April 6, 1943. E. A. NELSON 2,315,810

METHOD OF ROLLING SHEET METAL AND APPARATUS THEREFOR

Filed April 26, 1941 3 Sheets-Sheet 1

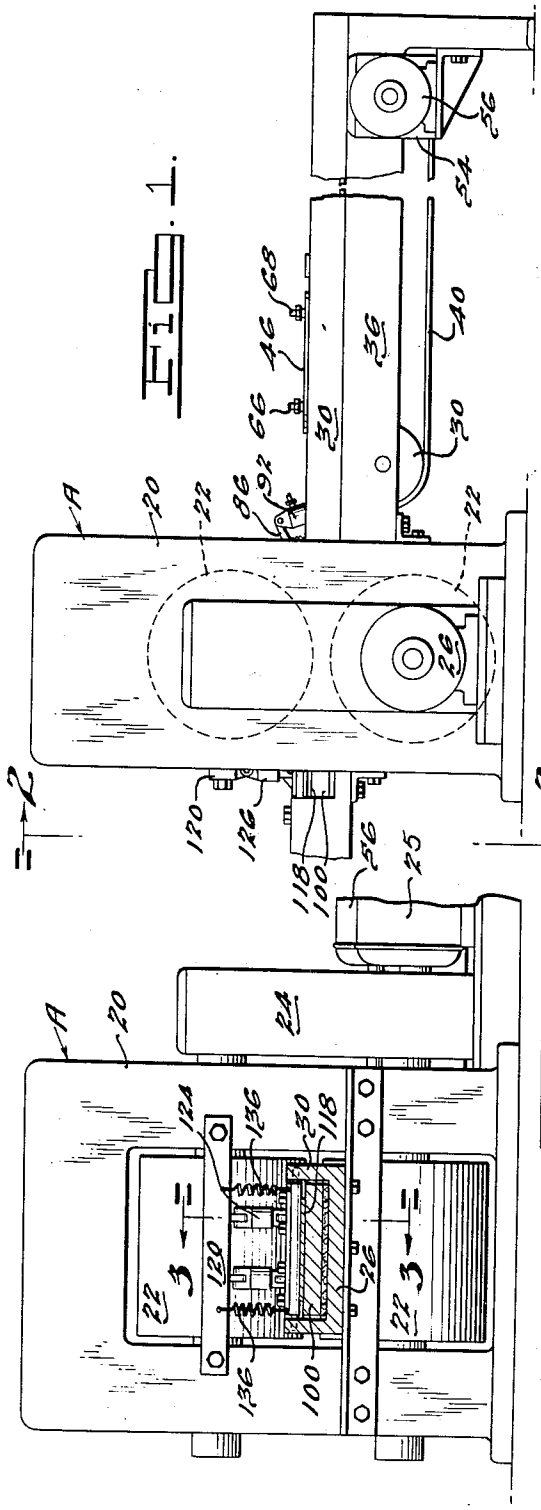


Fig. 1.

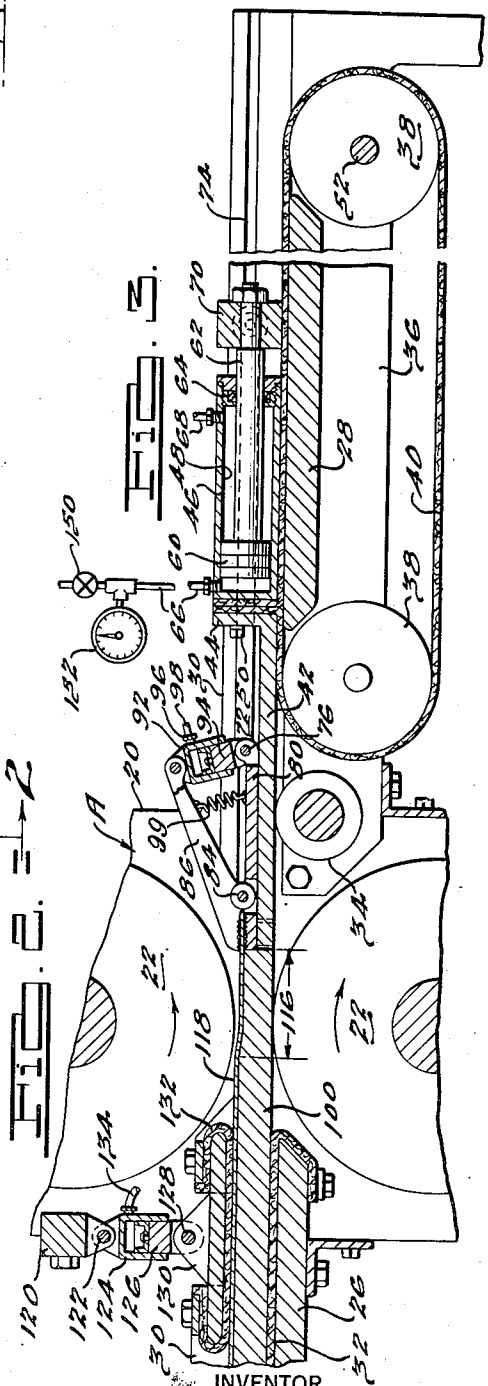


Fig. 2.

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Filed April 26, 1941 3 Sheets-Sheet 2

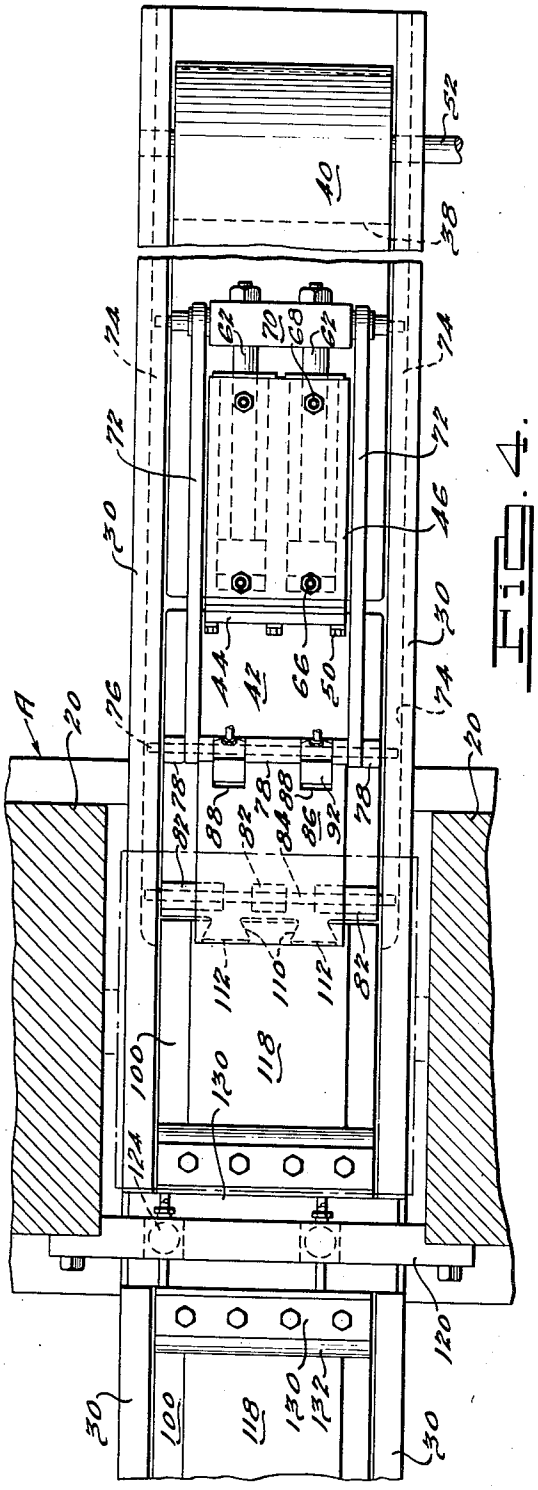


Fig. 4.

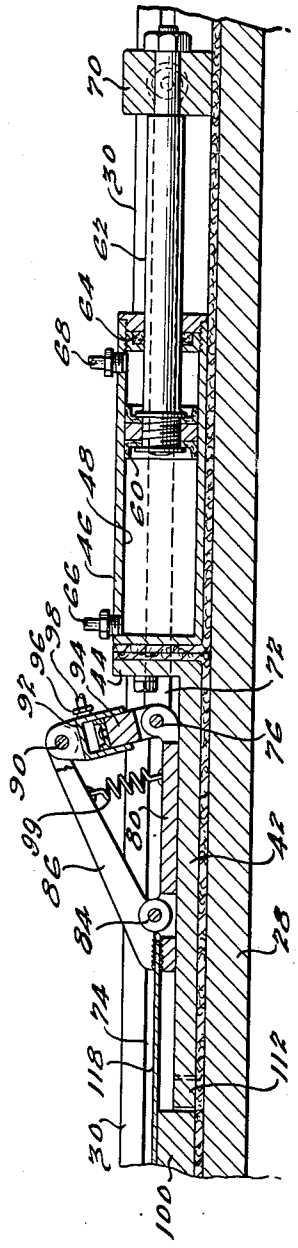


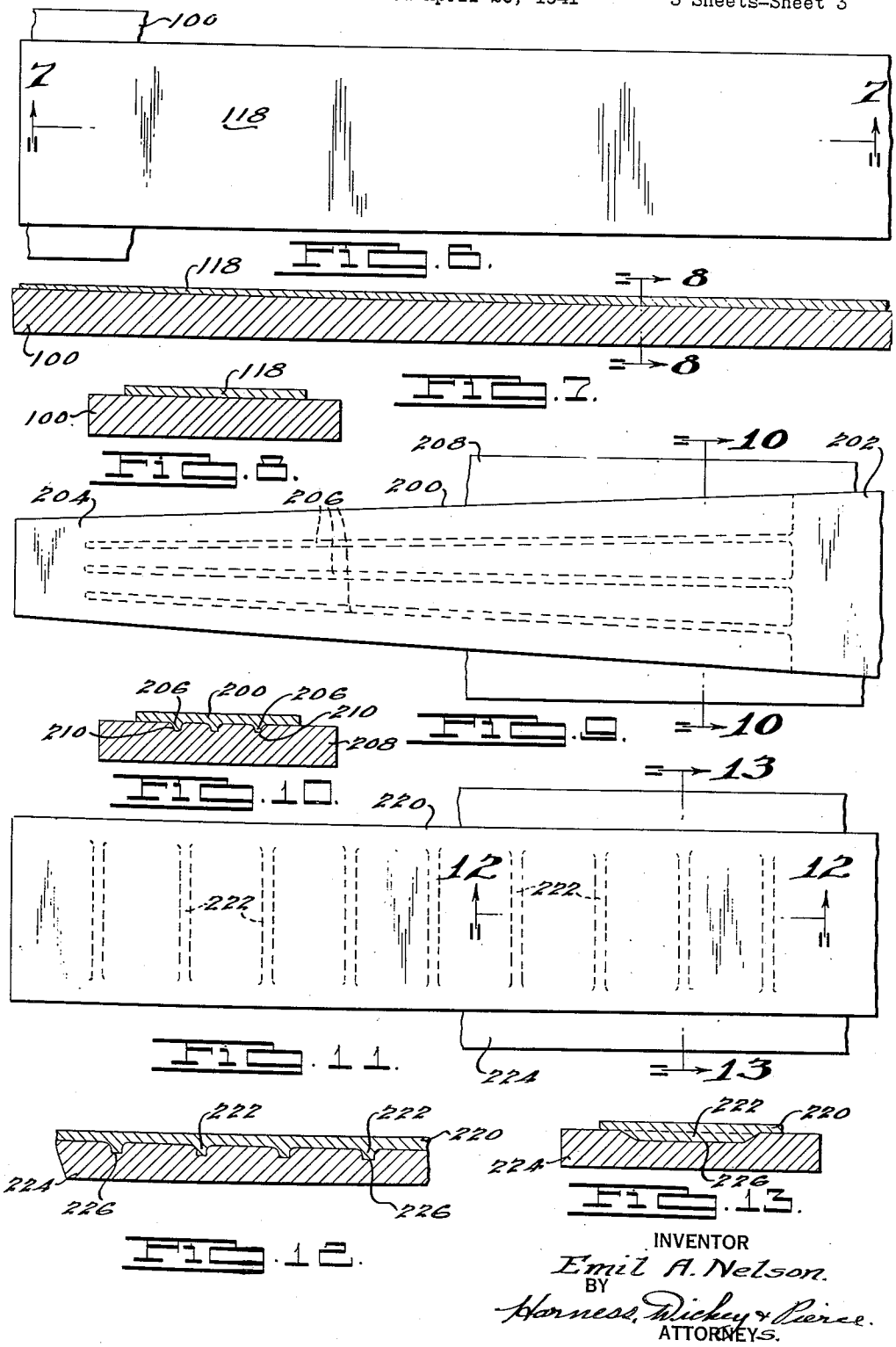
Fig. 5.

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# UNITED STATES PATENT OFFICE

2,315,810

## METHOD OF ROLLING SHEET METAL AND APPARATUS THEREFOR

Emil A. Nelson, St. Clair Shores, Mich.

Application April 26, 1941, Serial No. 390,490

13 Claims. (Cl. 80—19)

This invention relates to the rolling of sheet metal and particularly to the rolling of metal sheets to provide them with varying cross-sectional configurations and has particular relation to the rolling of metal sheets which taper in thickness over a portion or all of the length thereof.

Objects of the invention include the provision of a method of operating upon a metal sheet to vary its transverse cross-sectional configuration at different points in the length thereof; the provision of a method of rolling metal sheets to vary the thickness thereof at different points in the length of the sheet; the provision of a method of rolling metal sheets to tapered or other conformation comprising passing a sheet between a pair of cylindrical rolls having a constant center distance and in contact with a mandrel varying in cross-sectional configuration in a manner complementary to the variations desired in the final sheet; the provision of a method of rolling metal sheets as above described in which the advanced edge of the sheet passing through the roll is placed under a pull or tension tending to advance the sheet at a faster rate of travel than the peripheral speed of the rolls; the provision of a method of rolling metal sheets as above described in which both the mandrel and the sheet are placed under a pull or tension tending to advance them through the rolls; the provision of a method as above described in which the pulling force applied to the mandrel is different from the pulling force applied to the sheet; and the provision of a method as above described in which a pulling force is applied to the sheet and mandrel being passed through the rolls and a retarding force is applied to the sheet and mandrel on the entrance side of the rolls.

Other objects of the invention include the provision of apparatus for rolling metal sheets to varying cross-sectional configurations; the provision of means for rolling metal sheets to varying cross-sectional configurations including a pair of cylindrical rolls arranged in spaced relation and with their axes held at a constant distance with respect to each other, a mandrel adapted to be passed through the rolls and having a cross-sectional configuration varying in complementary relation with respect to the desired varying cross-sectional configuration of the desired final product, together with means for applying a pull on the forward end of a sheet associated with the mandrel and being passed through the rolls therewith, tending to advance the forward end of the sheet at a faster rate of movement than the peripheral rate of movement of the rolls; the provision of apparatus as above described in which means are also provided for exerting a pull on the mandrel in its passage through the rolls; the provision of apparatus as above described in which the means provided for exerting a pull on the sheet is movable with the means provided for exerting a pull on the mandrel; the provision of apparatus as above described in which the means for exerting a pull on the sheets includes releasable jaw means for gripping the forward end of the sheet being passed through the rolls; the provision of apparatus as above described in which the means for exerting a pull on the mandrel comprises a reversibly movable belt-like element; the provision of apparatus of the type above described in which the means for exerting a pull on the forward edge of the sheet comprises fluid operated means operatively connected to the belt and bodily movable therewith; and the provision of apparatus as above described in which means are provided on the entrance side of the rolls for gripping the sheet and the mandrel to apply a retarding effect thereto during the passage of the sheet and the mandrel through the rolls.

The above being among the objects of the present invention the same consists in certain novel features of construction, combinations of parts, and step or steps of operation to be hereinafter described with reference to the accompanying drawings, and then claimed, having the above and other objects in view.

In the accompanying drawings which illustrate a suitable embodiment of apparatus constructed in accordance with the present invention and which is suitable for use in carrying out the method of the present invention, and in which like numerals refer to like parts throughout the several different views,

Fig. 1 is a more or less diagrammatic, partially broken, side elevational view of rolling apparatus constructed in accordance with the present invention;

Fig. 2 is a transverse sectional view taken on the line 2—2 of Fig. 1;

Fig. 3 is an enlarged, fragmentary, vertical sectional view taken longitudinally through the rolling apparatus shown in the previous views and illustrating the construction of the same in greater detail and showing the positions which the various parts assume as a rolling operation is about to be initiated;

Fig. 4 is an enlarged, fragmentary, horizontal sectional view taken through the rolling appa-

ratus shown in the previous views in a plane passing between the rolls and above the mandrel thereof;

Fig. 5 is a fragmentary view of a portion of the apparatus shown in Fig. 3, in the same plane as Fig. 3, but on a larger scale and illustrating the relation of certain parts thereof after the sheet has passed a further distance through the rolls;

Fig. 6 is an enlarged, fragmentary, plan view showing a rolled sheet supported on the mandrel employed in the apparatus shown in the previous views;

Fig. 7 is a vertical sectional view taken on the line 7—7 of Fig. 6;

Fig. 8 is a vertical sectional view taken transversely of the mandrel and sheet shown in Figs. 6 and 7 and taken as on the line 8—8 of Fig. 7;

Fig. 9 is a view similar to Fig. 6 but illustrating a modified form of mandrel and resulting sheet;

Fig. 10 is a vertical sectional view taken transversely of the mandrel and sheet shown in Fig. 9 as on the line 10—10 thereof;

Fig. 11 is a view similar to Figs. 6 and 9 but showing a still modified form of mandrel and sheet;

Fig. 12 is an enlarged fragmentary, vertical sectional view taken longitudinally of the mandrel and sheet shown in Fig. 11 as on the line 12—12 thereof; and,

Fig. 13 is a vertical sectional view taken transversely of the mandrel and sheet shown in Fig. 11 and taken as on the line 13—13 thereof.

The desirability of producing sheets of metal of tapering thickness over the whole or part of the length thereof, or otherwise having varying cross-sectional configurations, has long been recognized and although many attempts have been made to produce such sheets none of them have been commercially practical. The use of sheets of tapered conformation has a possibility of wide application either in the form of sheets or fabricated into structural members for various uses. One of the principal possible fields at the present time is in connection with the fabrication of aircraft where sheets of tapered conformation may themselves be employed as the covering for the wings and fuselage and such sheets may be fabricated into structural members such as spars or the like for the wings or fuselage to automatically obtain the desired variation in required strength over the length thereof coupled with minimum weight and without the necessity of riveting together separate elements each of a different and constant thickness.

The present invention may be used for forming tapered or other sheets having a varying cross-sectional configuration from any desired metal. Where such sheets are to be employed in airplane construction they will, of course, ordinarily be formed of light metal such as aluminum or magnesium and in such event the rolling operation may be performed while the metal is in a cold state. Where such sheets are to be formed from steel, for instance, they may if desired or necessary be heated for the purpose of the rolling operation. The apparatus shown in the accompanying drawings has been designed primarily for rolling light metal sheets and, accordingly, no means for maintaining them in heated condition is illustrated since it is not necessary, but those skilled in the art will readily understand how this may be accomplished where necessary or desired.

In accordance with the practices of the present invention the tapered or otherwise formed sheets are made from conventional rolled sheets of constant thickness throughout and these stock sheets may be operated upon in a rolling mill of conventional construction and employing conventional rolls. Preferably the rolling mill is of a type in which the rolls can be securely locked in a predetermined spaced relationship with respect to each other and in a manner which will prevent springing of the rolls away from each other under the stress of the rolling operation. The rolls employed are conventional cylindrical rolls. For the purpose of ease and clarity of description it will hereinafter be assumed, unless otherwise specified, that the sheet to be produced is to have a uniform taper from one end thereof to the opposite end thereof, in other words one end of the sheet will be thicker than the opposite end of the sheet and the thickness will vary uniformly from one end thereof to the opposite end thereof.

In following out the practices of the present invention to form such a tapered sheet from a stock sheet of uniform thickness and by means of a rolling mill having cylindrical rolls, a member is formed preferably having a length greater than and a width equal to or greater than the width of the piece of stock to be worked upon. This member functions in some respects as a die, and in some respects as a platen but for the want of a better term is referred to herein, both in the specification and claims, as a "mandrel." This mandrel may be made from a suitable thickness of hardenable steel plate one or both sides of which are machined or otherwise worked upon to taper its thickness over its length in exact accordance with the variation of thickness desired in the length of the finished sheet to be produced. The mandrel is preferably hardened after machining and its surface preferably polished or ground to bring it to a suitable degree of finish. The rolls of the rolling mill are adjusted in parallel relation with respect to each other and so that the space between them is equal to the thickness of the mandrel plus the desired thickness of the sheet to be produced at any point in the length of the mandrel and sheet. The sheet selected as the piece of stock is of equal thickness throughout and equal in thickness to and preferably a few thousandths thicker than the thick end of the desired tapered sheet to be rolled and this stock sheet is placed over or under, and preferably over, the mandrel, and the mandrel and the superposed sheet is positioned for entrance between the rolls of the mill with the thin end of the mandrel positioned to be introduced into the mill. The initial assembly of the mandrel and work sheet will, of course, vary in thickness according to the variation in thickness of the mandrel itself. Assuming the mill to be operating, the assembly comprising the mandrel and its superposed sheet is then inserted between the rolls and such assembly is then fed through the rolls. As will be appreciated, inasmuch as the rolls are positioned with a fixed center distance during the rolling operation the thickness of the assembly of the mandrel and the sheet as it emerges from the rolls will be uniform from one end thereof to the opposite end thereof. Inasmuch as the mandrel is of a hardened nature no reduction in the thickness of the mandrel can result in passing through the rolls and consequently such reduction in thickness must occur in the work sheet itself, the result being that the thickness of the work sheet is caused to be varied from one end thereof to

the other in a complementary manner to the variation in thickness of the mandrel, thus providing the desired final product.

It may be found necessary in some cases, because of the nature of the metal being rolled or because of the amount of reduction desired in thickness between one end of the final sheet and the other, that the tapering of the sheet be accomplished in two or more stages. In other words it may be necessary to first follow out the above described operations on a sheet of stock to thus taper it from one end to the other but with a less amount of taper than is desired in the final product, and then take this partially tapered sheet and pass it through one or more similar operations in each of which the degree of taper is increased. In such case, of course, a separate mandrel will be required for each pass through the mill and each mandrel will have a successively greater taper than its predecessor. Sheets of light metal tapered to an extent requiring reduction of thickness equal to 70% at one end thereof have been produced in one operation by the practices of the present invention and, accordingly, where light metal is being worked on it will be appreciated that seldom if ever will more than one pass through the rolls be required.

The steps of operation above described in the formation of a tapered sheet are, however, not sufficient in and of themselves, to be relied upon in the commercial manufacture of such sheets. This is for the reason that if a flat sheet of stock is simply placed on a mandrel and fed through the rolls as described, the thinner trailing end portion of the resulting tapered sheet will invariably be bent laterally in one direction or the other, an effect commonly known in the art as fishtailing, instead of having substantially straight sides throughout its length. Such fishtailing will either render the sheet unfit for use or else require such a large amount of trimming as to involve a scrap cost disproportionate to the advantages gained. I have found that in rolling a sheet over a mandrel as above described the material of the stock sheet is discharged from the rolls at a faster rate than the mandrel progresses through the roll. This effect is probably produced by an extruding effect on the metal of the stock sheet. I have found that in order to prevent the fishtailing of the sheet being rolled it is necessary to exert a continuous and substantial pull on the sheet as it emerges between the rolls and that where such substantial pull is applied to the sheet the fishtailing effect is eliminated and a commercial usable and satisfactory product results. The application of a drag to the sheet and the mandrel assembly as it passes into the rolls appears also to aid in the final product of a commercially usable product.

It also appears to be of material aid in producing a commercially satisfactory sheet in the manner described to also apply a pulling force on the mandrel but to a lesser extent than the pull on the sheet itself. The pull on the sheet and the pull on the mandrel may be entirely independent of one another or it may be accomplished by apparatus in which the pull on one is partially offset, dependent upon or otherwise affected by the pull on the other. In the broader aspects of the invention such pull may be relied upon in whole or in part to also turn the rolls instead of independently driving them. The apparatus shown in the accompanying drawings is illustrative of one form of apparatus which may be employed in carrying out the method of the present invention and in the explanation of which the method of the present invention will be more clearly brought out. The apparatus itself, however, involves certain novel features which in and of themselves form further features of the invention.

Referring now to the accompanying drawings a conventional strip mill is indicated generally at A and as including a frame 20 between the opposite sides of which a pair of cylindrical rolls 22 are rotatably supported in a conventional manner. The mill may, of course, be provided with the usual screw downs (not shown) for controlling the spacing of the rolls 22 but in any event it is important that whatever means are employed for locating the spacing of the rolls it be such as to enable the rolls to be firmly locked in the desired spaced relation in such a manner as to be substantially unyielding during the passage of a piece of work between them. The rolls 22 are geared or otherwise connected together for equal rotational movement by means of gearing or the like (not shown) contained within a housing 24 and may be driven by means of a conventional electric motor 25.

As best illustrated in Fig. 3 a fixed table 26 is associated with the mill A on the entrance side of the rolls 22 and a fixed table 28 is associated with the mill on the discharge side thereof, the table 26 extending into relatively close proximity to the rolls 22 while the table 28 is outwardly spaced therefrom. The tables 26 and 28 are provided with side rails 30 which project thereabove at each side thereof and are transversely spaced from one another by a distance slightly greater than the width of the mandrel which passes between them and which will hereinafter be more fully described. These side rails 30 are for the purpose of guiding the mandrel straight into the rolls and to aid in maintaining its straight relation in its passage therethrough. The table 26 as best illustrated in Fig. 3 is preferably but not necessarily provided with a covering 32 of suitable fabric or other material which may serve to exert friction tending to resist movement of the mandrel thereover during the rolling operation. A conventional supporting roll 34 is mounted between the opposite sides of the frame 20 between the rolls 22 and the table 28 for the purpose of supporting the work as it emerges from between the rolls.

The table 28 is provided with depending side members 36 between which at opposite ends of the table 28 are rotatably supported a pair of rolls or the like 38 encircling which is a belt 40. The belt 40 may be of any suitable or desirable construction as, for instance, link chain, fabric, rubberized fabric, or a combination of such elements, but as a matter of illustration only it is shown in the accompanying drawings as being of a fabric or rubberized fabric construction. The rolls 38 are so positioned that the top edges lie in parallel and substantially flush relationship with respect to the top surface of the table 28 and the belt 40 passes over the top of such table. The top of the belt 28 and the top of the covering 32 for the table 26 lie in the same horizontal plane as the upper edge of the lower roll 22 as indicated in Fig. 3.

Supported on the upper surface of the belt 40 and at certain positions of its movement also by the roller 34 is a slide member 42 having an integral vertically turned flange 44 at its righthand end as viewed in Fig. 3. Fixed to the flange 44 for equal movement with the slide 42 is a cylinder unit 46 which also rests on the upper surface of

the belt 40 and in the particular construction shown includes a pair of cylinders 48 arranged with their axes parallel to the path of movement of the slide 42 and the upper surface of the belt 40. In the particular construction shown the belt 40 is fixed for equal movement to the slide 42 and the cylinder unit 46 by bringing the free ends of the belt upwardly between the flange 44 and the opposed end of the cylinder unit 46 where they are firmly clamped between these parts by means of bolts 50. The belt 40 is caused to move on the rolls 38 by driving one of the rolls, the righthand roll 38 as viewed in Figs. 1 and 3 being the driven roll in the particular construction shown. In order to drive it, its shaft 52, which is non-rotatably connected to it, is connected into a gear reduction unit 54, shown in Fig. 1, which in turn is driven by an electric motor 56. The electric motor 56 is preferably either an induction motor or a direct current motor in order that it may exert a material amount of torque while turning considerably under its rated speed, this being for a purpose which will hereinafter be more fully described.

Each cylinder 48 has a piston 60 therein which is mounted upon a piston rod 62 projecting out of the righthand end of the cylinder as viewed in Figs. 3, 4 and 5 and such end of each cylinder is provided with a suitable packing gland 64 to prevent leakage of fluid therefrom around the shaft 62. Connections 66 and 68 lead into the opposite ends of each cylinder 48 for the purpose of introducing fluid and preferably a liquid under pressure into either end of the cylinder and exhausting it from the opposite end thereof.

The projecting ends of the piston rods 62 are connected to a cross-bar 70 as best illustrated in Figs. 3, 4 and 5 and at its opposite ends the cross-bar 70 is pivotally connected to a pair of links 72 which extend to the left as viewed in the figures mentioned on opposite sides of the cylinder unit 46. The extreme outer ends of the cross-bar 70 are received in grooves 74 formed in the inner faces of the side rails 30 adjacent the table 28, such grooves thus forming means for guiding the ends of the bar 70 during movement thereof longitudinally of the table 28. As also best brought out in Figs. 3, 4 and 5 the forward ends of the link 72 are pivotally connected to a cylindrical bar or shaft 76 the opposite ends of which are also guided in the grooves 74 and which bar is also received in transversely spaced bosses 78 formed at the rear edge of a slide 80 which rests upon the upper surface of the slide member 42. Adjacent to but slightly spaced from the lefthand end of the slide 80, the slide 80 is provided with a plurality of transversely spaced bosses 82 extending through which is a second cylindrical rod or shaft 84. The ends of the shaft 84 are also received in the grooves 74 for guiding movement therein.

Overlying the slide 80 is a clamping plate 86 which is preferably of the same width as the sheet to be rolled. The forward or lefthand end of the clamping plate 86 is aligned with the lefthand end of the slide 80, and in line with the various bosses 82 it is provided with complementary bosses fitting therebetween and rotatably surrounding the shaft 84 so that the clamping plate 86 as a whole is pivotal about the axis of the shaft 84. The clamping plate 86 is normally disposed at an angle with respect to the plane of the slide 80 but its forwardly projecting or lefthand end as viewed in the drawings is provided with a serrated or knurled lower face which when a work sheet is interposed between it and the opposed face of the slide 80 lies in substantially parallel relationship with respect to the upper face of the slide 80. That portion of the upper face of the slide 80 opposed to the serrated or knurled lower face of the clamping plate 86 is likewise serrated or knurled.

The rear or right end edge of the clamping plate 86 is notched out, as at 88, at transversely spaced points, shown as two in the particular embodiment of the apparatus shown, and received in these notches 88 and pivoted to the clamping plate 86 therein by means of a transversely extending shaft 90 is the upper end of a cylinder member 92. A piston member 94 reciprocably received in each cylinder 92 is arranged with its lower end pivotally mounted on the shaft 76 which also serves to connect the links 72 to the slide 80 as previously described. Each cylinder 92 is provided with a connection 96 leading into it above its piston 94 and such connection is connected by a flexible tube 98 to a suitable source (not shown) of fluid, and preferably liquid, under pressure. As will be appreciated, when fluid under pressure is introduced through the tube 98 and connection 96 into the interior of the cylinders 92 it will tend to project the pistons 94 from their corresponding cylinders 92 and cause the clamping plate 86 to pivot in a counterclockwise direction of rotation as viewed in Figs. 3 and 5, bringing the forward or clamping edge of the clamping plate 86 downwardly with respect to the forward edge of the slide 80. One or more springs 99 are tensioned between the clamping plate 86 and the slide 80 and constantly urge the clamping plate 86 toward a clockwise direction of rotation as viewed in Figs. 3 and 5, thereby tending to draw the forward clamping end of the clamping plate 86 away from the opposed surface of the slide 80.

As previously mentioned it is assumed, for the purpose of illustration in the particular embodiment of the apparatus shown, that it is desired to form a sheet of light metal such as aluminum of uniformly tapered character from one end thereof to the other and to accomplish this a mandrel 100 is employed. As perhaps best brought out in Figs. 6, 7 and 8 the mandrel 100 is preferably wider than the sheet which is to be operated on and where employed with apparatus of the specific character shown and described is preferably of such width as to be relatively closely but readily slidable between the side bars 30. While the average thickness of a mandrel to be used may vary considerably in different jobs, the mandrel should be sufficiently thick to enable it to be handled and passed through the mill without bending or distortion. This mandrel 100 shown tapers in thickness from one end toward the other end thereof by an amount exactly equal to the taper desired in the finished tapered sheet. In other words, if for example the finish tapered sheet is to taper uniformly in thickness an amount equal to five thousandths of an inch per foot of length, then the main body portion of the mandrel is correspondingly tapered. The mandrel is, of course, preferably made from a hardenable steel suitably hardened and with that surface thereof which is to receive the sheet suitably ground and polished to insure an equivalent finish on the sheet to be produced. The mandrel may, of course, be and preferably is of greater length than the finished sheet.

Any suitable means may be provided for connecting the forward or advanced end of the man-

drel, shown as the righthand end in Figs. 3, 4 and 5, for instance, to the slide 42 but preferably the connection is such as to enable the mandrel 100 and the slide 42 to be readily disconnected. The particular method shown in the drawings and as best brought out in Fig. 4 consists of forming dovetailed notches 110 in the forward edge of the mandrel and forming interfitting projections 112 on the forward edge of the slide 42. In this connection it will be observed from an inspection of Figs. 3 and 5 in particular that the advanced end of the mandrel 100 which is thus notched is reduced in thickness to approximately the same thickness as the slide 42, this being for the purpose of permitting the slide 80 to move to the left when moving to loading position as illustrated in Fig. 3 to bring its forward or lefthand end as viewed in Fig. 3 over the notched out portion of the mandrel. It will be appreciated that the mandrel 100 and slide member 42 may be disconnected from one another when the mandrel 100 is passed completely through the rolls 22 by simply lifting it upwardly and then away from the slide member 42.

Additionally, and as best brought out in Fig. 3, the forward or righthand end of the mandrel 100 is preferably reduced in thickness over a length such as indicated at 116 so that such forward end of the mandrel 100 and the sheet 118 superposed thereon may be introduced between the rolls 22 and the sheet clamped to the slide 80 before the rolls 22 will grip the mandrel and sheet between them. It will be understood that the end of the mandrel which is notched out at 110 and reduced in thickness over the length 116 is the thin end of the mandrel for reasons which will hereinafter be apparent.

On the entrance side of the rolls 22 or to the left thereof as viewed in Fig. 3 a bar 120 is extended between the opposite sides of the frame 20 and pivotally connected to the bar by means of pivot pins 122 are a plurality, shown as two, cylinders 124. Each cylinder 124 reciprocably receives therein a piston 126. The pistons 126 are in turn pivotally connected by means of pins 128 to a presser bar 130 which is preferably provided with a fabric or other frictional covering 132 fixed thereto and extending over the lower face thereof. The presser bar 130 is adapted to press downwardly upon the upper surface of the sheet 118 and act therethrough to force the mandrel 100 down into contact with the frictional surface 32 of the table 26, thereby to set up a frictional drag tending to resist movement of the mandrel 100 and sheet 118 through the rolls 22. Fluid and preferably liquid under pressure is introduced into the cylinders 124 through a suitable line 134 connected to a suitable source of pressure and preferably one or more springs 136 (see Fig. 2) cooperating between the presser foot 130 and the bar 120 constantly tend to raise the presser foot 130. Thus when pressure in the cylinders 124 is relieved the springs 136 will raise the presser foot 130, and when pressure is applied to the cylinders 124 such pressure acting on the pistons 126 will force the presser foot 130 downwardly against the force of such springs and into operative engagement with the surface of a sheet 118 passing therebelow.

In the operation of the apparatus thus described it is, of course, assumed that the mandrel 100 has been connected to the slide 42 by interengagement of the dovetailed edges thereof and that the motor 56 has been reversed so as to move the slide 42 to its extreme position of movement to the left and as viewed in Fig. 3. Fluid under pressure has been introduced into the cylinders 48 through the connections 58 and the fluid at the opposite ends of the cylinders has been allowed to escape through the connection 66 so as to move the pistons 60 and consequently the slide 80 to its extreme position of movement to the left as shown in Fig. 3. Pressure in the cylinders 92 and 124 has been relieved so that the cooperating springs 100 and 136, respectively, have lifted the forward or lefthand end of the clamping plate 86 and has lifted the presser foot 130. A sheet 118 of the desired material to be worked upon and of the required width and length is then placed upon the mandrel 100 and its forward or righthand end as viewed in Figs. 3, 4 and 5 is passed under the presser foot 130 and under the upper roll 22 until its forward or righthand edge passes under the clamping end of the clamping plate 86 and abuts against the hinge bosses thereof. As previously mentioned the sheet 118 is of a width preferably slightly wider than that desired in the final tapered sheet and of a length which experience has shown will provide a final sheet of the desired length, plus an additional amount which overlies the reduced portion 116 of the mandrel 100. This last portion is, of course, provided as an expedient in securing the sheet 118 to the slide 80, is not affected by the rolling operation and will be removed in trimming the rolled sheet to its final dimension. The sheet 118 is also preferably slightly greater in thickness than the maximum thickness desired in the final tapered sheet. If the rolls 22 are rotating at this time no clamping action on the sheet and mandrel between the rolls or movement of the sheet and mandrel will result because of the cut-away portion 116 of the mandrel 100 provided for preventing such clamping action.

The above operations having been accomplished, fluid under pressure is then introduced into the cylinders 92 and 124 with the result that the clamping plate 86 is caused to pivot in a counter-clockwise direction and to clamp the forward edge of the sheet 118 between it and the lefthand end of the slide 80, and also causing the presser foot 130 to press that portion of the sheet 118 thereunder firmly down into contact with the upper surface of the mandrel 100 and firmly press the mandrel 100 downwardly into contact with the covering 32 for the table 26.

If the rolls 22 are power driven and not already rotating, they are then put in operation, and the motor 56 is energized to cause the righthand roll 38 to turn in a clockwise direction of rotation as viewed in Figs. 3 and 5. Rotation of the roll 38 in the direction described causes the upper side of the belt 40 to move to the right as viewed in Figs. 3 and 5 carrying with it the slide 42, cylinder unit 46 and all of the parts interconnected therewith including the mandrel 100 and the sheet 118. Initial movement of the mandrel 100 and sheet 118 to the right as viewed in Fig. 3 will bring the mandrel 100 and sheet 118 into gripped relation between the rolls 22, and as soon as this occurs fluid under pressure is introduced into the lefthand end of the cylinders 48 and permitted to exhaust from the righthand end thereof. Once the mandrel 100 and sheet 118 is gripped between the rolls 22 it will, of course, be appreciated that no ordinary force exerted by either the belt 40 or the cylinders 48 will be capable of advancing the mandrel and the sheet through the rolls at a

rate faster than the rotation of the rolls 22 permits. In other words such forces will not be able to slide the mandrel 100 and sheet 118 through the rolls faster than the rolls rotate. On the other hand in order to be effective it will be appreciated that the pull on the belt 40 must exceed the pull exerted by the pistons 60 in the cylinders 48. Preferably the pull exerted by the belt 40 is roughly twice the pull capable of being exerted by the pistons 60.

Assuming the various operations and conditions above explained to be existing and the mandrel 100 and sheet 118 having been advanced into gripping relationship with respect to the rotating rolls 22, the mandrel 100 and sheet 118 will be drawn through the rolls 22 as well as being forced therethrough by the friction thereof with the rolls where the rolls are driven, overcoming the resistance of the presser foot 130, and will continue to pass through the rolls 22 until the sheet 118 has been acted upon over its length rearwardly or to the left of the cut-away portion 116 of the mandrel 100. Inasmuch as the rolls 22 are arranged with fixed axes and are of an unyielding nature the assembly of the mandrel 100 and sheet 118 in the condition which it finally emerges from the rolls 22 will be of uniform thickness from the reduced portion 116 of the mandrel 100 rearwardly or to the left. The mandrel 100 being of an unyieldable nature the material of the sheet 118 is the only element of the combination that may yield and, accordingly, in passing through the rollers 22 its thickness is necessarily reduced in an amount complementary to the taper of the mandrel. Thus the sheet 118 as it comes from the rolling process is tapered in thickness from one end thereof to the opposite end thereof excepting only that portion of the sheet which overlies the portion 116 of the mandrel 100 and which portion in the final product will ordinarily be removed as scrap.

During the rolling operation above described it will be appreciated that not only is the mandrel 100 being pulled in the direction of its movement through the rolls 22 but the sheet 118 is also being pulled in the direction of its movement through the rolls 22 and in a manner more or less independently of the mandrel and so that the advanced end of the sheet 118 may be moved at a different rate of speed than the mandrel 100. I have found that this feature is essential in order to prevent fishtailing of the sheet being rolled and is necessary for the following reasons. I have found that in rolling a sheet such as 118 upon a mandrel 100 the sheet 118 appears to extrude forwardly or in the direction of movement of the sheet through the rolls so that the end of the sheet which has passed through the rolls moves at a greater speed than the peripheral speed of the rolls.

The amount which the sheet 118 thus advances with respect to the peripheral speed of the rolls and the linear speed of the mandrel 100 will, of course, vary with the amount of reduction to which the sheet 118 is being subjected and to the material from which it is formed. As illustrative of this movement which occurs it may be stated that experiments have shown that a sheet such as 118 formed of aluminum and approximately six feet in length and tapering in thickness from 0.064" at one end to 0.020" at its opposite end will be projected from the rolls 22 at a faster rate than the peripheral speed of the rolls 22 and the linear speed of the mandrel 100 by an amount equal to 0.056" per inch of travel of the mandrel 100 and/or peripheral movement of the rolls 22. This discharge of the sheet from the rolls 22 at a greater speed than the peripheral speed of the rolls is probably due to an extruding effect upon the metal of the sheet 118 during its passage through the rolls, but in any event I have found that it is necessary in order to prevent fishtailing of the final product to keep the sheet 118 on the discharge side of the roll under a constant and material tension and at the same time it is preferable to retard the passage of the sheet and the mandrel into the rolls as by means of a presser foot such as 130 or other equivalent means. This tension on the sheet 118 as it passes through the rolls is, of course, obtained by means of fluid pressure in the cylinders 48 acting on the pistons 60, the pistons 60 and parts connecting them to the advanced edge of the sheet 118 moving to the right as viewed in the drawings, with respect to the belt 40, slide member 42 and mandrel 100, until near the end of the operation these parts may have assumed the relative positions indicated in Fig. 5. In connection with the passage of the sheet 118 through the rolls 22 it may be stated that experiments indicate that it is preferable, particularly where the amount of reduction of the sheet 118 is relatively great, that its passage through the rolls 22 be relatively slow, for instance at a rate of 24 to 48 feet per minute, so that the metal being displaced in the sheet 118 by the rolls may have ample time to flow. Sheets thus rolled at the speeds indicated appear to be superior to sheets rolled at higher speeds, although it is to be understood that higher speeds may unquestionably be utilized particularly where the amount of reduction of the sheet at its thin end is less than the particular instance cited. It will also be appreciated that in the particular instance cited the thin end of the completed sheet has been reduced approximately 70% in thickness as compared to its original thickness, this large amount of reduction in the thickness being approximately three times as great as it is possible to successfully obtain in the commercial rolling of flat sheets in accordance with present day practices.

The sheet 118 thus having been rolled as above described and having been passed through the rolls 22, the feed of fluid under pressure to the lefthand end of the pistons 60 is stopped and the motor 56 is de-energized so as to stop the belt 40. The fluid pressure in the cylinders 92 and 124 is thereupon relieved permitting the springs 100 and 136 to release the clamping plate 86 from the sheet 118 and to raise the presser foot 130, and the sheet 118 is then removed. The motor 56 is then reversed so as to move the slide 42 and the mandrel 100 to the left to their initial loading positions and fluid under pressure is admitted to the righthand side of the piston 60 and allowed to escape from the lefthand end of the cylinders 48 so as to permit the slide 80 to return to its loading position, after which another blank sheet 118 may be inserted into place and the sequence of operations described and repeated.

One thing may be noted in connection with the pull exerted by the cylinders 48 and the pistons 60 on the sheet being rolled and that is where a relatively narrow sheet is being rolled and brought to relatively thin condition at one end thereof it may be desirable to reduce the fluid pressure on the pistons 60 as the thickness of

the sheet 118 is reduced by the rolls 22 so as not to endanger pulling the sheet apart. While this may be accomplished in any suitable manner, either automatically or manually, one method of accomplishing this manually is illustrated in Fig. 3 in which it will be noted that the supply line 66 is provided with a manually operable control valve 150 and a pressure gauge 152 is interposed between the valve 150 and the forward end of the cylinders 48. Particularly where the mandrel and sheet are fed through the rolls at the slow rate above indicated as preferable, an operator may manually operate the valve 150 to gradually reduce the pressure being applied to the piston 60 as the sheet 118 progresses through the rolls 22. The condition desired, of course, is to maintain a substantially constant tensile stress on the sheet 118.

It should be appreciated by those skilled in the art that the mounting of the cylinder assembly 46 on the belt 40 could be dispensed with in practicing the method of the present invention and the cylinder assembly 46 be independently and fixedly mounted and connected in the manner shown or otherwise with the advanced end of the sheet 118. Under such circumstances the belt 40, its driving means and connection to the mandrel 100 might be dispensed with entirely where the rolls 22 are driven, the friction between the lower roll 22 and the mandrel being relied upon to pass the mandrel through the rolls without any pulling force being applied thereto. The only disadvantage of such modified construction would be that the cylinder assembly 46 would be required to be of a length in excess of the length of the sheet 118 being rolled, whereas in the particular apparatus illustrated the length of the cylinder assembly 46 need only be slightly greater than the amount which the sheet 118 advances from the rolls in excess of the peripheral travel of the rolls. Consequently with the construction shown the cylinder assembly 46 is of minimum length, is relatively inexpensive to build or purchase and, having a short stroke, may be readily and quickly operated particularly when returning it to its loading position. It will also be appreciated by those skilled in the art that from the standpoint of the broad method of the present invention the use of the belts 40 to move the mandrel 100 is merely one expediency and that movement of the mandrel 100 may be accomplished in a suitable or desirable manner either independently of or simultaneously with the means for applying a tension on the sheet 118.

From the above it will be appreciated that if instead of desiring a finished sheet of uniform taper from one end thereof to the opposite end thereof a sheet having different degrees of taper, or only one or different portions of the length thereof tapered, all that is necessary to do is to form a mandrel whose thickness tapers or varies in a complementary manner to that of the desired final sheet and after superimposing a sheet of material of uniform thickness over the mandrel and of a maximum thickness equal to or preferably slightly greater than the maximum thickness in the desired final sheet, pass the same through the rolls in the same manner as described in connection with the sheet 118 to obtain the desired final product. It is also possible to form ribs either longitudinally or transversely of such sheet or depressions or pockets in such sheets in addition to the taper applied thereto by following out the same general practices.

For instance, in Figs. 9 and 10 the sheet 200 there shown may be provided with a thick end 202 and a thin end 204. It is of greater width at its thick end than at its thin end. Additionally, it is provided on its under surface with a plurality, illustrated as three, generally longitudinally extending ribs 206 which ribs may converge slightly toward one another towards the thin end of the sheet as illustrated. The ribs themselves may taper in depth from one end thereof towards the opposite end thereof. In such case the mandrel 208 which is employed in accordance with the present invention to form the sheet 200 is tapered over its length in complementary relationship with respect to the desired taper over the length of the sheet 200. Additionally its upper surface is provided with grooves 210 complementary to the ribs 206 to be formed on the sheet. The original sheet of stock which is employed to make the sheet 200 will, of course, be of substantially less length than the finished sheet 200 under the circumstances assumed, it will be tapered in width and have a wide end equal to the wide end 202 of the finished sheet 200 or of slightly greater width and a narrow end of substantially the same or slightly greater width than the narrow end 204 of the sheet 200. In thickness it will preferably be equal to the combined thickness of the sheet 200 and the ribs 206 at the thick end of the finished sheet. Obviously as such sheets and mandrel are passed through the rolls 202 described or equivalent rolls and otherwise acted upon in the manner described, it will be transformed into the desired final sheet 200.

On the other hand a tapered sheet such as the sheet 220 illustrated in Figs. 11, 12 and 13 having transversely extending ribs 222 on its lower surface may be desired. In such case the cooperating mandrel 224 will be tapered in thickness over its length or a portion of its length in accordance with the desired taper or variation in thickness in the desired final sheet and its upper surface will be provided with transversely extending grooves 226 complementary to the desired ribs 222 to be formed in the sheet 220. The blank sheet or work sheet which will be employed in such case will preferably have a thickness equal to the maximum thickness of the sheet 220 and ribs 222 at the thick end of the sheet and in passing the mandrel 224 and blank sheet received thereon through the rolls it will be formed to the desired final shape and thickness in the same general manner as in the preceding cases as will be appreciated.

One thing may be noted, however, in the practices of the present invention and which will be of aid from a commercial standpoint, and that is that because of the difficulty liable to be experienced in connection with the rolling mill employed in connection with the invention in adjusting the rolls to bring them to the desired spacing and parallelism, it is preferable in designing different mandrels for use in rolling sheets of various sizes, thicknesses, tapers or otherwise on a single mill to so construct the mandrels that all of them with their superposed sheets may be passed through the rolls without necessitating adjustment of the position of the rolls. In other words when designing mandrels to roll various tapered or other sheets varying in some respects from one another it will be found to be of great aid to so design them that the combined final mandrel and sheet thickness of all of them are identical, as in such case one mandrel may be substituted for another one in the mill but without

requiring adjustment of the rolls of the mill and subsequent checking and re-adjustment of the rolls to bring them to the desired spacing and parallelism. Under such conditions it will be found that a number of sheets each having different characteristics may be relatively rapidly rolled one after the other or in multiples simply by changing mandrels in each instance.

From the above it will be appreciated that the present invention provides a method by means of which sheets of metal which vary in thickness from one end thereof to the other end thereof or over a portion of the length thereof may be quickly and accurately produced from ordinary stock sheets of uniform thickness. It will also be appreciated that apparatus to carry out such method may be embodied in a number of different mechanisms of varying types and construction, the particudar apparatus shown by way of illustration constituting a preferred apparatus for use in carrying out the method and itself involving certain features constituting a more specific part of the present invention.

Having thus described my invention which I claim by Letters Patent is:

What I claim is:

1. In the manufacture of metal sheets differing in thickness and/or contour at different points in the length thereof, the steps of forming a plate-like mandrel of a length and width at least as great as the length and width of the desired final product and varying in thickness and/or cross-sectional configuration at different points in the length thereof in a manner complementary to the variation desired in the final product, placing a sheet of the desired metal and of uniform thickness throughout in contact with a surface of said mandrel to form an assembly, passing said assembly through power driven rolls maintained at a fixed axial distance with respect to each other and spaced from each other by a distance less than the maximum thickness of said assembly, and constantly maintaining that portion of said sheet discharged from said rolls under a sufficient longitudinal tension during passage of said sheet through said rolls to move the leading edge of said sheet at a greater speed than said mandrel.

2. In the manufacture of metallic sheets having different thicknesses and/or cross-sectional configurations at different points in the length thereof, the steps of forming a plate-like mandrel of at least the width and length of the desired final sheet and varying in thickness and/or cross-sectional configuration at different points in the length thereof in a manner complementary to that desired in the final sheet, applying a sheet of metal of constant thickness throughout against one surface of said mandrel to provide an assembly, passing said assembly through cylindrical power driven rolls having their axes fixed with respect to each other and with the rolls spaced from each other by a distance less than the maximum thickness of said assembly, continually applying a force to said mandrel during its passage through the rolls tending to advance it therethrough, and continuously applying a pulling force to the advanced edge of said sheet during its passage through said rolls tending to advance it at a greater speed than said mandrel.

3. In the manufacture of metallic sheets having different thicknesses and/or cross-sectional configurations at different points in the length thereof, the steps of forming a plate-like mandrel of at least the width and length of the desired final sheet and varying in thickness and/or cross-sectional configuration at different points in the length thereof in a manner complementary to that desired in the final sheet, applying a sheet of metal of constant thickness throughout against one surface of said mandrel to provide an assembly, passing said assembly through cylindrical power driven rolls having their axes fixed with respect to each other and with the rolls spaced from each other by a distance less than the maximum thickness of said assembly, applying a force to said mandrel in addition to the force applied thereto by said rolls tending to advance it through said rolls, and applying a force to the advanced end of said sheet, in addition to the force applied to said sheet by said rolls, tending to pull said sheet through said rolls in advance of said mandrel.

4. In the manufacture of a sheet of metal tapered in thickness in the direction of its length, the steps of forming a mandrel of a length and width corresponding to that portion of said sheet which is to be tapered and tapered in thickness in a manner complementary to the desired taper in said sheet, placing a sheet of metal of uniform thickness throughout against a face of said mandrel to form an assembly, and then passing said assembly between cylindrical rolls fixedly spaced with respect to each other by a distance less than the maximum thickness of said assembly, constantly maintaining that portion of said sheet which has passed through said roll under a material tension during the passage of said sheet through said rolls whereby to advance it at a greater speed than said mandrel, and exerting a pull on said assembly during its passage through said rolls tending to retard its passage through said rolls.

5. In the manufacture of a sheet of metal tapered in thickness in the direction of its length, the steps of forming a mandrel of a length and width corresponding to that portion of said sheet which is to be tapered and tapered in thickness in a manner complementary to the desired taper in said sheet, placing a sheet of metal of uniform thickness throughout against a face of said mandrel to form an assembly, and then passing said assembly between cylindrical rolls fixedly spaced with respect to each other by a distance less than the maximum thickness of said assembly, applying a force to said mandrel during its passage through said rolls tending to pull it through said rolls in advance of said mandrel, separately applying a force to said sheet during its passage through said rolls tending to pull said sheet through said rolls, and exerting a pull on said assembly during its passage through said rolls tending to retard its passage through said rolls.

6. Rolling apparatus comprising, in combination, a rolling mill including a pair of spaced cylindrical rolls rotatably mounted therein in a fixed, spaced relation with respect to each other, a plate-like mandrel of different thickness at different points in the length thereof adapted to receive a sheet of metal thereon and to be passed with said sheet of metal between said rolls, and means on the discharge side of said mill cooperable with a sheet being passed through said mill with said mandrel for placing that portion of said sheet between its advanced end and that portion thereof gripped between said rolls and said mandrel under a material tension.

7. Sheet rolling apparatus comprising, in combination, a pair of cylindrical rolls, means for

rotatably supporting said rolls in spaced relation and with their axes at a fixed distance with respect to each other, a plate-like mandrel adapted to receive thereon a sheet of metal and adapted to be passed with said sheet thereon between said rolls, means for applying a pull to said mandrel during its passage through said rolls tending to move it at a greater speed than the peripheral speed of said rolls, and means for applying a pull to said sheet during its passage through said rolls tending to advance said sheet through said rolls at a greater speed than the peripheral speed of said rolls and the linear speed of said mandrel.

8. Rolling apparatus comprising, in combination, a rolling mill including a pair of rotatable cylindrical rolls arranged in spaced relation and at a fixed distance between the axes thereof, a plate-like mandrel having different thicknesses at different points in its length adapted to receive thereon a sheet of metal to be rolled and to be passed therewith through said rolls, means on the discharge side of said mill cooperable with said mandrel during passage thereof between said rolls for applying a pull on said mandrel, and additional means associated with the last mentioned means inter-engageable with the advanced end of said sheet for applying a pull to said advanced end of said sheet during the passage of said sheet through said rolls tending to move said advanced end at a faster rate of speed than said mandrel.

9. Apparatus for rolling metal sheets comprising, in combination, a rolling mill including a pair of rotatable cylindrical rolls arranged in spaced relation, a plate-like mandrel and adapted to be passed between said rolls and to support a work sheet against one face thereof during said passage, means on the discharge side of said mill and movable in the direction of movement of said mandrel therethrough connectible to said mandrel to exert a pull thereon during its passage between said rolls, and means in addition to the last mentioned means connectible with said sheet during its passage beteween said rolls operable to apply a pull to said sheet during its passage between said rolls to advance the forward end of said sheet at a different rate of speed than said mandrel.

10. Apparatus for rolling metal sheets comprising, in combination, a rolling mill including a pair of rotatable cylindrical rolls arranged in spaced relation and fixed against bodily movement with respect to each other, a plate-like mandrel adapted to be passed beteween said rolls and to support a sheet against one face thereof during said passage, means on the discharge side of said mill and movable in the direction of movement of said mandrel therethrough connectible to said mandrel to exert a pull thereon during its passage between said rolls, and means on the entrance side of said rolls tending to retard the movement of said mandrel and sheet into said rolls.

11. Apparatus for rolling metal comprising, in combination, a pair of cylindrical rolls, means rotatably supporting said rolls in spaced relation and at a fixed axial distance with respect to each other, a plate-like mandrel adapted to receive a sheet of metal to be rolled against one face thereof and to be passed with said sheet of metal between said rolls, means on the discharge side of said rolls movable in the direction of movement of said mandrel and sheet therethrough connectible with said mandrel, means for moving the last mentioned means, additional means on the discharge side of the roll connectible with the advanced edge of said sheet during its passage between said rolls, and additional means for applying a force to the last mentioned means tending to move it in the direction of said sheet through said rolls to maintain the said sheet under tension during its passage through said rolls.

12. Rolling apparatus comprising, in combination, means rotatably supporting a pair of cylindrical rolls in spaced relation with respect to each other, a plate-like mandrel of different thickness at different points in its length adapted for passage between said rolls and adapted to support a work sheet thereon during said passage, belt-like means on the discharge side of said roll arranged with one surface thereof movable in the direction of movement of said mandrel and sheet through said rolls, means for connecting said belt-like means to said mandrel, means for driving said belt-like means whereby to exert a pull on said mandrel during its passage through said roll, a pulling device secured to said belt-like means for equal movement therewith, and means for connecting said pulling device to the advanced edge of said sheet.

13. Rolling apparatus comprising, in combination, means rotatably supporting a pair of cylindrical rolls in spaced relation with respect to each other, a plate-like mandrel of different thickness at different points in its length adapted for passage between said rolls and adapted to support a work sheet thereon during said passage, belt-like means on the discharge side of said roll arranged with one surface thereof movable in the direction of movement of said mandrel and sheet through said rolls, means for connecting said belt-like means to said mandrel, means for driving said belt-like means whereby to exert a pull on said mandrel during its passage through said roll, hydraulically actuated pulling means secured to said belt-like means for equal movement therewith and including a part movable relative thereto in the direction of movement of said belt-like means, and means for securing said part to the advanced end of said sheet whereby to apply a pulling force to the advanced end of said sheet during the passage of said sheet between said rolls to advance said end at a faster rate than said mandrel is advanced through said rolls.

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