Jan. 30, 1962 N. H. POLAKOWSKI 3,018,676

APPARATUS FOR ROLLING STRIP METAL

Filed Dec. 31, 1956 4 Sheets-Sheet 1

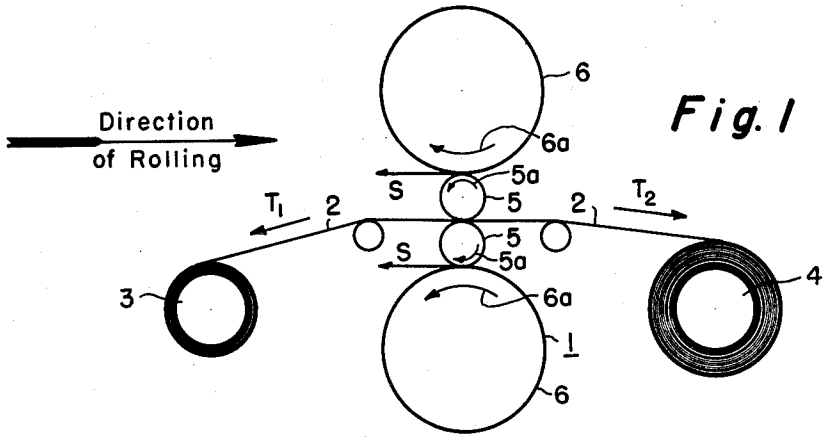


Fig. 1

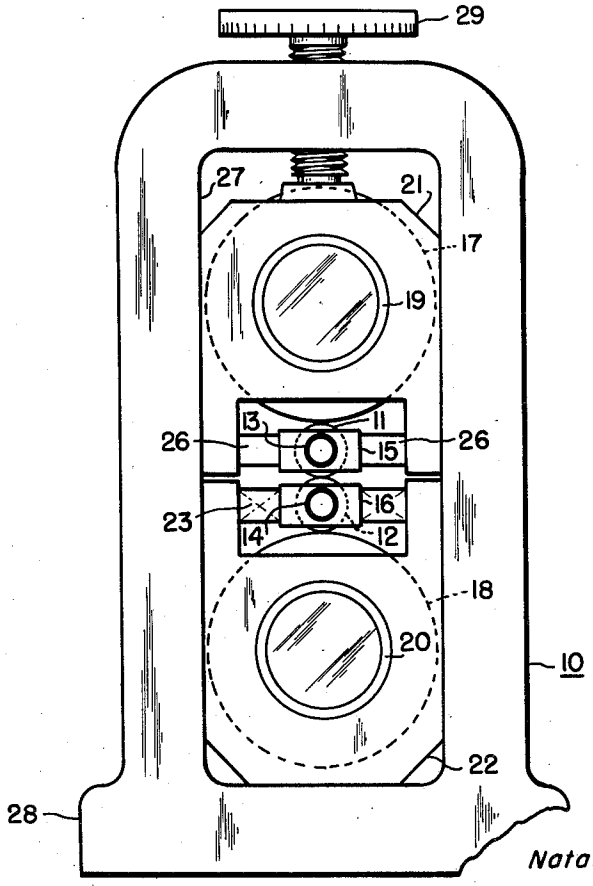


Fig. 2

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Filed Dec. 31, 1956 4 Sheets-Sheet 2

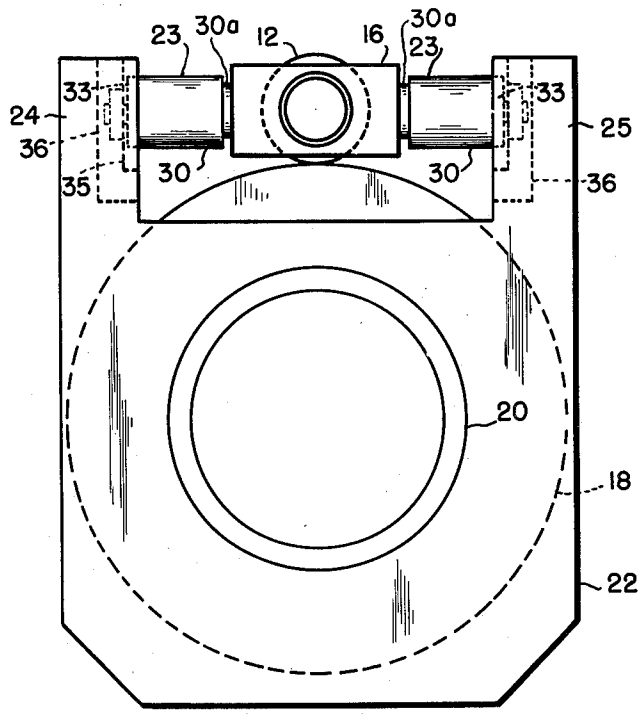


Fig. 3

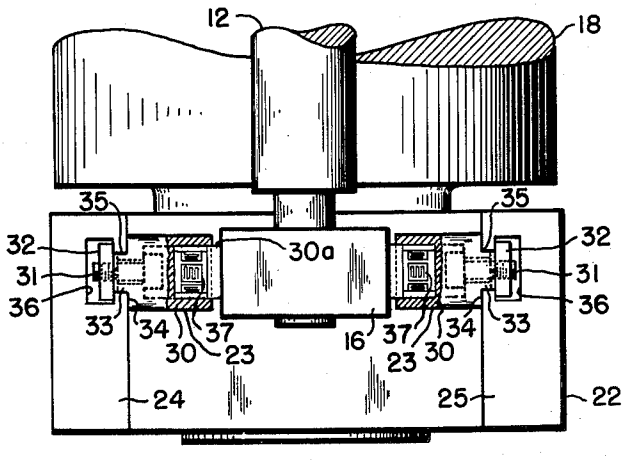


Fig. 4

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APPARATUS FOR ROLLING STRIP METAL

Filed Dec. 31, 1956 4 Sheets-Sheet 3

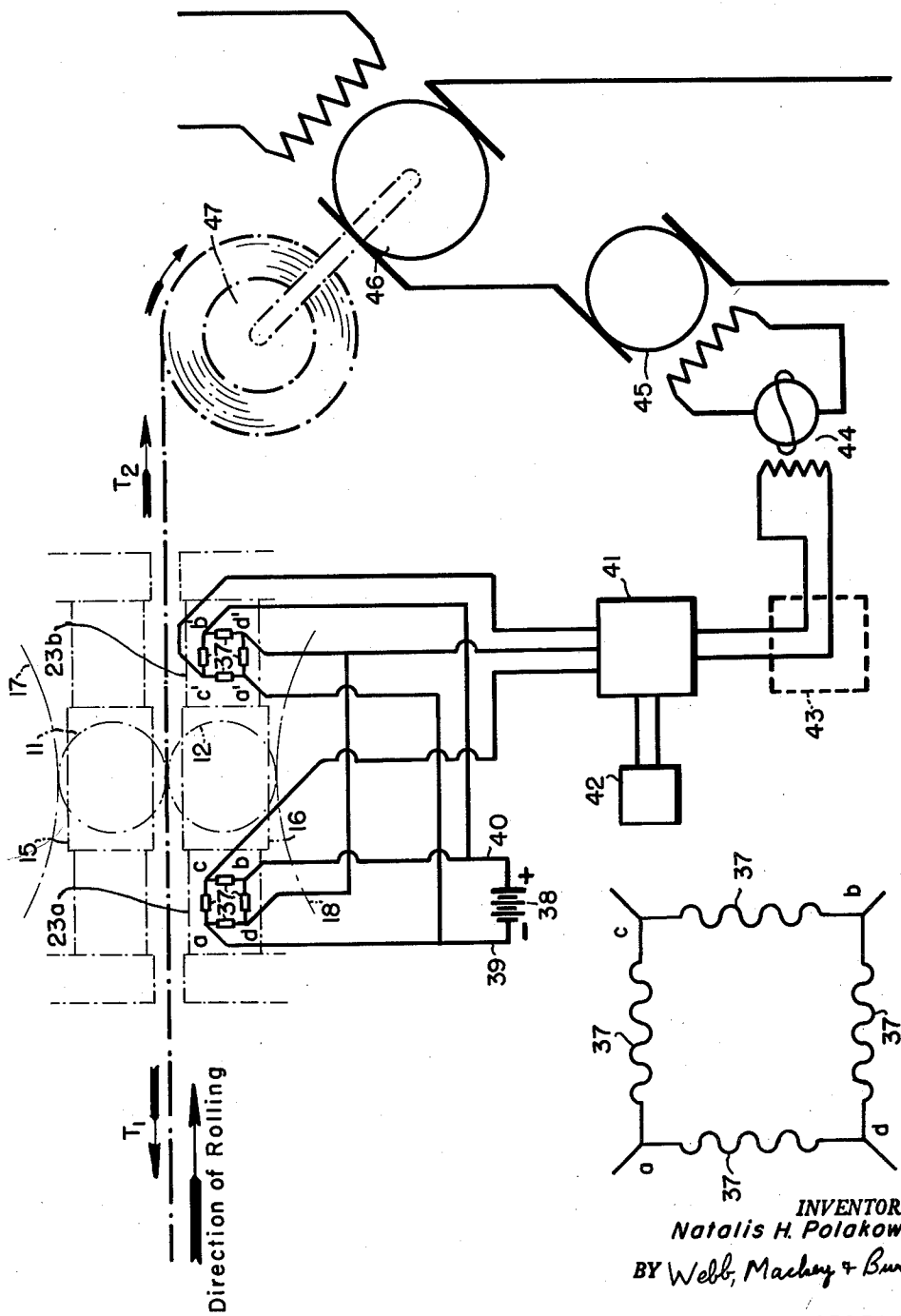


Fig. 5

Fig. 6

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APPARATUS FOR ROLLING STRIP METAL

Filed Dec. 31, 1956 4 Sheets-Sheet 4

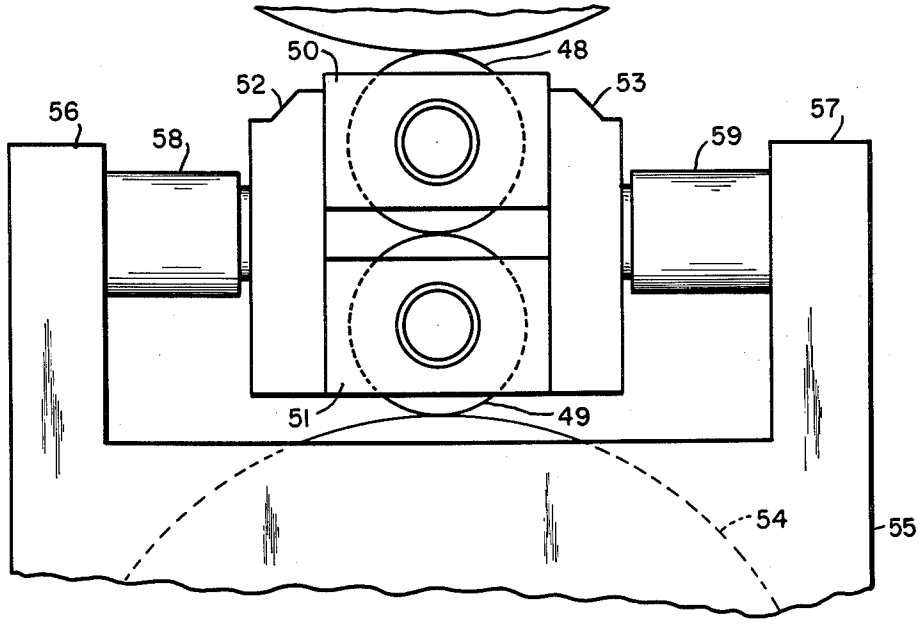


Fig. 7

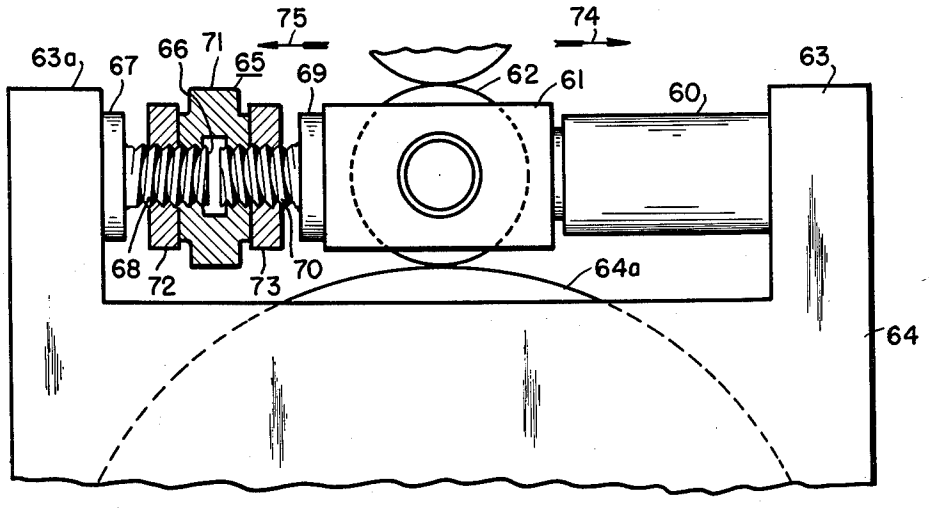


Fig. 8

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3,018,676

APPARATUS FOR ROLLING STRIP METAL

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3 Claims. (Cl. 80—32)

This invention relates generally to rolling metal strip, sheet and strip sheet, and more particularly to apparatus for cold rolling metal into thin strip, thin sheet, or foil.

Metal strip and sheet are rolled on various types of rolling mills, including 2-high mills, 3-high mills, 4-high mills having driven work rolls, cluster mills, and so-called Sendzimir mills. In recent years, a 4-high mill having driven back-up rolls has proved superior to other types of rolling mills heretofore employed. Among the advantages of the 4-high driven back-up roll mill are:

(1) Small diameter work rolls with the diameter of the roll body being below the minimum practicable diameter of work rolls on 4-high mills with driven work rolls. Use of such small work rolls on the 4-high driven back-up mills is made possible by driving the backing rolls through conventional mill drives with the backing rolls driving the small work rolls through frictional engagement therewith.

(2) Ability to roll strip economically, efficiently, and without intermediate anneals to much lighter final gauges than is possible with larger diameter work rolls such as those employed on the driven work roll 4-high mills.

(3) Use of work rolls which need not have identical diameter.

(4) Easy and efficient work roll changes.

(5) Use of work rolls made from tungsten carbide which has excellent wearing properties and which greatly reduces roll flattening.

(6) Work rolls free from high torsional stresses during rolling of strip metal.

Since the work rolls in the 4-high driven back-up roll mill are subject to deflection in a horizontal plane, the mill has an inherent weakness which presents serious problems when utilizing it to its greatest advantage, namely, when rolling wide widths to thin gauges. For this reason, the work rolls of the mill have a barrel length to diameter ratio of about 10 to 1 or less although a ratio of 15 to 1 or 20 to 1 would be more advantageous.

In FIGURE 1 of the accompanying drawings, there is shown a schematic diagram of a 4-high driven back-up roll mill 1 threaded with metal strip 2 and having on each side thereof a reel. Reel 3 functions as a pay-off or feed reel and reel 4 functions as a winding reel. The strip 2 is uncoiled under a tension force T_1 from the pay-off or feed reel 3 and then is delivered to the mill 1 where it is reduced in thickness by the work rolls 5. The winding reel 4 coils the reduced strip under a tension T_2. Assuming that both the back tension T_1 and the forward tension T_2 are zero, the total power required to deform plastically the strip is supplied through the back-up rolls 6 to the work rolls 5. Arrows 6*a* show the direction of rotation of the backing rolls 6 and arrows 5*a* show the direction of rotation of the work rolls 5. Rotation of the work rolls against resistance of the metal strip to deformation is enforced by horizontally acting tangent friction forces S exerted by the driven backing rolls 6. The S forces act in a direction opposite to that of strip travel and induce stresses in the work rolls 5. For a specific material and a constant draft, these stresses increase with increasing strip width and decreasing work roll diameter. Increase of the stresses S results from the fact that rolling torque has an approximate linear relationship to work roll diameter, whereas roll strength varies

with the cube of the roll diameter. A gradual reduction of the work roll diameter unavoidably brings about a situation where deflection of the laterally unsupported work rolls becomes excessive, thereby adversely affecting the shape of the strip or generating excessive bending stresses which tend to break the work rolls.

The presence of back tension T_1 in the strip increases this deflection of the work rolls in their horizontal plane. On the other hand, the forward tension T_2 opposes the deflection in the horizontal plane due to both S and T_1. Thus, the presence of forward tension is highly desirable for it neutralizes the bending stresses of the work rolls in 4-high driven back-up roll mills. Where the horizontal forces in a 4-high driven back-up roll mill have the following relationship: $2S+T_1=T_2$, the work rolls themselves are free from bending stresses which tend to affect the shape of the strip and/or tend to fracture the work rolls themselves.

In rolling operations on the 4-high driven back-up roll mills, it is practically impossible to obtain and maintain a relationship between the bending forces where $2S+T_1=T_2$ with satisfactory results by manual adjustment of the mill motor and reel motors with conventional measuring and control devices normally present on the mills. Besides, if the mill operator were to attempt to manually adjust those motors, he would be unable to satisfactorily perform his normal duties during regular mill operation. Hence, it is highly desirable that the 4-high driven back-up roll mills have a device for continually and automatically balancing the horizontal force components of the work rolls and thereby reduce, or even eliminate, the dangerous horizontal bending stresses in the work rolls.

Heretofore, others have attempted to solve this problem of reducing, if not eliminating, horizontal bending forces in the work rolls. However, their efforts were unsuccessful because the devices employed introduced to the mill stand various elements and accessories which reduced accessibility to the roll pass and to the strip adjacent the roll pass, thereby rendering threading of the mill difficult. In addition, these devices rendered it extremely difficult to remove cobbles in the strip and they were exposed to serious damage when strip breakage occurred. Also, the previously proposed devices required rather excessive alterations to the mill for their installation, were bulky, expensive, and complicated.

My invention provides an apparatus for automatically balancing the horizontal forces acting upon the work roll of a 4-high driven back-up roll mill without adding to the mill any superstructure or apparatus which impairs accessibility to the work rolls or which renders difficult threading of the material through the mill. In addition, my invention does not add to the mill stand any elements which are subject to damage or breakage when the strip tears. Specifically, my invention is designed for use in a driven back-up roll mill having a stand which mounts a pair of work rolls and a backing roll for each work roll with the stand having a receptacle on each side thereof for receiving the ends of the work rolls and of the backing rolls. The mill has in addition a means on one side of the stand for winding up the strip material rolled on the mill and for applying a forward tension to the material. My invention comprises the combination of a member responsive to the forces which tend to deflect the work roll in substantially the horizontal plane. This member is disposed substantially adjacent an end of a work roll in a receptacle of the stand, is interposed between the work roll and a side of the receptacle and is arranged therein to sense the forces which tend to deflect the work roll in substantially a horizontal plane. Means connect the member to cooperating means which control the operation of the means for winding up the

strip material and applying a forward tension thereto so that the winding and tension means increases and decreases the amount of forward tension applied to the strip in accordance with the direction the work roll tends to deflect in substantially a horizontal plane.

In FIGURES 2–6 of the accompanying drawings, I have shown preferred embodiments of my invention, in which:

FIGURE 2 is a side elevational view of a rolling mill equipped with my invention;

FIGURE 3 is an enlarged side view of the assembly of the lower backing roll chock and of the lower work roll chock of FIGURE 2;

FIGURE 4 is a plan view of FIGURE 3;

FIGURE 5 is a schematic wiring diagram of my invention;

FIGURE 6 is an enlarged schematic view of one of the Wheatstone bridges used on one of the load cells used in my invention;

FIGURE 7 is a side elevational view of a second embodiment of my invention; and

FIGURE 8 is a side elevational view partly in section of a third embodiment of my invention.

As shown in FIGURE 2, the mill **10** has work rolls **11** and **12** journalled in antifriction bearings **13** and **14** and mounted in chocks **15** and **16**. The work rolls **11** and **12** are supported by backing rolls **17** and **18** journalled in antifriction bearings **19** and **20** mounted in back-up roll chocks **21** and **22**. Each work roll has an antifriction bearing and a chock on each end thereof, as does each backing roll. Each of the work roll chocks **16** supporting the lower work roll **12** is maintained in its correct position by two identical pressure meters or load cells **23** (to be described more in detail hereinafter) which function as spacers between the work roll chocks **16** and the two projections **24** and **25** of the back-up roll chocks **22**. Each of the two chocks **15** of the upper work roll **17** also has on each side thereof a spacer **26** which may be a separate body or may be integral with the work roll chock **15**.

The work rolls and back-up rolls together with their respective bearings and chocks are mounted in a window or receptacle **27** of the mill housing **28**. A screw-down mechanism **29** positions the upper back-up roll and work roll vertically by moving the upper backing roll chock **21** up and down. This screw-down mechanism adjusts the height of the roll pass, thereby permitting the mill to vary the amount of reduction made upon strip rolled on the mill.

FIGURES 3 and 4 show the pressure meters **23** and their mounting in the back-up roll chock **22**. Each meter **23** as shown in FIGURES 3 and 4 is a load cell which comprises a hollow cylindrical steel body **30** fastened to the chock **22** by a bolt **31** and nut **32**, and a load column **30***a* mounted in the cylinder **30**. The load column extends through the cylinder and engages the work roll chock **16**. The cylinder is secured against rotation by a guide portion **33** projecting from its base **34** and fitting snugly into a slot **35** by a T groove **36** machined vertically in the chock extension or projection **24** of the backing roll chock **22**. The load cell can be moved vertically up and down when necessary and is fixed in a desired position by tightening nut **32** against the inner face of the T groove **36**. Any horizontal force acting axially upon the load column **30***a* is measured by an elastic strain in the load column by a set of four resistance strain gauges **37**, commonly known as SR–4 gauges, cemented thereon. The gauges **37** are mounted on the outside surface of the column **30***a* and are interconnected to form a Wheatstone bridge.

The load cells **23** cooperate to balance the horizontal forces acting upon the work rolls **11** and **12**. Each of the load cells **23** in FIGURE 5 has four strain gauges **37** interconnected to form a Wheatstone bridge, *a*—*b*—*c*—*d*, on cell **23***a*, and a second Wheatstone bridge, a^1—b^1—c^1—d^1, on the other cell **23***b*. A low voltage direct current source **38** which may be either a stabilized voltage rectifier or a battery energizes the Wheatstone bridges and is connected thereto through terminals **39** and **40**. There is no positive mechanical connection or tie-in between the chock **16** and either of the two load cells **23***a* and **23***b*, thus these cells respond only to compressive loads and are unaffected by tension loads or forces. Consequently, cell **23***a* responds only to compressive forces directed to the left, viewing FIGURE 5, and cell **23***b* responds only to compressive forces directed to the right, viewing FIGURE 5.

When no external forces are applied to the load cells **23***a* and **23***b*, the two Wheatstone bridges are balanced and the potential difference between their output terminals *c*—*d* and c^1—d^1 is zero. When, however, a force is present and dependent upon whether it is directed to the right or left, viewing FIGURE 5, an elastic strain is generated in the wall of one of the load cells, thereby throwing one of the Wheatstone bridges out of balance. Assuming that the resultant horizontal force is directed to the left, viewing FIGURE 5, an axial elastic compression cylinder **30** of cell **23***a* generates a voltage output on terminals *c*—*d*, with *c* being a negative terminal and *d* being a positive terminal. This voltage is directly proportional to the magnitude of the resultant horizontal force. Similarly, a force acting in the opposite direction throws Wheatstone bridge a^1—b^1—c^1—d^1 out of balance, whereby the strain gauge functions to generate a voltage on output terminals c^1 and d^1. However, this Wheatstone bridge is turned 90° relative to Wheatstone bridge *a*—*b*—*c*—*d*; consequently, the polarity of the output terminals c^1 and d^1 is opposite to that of the polarity of terminals *c* and *d* with c^1 and being positive and d^1 negative.

There are two identical load meters mounted on the other end of the work roll **12** and the two load meters on the left-hand side of the work roll **12**, viewing FIGURE 3, are connected in series to deliver a double voltage output and increase the sensitivity of my apparatus. The two load meters on the other side of the roll **12** are similarly connected. In other words, the two load cells on the left-hand side of the lower work roll will effectively function as a single unit as well as the two load cells on the right-hand side of the work roll.

As shown in FIGURE 5, the output of the Wheatstone bridges is a monitoring signal used in a closed-loop regulating system comprising a pre-amplifier **41**, a source of adjustable reference voltage **42**, an intermediate amplifier **43** which may be eliminated depending upon the useful output of the pre-amplifier **41**, a rotating amplifier **44**, and a booster generator **45** having its armature connected in series with the armature of the reel motor **46**.

Assuming that a certain instant the net resultant of the horizontal forces is directed towards the left, viewing FIGURE 5, a small voltage is applied by the load cell **23***a* to amplifier **41** which amplifies the difference between the voltage of the output terminals *c* and *d* of the Wheatstone bridge and the reference voltage supplied by the source **42**. The voltage difference passes through the intermediate amplifier **43** to the rotating amplifier **44** which excites the field of the booster generator **45**. This causes the booster generator to produce voltage which is added to that supplied to the armature of the reel motor **46** by a main generator (not shown). This additional voltage speeds up the motor and thereby increases the tension exerted on the strip by the tension reel **47**. This continues until the potential difference on the output terminals *c* and *d* of the Wheatstone bridge becomes substantially equal to that of the reference voltage **42**.

If the reference voltage **42** is zero, the reel motor **46** continues to accelerate until tension T_2 exerted by the reel becomts equal to $2S+T_1$; i.e., when the voltage on the output terminals of the appropriate Wheatstone bridge is also zero.

Should the reel motor **46** increase its speed to a point where T_2 exceeds T_1+2S, the strain gauges which form a part of Wheatstone bridge $a^1—b^1—c^1—d^1$ produce a voltage on its output terminal $c^1—d^1$ of opposite polarity to that delivered by output terminals $c—d$. The polarity of the output voltage from amplifiers **41**, **43**, and **44** is then reversed and voltage generated in the booster generator **45** is subtracted from that supplied to the reel motor **46** from the main generator. Thus, the motor **46** slows down, thereby reducing tension in the strip until the output of the load cells on the right, viewing FIGURE 5, falls to zero and equilibrium between T_1+2S and T_2 is once again restored.

If desired, it is possible to artificially introduce a controllable amount of unbalance between the forwardly and rearwardly directed horizontal forces by merely resetting the reference voltage **42**.

To avoid tearing the strip by excessive amounts of tension T_2, suitable limiting circuits can be employed which limit the maximum tension exerted by a tension reel. A monitoring apparatus may also be employed to signal the operator when such a condition is present. Further refinements for avoiding tearing of the strip can be obtained by using a programming controller which automatically limits the maximum tensions in a number of successive passes until the strip is reduced to final gauge.

A multi-pole switch (not shown) connects the whole control system alternately to one or the other of the reel motors since, generally, the driven back-up roll mills are of the reversing type.

In addition to the load cells **23***a* and **23***b*, I can use other types of load sensitive devices or transducers for producing the primary monitoring signal for balancing the horizontal forces through the appropriate circuits. Examples of other devices which may be employed include hydraulic capsules and inductive or capacitor-type load meters. All these instruments are based on well-known principles and a detailed description is not deemed necessary.

FIGURE 7 shows an embodiment of my invention which senses the total horizontal forces acting upon both work rolls **48** and **49** mounted in chocks **50** and **51**. As shown, two spacer bars **52** and **53** straddle the two work roll chocks **50** and **51** with spacer bar **52** abutting against one end of both chocks **50** and **51** and with the other spacer bar **53** abutting against the other end of both chocks **50** and **51**.

A backing roll **54** for the lower work roll **49** is mounted in a chock **55** having two projections **56** and **57** on each end thereof. Interposed between projection **56** and spacer bar **52** is load cell **58** which engages both the spacer bar **52** and the projection **56** and interposed between the other projection **57** and the other spacer bar **53** is a second load cell **59** which also engages both the spacer bar **53** and the projection **57**. These two load cells **58** and **59** are the same as load cells **23** and function in the same manner. Consequently, it is not necessary to describe their operation.

FIGURE 8 shows another embodiment of my invention which uses only one load cell **60** on each end of the work rolls. In this embodiment, the load cell **60** is interposed between one side of a chock **61** which mounts a lower work roll **62** and a projection **63** of a backing roll chock **64** for the lower backing roll **64***a*. The load cell engages both the projection **63** and the chock **61**.

Connected in series with the load cell **60**, projection **63**, and the work roll chock **61** is a preloading device **65**. This device comprises a turnbuckle bolt **66** having spacer element **67** affixed to the outer end of left-hand threaded element **68**, and a second spacer element **69** affixed to the outer end of right-hand threaded element **70**. An adjustment nut **71** of the turnbuckle bolt forces the spacer elements apart or brings them together depending upon the direction of rotation thereof. As shown, the preloading device is interposed between the other projection **63***a* of the backing roll chock **64** and the other side of the lower work roll chock **61**.

Two lock nuts **72** and **73** which straddle the adjustment nut and are mounted upon the threaded elements secure the adjustment nut in position.

The embodiment of FIGURE 8 is responsive to both compressive and tensive forces, therefore, only one load cell is required. In operation, the preloading device is set to exert a horizontal force upon the work roll chock **61** by rotating adjustment nut **71** to spread apart the spacer elements so that there is a certain pressure between the load cell and the work roll chock when there is no strip between the work rolls and the work rolls are not rotating.

The presence of a preload upon the load cell **60** does not affect the functioning of the embodiment of FIGURE 8 except that one must make adjustment for the preload condition. In other words, when there is a balancing of the horizontal forces acting upon the work rolls, the reference voltage is not zero and allowance must be made for this condition. Consquently, this embodiment is adjusted to take into account the preload.

Referring to FIGURE 8, when metal is reduced between the mill work rolls, if horizontal forces generated by rolling the metal act in the direction of arrow **74**, they increase pressures above the preload pressure on the load cell **60** whereupon my invention causes the winding reel to reduce the amount of forward tension exerted on the strip to bring the horizontal forces into balance. If the horizontal forces generated by rolling act in the direction of arrow **75**, they reduce pressures below the preload pressure, thereby causing the winding reel to exert more forward tension on the strip to bring the horizontal forces into balance.

My invention has important advantages which make it highly desirable for operators of 4-high driven back-up roll mills since it is responsive to the net difference between horizontal forces acting upon work rolls on either the front or rear side of the mill, which forces deflect the work rolls from their neutral position. My apparatus produces a monitoring signal which acting through a suitable control system causes the motor of the forward tension or wind-up reel to change speed and thereby alter the amount of forward tension exerted upon the material. In addition, my apparatus effects a balancing of horizontal forces upon the work rolls of a mill without employing apparatus or equipment which renders accessibility to the roll pass and to the work rolls difficult. Furthermore, my invention in no way hampers threading of the material through the mill and does not introduce to the mill structure elements which may be damaged when the strip rolled thereon breaks and which make removal of cobbles in the material hazardous, difficult, and time-consuming.

My invention permits use of very slender work rolls, namely rolls having barrel lengths to roll diameter ratios greater than 10 to 1 and in the range of 15 to 1 or higher. Such slender work rolls are highly desirable for rolling metals such as stainless steel and high carbon steel in wide widths to thin gauges.

While I have described a certain presently preferred embodiment of my invention, it is to be understood that it may be otherwise embodied within the scope of the following claims.

I claim:

1. In apparatus for rolling strip material, including a stand for mounting a pair of work rolls and at least one backing roll for each work roll, said stand having a receptacle on each side thereof, a pair of work rolls, at least one backing roll for each work roll and means on one side of the stand for winding up strip material rolled on said apparatus and for applying a forward tension to the material, the combination comprising supporting means for the ends of each of said work and backing rolls, said supporting means being positioned in

the receptacles of said stand, the supporting means for at least one of said backing rolls having side projections extending past and one to each side of its corresponding supporting means for its work roll, two members responsive to forces which tend to deflect said work rolls in substantially a horizontal plane, one of said members being positioned on one side of a work roll and the other of said members being positioned on the other side of said work roll, each of said members being disposed substantially adjacent an end of a work roll in a receptacle of said stand, being interposed in a horizontal plane between said side projections of said supporting means for a backing roll and the supporting means for said work roll engaging said side projection at one end and said supporting means for its work roll at the other end, and said members being arranged to sense said forces which tend to deflect said work rolls in substantially a horizontal plane, means connecting said two members to cooperating means for controlling the operation of said means for winding up strip and applying a forward tension thereon, so that the winding and tension means increases and decreases the amount of forward tension applied to strip rolled on said stand in accordance with the direction said work rolls tend to deflect in substantially the horizontal plane.

2. The apparatus of claim 1 characterized by each of said two members responsive to work roll deflection being a load cell responsive only to compression forces.

3. The apparatus of claim 1 characterized by each of said two members responsive to work roll deflection being a load cell responsive only to compression forces and by said cooperating means comprising an amplifier connected to each of said load cells, said amplifier being connected to the field of a generator which is electrically connected to an electric motor for driving the means for winding up the strip material and for applying a forward tension to the material.

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