in the material between the work rolls and the reel comprising, a motor drivably connected to said reel and having an armature winding and a field winding, a generator having an armature winding and a field winding, means interconnecting said armature windings, means for developing a first signal voltage proportional to the desired tension, means for developing a second signal voltage responsive to the tension of the material being rolled, exciter means for said generator field winding, means connecting said generator exciter means to be responsive to said first and second signal voltages, means for developing a third signal voltage responsive to the armature current of said motor, exciter means for said motor field winding, means connecting said motor exciter means to be responsive to said second and third signal voltages to maintain said third signal voltage constant with respect to said second signal voltage.

6. In combination with work rolls and a reel, a control system for holding a constant tension in the material between the work rolls and the reel comprising, a motor drivably connected to said reel and having an armature winding and a field winding, a generator having an armature winding and a field winding, means interconnecting said armature windings, means for developing a first signal voltage proportional to the desired tension, means for developing a second signal voltage responsive to the tension of the material being rolled, exciter means for said generator field winding, means connecting said generator exciter means to be directly responsive to said first signal and inversely responsive to said second signal voltage, means for developing a third signal voltage responsive to the armature current of said motor, exciter means for said motor field winding, means connecting said motor exciter means to be responsive to the difference between said second and third signal voltages to maintain said third signal voltage constant with respect to said second signal voltage.

7. In combination with work rolls and a reel, a control system for holding a constant tension in the material between the work rolls and the reel comprising, a motor drivably connected to said reel and having an armature winding and a field winding, a generator having an armature winding and a field winding, means interconnecting said armature windings, means for developing a first signal voltage proportional to the speed of said work rolls, means for developing a second signal voltage proportional to the tension of the material being rolled, exciter means for said generator exciter means to increase the output voltage of said generator in response to an increase in said first signal voltage and decrease the output voltage of said generator in response to an increase in said second signal voltage, means for developing a third signal voltage proportional to the armature current of said motor, exciter means for said motor field winding, means connecting said motor field exciter means to increase the current in said motor field winding in response to an increase in said third signal voltage and decrease the current in said motor field winding in response to an increase in said second signal voltage, control means connected to said generator exciter means for providing a signal proportional to the desired tension.

8. In combination with work rolls and a reel, a control system for holding a constant tension in the material between the work rolls and the reel comprising, a motor drivably connected to said reel and having an armature winding and a field winding, a generator having an armature winding and a field winding, means interconnecting said armature windings, means for developing a first signal voltage proportional to the desired tension, tensiometer means for developing a second signal voltage proportional to the tension of the material being rolled, exciter means for said generator field winding, means connecting said generator exciter means to increase the output voltage of said generator in response to an increase in said first signal and decrease the output voltage of said generator in response to an increase in said second signal voltage, means for developing a third signal voltage proportional to the armature current of said motor, exciter means for said motor field winding, means connecting said motor field exciter means to increase the current in said field in response to an increase in said third signal voltage and decrease the current in said motor field winding in response to an increase in said second signal voltage, control means connected to said generator exciter means for providing a signal voltage proportional to the desired tension.

9. In combination with work rolls and a storage reel, a control system for holding a constant tension in the material between the work rolls and the reel comprising, a motor drivably connected to said reel and having an armature winding and a field winding, a generator having an armature winding and a field winding, means interconnecting said armature windings, means for developing a first signal voltage proportional to the speed of said work rolls, tensiometer means of the deflection roll variable reactance type for developing a second signal voltage proportional to the tension of the material being rolled, exciter means for said generator field winding, means connecting said generator exciter means to increase said generator voltage in response to an increase in said first signal and decrease said generator voltage in response to an increase in said second signal voltage, means for developing a third signal voltage proportional to the armature current of said motor, exciter means for said motor field winding, means connecting said motor exciter means to increase said field current in response to an increase in said third signal and said second signal voltage, control means for said generator for selecting the desired tension in the material being worked.

10. In combination with work rolls and a storage reel,

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a control system for holding a constant tension in the material between the work rolls and the reel comprising, a motor drivingly connected to said reel and having an armature winding and a field winding, a generator having an armature winding and a field winding, means interconnecting said armature windings, means for developing a first signal voltage responsive to the speed of said work rolls, means for developing a second signal voltage responsive to the tension of the material being rolled, exciter means for said generator field winding, means connecting said generator exciter means to be responsive to said first and second signal voltages, means for developing a third signal voltage responsive to the armature current of said motor, exciter means for said motor field winding, means connecting said motor exciter means to be responsive to said second and third signal voltages, means integrating the difference between said second signal and said third signal to compensate for material build-up on said reel, control means for said generator for selecting the desired tension in the material being worked.

11. In a control system for a reel motor having a field winding and an armature winding, a motor field current regulator having a relatively long time constant and being responsive to increase motor field current in response to an increase in motor armature current and decrease motor field current in response to an increase in the tension of the material being reeled, a generator connected to supply said armature winding, a voltage regulator connected to regulate the voltage supplied to said motor by said generator, said regulator having a relatively short time constant and being responsive to decrease the generator voltage in response to an increase in the tension

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of the material being reeled and increase the generator voltage in response to an increase in the speed of the material being reeled.

12. In a control system for a reel motor having a field winding and an armature winding, a motor field current regulator having a relatively long time constant and being differentially responsive to a signal responsive to motor armature current and a signal proportional to the tension of the material being reeled, a generator connected to supply said armature winding, a voltage regulator connected to regulate the voltage supplied to said motor by said generator, said regulator having a relatively short time constant and being differentially responsive to a signal responsive to the speed of the material being reeled and a signal proportional to the tension of the material being reeled, means connected to said generator voltage regulator for introducing a signal proportional to the desired tension.

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