

Oct. 26, 1943.

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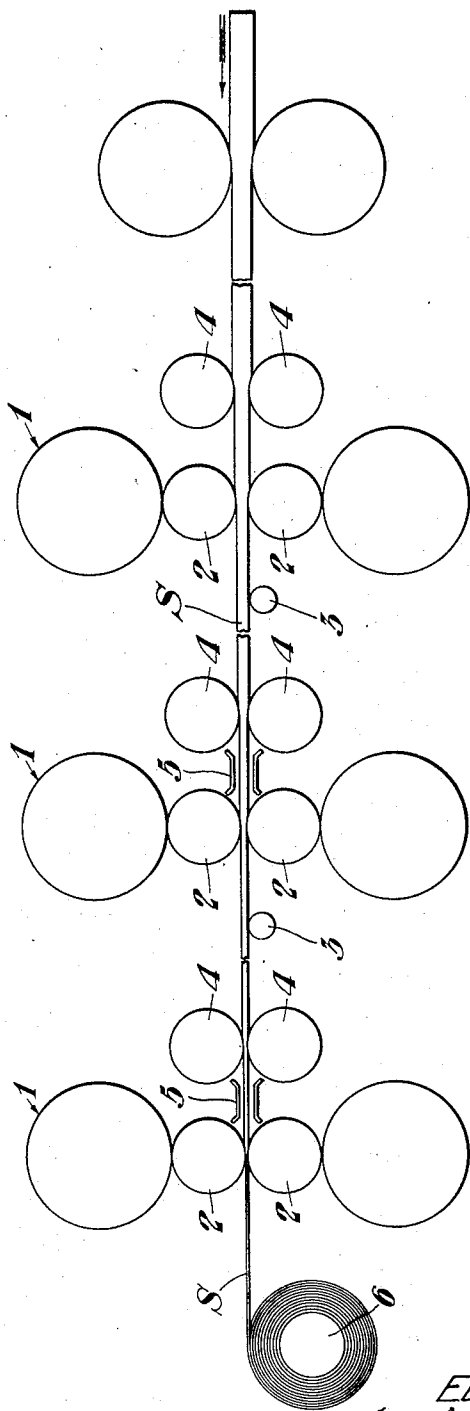
2,332,803

METHOD AND APPARATUS FOR REDUCING METAL BODIES

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3 Sheets-Sheet 1

FIG. 1.



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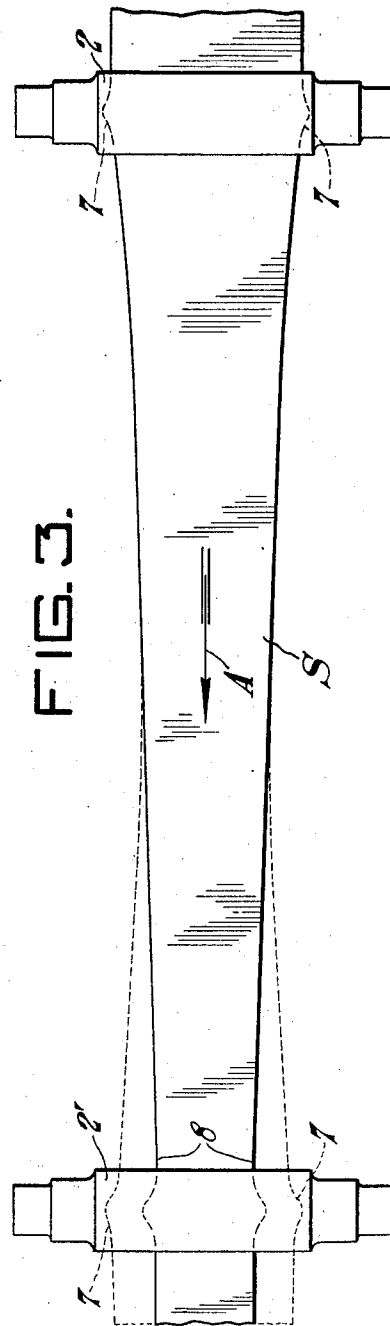
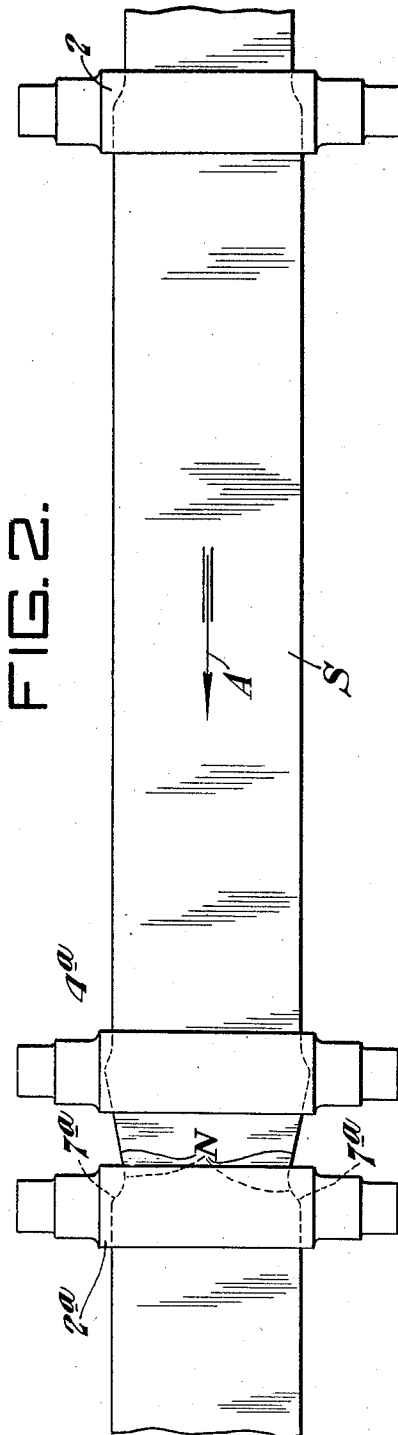
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METHOD AND APPARATUS FOR REDUCING METAL BODIES

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3 Sheets-Sheet 2



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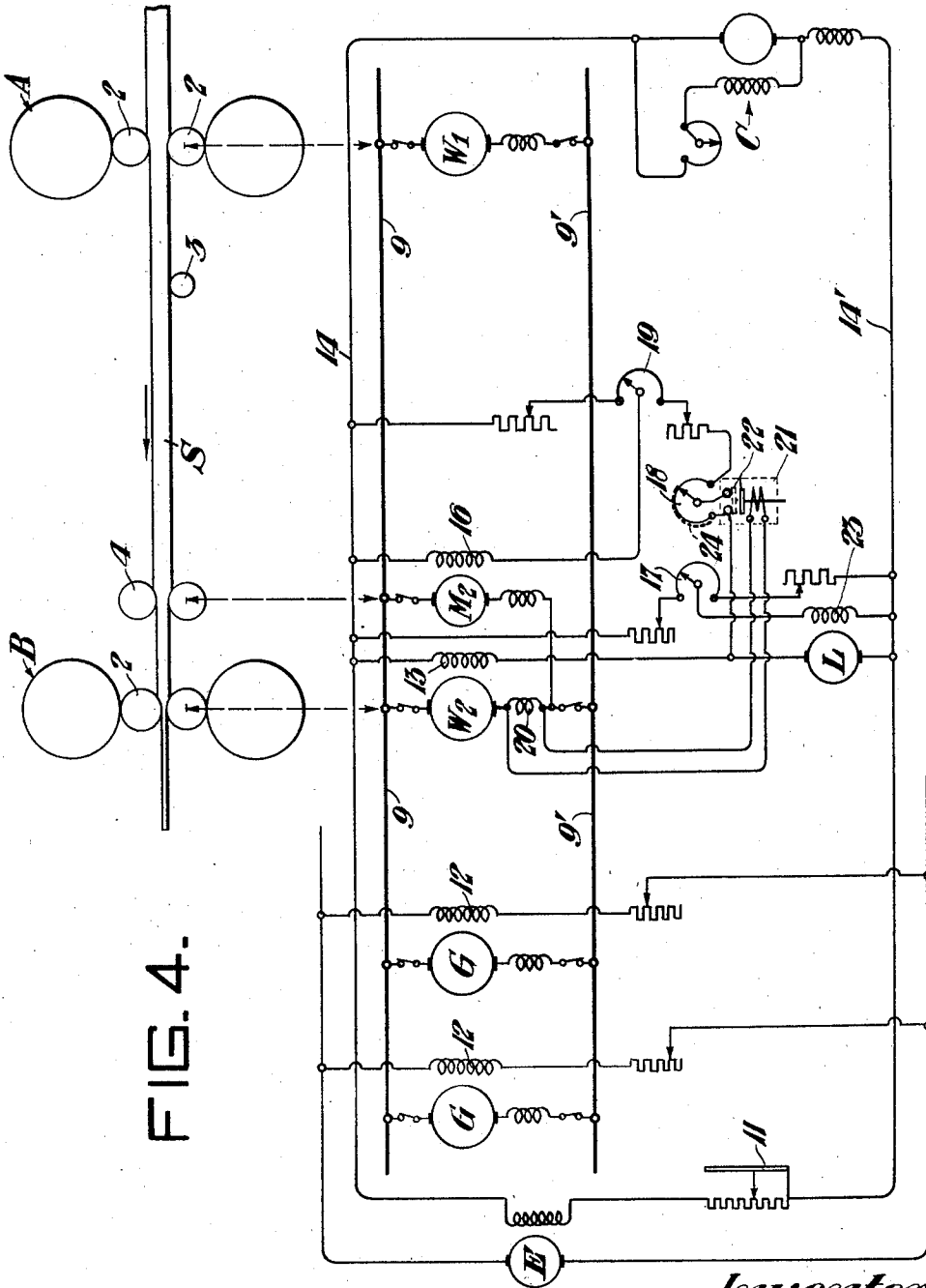
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METHOD AND APPARATUS FOR REDUCING METAL BODIES

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3 Sheets-Sheet 3



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METHOD AND APPARATUS FOR REDUCING METAL BODIES

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13 Claims. (Cl. 80—35)

This invention relates to the reduction of the cross-sectional area of metal bodies by plastic deformation. Although not limited thereto, it is peculiarly well suited to the tension rolling of metals of low elastic limit, such as steel strips, sheets and like plastically deformable metals of any description.

There are two fundamental forces, which, when applied in sufficient magnitude either singly or in combination to a metal body, cause it to flow plastically to alter and reduce its cross-sectional area and shape. These are the forces of compression and tension. The former is usually applied to a work piece by forcing it to move between rolls or dies having a restricted area of pass, which compresses the work piece into a smaller section and displaces its volume longitudinally. Tension may be applied alone to cause the metal to stretch, thus to become longer and of lesser cross-sectional area, or in combination with compression, as is the case when non-driven rolls or dies are employed to compress the work piece, tension must be utilized to draw it through.

Compression and tension may coact to elongate and reduce the cross-sectional area of a work piece, and this coaction may take place in several ways:

Firstly, as has already been mentioned, a metal body may be pulled through stationary or roller dies, whereby the metal at the exit side of the zone of compression is under tension, while that behind the zone of compression is not under tension.

Secondly, the compression dies may be driven to cause the metal to move therethrough and become reduced, which movement may be resisted anteriorly of the zone of compression to impose tension on the material approaching the rolls, in the absence of tension at the exit side thereof.

Thirdly, a work piece may be tensioned before and after the compression zone, so that, with driven rolls, the values of forward and back tension may be different, or of the same order, as where a work piece is tensioned through non-driven dies.

Of the several methods, tension alone is rarely used because of the difficulty experienced in controlling the radial components which cause the mass of a work piece to draw toward its draft axis when tensibly stressed beyond its elastic limit. This phenomenon, popularly referred to as "necking-down," makes reductions of metal bodies by tension alone more feasible where

such bodies have a thickness to width factor approaching unity, or are round, as in the case of bars, rods, and wire.

Similarly, reduction by compression and forward tension, as where a work piece is pulled through dies or idle rolls, with no back tension, finds greater applicability in the drafting of square or round sections than in the reduction of flat sections, since these latter present a greater surface for frictional contact with dies or rolls in comparison to the cross-sectional area of the stock to be reduced—a perfectly round section affording the optimum conditions of minimum frictional contact surface to area of mass in this regard. Consequently, in flat sections, an excessive forward pull is needed to effect the draft, resulting in the necking-down (in width) of flat stock beyond the compressive zone.

Tensions back and forward may be applied to reduce flat stock through a compression means, but, unless such means is positively driven, as by live rolls, to advance the material, the back tension must always be limited by the forward tension; otherwise, the work piece would move backwards through the compression zone. Since the cross-sectional area of the work piece after reduction is less than before reduction, the total forward tensile force applied, even if it were no more than equal to the back tensile force, would give substantially the same effect as a higher tension per unit of sectional area. Add to this sufficient additional pull posteriorly of the die necessary to advance the stock, and the tension per unit of sectional area will have become so high as to exceed the elastic limit of the material, causing it to neck-down in width.

Opposed to this is the relatively heavy section of metal entering the die, to which is applied a tensile force less than the forward pull, rendering the unit tension (backward) of such a low value as drastically to limit the drafting.

The reasons for this limitation are to be found in the principles underlying reduction by compression alone. With few exceptions, reduction by compression is limited to the production of flat metal stock, most of which is produced by rolling between driven work rolls. Heavy sections of stock are, preparatory to rolling, heated to such temperatures wherein they are readily deformable and are then forced into and through the work rolls which reduce the gauge thickness and effect the elongation thereof. So long as the metal is sufficiently thick to provide a larger inner mass to become plastic under pressure, and, thus, to extrude through the work rolls dur-

ing reduction, the gauge thickness may be progressively diminished. After the mass has become relatively thin, the internal plastic flow is practically eliminated, causing the ensuing reducing and consequent elongation to come from the superficial areas of the work piece. Since, however, reduction is a matter of volumetric displacement, and since the superficial areas present relatively no volume, the resultant reduction is rendered practically negligible beyond this point. This is true whether the material be hot or cold in the absence of tension.

The high compression necessary to overcome the limit of elasticity of the metal is effective to clamp the metal firmly between the rolls. In thin gauge stocks, where extension of the inner mass is negligible, the clamping effect prevents the plastic flow of metal so materially as to preclude reduction by compression alone beyond a limited extent. With the rolls in motion, this resistance to flow through the rolls results in a wringer action upon the work piece, causing a bulge of metal to accumulate anteriorly of the pass, which in turn jams or wedges the rolls, and creates enormous friction which is reflected in the excessive compressive load factors beyond which a mill cannot go. This frictional component cannot be overcome by any known means in straight compression rolling to allow reductions of flat metal stock to gauge thicknesses less than .050" in widths up to 60" wide, nor less than .080" in widths of 60" wide or more, this being true whether the stock is heated to high temperatures, or is relatively cold.

In order to make possible the reduction of gauge thickness of flat metal stock to less than .050" or .080", depending on the width, it is necessary to subject the material to such a tensile stress upon the approach side of the compression zone so as to materially lower the average unit compression stress at this point by reducing the bulge of metal that tends to jam into the pass. This tension is applied to the stock upon the entering side of the rolls, and is of such an order as would cause the stock, after passing through the rolls, to neck-down, if it were applied forwardly of the latter. This precludes the use of stationary dies or idle rolls as the compressive means, and requires that the reduction be made through positively driven work rolls, which not only compress the material, but effect the advancement thereof as well.

Back tensions of the order contemplated under the present invention have not been possible heretofore in hot mill practice because of the extremely low elastic limit of flat stock under normal hot rolling conditions. Because of the low elastic limit of hot roller stock, the production of relatively thin gauge flat material such as iron and steel sheets and strip has not been possible under conventional hot mill practice.

Although the present invention is chiefly directed to the application of tension in the reduction by rolling of metals having a relatively low limit of elasticity and is specifically concerned with the application of back tension to the hot rolling of steel strips, sheets and similar materials, it is also applicable to the reduction of such metals or products in cold condition. By rendering the tensioning of such material anteriorly of the rolls possible, the limitation upon gauge thicknesses producible by hot mills is entirely removed, rendering feasible the reduction to gauges of .010" and less.

In addition to the work factors involved, tension rolling is known to be beneficial to the finish or surface condition of the metal in that it avoids excessive friction, reducing the probability of so-called pinchers, cobbles, etc., and insures that the metal tracks fairly into the dies or rolls. Because of these improved operating conditions, substantial increases in speed have been made in cold reduction methods, increasing both the yield and quality of product produced on the present-day mills. Furthermore, since a work piece is subjected to both static and sliding friction in the roll pass, its metallic fibers are subjected to different degrees of stress, those acted upon by static friction becoming stressed differently than those acted upon by sliding friction. Thus, this non-uniform stressing of the fibers naturally distorts them, causing the overall metal piece to be unequally strained, and, consequently, wavy, distorted, and devoid of the much to be desired flatness. Since tension reduces the frictional components, as previously noted, it is not the least of its advantages that it minimizes the fiber distortion, and allows practically dead flat material to be produced. Although proper lubrication can be considered as an important factor in reducing the troublesome friction, it cannot be regarded as a substitute for tension in this respect, but rather as an adjunct to the indispensable tension assisting toward the desired end.

Because of the low limit of elasticity of hot mill material, and because of the impracticability of applying efficient lubrication thereto, it has not been possible heretofore to enjoy any of these advantages accruing to cold reduction methods, whereby hot rolling has had to terminate at the heavier gauges. As has been said, any considerable tension either before or after the introduction of the hot metal to the rolls, causes it to neck-down in lateral dimensions, whereby, under continuous mill operations, the finishing material is prohibitively narrowed in relation to its starting width.

By way of distinction, there has been, in the past, means for applying very light tensions intermediate the stands of continuous hot mills, which, by so-called "looping" devices serve to make possible a sufficiently light tension between the stands, by providing manual control of the delivery speeds of the mill motors. These, however, are little more than slack or loop prevention devices, and, as such, are of little value in reducing the area of rolling contact, or the compressive loads of the mill, even though they greatly assist in securing the correct tracking of the strip, thus to minimize edge-curling, cobbles, pinchers, lappers, etc. The capabilities of the hot mill have thus been determined largely by the elastic limit of the material and its ability to withstand very slight tensions without necking-down in width.

The phenomenon of necking-down, or that tendency of metals under sufficient tensile stress to flow plastically to gather toward, and evenly distribute its mass about, the axis of draft, is directly correlated to the elongation per unit length of specimen under consideration. The longer the unit length of specimen under stress, the greater is the elongation, and proportionally greater is the necking-down. Conversely, the shorter the unit length of specimen under stress, the less the elongation, and the less the extent of necking-down, even though the tensile stress in either case remains the same.

In cold mill practices, particularly in tandem rolling, the strip is tensioned by regulating the speed of the several mill stand roll motors, so that any forward stand tends to take in strip at a greater rate than the preceding stand delivers it. Thus, the unit length of specimen in this case becomes that amount of strip extending between stands, or a length equal to the distance between adjacent passes. Because of the high limit of elasticity of cold strip, this considerable length under tension is admissible without incurring the risk of appreciable necking-down.

In hot mill practices, particularly in tandem hot strip mills, the distance of eighteen (18) feet or more between passes is such as to render the application of sufficient tension appreciably to alleviate the frictional component of the succeeding compressive zone, or roll pass, impossible without necking-down the strip an inadmissible amount. Therefore, although very moderate tensions have been applied to hot strip mills by the manual control of the mill motors with the assistance of so-called "looping" devices, thus to reduce lapping, pinchers, cobbles, etc., no substantial diminution of the rolling frictional components or the compressive load factors have been possible, and the gauge values have been accordingly limited to the heavier thicknesses of strip.

In recognizing that the amount of necking-down in width of materials of low elastic limit is dependent, among other things, upon the length subject to tension, which would normally correspond to the distance between the passes of a continuous mill, I have discovered that, by diminishing the tensioned length of material to a dimension which is as small as possible, an exceedingly high tension can be applied from which is derived all of the benefits attendant upon the application of tension to cold rolling, as well as other advantages which will be discussed more in detail hereinafter, without necking-down the material more than an allowable amount.

In the preferred embodiment of my invention, I propose to apply a tensile force to the material upon the approach side of each reducing stand, which, in point of application, is as close as practicable to the work rolls. As an illustration, the tensioned length in proportion to the width of the material, may be unity or less. In giving effect to this teaching in a manner which would appear to be the best embodiment, it is contemplated that a set of auxiliary rolls be applied to the strip upon the approach side of the mill as close as possible to the work rolls, which auxiliary rolls will be sufficiently compressively loaded to effect some reduction in thickness of the strip and be so controlled, in relation to the preceding set of work rolls, and to the succeeding set of work rolls, that the hot strip upon the entry side thereof will be under substantially no tension, but will be under relatively high tension from the exit side thereof to the reducing zone of the succeeding work rolls to which they are proximate. Such an apparatus will function thus to subject the material, as it enters the work rolls, to a very high order of back tension over such minimum distance of strip length that, when posed against the lateral retaining effect derived from the clamping action of the auxiliary rolls and the work rolls upon the strip, causes a minimum amount of necking-down. Such necking-down may be of an order in which, on the thicker sections the lateral extrusions or flow tending

to widen the strip in the compressive zones will offset that lost by necking-down in response to such tension, or if not offset thereby, can at least be made of such an order that it can be allowed for in the over-all reduction, and thus made economically and practicably feasible.

The purpose is to regulate the flow of material into the work rolls in such a manner as to cause it to stretch, and become reduced in thickness to the point where the work rolls perform relatively little compressive function to bring the work piece to gauge, and thus act more as sizing and shaping devices than as deforming dies. The only limits upon this seem to be that the material shall not be reduced in thickness by stretching beyond the point where tractive effort between the rolls and work piece ceases. Because the effect of such auxiliary rolls is to regulate the amount of material fed into the work rolls, they have been designated as "metering" rolls, by which term, for convenience and clarity of expression, they will be hereinafter called.

It is, therefore, the primary object of the present invention to provide novel method and means for reducing materials capable of plastic deformation, and particularly such materials having a low limit of elasticity, by the coaction of compressive and tensile forces thereon in which such tensile forces are of an order sufficient to exceed the elastic limit of such material, without necking-down the material in width more than an admissible amount.

It is another object to provide means for hot rolling strip steel under tension wherein the tension applied is in excess of the elastic limit of the material, while critically controlling the necking-down thereof in width as well as in thickness.

It is still another object to provide means for tension-rolling materials of low elastic limit which will enable the adoption and use of much lighter equipment than is at present possible, which will also permit of the substantial reduction in number of passes to the same gauge, and to lighter gauges, in the case of hot strip steel.

It is a further object to provide for the production of hot strip steel to gauges heretofore obtainable only by cold mill methods.

It is a further object to provide for the production of a strip steel in such a manner that, from the same slab temperatures as now applied, fewer reductions will be necessary to attain an exceedingly light gauge, thus preserving the heat of the work piece, and permitting it to be coiled at very high temperatures later effective in self-annealing the coil.

It is a further object to provide for the production of hot strip in such a manner that its surface will be relatively free from scale and other imperfections, and which, in gauge and finish, will closely approach cold strip produced by cold reduction methods.

It is a further object to increase the yield of hot strip mills per operating period and to minimize the production of scrap, particularly on wide width sheets and strip.

It is a further object sufficiently to stretch hot strip material without undue necking-down to elongate fibers of the metal sufficiently so as to render subsequent cold reduction and/or roller and stretcher leveling unnecessary.

It is still a further object so to reduce the compressive load of each of the finishing stands of a hot mill as substantially to minimize roll deformation, and to enable the use of relatively light 2-high mills where 4-high mills are now em-

ployed, and with better uniformity in gauge of product across the width.

Many other objects and advantages, particularly with respect to the economics of present day hot mill operations, and hot mill operations versus cold mill operations, will become apparent from the following specification when considered in conjunction with the accompanying drawings, in which:

Figure 1 represents a schematic elevational view of a continuous mill to which a preferred form of the invention has been applied.

Figure 2 is a partial plan view of Figure 1, illustrated with the backing-up rolls removed from the 4-high rolls.

Figure 3 is a schematic plan view illustrating the phenomenon of necking-down as would result from the application of substantial tensions to present hot mill equipment and practices, and

Figure 4 is a diagrammatic view illustrating an electric control for such a mill designed to give effect to the present invention.

In the drawings, with reference to Figures 1 and 2, a continuous hot mill comprising conventional 4-high stands 1—1, having work rolls 2, and conventional looper control 3 between stands, is provided with metering rolls 4 at the approach side of each of the 4-high mill stands, and as close thereto as is practicable. Guides 5 may be applied to facilitate the passage of the material between the metering rolls 4 and the work rolls 2, in each instance. A coiler 6, adapted to exert a moderately low tension upon the material as it is delivered from the last finishing stand, is shown for coiling the material in even, tight coils. It is obvious that, if it is desirable, the flat type of run-out tables may be provided for use with the present invention as is customary on the hot mills currently in vogue.

The arrangement of parts is such that a hot strip S, between its point of exit from work rolls 2 of one stand, to its point of entry into the metering rolls 4 of the succeeding stand, is under no tension, or tension of a moderately low value, such as is conventionally applied. This is insufficient to cause necking-down, but assists in the correct feeding of the material into the metering rolls, and prevents lappers, pinchers, and cobbles at this point. Thus, throughout the larger linear extent of strip disposed between the work passes, no tension greatly in excess of the elastic limit of the work piece is applied. For this purpose, and as will be later described in connection with Figure 4, the metering rolls 4 are driven in relation to the preceding work rolls 2 so as to receive the material at substantially the same rate as it is delivered by the latter. To insure that this relationship is maintained, the conventional looper or tensioning roll control 3 may be provided.

The work rolls 2 succeeding the metering rolls 4, with which the latter are associated, are controlled to forward the strip at a greater rate than it is delivered by the metering rolls, thus to exceed the elastic limit of the material over a very short distance of its length, so as to give effect to the back tension, and its attendant advantages, as previously described. To oppose this tension, the metering rolls clamp the strip sufficiently firmly to perform a slight reduction of the material—from one to ten percent reduction in gauge being representative.

In the interest of winding moderately tight coils, the coiler 6 may be controlled to exert a moderately low tension on the strip as it leaves the last finish stand to be able to wind suitable

coils without necking-down, and without allowing substantial oxidation of the inner faces thereof. In this connection, the scale which is formed on the steel at high temperatures is known to be deoxidized or reduced back to steel again when it is coiled within moderately tight wound convolutions and allowed to stand. It should be noted, however, that the present invention, by virtue of the heavy back tension applied, would cause any scale that is formed to be cracked off and blown away upon the approach side of each work zone, thus leaving only slight amounts of secondary scale, which is reformed on the strip between passes, and between the last pass and the coiler. This minimization of scaling, and the partial reduction of what scale does form, effects an advantageous savings in pickling practices.

In Figure 3 there is disclosed a conventional type of mill in which the strip is passed between work rolls 2—2' in the direction of the arrow A. When the mill is thus threaded but not running, and tension is applied, under this static condition the strip tends to reduce in width, coming to its narrowest dimension at a point equidistant from the compressive zones of the work rolls 2—2', as is represented by the broken lines in this figure. The material at such zones tends to extrude sideways, provided it is of sufficient thickness to do so, as is indicated at 7 in Figure 3, and is afforded lateral support by the clamping action of the rolls. When the mill is operating with such tension, the effect is to cause the necking-down action to progress between stands (the laterally clamped strip becoming tractable under motion) so that the narrowest point occurs immediately adjacent the entry of the material into the second stand, as is represented by the solid lines 8. If applied throughout a sufficient number of passes, the strip would ultimately lose most of its transverse dimension and thus become unsuitable for wide strip applications.

As contrasted with this, the action of the present invention is disclosed in Figure 2 in which the strip S, between the work rolls 2 and the metering rolls 4a and moving in the direction of the arrow A, is not under such tension as will cause substantial necking-down, while between the metering rolls 4a and the succeeding work rolls 2a, the material, though subjected to heavy tension, is of insufficient longitudinal extent to cause the necking-down factor to be appreciable.

In this figure it will be seen that the strip S, moving in the direction of the arrow A, extends between the work rolls 2 and the metering rolls 4a at maximum width since, in this and corresponding zones, it is under substantially no tension. Between the metering rolls 4a and the work rolls 2a a heavy tension in excess of the elastic limit is imposed upon the strip, which is caused to neck down, as indicated at N. Since this is not a static load, but is applied with the mill's running to advance the material, the narrowest portion of the strip, as a result of necking down, occurs immediately before the compressive zone of the work rolls 2a. Upon entering this zone, the material, if sufficiently thick to do so, spreads laterally as is indicated at 7a, whereby a substantial amount, if not all, of its pre-tensioned width may be recovered. From the work rolls 2a to the metering rolls (not shown) of the succeeding pass, the strip is again relieved from substantial tension and tends to maintain the maximum width resulting from its compression in the work rolls 2a, as is indicated at 7a. The

same procedure is repeated in connection with the succeeding and preceding metering rolls and work rolls (if any) so that the material is repeatedly necked down, as indicated at N, and restored to width as at 1a, and forwarded under a substantial absence of tension, whereby its recovered width is substantially retained. In this manner, even should there be sustained some over-all diminution in strip width by virtue of the necking down, it will be of such a moderate amount as to be allowable for in advance by selecting a work piece sufficiently over-size to produce a final strip of the required width under the conditions of properly regulated tension here contemplated.

Various methods may be utilized to provide control of the amount of tension developed in the strip between the work rolls of a mill stand and the associated metering rolls. The arrangements to this end herein described are suitable for giving effect to the invention in a satisfactory manner, but should be regarded as illustrative rather than as restrictive.

Electrical control might be employed, for example, in an arrangement similar to that shown in Figure 4. In this system, tension control is obtained by using variable field strength applied to the shunt fields of the work roll drive motor and to the similar field of the associated metering roll motor.

There is illustrated in Figure 4 a portion of the finishing stands of a tandem rolling mill. The operating speed of the mill as a unit is controlled by the variable voltage method of the Ward-Leonard system in the illustrated embodiment. One or more constant speed main generators G have their shunt fields 12 separately excited by the exciter E, the value of excitation and, consequently, the terminal voltage of the main generator being variable by operation of the motor driven rheostat 11. A preselected variable voltage determined by the desired operating speed of the mill is impressed upon the various mill drive motors through the variable voltage bus lines 9 and 9'.

The mill drive motors W₁, W₂ (the armatures of which are mechanically connected to the work rolls 2) have their shunt fields 13 excited from a constant potential source of current, supplied through the lines 14 and 14', from any suitable source of supply, as for instance, a general exciter unit C. To provide control for changing the operating speed of an individual mill stand, a counter-E. M. F. exciter L is placed in series with the shunt field 13 of each individual mill stand drive motor W, the speed of which is inversely proportional to its shunt field strength. The excitation of the shunt field 23 of the exciter L is controlled by means of a manually operated rheostat 17 in series with this field.

A pair of metering rolls 4, disposed closely adjacent to the work rolls 2 at the entry side of the latter, are mechanically connected to a motor M₂, the shunt field 16 of which is excited from the common supply lines 14 and 14'. This field 16 is also in series with the exciter L and the motor speed is variable in response to operation of the rheostat 17. Thus, the speed of the drive and tension combination of any stand may be changed as a unit without disturbing the relation therebetween, and while maintaining the drive and tension combinations of other stands at a constant speed. It is to this rheostat 17 that the looper device 3 may be mechanically connected automatically to control the condition of

tension or slack between adjacent stands (e. g., A and B, Fig. 4).

Independent speed control of the metering rolls 4 is obtained by manual operation of the rheostat 19 which is in series only with the shunt field 16 of the metering roll motor, of which M₂ is typical.

Provisions is made for controlling the amount of tension in that portion of the strip which is between the work rolls 2 and the associated metering rolls 4 by the use of the manually operated rheostat 18 which is also in series with the shunt field 16 of the motor M₂. Decreasing the resistance in the rheostat 18 increases the field strength of the motor M₂ resulting in a decrease in speed of this machine.

For the purpose of describing the operating sequence, let it be assumed that the mill operator decides upon the drafting practice to be followed in reducing the work piece from its roughing stand exit gauge to the gauge desired in the finished product. The per cent reduction to which each stand subjects the work piece includes consideration of the required screwdown pressure, linear speed of strip travel and distribution of load among the individual stands within proper limits of the respective mill stand drive motor ratings.

The finishing train (of which the stands illustrated in Figure 4 may be considered a part) running light, is accelerated to desired rolling speed by the progressive increase of voltage generated in the main generators G by operation of the motor driven rheostat 11. As conventional equipment, each stand is provided with a speed measuring and indicating device such as, for example, a tachometer generator with associated meters (not shown) calibrated in linear speed of strip travel and having adjustment of calibration for different roll diameters. Each set of metering rolls should also be provided with similar devices. The operator observes the indicated peripheral speeds of the work rolls 2 and the associated tension rolls 4, and, if the speed of the latter differs from that of the former, the rheostat 19 is adjusted so that the surface speed of the metering rolls 4 is matched with that of the associated work rolls 2. This regulation is particularly advantageous when work rolls of a certain diameter are replaced by others having a different diameter.

Assuming that the front end of the work piece S has passed through the first finishing stand A and has been subjected to a pre-selected reduction, it is conveyed forward until it is engaged by the metering rolls 4 of stand B. The horizontal component of the compressive force exerted by the tension rolls 4 continues to move the work piece into engagement with the work rolls 2 of stand B in which it is subjected to an additional pre-selected reduction.

When reduction is initiated in stand B, the drive motor W₂ of this stand draws an increased value of load current, causing a substantial voltage drop across its compensating field-winding 20. This drop is utilized to energize the coil of a load relay 21 to operate contactor 22 shunting out a pre-selected portion 24 of the resistance in the tension control rheostat 18 sufficient to result in the relative reversal of the torque exerted by the motor M₂. This relative torque reversal in the motor M₂ creates a generator action which exerts a retarding influence or drag upon the forward movement of the strip S through the metering rolls 4, causing tension to be developed

in the strip between these rolls and the work rolls 2 with which the former are associated.

The amount of tension developed in the strip S is proportional to the increase in the shunt field (16) strength of the motor M₂ caused by shunting out some portion 24 of the resistance in rheostat 18. It will be recalled that for a given design of motor, the torque is proportional to the product of the field flux and the armature current. When the direction of the armature current is reversed, the product becomes negative and the torque is reversed. The speed of the motor varies inversely as the flux or ampere turns in the shunt field circuit.

When the resistance 24 of rheostat 18 is shunted out the normal speed of the motor M₂ tends to decrease a proportional amount. Since, however, this motor is mechanically connected to the metering rolls 4 which are turned by the strip S as the latter is advanced by the work rolls 2, the armature of the metering roll drive is made to revolve at the greater previously established speed, thus creating counter E. M. F. greater than the applied voltage. Accordingly, the armature current flows in the opposite direction, and a reverse torque is developed in the machine M₂, causing it to become, in effect, a drag generator.

It will be understood that the foregoing, illustrated in conjunction with but two stands (A and B) of the finishing train, involving work roll motors W₁ and W₂, and metering roll motor-generator M₂, is applicable to as many stands of the finishing and even roughing trains or reversing mills as it is desired to apply the invention.

By virtue of the heavy tension thus realized, the wave or bulge of metal which is known to form at the approach side of conventional hot mills is entirely eliminated, substantially reducing the friction and area of contact between the work rolls and the strip, thus resulting in a substantial minimization of the compressive load to which the mill must subject the strip for the same amount of reduction, or resulting in a greater reduction at the same compressive load.

Among the outstanding advantages of the present method is that which will enable hot strip steel to be reduced to gauges heretofore impossible of attainment. Thus, it is entirely feasible in accordance with the present invention to reduce strip steel down to tin plate gauge and then, by virtue of the residual heat of the material in coiled form, to enjoy the benefits of self-annealing, for strain removal and grain growth, to produce a material without any further processing that will compete directly with cold strip. In this respect, it will be borne in mind that cold-reduced strip must be annealed one or more times, and subjected to several cleaning operations as a result thereof. The present invention, to the contrary, entails no annealing, and has only very light pickling requirements, as previously described. Furthermore, from the standpoint of physical properties, the hot strip here contemplated need not be roller or stretcher leveled to meet the exacting requirements of the present cold strip trade, and might need only one light pass on a cold mill to develop the surface properties now enjoyed by material produced predominately by cold mill methods.

Because of the great relief in compressive stress, hot mills for rolling metal hot from slab to very thin gauge strip are envisioned that require no more than four or five stands, including both the roughing and finishing trains, where now ten are employed. In fact, by proper appli-

cation of the metering function herein contemplated, a large mass of metal, such as an ingot, bloom, billet, or slab, if heated nearly to the melting point, could be reduced to sheet or strip gauge in one pass by correlating the metering roll speed to the work roll speed to stretch the work piece to gauge, or nearly to gauge, before entering the work rolls. Such an application could advantageously be made in connection with continuous casting processes, immediately after the metal has passed from the molten to the solid state.

In addition, the more conventional types of hot mills may not need to be of the same heavy construction as at present, and, in fact, 2-high mills instead of the present 4-high mills are believed to be entirely feasible within the practice of the present invention. Thus are the economics of hot mill practices vastly improved, and rendered superior to combined hot and cold mill methods, which have heretofore been necessary in the production of light gauge sheet and strip. It will be appreciated that these economies are more manifest on wide gauge material, wherein the actual pressure loads, and the difficulty of feeding sheets through without edge stretching, cobbles, pinchers, and so forth, are greatly enhanced, although the invention will find many economical applications to the narrow strip field, as well as in the reduction of hot rods and wire, or any material, whether hot or cold, having low elastic limit. Nor need the work piece be of substantial longitudinal dimension to enjoy the full benefits of this invention, since the advantages flowing from back tension may be applied to any work piece sufficiently long to extend throughout the major portion of its length during the reduction from the metering rolls to the work rolls at any given pass.

Even though the invention has been disclosed as applied to continuous mills, it will be appreciated that it is equally applicable to reversing mills, in which case a pair of metering rolls will be disposed at each side of the work rolls with those upon the approach side of the mill being used for tensioning purposes, while those on the exit side can be disposed so as to assist in the forwarding of the strip through the mill, or may be lifted out of the pass line so as to permit the strip to pass therebetween without engagement.

It will be equally obvious that other tensioning means besides tension rolls as here illustrated can be applied without departing from the teachings of this invention. Various types of frictional drags, from dynamic brakes to staggered bearings (as in breaker rolls to impart sinuous travel) may be utilized, so long as the distance through which the tensioned work piece must run without lateral support is minimized, and fairly well proportioned to the width of piece.

The advantages to be derived from placing the metering rolls as close to the work rolls as possible can well be appreciated from the foregoing specification. However, the metering function can be performed just as satisfactorily by rolls placed any distance from the work rolls, or at any point intermediate the stands of a tandem mill, if more or less necking-down in width is not objectionable. In fact, a controlled necking-down can be derived by such an arrangement that can be turned to advantage rather than otherwise, while the prestretching-to-gauge benefits of unloading the mill work rolls to reduce friction and produce stress-free, flat

stock, etc., obtain just as in the previously discussed closed-roll arrangement.

From the foregoing it will be seen that the present invention is concerned essentially with the prestretching of metal in a controlled manner nearly to gauge as it enters work rolls, to relieve the latter of excessive frictional and compressive load factors, using the work rolls themselves as a tractive clamp against which tension is applied as the metal is forwarded thereby. In hot mill applications, such as continuous hot strip mills, the length of metal subjected to stretching tension is preferably minimized anteriorly of the work rolls, which clamp the metal to maintain its dimension of width, whereby the ratio of tensioned length to supported width is as low as possible to reduce the necking-down in width. Therefore, stated another way, the invention is essentially a means and method of controlling the necking-down of metal sections, in both transverse dimensions (thickness and width) to give a finished work piece of the required shape and uniformity.

Since the apparatus for giving effect to the novel relationships herein disclosed may assume a variety of forms, it is intended that the herein disclosed embodiment be regarded as illustrative rather than restrictive. Accordingly, it is not intended that the present invention be limited thereby, other than is called for by the recitation of the appended claims.

I claim:

1. In the production of flat metal objects of low elastic limit by rolling, such as hot steel sheets and strip, the improvement which includes passing such an object through reducing rolls driven to advance the work piece, resisting the advance of the work piece into the rolls by a force applied uniformly thereto closely adjacent its point of entry into said rolls, said force being in excess of the elastic limit of the material.

2. The method for continuously reducing flat metal shapes of low elastic limit which includes successively passing such material through a plurality of reducing zones spaced apart a distance equal to a multiple of the width of the material, maintaining the greater part of said material between zones under insufficient tension to cause appreciable necking-down thereof, while subjecting a small part of said material between zones, adjacent the entry of each, to a tension sufficient to stretch the material.

3. The method of reducing metals having a relatively low limit of elasticity while undergoing reduction, which includes forwarding the metal through reducing means to reduce its gauge thickness, applying a tensile pull to the metal in excess of its elastic limit so as to resist its entry into the reducing means, limiting the necking-down in width thereof by supporting the extremities of the tensioned portion of the metal to counter the necking-down forces effective to reduce the width gauge thereof, and maintaining said supported extremities in close proximity.

4. The method of reducing flat metal stock which includes stretching the stock between two bearings spaced less than the width of the stock apart, and compressively rolling said stock by at least one of said bearings.

5. The method of reducing flat metal stock which includes stretching the stock between two bearings spaced less than the width of the stock apart and compressively rolling said stock by at least one of said bearings, while retaining sub-

stantially the prestretched width of the stock at said bearings.

6. The method of reducing flat metal stock which includes stretching the stock longitudinally between two bearings spaced along its length not more than the width of the stock apart, compressively reducing the stock by said bearings, and retaining the greater transverse dimension of the stock at said bearings during the stretching operation.

7. The method of continuously reducing successive portions of flat metal stock which includes stretching the stock longitudinally between two bearings spaced along its length not more than the width of the stock apart, moving the stock between said bearings, and continuously retaining the greater transverse dimension of the stock at said bearings during the stretching and moving operation.

8. The method of continuously reducing successive portions of flat metal stock which includes stretching the stock longitudinally by applying tension thereto in excess of its elastic limit, supporting the tensioned portions of said stock to preserve the flatness and with thereof at a plurality of bearings spaced along the stock's length not more than the width of the stock apart, and continuously forwarding the stock.

9. The method of reducing flat metal stock which includes advancing the stock through and by driven compression rolls to reduce its thickness, tensioning the stock upon the approach side of the rolls for a distance along its length not in excess of the width of the stock, thereby simultaneously stretching and compressing the stock progressively along its length, and supporting said stock at least adjacent the extremities of the tensioned extent thereof to retain substantially its prestretched width during the reducing operation.

10. The method of reducing flat metal stock continuously which includes tensioning and compressing the stock simultaneously to exceed its elastic limit, and supporting the stock throughout the tensioned portion thereof by width-retaining bearings spaced longitudinally of the stock no more than the width of the stock apart, at least one of which acts on said stock to effect the compressing thereof.

11. In a hot rolling of metals the improvement which includes passing a preheated body between a pair of compression rolls to reduce and elongate said body, introducing said reduced and elongated body into a second pair of compression rolls, and, within a distance from the second pair of rolls not substantially greater, and preferably less, than the width of said body, introducing said body into a third pair of compression rolls, driving the first and third pairs of rolls to forward the body, driving the second pair of rolls at a surface speed so related to the surface speed of the first pair of rolls as to minimize tensioning the body therebetween, and driving the third pair of rolls at a higher surface speed than said second pairs of rolls, while the body is in engagement with the three pairs of rolls.

12. Apparatus of the class described comprising a plurality of principal work rolls, a plurality of metering rolls interposed between said work rolls, said metering rolls being placed closely adjacent the latter upon the entering side thereof, means for driving proximate metering and work rolls differentially, and means for

maintaining the surface speeds of preceding work rolls and succeeding metering rolls in such relation that the latter rolls receive a work piece at substantially the same rate as the former rolls deliver it.

13. In a rolling mill, means for compressively acting on different portions of a contiguous

work piece at points no greater a distance apart than the maximum width of work piece that can be accommodated thereby, said means being adapted to stretch the work piece therebetween, and to support its edges to maximum width position during the stretching operation.

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