Sept. 8, 1970 K. T. LAWSON ET AL 3,527,078

STRIP FLATTENING

Filed Aug. 12, 1968 9 Sheets-Sheet 1

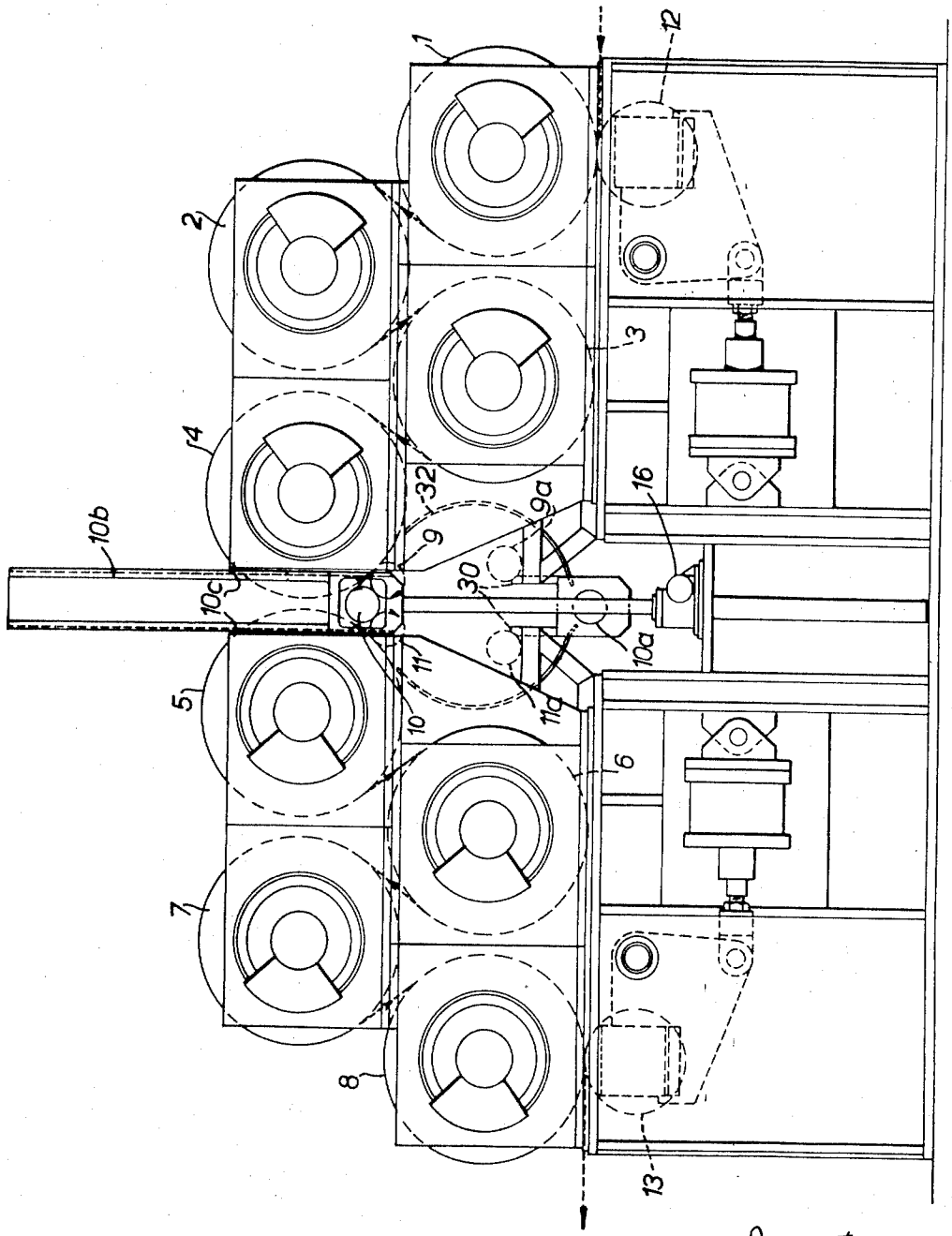


FIG. 1.

Inventors:
Kenneth Thomas Lawson
and
Jerzy Franciszek Nofer
BY Baldwin Wight Diller & Brown
Attorneys

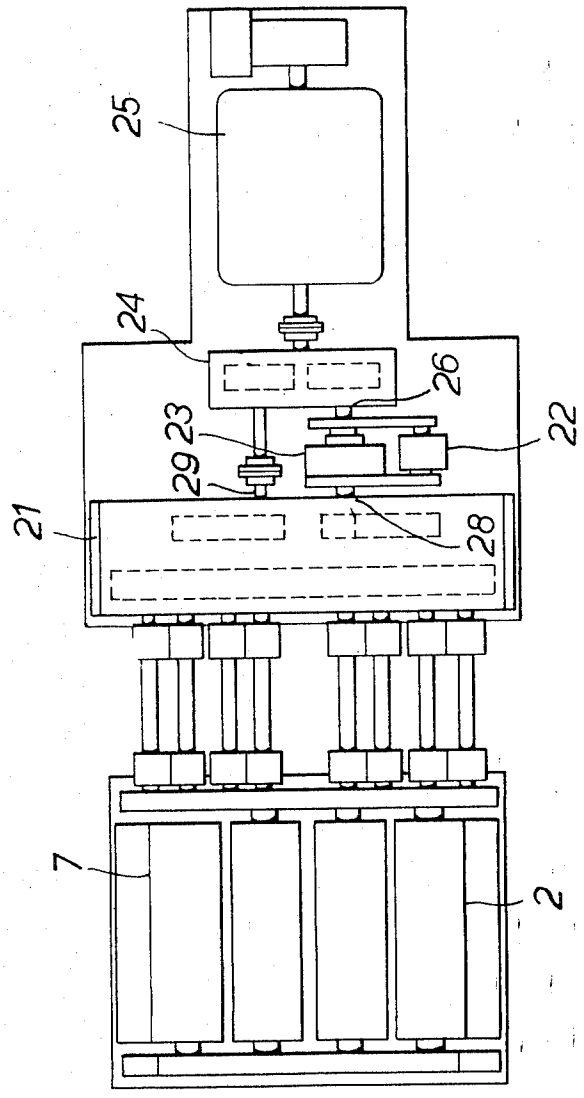


FIG. 2.

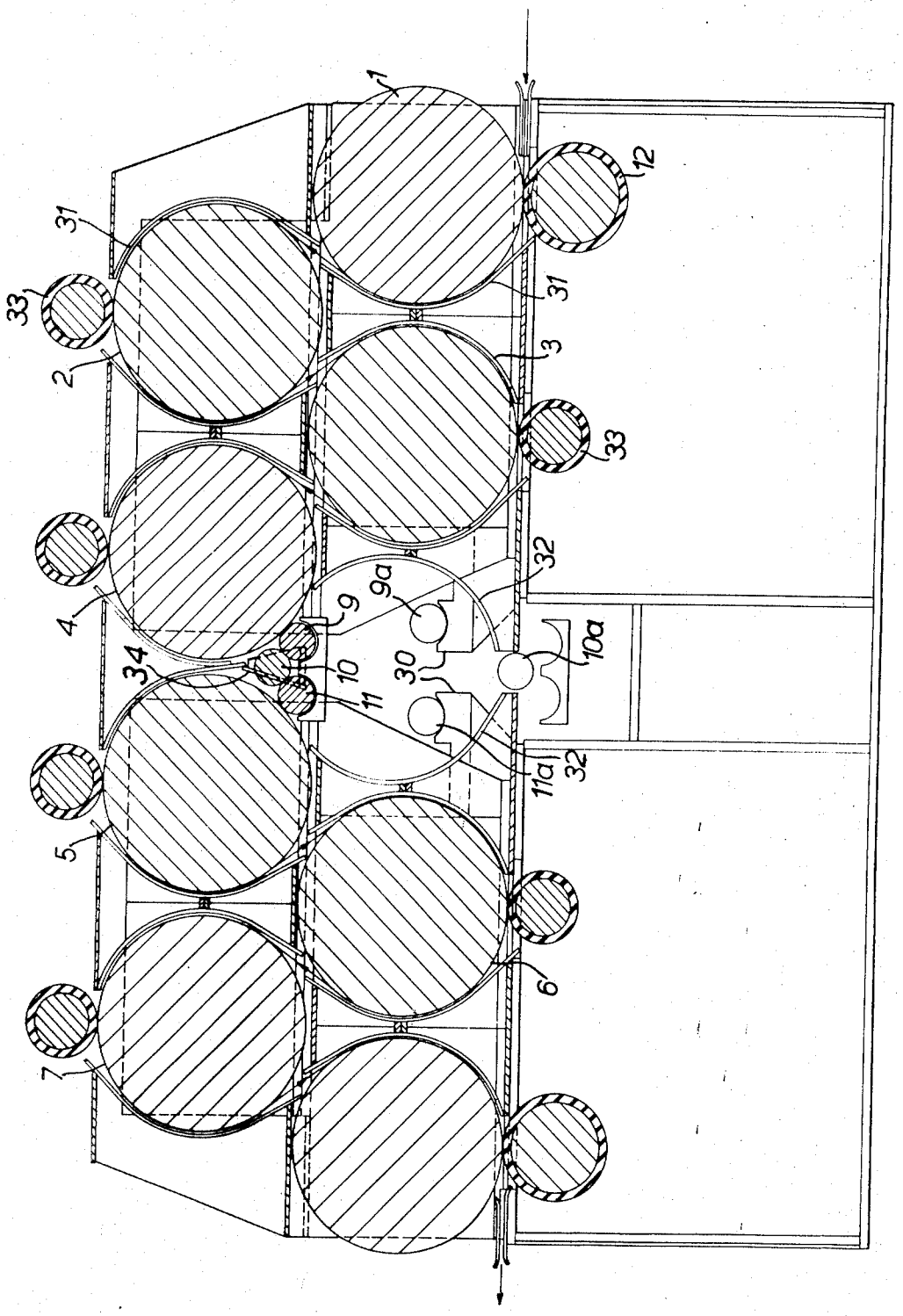


FIG. 3.

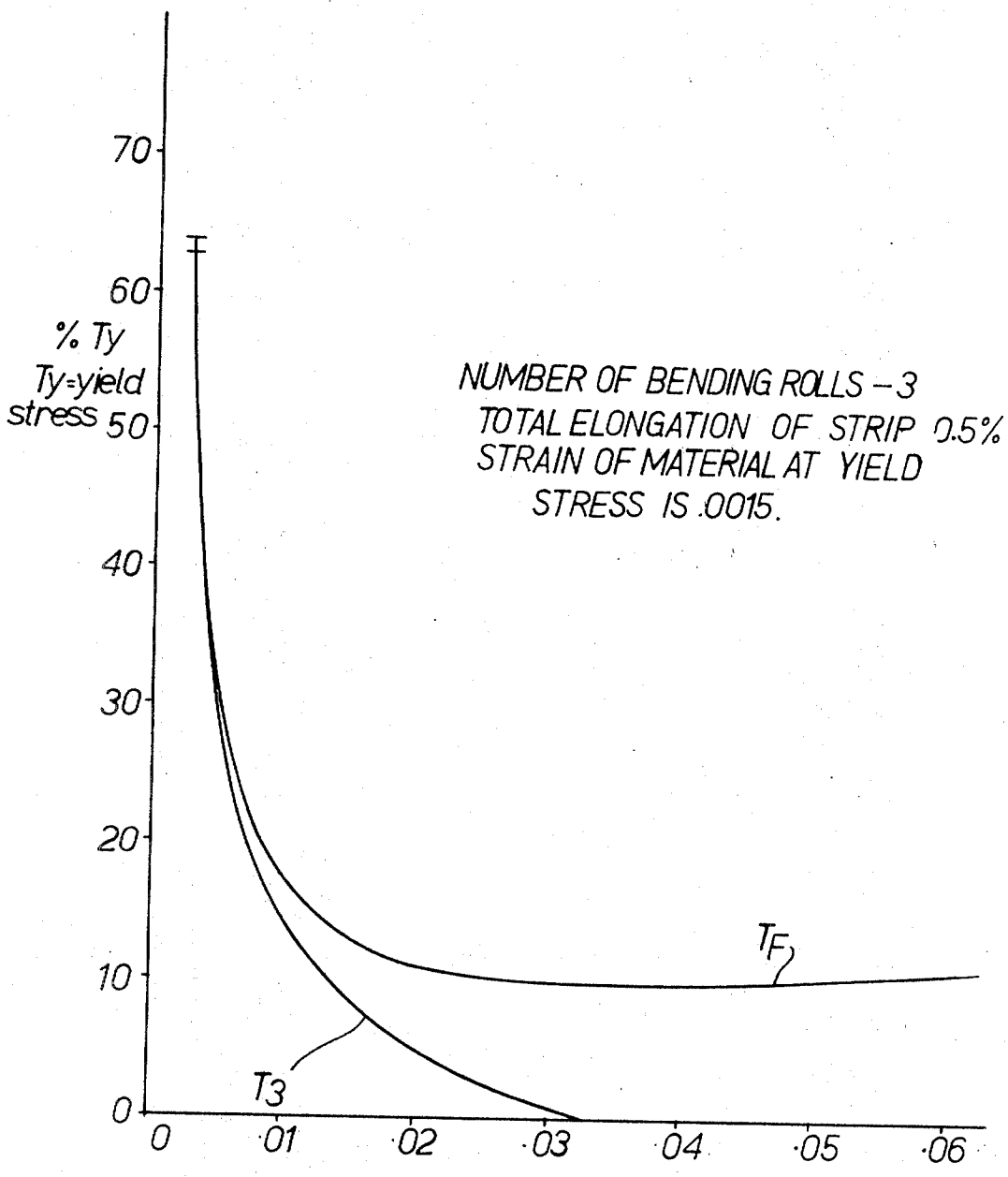

70
60
% Ty
Ty=yield
stress
50
40
30
20
10
0
0
·01
·02
·03
·04
·05
·06
NUMBER OF BENDING ROLLS – 3
TOTAL ELONGATION OF STRIP 0.5%
STRAIN OF MATERIAL AT YIELD
STRESS IS .0015.
T_F
T_3

FIG. 4.

Sept. 8, 1970 K. T. LAWSON ET AL 3,527,078

STRIP FLATTENING

Filed Aug. 12, 1968

9 Sheets-Sheet 5

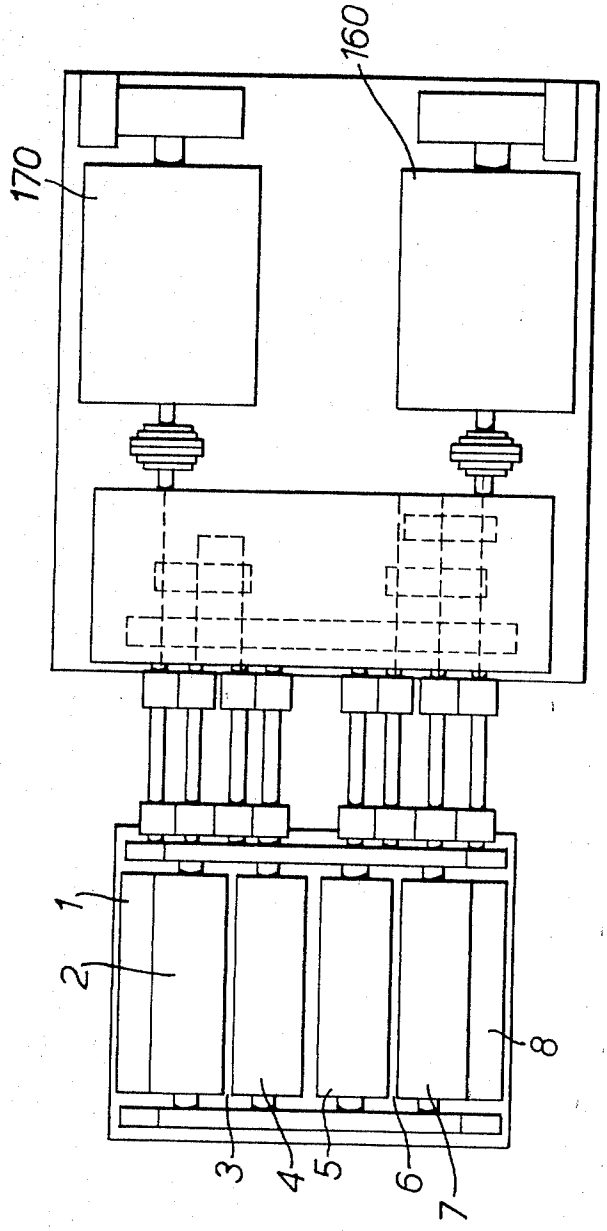


FIG. 5.

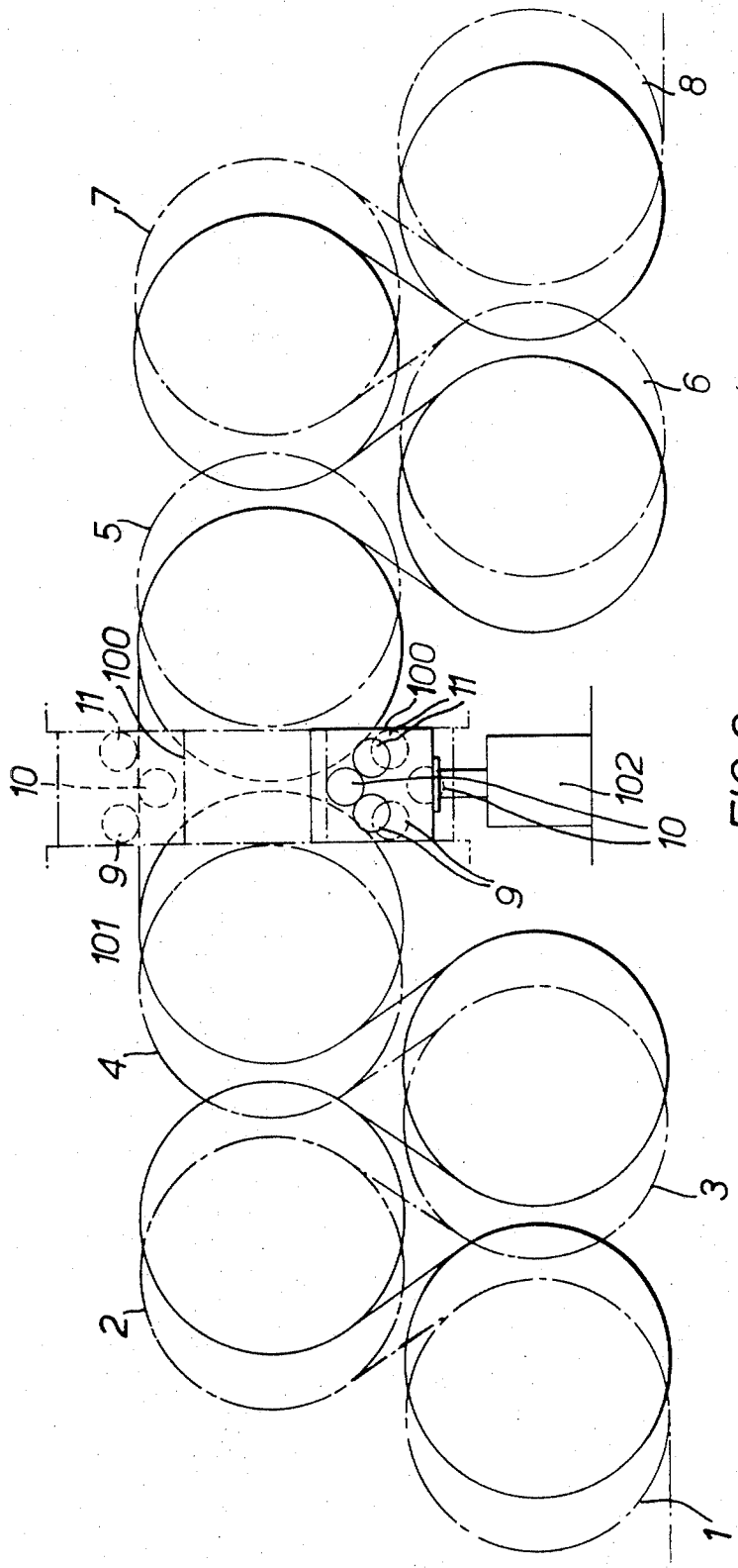
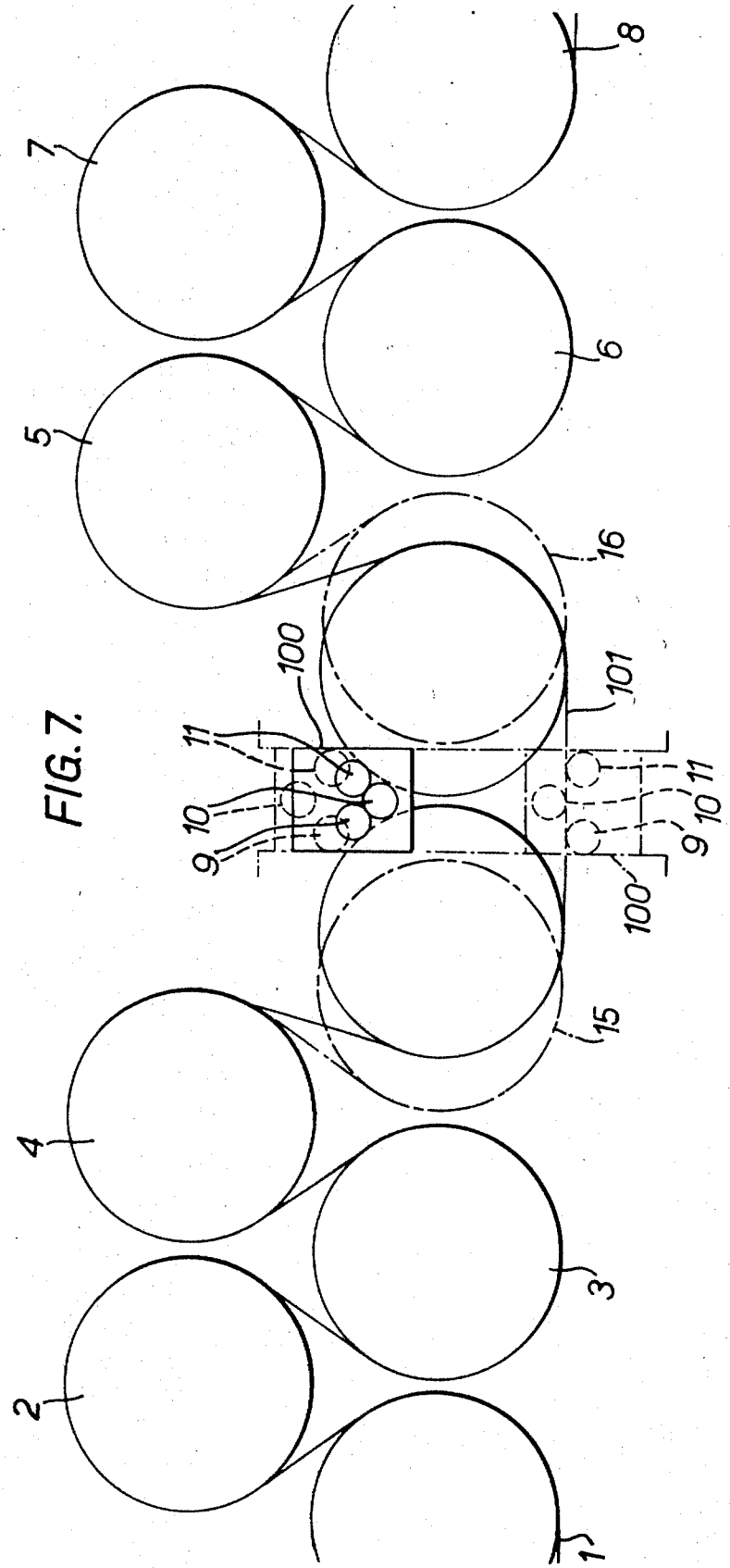


FIG.6.

FIG. 7.



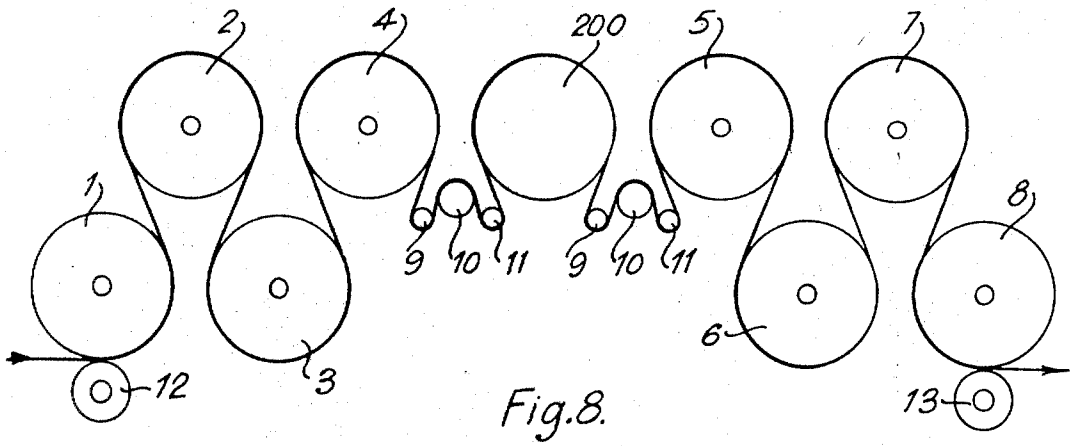


Fig.8.

Fig. 9.

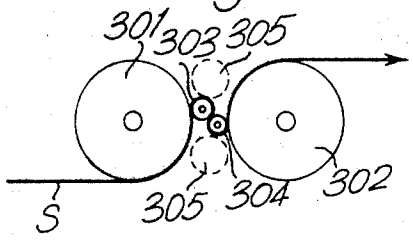


Fig. 10.

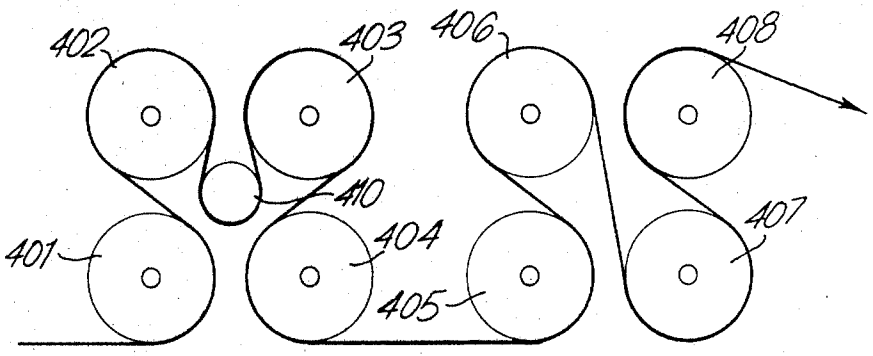
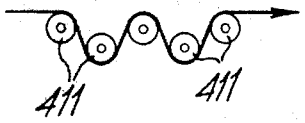


Fig. 10a



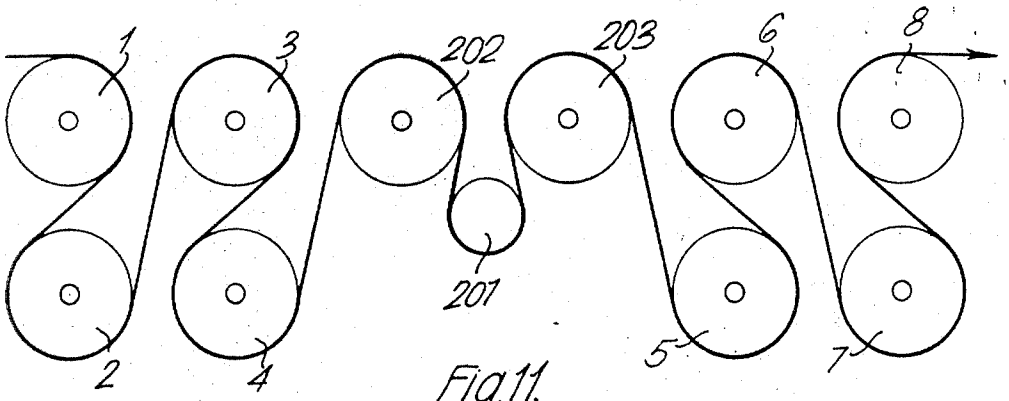


Fig. 11.

United States Patent Office 3,527,078 Patented Sept. 8, 1970

3,527,078

STRIP FLATTENING

Kenneth Thomas Lawson, Marton, and Jerzy Franciszek Nofer, Middlesbrough, England, assignors to Head, Wrightson and Company, Limited, Thornaby-on-Tees, Yorkshire, England, a corporation of the United Kingdom

Filed Aug. 12, 1968, Ser. No. 752,009
Int. Cl. B21d 1/02
U.S. Cl. 72—160 15 Claims

ABSTRACT OF THE DISCLOSURE

Continuous metal strip is flattened by driving it at two spaced locations at speeds differing by a predetermined proportion, and between these locations the strip is subjected to the action of a roll system in which the strip enwraps a floating roll so as to cause the roll to pinch the strip against further rolls at the points of which the strips wraps onto and unwraps from the floating roll. This may be followed by a further stretch levelling operation. Apparatus is provided comprising first and second sets of bridle rolls and between them in one case a pair of floating rolls co-acting with a central roll and the innermost rolls of the bridles and in a second case a pair of floating rolls coaching with each other and a pair of large diameter backing rolls. In an alternative form of apparatus a further downstream bridle is provided, each bridle being driven at a speed higher than the previous one by a selected proportion, so that the strip is subjected to a further stretching operation either with or without the action of bending rolls. In each case the floating roll or rolls have a diameter at least 25 times the thickness of the strip to be heated and a radius small enough for the strip to be subject to plastic deformation when bent to this radius under the influence of the tension to which it is subjected.

The invention relates to the flattening of continuous metal strip, particularly for the purpose of removing such faults in strip shape as long or wavy edges or long middles as may be produced during previous reduction in a rolling mill and for relieving any residual forces within the strip which may tend to cause unevenness.

In order to eliminate such defects, successive portions of the strip are subjected to forces which cause plastic deformation of the metal, thus removing residual forces which tend to cause unevenness in the strip as well as eliminating any actual dimensional unevenness.

In the past two main approaches have been adopted in deforming the strip; firstly, stretch levelling, which entails subjecting successive portions of the strip to a longitudinal force sufficient to stretch the strip beyond its yield point. This often gives satisfactory results, but it will be appreciated that, particularly with strip in large widths or heavy gauges, the forces required to be applied are very high, requiring extremely robust equipment, and also there are problems associated with retaining adequate control over the degree of elongation occurring in the unsupported strip during stretching, which may therefore be uneven after stretching. Moreover, where appreciable elongation is required to flatten the strip, unsightly marks known as stretcher strains may be produced.

The other main method is roller levelling, which entails passing the strip between two staggered interlaced series of rollers, whereby it is flexed sharply first in one direction then the other. Conventional roller levellers are generally considered less effective than stretch levellers.

Various attempts have been made to improve the performance of levellers by combining the stretching and

bending principles, and here again two main approaches have been adopted. One is merely to apply increased longitudinal tension to the strip as it passes through a roller leveller. Although this tension may not be sufficient in itself to stretch the strip, it makes the strip hug the bending rolls in the leveller more tightly, thus assisting to ensure plastic deformation of the strip during bending providing the bending rolls are a suitable diameter. The problems of this approach are that the tensions required to ensure that the strip accurately follows the contours of the bending rolls produce increased forces in the bending rolls and make it more difficult to keep deflection of the rolls within reasonable bounds. These problems are aggravated when it is desired that the levellers should handle wide strip, particularly when the same machine may be required to handle a considerable range of thicknesses.

The other approach has been to reduce the size of the bending roll to well below that which will ensure plastic deformation of strip of the smallest gauge to be treated, but the use of such small rolls presents its own problems in that it is difficult to provide them with adequate support and also they are liable to rapid wear and fracture.

We have found that a soution both to the problem of supporting the rolls and of making the strip hug the bending rolls is provided by using particular apparatus comprising inter alia a roll arrangement similar in principle to one which has previously been proposed in U.S. Pat. No. 2,291,361 for the implementation of a method of hardening continuous soft or annealed ferrous material. The method utilises the simultaneous application of tension, bending over a small diameter bend roll, and rolling of the strip under pressure of the small diameter bend roll which is pressed against a pair of backing rolls by the tension in the strip. The arrangement is such that a loop in the strip passes through a narrow gap between two backing rolls of substantial diameter, a very small diameter roll or rod being inserted in the loop. On application of tension to the strip, the small bending roll is pulled into a gap between the backing rolls, and the strip is constrained to follow a path over one backing roll round the bending roll and over the second backing roll. The bending roll is held in place by the strip itself, and the bend roll and strip are very adequately supported by the large diameter backing rolls which are sufficiently stiff to render roll deflection under load quite negligible. This arrangement makes it possible to utilise a bend roll as small as ⅛" diameter, which would be quite impracticable with conventional backing rolls. However, there still remains the problem of wear or breakage of the bending roll, and moreover, when the arrangement is used for stretching continuous strip material it has certain limitations. The buildup of tension in the strip appears to depend mainly on the amount of work expended in bending and rolling the strip on the small diameter bending roll and on the frictional drag in roll bearings, etc., so that the amount of elongation to which the strip is subjected varies according to the thickness and material properties of the strip being handled and cannot be adjusted and controlled by means of this apparatus in its basic form. Moreover, using the ratios of strip thickness to bending roll diameter hitherto proposed, the degree of reduction and elongation of the strip tends to be excessive for levelling purposes, although it may be useful for strip reduction. Finally, the patentee himself admits, and in fact requires that "surface fractures" be formed in the strip. It is believed that he is referring to the phenomenon known as Lüders' lines, a form of surface defect that it is in most instances extremely important to avoid in levelling operations. This apparatus is thus unacceptable for normal levelling purposes.

A similar roll system has also been proposed in U.S.

Pats. 2,332,796 and 3,238,756 for the purpose of obtaining strip reduction. Whilst many levelling operations are accompanied by some reduction of the strip, this is quite incidental to the main purpose of the operation, i.e. levelling. These patents contain no suggestion that the apparatus they disclose can, suitably modified, form the basis of an exceptionally efficient strip levelling system, and indeed, even were the theoretical considerations involved in strip reduction and strip levelling not quite different, thus contraindicating the applicability of apparatus useful in the one art to the other art, the disclosure of Pat. No. 2,291,361 would suggest that they were useless for this purpose. Thus although British patent specification No. 1,002,936 in the form in which it was originally published showed strip flattening apparatus consisting of several of the roll arrangements of No. 2,291,361 in series, it is found in practice that the arrangement is inoperative for a number of reasons, including a tendency to damage the strip. The above British specification was later amended to exclude this matter.

The object of the invention is to provide a machine capable of flattening at high speed continuous strip over a wide range of material properties, thicknesses and widths and faulty shape, and in which provision can readily be made for easy threading of the strip.

Surprisingly, we have found however that improved stretch levelling apparatus is produced if a similar bending roll system to that described above in which the diameter of the bending rolls has a particular relationship discussed below to the thickness of the strip is flanked by means positively driving the strip, the driving means subsequent to the bending roll system being adapted to drive the strip at a predetermined faster rate than the means preceding the bending roll system, the percentage increase in speed being equal to the degree of elongation in the strip which is found necessary to produce the desired levelling effect. The bending roll system must however be such as to permit easy threading of the system by the strip to be treated, this threading operation having previously provided a considerable impediment to the use of roll systems of the type discussed.

A complex system of stresses is developed in the strip in the region of the first and third rolls of the three roll system owing to the combined action of longitudinal tension, bending around the bending rolls and rolling between the bending rolls and adjacent rolls and high stresses in excess of the elastic limit can be developed locally in the strip so that permanent deformation takes place. The net result is that strip can be made to undergo permanent elongation even though the overall longitudinal tension in the strip is itself insufficient to cause permanent extension. In fact the machine can be so designed that the overall longitudinal tension applied by the bridle rolls is only a small fraction of that needed to cause general yielding and permanent extension in the strip.

Exemplary embodiments of the invention are described with reference to the acompanying drawings, in which:

FIG. 1 is a side elevation of a preferred embodiment of a leveller in accordance with the invention,

FIG. 2 is a plan view of the same leveller,

FIG. 3 is a vertical longitudinal section,

FIG. 4 is a graph showing the influence of the ratio of bending rolls, diameter to strip thickness on the performance of roller levellers,

FIG. 5 is a plan view showing an alternative form of transmission,

FIGS. 6 and 7 are diagrammatic cross sections of modifications of the leveller showing alternative methods of providing for threading of the leveller,

FIG. 8 shows diagrammatically an alternative embodiment of the leveller,

FIG. 9 shows diagrammatically an alternative form of roll system for use in the invention,

FIG. 10 shows diagrammatically a further embodiment of the invention,

FIG. 10*a* is a diagrammatic detail showing a development of the embodiment of FIG. 10, and

FIG. 11 shows diagrammatically an alternative form of apparatus for implementing the method of the invention.

Referring to FIGS. 1–3, rolls **1**–**4** and **5**–**8** are drag and pulling bridle rolls respectively for driving and tensioning the strip, and constitute first and second positive drive means respectively. They are mounted in antifriction bearings and driven via a transmission to be described below from a single motor **25**.

On leaving roll **4** the strip under tension passes between the roll **4** and a roll **10** and forms a loop around a bending roll **9** before passing back between rolls **4** and **10**, over roll **10**, and between rolls **10** and **5** to form a loop embracing a bending roll **11**, the tension in the strip supporting rolls **9** and **11** respectively adjacent to rolls **4** and **10** and rolls **10** and **5**, the strip being nipped between the rolls. Rolls **9** and **11** are constrained against axial movement in order to prevent them moving out of the machine laterally, but they are free to take up a radial position as dictated by the geometry of the strip and rolls **4**, **5** and **10**. The rolling load on the strip applied between rolls **4** and **9**, **9** and **10**, **10** and **11**, **11** and **5** depends upon the magnitude of strip tension and the relative positions of the rolls. Roll **10** runs in journal bearings and is mounted in bearing housings **10***b* which can slide along vertical guides **10***c*. The position of roll **10** is adjustable by means of a worm drive and screw jack **16** to control over a limited range the rolling load on the strip. Rolling of the strip is advantageous in that it improves surface finish and tends to prevent formation of unsightly stretcher strain markings. However, the rolling forces applied are quite small in comparison to rolling forces applied in conventional skin pass rolling mills and the elongation of the strip is achieved almost entirely by tension and bending. Indeed the chief advantage of the roll arrangement employed is that it enables the bending rolls to be adequately supported in such a way that deflections are greatly minimised and friction losses in bearings are minimised, whilst proper contact of the strip with the rolls is ensured. Rolls **9**–**11** can be retracted to the positions **9***a*–**11***a* shown in broken lines to simplify threading of the leading edge of strip material through the machine.

The bridle rolls **1** to **8** are driven via shafts **28** and **29** respectively through two sets of gears in gearbox **21**. A variable speed gearbox **22** and planetary gearbox **23** form the means for varying and controlling the amount of elongation applied to the strip by adjusting the relative speed of bridles **1**, **2**, **3** and **4** to bridle rolls **5**, **6**, **7** and **8**. From gearbox **24**, output shaft **26** drives the input gear in planetary gearbox **23** and via variable speed gearbox **22**, the casing carrying the planet gears of planetary gearbox **23**. The speed of shaft **28** relative to the speed of shaft **29** is therefore adjustable by selecting different gear ratios on the variable speed gearbox **22** and this enables the relative speed of bridle rolls **1**, **2**, **3** and **4** to **5**, **6**, **7** and **8** to be adjusted.

For the purpose of threading the leading end of a new coil of material through the stretch levelling machine, roll **10** is lowered by means of the jack **16** into position **10***a* (see FIG. 1) and bending rolls **9** and **11** take up positions **9***a* and **11***a* on supports **30**. FIG. 3 shows cylindrical guides **31** around the bridle rolls and also rubber covered pinch rolls **33** which are pneumatically operated. Strip is fed between bridle roll **1** and pinch roll **12** and the leading edge is guided around the drag bridle rolls by guide plates **31**. As the leading edge advances the pinch rolls **33** are operated to press the strip against the bridle rolls; slow rotation of the bridle rolls feeds the strip forward and through the machine. The strip follows a path around guides **32** is deflected by plate **34** and is then threaded around the exit bridles **5** to **8**.

After threading, the threading pinch rolls **33** are retracted and deflecting plate **34** removed and roll **10** is moved to its operating position taking with it the loop of strip formed in guides **32** and also rolls **9** and **11**. The clutch and brake fitted into the drive to the drag bridles can then be operated to enable rolls **5** to **8** to remain stationary whilst rolls **1** to **4** are reversed until the strip is pulled tight around bending rolls **9** and **11** and throughout the machine. The clutch and brake are then released and the machine is set into operation in the normal way.

Principal data for a typical stretch levelling machine is given below as an example.

Material	Steel strip (21 tons/in.^{2} at 2% proof stress).
Maximum strip width	72".
Maximum strip thickness	0.078".
Operating speed	600 f.p.m.
Bridle roll diameter	30".
Bending roll diameter	4".
Number of bending rolls	3.
Main drive motor	850 H.P.
Face width of rolls	78".
Strip thickness (inches)	0.015; 0.032; 0.048; 0.078.
Percent elongation	2.0; 1.9; 1.6; 1.1.

It will be readily appreciated that the invention described herein is not limited to the above dimensions and in fact bridle rolls will often vary between 20" to 48" diameter, bending rolls may vary within the range 1" to 4", whilst to increase stiffness and support, the centre roll **10** in FIG. 1 may vary in the range 4" to 12", and even these values may be exceeded in exceptional circumstances. The effect of roll **10** as an additional bending roll diminishes as its diameter increases but this can be allowed for in design.

FIG. 4 presents typical data for use in design of stretch levellers according to the invention and deals with a particular case of stretching in apparatus similar to that described above using three bending rolls **9**, **10**, **11** to produce a permanent elongation in the strip of ½%, the yield strain of the strip material being 0.15%. This shows how the tensile stress in the strip varies with the ratio t/D (strip thickness to bending roll diameter ratio). (Tensile stress (T_B or T_F) is defined as the tension force in the strip immediately before or after the bending rolls divided by the cross-sectional area of the strip and expressed as a percentage of the yield stress for the strip material.)

Two points are significant:

(a) Strip tension increases rapidly as t/D decreases below the value of 0.01. This means that the loads on the machine become considerable for t/D values below 0.01 and the general size and number of bridles and driving gears, etc., may be increased appreciably thus increasing the cost of the machine. Clearly it is an advantage for t/D to be greater than 0.01.

(b) The difference between front and back tension in the strip increases rapidly for t/D values greater than about 0.02 and in fact the back tension becomes negligibly small at higher t/D values. Now the difference in front and back tensions represents the force needed to drag the strip through the bending rolls in the absence of any tension exerted by the drag bridle and this force is a function of the work done in bending the strip. As t/D increases more and more work is done in bending the strip until the strip tension necessary to drag the strip through becomes so great that the desired elongation of the strip is exceeded. Thus a machine with too many undriven bending rolls or with bending rolls of too small a diameter could only produce elongations beyond a certain range. To be able to control strip elongation within a useful range of say up to 2% it is essential not to exceed a certain t/D ratio and not to exceed a certain number of undriven bending rolls. In certain cases, elongations up to 5% may be possible.

Our experience indicates a preferred range of values for t/D lies between 0.01 and 0.02, but of course we do not restrict ourselves to this range. Most machines have to deal with a wide range of required elongations and strip thicknesses and to avoid having to replace bending rolls during operation in order to adjust t/D values for each strip thickness, etc., it may be better to design a machine with a wider range of t/D values. It will be seen from the above example, for instance, that t/D values vary from 0.02 for 0.078" strip with 4" bending rolls to 0.00375 for 0.015" strip with 4" bending rolls and this is quite acceptable. However, to maintain control of elongation and to achieve a practical robust machine it is essential to adopt values for t/D which are as small as possible and we would always try to maintain t/D within the range 0 to 0.02 and would certainly never exceed $t/D=0.04$, i.e. the diameter of the floating rolls would be at least 25 times the thickness of the strip.

A machine has been proposed using a bending roll captive within a loop in the strip but it relies in the only empirical example given on drag tension produced by the bending of 0.0107" strip over a small (⅛" diameter) bending roll ($t/D=0.08$) in order to achieve hardening of the strip, and as our own work shows this will not give adequate control of strip elongation, and there appears to be no means of varying and controlling strip elongation in order to deal with various strip materials with different material properties and thicknesses, etc. The present invention overcomes these drawbacks.

The above figures for the ratio t/D, although discussed in relation to a three roll bending roll assembly (two floating rolls and one fixed roll, all of approximately equal diameters) apply regardless of the actual number of bending rolls employed, and, in the range being considered, the actual arrangement of the bending rolls. The use of differing numbers of rolls or rolls of differing diameters merely affects the value of the overall tension applied to the strip in order to achieve a given elongation. A small number of bending rolls involves higher tensile forces in the strip, whereas a large number would enable these forces to be reduced. There is for any particular application an optimum number of rolls to give minimum cost of machine and maintenance.

Various modifications and additions may be made to the apparatus described.

It may be useful to incorporate a simple unbacked roller leveller immediately after the leveller of the invention. The roller leveller may be a separate machine or it may be part of the basic stretch levelling machine. Strip which has had long edges, etc., removed by stretch levelling may still have longitudinal curvature when it leaves the machine. If some strip tension is maintained when the strip leaves the tension levelling machine then the strip will be held straight longitudinally so that longitudinal curvature may not be apparent. However due to the effect of lateral contractions or expansions—the Poisson ratio effect—the strip may be observed to have lateral curvature, i.e. it will be curved transversely and not longitudinally. It may not be necessary to remove this curvature if the strip is to be immediately re-coiled. However if the strip were not to be re-coiled, for instance if it were to be cut into sheets, then it would be essential to straighten the strip and a roller leveller would be necessary. Such a leveller could be a simple 3 or 5 roll roller leveller, without backing rolls.

FIG. 5 shows an arrangement of machine which has a motor drive **160** (preferably a D.C. speed controlled motor) to the pulling bridle rolls 5 to 8 and a drag generator **170** braking the drag bridle rolls **1** to **4**.

Yet another version of the stretch levelling machine has an auxiliary D.C. motor drive coupled to the casing of the planetary gearbox **23** (see FIG. 2). This motor is controlled to apply constant torque on pre-determined values and its function is to relieve the load on the variable speed gearbox **22**.

As another variation, the auxiliary D.C. motor can be used to drive the casing of the gearbox **23** and the variable speed gearbox **22** can be omitted entirely. In this case the D.C. motor would have a speed control so that speed could be adjusted to pre-determined values in order to control the amount of elongation on the strip. This particular arrangement has the advantage that the auxiliary motor can be operated when the main drive is stationary to drive the drag bridles whilst the pulling bridles remain stationary. This gives a means for tensioning the strip in the machine immediately after threading and prior to normal running.

Referring now to FIGS. 6–7, two alternative ways of providing for threading of the leveller are described, reference numerals being the same where applicable as those in the embodiments already described.

In both figures, the three roll system comprising rolls **9**, **10**, **11** is carried by a mounting block **100** in which the rolls are movable between the position shown in broken lines and their normal working positions shown in solid lines. The block **100** itself is movable between a working position shown in solid lines and a loading position shown in broken lines, whilst in FIG. 6 the entire series **1**, **2**, **3**, **4** and **5**, **6**, **7**, **8** of bridle rolls are displaceable between a working position shown in solid lines and a loading position shown in broken lines: in FIG. 7 only two additional rolls **15** and **16** are so displaceable.

To load the leveller in either case, the various movable parts referred to are moved to their position shown in broken lines, thus defining a straight path **101** for the strip which is thus readily threaded through the three roll system. The block **100** is then returned to its working position, the roll **10** pushed back through the gap between rolls **9** and **11** taking the strip with it by means of a jack **102** (see FIG. 6) which positively maintains this roll in its working position, the bridle rolls are returned to their working positions and the rolls **9** and **11** drawn into their working positions by the application of tension to the strip.

The leveller may be modified by the provision of additional three roll systems between the first and second series of bridle rolls, the system being separated by additional bridle or deflector rolls. Such a modified leveller is shown in FIG. 8, wherein bridle rolls **1–8**, and pinch rolls **12**, **13** are provided as in the embodiment of FIG. 1. However, two sets of rolls **9**, **10**, **11** are provided, separated by an idle backing roll **200**. The advantage of this arrangement is that reduction of the strip is distributed between a larger number of individual forming operations, and the danger of defects such as Lüders' lines appearing is still further reduced; but on the other hand the amount of rolling to which the strip is subject is increased, and this may cause a degree of hardening of the metal which is excessive for some purposes.

In other cases it will be found that efficient operation may be achieved using only a single floating roll **201**, as illustrated in FIG. 11. The single floating roll is supported by two large diameter idle backing rolls **202**, **203**, and the strip driven by sets of bridle rolls **1–4**, **5–8** as in previous embodiments.

The idle rolls **202**, **203** are journalled in a frame so that they are, when the apparatus is in use, separated by a gap less than the diameter of roll **201**, the apparatus defining a path for the strip which passes around roll **202**, through the gap, around the roll **201** which has no fixed journals, back through the gap and around roll **203**, so that when tension is applied to the strip roll **201** is drawn into the gap and pinches the strip against rolls **202** and **203** at the points where the strip is bending to conform to the contour of roll **201**. By making the journals of roll **202** and roll **203** displaceable relative to each other, the use of rolls **201** having different diameters is readily allowed for, and the penetration of the roll **201** into the gap can also be varied so as to alter the contribution the rolling action generated makes to the reduction and consequent elongation of the strip. Moreover the rolls **202** and **203** can be separated to permit roll **201** and its surrounding loop to be passed between them during threading of the machine.

The basic three roll arrangement which has been utilized in the various previously described embodiments has certain inherent disadvantages. Firstly, action on the strip takes place at the two points at which it is pinched between the work and backing rolls, with the result that slippage occurs between the backing and work rolls and the strip at these points. This problem is discussed in U.S. patent specification No. 2,332,793 (Hume). This specification proposes various solutions to this problem, but none overcome the second disadvantage of the arrangement which is that the treatment of the strip is asymmetrical in that one side of the strip is subjected to the action of the large diameter backing rolls whilst the other side is subjected to the action of the small diameter work roll. The result is that the two sides of the strip are likely to have different finishes and degrees of surface hardness which is often undesirable. An alternative arrangement which overcomes these disadvantages and which may be substituted in the embodiments described for the three roll system is illustrated diagrammatically in FIG. 9, showing a roll arrangement for incorporation in strip processing apparatus comprising two relatively large diameter backing rolls **301**, **302** separated by a gap of width less than the sum of the diameters of two relatively small diameter floating rolls **303**, **304**, the roll arrangement defining a path for strip S passing in a first direction over the first backing roll **301** and through the gap, around the first floating roll **303** in the opposite direction, through the gap and around the second floating roll **304** in said first direction, and through the gap and over the second backing roll **302** in said opposite direction. A pair of steady rolls **305** may be provided on either side of the gap to contact the floating rolls via the strip so as to stabilize their position within the gap.

The advantages of this arrangement are firstly that most of the rolling action on the strip takes place at the nip of the two floating work rolls, with the result that problems due to slippage between the work rolls, the strip and the backing rolls are much reduced. Secondly, both sides of the strip will be treated directly by the smaller diameter rolls so that both sides of the strip will have identical finishes on leaving the device.

A further embodiment of the invention is shown in FIG. 10. It is found that strip which has been subjected to a moderate degree of stretching in apparatus according to any one of the previously described embodiments may then be subjected to a further stage of stretching by a more conventional form of stretch levelling without the formation of stretcher strains. It is found that the forms of apparatus already described above are often not ideal for applications in which an elongation of the strip exceeding 2% is required, due to speed differentials between the various rolls carrying out combined bending and rolling operations becoming excessive and in some instances causing surface marking of the strip and rapid roll wear due to slippage. Moreover, with large elongations, and in some cases even with lower elongations, the amount of rolling received by the strip may be excessive, leading to an undesirably high degree of hardening of the strip.

In the present case, the stretching is carried out in two stages, in only the first of which is the strip subject to rolling by suitable proportioning of the degree of stretch achieved in each stage, and it is possible to obtain much higher elongation of the strip and therefore more efficient elimination of flatness defects without subjecting the strip to excessive hardening or risking the introduction of surface defects due to roll slippage or the formation of Lüders' lines.

To this end, the apparatus comprises a first set of bridle rolls **401**, **402**, a second set of bridle rolls **403**, **404** and a third set of bridle rolls **405**, **406**, **407**, **408**. Either all rolls are driven, or it may be desirable to leave rolls **402** and **403** undriven, but in any event the drive to the rolls is contrived so that rolls **405–408** run faster by a predetermined and preferably adjustable margin than rolls **403** and **404**, and these latter rolls in turn run at a speed higher by a predetermined and preferably adjustable margin than rolls **401** and **402**.

Rolls **402** and **403** are separated by a gap narrower than a small diameter floating roll **410**, which unlike the bridle rolls is of such a diameter that the strip during processing will suffer plastic strain on being bent to conform to its periphery. It is preferred however that the ratio of strip thickness to roll diameter should not exceed 0.04. The roll **410** is trapped in a loop in the strip passing between rolls **402** and **403**, and during operation is fully floating, being supported solely by the strip. The tension set up by the speed differential between rolls **401** and **402** and rolls **403** and **404** draws the rolls **410** tightly into the gap between rolls **402** and **403**, causing the strip to conform to roll **410**, and roll **410** to press the strip against rolls **402** and **403**. Thus at the nips between rolls **402** and **403** and roll **410** the strip is both plastically bent and rolled.

The strip may either pass directly from roll **404** to roll **405**, as shown in FIG. 10, being stretched solely by the tension set up by the speed differential between the second and third sets of bridle rolls, or, as shown in FIG. 10*a*, it may be flexed first one way, then the other, over a series of small diameter bending rolls **411**, in the manner described for example in British patent specifications 655,444 and 758,420. The introduction of the bending rolls decreases the tension required between the second and third set of bridle rolls, since the bending of the strip contributes to straining it beyond its yield point. However, the use of such bend rolls tend to leave the strip with a residual longitudinal curvature which may require subsequent further treatment of the strip by means of a series of bending rolls of increasing diameter interlaced in the manner of a roller leveller, this treatment being applied to the strip after it leaves the apparatus proper.

In use, the speed differentials of the three sets of bridle rolls **401** and **402**, **403** and **404**, and **405–408** are set so that the total elongation of the strip required is divided into two parts, the first part between the first two sets of bridle rolls being such that the rolling action on the strip is high enough to harden the strip sufficiently to prevent formation of Lüders' lines in the second stage, but not so high that excessive hardening of the strip takes place, or excessive slippage occurs between the strip and the rolls **402**, **410** and **403**.

Various expedients may be adapted in the first stage to alter the ratio of stretching to hardening due to rolling that occurs. For example, if the separation between the rolls **402** and **403** is adjustable, the angle between the points at which the strip is nipped by roll **410** and the centre of this roll is varied, thus altering the roll pressure set up by the roll at the nip points. Alternatively, the whole assembly of rolls **401–404** and roll **410** may be replaced by any of the embodiments of the invention previously described.

What we claim is:

1. A method of stretch levelling continuous metal strip comprising positively advancing the strip at two spaced locations at speeds differing by a percentage at least equal to the percentage elongation required to produce flatness in the strip, and between said spaced locations passing the strip through at least one roll system in which the strip entraps a floating roll so as to cause said floating roll to pinch said strip against further rolls at the points at which the strip wraps onto and unwraps from said floating roll, the diameter of the floating roll being such that wrapping of the strip thereonto in combination with the tension to which it is subjected will cause plastic deformation thereof, and that the ratio of the thickness of the strip to the diameter of the roll does not exceed 0.04.

2. A method according to claim **1**, wherein the strip is positively advanced at a third downstream location at a rate corresponding to a further predetermined elongation of the strip.

3. A method of stretch levelling continuous metal strip comprising passing the strip through two sets of bridle rolls advancing the strip at rates differing by a predetermined proportion, and between said sets of bridle rolls subjecting the strip to the action of further roll means adapted plastically to flex the strip first in one direction and then in another, said roll means including at least one roll supported in the gap between two further rolls separated by less than the diameter of the first roll by a loop in said strip passing between said further rolls and embracing said first roll, the latter having a diameter such that the strip will, both in wrapping onto and unwrapping from said roll, be subjected to bending stresses which, in combination with the tension stresses applied as the result of the differential between the rates of advance of the strip by the bridle roll sets, will subject the strip to plastic strain over the major part of its thickness, the ratio of thickness of the strip to the diameter of this roll not exceeding 0.04, and the difference between the rates at which the strip is advanced through the bridle roll sets is set at a level below which Lüders' lines, excessive hardening, or marks due to roll slippage occur on or in the strip.

4. Apparatus for stretch levelling continuous metal strip comprising a first series of bridle rolls, means for driving at least some of said rolls, a second series of bridle rolls, means for driving at least some of said rolls, means maintaining a preselected speed differential of up to 5% between said first and second driving means, and a three roll system between said series of rolls defining a path for the strip in the course of which the strip passes through a gap between the last bridle roll of the first series and the middle roll of the three roll system, around the first roll of the three roll system, back through the gap and around said middle roll, through a gap between said middle roll and the first roll of said second series of bridle rolls, around the third roll of the three roll system and back through said second gap, spacing of the various rolls being such that they are maintained in nesting relationship by the tension in the strip to be handled, the ratio of the thickness of the strip to be handled to the diameter of said first and third rolls of the three roll system not exceeding 0.04, whilst the radius of these rolls is such that bending of the strip to be handled to this radius in combination with the tension to which it is subjected will cause plastic deformation thereof, said first and third rolls being located by the strip itself and the remaining rolls being positively located.

5. Apparatus according to claim **4**, wherein all the rolls of the three roll system are of substantially the same diameter.

6. Apparatus according to claim **4** comprising means for unnesting the rolls of the three roll system from each other and the bridle rolls, and withdrawing the centre roll of the three roll system between the other two rolls, and for returning the rolls to their normal position, whereby to define an unobstructed path for strip during threading of the leveller and to deform the strip to follow its above defined path on return of the rolls to their normal position.

7. Apparatus according to claim **6**, wherein the unnesting means comprise means permitting displacement of said other two rolls from the rolls with which they nest and from each other, and means withdrawing the centre roll between said two rolls to a sufficient distance to permit a loop shaped path of large diameter to be

defined through which strip may readily be constrained to pass during threading.

8. Apparatus according to claim 6 wherein means are provided to bodily move the unnested rolls to a position where a straight threading path may be defined between the last bridle roll of the first series and the first bridle roll of the second series.

9. Apparatus according to claim 6 wherein said bridle rolls or the complete series of which they form part are displaceable apart to permit the passage between them of the three roll system.

10. The modification of the apparatus of claim 4, wherein two or more three roll systems are provided between the first and second series of bridle rolls, the systems being separated by additional bridle or deflector rolls.

11. Apparatus according to claim 4 in which the position of the centre roll of the or each three roll system relative to the bridle rolls abutting the system is adjustable whereby to control the rolling load applied to the strip.

12. Apparatus for stretch leveling continuous metal strip comprising first means for positively driving the strip, second means for positively driving the strip at a speed higher by a predetermined proportion than said first driving means, and third means for driving the strip at a speed higher by a predetermined proportion than said second means, and between said first and second driving means a roll system defining a path for the strip and comprising a floating roll and at least two other rolls adjacent said floating roll and separated by less than the diameter thereof, the strip path passing between said other rolls and around said floating roll, the latter having a diameter greater than 25 times the thickness of the strip to be rolled and small enough for the strip to be subject to plastic deformation when bent to that radius under the influence of the tension to which the apparatus subjects it.

13. Apparatus according to claim 12, wherein a series of small diameter bending rolls define a sinuous path for said strip between said second and third strip driving means.

14. Apparatus for stretch levelling continuous metal strip comprising first means for positively driving the strip, second means for positively driving the strip at a speed higher by a predetermined proportion than said first driving means, and between said driving means a roll arrangement comprising two relatively large diameter backing rolls separated by a gap of width less than the sum of the diameters of two relatively small diameter floating rolls, the roll arrangement defining a path for strip passing in a first direction over the first backing roll and through the gap, around the first floating roll in the opposite direction, through the gap and around the second floating roll in said first direction, and through the gap and over the second backing roll in said opposite direction, the small diameter rolls having a diameter greater than 25 times the thickness of the strip to be rolled but small enough for strip to be subject to plastic deformation when bent to that radius under the influence of tension set up in the strip by said driving means.

15. Apparatus according to claim 14 where steady rolls are located on either side of the gap to contact the floating rolls via the strip, whereby to stabilize the position of the latter within the gap.

References Cited

UNITED STATES PATENTS

2,332,796	10/1943	Hume	72—60
2,432,828	12/1947	Stone	72—160
3,326,026	6/1967	Guillot	72—163
3,389,591	6/1968	Moline	72—160 X
3,394,574	7/1968	Franek et al.	72—164 X

MILTON S. MEHR, Primary examiner

U.S. Cl. X.R.

72—163, 205, 227