APPARATUS FOR TENSIONING STRIP

Filed July 6, 1960 4 Sheets-Sheet 1

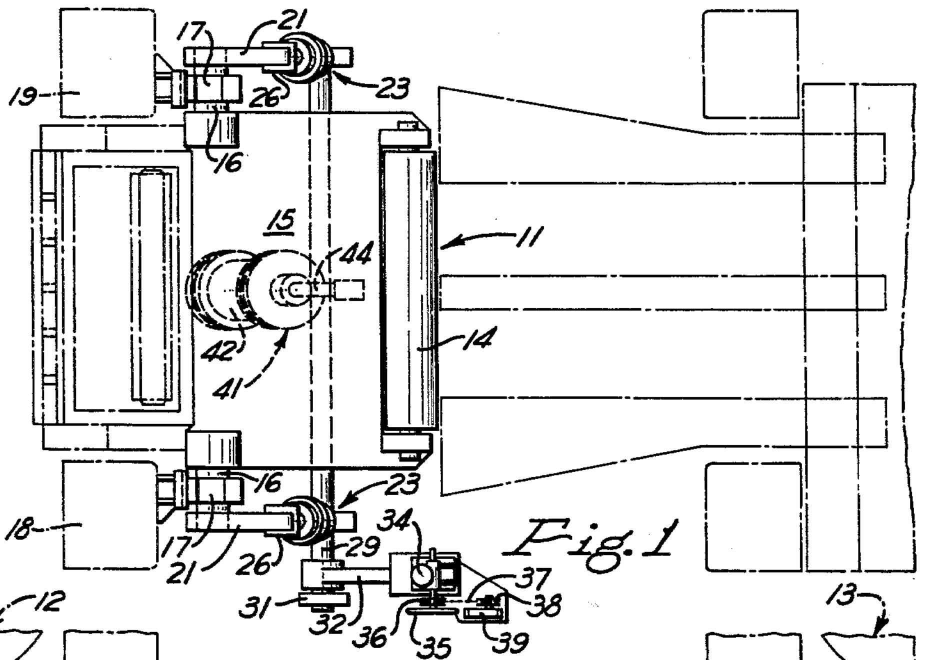

Fig. 1

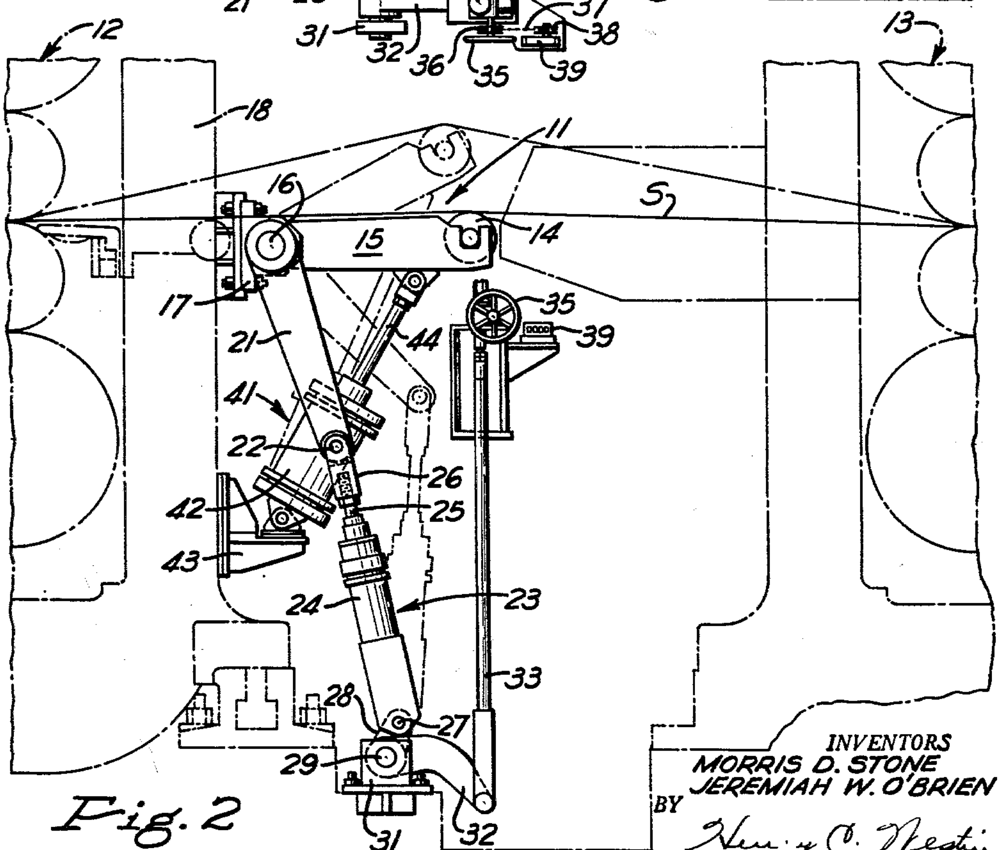

Fig. 2

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APPARATUS FOR TENSIONING STRIP

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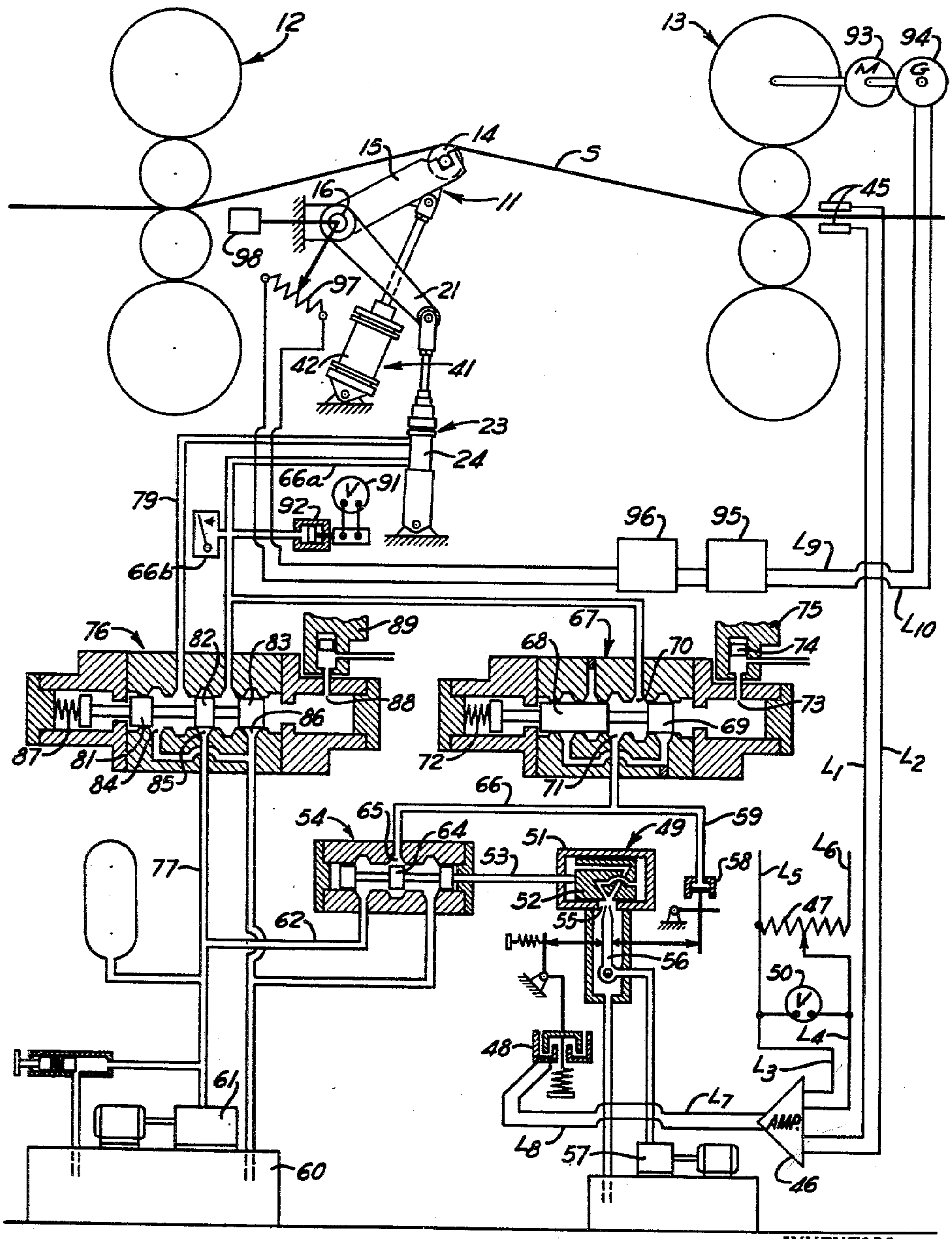

Fig. 3

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APPARATUS FOR TENSIONING STRIP

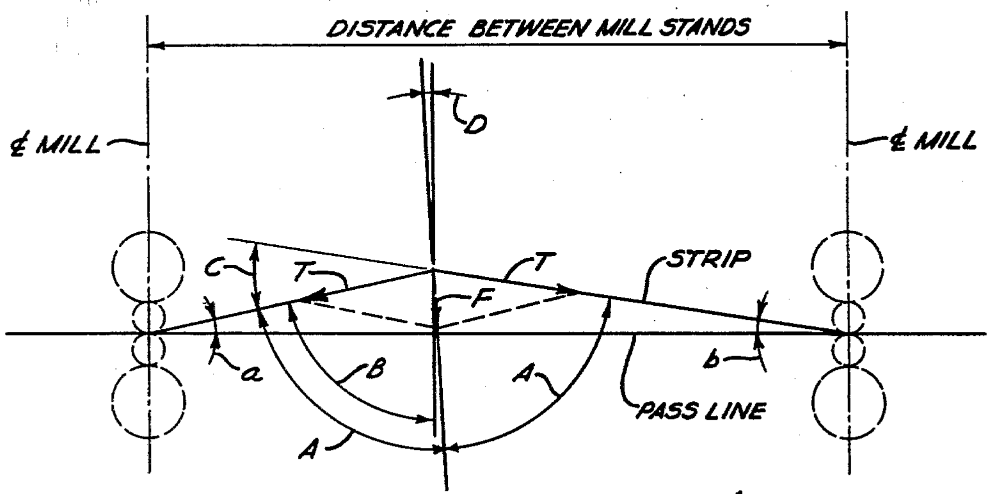

Fig. 4

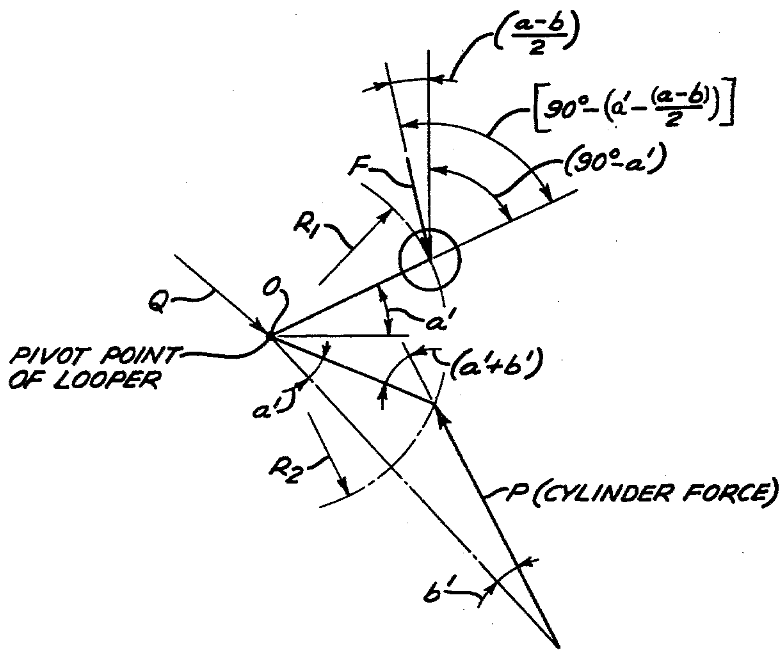

Fig. 5

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APPARATUS FOR TENSIONING STRIP

Filed July 6, 1960 4 Sheets-Sheet 4

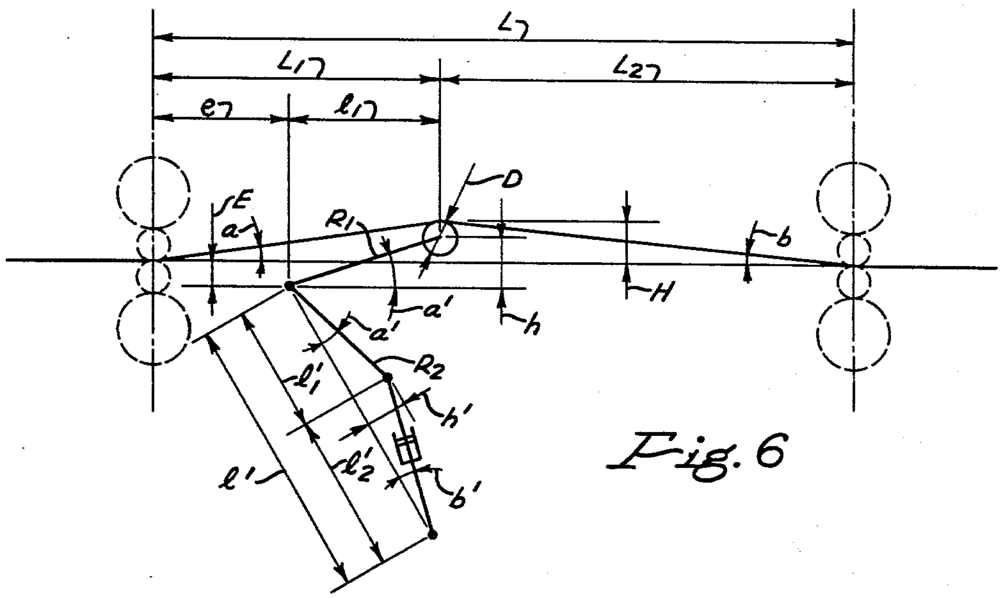

Fig. 6

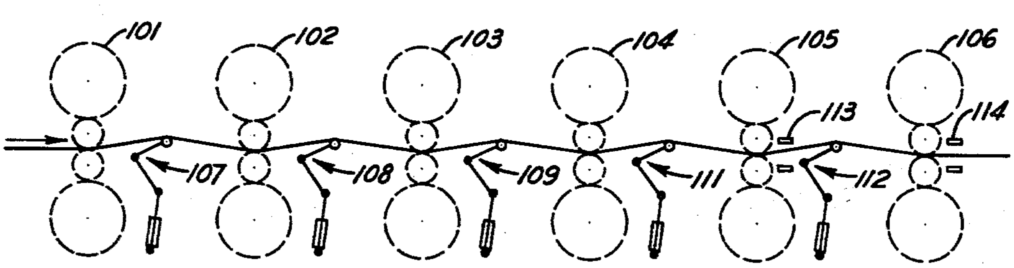

Fig. 7

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United States Patent Office

3,169,420
Patented Feb. 16, 1965

3,169,420

APPARATUS FOR TENSIONING STRIP

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Filed July 6, 1960, Ser. No. 41,051
11 Claims. (Cl. 80—35)

This invention relates to a method of and an apparatus for accurately measuring, constantly controlling and rapidly varying tension imposed upon a strip of material while passing between two or more units and, in particular, to a method and apparatus by which tension imposed upon strip material may be constantly and accurately controlled, determined and varied irrespective of and within practical limits of the distance the strip may be deflected away from a straight line plane during its travel between the units.

Heretofore, particularly in the rolling mill art, many types and variations of apparatuses have been employed to engage the strip as it passed between adjacent mill stands either to maintain the strip taut or to function as a strip tension indicating device. But, due to the inertia and multiplicity of moving parts employed, not only has it been found that the devices are not accurate by reason of the slowness of response but, of more importance, is the fact that strip tensions will vary considerably depending upon the distance the strip is deflected away from the pass line between the rolling mills along which the strip passes during processing. Inasmuch as this variation of tension is well recognized both by mill builders and operators, attempts have been made to maintain the loop of strip at a constant height but this has been found not to be always possible to attain irrespective of the sensitiveness of the devices employed, so that even if the variation of the loop height is relatively small as a rolling operation progresses, the tension of the strip will vary quite considerably. The most serious effect of this condition is that the varying tensions result in longitudinal gauge variations and irregularities in the width of the strip.

Another shortcoming of the present day strip deflecting or strip tension indicating devices is the fact that they are limited to one particular mode of operation, that is to say that they either operate to maintain the strip taut or to indicate tension. In today's modern high speed precision tandem mills, gauge control is of paramount importance to the producer as well as to the consumer of the rolled strip. Because of the multitude of variances inherently present in the rolling of various types and grades of metals having different metallurgical characteristics and which are rolled under different conditions depending on the desired result, it is highly desirable in order to improve the uniformity of strip gauge to provide an efficient and effective means of operating the respective mills, under several different predetermined tension conditions. In this manner the mills can be operated either under varying degrees of tensions or under conditions where the tensions are maintained substantially constant in all mills, or under other conditions where a predetermined variable tension is imposed upon the strip in all or substantially all stands. Furthermore, where it is desirable, the strip tensioning devices will work in conjunction with the mill motors or the mill screwdowns. Various combinations of two or more of these different modes of operation can be attained by embodying the features of the invention in the operation of the various stands of the mill.

Moreover, it is well known in the art that tension is an expeditious way of effecting nominal strip reductions,

in which two of the most common practices of using this technique is to impose the tension on the strip by operation of the two adjacent mills at different speeds or by the employment of tension reels. The technique of imposing a tension force on the strip as it passes between the mill stands by the so called strip looper roller has not been found to be acceptable in the rolling mill art. The fundamental reason for this is the fact that heretofore there was no practical way of imposing a controlled predetermined tension. This is not to say that those skilled in the art did not recognize the virtues of the looper-tension procedure. It is axiomatic that the use of a tension-looper device to impose tension for the purpose of longitudinal strip gauge control would be appreciably more effective than either of the aforesaid procedures in view of the rapidity and controllability at which the looper can be made to respond to a signal indicating an off-gauge condition.

The present invention provides a method of rolling in which a constant tension and/or a variable controlled tension may be imposed on the strip while it passes through a tandem mill in which the longitudinal gauge and width will be controlled so that variation in thickness can be corrected.

Another object of this invention is to provide a loop forming strip tensioning device, the elements of which are so arranged and related to one another and to the mill and strip that for a given actuating pressure exerted upon the device the tension of the strip is maintained substantially constant over the entire range of heights to which the strip may be deflected above the pass line by the device.

A further object of this invention is to provide a loop forming strip tensioning device by which the tension imposed upon the strip may be held substantially constant and readily varied simply by varying the actuating forces exerted upon the device irrespective of the distance the strip may be deflected away from the pass line on normal operation of the device.

An additional object of this invention is to provide a strip tensioning device by which existent strip tension as the strip is passed from one unit to another may be readily ascertained for any and all varying heights of the strip loop above the pass line.

Another object of this invention is to provide a strip deflecting device that may be selectively employed to impose a constant tension on a strip passing thereover or a controlled variable tension or it may be used to measure tension.

Still a further object of this invention is to provide a strip tensioning device in combination with a pair of rolling mills having elements associated therewith for controlling the speed of at least one of the mills for maintaining the height of the loop substantially constant.

Another object of this invention is to provide adjustable means for the tensioning device adapted to maintain the predetermined geometrical relation of the elements thereof.

Another object of this invention is to provide a loop forming strip tensioning device which is inexpensive to manufacture and relatively simple and accurate of operation.

One of the forms of the invention disclosed herein embodies a strip loop forming tension roller for engaging and applying a transverse force to one face of strip material passing from one rolling mill to another for processing. It is one of the features of this invention that the major portion of the elements making up the device, especially the actuating and control elements thereof, may, if such be desired, be located a substantial distance away from the pass line of the strip. This is particularly important and especially advantageous when hot strip material is being processed in the mills. By placement of the actuating and control mechanisms, such as the hydraulic cylinders and the like, where such are employed, a substantial distance away from the strip, the critical elements of the device would not be subjected to the high temperatures of the strip and, consequently, inaccuracies and damage which would otherwise be caused thereby are avoided. The tension roller, in one embodiment, is supported upon a pivotal shaft located adjacent to the strip pass line, which has a pair of struts connected thereto at one end which struts, in turn, are also connected to a pair of pressure actuated extensible struts secured to a pivotal shaft located a substantial distance away from the pass line. Prior to this invention, it was commonly considered to be important that if controlled tension and/or a direct indication thereof were to be obtained at all times, based upon pressures involved for actuating the device, irrespective of the height of the loop in the strip above the pass line where an extensible strut was employed in the arrangement, the struts must be so located that they are always substantially parallel to the two portions of strip as the strip is deflected away from its horizontal pass line.

The objects recited heretofore, as well as the various other novel features and advantages of this invention, will become more apparent by making reference to the following description and the drawings referred to therein of which:

FIG. 1 is a plan view of a loop forming strip tensioning device embodying the features of the invention described herein arranged between two rolling mills;

FIG. 2 is a side elevational view of the device shown in FIG. 1 illustrating, in addition, the rolls of the mills;

FIG. 3 is a schematic diagram of the control system employed with the device disclosed;

FIG. 4 is a force diagram for the strip shown in FIG. 2;

FIG. 5 is a free body diagram for the bell crank shown in FIG. 2;

FIG. 6 is a second force diagram for the purpose of facilitating a discussion of the physical embodiments of the preferred arrangement, and

FIG. 7 is a schematic elevational view of a tandem rolling mill adapted to practice the rolling methods disclosed herein.

With reference to the drawings, FIGS. 1 and 2, there is shown therein a loop forming strip tensioning device **11** by which strip S passing from one unit to another, such as for example, from rolling mill **12** to rolling mill **13**, is deflected upward from the normal horizontal pass line defined between the mills to form a loop that may be varied considerably in height depending upon the slack between the mills and the limit of travel of the device **11**.

The device **11** comprises an idle tension roller **14** rotatably supported in suitable bearings at the outer end of an apron **15** which is supported in turn at its inner end upon a pivot **16** secured in bearings **17** conveniently affixed to the faces of the mill housing posts **18** and **19** of mill **12**. In the embodiment of the invention shown in FIGS. 1 and 2, the pivot **16** has been located adjacent to and slightly below the strip pass line, the distance from the pass line being equal to the radius of the tension roller **14**. This distance, of course, can be varied as conditions dictate without departing from the scope of the invention disclosed.

To each end of the pivot **16**, there is secured a strut **21** which is provided with a pivot **22** at the lower outer end. It will be observed that the apron **15** and strut **21** take the form of a bell crank which term will be used to refer to these elements hereafter. Below each of the struts **21** there is a second strut designated generally by numeral **23** comprising a cylinder assembly **24** from which extends its piston rod **25**, having at its outer end a clevis **26** threaded thereon and secured for pivotal movement to the pivot **22**.

As shown particularly in FIG. 2, the lower end of each which is provided with a pivot **22** at the lower outer end. of an arm **28** secured to a shaft **29** rotatably supported in bearings **31** secured to the foundation adjacent to the shoe plates of the mill. Also keyed to the shaft **29**, there is a lever **32** to the outer end of which there is pivotally secured a rod **33** which is threaded for a portion of its length at the upper end. The threaded end portion of the rod passes through a gear box **34**, as best seen in FIG. 1, in which the threads of the rod are engaged with a centrally threaded worm wheel which is engaged with a suitable worm rotated by a handwheel **35**. Since the threaded worm wheel is suitably supported within the gear box **34** to prevent its being displaced vertically when rotated, the threaded rod consequently will move up or down depending upon which direction the wheel **35** is rotated. On the shaft of the handwheel, there is a sprocket **36** over which passes an endless chain **37** which engages with a sprocket **38** of a counter **39** positioned adjacent to the handwheel **35**. On rotation of the handwheel **35**, the rod **33** will move up or down depending upon the direction of rotation and, consequently, the pivot **27**, due to the movement of the lever **32**, will also be moved to a new position. Since the cylinder **24** is not, at the time, under pressure the piston contained therein will freely move thus to change the effective length of the strut **23** to compensate for movement of the pivot **27**. Hence, no movement of the strut **21** takes place. Movement of the pivot **27** will, therefore, change the distance between an imaginary line, drawn between the two pivots **16** and **27**, and the pivot **22**, the point of juncture of the two struts. In order that the roller **14** will exert a constant tension on the strip when a constant pressure is introduced into the cylinder **24**, the distance between the aforementioned imaginary line and the pivot **22** must bear a constant relationship to the distance the strip is deflected away from the pass line by the roller **14**, which relationship is effected by properly proportioning the struts with respect to the distance between the mills, location of the tension roller **14** and the location of the pivots **16** and **27**.

For balancing the weight of the strip loop forming tensioning device and, if desired, also the weight of the strip against which the roller **14** bears, a piston cylinder assembly **41** is provided with the cylinder **42** thereof pivotally connected to a bracket **43** and the outer end of the piston rod **44** connected to the apron **15**. Although a separate stop may be used for the purpose, the piston cylinder assembly **41** serves as a stop for supporting the roller **14** and the assembly connected to the piston rod **44** at the lowest position determined by the final low position of the piston rod. The lowest position of the roller **14** is such that the upper surface thereof extends slightly above the horizontal pass line of the strip so that strip in passing thereover will have a slight loop in it even before the roller **14** is pivoted upward.

In FIGURE 3, there is shown an exemplary control system that will permit the tensioning device to be employed in one of three separate modes, namely as a constant strip tension exerting device, as a variable controlled strip tension exerting device to effect strip gauge control or as a strip tension measuring device in which in each of the modes of operation the result desired will be independent of the position of the looper roller. In an arrangement wherein only constant tension and tension metering is desired, the arrangement could be appreciably simplified. However, in order to afford a full and complete understanding of the merits of the tensioning device disclosed herein, a more comprehensive arrangement has been selected wherein a single system will effect the three separate modes of operation.

With reference then to FIGURE 3, there is shown schematically the rolling mills **12** and **13**, the novel tensioning device 11, including its roller 14, apron 15, pivot 16, cylinders 24 and 41 and the strip S extending between the mills, the lower surface of which is engaged by the roller 14. In the arrangement shown, a strip thickness measuring device 45 is provided on the delivery side of the mill 13 which in the form shown is an X-ray device, but which could be other types of apparatus, such as a mill load indicator unit or the like. The X-ray device 45 is electrically connected to summarizer amplifier 46 by electrical lines L_1 and L_2 to which also are connected lines L_3 and L_4 running from a potentiometer 47 having input lines L_5 and L_6 extending from a voltage source not shown. A voltmeter 50 is provided across lines L_3 and L_4 and serves to measure and indicate the voltage output of the potentiometer 47.

The amplifier 46 is connected electrically to a permanent magnetic unit 48 including a moving coil through lines L_7 and L_8 which is adapted to cooperate with an hydraulic proportioning control unit 49 (sometimes hereinafter referred to as an hydraulic regulator) which is, as are all the other components employed in the system, a commercially available unit, designed to convert a variable electrical input into a proportional hydraulic output. It is considered to be sufficient to designate that the unit 49 consists of a double acting cylinder 51 having a piston 52 and a rod 53, the rod thereof being connected and serving to actuate the spool element of a pressure regulating valve 54. The piston 52 is provided with two internal passageways, one communicating with the front and the other with the back thereof and wherein one of their ends terminates at the bottom of the piston into a common orifice 55. A pilot 56 is pivotally arranged to discharge fluid conducted thereto from a pump 57 into the orifice 55. Movement of the piston 52 is accomplished by causing the pilot 56 to pivot by means of an horizontal mechanical force created by the magnetic coil 48. This action effects a movement of the pressure regulator valve 54 in which case the pressurized fluid issuing from the valve is fed to a Bourbon tube 58 through piping 59 where the fluid pressure is converted into a proportional horizontal mechanical force that is applied to the right side of the pilot, so that when this pressure balances the pressure of the magnetic unit 48, the proper cylinder pressure will obtain and be so maintained at all times so long as there is no change in the voltage output of the amplifier 46.

The hydraulic medium for the main system is pumped from a sump 60 by a pump 61 and is delivered to the pressure regulator valve 54 through piping 62. The hydraulic output of the valve 54, as effected by the position of its center land 64 relative to the port 65, is delivered into piping 66 which communicates with a main control valve 67. The main control valve 67 is connected to the rear of cylinder 24 by piping 66*a* and a constant pressure is exerted in the cylinder 24 of the strip tensioning assembly 11. A pressure switch 66*b* is provided for a purpose to be explained hereinafter. As is customary in valve design, the spool of the main control valve 67, having lands 68 and 69 which cooperate with the ports 70 and 71 respectively is urged by a spring 72 in one direction and in the opposite direction by the fluid of an auxiliary valve 73, the intake fluid of which may be interrupted by a plunger 74 of a solenoid valve 75.

A valve 76 of a type similar to the valve 67 is connected by piping 77 to the pump 61 and by piping 79 to the front of the cylinder 24, whereby fluid under pressure can be admitted to the front of the cylinder for the purpose of lowering the roller 14. The spool of this valve is provided with three lands, namely 81, 82 and 83, which cooperate with ports 84, 85 and 86 respectively. The opposite axial movement of the spool is effected by a spring 87 and the fluid pressure of an auxiliary valve 88 which cooperates with a solenoid valve 89, both valves being similar in construction and operation to the valves 73 and 75.

A second voltmeter 91 is provided being connected to a hydraulic-electric conversion unit 92 located immediately adjacent to the rear of the cylinder 24 so that the pressure losses of the system can be readily determined whereby the potentiometer 47 can be adjusted to compensate for such losses as indicated by comparing the readings of the voltmeters 50 and 91. These voltmeters are, accordingly, calibrated in pounds of strip tension and, in addition, the meter 91 serves as the tension metering gauge and as an electrical transmitter, the function of which will be more fully explained hereinafter.

A brief description of the operation of the electric-hydraulic control system shown in FIG. 3 will now be given. Assuming that the strip tensioning device 11 is to be operated to effect a vernier correction in the longitudinal gauge variation of the strip, should the strip be off-gauge, an electrical impulse representing the error in the longitudinal strip gauge variation is introduced into the summarizing amplifier 46 through lines L_1 and L_2 from the X-ray gauge 45. The potentiometer 47 has, of course, previously been set at the desired tension value which results in a corresponding electrical impulse being fed to the amplifier through lines L_3 and L_4. The output of the amplifier, which represents a summation of the two aforesaid electrical impulses, is fed to the magnetic unit 48 and the vertical movement of its coil is converted into a horizontal force which acts on the one side of the balanced pivoted pilot 56 of the hydraulic regulator 49. As previously mentioned, the other side of the pilot 56 is subjected to the hydraulic pressure of the Bourdon tube 58 which is converted into a horizontal mechanical force. It will be observed that on the operation of the pump 61, the fluid in the piping 62 will pass through the pressure regulating valve 54 notwithstanding the position of the land 64 thereof, thereby constantly transmitting fluid to the hydraulic side of the pilot 56 through the piping 59.

Preliminary to causing fluid to be admitted to the rear of the cylinder 24, both solenoids 75 and 89 are caused to be energized, by suitable means not shown, whereby the spools of the valves 67 and 76 are forced hydraulically to the left so that the lands 82 and 83 of the valve 76 cover the ports 85 and 86 and the lands 68 and 69 of the valve 67 clear the ports 70 and 71. Consequently, fluid is caused to be admitted only to the rear of cylinder 24. The pressure will be regulated by the relative position of the land 64 with respect to the port 65 of the pressure regulator valve 54, which position is determined by the location of the piston 52 of the hydro-proportioning control unit 49. In this manner the hydraulic pressure admitted to the rear of the cylinder 24 is made directly proportional to the differential in the gauge variation, which pressure represents either the total or partial necessary correcting force which must be imposed upon the arms 21 of the strip tensioning unit 11. Whether or not this pressure is equal to the necessary correcting force will depend on the multiplying effect of the linkage system of the tension unit 11. As more fully explained hereinafter, the correcting pressure, while it may vary pursuant to the output of the amplifier 46, will not be affected by the varying positions of the roller 14. In other words, such pressure will be at all times directly proportional to the fluid pressure of the regulator valve 54.

When the strip tensioning device is to be used to impose a constant tension on the strip and not to correct for gauge variations, the potentiometer 47 is regulated until the reading of the voltmeter 50 corresponds to the desired tension value and, since there will be no strip thickness off-gauge signal from the X-ray unit 45, the amplifier 46 will transmit an impulse proportional to the voltmeter's reading and the proportioning control unit 49 will in turn cause the proper pressure to be admitted to the rear of the cylinder 24. The other valves and elements will assume the same positions and functions in the same manner as in the case where the tensioning device was employed to correct for gauge inaccuracy, as previously discussed.

In the event the strip tensioning device is to be used as a tension metering gauge for instantaneously and accurately determining the magnitude of tension being imposed on the strip as it passes between the mills, the solenoid **75** is de-energized to permit plunger **74** thereof to interrupt the flow of fluid into the right side of the valve **67** so that the spring **72** thereof will force the spool to the right, as one views FIG. 3, and cause the land **68** to cover the input port **71** whereby fluid in the cylinder **24** is prevented from escaping through the valve **67**. The position of the spool of the valve **76** remains unchanged and as previously mentioned covers the ports **85** and **86** so that no fluid can be admitted to the front of the cylinder **24** nor escape from the opposite end.

As shown in FIG. 3, the necessary drain ports and piping are provided in order to complete the hydraulic circuit and facilitate the lowering of the roller **14** on the reverse operation of the cylinder **24**. It is considered to be sufficient to point out that the piston of the cylinder is retracted to lower the roller **14** by de-energizing both solenoids **75** and **89** thereby effecting movement of the lands **82** and **83** of the valve **76** and the lands **68** and **69** of valve **67** to open the ports **85** and **86** in the former and to close the port **71** in the latter. Pressure will then be admitted to the front of the cylinder through piping **79** and permitted to escape from the rear of the cylinder **24** through drain piping connected to the valve **76**.

The hydraulic-electrical conversion unit **92**, in addition to being connected to the voltmeter **91**, may be connected to a speed control unit **95**, which cooperates with the mill motor **93** whereby the mill speed will be regulated to adjust the tension of the strip.

For controlling at all times the extent of the loop between the mills **12** and **13**, an electrical control system for the motor **93** of the mill **13** is provided. This system, as shown specifically in FIG. 3, in conjunction with the mill motor **93**, consists of a generator **94** connected thereto by lines L_9 and L_{10}. The generator is in turn electrically connected to a control unit **95** and a speed regulator **96**, the regulator being connected to a potentiometer **97**. As shown, the potentiometer is actuated by rotation of the shaft **16** as the roller **14** is raised or lowered.

In the event the strip loop should rapidly grow, i.e., become slack and deflect away from the roller **14** when the strip tensioning device is being employed in its tension metering mode, the roller under normal conditions will not rise to continue to engage the strip since the cylinder is blocked. To provide for this eventuality, a pressure switch **66***b* is connected into the piping **66***a* and is designed to operate at a preselected drop in pressure in the piping **66***a*. The pressure switch **66***b* is electrically connected to the solenoid valve **75** and causes the energization of the solenoid when a low pressure condition occurs thereby causing the valve **67** to open to admit fluid into the cylinder **24** to raise the roller **14** in pursuit of the strip. When the roller **14** engages the strip, the tensioning unit will operate in its constant tension mode. Immediately on the raising of the roller **14**, the potentiometer **97** will come into operation and effect a speed adjustment of the mill motor **93** thereby reducing the strip loop to the optimum height. A reconversion of the tension unit for metering is brought about by the actuation of a limit switch **98** connected also to the shaft **16** and adapted to be actuated when the roller **14** is in a predetermined position at which time the solenoid **75** is de-energized to close the valve **67**.

It will be appreciated that the potentiometer **97** in the preferred form will be operative also in the constant tension and gauge control modes. Although, as mentioned heretofore, a substantial constant tension can be imposed upon the strip by introducing a constant pressure to the cylinder **24** irrespective of the height that the strip may be deflected, for operational convenience it is desirable to maintain the height of the loop relatively constant and preferably midway between the extreme upper and lower positions.

Reference is now made to the theory of that phase of the present invention that has to do with the tensioning device designed to exert a substantial constant tension on the strip, notwithstanding the position of the tensioning roller **14** within the limits of its range of operation. In prior designs of strip tensioning apparatus, it was appreciated that a constant tension could be obtained if the arms that supported the tensioning roller were maintained at all times parallel or substantially parallel to the path of the strip, with the further requirements that the roller be limited to a substantial vertical movement and that the pressure of a constant pressure means be imposed directly upon and in a direction axially of one of the roller arms. An arrangement incorporating this technology, while sound in theory, was found infeasible in practice because in order to satisfy the aforesaid prerequisites, such as device would be both uneconomical to manufacture as well as impractical.

Basic geometrical principles show that, if a strip engaging roller is arranged midway between two units wherein the roller forms the junction between two extensible struts connected thereto and comprising piston cylinder assemblies, the other ends of the struts being located on the centerlines of the respective units, thus constraining the motion of the roller to a vertical path during which motion the struts remain always parallel to the strip, the tension induced on the strip on the actuation of the assemblies will, for all positions of the roller, always be equal to the compression forces in the struts. Conversely a force imposed in the same geometric manner upon the roller by the strip will be proportionally transmitted to the arms of the tensioning device. By using the same geometrical analysis, it is self-evident that any substantial variation in the geometry will produce a strip tension that will radically vary as the height of the tensioning roller varies. Stated in its simplest terms, the reason for this result is that the constant relation between the angles is disrupted.

As heretofore mentioned, it is one of the principal features of this invention to provide a strip tensioning device wherein the critical limitations of the prior design, namely that the arms of the looper roller must be maintained substantially parallel to the path of the strip, may be disregarded as well as the requirement that the force exerted on the looper assembly must be imposed directly upon the roller. Moreover, the necessity of the roller being moved vertically is lessened so that greater freedom of design is achieved and the inertia is substantially reduced.

The unique result of the strip tensioning device as disclosed herein was achieved by the discovery that a mechanical linkage system can be provided that will provide a substantially constant strip tension and wherein there is no requirement that the arms supporting and actuating the roller must be arranged parallel to the strip, that the force be imposed directly upon the roller or that the roller must be confined to move in a substantial vertical path.

It must be appreciated that in the parallel strip arm arrangement of the prior art the corresponding angles formed by the strip and the strip's pass line, and the angles formed by arms and a plane parallel to the pass line connecting the pivot points of the arms were equal or substantially equal notwithstanding the positions of the looper. Conversely, should corresponding angles be not maintained equal, the tension imposed on the strip would vary and be indeterminate. The present inventors have discovered that notwithstanding this fact a directly proportional relationship between the strip tension and the force exerted to actuate the device may be obtained by reason of the fact the various angles formed by the strip and the pass line and the linkage arms will bear compensating relationship to each other whereby a substantially constant tension is imposed on the strip even though the range of movement of the tension roller is quite extensive. This relationship is expressed algebraically as

$$\frac{\left[\frac{R2}{R1}\right]\sin\,[a'+b']}{2\cos\left[a'-\frac{(a-b)}{2}\right]\quad\left[\frac{a+b}{2}\right]}\approx\text{constant}$$

in which the various quantities are part of the geometry formed by an arrangement wherein for a given distance between two succeeding mills, two pivot points are selected, one on which a bell crank is mounted and to one end of which a tension roller is secured. To the other end of the bell crank a pressure means is connected, in which construction the other end of the pressure means is connected to the other pivot and constitutes one of the links of the system and wherein as the strip varies in height, the constant relationship is maintained.

The aforesaid relationship can be expressed in several other ways, as for example, in terms of the relationship that the torque developed by the linkage system has to the strip tension and the portion of the arm that carries the tension roller. The algebraical expression for the relationship is

$$\frac{T_L}{\cos\left[a'-\frac{a-b}{2}\right]\sin\left[\frac{a+b}{2}\right]}\approx\text{constant}$$

where T_L is the torque about point "0" (see FIG. 5), T is the strip tension and the angles a and b are, as indicated above, and a' is the angle between the arm of the tension roller and the pass line.

For the derivation of the foregoing equation, reference is made to the force diagram shown in FIG. 4 and the free body diagram of the bell crank shown in FIG. 5. With reference first to the force diagram wherein T=the strip tension and F=the resultant force on the roller 14:

$$C=a+b$$

$$2A+(a+b)=180$$

$$\therefore A=90-\left[\frac{a+b}{2}\right]$$

$$B=90-a$$

$$D=A-B=90-\left[\frac{a+b}{2}\right]-90+a=\frac{a-b}{2}$$

$$F=2T\cos\left[90-\frac{(a+b)}{2}\right]=2T\sin\left[\frac{a+b}{2}\right]$$

Equation No. 1

With reference now to the free body diagram shown in FIG. 5, there is shown applied to the bell crank having arms R1 and R2 the resultant strip force F at its angular position as determined from Equation No. 1 and upon which also has been imposed the cylinder force P at its point of application.

Taking moments about point "0":

$$FR_1\sin\left\{90-\left[a'+\frac{(a-b)}{2}\right]\right\}=PR_2\sin\,[a'+b']$$

$$F=\frac{P\left[\frac{R2}{R1}\right]\sin\,[a'+b']}{\sin\left\{90-\left[a'+\frac{(a-b)}{2}\right]\right\}}=\frac{P\left[\frac{R2}{R1}\right]\sin\,[a'+b']}{\cos\left[a'-\frac{(a-b)}{2}\right]}$$

Equation No. 2

Equating 1 and 2:

$$2T\sin\left[\frac{a+b}{2}\right]=\frac{P\left[\frac{R2}{R1}\right]\sin\,[a'+b']}{\cos\left[a'-\frac{(a-b)}{2}\right]}$$

or

$$T/P=\frac{\left[\frac{R2}{R1}\right]\sin\,[a'+b']}{2\cos\left[a'-\frac{(a-b)}{2}\right]\sin\left[\frac{a+b}{2}\right]}$$

Equation No. 3

For illustrative purposes, the constancy of relationships of tension to pressure represented by the above equation can be exemplified by assuming actual dimensions and for which purpose reference is made to the force diagram shown in FIG. 6. In order to afford a complete understanding of the theory of the constant relationship two different physical embodiments have been selected, one wherein the arms of the bell crank are equal, designated hereinafter as Case No. 1 and the other wherein the arms of the bell crank are not equal, designated hereinafter as Case No. 2. With respect to each case, the tension value for three different positions of the tension roller, namely low, intermediate and high will be computed.

CASE NO. 1

$L=222''$
$l'=100''$
$R_1=R_2=43''$
$e=65''$
$D=12''$
$E=6''$

Position No. 1

$H=2''$

under these conditions:

$a=.0185$ radians
$b=.0175$ radians
$a'=.0465$ radians
$b'=.0350$ radians

substituting in Equation No. 3:

$$T/P=\frac{\left(\frac{43}{43}\right)\sin\,(.0465+.0350)}{2\cos\left[.0465-\frac{.0185-.0175}{2}\right]\sin\left(\frac{.0185+.0175}{2}\right)}=$$

$$\frac{\left(\frac{43}{43}\right)(.0815)}{(1.998)\,(.018)}=2.26$$

Position No. 2

$h=H=10''$

under these conditions:

$a=.0933$ radians
$b=.0866$ radians
$a'=.2347$ radians
$b'=.1702$ radians

substituting in Equation No. 3:

$$T/P=\frac{\left(\frac{43}{43}\right)\sin\,(.2347+.1702)}{2\cos\left(.2347-\frac{.0933-.0866}{2}\right)\sin\left(\frac{.0933+.0866}{2}\right)}=$$

$$\frac{\left(\frac{43}{43}\right)(.3939)}{(1.947)\,(.0898)}=2.25$$

Position No. 3

$H=22''$

under these conditions:

$a=.2125$ radians
$b=.1812$ radians
$a'=.5371$ radians
$b'=.3511$ radians

substituting in Equation No. 3:

$$T/P=\frac{\left(\frac{43}{43}\right)\sin\ (.5371+.3511)}{2\cos\left[.5371-\frac{.2125-.1812}{2}\right]\sin\left(\frac{.2125+.1812}{2}\right)}=\frac{\left(\frac{43}{43}\right)(.7760)}{(1.735)\ (.1956)}=2.29$$

The maximum amount of variation will then be:

Maximum amount of variation=

$$\frac{1}{2}\,\frac{\text{max. value}-\text{min. value}}{\text{average value}}=\frac{1}{2}\,\frac{2.29-2.25}{2.27}=\frac{.02}{2.27}=.0088$$

In the operation of this tension unit, it will be observed that the maximum amount of variation that may be experienced is only plus or minus .88 percent.

CASE NO. 2

$L=222''$
$l'=100''$
$R_1=43''$
$R_2=40''$
$e=65''$
$D=12''$
$E=6''$

Position No. 1

$H=2''$

under these conditions:

$a=.0185$ radians
$b=.0175$ radians
$a'=.0465$ radians
$b'=.0310$ radians

substituting in Equation No. 3:

$$T/P=\frac{\left(\frac{40}{43}\right)\sin\ (.0465+.0310)}{2\cos\left[.0465-\frac{.0185-.0175}{2}\right]\sin\left(\frac{.0185+.0175}{2}\right)}=\frac{\left(\frac{40}{43}\right)(.0774)}{(1.998)\ (.018)}=2.00$$

Position No. 2

$H=10''$

under these conditions:

$a=.0933$ radians
$b=.0866$ radians
$a'=.2347$ radians
$b'=.1511$ radians

substituting in Equation No. 3:

$$T/P=\frac{\left(\frac{40}{43}\right)\sin\ (.2347+.1511)}{2\cos\left[.2347-\frac{.0933-.0866}{2}\right]\sin\left(\frac{.0933+.0866}{2}\right)}=\frac{\left(\frac{40}{43}\right)(.3763)}{(1.947)\ (.0898)}=2.00$$

Position No. 3

$H=22''$

under these conditions:

$a=.2125$ radians
$b=.1812$ radians
$a'=.5371$ radians
$b'=.3022$ radians

substituting in Equation No. 3:

$$T/P=\frac{\left(\frac{40}{43}\right)\sin\ (.5371+.3022)}{2\cos\left[.5371-\frac{.2125-.1812}{2}\right]\sin\left(\frac{.2125+.1812}{2}\right)}=\frac{\left(\frac{40}{43}\right)(.7442)}{(1.734)\ (.1956)}=2.04$$

The maximum amount of variation will then be:

Maximum amount of variation=

$$\frac{1}{2}\,\frac{\text{max. value}-\text{min. value}}{\text{average value}}=\frac{1}{2}\,\frac{2.04-2.00}{2.02}=\frac{.02}{2.02}=.0099\approx.01$$

In the operation of this tension unit, it will be observed that the maximum amount of variation experienced is only plus or minus 1.00 percent.

It is another novel feature of this invention to employ two or more of the novel strip tensioning devices herein disclosed in a continuous processing rolling mill, whereby they cooperate to provide uniformity of strip gauge longitudinally. With reference to FIG. 7, there is shown a finishing train of a tandem hot strip mill consisting of succeeding roll stands, namely 101, 102, 103, 104, 105 and 106, in which at the delivery side of the first five stands strip tensioning devices 107, 108, 109, 111 and 112 are arranged, each of which can be operated in one of the three modes described heretofore, i.e., as a constant tension exerting means, a variable controlled strip tension exerting device and as a tension metering means, respectively.

In one method of operating the mill, the strip tension devices 107, 108 and 109 are actuated to exert a constant tension on the strip as it passes between the mills 101 and 102, 102 and 103, and 103 and 104. The last two tension units 111 and 112 are employed as gauge control devices and, accordingly, X-ray strip thickness gauges 113 and 114 are provided, the gauge 113 co-operating with the strip tension device 111 and the gauge 114 with the strip tension device 112. These units are adapted to function in the manner heretofore discussed.

It will be appreciated that by employing the strip tensioning device to exert a constant tension in all or substantially all the stands, the tension in such stands at all times during the rolling process will be directly proportional to the predetermined optimum presure of the cylinders 24 whereby over tensioning of the strip will be eliminated and, accordingly, the variation in strip thickness and width incident to such excessive forces are avoided. In addition, one or more of the strip tensioning units may be operated to effect gauge control by imposing a correction force that will, in effect, be a vernier correction in the longitudinal gauge variation, the net result of the combined applications of the modes being to effect a more uniform rolled strip.

A method of rolling in which all the tensioning devices are employed to impose a variable controlled strip tension to effect strip gauge control in all or substantially all of the stands may be utilized.

In other applications of the mill, it may be desirable to apply a constant tension on the strip passing through the several former stands and employ the strip tension devices in the last one or more stands as tension metering gauges in which similar results may be realized. This rolling mill procedure finds usefulness in avoiding excessive tensions when the last mill stands have provisions for controlling the variations in strip thickness by adjusting the motor speeds to impose a gauge correcting tension on the strip or by changing the roll setting to accomplish the same end, both systems receiving a correctional signal from an X-ray gauge or equivalent device. In this application, the signal from the strip tension metering gauge will prevent the mill from applying excessive tensions.

In accordance with the provisions of the patent statutes, we have explained the principle and operation of our invention and have illustrated and described what we consider to represent the best embodiment thereof. However, we desire to have it understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically illustrated and described.

We claim:

1. A device for imposing a tension upon strip defining a pass line between two units, comprising a first pivot, a roller, an arm connected to said roller and connected to and adapted to be angularly displaceable about said pivot for causing the roller to engage one face of and force said strip away from said pass line at varying distances thereby to impose a tension upon said strip, the ratio between the strip deflecting force imposed by said roller and the tension developed in said strip by said force varying with the distances said strip is displaced away from said pass line, a first strut rigidly connected at said first pivot to and for displacing said arm, a second pivot spaced from said first pivot and a force actuated extensible strut connected at one end to said second pivot and at its opposite end to the other end of said first strut, said arm, struts, pivots and roller being operatively arranged with respect to each other, to the distance between the units and to the varying distances of the strip relative to said pass line so that the ratio between the force exerted by said roller on said strip and the force in said extensible strut bears a substantial constant relationship to the varying ratio between said strip deflecting force and strip tension, whereby the strip tension will be maintained substantially constant irrespective of the distance said strip is displaced away from said pass line, as long as the force in the extensible strut is held substantially constant.

2. A device for imposing a tension upon strip defining a pass line between two units according to claim 1 in which the arm is connected between said roller and said first pivot and so positioned with respect to said strip that an imaginary line passing through said pivot and the center of said roller bears a non-parallel relationship to the strip when the strip is deflected away from said pass line.

3. A device for imposing a tension upon strip between two units according to claim 2 in which said arm is connected to said roller and said first pivot, and said first strut is angularly disposed about said first pivot relative to said arm.

4. A device for imposing a tension upon strip between two units according to claim 1 in which said arm is connected to said roller and said first pivot, and means connected to said extensible strut for applying a constant force in a direction to extend said extensible strut.

5. A device for imposing a substantially constant tension upon strip between two units comprising a first pivot, a roller, an arm connected to said roller and adapted to be angularly displaced about said pivot for causing said roller to engage one face of and imposing a tension upon said strip, a first strut connected at one end to said arm at said pivot, a second pivot, one of said pivots being adjustable relative to the other, a force actuated extensible strut connected at one end to said second pivot and at its opposite end to the other end of said first strut, and means connected to and for selectively positioning said adjustable pivot.

6. A device for imposing a tension upon a continuous strip defining a pass line between two units comprising a tension roller adapted to bear against one face of said strip, a fixed pivot adjacent to said pass line, a member connecting said roller and said fixed pivot, a first strut connected at one end to said member and angularly displaced about said fixed pivot relative to said member, an adjustable pivot remote from said pass line, an extensible strut connected at one end to said adjustable pivot and at its opposite end pivotally connected to the other end of said first strut, and means connected to and for selectively displacing said adjustable pivot with respect to said fixed pivot thereby to establish a desired relationship in space between said struts and said roller.

7. A device for imposing a tension upon a strip defining when undeflected a pass line between two units, the deflected strip and the pass line forming a triangle, of which the pass line constitutes the sides of two acute angles, comprising a first pivot, an arm connected to and adapted to be angularly displaced about said pivot, a roller connected to the other end of said arm for engaging one face of and deflecting said strip away from said pass line thereby to impose a tension upon said strip, a first strut having one end connected to said arm, a second pivot and a force actuated extensible strut connected at one end to said second pivot and at its opposite end to the other end of said first strut, said arm, struts, pivots and roller being operatively arranged with respect to each other, to the distance between the units and to the position of the strip as deflected that a substantially constant value is obtained for the following expression:

$$\frac{\left[\frac{R2}{R1}\right]\sin\,[a'+b']}{2\cos\left[a'-\frac{(a-b)}{2}\right]\sin\left[\frac{a+b}{2}\right]}$$

wherein R1 is the length of the arm, R2 is the length of the first strut, a and b are the acute angles formed by the deflected strip and pass line and a' and b' are the acute angles formed by the two struts and an imaginary line passing through the two pivots.

8. A device for imposing tension upon a strip defining, when undeflected, a pass line between two succeeding units, the deflected strip and the pass line forming a triangle of which the pass line constitutes one of the sides of two acute angles, comprising a movable member adapted to be engaged with the strip at varying heights of loops and imposed a force thereon, the ratio between the strip deflecting force imposed by said movable member and the tension employed in said strip by said force varying with the distances said strip is displaced away from said pass line, a linkage system comprising at least two connected links, one at least being a variable length link, one end of each link being connected to one of two spaced-apart pivot points, said movable member and one of said links being connected together at one of said pivot points, at least one of said links being substantially non-parallel to the strip at any position of said movable member, means for generating a mechanical effort connected to said linkage system, said movable member and said linkage system being connected together and operatively arranged with respect to each other, to the distance between the units and to the position of the strip as deflected, such that the ratio between the force exerted by said movable member on said strip and the mechanical effort in said linkage system bears a substantial constant relationship to the varying ratio between said deflecting force and strip tension, whereby the strip tension will be maintained substantially constant, irrespective of the distance said strip is displaced away from said pass line, as long as the mechanical effort in said linkage system is held substantially constant.

9. A device for measuring or imposing tension upon a strip defining, when undeflected, a pass line between two succeeding rolling mills, the deflected strip and the pass line forming a triangle of which the pass line constitutes one of the sides of two acute angles, comprising a movable member adapted to be engaged with the strip at varying heights of loops, a linkage system com-

prising at least two connected links, one at least being a variable length link, one end of each link being connected to one of two spaced-apart pivot points, said movable member and one of said links being connected together at one of said pivot points, at least one of said links being substantially non-parallel to the strip at any position of said movable member, a force generating means connected to said linkage system, said movable member and said linkage system being connected together and operatively arranged with respect to each other, to the distance between the rolling mills and to the position of the strip as deflected, such that a substantially constant value is obtained for the following expression:

$$\frac{\sin(a'+b')}{\cos\left[a'-\frac{(a-b)}{2}\right]\cdot\sin\left[\frac{(a+b)}{2}\right]}$$

wherein a and b are acute angles formed by the deflected strip and said pass line, and a' and b' are acute angles formed by the two links and an imaginary line passing through said two pivot points.

10. A device for measuring or imposing tension upon a strip defining, when undeflected, a pass line between two succeeding rolling mills, the deflected strip and the pass line forming a triangle of which the pass line constitutes one of the sides of two acute angles, comprising a first pivot, a movable member, an arm connected to said member and adapted to be angularly displaceable about said first pivot for causing said member to engage one face of and force said strip away from said pass line at varying distances thereby to impose a tension upon said strip, a linkage system comprising at least two connected links, one at least being a variable length link and one end of each link being connected to second and third spaced-apart pivot points, said movable member and one of said links being connected together at one of said pivot points, at least one of said links being substantially non-parallel to the strip at any position of said movable member, a mechanical effort generating means connected to said linkage system, said movable member and said linkage system being connected together and operatively arranged with respect to each other, to the distance between the rolling mills and to the position of the strip as deflected, such that a substantially constant value is obtained for the following expression:

$$\frac{T_L}{\cos\left[a'-\frac{a-b}{2}\right]\cdot\sin\left[\frac{a+b}{2}\right]}$$

wherein T_L is the torque generated about said first pivot point of said linkage system, a and b are acute angles formed by the deflected strip and said pass line and a' is an acute angle formed by a line parallel to said pass line and a line passing through said movable member and said pivot point.

11. A device for engaging a strip passing between two succeeding rolling mills adapted to be selectively employed to impose a constant tension on said strip or a variable tension to effect gauge control, or to measure the magnitude of the tension on said strip, comprising a movable member adapted to engage and from a loop in said strip of varying heights, force generating means, a linkage system connecting said member to said force generating means and so arranged and disposed that a direct, substantially constant, relationship is maintained with respect to the tension imposed upon said strip and the force applied thereto irrespective of the position of said member, a force gauge associated with said force generating means for measuring the force within said force generating means, a strip thickness measuring device associated with said force generating means, control means associated with said force generating means and said force gauge and said strip thickness measuring device, adapted to selectively effect an exerting of a constant force over the total travel of said member, or a variable force, or a measuring of the force within said force generating means, and means associated with said control means for varying the force supplied in proportion to the degree of gauge control desired.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,169,420 February 16, 1965

Morris D. Stone et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 4, line 4, strike out "which is provided with a pivot 22 at the lower outer end." and insert instead -- cylinder 24 is mounted on a pivot 27 provided at the end --; column 5, line 39, for "Bourbon" read -- Bourdon --; column 9, line 6, insert -- sin --, between the two sets of brackets below the division line; column 16, line 12, after "said" insert -- first --; line 18, for "from" read -- form --.

Signed and sealed this 3rd day of August 1965.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents