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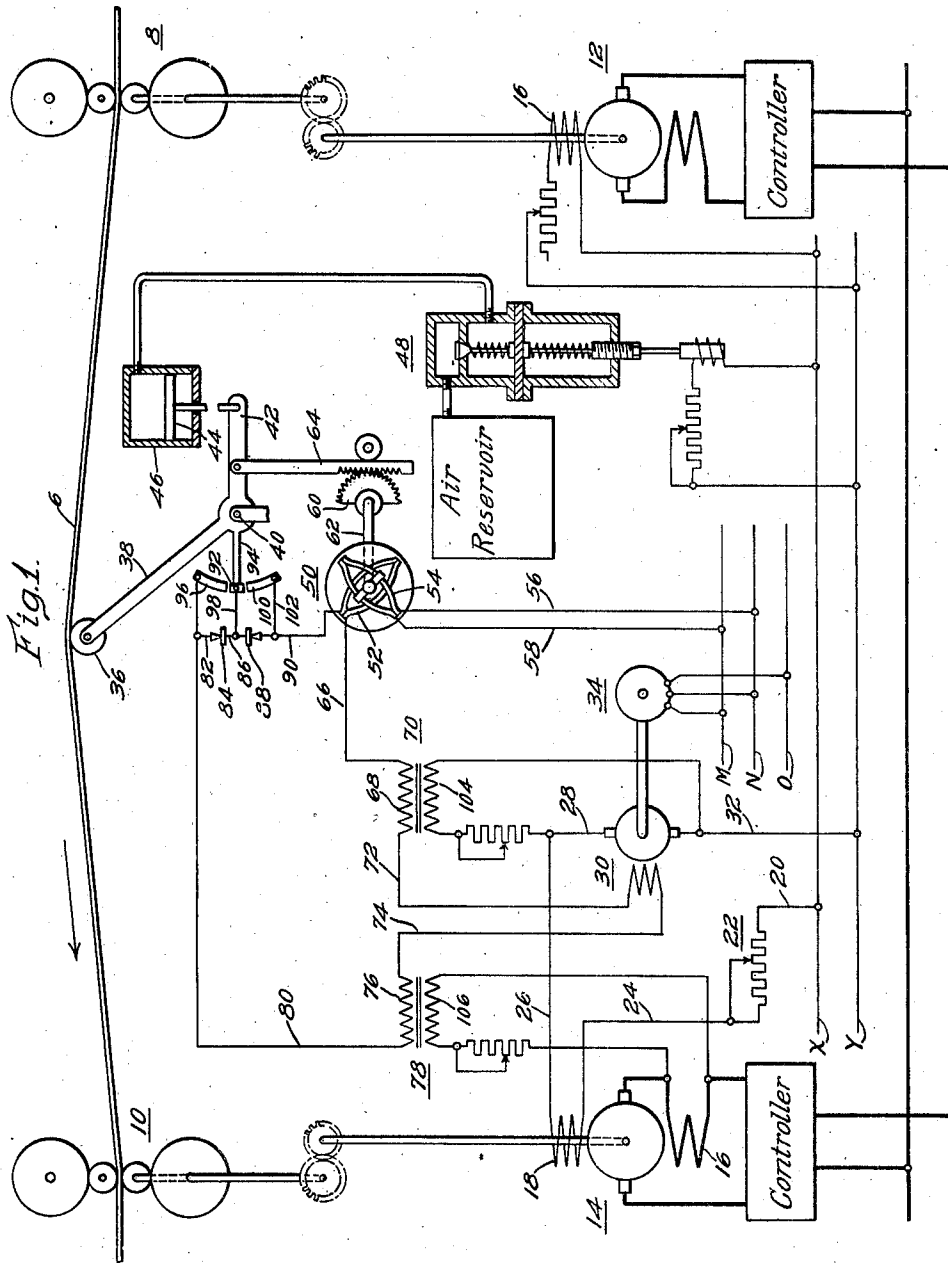
W. G. COOK

2,210,708

TENSIOMETER CONTROL SYSTEM

Filed May 25, 1938

2 Sheets-Sheet 1



WITNESSES:

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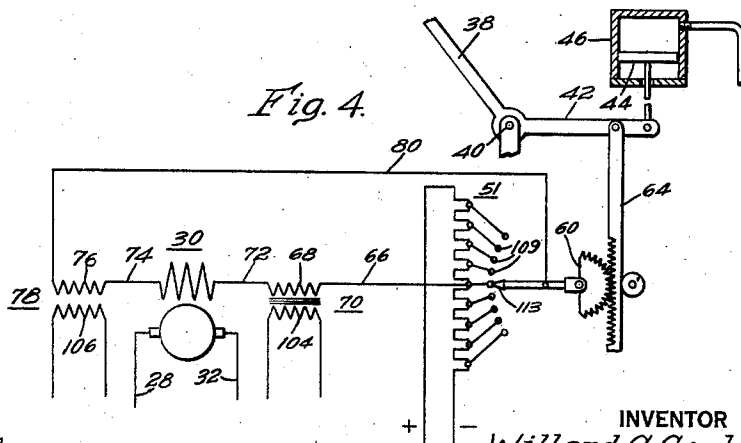
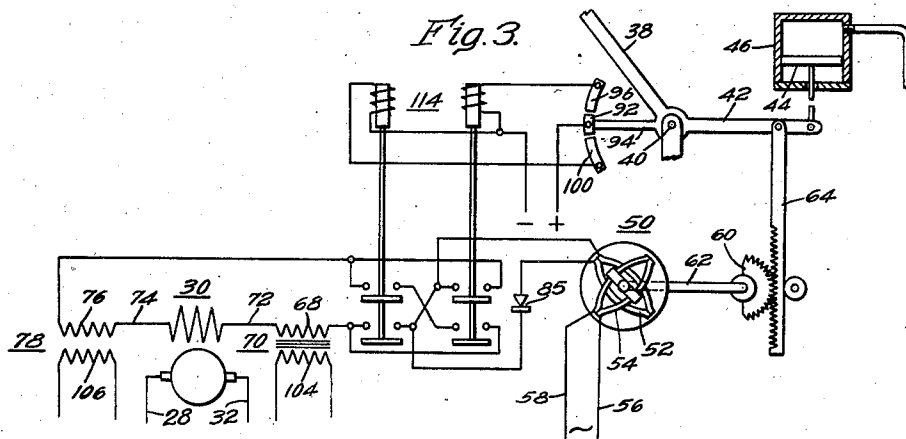
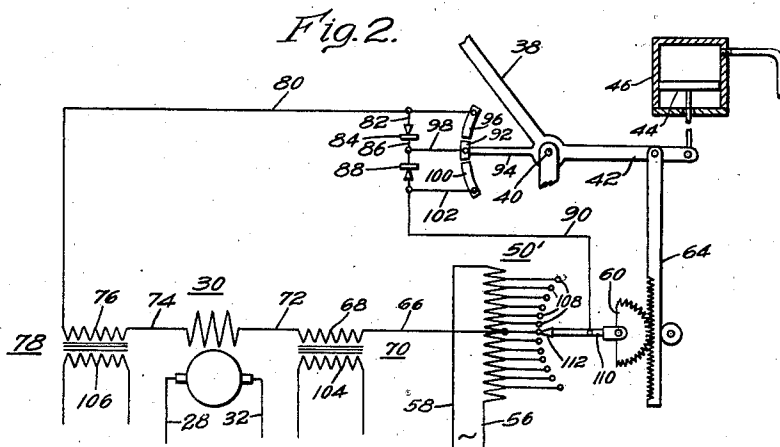
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TENSIOMETER CONTROL SYSTEM

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2 Sheets-Sheet 2



WITNESSES:

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UNITED STATES PATENT OFFICE

2,210,708

TENSIO METER CONTROL SYSTEM

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Application May 25, 1938, Serial No. 209,975

12 Claims. (Cl. 80-35)

My invention relates, generally, to tensiometer control systems, and more particularly, to systems for controlling the tension on steel strip as it is being passed through a rolling mill.

5 In my patent application Serial No. 165,287, filed September 23, 1937, I have disclosed a tension control system in which tension is applied to the strip as it passes between adjacent roll stands by a tensioning roller member applying a transverse deflecting force to the strip. The deflection of the strip is kept within predetermined limits by controlling the speed of the leading roll stand motor by means of a vibrating regulator which is controlled, through a synchro-
10 tie system, in accordance with the position of the tensioning roller.

One object of my invention is to provide for simplifying the above-described tensiometer control system and improving its operation by eliminating the vibrating regulator, synchro-tie system and other auxiliary relay devices and substituting apparatus therefor which is of more simple construction.

Another object of my invention is to provide a tension control system for a strip rolling mill which has a minimum of operating parts, which is simple in operation, and which is inexpensive to manufacture, install and maintain.

These and other objects and advantages of my invention will be apparent from the following detailed description taken in connection with the accompanying drawings in which:

30 Figure 1 is a diagrammatic view of a tension control system embodying the principal features of my invention, and

35 Figs. 2, 3 and 4 are diagrammatic views of modifications of that part of the control system shown in Fig. 1 which provides the proper energization for the booster generator.

40 In carrying out my invention I provide a booster generator in the field circuit of the roll stand motor and control the motor speed by exciting the booster generator with a current of a polarity and value dependent upon the direction and amount of deflection of the strip from a predetermined position. Alternative systems for providing the desired booster generator excitation are provided, using a variable ratio transformer principle or a resistance potentiometer principle.

50 Referring now to Figure 1 of the drawings, a strip of material 6 such as steel is shown passing between two adjacent reducing roll stands 8 and 10 in the direction indicated by the arrow. The rolls of the roll stand 8 are driven by a motor 12

and rolls of the roll stand 10 are driven by a motor 14, the motor 14 being controlled by any suitable controller as shown and having a series field winding 16 and a shunt field winding 18. Energization of the shunt field winding 18 of the motor 14 is provided by connecting the shunt field winding to any suitable source of direct current power of substantially constant potential represented by the conductors X and Y. This energizing circuit extends from conductor X, through conductor 20, rheostat 22, conductor 24, field winding 18, conductors 26 and 28, the armature of a booster generator 30 and conductor 32 to the conductor Y. The booster generator 30 is continuously driven at a substantially constant speed by any suitable motor 34 here shown as an alternating current motor connected to a source of alternating current power indicated by the conductors M, N and O. It will be apparent that the speed of the motor 14 may be varied by varying the current flow in its field winding 18 by either adjusting the rheostat 22 or varying the energization of the field winding of the booster generator 30 to vary its voltage.

25 Tensioning of the strip 6 between the roll stands 8 and 10 is provided by causing a roller 36 mounted on an arm 38 to bear against the strip 6 and to deflect the strip from the normal pass line. The arm 38 has a pivotal mounting 40 and has a connected arm 42 disposed substantially horizontally and acted upon by a fluid pressure operated piston 44 in a fluid pressure cylinder 46. The tension applied to the strip 6 by the idling roller 36 is governed by the fluid pressure in the cylinder 46 and this pressure is maintained constant at a predetermined adjustable value by means of an adjustable pressure-regulating reducing valve 48 whose low pressure side is connected to the cylinder 46 and whose high pressure side receives air pressure from the air reservoir shown. The functioning of the piston operated idling roller 36 controlled by the regulating valve 48 to maintain a predetermined constant tension on the strip 6 is explained in detail in the copending application of G. P. Lessman, Serial No. 133,419, filed March 27, 1937, now Patent No. 2,189,609, issued February 6, 1940.

50 In order to limit the degree of deflection of the strip 6 by the idling roller 36 and to thus secure the proper tensioning of the strip 6, a regulating means for controlling the speed of the roll motor 14 is provided and, in this instance, comprises a variable ratio transformer 50 having a secondary winding 52 and a primary winding 54.

The primary winding 54 of the transformer 50 is connected by conductors 56 and 58 to the phase conductors M and N of the alternating current source of power represented by conductors M, N and O. The primary winding 54 of the transformer 50 is normally positioned at right angles to the secondary winding 52, and in this position causes no electromotive force to be induced in the secondary winding 52. The primary winding 54 is rotatable in either direction with respect to the winding 52 to vary the coupling between the winding 52 and the winding 54 and to thus vary the amount of electromotive force induced in the secondary winding 52.

The rotation of the primary winding 54 may be secured by mechanically connecting it to a gear 60 by means of a shaft 62, the gear 60 engaging a rack 64 which is connected to be moved vertically by rotation of the arm 42 about the pivot 40. Thus the increase or decrease of the deflection of the strip 6 will cause an increase in the value of the electromotive force induced in the winding 52 of variable ratio transformer 50.

The secondary winding 52 of the transformer 50 is connected in series circuit relation with the field winding of the booster generator 30 through a circuit which comprises conductor 66, the secondary winding 68 of a transformer 70, conductor 72, field winding of booster generator 30, conductor 74, the secondary winding 76 of a transformer 78, conductor 80, conductor 82, rectifier unit 84, conductor 86, rectifier unit 88 and conductor 90.

The rectifier units 84 and 88 are connected to pass opposite polarities of current in the circuit of the secondary winding 52. The rectifier unit 84 is connected to be shunted when the deflection of strip 6 increases beyond the predetermined normal amount represented by the positioning of the strip and its tensioning device in the drawing by the engagement of the movable contact element 92 which is supported to be moved upon movement of the arm 38 by a supporting arm 94 with the fixed contact element 96 through a circuit which comprises conductor 82, conductor 80, contact elements 96 and 92, and conductors 98 and 86. A similar shunting circuit is provided for rectifier unit 88 comprising conductor 86, conductor 98, movable contact element 92, contact element 100 and conductors 102 and 90.

In the operation of the device, with the elements of the device in the normal positions indicated by Fig. 1 of the drawings, the normal deflection of the strip 6 is as indicated and the roll motor 14 is receiving sufficient excitation to maintain a strip speed which will keep the strip in this normal degree of deflection, and under these normal conditions the booster generator 30 is not excited and is, therefore, not effecting the excitation of the roll motor 14.

If, now, for any reason, the deflection of the strip 6 should increase the relative movement of the primary and secondary windings 54 and 52 of variable ratio transformer 50 will cause an electromotive force to be induced in the secondary winding 52 having a value which is proportional to the amount of the relative displacement of the primary winding 54 from its normal position and the engagement of the contact element 92 with the contact element 96 will close the shunting circuit for the rectifier element 84, permitting direct current impulses to flow in the circuit of the winding 52 and the field winding of the booster generator 30 in a direction such

as to cause the booster generator 30 to generate a potential in the circuit of the field winding 18 of the roll stand motor 14 of such polarity as to reduce the current flow in the field winding 18.

The reduction of the excitation of the motor 14 by the decrease in the current flow in its field winding 18 will cause the motor 14 to increase its speed and to thus take up slack in the strip 6 and reduce its deflection. In this manner the system will operate to keep the deflection of the strip below a predetermined amount.

In a like manner, when for any reason the deflection of the strip 6 decreases a predetermined amount below its normal deflection, the speed of the roll stand motor 14 will be decreased to permit the deflection to return to normal by means of the rotation of the primary winding 54 from its normal position and the engagement of the contact elements 92 and 94 to provide a shunting circuit for the rectifier element 88.

Anticipating circuits are provided for preventing hunting of the system and comprise a transformer 70 whose primary winding 104 is connected in parallel relation with the armature of the booster generator 30 and whose secondary winding 68 is connected in the circuit of the field winding of the booster generator 30 as hereinbefore described. A transformer 78 has a primary winding 106 connected in parallel relation with the series field winding 16 of the roll motor 14 and a secondary winding connected in the circuit of the field winding of the booster generator 30 as hereinbefore described. With the primary winding 104 of the transformer 70 connected as described, it will be seen that any change in the potential generated by the booster generator 30 will cause a change in the current flow in the primary winding 104 and this change in current flow will cause an electromotive force to be induced in the secondary winding 68 of the transformer 70. In a like manner, any change in the current flow in the armature circuit of the roll stand motor 14 will cause a change in the potential drop across its series field winding 16 which in turn will cause a change in the current flow in the primary winding 106 of the transformer 78, and the change in current flow in the winding 106 will cause an electromotive force to be induced in the secondary winding 76 of the transformer 78.

The change in the generated potential of the booster generator 30 will be caused by the change in its excitation and the change in the current flow in the armature of the roll stand motor 14 will be caused by a change in its excitation. The secondary windings 68 and 76 of the transformers 70 and 78 are so related with the circuit of the field winding of the booster generator 30 as to cause a decrease in the current flow in the field winding of the booster generator 30 when the potential of the booster generator 30 increases in one direction, and a decrease in the current flow of the field winding of the booster generator 30 when the potential of the booster generator 30 increases in the other direction. The secondary winding 76 of the transformer 78 is so related with the circuit of the field winding of the booster generator 30 as to cause a decrease in the current flow in the field winding of the booster generator 30 when the current flow in the armature of the roll stand motor 14 increases. Thus the anticipating circuits which include the transformer 70 and 78 will anticipate the changes to be made by the change in the excitation of the booster generator 30 and will

decrease the degree of excitation of the booster generator 30 which causes these changes in advance of the actual changes to prevent the changes from varying from one extreme to another. Thus, before the speed of the roll stand motor 14 has been increased or decreased to prevent the full correction of strip deflection necessary to return the deflection to the normal amount, the change in the excitation of the motor 14 will be lessened to prevent the motor from overrunning or changing beyond its necessary final speed. In this manner, the anticipating circuits described will prevent hunting of the motor 14.

In Figs. 2, 3 and 4 there are shown modifications of part of the system of Fig. 1 in which different apparatus for securing the necessary changes in the excitation of the booster generator are provided. In these figures, the apparatus shown may be substituted for the analogous parts of the apparatus of Fig. 1, and similar parts have the same reference characters in the several figures.

Referring to Fig. 2, the auto-transformer 50' may be substituted for the variable ratio transformer 50 of Fig. 1, the other parts of the system remaining the same. The auto-transformer 50' is connected to a suitable source of alternating current through the conductors 56 and 58 and is provided with a series of taps to which a series of contact elements 108 are connected. A contact arm 110 is connected to gear 60 to traverse the series of contact elements upon movement of the gear 60 by changing deflection of the strip as explained in the discussion of the system of Fig. 1, the contact arm causing the contact element 112 to traverse the series of contact elements 108. The conductor 66 is connected to substantially the middle tap of the auto-transformer 50' and in the normal position of the tensioning device, the contact element 112 engages the tap corresponding to this midposition so that in the normal position of the elements there is no potential induced in the circuit of the field winding of the booster generator 30. It will be seen that the same effects will be produced by this auto-transformer operated as described as were produced by the variable ratio transformer 50 of the system of Fig. 1.

In Fig. 3 there is shown a system in which a single rectifier 85 is connected in circuit with the field winding of the booster generator 30 and the secondary winding 56 of a variable ratio transformer 50 operated in the manner shown in the system of Fig. 1, and the reversal of the direction of current flow in the field winding of the booster generator 30 is provided by selective contact elements 92, 94 and 96 which operate an electromagnetic reversing switch 114. It will be apparent that in this system as in the systems of Figs. 1 and 2 the degree of energization of the field winding of the booster generator 30 will depend upon the amount of deflection of the strip from its normal position and that the polarity of energization of the field winding of the booster generator 30 will depend upon the direction of the deflection of the strip from its normal position, and the booster generator will act accordingly to correct the condition and bring the strip deflection back to normal.

In Fig. 4, there is shown a potentiometer type rheostat 51 which may be connected to any source of direct current as shown and which has a tap at its mid point connected to the conductor 66 of the circuit of the field winding of the booster

generator 30, and which has a series of taps connected to a series of contact elements 109. The contact element which is connected to the middle tap is normally engaged by a movable contact element 113 which is made to traverse the series of contact elements 109 by the gear 60 which is operated by the rack 64 as described in the connection with the discussion of the systems of Figs. 1 and 2.

In this system it will be seen that the amount of potential applied to the field winding circuit of the booster generator 30 will depend upon the amount of deflection of the strip from normal position since the deflection governs the number of contacts of the series of contacts 109 traversed by the movable contact 113, and the polarity of the potential applied to the field winding circuit of the booster generator 30 will be determined by the direction of the deflection of the strip from normal since the polarity of the potential drop between the mid point contact to which conductor 66 is connected and the taps above this mid point are opposite to the polarity of the potential drop between this mid tap and the taps below the mid tap, as the circuit of the field winding of the booster generator is connected between these taps by the movable contact 113.

It is to be understood that the variable ratio transformers disclosed herein need not be the specific movable coil transformer or the auto-transformer described, but may be any transformer that will perform the function of these transformers in this system. A transformer whose ratio is varied by moving its core relative to both its primary and secondary windings would perform the desired function equally as well as those described and it is to be understood that such a transformer is within the purview of my invention.

It will be seen that I have provided a system for maintaining a constant tension upon a strip of material as it is passing between adjacent reducing roll stands which will function to govern the speed of the driving motor of one of the roll stands to maintain the deflection of the strip within predetermined limits and which is provided with an anticipating circuit for preventing hunting of the driving motor which system has a minimum of operating parts and which is simple in operation and inexpensive to manufacture, install and maintain.

In compliance with the requirements of the patent statutes, I have shown and described herein the preferred embodiments of my invention. It is to be understood, however, that the invention is not limited to the precise constructions shown and described, but is capable of modification by one skilled in the art, the embodiments herein shown being merely illustrative of the principles of my invention.

I claim as my invention:

1. In a tandem strip rolling mill, tensioning means bearing upon the strip as it passes between adjacent roll stands of the mill subjecting the strip to a transverse force to thus deflect and tension the strip, a variable speed motor connected in driving relation with the rolls of one of the adjacent roll stands, a source of substantially constant excitation for said variable speed motor, a continuously-driven generator connected to increase or decrease the excitation of said motor depending upon the polarity of the excitation of said generator, the amount of said increase or decrease depending upon the amount

of excitation of said generator, and means controlled in accordance with the deflection of said strip by said tensioning means for selectively exciting said generator with a polarity and with an amount of excitation dependent upon the direction and proportional to the amount of deflection of said strip from a predetermined position.

2. In a device for maintaining tension on a length of material as it passes between two work devices, tensioning means bearing on the length of material between the work devices and subjecting the length of material to a transverse force to thus deflect and tension the length of material, a variable speed motor connected to drive one of the work devices, electrical means for selectively varying the speed of said motor depending upon the polarity and degree of energization of said electrical means, and means responsive to the deflection of said length of material for energizing said electrical means with a polarity and to a degree dependent upon the direction and degree of deflection of said length of material from a predetermined position, said means responsive to said deflection comprising a continuously energized variable ratio transformer, rectifier means connected in circuit with the output side of said transformer, means governed by the direction of deflection of the strip from a predetermined position for selectively connecting said rectifier means to selectively govern the polarity of the rectified output of said transformer and means controlled by the degree of deflection of the strip from said predetermined position for varying the ratio of said transformer.

3. In a tandem strip rolling mill, tensioning means bearing upon the strip as it passes between adjacent roll stands of the mill subjecting the strip to a transverse force to thus deflect and tension the strip, a variable speed motor connected in driving relation with the rolls of one of the adjacent roll stands, a source of substantially constant excitation for said variable speed motor, a continuously-driven generator connected to increase or decrease the excitation of said motor depending upon the polarity of the excitation of said generator, the amount of said increase or decrease depending upon the amount of excitation of said generator, and means controlled in accordance with the deflection of said strip by said tensioning means for selectively exciting said generator with a polarity and with an amount of excitation dependent upon the direction and amount of deflection of said strip from a predetermined position, said means controlled in accordance with the deflection of the strip comprising a continuously energized variable ratio transformer, rectifier means connected in circuit with the output side of said transformer and the field winding of said generator, means governed by the direction of deflection of the strip from a predetermined position for selectively connecting said rectifier means to selectively govern the polarity of the rectified output of said transformer and means governed by the degree of deflection of the strip from said predetermined position for varying the ratio of said transformer.

4. In a device for maintaining tension on a length of material as it passes between two work devices, tensioning means bearing on the length of material between the work devices and subjecting the length of material to a transverse force to thus deflect and tension the length of material, a variable speed motor connected to drive one of the work devices, electrical means for

selectively varying the speed of said motor depending upon the polarity and degree of energization of said electrical means, and means responsive to the deflection of said length of material for energizing said electrical means with a polarity and to a degree dependent upon the direction and degree of deflection of said length of material from a predetermined position, said means responsive to the deflection of the length of material comprising a variable resistor continuously energized from a source of direct current and having a movable contact element, means connecting said electrical means in circuit with said resistor at a point intermediate the ends of the resistor and with said movable contact element, means whereby the deflection of said length of material governs the movement of said movable contact element, said movable contact element being so positioned as to engage said resistor at said point intermediate the ends of the resistor when the length of material is deflected to said predetermined position.

5. In a device for maintaining tension on a length of material as it passes between two work devices, tensioning means bearing on the length of material between the work devices and subjecting the length of material to a transverse force to thus deflect and tension the length of material, a variable speed motor connected to drive one of the work devices, electrical means for selectively varying the speed of said motor depending upon the polarity and degree of energization of said electrical means, and means responsive to the deflection of said length of material for energizing said electrical means with a polarity and to a degree dependent upon the direction and degree of deflection of said length of material from a predetermined position, said means responsive to the deflection of the length of material comprising a continuously energized auto-transformer having a series of taps intermediate the ends of its windings, a movable contact element for selectively engaging said taps, means for moving said movable contact element in accordance with the deflection of the length of material, means connecting said electrical means in circuit with said movable contact element and with said transformer at a point intermediate the ends of said series of taps, said movable contact element being so adjusted as to engage the tap corresponding to the point of connection of said electrical means to said transformer when the length of material is in said predetermined position, rectifier means in circuit with said transformer and said electrical means, and means responsive to the direction of deflection of the length of material from said predetermined position for selectively connecting said rectifier means to provide said polarity of energization for said electrical means.

6. In a tandem strip rolling mill, tensioning means bearing upon the strip as it passes between adjacent roll stands of the mill subjecting the strip to a transverse force to thus deflect and tension the strip, a variable speed motor connected in driving relation with the rolls of one of the adjacent roll stands, a variable resistance element continuously energized from a direct current source and having a contact element movable along said resistance element, means whereby the said contact element is moved in one direction or the other in accordance with the direction and amount of deflection of the strip from a predetermined normal position, said movable contact element being so positioned as to occupy a predetermined point on said resistance element

when the strip is deflected to the said normal position, and means whereby the excitation of said driving motor is varied in accordance with the polarity and the amount of the potential drop between said predetermined point on said resistance element and said movable contact element.

7. In a tandem strip rolling mill, tensioning means bearing upon the strip as it passes between adjacent roll stands of the mill subjecting the strip to a transverse force to thus deflect and tension the strip, a variable speed motor connected in driving relation with the rolls of one of the adjacent roll stands, a variable resistance element continuously energized from a direct current source and having a contact element movable along said resistance element, means whereby the said contact element is moved in one direction or the other in accordance with the direction and amount of deflection of the strip from a predetermined normal position, said movable contact element being so positioned as to occupy a predetermined point on said resistance element when the strip is deflected to the said normal position and means whereby the excitation of said driving motor is varied in accordance with the polarity and the amount of the potential drop between said predetermined point on said resistance element and said movable contact element, said excitation varying means comprising a continuously driven generator having a field winding and having its armature connected in series circuit relation with the field winding of said driving motor, and a series circuit including said field winding of said generator and the portion of said variable resistance between said predetermined point and said movable contact element.

8. In a tandem strip rolling mill, tensioning means bearing upon the strip as it passes between adjacent roll stands of the mill subjecting the strip to a transverse force to thus deflect and tension the strip, a variable speed motor connected in driving relation with the rolls of one of the adjacent roll stands, a variable resistance element continuously energized from a direct current source and having a contact element movable along said resistance element, means whereby the said contact element is moved in one direction or the other in accordance with the direction and amount of deflection of the strip from a predetermined normal position, said movable contact element being so positioned as to occupy a predetermined point on said resistance element when the strip is deflected to said normal position, and means whereby the excitation of said driving motor is varied in accordance with the polarity and the amount of the potential drop between said predetermined point on said resistance element and said movable contact element, said excitation varying means comprising a continuously driven generator having a field winding and having its armature connected in series circuit relation with the field winding of said driving motor and a series circuit including said field winding of said generator and the portion of said variable resistance between said predetermined point on said resistance element and said movable contact element, and means for producing in said series circuit a potential whose amount and polarity are proportional to and determined by the rate of change and the direction of change of the current in the armature circuit of said driving motor.

9. In a tandem strip rolling mill, tensioning means bearing upon the strip as it passes between

adjacent roll stands of the mill subjecting the strip to a transverse force to thus deflect and tension the strip, a variable speed motor connected in driving relation with the rolls of one of the adjacent roll stands, a variable resistance element continuously energized from a direct current source and having a contact element movable along said resistance element, means whereby the said contact element is moved in one direction or the other in accordance with the direction and amount of deflection of the strip, said movable contact element being so positioned as to occupy a predetermined point on said resistance element when the strip is deflected a predetermined amount, and means whereby the excitation of said driving motor is varied in accordance with the polarity and the amount of the potential drop between said predetermined point and said movable contact element, said excitation varying means comprising a continuously driven generator having a field winding and having its armature connected in series circuit relation with the field winding of said driving motor and a series circuit including said field winding of said generator and the portion of said variable resistance between said predetermined point and said movable contact element, and means for producing in said series circuit a potential whose amount and polarity are proportional to and determined by the rate of change and the direction of change of the potential generated by said generator.

10. In a tandem strip rolling mill, tensioning means bearing upon the strip as it passes between adjacent roll stands of the mill subjecting the strip to a transverse force to thus deflect and tension the strip, a variable speed motor connected in driving relation with the rolls of one of the adjacent roll stands, a variable resistance element continuously energized from a direct current source and having a contact element movable along said resistance element, means whereby the said contact element is moved in one direction or the other in accordance with the direction and amount of deflection of the strip, said movable contact element being so positioned as to occupy a predetermined point on said resistance element when the strip is deflected a predetermined amount and means whereby the excitation of said driving motor is varied in accordance with the polarity and the amount of the potential drop between said predetermined point and said movable contact element, said excitation varying means comprising a continuously driven generator having a field winding and having its armature connected in series circuit relation with the field winding of said driving motor and a series circuit including said field winding of said generator and the portion of said variable resistance element between said predetermined point and said movable contact element and means for producing in series circuit a potential whose amount and polarity are proportional to and determined by the rate of change and the direction of change of the current in the armature circuit of said driving motor, and means for producing in said series circuit a potential whose amount and polarity are proportional to and determined by the rate of change and the direction of change of the potential generated by said generator.

11. In a tandem strip rolling mill, tensioning means bearing upon the strip as it passes between adjacent roll stands of the mill subjecting the strip to a transverse force to thus deflect and tension the strip, a variable speed motor connected in driving relation with the rolls of one of the

adjacent roll stands, a source of substantially constant excitation for said variable speed motor, a continuously-driven generator connected to increase or decrease the excitation of said motor depending upon the polarity of the excitation of said generator, the amount of said increase or decrease depending upon the amount of excitation of said generator, means controlled in accordance with the deflection of said strip by said generator with a polarity and with an amount of excitation dependent upon the direction and amount of deflection of said strip from a predetermined position, means controlled by the direction of change and the rate of change of the current flow in the armature circuit of said driving motor for changing the excitation of said generator in such a manner as to decrease the change in the excitation of said generator which is causing said change in the current in said motor armature circuit, and means controlled by the direction of change and the rate of change of the potential generated by said generator for changing the excitation of said generator in such a manner as to decrease the rate of change of the potential generated by said generator.

12. In a device for maintaining tension on a length of material as it passes between two work

devices, tensioning means bearing on the length of material between the work devices and subjecting the length of material to a transverse force to thus deflect and tension the length of material, a variable speed motor connected to drive one of the work devices, electrical means for selectively varying the speed of said motor depending upon the polarity and degree of energization of said electrical means, and means responsive to the deflection of said length of material for energizing said electrical means with a polarity and to a degree dependent upon the direction and degree of deflection of said length of material from a predetermined position, said means responsive to said deflection comprising a continuously energized transformer having relatively movable primary and secondary windings for varying the transformer ratio, rectifier means connected in circuit with the output side of said transformer, means controlled by the direction of deflection of the strip from a predetermined position for selectively connecting said rectifier means to selectively control the polarity of the rectified output of said transformer, and means controlled by the degree of deflection of the strip from said predetermined position for varying the relative positions of the windings of said transformer.

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