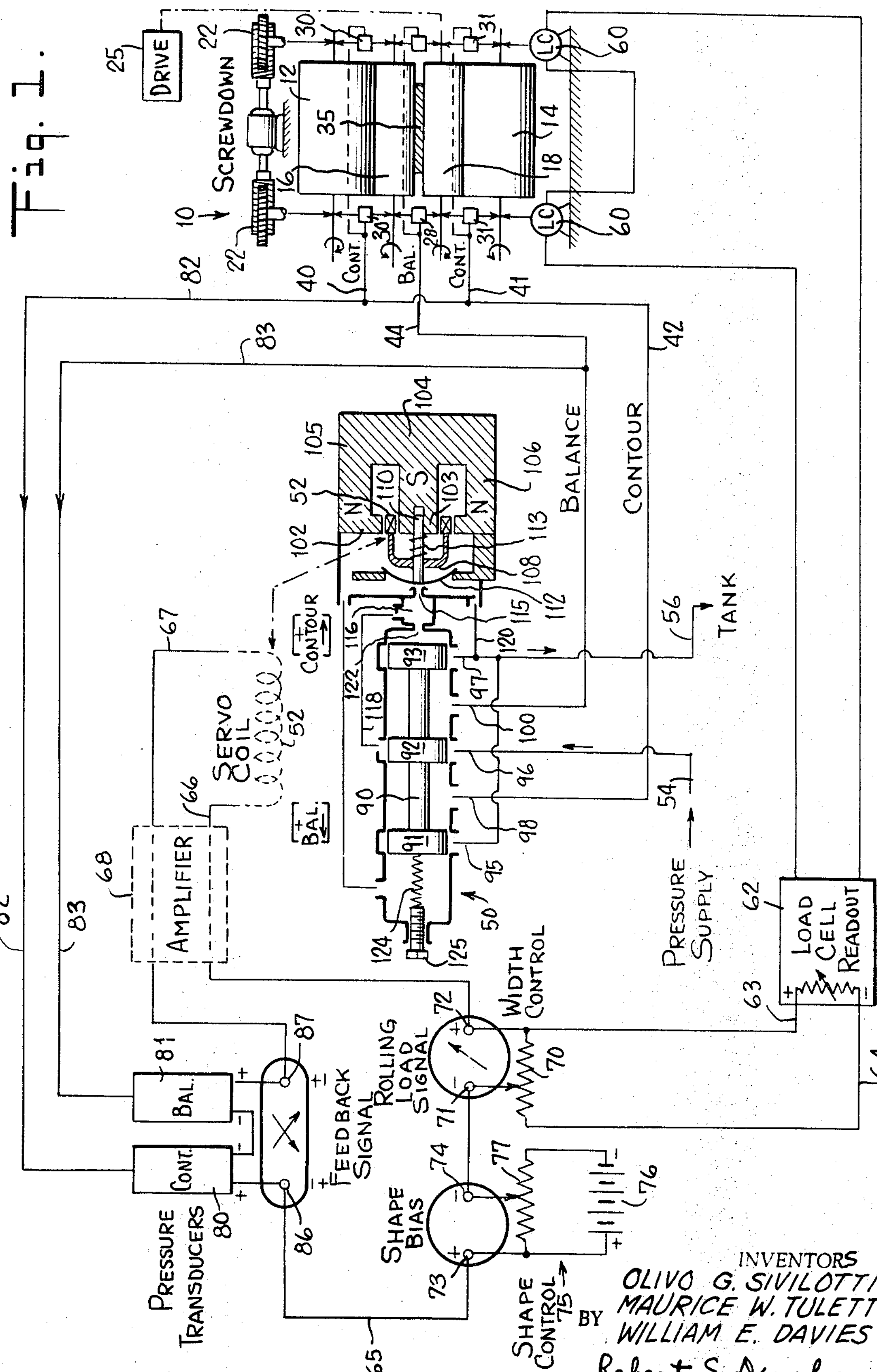
Oct. 20, 1970 O. G. SIVILOTTI ET AL 3,534,571

ROLLING MILL CONTROL

Filed March 14, 1968 5 Sheets-Sheet 1



INVENTORS
OLIVO G. SIVILOTTI
MAURICE W. TULETT
BY WILLIAM E. DAVIES

Robert S. Dunham
ATTORNEY

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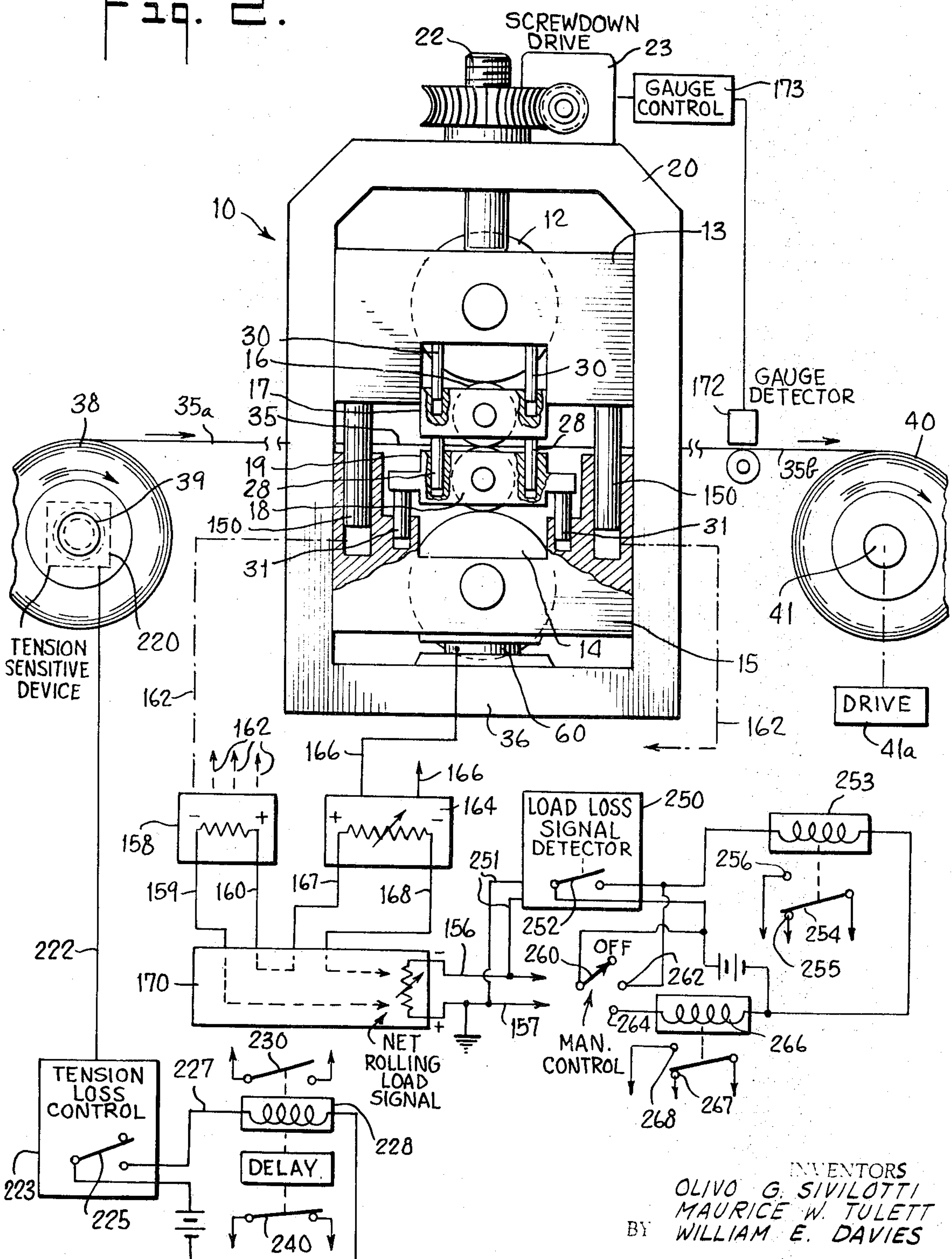
Fig. 2.



INVENTORS
OLIVO G. SIVILOTTI
MAURICE W. TULETT
WILLIAM E. DAVIES
BY Robert S. Dunham
ATTORNEY

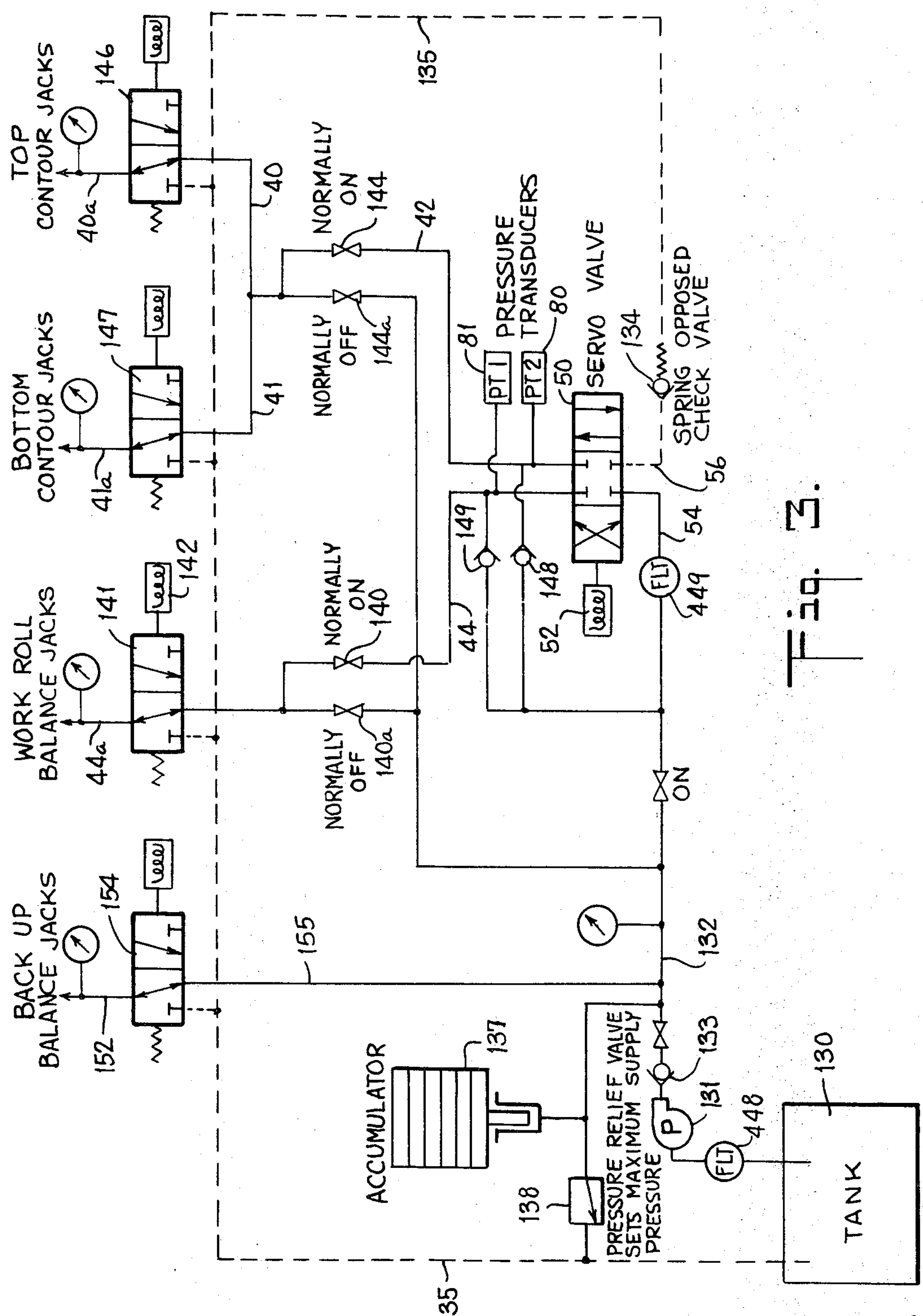


Fig. 3

INVENTORS
OLIVO G. SIVILOTTI
MAURICE W. TULETT
BY WILLIAM E. DAVIES

Robert S. Dunham
ATTORNEY

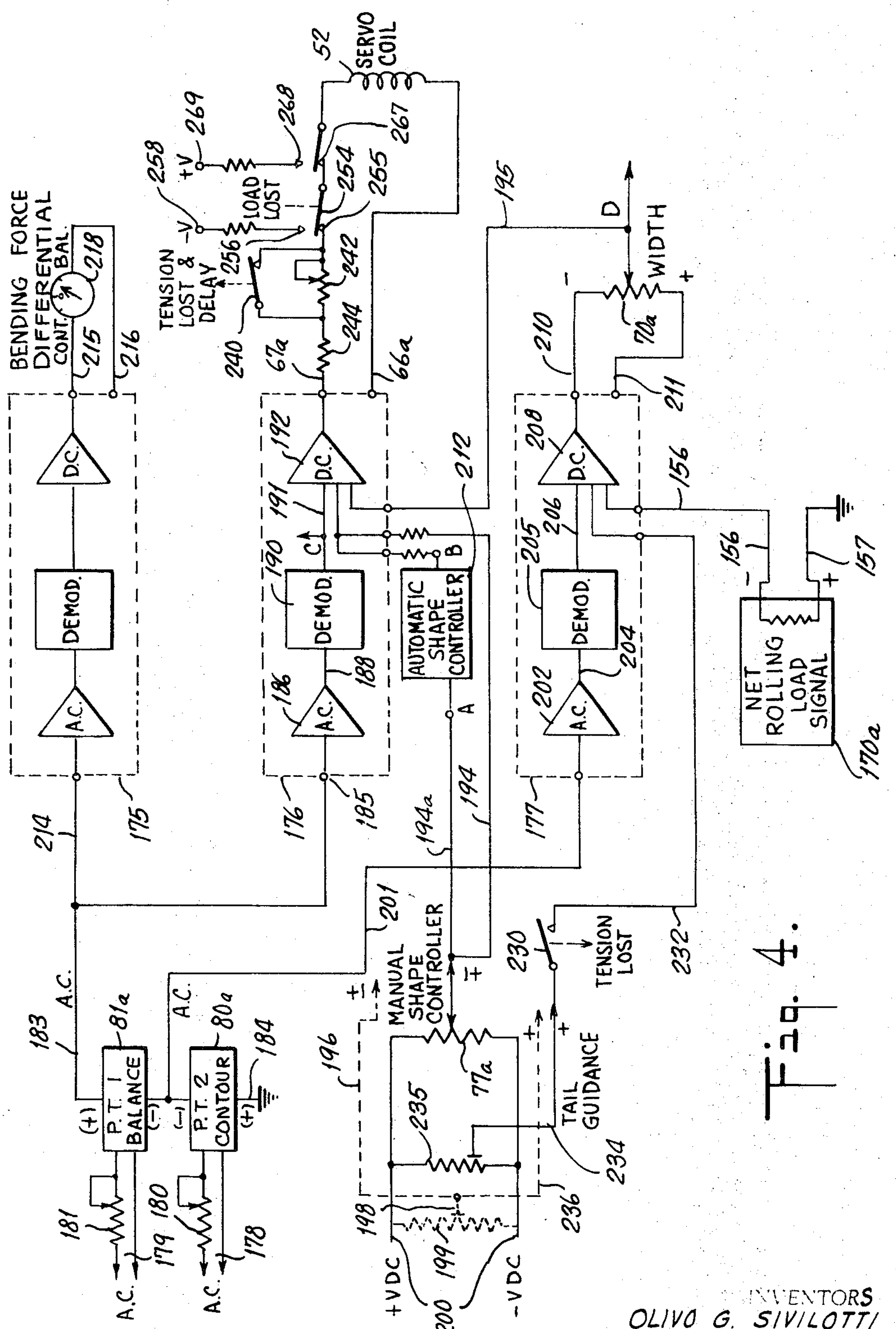


Fig. 4.

INVENTORS
OLIVO G. SIVILOTTI
MAURICE W. TULETT
BY WILLIAM E. DAVIES
Robert S. Dunham
ATTORNEY

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ROLLING MILL CONTROL

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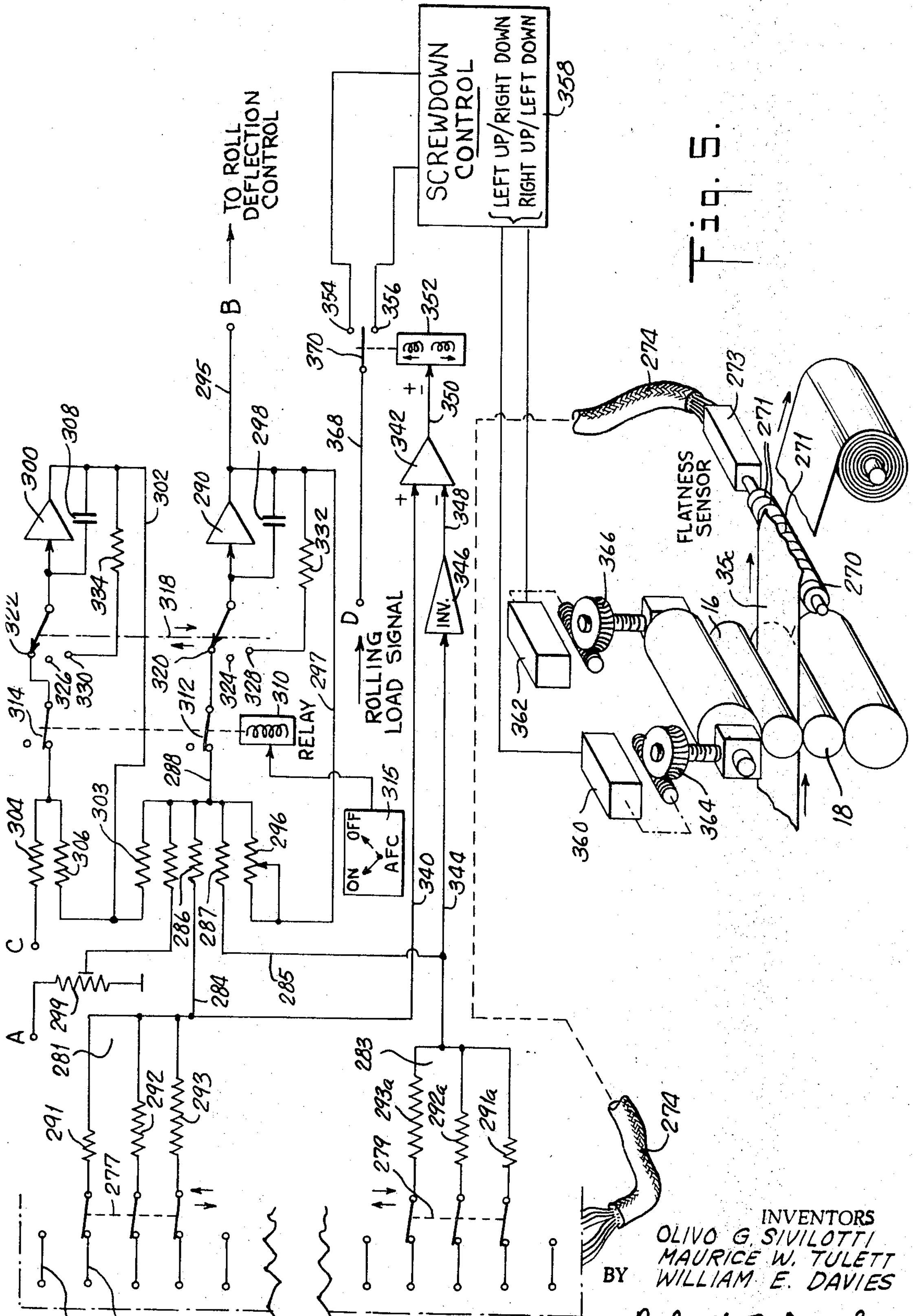

Fig. 5.

INVENTORS
OLIVO G. SIVILOTTI
MAURICE W. TULETT
WILLIAM E. DAVIES

BY Robert S. Dunham
ATTORNEY

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3,534,571
ROLLING MILL CONTROL

Olivo G. Sivilotti, Maurice W. Tulett, and William E. Davies, Kingston, Ontario, Canada, assignors to Alcan Research and Development Limited, Montreal, Quebec, Canada, a corporation of Canada

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U.S. Cl. 72—8 36 Claims

ABSTRACT OF THE DISCLOSURE

To maintain a desired condition, e.g., flatness, of the rolled metal strip, bending forces at the ends of the work rolls of a 4-high mill, preferably applied by the conjoint effect of balance jacks and contour jacks, are adjusted in accordance with the sum of a factor that accounts for the basic, thermally-affected shape of the rolls and a factor automatically responsive to changes of rolling load, the second factor being adjustable in proportionality of response, to suit the width of the strip. Apparatus effectuating these control functions on the difference of pressures in the balance and contour jacks, through a servo system, maintains a desired work roll gap throughout a rolling pass, and preferably includes means modifying the gap shape to preserve tail guidance of the strip as it loses tension at the end of the pass, and coacting means successively reducing the load-responsive control and increasing balance jack effectiveness, to keep the work rolls against the backup rolls when the tail leaves the gap. Means for sensing flatness or off-flatness of the rolled strip may automatically provide part or all of the first above-mentioned factor of bending jack force adjustment, advantageously at a slower rate than the rolling load control, and may include supplemental manual and signal-holding control arrangements as well as means to account for other or longer-term factors affecting strip shape, a further feature being means differentially responsive to off-flatness adjacent to the respective strip edges for adjusting the screwdowns on the chocks at opposite ends of the rolls in different directions to correct unbalance when it occurs between the screwdown load forces.

FIELD OF THE INVENTION

This invention relates to the rolling of metal strip, and in a special sense is concerned with apparatus and methods for regulating or governing rolling operations with a 4-high mill to achieve a predetermined cross-sectional configuration of the work roll gap or bite, particularly by automatic control of roll deflection, as for the purpose of attaining a desired flatness of the sheet product. Thus the present improvements are concerned with rolling reduction of metal in sheet form, as for example where a strip of aluminum (including aluminum alloys) having continuity over a relatively long length, is passed through the mill to reduce its thickness or gauge, by virtue of the rolling pressure exerted between the work rolls. While the invention is of advantage in cold rolling operations for aluminum strip and is therefore so exemplified below, it is conceived that the apparatus, systems and procedures are applicable to other metals and to other types of rolling such as hot rolling.

Particular aims of the invention are to provide means and methods for readily taking into account various circumstances which affect the shape or surface configuration of the rolled strip, including particularly factors which tend to deform or deflect the rolls and thus in turn to modify the flatness or other desired shape of the product, as well as its gauge. In the situation of required flatness of the strip, the indicated factors tend to modify the

roll gap, i.e., the space which is defined by the working surfaces of the rolls that engage the strip, to the extent that departures from parallelism of this gap, under rolling condition, will produce greater or less off-flatness. At different regions across a mismatched roll gap, the longitudinal bands or sections of the strip not only vary in actual thickness but are differently elongated by the rolling function, so that the areas of metal considered from place-to-place across the strip are nonuniform in length in the direction of rolling. These lengthwise bands are generally longer at the thinner regions of the rolled sheet product. Such nonuniformity of length is conventionally defined as off-flatness, being usually evidenced by waves, pockets or other detectable departures from straightness and flatness of the strip. In other words, this nonuniformity is exhibited by actual bends or waves in one portion or another of the sheet, as well as by varying thickness or gauge across the product. As stated, the present improvements are designed to provide control of the rolling operation and especially of roll deflection, in a basically automatic manner and in such way as to minimize or essentially obviate undesired departures from flatness or from uniformity of other selected configuration.

DESCRIPTION OF THE PRIOR ART

It is well known that the rolling load, i.e., the compressive force or pressure applied to the work rolls for transmission to the aluminum or other strip, tends to deform the work rolls, deflecting them in the direction of constituting the roll gap and consequently the cross-section of the strip with a so-called crown, meaning that the gauge or thickness at the center of the strip is greater than at the sides. It is also known that the heat developed in the rolls during the operation, i.e., in cold rolling, tends to deform the rolls by giving them a so-called thermal crown; since the heat is better dissipated at the ends of the rolls, greater expansion remains at the central region, causing the described crown or bulge.

As stated, the effect of rolling load, which tends to deform or bend the work rolls toward each other at their ends, is essentially the reverse of that of the thermal crown. To some extent, these phenomena of deformation therefore counteract each other and efforts are usually made to accommodate any uncompensated remainder, in one way or the other, by preshaping the work rolls, e.g., by grinding a crown if the load deflection is expected to predominate, or by grinding a concave surface if the thermal effects are likely to be greater.

Experience indicates, however, that compensation sought only by interrelating the thermal deformation, the original cold shape, and the elastic deformation under rolling load is often a very poor approximation; it is not truly reliable and the delivered strip may have undesirable off-flatness through parts or all of its length, despite attempted adjustments by the operator during the pass. A prime source of difficulty is change in rolling load, not only as needed to provide different delivered gauges for different passes (where the mill is used for a variety of tasks or for successive reductions) but also especially as required to accommodate changes of condition during a given pass. The rolling load must ordinarily be decreased substantially, i.e., by adjusting the screwdown pressure, as the mill is brought up to speed, and adjustments during the pass are often needed or occur in order to maintain gauge, whether by automatic or manual gauge control. Variations in hardness of the metal, or in thickness of the entering strip, are also among the factors that require or may indeed occasion (for a given screwdown setting) change in rolling load. All of these and other factors alter the elastic deformation of the work rolls, in a manner which cannot be precompensated and which is detrimental to desired strip shape, e.g., flatness. The thermal effects may also vary, and although these changes are not of such rapid occurrence between the beginning and end of a single pass, there may be variations between passes. A factor of similar effect is the surface wear of the work rolls.

Skilled operators have tried to do the best they can in correction of off-flatness, as by changing roll coolant flow rates, rolling speed and other factors, even perhaps to the sacrifice of optimum uniformity of gauge, but it is practically impossible to get satisfactory control. In the first place, the tension in the issuing strip, being an elastic stretch, tends to effect a temporary straightening, or to make the surface appear flat, thus masking the poor results. Even if the operator detects off-flatness, the controls available cannot be brought into play with any promptness, so that much inferior product is produced before correction occurs.

Supplemental adjustments or control features have been proposed or used for aid in achieving flatness, such as various arrangements of special jacks, between the chocks of the several rolls, to apply supplemental forces to bend the rolls elastically. For instance, so-called balance jacks have been placed between the chocks of the upper and lower work rolls at each end of the latter, so as to apply, at the roll axes, a bending force in opposite direction to the effect of rolling load on the strip in bending the rolls toward each other near their ends. Indeed it has been proposed to change the pressure in these jacks in some automatic response to changes of screwdown load, but no way of achieving a properly proportional response, or of doing so conveniently, has been available. Another practice or proposal has been to provide so-called contour jacks between the chocks of the upper work rolls and the chocks of the upper backup rolls, and likewise between the corresponding chocks of the lower work and backup rolls; some automatic relation of these jacks to change in operating condition has been suggested, but again without affording any properly proportioned response to load or other factors.

Accordingly rolling mill control, for roll contour and strip flatness, has in practice remained a problem of manual adjustment, even with the aid of balance jacks or other supplemental equipment for altering the elastic deformation of the several rolls, and has not permitted any assurance of success in attaining desired results. Ordinarily the operator tries to make a judgment from the appearance of the leading portion of the strip as it slowly issues during the initial threading process and before the tension at high speed has masked the waves or pockets, with the hope of anticipating the change in roll deflection that will occur when full rolling speed is applied.

The operator's effort is to bias the strip flatness condition, during threading, in some way that will obtain good flatness when the mill is at speed and the strip is on gauge. This has at least three disadvantages, namely: the strip is off-flat at both beginning and end, requiring the leading and tail portions of the coil to be scrapped; operating difficulties are associated with the rewinding of these badly off-flat sections; and most importantly, the adjustment is not sufficiently accurate to assure good flatness during the run of the mill. There is no way of taking proper account of rolling load changes that occur or are required as the pass progresses. In other words, regardless of the availability of roll-bending jacks, the operator proceeds largely by guesswork, and even if he could observe off-flatness of the strip at speed (which he has difficulty in doing), corrective manual adjustments are too slow to insure the absence of nonflat sections.

SUMMARY OF THE INVENTION

To the end of avoiding or minimizing these difficulties, and especially to provide an improved control system and procedure having rapid automatic response to change in rolling conditions, it has now been found that highly effective control of work roll deflection, in response to changes of rolling load and for the purpose of maintaining strip shape (e.g., flatness) can be effectuated by adjustment of bending force on the work rolls, when such adjustment is provided as the sum of two factors, namely a basic shape adjustment that takes care of thermal effects and that may be achieved, for instance, when the mill is running slowly at the start, and a factor that can then depend automatically and proportionately on the actual rolling load, for example as sensed by load cell means between the chocks of the upper backup rolls and the screwdown or between the lower backup roll chocks and the frame or base of the mill stand. It has further been discovered that the proportionality of the required change of bending force on the work rolls (as measured or represented, for instance, by pressure in appropriate balance jacks, or most preferably by difference of pressure in coacting sets of balance and contour jacks) to changes in rolling load, i.e., as required for automatically modifying the elastic deformation of the work rolls to maintain strip flatness, is determinable, for any given mill, directly in accordance with the width of the strip.

That is to say, the proportionality of change of work roll bending force to change of rolling load varies linearly with the width of the strip being rolled (a greater change of applied bending force being required to compensate a given increment of change in rolling load for narrower strip, and a lesser change for wider strip), and can therefore be so set for each pass, as by a control element reading in units of width. Hence upon also setting the shape adjustment factor as explained above, change in roll bending force (as the difference of pressure of balance and contour jacks) can thereafter be effected in proportion to the proportioned rolling load signal, in a way that compensates or accommodates the effects of rolling load variation with unusual accuracy, for achieving a high degree of flatness or other uniformity of strip shape.

Basically, a useful embodiment of the present system thus includes bending jack means for the work rolls, means for sensing the rolling load and servo or like means for adjusting the pressure of the bending jack means from a control organization responsive to the sensed rolling load. The control instrumentalities include two elements of bias or quantity that jointly coact in governing the servo means. One such quantity is a first signal that is preliminarily, or from time to time, adjustable for the basic, desired shape of the roll gap. This adjustment, conveniently manual, affords a base or nominal setting of the bending force of the jack means; it has been discovered that the setting of this first signal remains effective at all rolling loads, although the actual value of bending force is changed by the second signal or control. Such second signal, being the principal and automatic control, is the reading of actual rolling load, proportioned in accordance with the width of the strip as stated above, and is then highly and accurately efficacious for direct, automatic control, to keep the roll gap at a constant shape uniformly during the run and thus specifically to maintain desired and very superior flatness of the strip.

Although useful results are obtainable with a bending jack system that involves only balance jacks, i.e., between the chocks of the upper and lower work rolls, notably superior control and maintenance of flatness is attained with a combination of balance jacks and contour jacks, the latter being interposed between the work roll chocks and the backup roll chocks at both the upper and lower sides of the mill. The control is then exercised, in effect, on the difference of pressures in the balance and contour jacks, as representing the bending force on the work rolls through a range of roll deformation that extends in both directions, e.g., upward and downward at the roll ends, from a point of balanced or zero force.

While the basic controlling quantity or signal is that

of the rolling load, and the system and method are practicable simply in response to load cell determinations of screwdown force as noted above, greater accuracy and superior results have been achieved by a control effected in accordance with the rolling load as exerted at the line of contact between the backup rolls and the work rolls. Thus specifically, for instance, the load cell signal which measures the screwdown force can be utilized as diminished by a corresponding signal derived from the pressure in the contour jacks. That is to say, the net rolling load signal (which is adjusted, in its proportional significance, according to strip width) is conveniently determined as the screwdown load minus the opposing load exerted by the contour jacks, the latter value, of course, being very substantially smaller than the screwdown load, particularly so at normal values of the latter in high speed operation. It will be understood, nevertheless, that general references herein to rolling load or rolling force as a control quantity are intended (unless otherwise expressed) to be understood in a generic sense, meaning such value whether or not it is diminished by the contour jack load; but as stated, optimum results have been achieved in the latter case.

The defined control of bending force on the work rolls in response to changes of rolling load for maintaining constant flatness or other desired shape of the rolled strip, has been found exceptionally effective in 4-high mills where the length of the work roll to backup roll contact line (or the axial length of the working surface of each work roll) is not greater than about 4.5 times the diameter of the work roll; in a specific aspect the invention is directed to situations within this range. Thus at ratios of work roll length to work roll diameter below the stated value, for instance 4:1 or 3:1, very effective results are obtainable, but it appears that with mills where the work roll diameter is relatively very small, e.g., where the ratio is 6:1, the basic relationship discovered to afford the described automatic control function, may not generally prevail.

The invention is also designed to accommodate automatically, in cooperation with the automatic control of work roll deflection, two conditions that occur successively at the end of a rolling pass. When the tail end of the strip leaves the supply reel, losing back tension, there is a tendency for the strip to move sidewise in one direction or the other, so as to be improperly aligned for passage between the rolls and for rewind in the finished coil. Accordingly, in response to detection of the loss of back tension, as by appropriate means, a small signal is introduced in the control in opposition to the rolling load signal, whereby the servo system causes the bending jack means to function as if there were a reduction of rolling load. More particularly, by increase of contour jack pressure and decrease of balance jack pressure in the preferred system, the roll gap is caused to assume a crown rather than a parallel shape, with the effect of keeping the strip centered and preventing its wandering to either side.

When the strip finally leaves the gap and causes loss of rolling load pressure, it is important to keep the work rolls in firm contact with the backup rolls, to avoid skidding and corresponding damage to the roll surfaces. For a special purpose in anticipation of such departure of the strip, the invention preferably includes a delayed response from the back tension sensing signal, timed to be effective shortly before the tail of the strip reaches the gap, so as to introduce a considerable attenuation in the signal circuit which controls the servo function, i.e., the circuit into which the rolling load signal is continuously supplied.

Upon actual release of the strip from the gap, there is an instantaneous reaction caused by the release of elastic stretch in the mill housing, i.e., an instantaneous impulse forcing the chocks of the work rolls toward each other, thus momentarily heightening the effective pressure or force of the balance jacks and keeping the work rolls in contact with their respective backup rolls. In the control circuit, however, where the pressure in the balance jacks is present as a feedback signal, this instantaneous increase of balance jack pressure appears as a large error signal, while at the same time the rolling load signal itself falls to a lower value or to zero. Accordingly, by one or both of these latter effects the control system would normally tend to operate the bending jacks as if to drive the work rolls toward each other, e.g., by increasing the pressure greatly in the contour jacks and reducing it in the balance jacks, but the attenuation which has now been inserted in the control circuit prevents any such rapid response and indeed only permits a very small or slow alteration of the bending jack forces. Meanwhile a separate signal, directly responsive to loss or to rapid reduction of rolling load, may operate to substitute a special control quantity for all of the automatic bias values, such as to drive the bending jack means in a direction to maintain the desired contact between each work roll and its backup roll. In this fashion, skidding or other malfunction at the very end of the pass is automatically averted and the balance jacks are brought into full and essentially sole play, so that the mill can be brought to rest in proper condition.

The described system affords an effective automatic control of roll deflection throughout a selected pass, in such fashion as to maintain the desired strip shape, e.g., a high degree of flatness, at all times. Initial setting of the control is only required in two respects, in accordance with the width of the strip being rolled, and by a separate instrumentality, in order to achieve desired flatness or parallelism of the roll gap at the very beginning of rolling operation when the strip is moving slowly and the attendant can readily determine the attainment of the desired condition, e.g., by visual observation. Thereafter as the mill gets up to speed and continues at a desired high rate, the deflection of the work rolls is automatically adjusted whenever necessary so as to preserve the desired strip shape or roll gap configuration. Changes in rolling speed, changes in hardness of the strip, adjustments whether manual or automatic to maintain gauge, and like variations, are all compensated accurately by suitable change in the bending force on the ends of the work roll axes; guesswork by the operator is eliminated.

To the extent that the thermal crown or thermal effects may vary, such change is of a very slow nature and ordinarily does not occur to a significant extent during a pass, unless the time between passes has been unduly long with corresponding significant cooling of the rolls. In such event, or if other reasons require it, the operator can adjust the initial shape control during the run, and indeed to do so he may reduce the tension or even slow the mill down for observation of the strip, without any interference whatever as to the automatic control function in response to change of rolling load. Alternatively the system may also, as described below, include automatic means that supplementarily alter the roll bending forces so as to compensate for changes of roll shape due to thermal drift, wear or other phenomena responsible for slow changes in strip flatness.

Because of the availability of shape adjustment essentially as the mill is threaded, the operator is not compelled to overcompensate at such time, and in consequence there is an avoidance of the bad off-flatness which such past practice has created in the leading portions of the strip and indeed also at the trailing end where reversion of the original distortion would occur. Rewinding problems are thus avoided and likewise loss by necessary scrapping of these parts of the product.

Finally, this system is further such as to compensate for the special requirements of loss of back tension and loss of rolling load as the tail end of the work approaches and leaves the mill. The strip is steered in proper alignment and a balance function of mill operation is automatically assumed, replacing the regulating mode during this final brief period, whereby the work rolls are kept against the backup rolls when the mill is brought to a halt.

BRIEF DESCRIPTION OF THE DRAWINGS

Certain embodiments of the improved system and corresponding diagrammatic illustration of the methods of the invention are set forth, by way of example, in the accompanying drawings, wherein:

FIG. 1 is a diagrammatic view of basic elements of a system according to the invention, shown in simplified form;

FIG. 2 is a side view of a rolling mill for strip, simplified as to detail, including certain elements of the invention and also including circuit diagrams of supplemental control instrumentalities;

FIG. 3 is a hydraulic circuit diagram, in simplified form, appropriate for control of a mill as shown in FIG. 2 and employed with further instrumentalities as in other views;

FIG. 4 is a schematic diagram of electrical and electronic control arrangements, appropriate for governing the hydraulic system of FIG. 3, in association with instrumentalities as shown in FIG. 2; and

FIG. 5 is a schematic diagram showing additional features of automatic strip shape control, exemplified as related to FIG. 4.

DETAILED DESCRIPTION

Referring to FIGS. 1 and 2, the invention is illustrated as applied to a 4-high mill **10** including upper and lower backup rolls **12, 14**, having their necks or shafts respectively carried in conventional chocks **13, 15**, and arranged to bear on upper and lower work rolls **16, 18**, which in turn are respectively carried, at their necks or shafts, by chocks **17, 19**. The entire assembly is supported in the usual frame or housing **20**, with conventional screwdowns indicated schematically at **22** and bearing on the upper backup roll chocks **13**, with appropriate gearing or like drive as indicated at **23** for adjusting the pressure applied by the screwdowns to the rolls.

It will be understood that parts shown at one side in FIG. 2 are duplicated at the opposite side, the entire assembly being diagrammatically revealed in FIG. 1, but with omission there of the housing and chocks, for clarity. Likewise, the detailed structural arrangement of the mill is largely omitted, such as the vertical slide supports for the chocks and many other features and controls as known and appropriate for rolling mills, including suitable driving means for the work rolls, as indicated by the legend at **25** in FIG. 1.

For purposes of the invention, balance jacks **28** are interposed between the upper and lower work roll chocks **17, 19**, and contour jacks are similarly interposed between the work roll chocks and the upper and lower backup roll chocks, i.e., jacks **30** between the upper work and backup rolls, and jacks **31** between the lower work and backup rolls. All of these jacks may be of known, conventional nature such as heretofore sometimes employed (under manual control), being rugged hydraulic cylinders with heavy plungers, arranged to exert force between the associated roll chocks upon introduction of hydraulic liquid under pressure. Conveniently, at each location, i.e., between each pair of chocks, there may be two jacks on each side of the mill as shown in FIG. 2, although conceivably a single jack at each side would suffice, or alternatively more than two jacks may be employed in parallel. FIG. 1 indicates, for simplicity, a single jack on each side at each locality. In all instances, all jacks of a given situation are hydraulically connected in parallel, as for example in reference to FIG. 2, all of the four upper jacks **30** (including the opposite pair, not shown) are supplied simultaneously from a single conduit for hydraulic liquid under pressure, the same being likewise true of the entire set of jacks **28** and the set of jacks **31**. Identification of these devices as balance and contour jacks is in accordance with known terminology for jacks so situated.

This complete system of jacks constitutes means for applying bending force to the necks of the work rolls, relative to the entire stand of rolls as engaged by the screwdown, the direction and extent of such force being dependent on the relative values of initial pressure and resulting displacement of the jacks coacting on each work roll. Thus, if the pressure of the contour jacks predominates, the ends of the work rolls tend to be bent toward each other, as to overcome a thermal crown of the rolls, or to create a crowned roll gap between what might otherwise be parallel roll surfaces, while predominance of pressure in the balance jacks, over the contour jacks, tends to bend the work rolls away from each other at their ends, as for example where desired to overcome a crowned or bulging roll gap that would otherwise exist. The bending forces applied to the work rolls, whether by action of the rolling load or by function of the bending jack system, are effected within the elastic limits of each work roll structure. As exerted by the jacks on the work roll necks, the bending force is proportional to the extent of bending displacement (by Hooke's law) and is measurable by the pressure excess in the predominating jacks. Thus, increase in deflection by bending requires a corresponding greater force and thus involves a proportionately higher pressure (to maintain the deflected condition) in that one of the balance or contour jack sets which predominates in effectuating bending.

The entire assembly is, as stated, maintained under rolling pressure, i.e., for desired reduction of the aluminum or other metal strip **35** traversing the bite of the work rolls **16, 18**, by the screwdowns acting through the backup roll chocks and the rolls of the stand, against the base **36** of the mill. The strip to be rolled is supplied from a coil **38** carried on a reel or shaft **39** provided with appropriate drag or mechanical resistance means (not shown) to maintain back tension on the portion of strip **35*a*** traveling to the work rolls, while the rolled strip of desired reduced gauge, traveling from the mill as at **35*b*** is rewound in a coil **40** on an appropriate reel on a shaft **41**, which is driven by means of the usual sort, indicated by the legend at **41*a***. As stated, the function of the present system and method is to maintain a desired uniformity of the roll gap, notably a configuration of parallelism appropriate to maintain flatness, the roll gap being the space between the work rolls **16, 18** that is occupied by the passing strip **35** while the latter is reduced in gauge by the force or load between these rolls.

Referring now particularly to FIG. 1, where the roll stand **10** is shown schematically as indicated above, the hydraulic liquid connection to the upper and lower contour jacks **30, 31** is provided by conduit lines **40, 41**, joining in a common pipe or conduit **42**, while similar hydraulic connection to the balance jacks **28** is provided by a pipe or conduit **44**. Hydraulic liquid, e.g., suitable oil, water or other liquid, oil of appropriate character being preferably employed as is known for jack systems of this sort, is supplied to or discharged from the balance and contour jack systems in appropriate manner (with the systems kept filled as required, when no flow of liquid is taking place) by a control valve assembly, as for instance an electro-hydraulic servo-valve **50** (an example being such a valve as manufactured by Moog, Inc., U.S.A.), having an electrical control coil **52** that is shown both in location in the valve and diagrammatically in dotted lines for convenience of circuit illustration. Hydraulic liquid is supplied under high pressure to the valve through a conduit line **54** and such liquid is discharged as to an appropriate reservoir through a line **56**.

The basic control of the invention is exerted in proportion to rolling load in the mill **10**, or changes of such load, and is advantageously sensed in a continuous manner by suitable means for detecting pressure or force, as for example by load cells or load cell assemblies which can be embodied between the screwdown on each side and the upper backup roll chocks or between the lower backup roll chocks and the base or frame of the mill, FIG. 1 showing for example a pair of such load cells **60**, **60** in the latter location. These cells may be of any suitable, known character, as of the magneto-elastic type or as constituted by wire-type strain gauge assemblies, cells of the magnetic or magneto-elastic nature being selected for embodiment in the systems here described. Thus to obtain the total load, the cells **60** are suitably connected together, with appropriate summing means (not shown) if necessary, and their electrical response is applied through an appropriate readout circuit **62**, of known, conventional character for such purposes, so as to yield an electrical signal at the terminals **63**, **64** of the latter device that varies in magnitude in proportion to the total rolling load or force of the mill.

The positioning of the servo-valve **50** is effected by its electrical coil or winding **52** which in turn is controlled by the rolling load signal derived from the terminals **63**, **64**. While other types of control system can be used for operating this or other valve control for the bending jack assembly, notably effective results are attained with a feedback arrangement, i.e., wherein a signal from the bending jack means is supplied in opposition to the basic control signals in the circuit for the servo coil **52**, and such system is therefore illustrated by way of example, the function being to cause the current in the coil to return to an appropriate value, e.g., zero, after each change of bending jack situation has been brought about. For simplicity of explanation, the coil **52** is shown as having a simple, series control circuit **65**, which when unbalanced supplies an operating signal to the terminals **66**, **67** of the coil, if desired through an appropriate amplifier **68** or like device, e.g., to supply current to the coil in accordance with the presence of a voltage signal in the circuit **65**.

The terminals **63**, **64**, carrying the primary rolling load signal, are connected across the input of a potentiometer **70**, having an adjustable, reduced output at the terminals **71**, **72**, shown for simplicity as a part of the control circuit **65**. A separate bias signal is also applied in the same series circuit at the terminals **73**, **74**, being the output of an adjustable electrical source such as the voltage source **75**, here shown as comprising an appropriate voltage supply **76** across the input of a potentiometer **77**. For reading the pressures of the contour and balance jack sets respectively, suitable pressure transducers **80**, **81** have liquid pressure sensing connections, indicated by the lines **82**, **83**, respectively extending to the liquid supply system **40**, **41**, **42** of the contour jacks and to the liquid supply line **44** of the balance jacks. Devices suitable for this purpose are known, and need not be described in detail, each being adapted to yield an electrical signal across its output terminals, proportional to the sensed pressure. For simplicity of illustration in FIG. 1, all of the signal-delivering means are shown as direct current devices, e.g., interposing a corresponding D.C. signal voltage in the control circuit **65**.

The outputs of the pressure transducers are illustrated as connected in series but in opposed relation respecting their electrical polarity, thus providing at the terminals **86**, **87** a signal which, in effect, varies in accordance with the difference of pressures in the contour and balance jack systems to represent a totalized measure of the bending force (in direction and value) applied to the necks of the work rolls. These terminals **86**, **87** form part of the circuit **65**, serving to introduce the feedback signal, in generally opposing relation to the control signals, or their net result, as derived across the terminals **71**, **72** and **73**, **74**. For convenience of illustration, it being understood that other polarities or arrangements may be employed as will be apparent below (with or without supplemental fixed bias as necessary), the rolling load signal is a varying D.C.

voltage, of positive polarity at the terminal **72**, which is in effect connected to the lefthand terminal **66** of the servo coil **52**. The shape bias signal is in this instance selected as a D.C. voltage of polarity opposite to the load signal, i.e., its terminal **73**, on the side toward the opposite terminal **67** of the coil **52**, being positive in polarity. With the output of the transducers **80**, **81** connected in opposed, series fashion, the net signal at the terminals **86**, **87** depends in polarity and value on the difference of pressures sensed by the transducers. Thus for instance, if the balance jack force predominates, the feedback signal will be of positive polarity at the terminal **87**, nearest the terminal **67** of the coil **52**, while it will be of negative polarity at such terminals (and positive at the terminal **86**) if the contour jack forces predominate, e.g., if the necks of the work rolls are bent more or less toward each other.

The function of the complete circuit extending to the servo coil **52** is to establish a current in this coil upon unbalance of the circuit **65**, of direction and extent corresponding to the direction and extent of unbalance. The valve **50** is then actuated in corrective direction and amount, i.e., so as to increase the pressure in one of the contour and balance jack sets and decrease it in the other, until change of reading of the transducers **80**, **81** restores balance to the circuit. Indeed the system is also self-correcting, in that if an error signal appears because of leakage or other departure of the balance jack means from desired condition, the coil **52** and valve **50** will function to restore such condition in the same manner. While other valve or control devices for the hydraulic supply to the bending jack means may be utilized, the device **50** shown for example is suitable, being a known structure of electromagnetically actuated character, including a hydraulic amplifying stage for shifting the valve.

Specifically, the device has a sliding spool assembly **90** which carries three spaced closure rings **91**, **92** and **93** normally disposed in closing relation, respectively, to a discharge port **95**, a liquid supply port **96** and another discharge port **97**, the discharge ports being connected together and to the outlet conduit **56**. Intermediate the ports **95**, **96** and **97**, are ports **98** and **100** respectively connected to the contour and balance jack lines **42** and **44**, and closed from either the inlet port **96** or the outlet ports **95**, **97** by the adjacent rings **91**, **92** and **93** in their null or balanced position.

The coil **52** is an annular winding suspended in the manner of the voice coil of a permanent-magnet speaker in an annular space between opposite poles **102**, **103** of a permanent-magnet assembly, the pole **102** being a circular ring around the outside of the coil and the pole **103** being a central, cylindrical element within the coil, the magnet structure being completed by a central portion **104** extending to the pole **103** and connecting portions **105**, **106** which may be the permanently magnetized parts, the magnetic circuit thus providing an annular gap in which the coil **52** may float. The coil **52** carries a supporting spider or cone **108** which extends to a centering pin or target element **110**, that in turn, through a diaphragm **112**, is urged by pressure of a coil spring **113** toward the opening of a nozzle **115**. The nozzle leads from a chamber **116** continuously supplied with fluid under pressure (through a suitable inlet orifice) from a bypass **118** leading around the closure ring **92** to the inlet port **96**. From the outer side of the orifice, i.e., beyond the nozzle, a passage **120** including an outlet orifice, leads to the discharge port **97**. The chamber **116** also communicates, through a small passage, with the end portion **122** of the chamber in which the spool **90** slides, whereby the pressure of the liquid in the chamber **116** in effect continuously urges the spool in one direction, being to the left as shown, such force being normally balanced by a spring **124** which is under compression at the other end of the spool and is adjustable for balance (with zero current in the coil **52**) by turning the screw **125** against the opposite end of the spring.

The design and adjustment of the parts including the force of the spring **113** and the setting of the spring **124** are such that when the coil **52** exerts no force, the target assembly **110–112** limits the discharge of fluid from the chamber **116** through the nozzle **115** sufficiently to maintain just enough pressure in the chamber space **116–122** to keep the valve spool **90** in the neutral position illustrated. If current flows through the coil in a direction to urge it to the left, for example, the target assembly tends to close the nozzle, correspondingly increasing the pressure in the chamber **116–122** and thus moving the spool to the left against the spring **124**. This action brings the liquid inlet port **96** into communication with the balance jack port **100**, while similarly opening a passage between the contour jack port **98** and the discharge port **95**. In consequence, hydraulic liquid under pressure is supplied to the balance jacks and liquid is drained from the contour jacks at a rate proportional to the extent of valve-spool movement and thus to the current in the coil. Assuming this motion has occurred in response to an error signal, a corresponding change in the net feedback signal across the terminals **86, 87** reduces the current in the servo coil **52** to zero, whereupon the pressure in the chamber **116** returns to normal and the valve-spool moves back to its neutral position, establishing the balance and contour jacks at the changed pressures and correspondingly changing the bending force on the necks of the work rolls, e.g., in this instance to bend them apart or further apart.

If a current of opposite direction passes through the coil **52**, a reverse effect occurs, in that the target exerts less force, permitting greater opening of the nozzle **115** and reduced pressure in the chamber **116**, with consequent drive of the spool **60** to the right under the unbalanced force of the spring **124**. Liquid under pressure is then allowed to flow into the contour jack lines **42, 40–41** and out of the balance jack line **44**. When the electrical circuit is restored to balance by change of the feedback signal at the terminals **86, 87**, the current in the coil **52** falls to zero and the valve-spool **90** is restored to neutral position, with the bending jack means in changed condition.

Returning to the control of the circuit **65** and considering its function as exemplified in carrying out a rolling operation with the mill **10**, it will be assumed that a strip to be rolled is threaded through the mill, between the work rolls, and initial screwdown pressure is applied, with the rolls slowly moving. The control device **70**, calibrated in width units, has been preliminarily adjusted to match the width of the strip, thus setting the output rolling load signal at the terminals **71, 72** in proper proportionality to the signal from the load cells **60** so that changes in rolling load can be exactly compensated, in maintaining strip flatness, by corresponding, linearly proportioned adjustment of the bending jack system. By observation of the slowly issuing strip, or other measurement as may be available to the operator, the control device **77** is now set until, through the instrumentality of the coil **52** and the servo-valve **50**, the bending jack means have been adjusted to establish a desirably flat condition, e.g., an effective parallelism of the work roll surfaces along the lines of engagement with the strip at the bite or gap. The adjustment is thus completed when the slow-moving strip is observed to be appropriately flat.

Simply to take one of various situations that may arise, it may be assumed that the work rolls are highly heated, as from an immediately preceding pass and thus tend to have a fully developed thermal crown. It may also be assumed that the rolls have been ground with a slight concave, so that the thermal crown is partially compensated by the initial roll shape, there still remaining (with no load) a small roll crown, in effect. The mill being threaded with strip and running slowly, the rolling load (applied screwdown force) may be considerable, as is usual in starting, and a correspondingly high signal from the rolling load appears at terminals **71, 72**. It can be further assumed that this high rolling load bends the

ends of the work rolls toward each other, not only overcoming the residual thermal crown but in fact producing a concave, causing a central bulge of the roll gap. The shape control **77** is then adjusted to provide a flat configuration of the issuing strip, i.e., to bring the roll surfaces at the bite into parallelism. Under the conditions of this example, the adjustment will be such as to produce some predominance of pressure in the balance jacks, over the contour jacks. In this situation, the bias signal at the terminals **73, 74**, resulting from the shape control, will be equal to the algebraic sum of the magnitudes of the rolling load signal at **71, 72** and the feedback signal (then neagtive at the terminal **86**) from the pressure transducers **80, 81**. In other words, the shape bias signal is the amount by which the load signal (**71, 72**) must be diminished to equal, arithmetically, the feedback signal that represents the jack-applied bending force required for parallelism. The shape bias signal will thereafter remain at this value, unless the operator finds, as he may, that thermal conditions have changed to a point requiring readjustment of the shape control **77**.

The operator may then bring the mill up to speed, with accompanying decrease of the screwdown load, as may be conventional. The decrease of rolling load is sensed by the load cells **60** and results in a corresponding decrease of rolling load signal at the terminals **71, 72**. This unbalance of the circuit causes operation of the servo valve **50** in the manner described above, specifically in a direction to increase the pressure in the contour jacks and to decrease it in the balance jacks. As a result the bending forces exerted at the necks of the work rolls are changed to have the precise amount and proper direction (toward or away from each other) to maintain a parallel shape of the roll gap at the changed rolling load; indeed one such load value might be such as to require no net applied bending force, whereupon the jack forces are equal and opposite, with zero signal at **86, 87**.

Thereafter, as changes occur in the rolling load, in one direction or the other, corresponding automatic adjustment of the forces of the bending jack system is accomplished, and good strip flatness is preserved throughout the entire pass. Indeed, in practice, the system automatically takes care of any and all changes that are reflected by the rolling load, whether intentionally or automatically occurring, as to maintain gauge or elongation, and as to accommodate varying hardness of the metal. Likewise, any leakage from the jack hydraulic system is similarly compensated, in that change in signal from one or the other of the transducers **80, 81** is read as an error in the circuit **65**, with consequent adjustment of the servo valve to restore jack pressures to intended values. The system is thus advantageously such that the current in the servo coil **52** more or less oscillates about zero so as to maintain a dynamic equilibrium.

A more detailed diagram of a suitable hydraulic circuit is shown in FIG. 3, but nevertheless simplified with respect to conventional structure or features of a hydraulic system that are not a part of the present invention. Suitable hydraulic liquid is stored in a tank **130** from which it is withdrawn by a pump **131** to be delivered in the high pressure conduit **132** through appropriate valves including a check valve **133**. The line **132** extends to the inlet **54** for the servo valve, from which the output line **56** runs through a spring-opposed check valve **134** to a main return conduit **135**, whereby the liquid can be discharged to the tank. The pressure of liquid in the supply lines **132, 54** is kept at a constant, high value by cooperation of a conventional accumulator **137** functioning to accommodate transient changes, and a pressure relief valve **138** which extends from line **132** to the return line **135** and which is set to maintain a preselected maximum supply pressure.

Line **44** extends from the servo valve **50** toward the balance jacks through a manual, normally open valve **140** and a remotely controllable valve **141**, the latter being operable, when desired, by deenergization of a solenoid **142**, to shift the work roll balance jack input **44***a* to drain into the line **135**. Likewise, the contour jack supply line **42** extends through a manual valve **144**, normally open, to the lines **40** and **41** respectively leading to the top and bottom contour jacks, through remotely controllable valves **146, 147**, similar to the valve **141**. The valves **146, 147** are normally held in position connecting the lines **40, 41** to the contour jack feed lines **40***a*, **41***a*. The pressure transducers **80, 81** (see also FIG. 1) are connected to appropriate localities for sensing the contour and balance jack pressures, i.e., with reference to the lines **42, 44** as shown. A check valve **134** advantageously functions to prevent complete draining of the jacks when the line **56** is connected to one or the other of the lines **42** and **44**; the spring of this check valve is set to allow opening of the valve only at some low minimum pressure sufficient to keep the jacks from collapsing when the system is not in use, but nevertheless of such character as to permit desired drainage from the jacks for the described automatic operation. Appropriate filters are included in the supply line **132**, e.g., as indicated at **448** and **449**.

When the automatic system is not operating, the valves **140, 144** can be closed, and normally closed valves **140***a*, **144***a* can be opened, connecting the high pressure line **132** to the several lines to the remote-controlled valves **141, 147, 146**; the latter can then be employed for manual control of the condition of the several jacks, as for example at a time of changing rolls.

The servo valve **50** is indicated schematically in FIG. 3 as any suitable device for attaining the desired function, for example the valve so designated in FIG. 1 and arranged, under control of the coil **52**, to shift the valve spool or like element in one direction, e.g., to the right, to connect the contour jack line **42** with the high pressure line **54** and the balance jack line **44** to the return **56**, and in the opposite direction, e.g., to the left, for reverse connection of the lines. In a presently preferred type of servo system as shown in FIGS. 1 and 3, the displacement of the valve spool **90** is proportioned in amount as well as in direction to the error signal appearing across the coil, so that the rate at which pressure builds up in one of the two groups of jacks (balance and contour) and falls in the other of them is proportioned to the magnitude of change required. In all cases, when the feedback signal from the pressure transducers has changed by the required amount to balance the error signal, reaching a null condition of the circuit **65**, the current in coil **52** falls to zero and the valve spool **90** returns to its null position, closing all of the jack hydraulic lines.

As will be readily understood, the hydraulic supply pressure set, by the relief valve **138**, to be available in the line **132–54**, is selected at a high enough value whereby the difference of contour and balance jack pressures can reach a desired maximum in either direction, corresponding to the contemplated maximum bending of the work rolls at their necks, both toward and away from each other. If the control of the valve **50** happens to require no forcible deflection either way, the contour and balance jack pressures are equal with the valve in null position; as the desired magnitude of deflection varies in either direction, the difference of jack pressures reached at corresponding balanced conditions of the servo system is necessarily proportional to such magnitude. Maximum deflection is obtained when the pressure in one of the sets of jacks reaches the full value of the hydraulic supply and at the same time the pressure in the other set is at minimum, e.g., as determined by the check valve **134**.

Biased check valves **148, 149** are respectively located in bypass lines between the contour and balance jack conduits **42, 44** and the liquid pressure line **132–54**; these valves are strongly biased to remain closed up to a pressure above that of the supply, but if a large pressure surge in the lines **42, 44** (or either of them) occurs, as is possible, at the end of a pass, the servo valve is bypassed and the pressure surge is contained below a safe value.

If the mill is of prestressed design, involving a special counterforce between the top backup chocks and the bottom backup chocks which is applied, as by jacks, wedges or other means, to put the mill frame and its parts under stress opposing the screwdown force to a minor extent, and which functions to achieve a more rigid assembly, it is necessary to substract this prestress force, in effect, from the signal of the load cells or equivalent means responsive to total screwdown force, in order to have a net rolling load signal for the present control system and method. In FIG. 2 the mill **10** is shown as prestressed by the use of backup roll balance jacks **150, 150** between the upper backup chock **13** and the lower backup chock **15**, it being understood that these and all other jacks shown in FIG. 2 are duplicated at the other side of the mill. These jacks are connected to the hydraulic system by a manifold conduit **152** (FIG. 3) that has branches which lead to the several jacks **150** (being one, or as shown in FIG. 2, two on each side) in a conventional manner, not shown. Through a remotely controllable valve **154**, similar to the valve **141**, hydraulic liquid is supplied to the line **152** by a line **155** from the liquid pressure supply line **132**. Although, if desired, manual or other control may be provided for the pressure in the backup roll jacks **150** in accordance with requirements of practice, the system is shown for simplicity (in FIG. 3) as keeping these jacks under full pressure of the system, applied as or before screwdown force is initiated at the beginning of a rolling pass.

In FIG. 2, means for producing a net rolling load signal across a pair of electrical conductors **156, 157** are schematically shown as including an instrumentality **158** that provides a readout to total backup balance jack force in suitable electrical terms, shown for simple illustration as a voltage across conductors **159, 160**. The device **158** may include pressure transducers of conventional sort (not shown) connected through hydraulic pressure-conducting lines **162** to the backup jacks **150** or their supply conduits, and appropriate electronic or other electrical means which may involve appropriate circuits of known character (likewise not shown) for producing an output voltage that is representative of the sum of the backup jack forces. A suitable readout device **164** is controlled by the load cells or load cell assemblies, of which one is indicated at **60** on the side of the mill shown in FIG. 2, through electrical connections represented at **166, 166**; this device may be of known character (and is therefore not shown in detail) for producing an electrical signal, illustrated as a varying voltage across conductors **167, 168**, that represents the total of the load cell readings as total force exerted by the screwdown on the backup chocks. The signal from the device **158**, across conductors **159, 160**, is appropriately subtracted from the signal dilevered by the device **164** across conductors **167, 168**, as in suitable electrical means **170**, to yield the desired net rolling load signal, for example as a varying voltage, across the conductors **156, 157**.

It will be seen that by subtracting the total backup roll balance jack force (exerted between the upper and lower backup chocks) from the total screwdown force exerted on the backup chocks, the difference is always the actual force extered between the backup rolls, i.e., on the work rolls and the strip, by the screwdown, and is therefore the net rolling load. Thus when a prestressed mill is used, means such as just described may be employed in FIG. 1 for delivering the variable rolling load signal voltage across the potentiometer **70**, e.g., by connecting the device **170** and lines **157, 156** (with appropriate polarity) to the lines **63, 64**, instead of the single readout device **62**.

For completeness of illustration, FIG. 2 shows a gauge control system, simply indicated as a device **172** for detecting the actual thickness or gauge of the issuing, product strip **35b**, and control means **173** that may be operated in response to the gauge detector **172** for adjusting the screwdown drive, and therefore the rolling load force, in order to maintain uniform gauge of the strip at a selected value. Means of this sort are known, including automatic systems, and are therefore not shown in detail, but they are significant in the present combinations of system and procedure, in that when the screwdown is adjusted for gauge regulation, the instrumentalities of the present invention automatically correct the deflection of the work rolls as required by the change of rolling load, to maintain flatness.

In FIG. 4 a somewhat more complete control system is schematically indicated, but nevertheless embodying the basic elements of preceding views and being understood to function, of course, with a 4-high mill and a hydraulic system of bending jacks as shown and described in connection with preceding views. Thus in FIG. 4 the servo coil **52** will be understood as functioning to control the value **50** of FIGS. 1 and 3, for adjustment of the balance and contour jacks, and the device **170a** will be understood as corresponding to the device **170** of FIG. 2 for delivering a continuous signal e.g., a D.C. voltage, varying in accordance with net rolling load, across the conductors **156**, **157**. Alternatively if the mill is not of prestressed design, a direct readout from the load cell system may be employed as at **62** in FIG. 1.

The circuit of FIG. 4 is exemplified as including certain known servo control units **175**, **176** and **177**, each being an electronic system which is designed to receive both an A.C. input signal and one or more D.C. signals of the nature of a control bias, to yield an amplified electrical output, in the form of a supply of current, as for example to the servo coil **52** (from the device **176**) which will depend on the relation of the input signals, in a manner analogous to the description of the circuit of FIG. 1. The specific arrangement of elements in the controllers **175**, **176** and **177** forms no part of the present invention, and devices of this sort are known and available.

For supplying the feedback signal from the work roll bending jacks, the pressure transducers **80a**, **81a** (of conventional type), that are connected to the hydraulic lines of the contour and balance jacks in exactly the same fashion as the elements **80**, **81** in FIGS. 1 and 3, are here shown as yielding an alternating current signal, the indicated opposition of polarity of these devices being thus actually an opposition of phase in their A.C. outputs, which can also be characterized as a phase difference of 180°. The devices **80a**, **81a** are energized from a suitable A.C. source, as indicated at **178**, **179**, with appropriately adjustable resistors **180**, **181** for initial sensitivity setting. The combined output from the series-opposed connection of the transducers is delivered across conductors **183** and **184** (the circuit being simplified by showing ground connections where convenient, as at **184**) and extends as an input at **185** to the servo controller **176**.

In the latter device, through an appropriate A.C. amplifier **186**, which is supplied with alternating current of the same frequency as the current supplied at **178**, **179**, the output at the line **188** can be an alternating current signal which may be taken as a measure of the value and direction of difference of the signals from the balance and contour jack systems. Whereas in FIG. 1, for simplicity of illustration, the net feedback signal was indicated as a D.C. quantity which would be zero at equal jack forces and would have a polarity and magnitude, dependent in one direction or the other, on a difference of such forces, the signal at **188** may be an alternating current value which has a phase and an amplitude dependent on the direction and magnitude of the bending jack forces.

Through a demodulating amplifier **190**, this signal may be converted to a D.C. quantity in the line **191** to a D.C. amplifier **192**, i.e., being a voltage which represents the difference of balance and contour jack forces. While this signal may have a range into values of opposite polarity, as at **86**, **87** in FIG. 1, an alternative and equally effective arrangement, providing the control circuit is otherwise suitably biased, is to utilize a signal varying only in quantity as indicated above, for example being zero when the contour jack pressure is maximum in respect to the balance jack pressure, and being maximum when the balance jack pressure correspondingly predominates at maximum difference of the latter system, and having a settable intermediate value representative of zero force difference, i.e., representative of equality of the feedback signals from the balance and contour jack systems at the transducers **80a**, **81a**.

The input circuit supplying the control or operating bias to the D.C. amplifier **192** also includes a continuing signal from the manually adjusted shape control potentiometer **77a**, via the conductor **194**, and a continuing signal from the width control potentiometer **70a**, via a conductor **195**. Return conductors of these bias input signals are omitted for the sake of clarity, except by indication of the other side of the shape control bias at **196**. While the latter bias may be a single magnitude, it may be convenient, where the bias or feedback signal from the pressure transducers (in line **191**) in a varying single magnitude, to provide for adjustment of the shape bias over a range extending to opposite polarities, e.g., a plus or minus D.C. voltage. Simply to indicate this alternative mode of signal presentation, the other line **196** of the shape bias signal is shown as connected to the center tap **198** of a voltage dividing resistor **199** across the D.C. supply voltage **200** for the shape control potentiometer **77a**.

The basic function of the system is the same as above explained relative to FIG. 1, namely that the main controlling signals reaching the input of the D.C. amplifier **192** are those of the initial shape control potentiometer **77a**, represented at the conductor **194**, the controlling signal of rolling load supplied as indicated by conductor **195** from the output of the width-adjusted control **70a**, and the feedback signal representing the pressure difference of the contour and balance jack systems, derived as explained above, and supplied as represented by the conductor **191**. The polarities and mutual arrangement of these signals for the control of the amplifier may assume various forms, including the aid of fixed or preliminarily adjustable bias as necessary and can be basically explained as accomplishing the functions already described.

That is to say, at an initial rolling load, the input to the D.C. amplifier should be such as to produce zero current in the servo coil circuit **66a**, **67a** when the shape controller **77a** has been adjusted for observed proper flatness of the strip, the balance and contour jack system then providing a feedback signal of necessary opposing effect, i.e., such that the combined shape and feedback signals balance the rolling load signal, the combination of the shape and feedback values being additive or subtractive depending on the mutual situation of polarity and magnitude of these signals. Basically, moreover, it should be remembered that as rolling load thereafter decreases, the result should be a decrease of balance jack pressure relative to contour jack pressure, to reach a null control point at each condition of rolling load. Hence the net effect of the combined feedback and shape adjustment signals should be of opposite polarity to the rolling load signal derived from the control device **70a**, throughout the operating range of rolling loads.

Thus in one suitable example of the system wherein the bending force difference signal, supplied at **191**, is of a single polarity varying from zero magnitude at maximum prevalence of contour jack bending force to maximum magnitude at maximum prevalence of balance jack bending force, the polarity of the rolling load signal, at **195**, may conveniently be of opposite effect in the control circuit, and the shape control device **77***a* can then be set, e.g., at the outset of a given rolling pass, to supply a signal through the line **194** which is of a polarity and magnitude as required for balancing the circuit to provide the desired condition of the strip.

It will now be seen that with appropriate initial calibration, the system of FIG. 4 is designed to function similarly to the system of FIG. 1, in permitting initial or presettable shape adjustment at initial (e.g., high) rolling load, and thereafter in providing automatic adjustment of roll deflection, in proportion to decrease and other changes of rolling load throughout the pass, for maintaining the desired strip flatness.

Whereas in the specific description of the figures reference has been made to the rolling load signal as being the net screwdown force determined in the manner of FIG. 1 or FIG. 2, it is found that more accurate and strictly proportional results, in maintaining the precise requirements of roll deflection over a large operating range of rolling loads, are achieved by subtracting, in effect, from the rolling load signal the actual opposing force of the contour jack system. As will be readily seen, this arrangement means that the actual rolling load response is then effected with respect to the load that the backup rolls exert by contact with the work roll; in other words the preferred control by rolling load signal is with respect to the rolling load determined at the line between the backup and work rolls.

Accordingly in FIG. 4 an A.C. signal derived from the contour jack transducer **80***a*, as indicated at the conductor **201**, is supplied to the separate servo control unit **177**, which may be similar to the unit **176**. There the contour jack signal is amplified in the A.C. amplifier **202**, in effect with modulation of an A.C. supply of the same frequency, and the A.C. signal at conductor **204** then controls the demodulating amplifier **205**, to yield a D.C. signal at the conductor **206** appropriately opposing and reducing the net rolling load signal, indicated at the conductor **156**, both of these signals being supplied as control bias to the D.C. amplifier **208**. In consequence the output at **210**, **211** of the unit **177** represents a current through the potentiometer **70***a* that varies with the adjusted rolling load signal, i.e., being a measure of the rolling load as applied by the backup rolls to the work rolls. It will be noted that the magnitudes of the signals supplied at **206** and **156** to the amplifier **208** may be readily calibrated in proportion to values of force, so that the net input bias signal is a measure of the force of the rolling load, adjusted in the manner indicated. The function of the principal control effected for the output of the amplifier **192** and for energization of the servo coil **52** is, of course, exactly the same in principle, as before, for the last-described special or adjusted of rolling load force.

The system may also include, if desired, automatic shape controlling means, for example cooperating with the initially set manual shape control **77***a*, to provide compensation for changes of thermal crown or other slow variation of roll gap configuration, such means being indicated at **212** and detailed in FIG. 5, as described hereinbelow.

To provide a visual reading of force differential, the signal from the combined balance and contour transducers **80***a*, **81***a* may also be supplied, as indicated at conductor **214**, to another servo control unit **175**, conveniently indentical with the units **176** and **177**, so adjusted that its output circuit at conductors **215**, **216** may include an electrical meter **218**, e.g., a voltmeter, that can be calibrated to provide a continuing indication of the difference of bending jack forces at all times.

It has been explained that at the end of a pass, where tension is lost at the tail end of the strip, the system provides automatic adjustment to increase the bending jack differential in the direction of greater contour jack pressure, for guiding the trailing portion of the strip against sidewise movement. Referring to FIG. 2, such action may be controlled by any suitable means for sensing tension loss in the entering strip **35***a*. Since torque, against unwinding, is maintained in the shaft **39** of the supply reel for the coil **38**, a torque-sensitive device **220** is schematically indicated as suitable to detect loss of tension, for example by decrease or absence of opposing torque in the shaft **39**. This may be a conventional device operating on magneto-elastic principles, or other known instrumentality, which need not be detailed here, but which supplies, as in the conductor **222**, an appropriate signal to a control means **223** that is adapted to close a switch **225** when tension is lost in the entering strip **35***a*. As shown, closure of the switch **225** closes the energizing circuit **227** of the winding of a relay **228**, and in turn causes immediate closure of the relay contacts **230**.

As shown in FIG. 4 the relay contacts **230**, which are normally open but close under circumstances described above, are arranged to supply a special bias signal, as indicated by the conductor **232**, to the control system for the servo coil, conveniently by introduction with the signals supplied to the D.C. amplifier **208** that is primarily designed to yield the net or adjusted rolling load signal. However, as will be apparent, this tension-loss signal can be introduced to like effect elsewhere in the control circuits for the servo coil. The special bias value inserted by closure of contacts **230** is basically a signal of opposite sense to that of the rolling load or of increase in rolling load, and may be derived from the same voltage source **200** that supplies the basic shape bias from the potentiometer **77***a*. Particularly, as indicated by conductor **234** the signal may be derived from a suitable tap on a voltage dividing resistor **235** across the source **200**. For purposes of illustration, the voltage in line **232**, **234** is indicated as positive (relative to its return conductor **236**) and thus arranged in opposing polarity to the indicated negative value of rolling load signal in the lead **156**.

The effect of this special bias signal is to create a bending force on the work rolls toward each other at their necks, more specifically to provide at least some small concavity at central regions of the rolls; the polarity of the signal being in a direction to increase the pressure in the contour jacks and decrease it in the balance jacks. Hence as the freed tail end of the strip approaches the mill, the slightly crowned gap provides desired tail guidance, preventing movement or oscillation sidewise and keeping the strip properly centered.

When the end of the strip actually leaves the roll bite it is highly desirable to adjust conditions so that the work rolls do not become loose, in effect, as a result of the loss of rolling load pressure and also so that response to such loss does not immediately alter the bending jack forces in a way to have the same or like effect, the major problem being to avoid skidding between the work and backup rolls or other improper contact between any of the rolls, that would injure or disfigure their surfaces or shapes.

To that end, the tension-loss-responsive relay **228** also includes a pair of normally closed contacts **240**, which upon energization of the relay are caused to open after a small, predetermined delay, as for instance such that these contacts open just before the end of the strip reaches the roll gap. A convenient delay time for a conventional 4-high mill is about one-half second. As shown in FIG. 4 the contacts **240** are normally closed to short-circuit a resistor **242** in the circuit of the servo coil **52**, but when these contacts open, this resistance is incorporated in series, and has the effect of greatly reducing or attenuating the response of the servo coil and its valve to changes of control signals. Specifically, the resistor **242** is such that in effect the saturation voltage of the amplifier **192** is now capable of delivering only a small fraction, even at maximum, of that current which would cause full opening of the valve. Hence the system is in result removed from the so-called regulating mode of control and readied for control by roll balance, i.e., for use of the balance jacks **28** to keep the work rolls separated and in forceable contact with the backup rolls.

For convenient functioning of the amplifier **192** and its controlled circuit embodying conductors **67***a* and **66***a* leading to the servo coil **52**, the amplifier may be such that it is capable of supplying, in effect, an output voltage proportional to the error signal at its input, until the amplifier reaches a saturation value. This saturation value of voltage is conveniently chosen as such that the current in the servo coil **52** is then sufficient to move the spool **90** (FIG. 1) to the limit of its motion in one direction or the other, depending on the direction of servo coil current. Thus at saturation, the valve is in effect opened fully, to allow full flow to either the roll balance or the roll contour line. The servo coil being a relatively low impedance element, this full flow current is in effect matched by a resistor **244** in series with the coil **52**.

When the tail end of the strip actually leaves the roll gap, there is an instantaneous increase of roll balance jack pressure as a consequence of the elastic reaction of the mill housings. That is to say, during rolling operation, the load between the backup roll chocks is exerted against the mill frame, involving elastic stretch in such structure. When rolling load is released, and although some of the reaction may be absorbed by the backup roll balance jacks **150** if they are employed, there is substantial instantaneous reaction upon the work roll balance jacks **28**, momentarily increasing their pressure and in any event, causing them temporarily to maintain the work rolls in firm contact with the backup rolls. Both this increase in balance jack pressure, as sensed by the transducer **81***a*, and the loss of rolling load as sensed by the load cells **60**, constitute signals in the servo coil control circuit which would drive the servo valve **50** to a position of greatly increasing the contour jack pressure and reducing that of the work roll balance jacks. However, because of the function of the contacts **240** and the now-included resistance **242**, the result of this error signal is minimized and any chance in bending jack pressures can only occur at a very slow rate, allowing time for operation of other means to bring full pressure into the balance jacks.

While manual control can be employed, as with the valves **141**, **146** and **147** of FIG. 3, to maintain balance jack pressure and relieve the contour jacks for keeping the work rolls in the desired contact with the backup rolls, FIGS. 2 and 4 indicate a further, automatic feature of the present system for this purpose. Thus a suitable device **250**, which is actuated by release of the rolling load and which can, for example, be controlled from the rolling load signal lines **156**, **157** as indicated at **251**, closes its contacts **252** and thereby causes energization of a relay **253**, shifting its contact arm **254** from a normal position of closure with contact **255**, so as to open the circuit at the latter point and to close a circuit between the arm **254** and a contact **256**. Referring to FIG. 4 it will be seen that the normally closed contact means **254**, **255** is a part of the control circuit of the servo coil **52**, and when the arm **254** engages contact **256**, the servo coil is now energized directly by a separate source of current indicated by the negative voltage terminal **258**. The polarity of the last-mentioned source is such that the servo coil drives the valve **50** to a position (e.g., to the left in FIGS. 1 and 3) where full flow of liquid under pressure is supplied to the balance jacks while the contour jacks are allowed to discharge to a minimum pressure value. In consequence the balance jacks keep the work rolls in the desired contact with the backup rolls, avoiding skidding or other difficulty as the mill is brought to rest.

It will thus be seen that in consequence of the several instrumentalities described, the system functions at the end of a rolling pass to provide suitable guidance for the tail end of the strip, i.e., keeping it aligned with the center line of the mill by changing the geometry of the roll gap from parallel to convex. Furthermore the system is automatically conditioned to avoid any immediate response of the bending jack system to loss of rolling load, affording time for a separate release-of-load signal (at the device **250**) to bring the jack system into special function and thereafter keep the work rolls appropriately engaged with the backup rolls.

The system may also include a manual switch **260**, which can be moved from its off position either to a contact **262** for continuously energizing the relay **253** and maintaining full balance jack force by the bias voltage supply **258** (as explained above; FIG. 4), or to a contact **264** for energization of a relay **266**, which opens the servo coil circuit at **267** and closes a connection at contact **268** for impressing a positive voltage **269** on the servo coil. In the latter situation, full contour jack force is exerted, as may be desirable in the course of roll changing operations or other work of adjusting or setting up the mill.

Referring to FIG. 5, the automatic shape control indicated at **212** in FIG. 4 may employ a strip flatness sensor of a previously devised type, having a multiplicity of pressure sensing elements carried in or by a billy roll **270**, i.e., a supplemental, free-running roll. Specifically, the strip **35***c* issuing under tension from the work rolls **16**, **18** bends over the roll **270** in rolling contact, where the individual pressure sensing devices **271** detect the flatness condition of the strip, there being less or more pressure in acocrdance with lessening or localization of strip contact, at each given place, as may be due to waves, valleys, peaks or other departure of the strip from complete flatwise engagement. Using a multiplicity of elements **271**, one covering for example each 3.3 inches of roll length, signals are transmitted through suitable collecting and multiple conducting means **273**, **274** to individual signal output circuits represented at **275**, **275** in the wiring diagram. It may be noted that the mill shown schematically in FIG. 5 can be such as to correspond with the mills in FIGS. 1 and 2 and to include the balance and contour jack systems, with related instrumentalities as illustrated in FIGS. 2, 3 and 4.

The strip flatness sensor **270–275**, which is in itself another invention and which is not here claimed per se, as likewise alternative arrangements of such means that may also be available or proposed, is thus adapted to deliver a multiplicity of output signals, as shown at **275** and respectively related to successive localities across the width of the mill. Each such signal may be a voltage proportional to the off-flatness of the strip in the corresponding location, as for instance signals having a range of plus or minus 10 volts D.C., which for cold rolling of aluminum strip may conveniently correspond to tensile strength differences of plus or minus 5000 p.s.i. In the present flatness control system interest is preferably confined to the areas of the strip nearest its lateral edges. Hence, for example, at the locality of the array of terminals **275**, a pair of movable gangswitch assemblies **277**, **279** are provided, each adapted to connect with a selected three adjacent sensor terminals. Thus at the outset, the switch devices **277**, **279** are positioned to read the outermost portions of the strip, i.e., over three sensing units in each case, corresponding, for example, to a band totaling 10 inches wide, more or less, adjacent the strip edge. The signals from each side of the strip are summed separately by the networks **281**, **283** and brought together electrically via conductors **284**, **285** and resistors **286**, **287** to a line **288** extending to the input of a summing amplifier **290**.

For preferred operation, the significance or importance of the signals decreases inwardly from the edge of the strip, and in consequence in each group of signal elements collected by the networks **281**, **283** the signals are progressively attenuated for the pressure sensing elements located inward of the strip edge, this function being indicated by the individual resistors **291**, **292** and **293** in the lines extending from the switch unit **277**. Thus resistor

292 may have, for example, twice the resistance of element 291, and resistor 293 may have four times the resistance of element 291. A similar relationship can be embodied in the resistors 291*a*, 292*a* and 293*a* in the signal lines from the switch unit 279.

The output of the amplifier 290, at 295, thus delivers a signal proportional to the sum of the off-flatness condition at the regions of the two strip edges. This signal can be supplied to appropriate roll deflection control means such as the instrumentalities hereinabove described; for example the amplifier output line, indicated at B, may be connected as similarly marked B for this complete unit 212 in the circuit of FIG. 4, thereby supplying such signal as a bias in the input of amplifier 192 for control of the bending jack system through the servo coil 52. Such bias may be proportioned, as will now be understood, for summation with the manual shape bias supply through the line 194, or if appropriately set at a suitable level, can supplant such bias. In all such cases, the signal supplied to amplifier 192 is furnished at appropriate polarity for coaction with the rolling load signal in line 195 and the bending jack feedback signal in line 191, in the same manner as previously explained relative to the bias signal derived from the manual shape controller 77*a*.

It is found that the proportionality constant, of the signal in line 295 relative to the off-flatness condition adjacent to the strip edges, depends on the width of the strip, since larger roll bending forces are required to compensate for a given off-flatness condition detected on narrower strips. The required adjustment may be conveniently obtained, for example, by a variable resistor 296 in the line 297 representing a component of a feedback circuit of amplifier 290, e.g., a conventional negative feedback. Thus for wider strips, the proportionality constant is reduced by adjustment of the resistor 296 to a low value of effective resistance, while for narrower strips, greater gain and larger proportionality constant is achieved with the resistor 296 at a larger value of resistance.

The feedback circuit of the amplifier 290 also includes a capacitor 298 of suitably large value at least to allow for the time lag of the sensor 270–271 in detecting the effect of a correction, which it initiates, in roll deflection. More particularly an advantageous function of the circuit including condenser 298 is that the output signal in the line 295 cannot change very rapidly, and thus as delivered at locality B in the circuit of FIG. 4, is characterized by only slow or delayed changes in contrast with the relatively fast action of the rolling load signal. Hence in the arrangement of strip shape controller of FIG. 5, the function of the signal at locality B is to provide a bias for control of the roll bending forces, sufficient to compensate for changes of roll shape due to thermal drift, wear or other phenomena responsible for slow changes in strip flatness. The controller of FIG. 5 further coacts in the complete combined system, in that it effects compensation, but only at a very slow rate, for such minor part of the rapid changes of strip flatness (that are brought about by changes of rolling load) as may be due to residual errors in the automatic roll deflection control system. Experience indicates that such errors are ordinarily slight but the cooperative effect of the supplemental circuit of FIG. 5 is to minimize them, at least over extended periods.

In some instances a residual off-flatness condition may be desired for strip regions adjacent the edge, as to relieve tensions in such localities and thereby prevent edge cracks or strip breaks. To that end a manually adjustable bias may be introduced as input to the amplifier 290 from a voltage divider 299, which can conveniently be supplied with its base potential from a branch 194*a* of the bias line 194 from the manual shape controlled 77*a* (FIG. 4), such connection being indicated by the letter A in both views.

A further coacting feature, which may be optionally employed, is indicated by the amplifier 300 having its output line 302 connected through the resistor 303 to provide an additional bias signal in the input of the basic shape control amplifier 290. The amplifier 300 is supplied by a signal proportional to the roll bending force exerted by the bending jacks, e.g., by connection of the amplifier input line 304 to the point C of line 191, as indicated in FIG. 4, e.g., the bending force feedback signal which is delivered as a bias to the servo control amplifier 192.

The amplifier 300 has a feedback circuit comprising the resistor 306 and a condenser 308, so proportioned, especially with a large value of capacity for the condenser, that the amplifier output in the line 302 can only change in an extremely slow manner, the capacitor thus affording a time constant which in effect is substantially larger than that of roll shape changes due to thermal drift, i.e., the signal changes which are produced in the line 295 as a result of readings of the flatness sensor 270–271. Hence the supplemental input into amplifier 290 from the circuit including the amplifier 300 has the effect of producing a controlled drift of the roll bending forces toward a balanced condition in a very slow way. Under such circumstances the result is to allow fundamental control of strip shape to be retained or effected by adjustment of coolant sprays (not shown) on the work rolls, variable control of such sprays across the rolls being an effective but inherently slow, conventional mode of roll shape adjustment. With the aid of the supplemental balance or bending force feedback signal from the amplifier 300, the manual or conceivably automatic adjustment of coolant sprays can thus in the very long run cause the rolls to assume and maintain a thermal shape such that in combination with the shape to which the rolls have been ground and the automatic variation of roll deflection due to rolling load (through the instrumentalities of FIG. 4), together with the shape adjustments (of intermediate slowness) due to the signal in lines 284, 285, the mill will consistently produce the essentially highest degree of flatness in the issuing strip. Under these circumstances, maximum range and maximum accuracy of fast regulation, by means of jack forces, are available to take care of rapid changes of rolling load as sensed by the load cells and signaled, for example, in the conductors 156, 157 of FIG. 4.

At the end of each pass before the strip leaves the mill and the flatness sensor becomes inoperative, it may be advantageous to retain the signal at point B, i.e., in the output 295 of the amplifier 290, at a constant level until rolling of the subsequent pass commences. For this purpose a normally energized relay 310 is deenergized to open the input circuits of both amplifiers 290 and 300 at the contacts 312, 314, respectively. The condition of relay 310 may be controlled from a suitable main governing circuit (not shown) for this automatic flatness control system, and thus may be responsive to loss of back tension on the strip or other appropriate signal; for simplicity this control, which can of course be manual, is indicated as an on-off device 315, arranged to provide the above contact release by relay 310 when shifted to the off position. The condensers 298 and 308 serve as a long-term memory, maintaining the output signal levels at their last-established values, e.g., until connection of the input signals is again restored at the beginning of the next rolling pass.

Circumstances may also make it desirable to change the shape control to a manual mode. For such purpose a selector switch 318 is arranged for simultaneous control of the input circuits of the amplifiers 290 and 300, having a first position with closure of contacts 320, 322 in the respective circuits for maintaining automatic operation, and a second, open position indicated at 324, 326 where both circuits are nonfunctional and manual control is therefore available. Thus if the change of control mode is desired during an operation of rolling at high speed, shift of the switch 318 to the position 324, 326 will afford no disturbance of the roll bending forces; the signal in line **295** will maintain its value over a long time (condenser **298** remaining charged), and for like reasons so will the signal in line **302**. If at the end of the rolling pass the operator wishes to reset the signal or otherwise adjust the control system, the switch **318** may be moved to a third position indicated at **328**, **330** for the respective amplifiers **290**, **300**, so that the capacitors **298**, **308** rapidly discharge through resistors **332**, **334**.

As will now be seen, the primary function of the shape control instrumentalities of FIG. 5 is to account automatically for roll shape changes due to thermal conditions, e.g., heating or cooling of the rolls, that may be significant but occur over relatively longer periods than the rolling load variations which are accommodated by the deflection control system of FIGS. 1 to 4. Further, an even slower compensation is attainable, if desired, for permitting basic control of thermal shape by conventional spray means—e.g., fundamentally controlling the temperature rather than relying solely on deflection to compensate for its variations—while nevertheless maintaining correction for all changes that cannot feasibly be reached with coolant spray control, e.g., rapid variations due to rolling load change, and variations of thermal origin or the like for which optimum correction, although slow, may nevertheless require faster response than by spray coolant adjustment.

A further automatic control embraced by the system of FIG. 5 is advantageously related to the relative position or adjustment of the two sides of the screwdown mechanism of the mill, specifically for controlling the effective condition of the two screws, that respectively bear on chocks at opposite ends of the rolls, to maintain symmetrical flatness of the strip across its width. To that end the summed signal from the flatness sensors at one side, i.e., derived at the switch **277**, is transmitted by a line **340** to an amplifier **342** while the signal from the sensors at the other side of the strip (switch **279**) is carried by a line **344** to an inverter device **346**, e.g., an electronic circuit of known character adapted to reverse the polarity of the signal, such signal being then also transmitted by line **348** to the amplifier **342**. In the latter device, these signals are algebraically summed, e.g., to yield an output in line **350**, which is proportional to the arithmetical difference of the input signals.

Hence a signal proportional to shape imbalance, if such exists, is delivered in the line **350** and is arranged to actuate a polarized relay **352** in one direction or the other, conveniently when such signal exceeds a calibrated threshold value and therefore represents a significant departure from symmetry of any nonflatness conditions adjacent to the strip edges. When energized in one direction, the polarized relay thus closes the circuit to a contact **354** and when energized in the other direction, to a contact **356**, such circuits extending to a screwdown control instrumentality **358** which may be of conventional sort for differentially adjusting the screws as well as for other purposes of maintaining effective balance of screwdown force on the roll chocks. For convenience of illustration, the control system **358** is shown as extending to lefthand and righthand drive instrumentalities **360**, **362** for the corresponding screwdown assemblies **364**, **366** of the mill, all of these parts being shown merely in diagrammatic fashion, as constituted by known elements and connections, otherwise available for rolling mill control. The system **358** may also, of course, provide for the usual identical, simultaneous adjustment of the screwdowns when desired, such as for various conventional purposes.

While the signal resulting from closure of the one or the other of the circuits controlled by the relay **352** may be derived from other sources, a special feature is the utilization of a rolling load signal, taken from the point D in the circuit of FIG. 4 and so designated at the line **368** of FIG. 5, leading to the movable contact **370** of the relay **352**. As will now be understood, when the contacts **370**, **354** are closed, the screwdown system will be operated differentially in one direction, e.g., moving the left screw downward and the right screw upward, while a reverse differential adjustment will occur on closure of contacts **370**, **356** as to move the righthand screw upward and the left screw downward. In either case the adjustment is terminated when the difference of off-flatness signals in the lines **340**, **348** becomes zero, or falls below the calibrated threshold, the result of the adjustment being thus to establish or restore symmetry of conditions in the issuing strip **35***c*.

By utilization of the rolling load signal at locality D in FIGS. 4 and 5 for this actuation of the screwdown control **358**, the screws are caused to move at a speed proportional to the adjusted rolling load signal from the load cells. It has been noted that the screwdown transfer function, being the extent of strip gauge correction effected per unit of screw displacement, is a function of net rolling load and of the width of the strip. It is correspondingly preferable to compensate for such variation of the stated transfer function, in order to avoid extreme conditions of instability or to avoid unsatisfactorily slow response, in the presently described differential screwdown adjustment. Since the signal (locality D, FIG. 4) from the output of the width-adjustment potentiometer **70***a* is inherently properly proportioned with respect to rolling load and width of the strip, use of this signal effectuates the desired compensation in a convenient manner. In summary, the special screwdown control thus automatically maintains symmetry, by operation of the polarized relay when significant departure from such condition arises. If the flatness condition as developed by the roll gap is in fact symmetrical, whether because of equal off-flatness or because the desired good flatness is present across the entirety of the strip, the relay **352** remains deenergized and no screwdown adjustment by the instrumentality **358** is required.

It will be appreciated that in FIG. 5, as in other diagrammatic views, the several electronic and other components, such as the amplifiers, may be of conventional construction appropriate to perform the stated functions, suitable amplifier or other circuits in each case being known and available. It will be similarly understood that whereas the diagrams have been simplified for purposes of illustration, as for instance by showing summation of signals in FIG. 5 with circuits of parallel connection, other modes of adding or combining signals may be actually employed, for example, when the signals are to be handled by increments of voltage bias rather than current values, such understanding being applicable, where appropriate, to other aspects of the several views of the drawings.

Reverting to the basic roll deflection control systems and methods illustrated in FIGS. 1 and 4, it will be appreciated that selection of circuit parameters and calibration of adjustable elements can be readily achieved in accordance with known principles, as will be necessary to accord with the dimensions, geometry, and contemplated operating characteristics of a particular rolling mill to which the invention is applied. Thus for a given mill the range of rolling loads and their values as read from load cell systems can be easily determined, as likewise the values of jack pressures and corresponding bending forces required for roll deflections that will be needed to accommodate a wide range of rolling loads and roll configurations, all being thus determinable by ready test or calculation. Indeed, for example, the transfer function that relates the proportionality of roll deflecting force to rolling load, i.e., the variation of the proportionality constant by which the ratio of change in jack pressure difference to change in rolling load varies with strip width, can be readily precalculated for a given mill in accordance with known principles, including the theory of beams resting on elastic foundations. As explained above, this variation of proportionality constant has been found to be a straight-line function, which can be plotted linearly from a high value for narrow strips to a low value for the widest strip (approaching zero at full width of the work rolls) and can thus be determined; for example, in FIG. 4 the basic, nonsignal bias of amplifier **208** can be adjusted, with simple test of the mill in operations using different widths of strip if necessary, to afford attainment of a proper slope of the linear graph of proportionality constant pursuant to adjustment of the width-setting potentiometer **70***a*, and similar basic calibration is attainable in the simplified system of FIG. 1, respecting the output of potentiometer **70**.

As explained, an important feature of the present method of roll deflection control involves separate adjustment of two components constituting the required signal or required value of roll bending force, for maintenance of strip flatness. Thus for instance, referring conveniently to FIG. 1, the desired controlled bending force represented by the feedback signal at **86, 87** can be considered as equal to the algebraic sum of the shape bias, being one parameter, and a second bias or signal that is derived from the rolling load and that equals, in effect, the product of the rolling load signal (at **63, 64**) and a second parameter, such second parameter being the proportionality constant which is in effect adjusted by the width control potentiometer **70**. Not only is the second parameter itself an essentially linear function of strip width as explained above, but for each setting of the parameters, both the last-mentioned product (the signal at **71, 72**) and the algebraic sum of the bias values (i.e., the sum of such product and the shape bias) which is equated to the required bending force are essentially linear functions of the rolling load.

By virtue of these discovered relationships, and their utilization as described in the method and system of the invention, effective control of strip flatness is achieved, relative to variations of rolling load, and also relative to inherent shape of the work rolls as affected by thermal conditions, the original configuration as ground, and the like. Indeed it will be seen that calibration of the several instrumentalities for a given circuit and mill can be readily achieved with simple tests if necessary, as by preliminarily measuring the total electrical signal required (for bending force control) to achieve actual strip flatness (e.g., as observable at reduced tension) for a plurality of rolling load values (measured at **63, 64**) with a given width of strip. Since these total values can be plotted as a straight-line function, the actual value for setting the shape bias control (as the constant term of the binomial) is determinable by extrapolation and thereupon the value of width control setting (at **70**) needed for maintenance of the individual straight-line function of the output **71, 72** (the other term) can be determined from the rolling load values with the aid of adjustment, if necessary, of the proportionality in the load cell readout (or in the amplifier **208** of FIG. 4). Final calibration of the potentiometer **70** in units of width is then attainable (in view of its own straight-line function as explained) upon similarly determining another setting of this device by like tests of the mill with a strip of another width.

In essence, by virtue of the principles discovered, including the basic linear relationships, the system is readily applicable to any desired rolling mill, for ultimate operation in the stated manner, whereby for rolling any given strip, the attendant first sets the device **70** (or **70***a*) to the strip width, and then as the rolling operation is initiated at slow speed, sets the shape control **77** (or **77***a*) to achieve desired flatness as observed. The bending jack system is thus automatically brought into function and as rolling proceeds, the necessary changes of bending force to accommodate changes of rolling load for maintained flatness are automatically achieved.

Extended tests have demonstrated that the response of the bending jack operation to rolling load change can be very rapid, e.g., involving a response time of less than ten milliseconds and usually of the order of three milliseconds. This fast response involves a more or less continuous tendency of hunting in the servo system, back and forth across a position of zero error signal, the effect being to promote rapidity of control, yet inherently without excessive departures as might impair the desired result of a continuously maintained flatness in the strip. By way of example, off-flatness of aluminum strip produced in cold rolling, without the present system and with ordinary methods of manual control, may involve waves or like nonflatness having a magnitude measurable, in terms of excess length of selected longitudinal bands of the strip, over average band length, of the order of 10 to 1000 parts per million, whereas the present system has been found capable of essentially reducing such errors, even down to the lowest limit, with consequent production of a desirably flat product.

As also indicated, the method and control system, having the desired linear relationships, is notably applicable to mills wherein the length of the contact line between each work roll and its backup roll is not greater than about 4.5 times the work roll diameter. Thus for example, highly effective results have been achieved in a 4-high mill, employed for cold rolling aluminum strip to gauges of 0.200 to 0.010 inch, wherein the diameter of each work roll was 21 inches, the backup roll diameter was 54 inches and the effective work roll length, i.e., its contact line with the backup roll, was 78 inches. Although the invention has been exemplified in cold rolling aluminum, the systems and method are applicable to such rolling of other metals, e.g., steel, brass, copper and the like. It is conceived that the apparatus and procedure are useful for hot mills, but maximum advantage of the invention, and indeed chief need for it, is at present understood to reside in the situation of the cold rolling of metal strip, i.e., to various intermediate and finish gauges.

It is to be understood that the invention is not limited to the structures and specific operations herein shown and described, but may be carried out in other ways without departure from its spirit.

We claim:

1. In a rolling mill control system, in combination with a 4-high mill having upper and lower backup rolls, upper and lower work rolls between the backup rolls, providing a roll gap for a strip of metal being rolled, chocks at the ends of each of said backup and work rolls, and supporting means for the backup roll chocks including screwdown means for maintaining rolling load on the backup rolls: means associated with said supporting means for detecting changes in rolling load, bending jack means for the work rolls including bending jacks between the upper work roll chocks and the lower work roll chocks, means controlled by the load-detecting means for adjusting the roll-bending force of the bending jack means in proportion to changes in rolling load, to counteract changes in roll gap shape due to changes in rolling load, means controlling said adjusting means for varying substantially only the proportionality thereof, settable to provide a desired proportion between changes in rolling load and the changes in bending jack force produced by said adjusting means, and separate means controlling the bending jack means for adjusting the bending force thereof, settable to provide a desired base condition of bending force which is subjected to change by operation of said first-mentioned adjusting means, for achieving substantially the same desired configuration of the rolled strip at all adjustments of bending force effected by said first-mentioned adjusting means in response to changes in rolling load.

2. A rolling mill control system as defined in claim **1**, in which said separate means includes and is controlled by means for sensing the flatness of the rolled strip, to effectuate said control of the bending jack means for maintaining a desired condition of flatness of the rolled strip.

3. In a rolling mill control system, in combination with a 4-high mill having upper and lower backup rolls, upper and lower work rolls between the backup rolls, providing a roll gap for a strip of metal being rolled, chocks at the ends of each of said backup and work rolls, and supporting means for the backup roll chocks including screwdown means for maintaining rolling load on the backup rolls: means associated with said supporting means for detecting changes in rolling load, bending jack means for the work rolls including bending jacks between the upper work roll chocks and the lower work roll chocks, means controlled by the load-detecting means for adjusting the roll-bending force of the bending jack means in proportion to changes in rolling load, to counteract changes in roll gap shape due to changes in rolling load, and means controlling said adjusting means for varying substantially only the proportionality thereof, settable to provide a desired proportion between changes in rolling load and the changes in bending jack force produced by said adjusting means, said bending jack means including bending jacks between the backup roll chocks and the respectively adjacent work roll chocks, said adjusting means being arranged to control the pressures in said first and second-mentioned jacks for changing the difference between the pressure in the first-mentioned jacks tending to push the work roll chocks apart and the pressure in the second-mentioned jacks tending to push the work roll chocks together, to effect adjustment of the roll-bending force of the bending jack means.

4. A rolling mill control system as defined in claim **3**, including separate means controlling the bending jack means for adjusting the pressure difference thereof, settable to provide a desired base pressure difference which is subjected to change by operation of said first-mentioned adjusting means, for achieving such shape of the roll gap, to be maintained by the first adjusting means, as will provide a desired configuration of the rolled strip.

5. In a rolling mill control system, in combination with a 4-high mill having upper and lower backup rolls, upper and lower work rolls between the backup rolls, providing a roll gap for a strip of metal being rolled, chocks at the ends of each of said backup and work rolls, and supporting means for the backup roll chocks including screwdown means for maintaining rolling load on the backup rolls: means associated with said supporting means for detecting changes in rolling load, bending jack means for the work rolls including balance jacks between the upper work roll chocks and the lower work roll chocks and contour jacks between the backup roll chocks and the respectively adjacent work roll chocks, means controlled by the load-detecting means for adjusting the forces of the bending jack means in proportion to changes in rolling load, to counteract changes in roll gap shape due to said changes in rolling load, said adjusting means effecting a change of the difference between balance jack pressures tending to push apart and contour jack pressures tending to push together the work roll chocks, said change of pressure difference being in proportion to the changes in rolling load, means in controlling relation to said bending jack means and settable to provide a predetermined base pressure difference in said jack means for establishing a base bending force on the work rolls about which the aforesaid adjusting means changes the bending force produced by said jack means in proportion to rolling load, and means to adjust said proportionality of control by said first-mentioned adjusting means, to provide a proportionality suitable for the width of the strip, comprising means which is arranged in controlling relation to said first-mentioned adjusting means for varying the proportionality thereof independently of said first settable means and which is settable to provide a desired proportion between changes in rolling load and the changes in bending force produced by said adjusting means.

6. In a rolling mill control system, in combination with a mill having upper and lower backup rolls, upper and lower work rolls between the backup rolls, providing a roll gap for a strip of metal being rolled, and supporting means for said backup and work rolls including means for maintaining rolling load on the backup rolls: controllable roll-bending means applying bending forces at the necks of the work rolls for coaction with forces exerted by rolling load to provide bending effect on the work rolls which is adjustably directed to vary the separation between said work rolls at their ends relative to central regions thereof, for altering the shape of said roll gap as traversed by a strip under rolling load, a plurality of control means in controlling relation to said roll-bending means, independently operative to adjust said bending forces and conjointly operative to determine said bending effect, for maintaining a predetermined roll gap shape, and means for detecting changes in rolling load, a first one of said control means being controlled by said detecting means, for adjusting said bending forces in proportion to changes of rolling load, and including independently controllable means for varying the proportionality of said last-mentioned adjustments to rolling load changes, and a second of said control means being adjustable to establish said predetermined gap shape which is subject to being maintained by operation of said first control means in response to changes of rolling load.

7. A system as defined in claim **6**, which includes means responsive to departure of a strip from the roll gap and arranged in controlling relation to said bending means, for adjusting said forces on the necks of the work rolls to keep said work rolls apart and respectively in contact with the backup rolls.

8. In a rolling mill control system, in combination with a mill having upper and lower backup rolls, upper and lower work rolls between the backup rolls, providing a roll gap for a strip of metal being rolled, and supporting means for said backup and work rolls including means for maintaining rolling load on the backup rolls: controllable roll-bending means applying forces at the necks of the work rolls, differentially exerted in directions to push said work rolls apart and together at their ends, for altering the shape of said roll gap as traversed by a strip under rolling load, a plurality of control means in controlling relation to said roll bending means, independently operative to adjust the differential effectiveness of said forces and conjointly operative to determine said differential effectiveness, for maintaining a predetermined roll gap shape, and means for detecting changes in rolling load, a first one of said control means being controlled by said detecting means, for adjusting said differential effectiveness of forces in proportion to changes of rolling load, and including independently controllable means for varying the proportionality of said last-mentioned adjustments to rolling load changes, to accommodate said proportionality to strips of different width relative to the rolls, and a second of said control means being adjustable to counteract effects of work roll configuration in causing departure of the roll gap from predetermined shape otherwise than by rolling load changes.

9. A system as defined in claim **8**, which includes means responsive to loss of tension of a strip traversing the roll gap for controlling the roll-bending means to adjust said differential effectiveness of forces to provide a convex shape of said roll gap for guiding the strip against sidewise displacement.

10. A system as defined in claim **9**, which includes means associated with said tension-loss-responsive means and operative in delayed response to said loss of tension, for attenuating the operation of the first-mentioned control means in control of the roll-bending means pursuant to change of rolling load, whereby upon subsequent departure of the strip from the roll gap and corresponding decrease of rolling load, said gap is maintained against rapid closure as would otherwise be caused by said first control means.

11. A system as defined in claim **10**, which includes means responsive to departure of a strip from the roll gap and arranged in controlling relation to said roll-bending means, for adjusting said differential effectiveness of forces to keep said work rolls respectively in firm contact with the backup rolls.

12. A system as defined in claim **8**, which includes means for sensing the flatness of the rolled strip, arranged in controlling relation to said second-mentioned control means, to maintain a roll gap shape which provides a desired condition of flatness of the rolled strip.

13. A system as defined in claim **12**, in which said flatness-sensing means includes means retarding its controlling operation over said second control means, whereby said second control means responds substantially more slowly to departures of the strip from flatness than the response of said roll-bending means to control by the first control means upon change of rolling load.

14. In a rolling mill control system, in combination with a 4-high mill having upper and lower backup rolls, upper and lower work rolls between the backup rolls, providing a roll gap for a strip of metal being rolled, chocks at the ends of each of said backup and work rolls, and supporting means for the backup roll chocks including screwdown means for maintaining rolling load on the backup rolls: means associated with said supporting means for detecting changes in rolling load, bending jack means acting on the work roll chocks for adjustably exerting forces on the work rolls to control the shape of the roll gap, means controlled by the load-detecting means for controlling the bending jack means to adjust said forces to counteract changes in roll gap shape due to changes in rolling load, and means responsive to release of engagement of a tail portion of a strip while said strip is traversing the roll gap, for supplementarily controlling the bending jack means to provide a convex shape of the roll gap for guiding the strip against sidewise displacement.

15. A system as defined in claim **14**, which includes means associated with said supplementary controlling means and operated in delayed response therteo, for attenuating the operation of the first-mentioned controlling means in control of the bending jack means pursuant to change of rolling load, whereby upon subsequent departure of the strip from the roll gap and corresponding decrease of rolling load, said gap is maintained against rapid closure as would otherwise be caused by said first controlling means.

16. A system as defined in claim **15**, which includes means responsive to departure of the strip from the roll gap and arranged in controlling relation to said bending jack means, for effecting adjustment of said forces to keep said work rolls respectively in firm contact with the backup rolls.

17. In a rolling mill control system, in combination with a 4-high mill having upper and lower backup rolls, upper and lower work rolls between the backup rolls, providing a roll gap for a strip of metal being rolled, chocks at the end of each of said backup and work rolls, and supporting means for the backup roll chocks including screwdown means for maintaining rolling load on the backup rolls: means associated with said supporting means for detecting changes in rolling load, bending jack means acting on the work roll chocks for adjustably exerting forces on the work rolls to control the shape of the roll gap, means controlled by the load-detecting means for controlling the bending jack means to adjust said forces to counteract changes in roll gap shape due to changes in rolling load, and means responsive to departure of a strip from the roll gap and arranged in controlling relation to the bending jack means, for effecting adjustment of said forces to keep said work rolls respectively in firm contact with the backup rolls.

18. A system as defined in claim **17**, which includes means responsive to release of engagement of a tail portion of the strip while said strip is traversing the roll gap and operative in anticipation of actual departure of the strip from the gap, for attenuating the operation of the first-mentioned controlling means in control of the bending jack means pursuant to change of rolling load.

19. In a rolling mill control system, in combination with a 4-high mill having upper and lower backup rolls, upper and lower work rolls between the backup rolls, providing a roll gap for a strip of metal being rolled, chocks at the ends of each of said backup and work rolls, and supporting means for the backup roll chocks including screwdown means for maintaining rolling load on the backup rolls: means associated with said supporting means for detecting changes in rolling load, bending jack means for the work rolls including balance jacks between the upper work roll chocks and the lower work roll chocks and contour jacks between the backup roll chocks and the respectively adjacent work roll chocks, means controlled by the load-detecting means for adjusting the difference in pressures of said balance jacks and contour jacks to change the roll-bending force of the bending jack means in proportion to changes in rolling load, for counteracting changes in roll gap shape, means in controlling relation to said bending jack means and adjustable to provide a base pressure difference of said balance and contour jacks for establishing a base condition of bending force on the work rolls relative to which the aforesaid adjusting means changes said bending force, and means to adjust the proportionality of control of the bending jack means by rolling load, to be suitable for the width of the strip, comprising means effective between said load-detecting means and said adjusting means and settable in control of said adjusting means to provide a desired proportion between changes in rolling load and changes in bending jack force produced thereby.

20. A system as defined in claim **19**, wherein said pressure-difference-adjusting means comprises electrically controlled valve means for controlling supply of fluid under pressure to said balance jacks and contour jacks, electrical circuit means for controlling said valve means, means for supplying a first electrical signal to said circuit means in response to said rolling load detecting means, varying in proportion to changes of load, and means for supplying a feedback electrical signal to said circuit means in accordance with the difference in pressures of said balance and contour jacks, said means adjustable to provide a base pressure difference comprising means for supplying a third electrical signal to said circuit means, said means settable to provide a desired proportion as to changes in rolling load comprising means settable to modify the first-mentioned electrical signal for said desired proportionality to changes in rolling load, and said circuit means being constructed and arranged to effect operation of said valve means in response to unbalance between said feedback signal and the conjoint effect of said first and third signals, for changing the pressure difference of said balance and contour jacks to restore balance in said circuit means by said feedback signal, for maintaining a predetermined roll gap shape.

21. A system as defined in claim **20**, in which said feedback signal supplying means includes means establishing a signal in accordance with the pressure in said contour jacks, said rolling load detecting means comprises means responsive to the force between the upper work roll chocks and the lower work roll chocks, said signal-establishing means being associated with said means supplying the aforesaid first signal for modifying the response of the latter to the load detecting means, to effect supply of said first signal as representing the rolling load force directly exerted on the work rolls by the backup rolls.

22. A system as defined in claim **21**, in which said mill includes backup jacks between said backup roll chocks for prestressing the mill and means establishing a signal in accordance with the pressure in said backup jacks, said load detecting means including means measuring the total screwdown force on the backup roll chocks, arranged in association with last-mentioned signal establishing means to supply a load signal representative of said total screwdown force diminished by the force of said backup jacks.

23. A system as defined in claim **20**, including means responsive to release of engagement of a tail portion of a strip while said strip is traversing the roll gap, for supplying an electrical signal to bias said circuit means for modifying said difference of jack pressures in a direction to increase the contour jack pressure and reduce the balance jack pressure, and thereby provide a convex shape of the roll gap for guiding the strip against sidewise displacement.

24. A system as defined in claim **23**, wherein said last-mentioned means includes delay means controlled thereby for modifying said circuit means, after a predetermined delay, to attenuate control of said valve means by said circuit means whereby upon subsequent departure of the strip from the roll gap and corresponding decrease of rolling load, said gap is maintained against rapid closure as would otherwise be caused by the aforesaid first signal responsive to rolling load.

25. A system as defined in claim **24**, which includes means responsive to departure of the strip from the roll gap for supplying an electrical signal to said circuit means to adjust said difference of jack pressures to a high preponderance of balance jack pressure, for keeping said work rolls respectively in firm contact with the backup rolls.

26. A system as defined in claim **20**, which includes means for sensing the flatness of the rolled strip, said means for supplying a third electrical signal comprising means extending to said circuit means and controlled by said sensing means for varying said third signal in response to departures of the rolled strip from a desired flatness, to effect unbalance of the circuit means and resultant adjustment of the jack pressure difference to modify the roll gap for restoration of said desired flatness.

27. A system as defined in claim **26**, which includes means intermediate said signal-varying means and said circuit means for retarding variations of said third signal in response to departures of the strip from flatness, whereby adjustment of the jack pressure difference in response to the flatness-sensing means is effected substantially more slowly than in response to the first electrical signal supplied under control of the rolling load detecting means.

28. A system as defined in claim **19**, in which said adjusting means and said means adjustable for establishing a base condition of bending force include a signal circuit, said load-detecting means and said adjustable means supplying control signals to said circuit, means responsive to said bending jack means for supplying a feedback signal to said circuit in accordance with the pressure difference of said jacks, and means for modifying the pressure difference of said jacks, in response to unbalance between said control signals and said feedback signals, to maintain a predetermined roll gap shape, said work rolls each having an axial length of working surface in contact with the back up roll which is not greater than about 4.5 times the diameter of the work roll.

29. In a rolling mill control system, in combination with a mill having upper and lower backup rolls, upper and lower work rolls between the backup rolls, providing a roll gap for a strip of metal being rolled, and supporting means for said backup and work rolls including means for maintaining rolling load on the backup rolls: controllable roll-bending means applying bending forces at the necks of the work rolls for coaction with forces exerted by rolling load to provide bending effect on the work rolls which is adjustably directed to vary the separation between said work rolls at their ends relative to central regions thereof, for altering the shape of said roll gap as traversed by a strip under rolling load, means for sensing the flatness of the rolled strip, and means controlled by said sensing means, for controlling said roll-bending means to maintain a predetermined roll gap shape which provides a desired condition of flatness of the rolled strip, said sensing means comprising a pair of means respectively disposed and arranged for detecting off-flatness at the edge regions of the strip, to provide signals respectively proportioned to such off-flatness, said means for controlling the roll-bending means comprising means responsive to the sum of said signals for effectuating maintenance of the aforesaid roll gap shape, said means for maintaining rolling load comprising a pair of separately adjustable screwdowns respectively acting on the opposite ends of the backup rolls, said system including means receiving and comparing said signals of said pair of detecting means for ascertaining predominance of either off-flatness signal over the other as indicative of imbalance of roll gap respecting the ends of the rolls, and means controlled by said signal-comparing means and in response to the existence and direction of such predominanc, for adjusting said screwdowns in mutually opposite directions to reduce imbalance between them.

30. In a rolling mill control system, in combination with a mill having upper and lower backup rolls, upper and lower work rolls between the backup rolls, providing a roll gap for a strip of metal being rolled, and supporting means for said backup and work rolls including means for maintaining rolling load on the backup rolls: controllable roll-bending means applying bending forces at the necks of the work rolls for coaction with forces exerted by rolling load to provide bending effect on the work rolls which is adjustably directed to vary the separation between said work rolls at their ends relative to central regions thereof, for altering the shape of said roll gap as traversed by a strip under rolling load, a plurality of control means in controlling relation to said roll-bending means, independently operative to adjust said bending forces and conjointly operative to determine said bending effect, for maintaining a predetermined roll gap shape, means for detecting changes in rolling load, and means for sensing the flatness of the rolled strip, a first one of said control means being controlled by said detecting means, for adjusting bending forces in proportion to changes of rolling load, and a second of said control means being controlled by said sensing means to establish said predetermined roll gap shape as one which provides a desired condition of flatness of the rolled strip, and which is maintained by operation of said first control means in response to rolling load.

31. A system as defined in claim **20**, in which said flatness-sensing means includes means retarding its controlling operation over said second control means, whereby said second control means responds substantially more slowly to departures of the strip from flatness than the response of said roll-bending means to be control by the first control means upon change of rolling load.

32. In a rolling mill control system, in combination with a 4-high mill having upper and lower backup rolls, upper and lower work rolls between the backup rolls, providing a roll gap for a strip of metal being rolled, chocks at the ends of each of said backup and work rolls, and supporting means for the backup roll chocks including screwdrown means for maintaining rolling load on the backup rolls: means for sensing the flatness of the rolled strip, bending jack means for the work rolls including balance jacks between the upper work chocks and the lower work roll chocks and contour jacks between the backup roll chocks and the respectively adjacent work roll chocks, and means controlled by said flatness-sensing means for adjusting the forces o fthe bending jack means to counteract departure of the roll gap from a predetermined shape which provides a desired condition of flatness of the rolled strip, said adjusting means effecting a change of the difference between balance jack pressures tending to push apart and contour jack pressures tending to push together the work roll chocks, and said change of pressure difference being governed by off-flatness of the rolled strip sensed by the sensing means.

33. In a rolling mill control system, in combination with a 4-high mill having upper and lower backup rolls, upper and lower work rolls between the backup rolls, providing a roll gap for a strip of metal being rolled, chocks at the ends of each of said backup and work rolls, and supporting means for the backup roll chocks including screwdown means for maintaining rolling load on the backup rolls: means associated with said supporting means for detecting changes in rolling load, bending jack means for the work rolls including balance jacks between the upper work roll chocks and the lower work roll chocks and contour jacks between the backup roll chocks and the respectively adjacent work roll chocks, means controlled by the load-detecting means for adjusting the forces of the bending jack means in proportion to changes in rolling load, to counteract changes in roll gap shape due to said changes in rolling load, said adjusting means effecting a change of the difference between balance jack pressures tending to push apart and contour jack pressures tending to push together the work roll chocks, said change of pressure difference being in proportion to the changes in rolling load, means for sensing the flatness of the rolled strip, and means in controlling relation to said bending jack means and adjustable under control of said sensing means to provide a controlled base pressure difference in said jack means for establishing a base bending force on the work rolls which represents a predetermined roll gap shape to afford a desired condition of flatness of the rolled strip, the aforesaid adjusting means being effective to modify said bending force for maintaining said predetermined shape against departures therefrom because of changes in rolling load.

34. A system as defined in claim 33, which includes means for retarding the controlling operation of said means under control of the sensing means, to delay change in said base pressure difference in response to sensed off-flatness of the rolled strip, so that the bending jack means responds substantially more slowly to the flatness-sensing means than to the load-detecting means.

35. A system as defined in claim 33, in which said sensing means comprises a pair of means respectively disposed and arranged for separately detecting off-flatness at the edge regions of the strip, said adjustable means being controlled by both said last-mentioned means in accordance with off-flatness detected by both, said screwdown means including a pair of separately adjustable screwdowns respectively acting on laterally opposite backup roll chocks, and said system including means controlled by said pair of off-flatness detecting means for comparing conditions detected thereby to ascertain predominance of off-flatness selectively adjacent each edge of the strip as indicative of imbalance of roll gap respecting the ends of the rolls, and means controlled by said comparing means and in response to the existence and direction of such predominance, for adjusting said screwdowns in mutually opposite directions to reduce imbalance between them.

36. A system as defined in claim 32 in which said sensing means comprises a pair of means respectively disposed and arranged for detecting off-flatness at the edge regions of the strip, to provide signals respectively proportioned to such off-flatness, said means controlled by said flatness-sensing means comprising means responsive to the sum of said signals, for adjusting the forces of the bending jack means to counteract departure of the roll gap from said predetermined shape.

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MILTON S. MEHR, Primary Examiner

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72—16

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,534,571 Dated October 20, 1970

Inventor(s) OLIVO G. SIVILOTTI; MAURICE W. TULETT and WILLIAM E. DAVIES

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 12, line 51, after "restore" insert --the--
Col. 14, line 36, after "readout" for "to" read --of--
line 56, for "dilevered" read --delivered
line 65, for "extered" read --exerted--
Col. 16, line 27, for "in" [second occurrence] read --is--
Col. 19, line 40, for "chance" read --change--
Col. 20, line 28, for "acocrdance" read --accordance--
Col. 21, line 72, for "controlled" read --controller--
Col. 28, line 51, for "width" read --widths--
Col. 29, line 55, for "end" read --ends--
Col. 32, line 15, for "predominanc," read --predominance--
line 38, after "adjusting" insert --said--
line 46, after "claim", "20" should read --30--
line 51, after "to" erase "be"
line 66, for "o fthe" read --of the--

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