Nov. 20, 1962 F. J. FUCHS, JR 3,064,711

DRAW BENDING APPARATUS

Filed Oct. 21, 1958 5 Sheets-Sheet 1

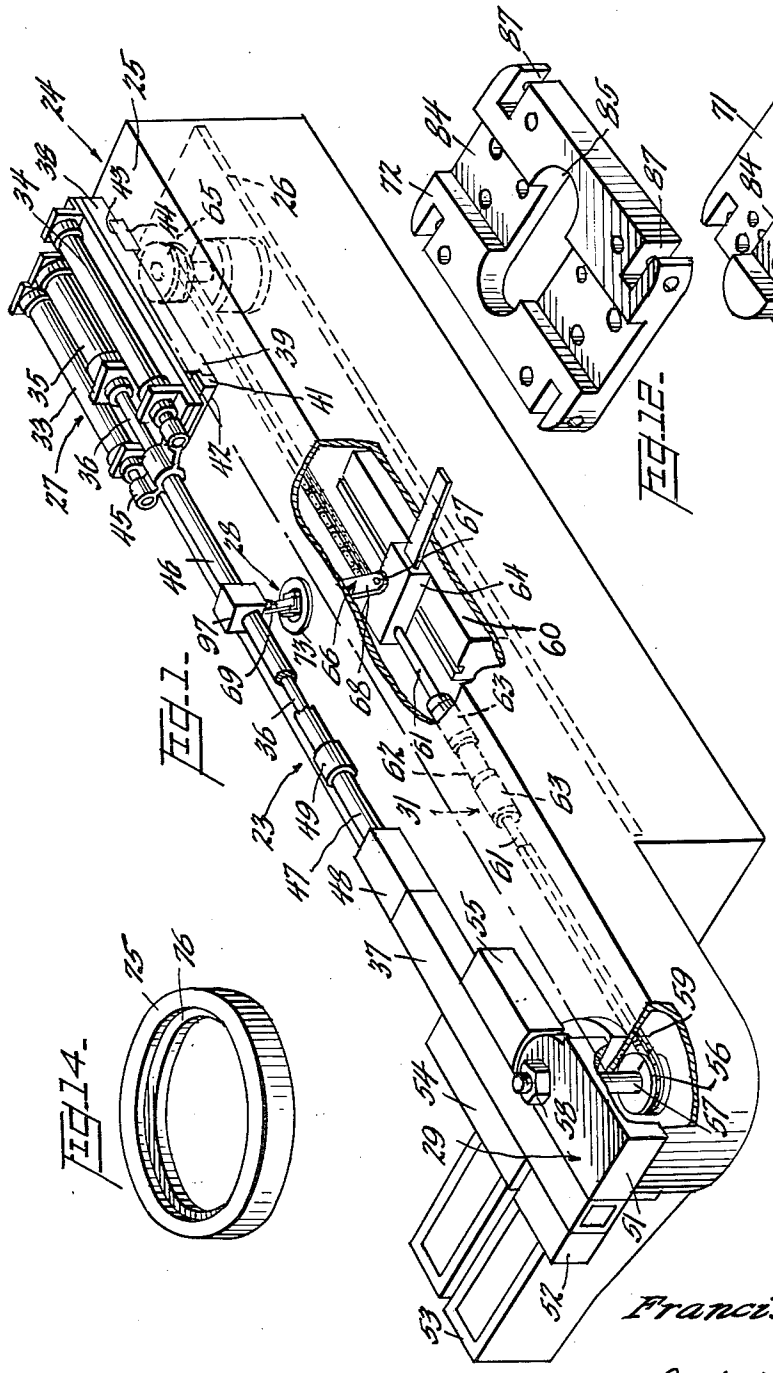


FIG. 1.

FIG. 12.

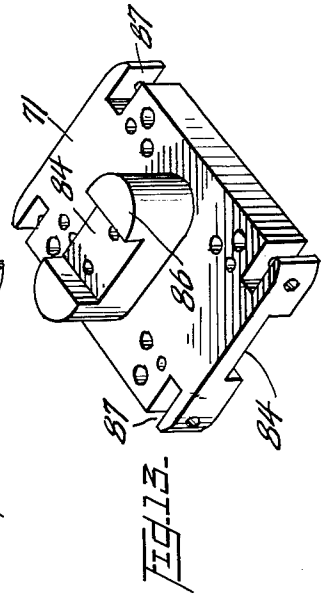


FIG. 13.

FIG. 14.

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Nov. 20, 1962 F. J. FUCHS, JR 3,064,711

DRAW BENDING APPARATUS

Filed Oct. 21, 1958 5 Sheets-Sheet 2

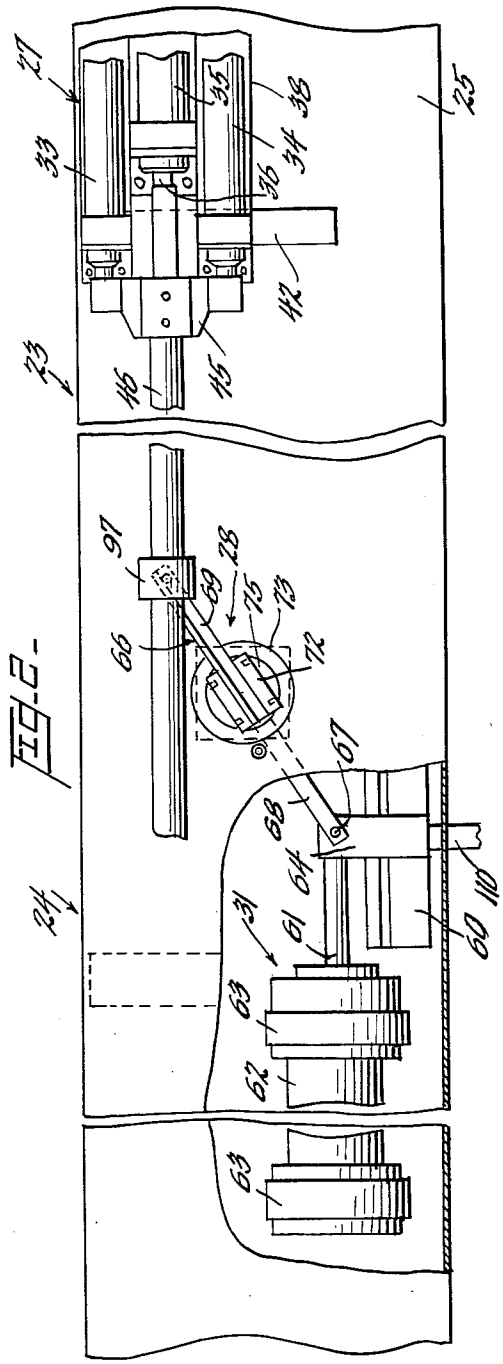


FIG. 2.

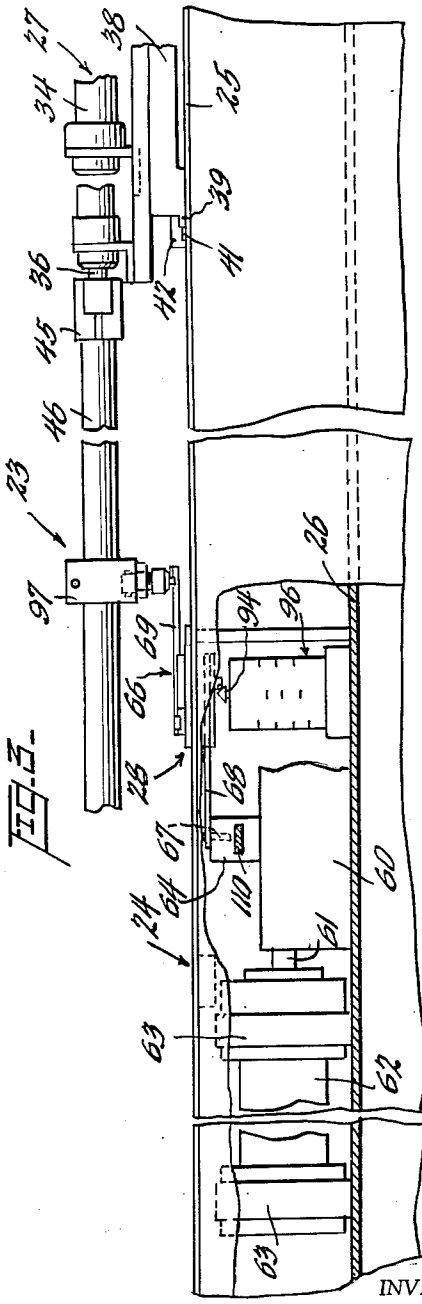


FIG. 3.

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Nov. 20, 1962 F. J. FUCHS, JR 3,064,711

DRAW BENDING APPARATUS

Filed Oct. 21, 1958 5 Sheets-Sheet 3

FIG. 4.

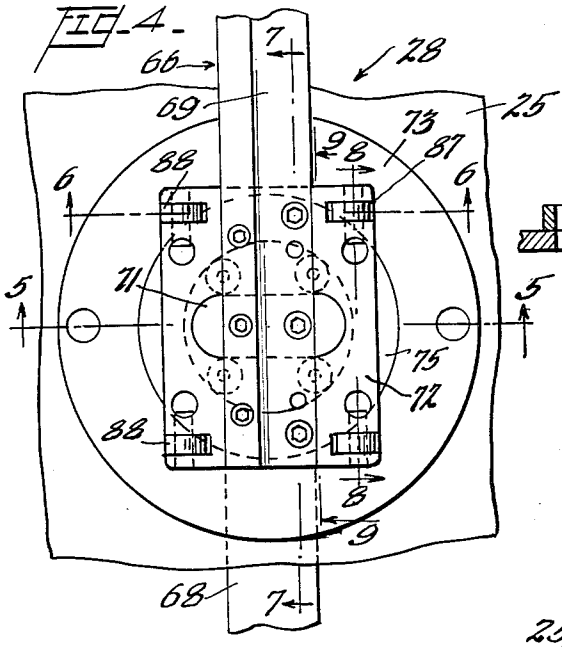


FIG. 5.

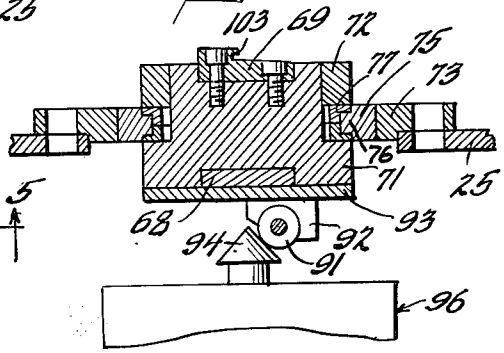


FIG. 6.

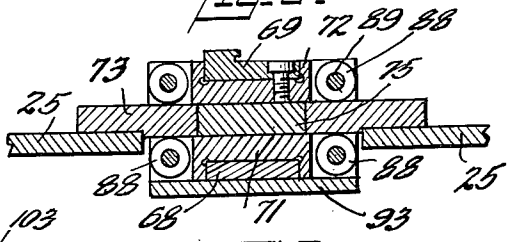


FIG. 7.

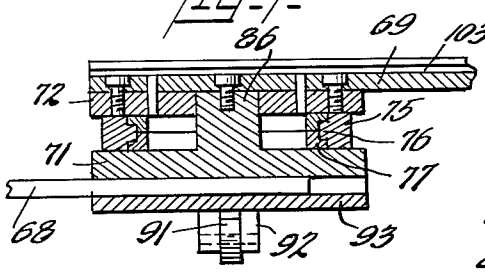


FIG. 8.

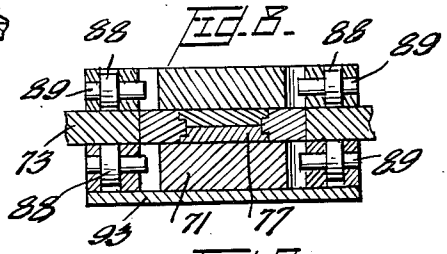


FIG. 11.

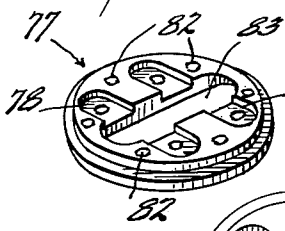


FIG. 9.

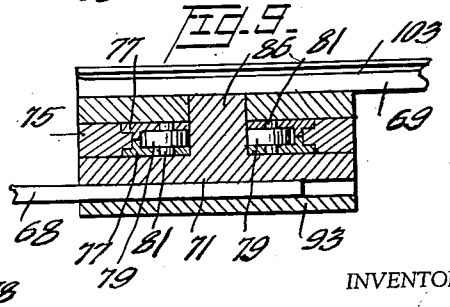
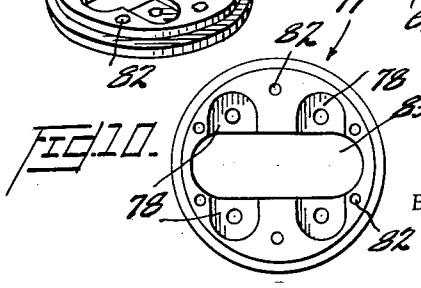


FIG. 10.



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Nov. 20, 1962 F. J. FUCHS, JR 3,064,711

DRAW BENDING APPARATUS

Filed Oct. 21, 1958 5 Sheets-Sheet 4

FIG. 15.

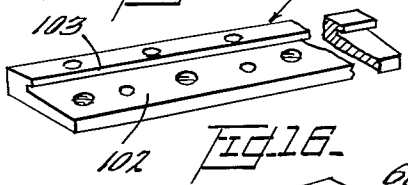


FIG. 16.

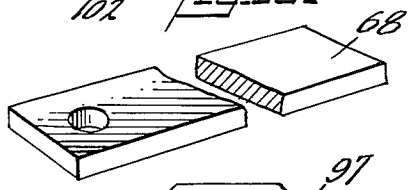


FIG. 17.

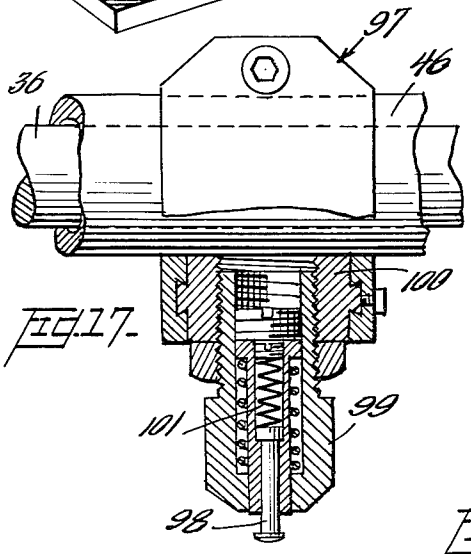


FIG. 18.

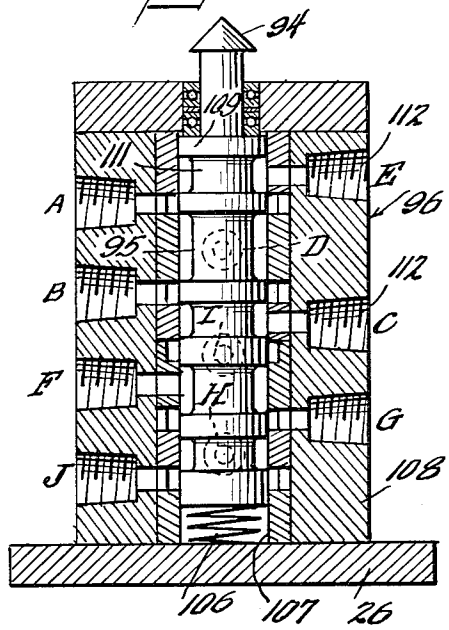
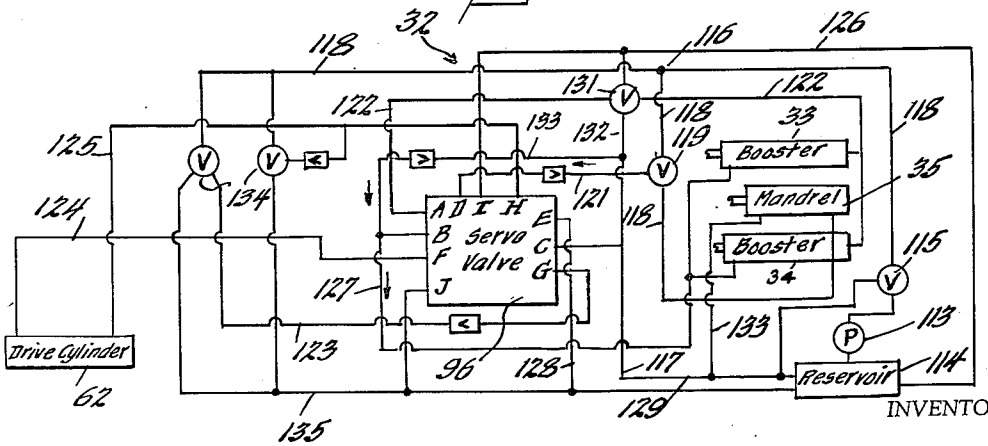


FIG. 19.



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Nov. 20, 1962 F. J. FUCHS, JR 3,064,711

DRAW BENDING APPARATUS

Filed Oct. 21, 1958 5 Sheets-Sheet 5

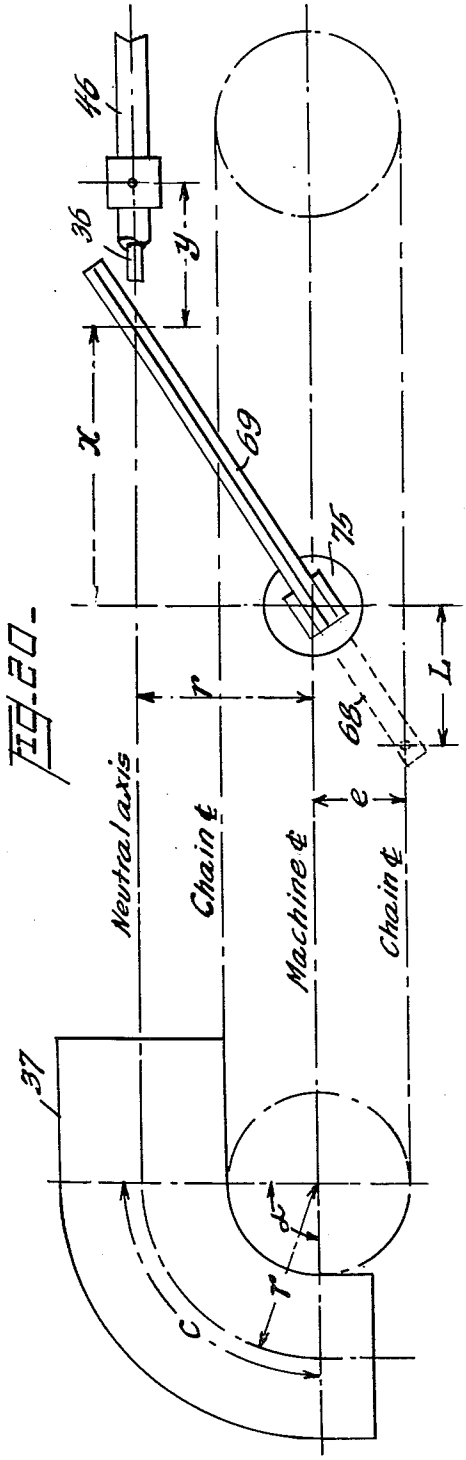


FIG. 20.

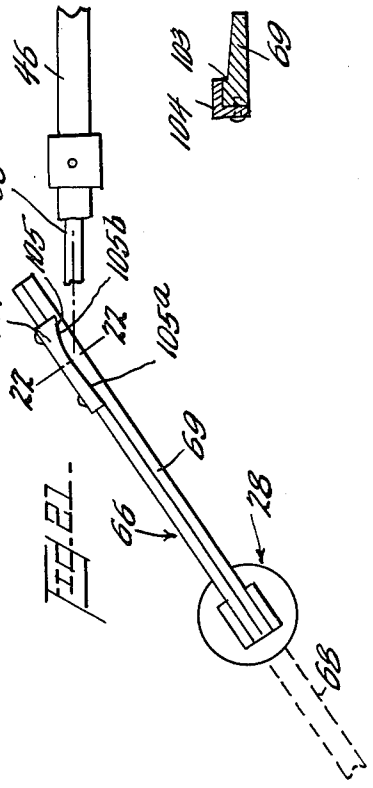


FIG. 21.

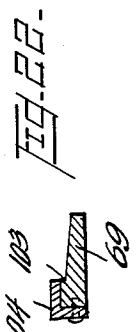


FIG. 22.

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United States Patent Office 3,064,711 Patented Nov. 20, 1962

3,064,711

DRAW BENDING APPARATUS

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Filed Oct. 21, 1958, Ser. No. 768,598
13 Claims. (Cl. 153—40)

This invention relates to draw bending apparatus and more particularly to draw bending apparatus having a servo-controlled system for correlating the travel of a tube-advancing booster with the amount of rotation of a bending form.

Tube bending machines generally of the nature of the present invention are used extensively in the manufacture of tubular products such as tubular chair frames, bicycle frames, towel bars, and the like. These bending machines are successful in the rapid and accurate bending of tubular stock to be assembled into products as aforementioned; however, conventional bending machines are incapable of controlling with exactness the extent to which tubular walls are stretched and compressed during the draw bending operation.

The effect of the drawing operation on the thickness of tubular walls at the area of bend is a significant factor in instances where the inside dimensions of a tube must be maintained uniformly throughout the length of the tube, as, for example, in wave guide tubing. Also, the lightweight tubing employed customarily in the fabrication of wave guides, or the like, is relatively thin-walled and ductile; hence, bending of such tubing must be made without an appreciable weakening of the walls due to the stretching thereof.

Conventional draw bending machines generally are composed of a rotatable bending form, a mandrel, a clamp die rotatable with the bending form for constraining a tube mounted over the mandrel against the bending form, a pressure die and a wiper die for firmly guiding the tube to prevent distortion and wrinkling while the tube is being drawn by the bending form. These machines in the past have been modified by the use of chains, springs, pulley and belt combinations, or the like, to feed a tube toward a bending form with the speed at which the tube is drawn by the rotatable bending form in order to offset any undue stress placed on the tube walls by reason of the formation of the bend.

An example of an improved draw bending machine is disclosed and claimed in my Patent 2,837,137, of June 3, 1958, entitled, "Boosting Mechanism for Bending Wave Guide Tubing with Controlled Neutral Axis." In this patent a mechanical booster head for advancing a tube by action of an extensible cross arm moves a predetermined distance proportional to the angular distance which a bending form rotates for a given radius of bend. By this arrangement there is effected a correlation between tensional force occasioned in drawing a tube with compressional force brought against the rearward extremity of the tube being bent.

The neutral axis of the tube, which is the hypothetical dividing line between compressional and tensional forces on a tube, is controlled through the correlation of tensional and compressional forces mentioned. By moving the neutral axis outwardly from the tube centerline toward the outer wall of the tube, the degree of thinning of that wall is controlled to prevent rupture of the wall by the deleterious tensional stress normally introduced in the outer bend in such operations. Also, the inner wall of the tube, the wall clamped against the bending form, is thickened only to a controlled degree.

It is an object of this invention to provide new and improved draw bending apparatus.

It is another object of the present invention to provide

a new and improved draw bending machine having a servo-controlled system for correlating the travel of a tube advancing booster with the amount of rotation of a bending form.

Still another object of this invention is to provide mechanism for controlling the advance of a tube toward a bending form continuously throughout the drawing of a straight tube into a bent tube whereby fluctuations in the desired correlation between the rate of travel of a tube-advancing booster and the rotation of a bending form are compensated automatically.

Illustrative of the above objects, apparatus exemplifying certain features of the invention may include a rotatable bending form for bending a tube, drive means coupled to the form for rotating the form, booster means engageable with a tube for applying pressure on the tube toward the bending form, power means for moving the booster means, and means connected operatively to the drive means, the power means, and to the booster means for correlating automatically the rate of rotation of the bending form with the rate of advance of the tube by the booster means.

A complete understanding of the invention may be had from the following detailed description of a specific embodiment thereof when read in conjunction with the appended drawings wherein:

FIG. 1 is a perspective view of apparatus forming a preferred embodiment of the invention with parts thereof broken away for clarity;

FIG. 2 shows a plan view of the apparatus with parts thereof broken away;

FIG. 3 illustrates a side elevation of the apparatus shown in FIG. 2 with parts thereof broken away;

FIG. 4 is an enlarged fragmentary plan view of a pivot assembly forming part of the apparatus shown in FIGS. 2 and 3;

FIG. 5 illustrates a fragmentary vertical section of the pivot assembly taken on lines 5—5 of FIG. 4 looking in the direction of the arrows;

FIG. 6 is a fragmentary vertical section of the pivot assembly taken on lines 6—6 of FIG. 4 looking in the direction of the arrows;

FIG. 7 is a fragmentary vertical section of the pivot assembly taken on lines 7—7 of FIG. 4 looking in the direction of the arrows;

FIG. 8 is a fragmentary vertical section taken on lines 8—8 of FIG. 4 looking in the direction of the arrows illustrating the mounting of the pivot assembly on a support ring;

FIG. 9 is a fragmentary vertical section taken on lines 9—9 of FIG. 4 looking in the direction of the arrows showing the connection between elements of the pivot assembly;

FIG. 10 is a plan view of a circular plate of the pivot assembly shown in FIG. 4;

FIG. 11 is a perspective view of the circular plate shown in FIG. 10;

FIG. 12 shows a perspective view of an upper control rod plate of the pivot assembly shown in FIG. 4;

FIG. 13 is a perspective view of a lower control rod plate of the pivot assembly shown in FIG. 4;

FIG. 14 illustrates in perspective view a bearing ring forming an element of the pivot assembly;

FIG. 15 is a perspective view, partly broken away, of an upper control rod of the pivot assembly shown in FIG. 4;

FIG. 16 shows an enlarged perspective view, partly broken away, of a lower control rod of the pivot assembly;

FIG. 17 is an enlarged view of a pin assembly, partly in section, mounted upon a booster rod;

FIG. 18 is an enlarged vertical sectional view of a

servo-valve designed to control the automatic operation of power-actuated members of the apparatus;

FIG. 19 is a schematic diagram of a hydraulic system of the apparatus;

FIG. 20 is a schematic diagram of the pivot assembly positioned in relation to a bending form and a booster means;

FIG. 21 illustrates an alternative embodiment of an element of the apparatus; and

FIG. 22 is a modification of the upper control rod of the apparatus shown in vertical sectional view taken on lines 22—22 of FIG. 21.

Referring now to the drawings wherein like reference characters designate like or corresponding parts throughout the several views, there is shown in FIGS. 1, 2, and 3, a machine 23 for draw bending tubing which may be, for example, rectangular wave guide tubing. The machine 23 includes a frame 24 with a top plate 25 and a lower horizontally-disposed shelf plate 26, onto which plates are assembled the novel components appurtenant to the machine.

The draw bending machine 23 includes a booster assembly 27 which is mounted on the top plate 25 for movement laterally of the longitudinal centerline of the machine, a pivot assembly 28 positioned intermediate the end portion of the top plate 25 and positioned substantially on the longitudinal centerline of the machine, and a rotatable bending form assembly 29 located on the machine top plate 25 with its center of rotation positioned substantially on the longitudinal centerline of the machine 23 at the end of the machine opposite the location of the booster assembly 27. A bending form drive assembly 31, and a hydraulic system 32 (FIG. 19) for actuation of the operative elements of the assemblies, is supported, for example, on the shelf plate 26.

The booster assembly 27 includes in general three hydraulic cylinders 33, 34, and 35, the latter being a mandrel cylinder for advancing a mandrel rod 36 into contacting engagement with the interior of a tube 37 which is to be draw bent by the bending form assembly 29. The cylinders 33, 34, and 35 are mounted on a common support 38 which is provided with a lower lip portion 39 slidably receivable in a guideway 41 of a guide bar 42. A slotted portion 43 of the support 38 is mounted slidably on an elongated block 44 of the machine top plate 25. Accordingly, the booster assembly 27 may be moved laterally with respect to the longitudinal centerline of the machine frame 24.

Horizontally spaced apart from the mandrel cylinder 35 and adjacent each side thereof are positioned hydraulic booster rod cylinders 33 and 34 which are coupled together cooperatively at their forward ends by means of a yoke 45. The arms of the yoke 45 are connected rigidly to the piston rods of the respective booster rod cylinders 33, 34 for simultaneous reciprocable movement therewith. Also, the yoke 45 is formed with a central aperture through which is received the mandrel rod 36 which moves independently with respect to the movement of a booster rod 46 which is fastened to the yoke 45.

The booster rod 46 is provided with a threaded end for coupling with an extension booster rod 47 having a booster element 48, or the like, mounted on the extremity thereof for application of pressure against the trailing edge of the tube 37. A conventional threaded sleeve coupling 49 is provided for attachment of the extension booster rod 47 onto the booster rod 46. As best shown in FIG. 1, the booster rod 46 is a hollow sleeve which receives coaxially the mandrel rod 36 for insertion into the tube 37 to support the walls thereof against collapse during the bending operation.

The bending form assembly 29, FIG. 1, is of a conventional design and may include a bending form 51 to which is clamped the tube 37 by means of a clamp die 52 mounted on a carriage 53 for lateral adjustment. A pressure die 54 and a wiper die 55 are spaced apart horizontally to receive the tube 37 therebetween for guidance into proper alignment for draw bending by the bending form 51. When thus positioned, the tube 37 is advanced by the drawing action of the bending form 51 on the forward end of the tube 37 held against the form 51 by the clamp die 52, and by the pressure exerted against the trailing edge of the tube 37 by the booster element 48.

For rotating the bending form 51 the drive assembly 31 includes a bending form sprocket 56 which is keyed for rotation on an axle 57 which in turn intersects perpendicularly the longitudinal centerline of the machine. The axle 57 passes through a vertically extending passage in the bending form 51 and is secured thereto by a suitable fastener such as nut 58. By this arrangement any angular movement of the sprocket 56 is imparted equally and simultaneously to the bending form 51.

A roller chain 59 is entrained about the bending form sprocket 56, one end of the chain 59 being engaged fixedly by means such as a clevis mounting, not shown, to a piston rod 61 of a double-acting hydraulic drive cylinder 62. The cylinder 62 is secured in position by suitable means such as brackets 63 fastened to the shelf plate 26 of the machine 23. The other end of the roller chain 59 is engaged fixedly by suitable means (not shown) to a slide block 64. The slide block 64 is connected to the piston rod 61 of the double-acting hydraulic drive cylinder 62 and is supported for axially slidable movement within a groove provided in support 60 fastened on the side wall of machine 23.

At the end of the machine remote from the location of the drive sprocket 56, FIG. 1, the roller chain 59 is passed around an idler sprocket 65 which is located preferably within the machine frame 24 beneath the booster assembly 27. The idler sprocket 65 is fastened to the shelf plate 26 for rotation about a vertical axis which intersects and is normal to the longitudinal centerline of the machine in a plane parallel to the top plate 25 and normal to a plane which includes the bending form sprocket 56, the roller chain 59, and the piston rod 61 of the hydraulic drive cylinder 62. Upon the controlled application of fluid pressure into the hydraulic drive cylinder 62, the chain 59 may be advanced by the piston rod 61 either to rotate the bending form 51 counterclockwise, or withdrawn to rotate the bending form 51 clockwise.

An arm 66 of the pivot assembly 28 is coupled pivotally at one end to the slide block 64 (FIGS. 1, 2, and 3) by a pivot stud 67. The arm 66 is composed of a lower control rod 68 and an upper control rod 69. Rods 68 and 69 are assembled together in a vertically spaced relationship along parallel longitudinal axes by means of a lower control rod plate 71 and an upper control rod plate 72. Referring to FIGS. 4 through 14, the specific structure of the pivot assembly 28 is shown from an assembled to a completely unassembled condition.

The entire pivot assembly 28, FIG. 4, is contained by a support ring 73 and is mounted within an aperture 74 formed through the top plate 25 of the machine frame 24. The assembly 28 is positioned for rotation about an axis which is normal to the longitudinal center-line of the machine. A bearing 75 is force-fitted, for example, in an abutting concentric position with respect to the support ring 73 and is provided with an inner circumferential projection 76 adapted to support pivotally two circular plates 77, each having an L-shaped outer periphery in cross section, FIGS. 10 and 11. The circular plates 77 are stacked one on the other to form a U-shaped mating surface for surrounding frictional engagement with the bearing 75 at its inner periphery and, in particular, about the projection 76 thereon. When the plates 77 are placed together in stacked fashion, machined slots 78 form recesses into which are mounted ball bearings 79 on means such as dowels 81. The circular plates 77 are fastened together by screws, or the like, which may be

engaged threadedly into vertically aligned holes 82 in each of the respective plates 77, FIGS. 10 and 11. Also, an elongated aperture 83 is formed centrally through each circular plate 77 and arranged to be in vertical alignment with the companion aperture of its matching plate 77 when the plates are finally assembled.

The upper control rod plate 72 and the lower control rod plate 71, shown in detail in FIGS. 4 through 9, are of the same rectangular configuration. The upper plate 72 is provided with a longitudinally extending slot 84 into which is received fixedly the upper control rod 69. Also, the lower plate 71 has similar slots 84, one for receiving the upper control rod 69 and another for receiving slidably the lower control rod 68 such that the lower control rod 68 may vary in length between the pivot stud 67 and the pivot assembly 28 as necessary when the arm 66 pivots.

The upper control rod plate 72 is formed with an elongated aperture 85 which corresponds in configuration with the apertures 83 provided in the circular plates 77. An upstanding central body portion 86 of the lower control rod plate 71, best shown in FIG. 13, is designed to be received through the apertures 83, and 85, for connection to the upper control rod 69. In this manner a rigid coupling between the lower control rod 68 and the upper control rod 69 is effected. By reference to FIG. 4, it may be understood readily that the upper control rod plate 72 overlies both the circular plates 77 and a portion of the support ring 73. The lower control rod plate 71 underlies the same relative elements as does plate 72, FIGS. 7 and 8.

The lower and the upper control rod plates 71 and 72 are each provided with side slots 87 to receive roller bearings 88 mounted on dowels 89. The roller bearings 88 of the plates 71 and 72 contact the support ring 73 on its opposite horizontal faces to enable a substantially frictionless translatory action to exist between these elements.

The upstanding central body portion 86 of the lower control rod plate 71 has a width slightly less than the width of the apertures 83 through which it is received slidably. By the axial length of each of the elongated apertures 83 being greater than the axial length of the central body portion 86 translatory movement of the body portion 86 is possible, through contact with the bearings 79, in a direction within the confines of the apertures 83 perpendicular to the axis of the arm 66. It is apparent therefore that the pivot assembly arm 66 moves not only in an angular pivotal path in bearing 75 about an axis of rotation normal to the plane which includes the machine top plate 25, but also in a path perpendicular to the axis of the arm 66 within the apertures 83.

A cam roller 91 is supported by the lower control rod plate 71 by a bracket 92 fixed to a cover plate 93. As shown in FIG. 5, the cam roller 91 is designed to contact operatively a servo-valve plunger 94 having a conical head, the centerline of which is coincident with the center of the support ring 73. The cam roller 91 moves with any translatory movement of the pivot assembly 28, and the plunger 94 is caused by such movement of the cam roller 91 to reciprocate in a vertical path whereby a spool 95, contained within a servo-valve 96, FIG. 18, is actuated.

A booster pin subassembly 97 is clamped removably at a preferred location on the booster rod 46, as shown in FIG. 17. A booster pin 98, carried by a pin housing 99, is designed to be adjustable laterally with respect to the longitudinal centerline of the machine 23 by the incorporation of a slide 100. A pressure spring 101 normally urges the pin 98 to project downwardly beyond the limits of the pin housing 99. The spring-biased pin 98 is designed to contact frictionally an inclined surface 102 of the upper control rod 69, FIG. 15, and, during normal bending operation of the machine 23, brings pressure to bear against a vertical step 103 formed on the upper control rod 69.

Referring to FIG. 18, wherein the servo-valve 96 is shown in cross-sectional view, the valve plunger 94 is positioned normally in uppermost vertical extension by means of a compression spring 106 positioned suitably within a passage 107 of the valve body 108. The valve plunger 94 is formed integrally, for example, with the elongated spool 95 which is provided with circular lands 109 and grooves 111. The lands 109 are of a thickness to close and to open effectively ports A through J which are drilled through the valve body 108. Counterbores 112 are provided for each port and are threaded to enable the coupling of a conventional hydraulic conduit fitting thereto. The sequence of operation of the servo-valve 96 is best explained in conjunction with the detailed description of the hydraulic pressure system, FIG. 19.

Operation

The tube 37 is clamped into position against the bending form 51, as shown in FIG. 1, by the clamp die 52, and guided by the pressure die 54 and the wiper die 55 which are forced into frictional contact with the tube 37 by fluid-operated means, not shown. The booster rod 46 and mandrel rod 36 are aligned with the centerline of the clamped tubing 37, and the pin subassembly 97 is fastened onto the rod 46 at a preferred location for preloading force against the rear of the tube 37 before the actual bending of the tube is started. Then the pin 98 is adjusted by means of a conventional dovetail slide 100 so as to lie on the desired neutral axis of the tube 37. The hydraulic system 32, FIG. 19, is furnished fluid under pressure by suitable pump means 113 which is in communication with a reservoir 144, and, through the operation of a four-way valve 115, the fluid may be introduced selectively into or exhausted from the system 32 at points 116 and 117.

To perform a bending cycle, fluid is introduced into the system 32 at point 116 into line 118, one branch of which leads to the rear of the mandrel cylinder 35. A sequence valve 119 is placed in line 118 to open a line 121 upon a predetermined threshold pressure being reached. This pressure is determined by the desired extent of advancement of the mandrel rod 36 toward the tube 37. The fluid is ported via the sequence valve 119 through the line 121 into the servo-valve 96 at port D, and, since at this stage the spool 95 of valve 96 is not depressed by operation of cam roller 91 on the valve plunger 94, the port A is open to receive the fluid flowing into port D. From port A the fluid is led through conduit 122 to the rear of the booster rod cylinders 33 and 34.

At this stage of the bending operation the booster rod 46 advances toward the bending form assembly 29, preloading pressure through the booster element 48 onto the rear of the tube 37. By means of such preloading the metal of the tube 37 is compressed at the area of the proposed bend in order to anticipate the rotation of the bending form 51. Thus, when the bending form 51 is caused to rotate and draw the tube 37, a predetermined amount of metal is forced into the outer and inner walls of the tube 37 at the area of the bend from the start of the operation.

When the pin 98 of the booster pin subassembly 97 strikes the vertical step 103 on the upper control rod 69, the pivot assembly 28 shifts within the apertures 83—83 in a manner as explained hereinbefore. The cam roller 91 moves with the pivot arm 66 when the pivot assembly shifts, depressing the plunger 94 of the servo-valve 96 to a neutral position, as shown in FIG. 18. As the plunger 94 is being depressed, the spool 95 is moved downwardly to open port G to port F.

The drive cylinder 62 is actuated when ports F and G are open to conduct fluid from the reservoir 114 to port G, thence through a pipe 124, to the cylinder 62. During the period of the actuation of the cylinder 62, the port A, FIG. 18, is closed so as to cut off the supply of fluid to the booster rod cylinders 33 and 34, thus stopping the advancement of the booster rod 46 with the booster pin

subassembly **97**. Fluid from the forward end of the drive cylinder **62** is exhausted through the line **125** to port H of the servo-valve to port J, and thence to the reservoir **114**.

Inasmuch as the roller chain **59** is connected to the slide block **64** and the arm **66** of the pivot assembly **28**, the upper control rod **69** pivotally moves away from the pin **98** of the booster pin subassembly **97**, and this in turn enables the spool **95** to rise within the servo-valve **96**. The spool-up positioning of the spool **95** attained in this fashion gradually closes port G to stop fluid flow to the drive cylinder **62**, and reopens port A to port D. Thus, the booster cylinders **33** and **34** again advance the booster rod **46** with the booster pin subassembly **97** toward the bending form assembly **29** and the pin **98** strikes the step **103** of rod **69** to repeat the performance which is stimulated by the movement of the servo-valve spool **95**.

If the force exerted by the pin **98** on the rod **69** exceeds a determined amount, the spool **95** is depressed by the cam roller **91** to cause spool **95** to open port B to port D so as to introduce fluid to the forward end of the booster cylinders **32** and **33** via line **127**. This action reverses the direction of travel of the booster rod **46**, and fluid from the rear portion of these cylinders is dumped through the conduit **122** to port A, to port E, and through the line **128** to the reservoir **114**. In this spooldown situation the bending form **51** continues rotating by reason of the fluid fed to drive cylinder **62** via ports G and F as above discussed.

In practice a suitable design for the servo-valve **96** is a spool having an upward movement from a neutral position (FIG. 18) of .060 inch, and a port C opening of .030 inch measured vertically. With this design the spool opposite port G closes this port if the spool moves upwardly .030 inch or more. This action stops rotation of the bending form **51**. As the arm **66** moves from contact with the pin **98**, the spool **95** rises to open port A thus porting fluid to the booster cylinders **32** and **33**. These cylinders are furnished fluid at the same time the drive cylinder **62** is fed until the spool **95** moves upwardly from the position shown in FIG. 18 a distance of .030 inch to close completely the port G. By the provision of such a servo-valve design, an accuracy of $\pm$.015 inch is possible between the travel of the booster rod **46** and the rotation of the bending form **51**.

The bending cycle is completed when, for example, a rod **110** attached to the slide block **64** trips a microswitch, not shown, to stop the action of the pump means **113**. The four-way valve **115** is then caused, in effect, to reverse the input and output points **116** and **117**, respectively, of the hydraulic system **32**. Thus, when the pump means **113** again is made operative, the fluid under pressure enters point **117** into the hydraulic system **32** through line **129**. A pressure valve **131**, situated in line **122**, is designed to open when fluid is introduced through a pilot line **132**, such that the servo-valve **96** is by-passed during the reversing operation. The reversing fluid is fed through lines **129**, **133**, and **127** into the forward portion of the booster cylinders **33** and **34** to withdraw the booster rod **46**. The exhaust from the rear of these cylinders is through line **122** to the pressure valve **131** which now has a port open to the reservoir line **126** by action of the fluid fed to the valve **131** through the pilot line **132**.

The action of the mandrel cylinder **35** is reversed when fluid through line **133** is fed into the forward portion of the cylinder **35**, and fluid is exhausted via line **118**, through sequence valve **119**, and to the reservoir **114**. By separate hydraulic means, not shown, the bending form assembly **29** is returned to a starting position, and dies **52**, **54**, and **55** are released from engagement with the tube **37**. Suitable pressure relief valves **134** are provided in the system **32** in communication with the reservoir **114** via line **135**.

To recapitulate, the action of the servo-valve **96** is as follows:

(1) in spool-up position,
- (*a*) Port J is closed;
- (*b*) Port H is open only to port G;
- (*c*) Port F is open (always open);
- (*d*) Port I is open;
- (*e*) Port B is open to port C;
- (*f*) Port C is open;
- (*g*) Port D is open (always open);
- (*h*) Port A is open to port D;
- (*i*) Port E is open (always open);

(2) in spool-neutral position, FIG. 18,
- (*a*) Port A is closed to port D;
- (*b*) Port D is open (always open);
- (*c*) Port E is open (always open);
- (*d*) Port B is closed;
- (*e*) Port G is open (always open);
- (*f*) Port I is closed;
- (*g*) Port G is open to port F;
- (*h*) Port F is open (always open);
- (*i*) Port H is open (always open);
- (*j*) Port J is open to port H;

and

(3) when the spool is in spool-down position,
- (*a*) Port J is open to port H;
- (*b*) Port H is open (always open);
- (*c*) Port G is open to port F;
- (*d*) Port F is open (always open);
- (*e*) Port I is closed;
- (*f*) Port C is closed;
- (*g*) Port B is open to port D;
- (*h*) Port D is open (always open);
- (*i*) Port A is open to port F;
- (*j*) Port E is open.

A second embodiment of the apparatus includes an upper control rod **169** having a clamp **104**, FIGS. 21 and 22, a cam surface **105** for engagement with the booster pin **98**, positionable selectively along the length of the rod **69**. By the utilization of the clamp **104** a predetermined variance in the correlation of the speed of rotation of the bending form **51** and the travel of the booster rod **46** is effected. For example, in the instance of the cam design shown, the relatively straight portion **105** enables a steady advance of the tube **37**, whereas portion **105***a* causes a fast advance of the tube **37** as generally possible at the beginning of the bending operation on the tube **37**. The steady advance is desirable after a tube has been work-hardened by the initial bending of a tube such that metal flow is retarded.

Theory of Operation

Referring now to FIG. 20, for preloading a predetermined pressure onto the tube **37** before the bending form **51** is caused to draw the tube **37**, the booster pin subassembly **97** is stationed a distance "Y" on the booster rod **46** from the step **103** of the arm **66**. As hereinbefore explained, when the pin **98** of the booster pin subassembly **97** urges the upper control rod **69** toward the bending form **51**, the spool **95** of the servo-valve **96** is depressed to deprive the booster cylinders **33** and **34** of their source of fluid, thus stopping the advancement of the booster rod **46**. The drive cylinder **62** then is fed fluid to drive the roller chain **59** and, consequently, the bending form **51** rotates.

The arc "C" described by rotation of the bending form **51** for a bend of angle α is equal to

$$2\pi r\frac{\alpha}{360^\circ}$$

and to the distance "X," where "*r*" is the radius measured from the center of rotation of the bending form to the desired neutral axis of the tube **37**. The booster pin subassembly **97** is adjusted laterally on the booster rod **46** to align the pin **98** on the desired predetermined neutral

axis. The pin subassembly 97 thus is positioned to strike the arm 66 at a point measured the distance "X" along the extended neutral axis from a construction line perpendicular to the longitudinal centerline of the machine passing through the center of the support ring 73 of the pivot assembly 28 when angle α equals 90°. By the offset positioning of the pin 98 with respect to the booster rod 46 and the mandrel rod 36, the neutral axis of the tube 37 is moved away from the tube centerline, since the distance the booster rod 46 travels and the arc distance "C" through which the bending form 51 rotates is governed by the position along the arm 66 which is contacted by the pin 98.

The instant machine is capable of performing bending of tubes of various sizes without the substitution of machine elements as has been the practice herebefore. In other words, the booster cylinders 33, 34 and the mandrel cylinder 35 are adjusted laterally on the machine by the mounting provided as discussed hereinbefore, thereby making it possible to align the booster rod 46 and the mandrel rod 36 on the centerline of each size of tubing desired to be bent. The lateral shifting of the pin 98 onto a neutral axis by means of the slide 100, provided by the pin assembly 97, causes the coaction between the drive assembly 31 and the booster assembly 27 to be related to the position of the neutral axis desired. Inasmuch as the booster rod 46 is aligned at all times on the centerline of tubing to be bent, the setting of pin 98 on the desired neutral axis the distance "X," which is the arc distance "C" measured on the neutral axis, determines the desired distance of travel of the booster rod 46 to accomplish a bent tube having walls at the bent portion of required thicknesses. The machine 23 is designed such that the attitude assumed by the arm 66 upon completion of a 90-degree bend is when the distance "L" is equal to zero. These dimensions are factors incorporated in computation of the proper distance "Y" at which the pin assembly 97 is to be attached to the booster rod 46 for a given tube size and neutral axis. These computations are explained in detail in my Patent No. 2,837,137.

The present invention provides mechanism for bending tubes, such as wave guides, in an accurate and positive manner such that bends in lightweight ductile material may be made with precision. The bending operation is controlled automatically to effect a bend in a tube without the customary extreme thinning of the outer wall of a tube.

Obviously, many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A tube bending machine which comprises a rotatable bending form, drive means coupled to the form for rotating the form, linkage means attached to the drive means and pivoted by the movement of the drive means, booster means for applying pressure onto a tube toward the bending form and cooperatively engageable with the linkage means, power means for moving the booster means, and means responsive to the cooperative engagement of the booster means with the linkage means for controlling the drive means and the power means such that a predetermined relationship exists between the advancement of a tube and the rotation of the bending form.

2. A tube bending machine which comprises a rotatable bending form, clamp means for holding a tube against the form; drive means coupled to the form for rotating the form; pivot means including a pivot member and an arm supported intermediate its ends on the pivot member, one end of the arm being connected to the drive means for simultaneous pivoting of the arm and the pivot member responsive to operation of the drive means; booster means for applying pressure onto a tube and for feeding a tube axially toward the bending form and engageable with the other end of the arm of the pivot means; power means for moving the booster means; and control means responsive to the engagement of the booster means with the arm of the pivot means for controlling the driving operation of the drive means and the operation of the booster power means such that a predetermined relationship between the advancement of a tube toward the bending form and the rotation of the bending form is effected.

3. A tube bending machine which comprises a rotatable bending form; clamp means for holding a tube against the form; drive means including a member movable in an axial path coupled to the bending form for rotation thereof; pivot means including a pivot member and an arm supported intermediate its ends on the pivot member, one end of the arm being connected pivotally to the axially movable member of the drive means for pivotal movement responsive to translatory movement of the drive means member; booster means for applying pressure onto a tube and for feeding a tube axially toward the bending form and engageable with the other end of the arm of the pivot means; power means for moving the booster means; and control means responsive to the engagement of the booster means with the arm of the pivot means for controlling the driving operation of the drive means and the operation of the power means such that a predetermined relationship between the advancement of a tube toward the bending form and the rotation of the bending form is effected.

4. A tube bending machine which comprises a rotatable bending form; clamp means for holding a tube against the form; drive means including a member movable in an axial path coupled to the bending form for rotation thereof; pivot means including a pivot member and an arm supported intermediate its ends on the pivot member, one end of the arm being connected pivotally to the axially movable member of the drive means for pivotal movement responsive to translatory movement of the drive means member; booster means for applying pressure onto a tube end for feeding a tube axially toward the bending form and including a pin assembly carried by the booster means, said pin assembly being engageable with the other end of the arm of the pivot means; power means for moving the booster means, and control means responsive to the engagement of the pin assembly with the arm of the pivot means for controlling the driving operation of the drive means and the operation of the power means such that a predetermined relationship between the advancement of a tube toward the bending form and the rotation of the bending form is effected.

5. A tube bending machine which comprises a rotatable bending form; clamp means for holding a tube against the form; drive means including a member movable in an axial path coupled to the bending form for rotation thereof; pivot means including a pivot member and an arm supported intermediate its ends on the pivot member, a clamp having a contoured face and supported on said arm, one end of the arm being connected pivotally to the axially movable member of the drive means for pivotal movement responsive to translatory movement of the drive means member; booster means for applying pressure onto a tube and for feeding a tube axially toward the bending form and including a pin assembly carried by the booster means, said pin assembly being engageable with the contoured face of the clamp on the arm of the pivot means; power means for moving the booster means; and control means responsive to the engagement of the pin assembly with the clamp for controlling the driving operation of the drive means and the operation of the power means with the feeding action such that a predetermined relationship between the advancement of a tube toward the bending form and the rotation of the bending form is effected.

6. A tube bending machine which comprises a rotatable bending form; clamp means for holding a tube against the

form; drive means including a member movable in an axial path coupled to the bending form for rotation thereof; pivot means including a pivot member and an arm supported intermediate its ends on the pivot member for pivotal and reciprocal movement, one end of the arm being connected pivotally to the axially movable member of the drive means for pivotal movement responsive to translatory movement of the drive means member; booster means for applying pressure onto a tube and for feeding a tube axially toward the bending form and including a pin assembly carried by the booster means, said pin assembly being engageable with the arm of the pivot means; power means for moving the booster means; and control means responsive to the engagement of the pin assembly with the arm for controlling the driving operation of the drive means and the operation of the power means such that a predetermined relationship between the advancement of a tube toward the bending form and the rotation of the bending form is effected.

7. A tube bending machine which comprises a rotatable bending form; clamp means for holding a tube against the form; drive means including a member movable in an axial path coupled to the bending form for rotation thereof; pivot means including a pivot member and an arm supported intermediate its ends on the pivot member for pivotal and reciprocal movement, one end of the arm being connected pivotally to the axially movable member of the drive means for pivotal movement responsive to translatory movement of the drive means member; booster means including a tube engaging rod; power means connected to the rod for movement thereof axially toward and away from the bending form; a pin assembly secured to the rod engageable with the arm of the pivot means, and control means responsive to the engagement of the pin assembly with the arm for controlling the driving operation of the drive means and the operation of the power means such that a predetermined relationship between the advancement of a tube toward the bending form and the rotation of the bending form is effected.

8. A tube bending machine which comprises a rotatable bending form; clamp means for holding a tube against the form; drive means including a power-operated cylinder having piston means movable in an axial path toward and away from the bending form and means connecting the piston means with the bending form for rotation of the form by axial movement of the piston means; pivot means including a pivot member and an arm supported intermediate its ends on the pivot member for pivotal and reciprocal movement, one end of the arm being connected pivotally to the piston means of the drive means for pivotal movement of the arm responsive to translatory movement of the piston means; booster means including a tube engaging rod; a power-operated cylinder having piston means connected to the rod for movement thereof toward and away from the bending form; a pin assembly secured to the rod engageable with the arm of the pivot means; and a control valve responsive to the engagement of the pin assembly with the arm and in communication with the drive means cylinder and the booster cylinder for controlling the driving operation of the drive means and the operation of the power means such that a predetermined relationship between the advancement of a tube toward the bending form and the rotation of the bending form is effected.

9. A tube bending machine which comprises a rotatable bending form; a power source; power-operated clamp means for holding a tube against the form; means communicating the power source with the clamp means for operation thereof; a power-operated mandrel means operatively connected to the power source and including a mandrel rod movable by the mandrel means axially toward and away from the form for inserting and retracting the mandrel into a tube held against the form; a power-operated booster means operatively conected to said power source and including a tube engaging booster rod movable toward and away from the form by the booster means for selectively feeding a tube axially toward the bending form, and a pin assembly clampingly secured to the booster rod for movement therewith; valve means in communication with the power source, the booster means, and the mandrel means for sequentially operating the mandrel means and the booster means; drive means including a power-operated means axially movable and coupled to the bending form for rotation thereof; pivot means including a pivot member fixed in location with respect to the bending form, an arm supportingly attached intermediate its ends to the pivot member for pivotal movement about an axis parallel to the axis of rotation of the bending form and for movement axially toward and away from the bending form, said arm being connected pivotally at one end to the power-operated means of the drive means and responsive to axial movement thereof to pivot the arm on the pivot member, the pin assembly being engageable with the arm at a position opposite the pivotal connection of the arm to the power-operated means for imparting translatory movement of the arm within the pivot member of the arm; a control valve in contacting operative engagement with the arm, the valve being actuable by translatory movement of the arm and in communication with the power-operated booster means, the power-operated means of the drive means, and the power source to correlate the operation of the power-operated booster and drive means.

10. In a tube bending machine having a rotatable bending form to which a tube is clamped for bending, drive means for rotating the form, mandrel means for inserting and retracting a mandrel into a tube clamped to the form for bending, means for aligning the mandrel means coaxially with a tube in position for bending, urging means for forcing the tube axially toward the form, laterally adjustable contact means carried by the urging means at a preselected point, pivotal and translatory means connecting the drive means and the contact means, control means engaged with the connecting means responsive to translatory movement thereof, and hydraulic circuitry connected operatively to the control means, the drive means, and the urging means for correlating the advance of the urging means with the rotation of the form by the drive means.

11. A tube bending machine comprising a rotatable bending form, drive means connected to the form for rotation thereof, pivotal and translatory means, an arm connected intermediate its ends to the pivotal and translatory means, booster means for urging a tube toward the form coaxially with the longitudinal axis of the booster means, a contact member attached to the booster means for axial movement therewith and adjustable laterally with respect to the longitudinal axis of the booster means, means for adjusting the booster means coaxially with a tube clamped to the bending form, one end of the arm being attached pivotally to the drive means for pivotal action about the privotal and translatory means responsive to translation of the drive means, the other end of the arm disposed in the path of the axial movement of the contact member, the arm and the pivotal and translatory means being translated in response to engagement of the arm with the contact means, valve means responsive to translation of the pivotal and translatory means, and means responsive to the valve means for operating the drive means and the booster means in a predetermined sequence whereby the speed of rotation of the form is correlated to the speed of urging the tube by the booster means.

12. A tube bending machine which comprises a bending form, clamps for retaining a tube against the form for bending the tube upon rotation of the form, means for rotating the form, boosting means for urging a tube clamped to the form axially toward the form, an arm connected at one end pivotally to the rotating means for movement axially therewith, a contact member connected to the boosting means for axial movement therewith and

disposed to intermittently engage the arm, control means responsive to the contact of the arm by the member for correlating the operation of the boosting means and the drive means, and a pivot assembly attached intermediate the ends of the arms for pivoting the arm responsive to axial movement of the rotating means whereby the arm is disengaged from the contact member and for translation responsive to the engagement of the contact member with the arm for actuating the control means, said pivot assembly including a mount, a bearing positioned concentrically within the mount in fixed contacting engagemet therewith, rotatable means having an elongated aperture formed therethrough supported for rotation within the bearing, a lower plate underlying the mount and below the rotatable means, the lower plate having an upstanding central portion of the configuration of the aperture of the rotatable means but of lesser length than the elongated aperture, the central portion of the lower plate being receivable slidably within the elongated aperture of the rotatable means and extending beyond the upper surface of the rotatable means, an upper plate overlying the mount attached to the upstanding portion of the lower plate, and roller means supported by the upper and the lower plates in contacting engagement with the mount whereby the upper and the lower plates may translate within the

aperture of the rotatable means a limited amount and rotate with the rotatable means within the bearing.

13. In a bending apparatus, means for gripping an article, a pair of movably mounted bending dies for holding a section of the article, means for moving the bending dies relative to the gripping means to bend the article, means for applying a force to compress the article in the dies during the movement of the bending dies, selectively operable means for increasing the effect of the force applying means, and means responsive to a predetermined degree of relative movement between said bending die moving means and said force applying means for operating said selectively operable means.

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