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METHOD AND APPARATUS FOR FORMING COMPOUND CURVATURES IN SHEET MATERIAL

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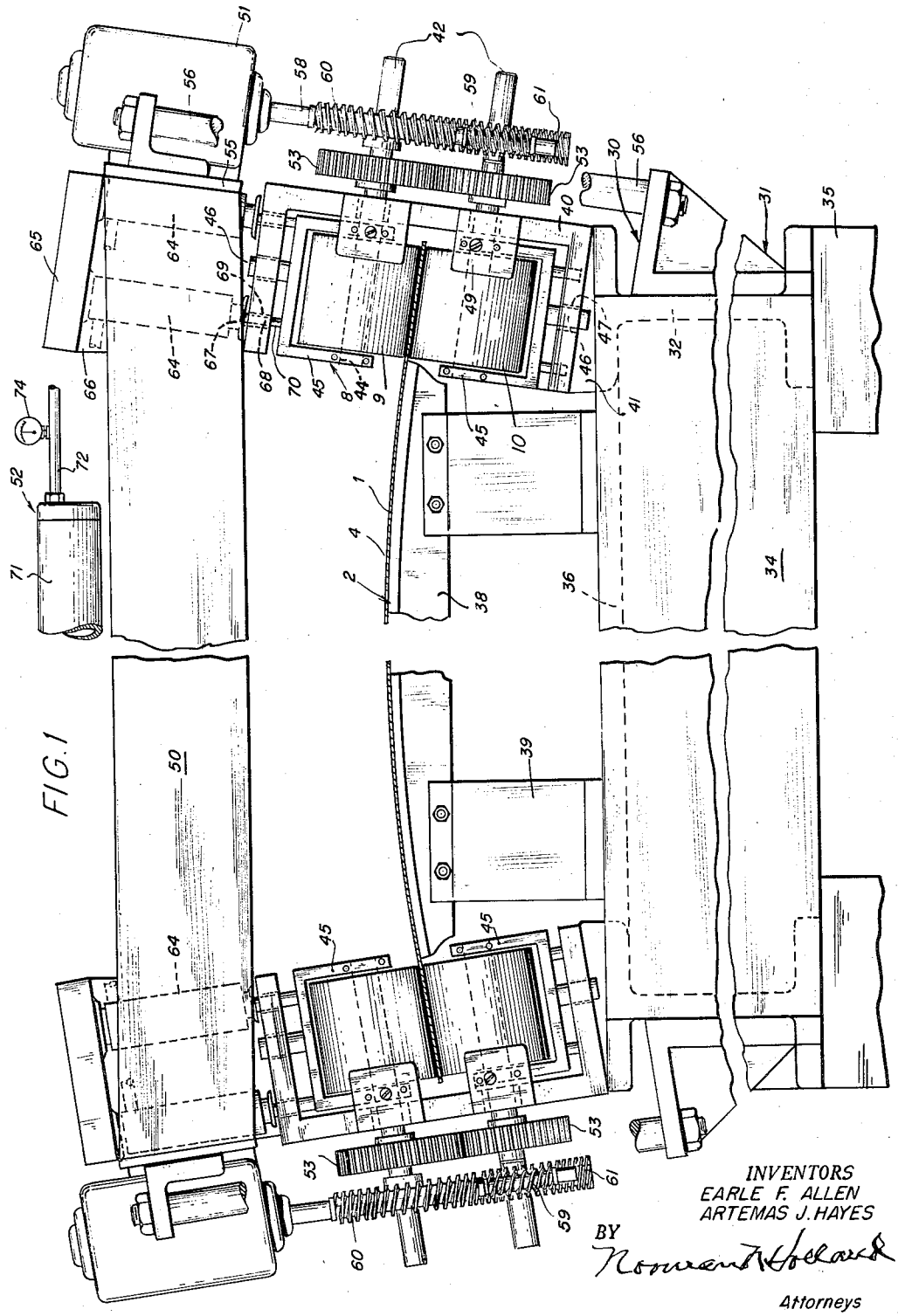


FIG. 1

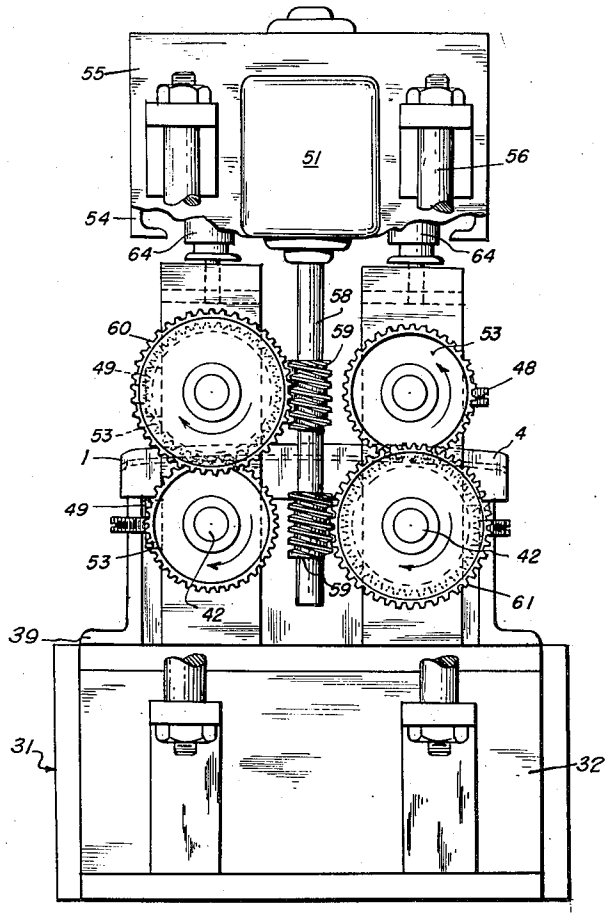
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FIG. 2



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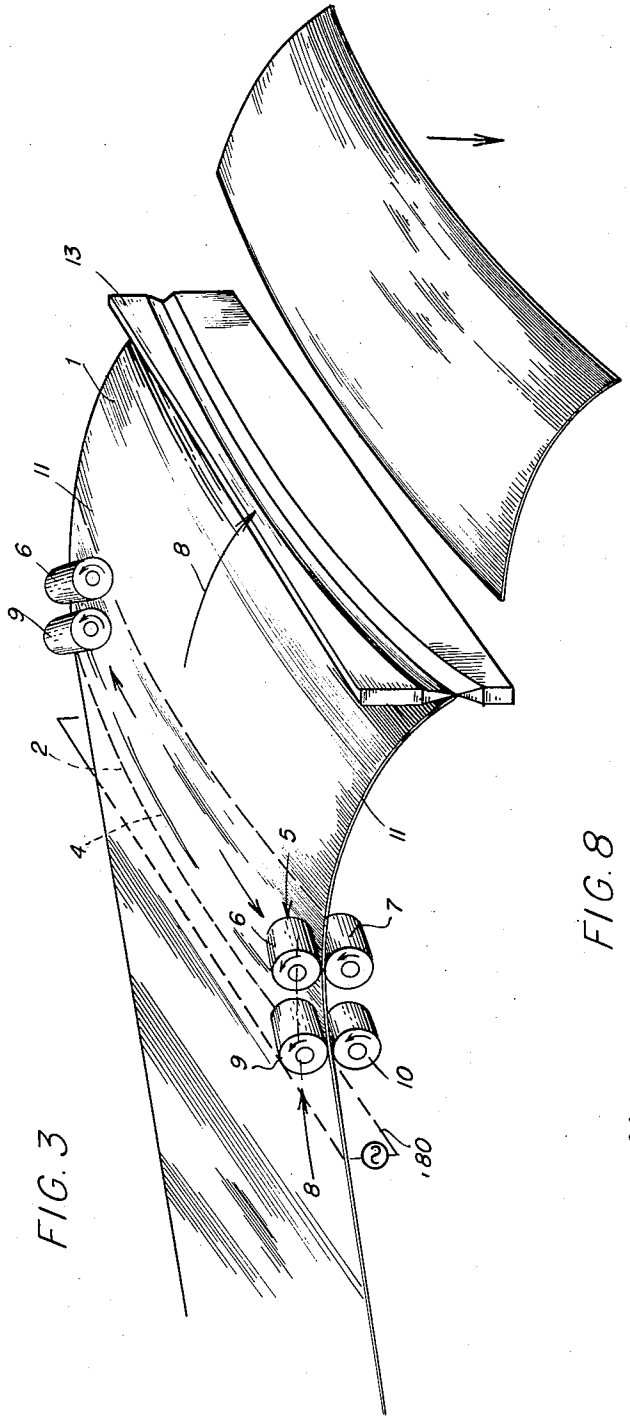


FIG. 3

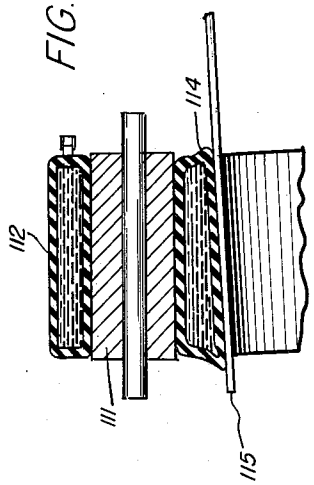


FIG. 9

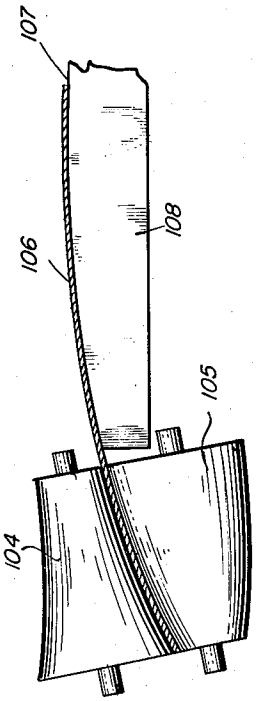


FIG. 8

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FIG. 4

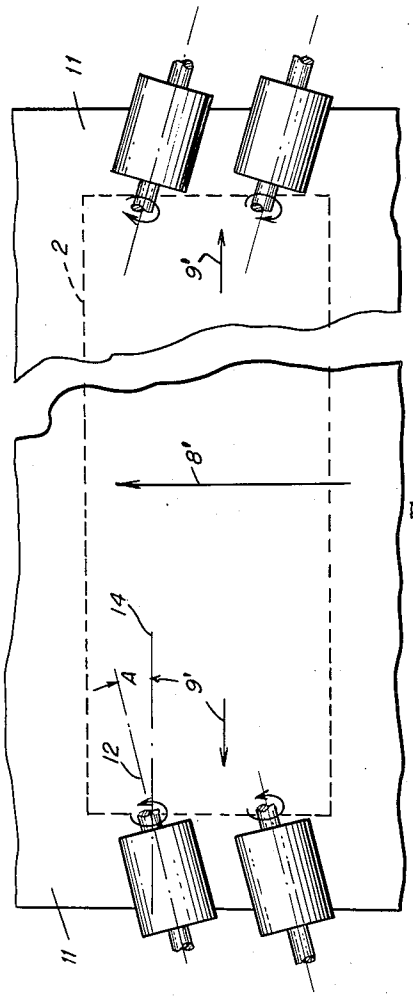
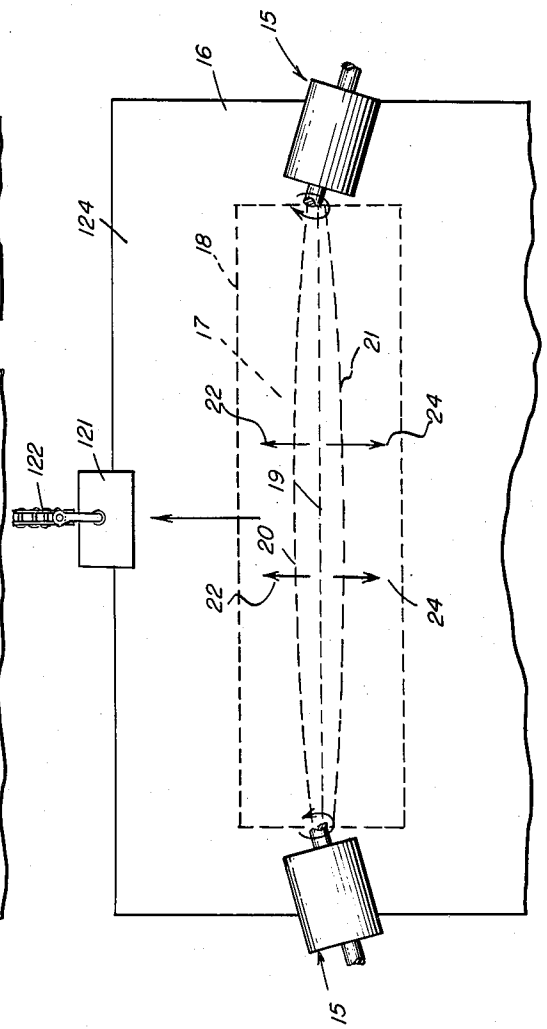


FIG. 5



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FIG. 6

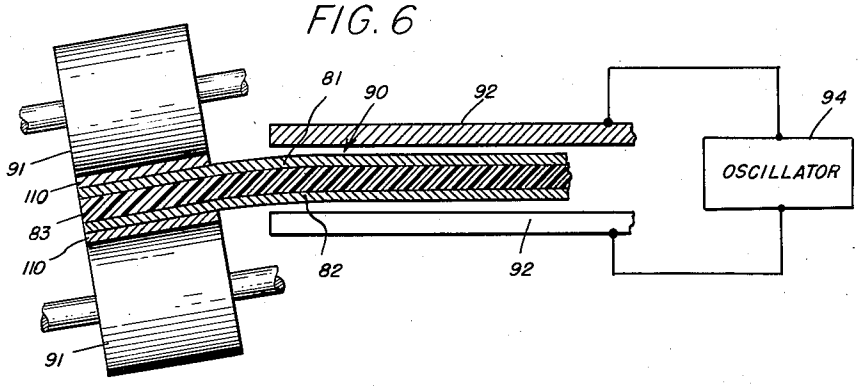


FIG. 7

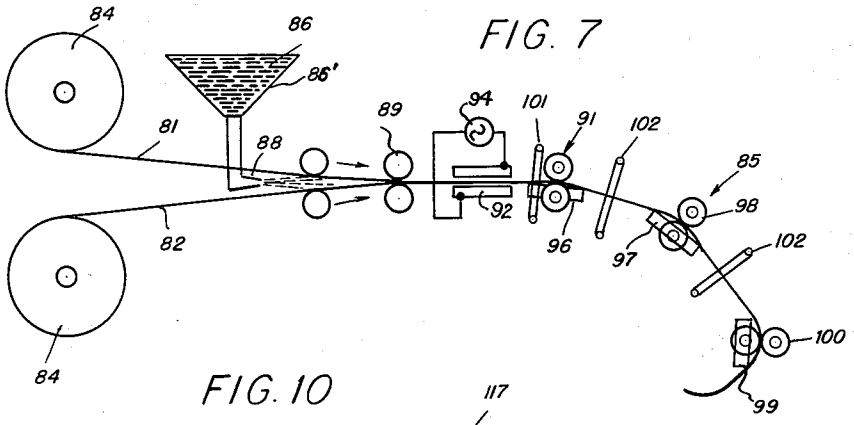
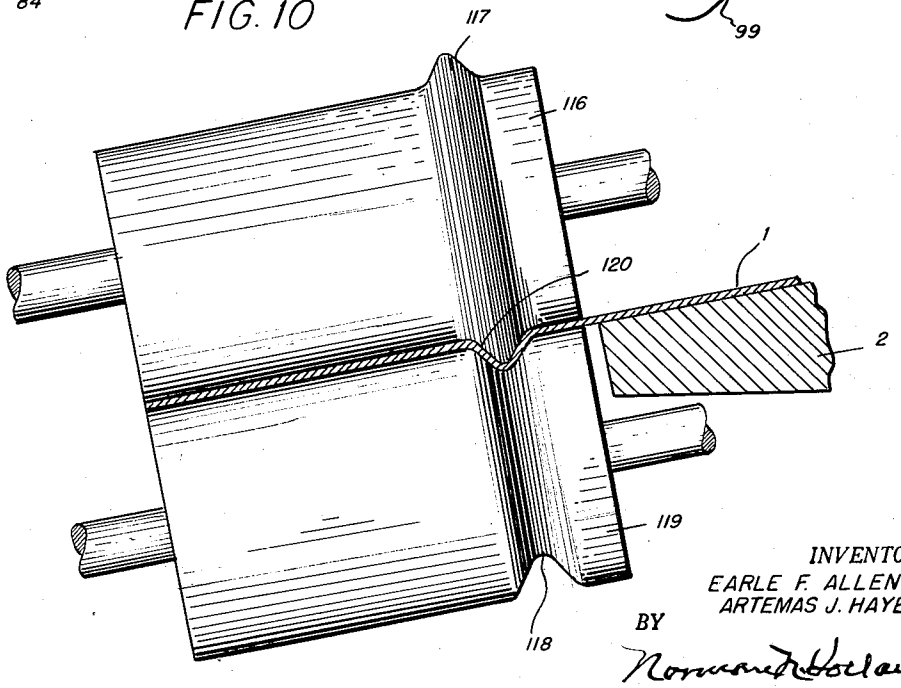


FIG. 10



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FIG. 11

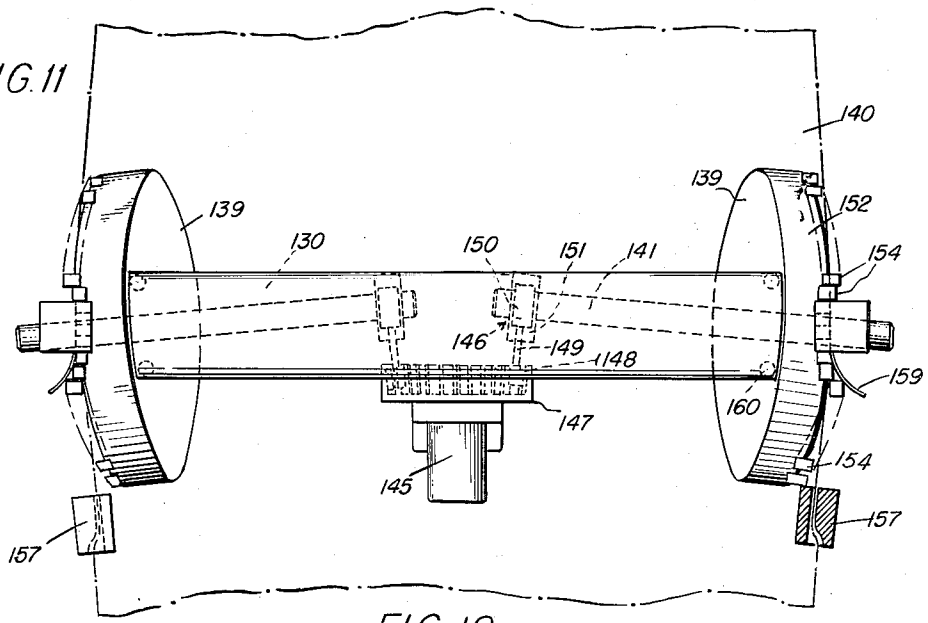
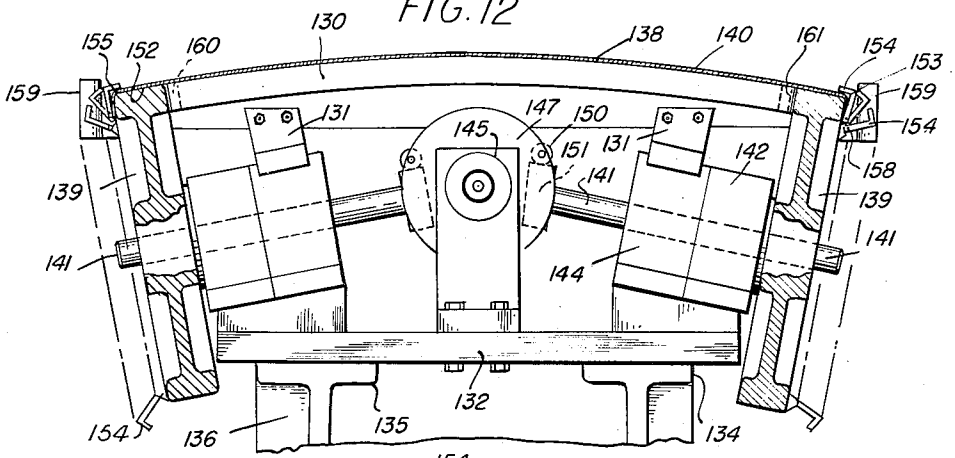


FIG. 12



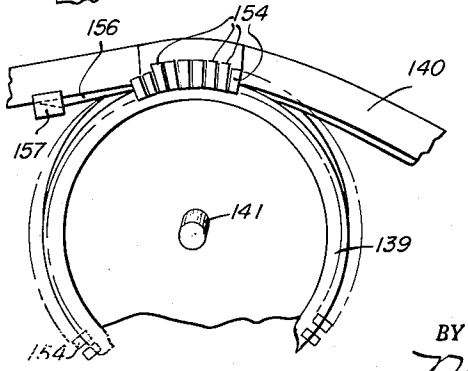


FIG. 13

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FIG. 15

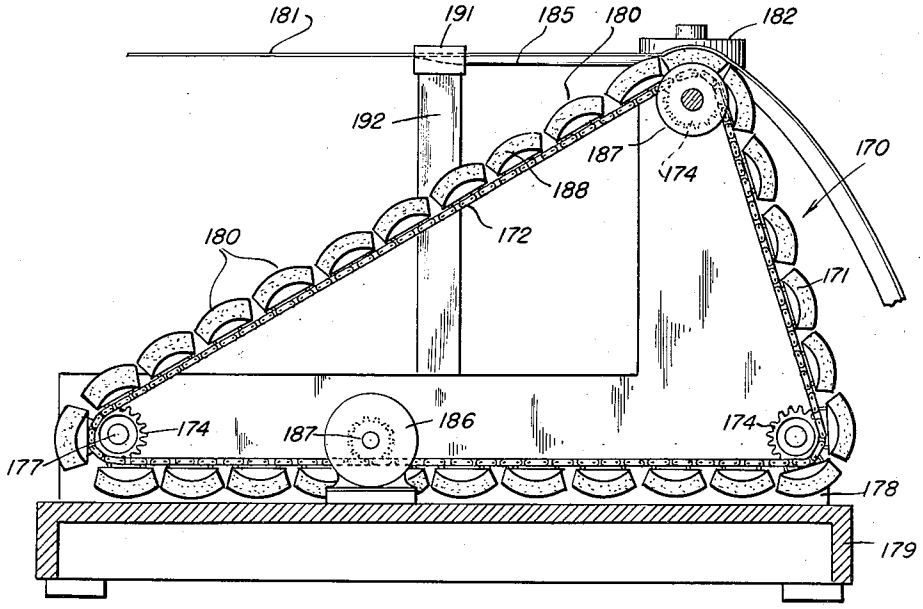
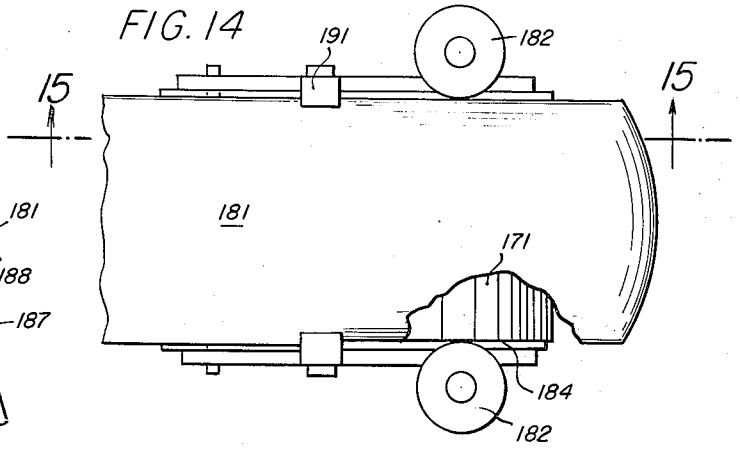


FIG. 14



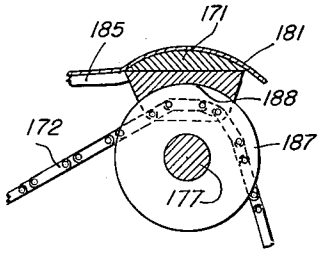
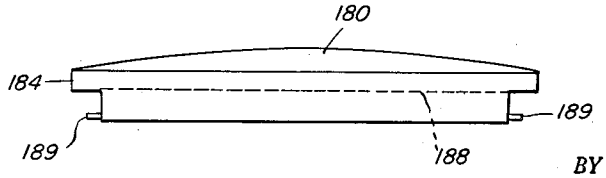


FIG. 17

FIG. 16



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United States Patent Office 2,969,826 Patented Jan. 31, 1961

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METHOD AND APPARATUS FOR FORMING COMPOUND CURVATURES IN SHEET MATERIAL

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Filed Oct. 3, 1956, Ser. No. 613,677

9 Claims. (Cl. 153—2)

The present invention relates to apparatus for and to a method of curving metal plates or sheets and more particularly to apparatus for and to a method of forming compound curvatures in a plate or sheet by progressive curving of incremental areas of the plate or sheet. The method and apparatus are used both for curving relatively thin metal, commonly designated as sheets, and relatively thick metal, commonly designated as plates. In this description and in the claims, the terms sheet and plate are considered to be equivalent and interchangeable.

Increasing use is being made of relatively large curved metal plates in many industrial, architectural, or other uses; however, the use of such curved plates has been limited in many cases due to their relatively high cost of manufacture. The relatively high cost of such curved plates results from the expensive types of bending machinery now used to form the plates, especially where compound curvatures are required, such as plates which are portions of a spherical surface.

Known types of plate forming machines and methods used to form compound curvatures in plates customarily form the complete, curved plate in a simultaneous bending action. This requires a relatively large complex machine to handle the plates and also requires an extremely powerful machine capable of supplying sufficient force to shape the whole plate simultaneously. Most of the presently used machines also use a large mold or platen which is designed for a particular final plate shape. Where a different plate curvature is desired, another platen must be formed having the shape of the plate desired. Such platens are difficult to form and are expensive in themselves so that where only a few curved plates are required, the expense of a platen is not justified.

Presently used plate curving machines also have a relatively low output as their operation is intermittent in nature, requiring the loading and unloading of individual plates or sheets rather than having a continuous bending action.

Accordingly, an object of the present invention is to provide an improved apparatus for and method of curving metal plates.

Another object of the present invention is to provide relatively simple and inexpensive apparatus for forming compound curvatures in metal plates.

Another object of the present invention is to provide apparatus for and a method of forming curved plates by the progressive shaping of small incremental areas of the plates.

Another object of the present invention is to provide a readily adjustable apparatus for forming a variety of compound curves in metal plates.

Another object of the present invention is to provide apparatus for and a method of continuously forming compound curvatures in a metal strip supplied from rolls.

Another object of the present invention is to provide a method of and apparatus for progressively forming compound curvatures in metal plates by the simultaneous heating and stretching of incremental areas of the metal plates.

Another object of the present invention is to provide a method of and apparatus for forming compound curvatures in metal plates with minimum power.

Other and further objects of the invention will be obvious upon an understanding of the illustrative embodiment about to be described, or will be indicated in the appended claims, and various advantages not referred to herein will occur to one skilled in the art upon employment of the invention in practice.

A preferred embodiment of the invention has been chosen for purposes of illustration and description and is shown in the accompanying drawings, forming a part of the specification, wherein:

Fig. 1 is a rear elevational view of the metal curving apparatus;

Fig. 2 is a side elevational view of the metal curving apparatus of Fig. 1 but omitting the work sheet;

Fig. 3 is a diagrammatic perspective view of the curving apparatus using four sets of rollers;

Fig. 4 is a diagrammatic view of the curving apparatus using four sets of rollers;

Fig. 5 is a diagrammatic view of the curving apparatus using two sets of rollers;

Fig. 6 is a fragmentary view of another embodiment of the apparatus according to the present invention;

Fig. 7 is a diagrammatic view of apparatus according to the invention for forming a curved laminated sheet using three curving stations;

Fig. 8 is a fragmentary view of another embodiment of the invention using curved rollers;

Fig. 9 is a sectional view of another embodiment of a set of rollers using a resilient rim on one roller;

Fig. 10 is an enlarged view of another embodiment of a set of rollers having grooving means thereon;

Fig. 11 is a top plan view of another embodiment of the plate curving apparatus using spaced wheels;

Fig. 12 is an elevational view partly in section of the apparatus of Fig. 11;

Fig. 13 is a side elevational view of the apparatus of Fig. 11;

Fig. 14 is a top plan view of another embodiment of the plate curving apparatus;

Fig. 15 is a sectional view taken along the line 15—15 of Fig. 14;

Fig. 16 is a front elevational view of a platen of the apparatus of Fig. 14; and

Fig. 17 is an enlarged fragmentary sectional view showing a platen and roller of the apparatus of Fig. 14.

The method of the present invention will first be described generally with particular reference to diagrammatic Figs. 3, 4, and 5.

In Fig. 3, a sheet or plate of metal 1 is shown being drawn over a platen 2 having its upper surface 4 curved in a predetermined manner to aid in the shaping action, as will be more fully described below. At each of the opposite ends of the platen 2, two pairs of rollers are located in such a position that the edges of sheet 1 are gripped between the rollers and are drawn over the platen 2 by the rotation of the rollers. The rollers comprise a forward set of rollers 5 having a top roller 6 and a bottom roller 7 and a rear set of rollers 8 having a top roller 9 and a bottom roller 10.

As seen in Figs. 3 and 4, each of the sets of rollers 5 and 8 grips the outer edge 11 of sheet 1 between the upper and lower rollers 6 and 7 and 9 and 10, respectively. Each of the sets of rollers is positioned so that the rotional axis, indicated at 12, of the roller forms an angle A, with a line 14 on sheet 1 drawn at right angles to the direction of motion of sheet 1 across platen 2. This

divergent mounting of the rollers causes the rotation of rollers to not only move the sheets forwardly over the platen but also to pull them outwardly so that sheet 1 is stretched laterally in the direction of the arrow 9' at the same time that it is moved forwardly over the platen in the direction of the arrow 8'. The angle A for each of the sets of rollers is adjusted for the particular material being shaped so that the material is stretched beyond its elastic limit and over the curved upper surface 4 of the platen 2 so that it is permanently deformed with a predetermined curvature, which is the function of the amount of strain in the material and the shape of the platen 2. In order to simultaneously apply stretching forces to the sheet 1 in a longitudinal direction as well as in the above-described lateral direction to provide an omni-directional stretching, the rear sets of rollers 8 are given a dragging action with respect to the forward rollers 5, so that the sheet or plate material between roller sets 5 and 8 is stretched by this dragging action.

The dragging action may be obtained by using a drive means for the forward rollers 5 and by using a braking means on the rear rollers 8, or it may be provided by driving both the front rollers 5 and the rear rollers 8 by positive drive means which rotate the rear rollers 8 at a slower speed than the forward rollers 5. The stretching action between the front and rear rollers is adjusted by controlling the drag of rollers 8 or the speed differential between roller sets 5 and 8. The portion of the sheet 1 between the four sets of rollers is stretched beyond its elastic limit longitudinally so that it is permanently curved longitudinally a predetermined amount in accordance with the amount of material strain and the curvature of platen 2.

Thus, it is seen that a sheet 1 supplied in relatively large plates or in a continuous strip from a suitable roller may be fed continuously over the platen 2 for a continuous shaping action by the lateral and longitudinal stretching action of the roller sets 5 and 8. Where a continuous strip of metal is being shaped, it is fed to suitable cutter means after the shaping which cuts the shaped metal into plates or sheets of suitable sizes.

In Fig. 5, another embodiment of the method of the present invention is diagrammatically illustrated in which two sets of rollers 15 are used to provide the curving action on a metal sheet 16. Rollers 15 are used to move the sheet 16 over the upper surface 17 of a suitably shaped platen 18. The roller sets 15 are mounted to roll on diverging paths with respect to the sheet 16 so that the sheet 16 is stretched laterally at the same time that it is moved longitudinally over platen 18. Where a curved platen is used having a curved surface such as a section of a sphere, it has been found that the two sets of rollers 15 provide not only the lateral stretching but that they also tend to stretch and curve the sheet 16 in a longitudinal sense in its direction of travel to provide generally omni-directional stretching of the sheet 16 and to form a compound curvature in sheet 16.

This stretching action is believed to be explained as follows. The lateral stretching of the sheet by the sets of rollers 15 causes the sheet 16 to stretch along a line indicated generally by the dotted line 19 between the opposite sets of rollers 15. Since the sheet 16 is stretched along line 19, it is clear that adjacent portions of the sheet 16 in the area indicated generally by lines 20 and 21 will also be stretched. The portions of sheet 16 adjacent lines 20 and 21, by being stretched, will seek to align themselves in the shortest distance over the curved surface of the platen 18 between the opposite edges of the platen 18. In so doing, the portions of the sheet 16 adjacent the lines 20 and 21 tend to move away from each other in the direction indicated generally by the arrows 22 and 24, respectively. The angle of the roller sets 15 may be adjusted to cause the metal adjacent the line 20 to be stretched beyond its elastic limit in a longitudinal direction, thereby causing it to conform to the shape of the platen 18 in a longitudinal sense at the same time as it is being shaped laterally by the lateral pull of the rollers 15 across platen 18.

A preferred embodiment of the apparatus to perform the above-described plate curving method is shown in Figs. 1 and 2. The plate curving machine 30 has a suitable rigid mounting base such as bed 31 formed, for example, of channels 32 welded or otherwise connected to rigid end plates 34. The bed 31 is mounted on a suitable support at the desired operating height by legs 35 or other support means. Mounted centrally of the bed 31 on a top 36 is the sheet curving platen 2 having a suitably shaped upper surface 4. The platen 2 in the preferred embodiment comprises a unitary molded member having mounting and stiffening ribs 38 on its undersurface by which it may be attached to the bed 31 by suitable brackets 39. Where the curved plates being formed are designed to have a curved surface corerspondning generally to a spherical section, for example, the upper surface 4 of the platen 2 will correspond generally to a spherical section with suitable modifications to account for any residual elasticity in the curved sheets after they leave the platen surface 4 which causes them to tend to at least partially resume their original flat shape.

The front and rear sets of rollers 5 and 8 are mounted at either side of the platen 2 above the side beam 32.

The details of the mountings of the sets of rollers and the pressure controls and drive means therefore is shown in Figs. 1 and 2. A C-shaped mounting bracket 40 is provided for each set of rollers, and it is fastened to the channel 32 by welding or other suitable means with a positioning shim 41 interposed between its lower surface and the channel 32 to slant the rollers at the proper angle so that their contact point with the metal sheet 1 is generally in the curved surface defined by the surface 4 of platen 2. The rollers 6, 7, 9, and 10 are each rotatably mounted on roller shafts 42 which are held in bearings 44 in yokes 45. The yokes 45 are pivotally attached by swivel mounting pins 46 in bearings 47 on the brackets 40. The pivotal mounting of the rollers allows for the adjustment of the angle A (Fig. 4) of the sets of rollers discussed above. Roller angle adjustment screws 48 are provided on brackets 49 supported on brackets 40, to adjust the angular setting of the yokes 45 and the rollers 6, 7, 9, and 10 mounted therein.

A support bar 50 is mounted to run laterally across the bed 31 above the platen 2 and the roller mounting brackets 40 to mount the drive motors 51 and the pressure control means 52 for the rollers. In the preferred embodiment shown, two support bars 50 are used with one mounted above the front set of rollers 5 and the other mounted above the rear set of rollers 8. Each support bar 50 comprises two channels 54 connected by side plate 55 which also connects the two support bars 50 together. The support bars 50 are attached to the channels 32 by mounting rods 56 bolted to brackets on the channels 32 and side plate 55.

A drive motor 51 for the roller sets on each side of the platen 2 is mounted on side plate 55 and has a drive shaft 58 extending downwardly to the roller shafts 42. Suitable worms 59 are mounted on the drive shaft 58 to engage worm gears 60 and 61 on the upper shaft of roller set 8 and the lower roller shaft of roller set 5, respectively. The lower shaft 42 of roller set 8 and the upper shaft of roller set 5 are coupled to the driven shafts by suitable gears 53.

As discussed above, the rear set of rollers 8 is driven at a slower speed than the forward set of rollers 5 to provide the longitudinal stretching action on the metal sheet 1. The gear ratios in the worm and worm gear connections between the drive shaft 58 and the roller shafts

42 are suitably selected to provide for the desired speed differential.

Where only the forward set of rollers 5 is driven and the rear set of rollers is run at a slower speed by means of a drag, the shafts 42 of said rear set are not connected to the drive motors but are instead connected to a suitable friction, magnetic, or other suitable brake means. Although two motors are shown in the preferred embodiment, a single motor may be used with suitable connecting shafts. Suitable commonly known speed controls are used on the motors as desired. Slight adjustments of the roller angle A (Fig. 4) may be made without appreciably affecting the meshing of the worm and work gears 59–61. Where the angle is changed by a large amount, the position of the drive motor 51 on plate 55 is adjusted as both roller sets are turned in the same direction. Motor 51 is adjustably mounted for this purpose to allow shaft 58 to be moved.

In order for the sets of rollers to stretch the metal sheet 1 both laterally and longitudinally during the curving action, it is necessary for the sheet 1 to be tightly gripped between the upper and lower rollers. Accordingly, a pressure means is provided to hold the rollers in contact with the sheet under a predetermined amount of pressure. In the preferred embodiment, hydraulic pressure controlling means is used which comprises hydraulic cylinder motors 64 which are fixedly mounted between the channels of the support bars 50 on a top plate 65. Top plate 65 is welded or otherwise attached to the support bars 50 and is inclined at an angle corresponding to the angle of tilt of the roller mounting brackets 40 by a suitable shim member 66. Two pressure controlled cylinder motors 64 are mounted on top plate 65 for each upper roller yoke 45 having their plungers 67 spaced from the upper surface of the mounting bracket 40 and in contact with two slidably mounted contact pins 68. Contact pins 68 are slidably mounted in suitable bearings 69 in the upper end of mounting bracket 40, and they have their lower ends 70 in sliding engagement with the upper surface of the roller yokes 45. Since the yoke swivel mounting pin 46 is also slidably mounted in the mounting bracket 40, downward motion of the plunger 67 against the contact pins 68 applies force to the roller yoke 45 and to the rollers 6 and 9.

Since the rollers are angled outwardly with respect to the longitudinal axis of the sheet 1 and since their line of contact is not at right angles to the direction of the movement of the sheet 1 in the bending machine, it is necessary for controlled slippage to occur between the rollers and the sheet 1. The amount of slippage is adjusted to provide the amount of longitudinal and lateral stretch desired by controlling the amount of hydraulic pressure applied to the pressure controlled cylinder motor 64. In the preferred embodiment, hydraulic pump 71 is shown connected by hydraulic lines 72 to each of the cylinder motors 64 so that an equal pressure is applied to all the cylinder motors. A suitable pressure indicator 74 is connected to the hydraulic lines to indicate the pressure applied. If desired, the roller sets on opposite sides of the platen 2 or each of the roller sets individually may be connected to a separate pressure regulator, so that the pressure on each roller may be separately controlled to provide for an adjustment of the grip action of the individual rollers and thus the stretching action on the sheet 1. Such individual hydraulic control systems are readily adapted for automatic control so that the pressure on the individual sets of rollers may be automatically adjusted by suitable sensing means as is necessary to control the position of the sheet 1 as it passes over the platen 2.

The above-described preferred embodiment of the apparatus is used in performing the plate curving method described in connection with Figs. 3 and 4, where four sets of rollers are used. Where the method shown diagrammatically in Fig. 5 is used with only two sets of rollers, the apparatus is generally similar to that shown in Figs. 1 and 2 with the forward set of rollers 5 eliminated or moved out of contact with the sheet 1. For metals and curvatures suitable for the curving method having only one set of rollers on each side, pressure controlling and roller driving systems are simpler and thus are more easily adjusted and operated.

During the longitudinal and lateral stretching action of the metal sheets, a work hardening may occur in the material. In some cases, this work hardening is desirable as it tends to stiffen the finished curved sheet, and in other cases the work hardening is objectionable since it occurs so rapidly as to interfere with the curving action on the platen 2 of the bending machine. Where it is desirable to anneal the metal plate being curved, it has been found relatively easy to heat the small incremental area being stretched between the rollers. Induction heating using a coiled wire positioned in the vicinity of the area being stretched may be used to inductively heat this area and to thus soften it to reduce the effects of the work hardening. A movable coil 80 coupled to a suitable source of alternating current, as seen in Fig. 3, may be positioned around or near the sheet 1 to heat any localized area as desired. Where it is desirable to heat or anneal the sheet 1 during the actual stretching operation, the coil 80 may be positioned adjacent to platen 2 where the stretching of the material is being done.

Fig. 7 shows another embodiment of the present invention. In this embodiment, a multi-layered curved sheet is being formed, and a continuous forming and curving operation is used. Separate sheets 81 and 82 are unwound from rollers 84 and they are moved towards the curving apparatus indicated generally at 85. A plastic filler 86 is inserted between the sheets 81 and 82 from a vat 86' through an elongated spray means 88. Drive rollers 89 press the sheets against the inner plastic layer to form the three-layer sheet 90 (Fig. 6) consisting of the outer metal layers 81 and 82 and an inner plastic bonding layer 83. Before passing through the first set of stretching rollers 91, the sheet 90 is heated by dielectric heating, as is shown in Fig. 6. The sheet 90 is passed between metal plates 92 which are connected to the output terminals of a suitable oscillator 94. The electric field between the sheets 92 heats the plastic bonding layer 83 by dielectric heating. This heating softens the plastic inner layer 83 to prepare it for the curving operation and also cures the plastic layer.

The curving operation shown in Fig. 7 is a multi-stage operation suitable where the degree of curvature and the thickness of the material requires more than one stretching and curving operation. Such a multi-stage curving operation may be used with the three-layer sheet of Fig. 6 or with a normal single-layer sheet.

In the three-stage method illustrated in Fig. 7, three platens are used having increasing amounts of curvature. Thus, rollers 91 first stretch the material over the relatively flat platen 96, and the sheet is then carried to platen 97 which has a more pronounced curvature for the stretching action on rollers 98. A third platen 99 having an even more pronounced curvature is used to provide the final stretching action with rollers 100. An inductive heating coil 101 is shown positioned immediately adjacent the first platen 96 to heat the strip during the initial curving. Inductive heating coils 102 are located between the stages to anneal or soften the sheet between the curving actions of the successive stages.

In the preferred embodiment shown in Figs. 1 and 2, the rollers, such as rollers 6, 7, 9, and 10, have a cylindrical shape. Where it is desired to carry out the exact curvature of the platen to extreme edges of the sheet, the sets of rollers have suitably contoured surfaces as seen in Fig. 8. In Fig. 8, the upper roller 104 has a generally concave surface, and the lower roller 105 has a convex surface, so that the point of contact of the rollers with the sheet 106 conforms to the curvature of the surface 107 of the particular platen 108 being used,

For relatively thin sheets of material or soft sheets, where it is desired to minimize the marking of the rollers on the sheets, edging strips **110** may be inserted on either side of the sheet being curved, such as sheet **90** of Fig. 6.

Fig. 9 shows another embodiment of the roller particularly adapted for use with the soft material wherein marking is objectionable. This roller has a central core **111** with a hollow tire **112** mounted thereon. The tire **112**, formed of rubber or some other suitable flexible material, is inflated with a suitable fluid to a predetermined pressure. Such a roller tends to spread slightly as indicated at **114** when contacting a sheet such as sheet **115** and therefore has a larger gripping area and exerts a relatively great force and a correspondingly lower contact pressure to minimize flattening of the edge of the sheet. Two such rollers may be used in a set of rollers or one such inflated roller may be used with a regular metal roller as shown.

Another embodiment of the roller sets is shown in Fig. 10. This set of rollers comprises an upper roller **116** having an outwardly extending flange **117** thereon which meshes with a complementary groove **118** in lower roller **119**. These rollers may be used in place of the regular rollers to form a curve or channel **120** at the edge of the sheet **1** to provide an interlocking and stiffening channel for the compound curved plates formed in the machine. Channel **120**, formed by the rollers **116** and **119**, will be slightly wider than the flange **117** since the rollers **116** and **119**, as described more fully above, are toed outwardly with respect to the sheet so that the flange **117** is not parallel with the direction of travel of the sheet.

Although the rollers at the edges of the sheet, such as the roller sets **5** and **8** of Figs. 1 and 2, may be used to move the sheet through the machine as well as to provide the longitudinal and lateral stretching action, in some instances where especially thick or hard sheets are being curved, an additional sheet moving means may be provided, such as the clamp **121** and the chain **122** shown attached to the forward edge **124** of sheet **16** in Fig. 5. In this embodiment, the chain **122** is drawn forwardly by a suitable drive means which is coordinated with the rollers to provide the correct combination of forward motion and stretching action on the sheet **16**.

Another embodiment of the plate curving apparatus is shown in Figs. 11, 12, and 13. In this embodiment, the sets of rollers at opposite edges of the platen are replaced with draw wheels which grip the edges of the sheet being curved to stretch it laterally and longitudinally over the platen surface, as will be more fully described below. A platen **130** is mounted by suitable brackets **131** each of which are attached to bearings **144** which are fastened on a top plate **132** over a bed **134**. Bed **134** comprises side channels **135** secured by end plates **136** and mounted at a suitable height. Platen **130** is generally similar to the platen **2** described above and has a curved upper surface **138** shaped to provide the desired curvature for the shaped plates. Draw wheels **139** are rotatably mounted on the bed **134** to grip metal sheet **140** and to move it over the upper surface **138** of the platen **130**. Draw wheels **139** are mounted on draw wheel shafts **141** which are positioned on the bed **134** by a thrust bearing **142** and an additional bearing **144**. The draw wheels **139** are turned by a drive motor **145** mounted on the top plate **132** and operatively connected to the draw wheel shafts **141** through gear system **146**. In the preferred embodiment, this gear system comprises gear **147** connected to the motor drive shaft and engaging the gear **148** on a worm shaft **149**. A worm **150** on the end of worm shaft **149** engages a worm gear **151** on the draw wheel drive shaft **141**.

As is seen in Fig. 12, the rims **152** of each of the draw wheels **139** are positioned at the edges of the platen **130**. The slanting position of the rim **152** is obtained by tilting the draw wheel shafts **141**. A series of clamps **154** are mounted around the entire circumference of the draw wheels **139** at the edge **153** of its rim **152** to engage the outer edge **155** of the sheet **140**. Only those at the upper side of the wheels **139** are shown in the drawing for purposes of clarity. Prior to coming in contact with the draw wheel **139**, a right-angled flanged **156** is formed on the edge **155** by a flanging die **157** mounted by suitable brackets (not shown) in advance of draw wheels **139**. Each of the clamps **154** is mounted on a pivot **158** so that it swings clear of the edge **153** of the draw wheel **139**, except as it reaches the upper portion of its circular path. At this point, a cam surface **159** swings the clamp **154** inwardly against the flange edge **156** of the sheet **140** to hold it tightly against the wheel surface. Cam **159** is designed to hold the clamp in contact with the metal sheet **140** for a distance approximately equal to the width of the platen **130**. As seen in Fig. 13, the draw wheels **139** are angled outwardly so that the clamps **154** on opposite sides of the platen **130** tend to move apart during the time that they are in contact with the sheet **140**, thereby stretching the sheet **140** and drawing it tightly against the curved surface **138** of the platen **130**. The longitudinal stretching of the sheet **140** on the curved platen surface causes compound stretching action generally similar to that described above in connection with Fig. 5, so that the incremental portion of the metal sheet **140** in contact with platen **130** is stretched both longitudinally and laterally. The outward angle of the draw wheels **139** is adjusted so that the metal sheet **140** is stretched sufficiently to be permanently deformed. This is done by stretching the metal beyond its elastic limit. Rollers **160** are provided on the edges of the platen **130** to contact the sides of the draw wheels **139** to prevent any binding action between the draw wheels **139** on the sides **161** of the platen **130**.

Another embodiment of the curving apparatus is shown in Figs. 14–17. In this embodiment, the same principles are employed for bending a large sheet by successively bending incremental areas of the sheet; however, a different embodiment of the stretching means is used. In this method, opposite edges of the sheet are gripped by a stationary gripping means and an incremental portion of the sheet between the gripping means is stretched by forcing a curved platen against this portion by sliding it thereagainst or by expanding it into contact therewith by suitable mechanical or hydraulic means. The apparatus shown in Figs. 14–17 has an articulated or moving type of platen. As the sheet material is moved between the gripping edges, the platen is simultaneously moved upwardly against the portion of the sheet between the gripping means to thereby stretch it and to permanently deform it in accordance with the shape of the contacting platen surface.

The curving apparatus of Figs. 14–17 comprises an articulated or moving platen **170** which comprises a series of individual elongated platen bars **171** mounted in parallel relationship to one another on spaced chains **172**. Chains **172** are mounted on sprockets **174** on shafts **177**. Shafts **177** are rotatably mounted on suitable bearings on spaced side plates **178**, which are welded or otherwise suitably fastened to a base **179**. The upper surface of each of the platens **171** has a curved sheet contacting surface **180** which is shaped to provide the desired contour in the sheet **181** being shaped by the apparatus. Sheet **181** is shaped by passing it between two horizontally spaced gripping means adjacent to the uppermost of the platens **171**. In the preferred embodiment, two spaced gripping wheels **182** are provided which are urged towards the side surfaces **184** of the platen, so that a flanged edge **185** of the sheet **181** is tightly gripped between the gripping wheel **182** and the edge **184** of the platens **171**. A drive motor **186** is connected by a suitable sprocket **187** to the platen mounting chains **172** so that the platens are driven around the sprockets **174** at a predetermined speed. As the platens move between the gripping wheels **182**, they simultaneously

grip the outer edges of the sheets in cooperation with the gripping wheels **182** and stretch the incremental portion of the sheet between the spaced gripping wheels **182** by being forced upwardly against the lower surface of the sheet **181** by a roller **187** which contacts the lower surface **188** of the platen **171**. Since the opposite edges of the sheet **181** are tightly gripped by the rollers **182**, the upwardly directed movement of the platen **171** against the sheet **181** by the turning of the roller **187** causes both a longitudinal and a lateral stretching of the sheet **181** and draws it tightly against the curved upper surface **180** of the platen **171**. A suitable drive means may be connected to the gripping wheels **182** to turn them so that they move the sheet **181** or a separate pull means such as the clamp **121** and chain **122** of Fig. 5 may be used. The sheet may be moved at a slower rate than the platens **171** to prevent ridges from being formed between the contact areas of the individual platens **171** with sheet **181**.

In order to provide a permanent deformation of the incremental portion of the sheet being stretched, the motion of the platen on the roller and the shape of the platen surface are set so that the sheet material is stretched beyond its elastic limit. After the stretching action by the platen **171** located on upper roller **187**, the chain **172** carries the platen **171** downwardly and away from the surface of the metal plate. The metal plate itself is fed by suitable means to suitable shears or other handling means.

The preferred embodiment of the platens **171** is shown in Figs. 16 and 17. The platen comprises a body portion **188** having mounting pins **189** at its opposite ends adapted to attach it to the chain **172**. The lower surface **188** has a cylindrically shaped channel adapted to engage the surface of the roller **187** to provide a firm base for the platen during the stretching operation. The upper surface **180** of the platen has a suitable shape designed for the particular curving being performed by the machine. The upper portion **180** may be made detachable from the body portion **188** so that it may be replaced where the different curvatures are being used and also so that the body portion may be made of a softer and lighter weight material than the upper stretching surface **180**. A flanging die **191** is mounted on a suitable bracket **192** at both sides of the apparatus to form the flanges **185** which are used by the gripping wheels **182**.

The operation of each of the embodiments of the curving apparatus has been described in detail above in the description of the apparatus and in the corresponding description of the methods.

It will be seen that the present invention provides a novel and useful method and apparatus for forming curved sheets. An extremely efficient and relatively low-cost method and apparatus are disclosed which form relatively large plates having compound curvatures by utilizing an incremental method which minimizes the size of the machinery and the power required to operate the machinery. The method and apparatus disclosed are also flexible in operation so that only minor adjustments and part changes are required to produce sheets having widely varying curvatures. The apparatus and methods are also adapted for use in curving individual plates or in curving and forming relatively large plates in a continuous operation using sheet materials supplied in rolled form. Since the curving operation is based on a principle of bending only incremental areas, the method and apparatus are also particularly adapted to a simultaneous heat treating of the material being bent. Only the small area actually being worked on or adjacent areas need be heated and thus the heating may be effectively concentrated and localized to produce the maximum benefit with a minimum amount of heat. The method and apparatus are particularly suitable for electrical heating methods, such as induction heating where the material is an electrical conductor, and dielectric heating where insulator material comprises a portion of the sheet.

As various changes may be made in the form, construction and arrangement of the parts herein without departing from the spirit and scope of the invention and without sacrificing any of its advantages, it is to be understood that all matter herein is to be interpreted as illustrative and not in a limiting sense except as required by the scope of the claims.

Having thus described our invention, we claim:

1. The method of forming compound curvatures in a metal sheet which comprises moving the sheet across and in contact with the convexly curved surface of a platen by gripping each of two opposite edges of the sheet at both ends of the platen with two pairs of spaced driving rollers, stretching the sheet lengthwise of the platen by positioning the axes of each two pairs of rollers so that they roll on diverging paths with respect to the motion of the sheet, and stretching the sheet laterally of the platen in the direction of the sheet motion by driving the rearward pair of rollers on each side of the platen at a lower rate of speed than the forward set of rollers.

2. Apparatus for continuously forming compound curvatures in a metal sheet of indefinite length comprising a platen having a convexly curved surface, gripping and sheet feeding means to grip incremental portions of opposite edges of the sheet and to draw the incremental portions along divergent paths at opposite sides of the curved platen whereby the sheet material between the gripped edges is moved over the platen in contact therewith by said gripping and sheet feeding means and is simultaneously stretched beyond its yield point both laterally and longitudinally of the direction of sheet movement and is thereby given a desired curvature in cross section and said gripping and sheet feeding means comprising two pairs of driving rollers at each of two opposite sides of the platen, each pair of rollers mounted to grip the metal sheet therebetween, the rotational axes of each pair of rollers aligned and positioned at an angle to the axis of the pairs of rollers on the opposite side of the metal sheet to cause the rollers on opposite sides of the platen to roll along diverging paths, means independent of said sheet for rotating the pair of rollers on each side of the metal sheet which are furthest advanced in the direction of the motion of the metal sheet at a given speed, and means for rotating the other pair of rollers on each side of the metal sheet at a lower speed than said given speed whereby the sheet material is stretched in the direction of its motion across said platen.

3. The apparatus as claimed in claim 2 in which the rollers of each of said pairs of rollers are forced toward each other by a pressure maintaining means whereby the sheet is tightly gripped by said rollers.

4. The apparatus as claimed in claim 2 in which the pressure maintaining means is hydraulic.

5. The apparatus as claimed in claim 2 in which independent controls are provided for the pressure maintaining means associated with the sets of rollers on one side of the platen.

6. Apparatus for continuously forming compound curvatures in a metal sheet of indefinite length comprising a platen having convexly curved surface, combined gripping and sheet feeding means at each of the opposite sides of said platen adapted to grip incremental opposite edge portions of the sheet and to draw the incremental edge portions along divergent paths at opposite sides of the curved platen, means independent of said sheet for operating said feeding means, whereby the metal sheet between the gripped sides is moved over the platen in contact therewith by said gripping and sheet feeding means and is simultaneously stretched beyond its yield point both laterally and longitudinally of the direction of sheet movement and is thereby given a desired curvature in cross setion.

7. The apparatus as claimed in claim 6 in which said gripping and sheet moving means comprises a pair of driving rollers at each side of the platen mounted to grip

the sheet therebetween, and the rollers of each pair having their axes of rotation aligned and positioned at an angle to the axes of the other pair.

8. The apparatus as claimed in claim 7 in which the rollers of each pair are forced toward each other by hydraulic pressure maintaining means.

9. The apparatus as claimed in claim 7 which further comprises independent controls for the hydraulic pressure maintaining means for the pair of driving rollers at one side of the platen.

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