United States Patent

Zmuda

[15] **3,650,140**

[45] **Mar. 21, 1972**

[54] METHOD AND APPARATUS FOR BENDING TUBING

[72] Inventor: **Daniel A. Zmuda,** Toledo, Ohio

[73] Assignee: **Questor Corporation,** Toledo, Ohio

[22] Filed: **Nov. 3, 1970**

[21] Appl. No.: **86,570**

Related U.S. Application Data

[62] Division of Ser. No. 736,317, June 12, 1968, Pat. No. 3,557,586.

[52] **U.S. Cl.**.....**72/296,** 72/369, 72/32

[51] **Int. Cl.**.....**B21d 11/02**

[58] **Field of Search**.....72/149, 152, 155, 158, 159, 72/214, 215, 216, 217, 296, 369, 304, 307, 309, 310

[56] **References Cited**

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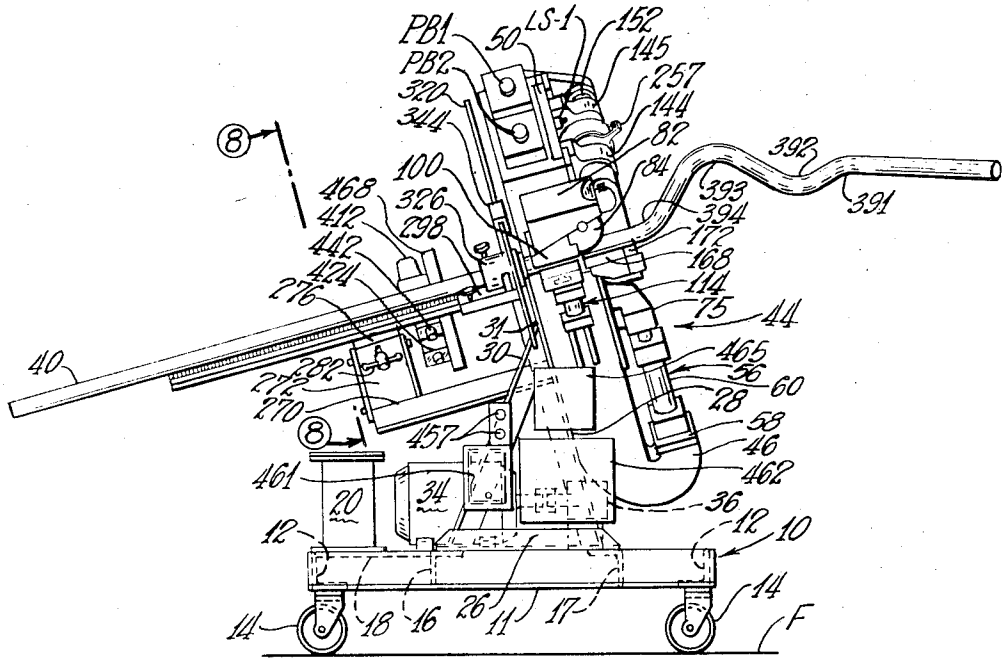
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Primary Examiner—Richard J. Herbst
Assistant Examiner—Michael J. Keenan
Attorney—Harry O. Ernsberger

[57] **ABSTRACT**

This invention embraces a method of and apparatus for forming or impressing successive bends in tubing, such as exhaust pipes for internal combustion engine exhaust systems, the method and apparatus providing for forming successive bends of various depths and angularities while maintaining positive control of the tubing during the successive operations to assure the proper orientation of the bends in the tubing.

9 Claims, 32 Drawing Figures



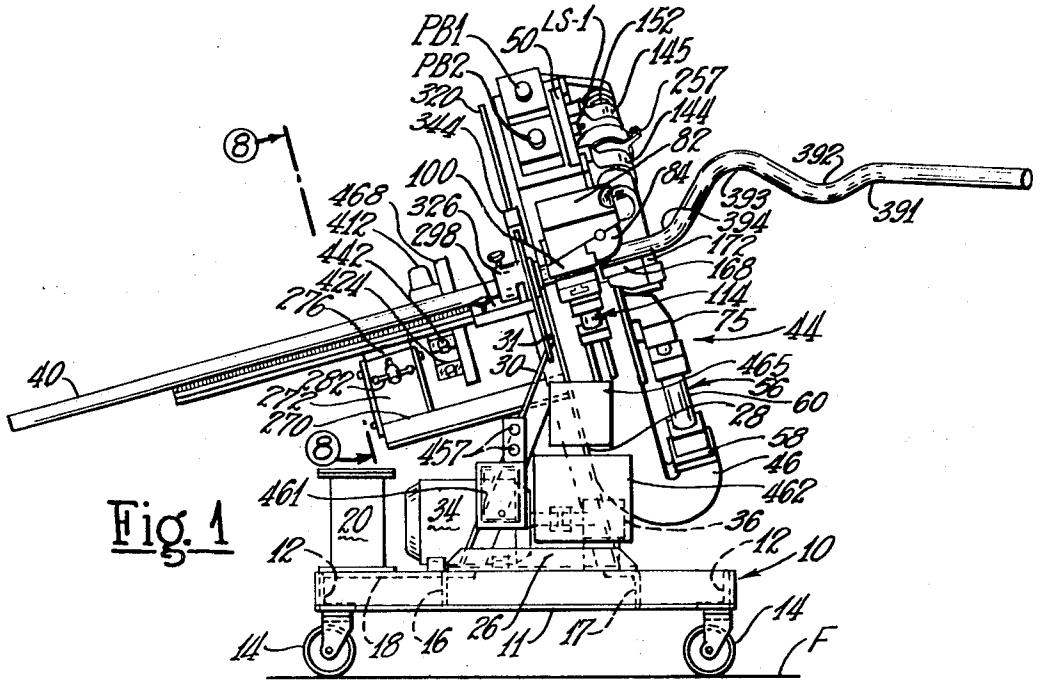


Fig. 1

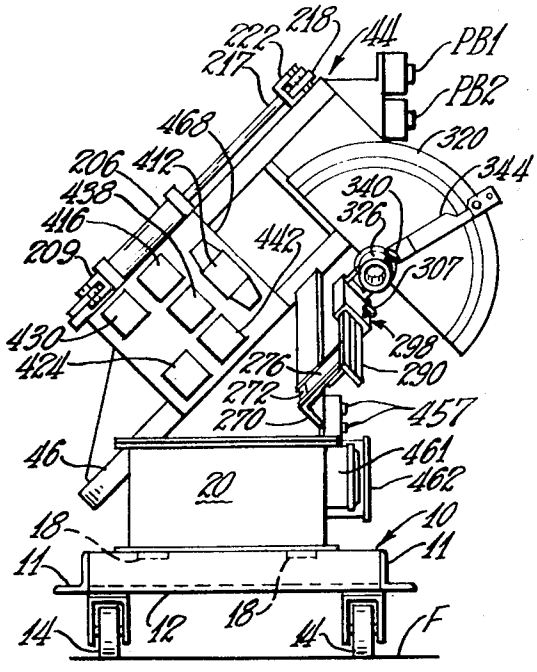


Fig. 3

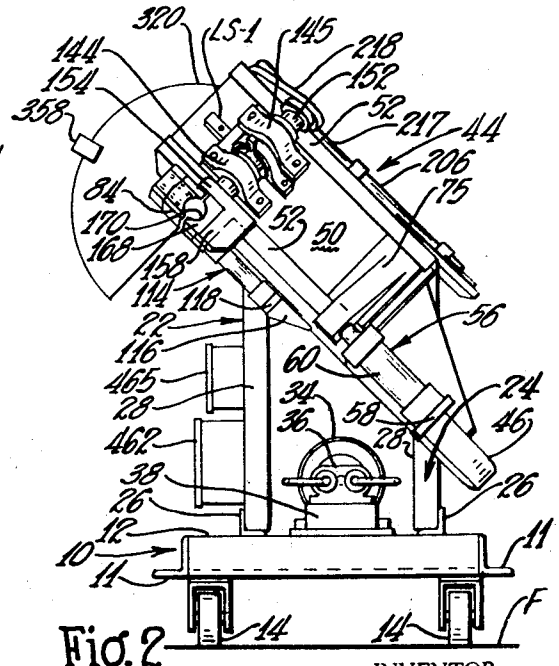


Fig. 2

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Fig. 6

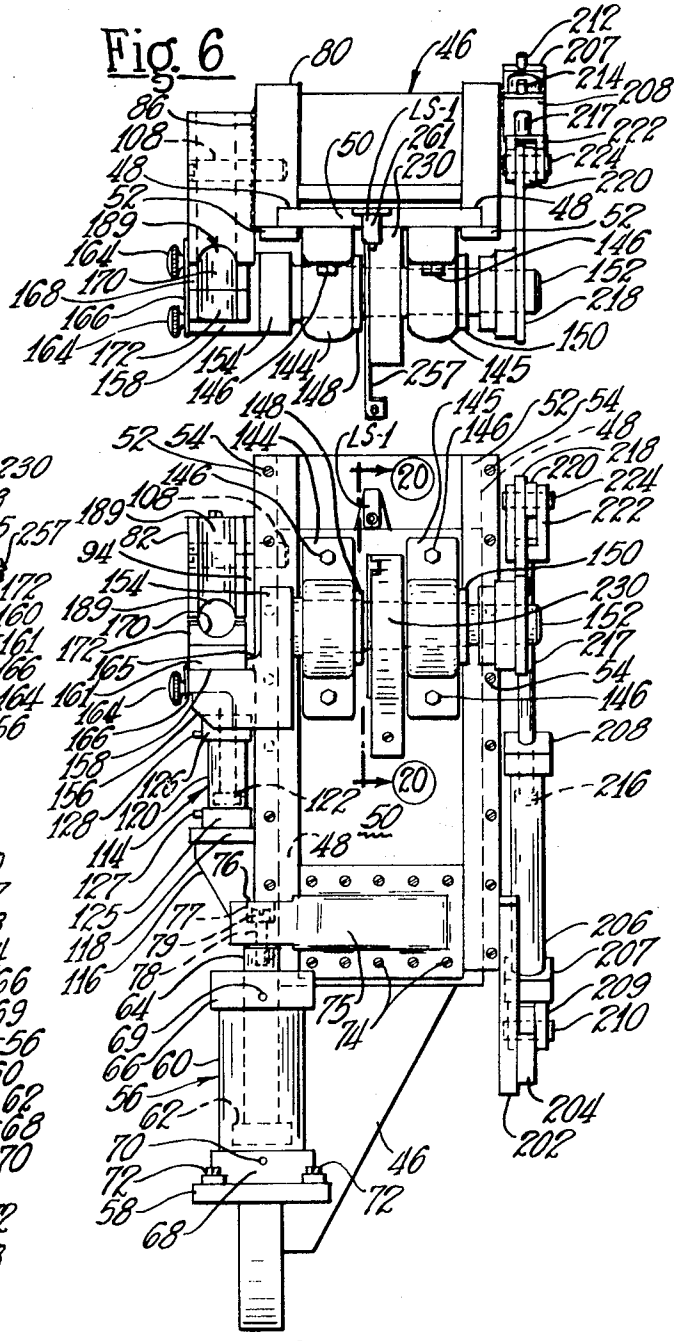


Fig. 4

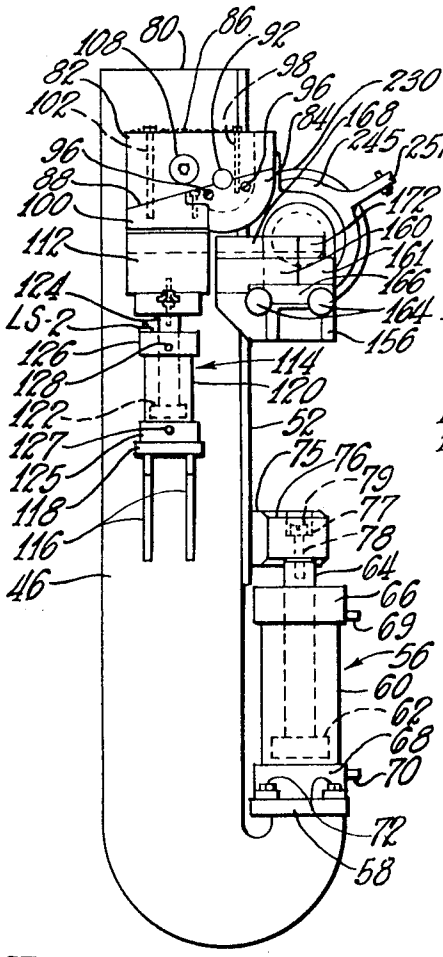


Fig. 5

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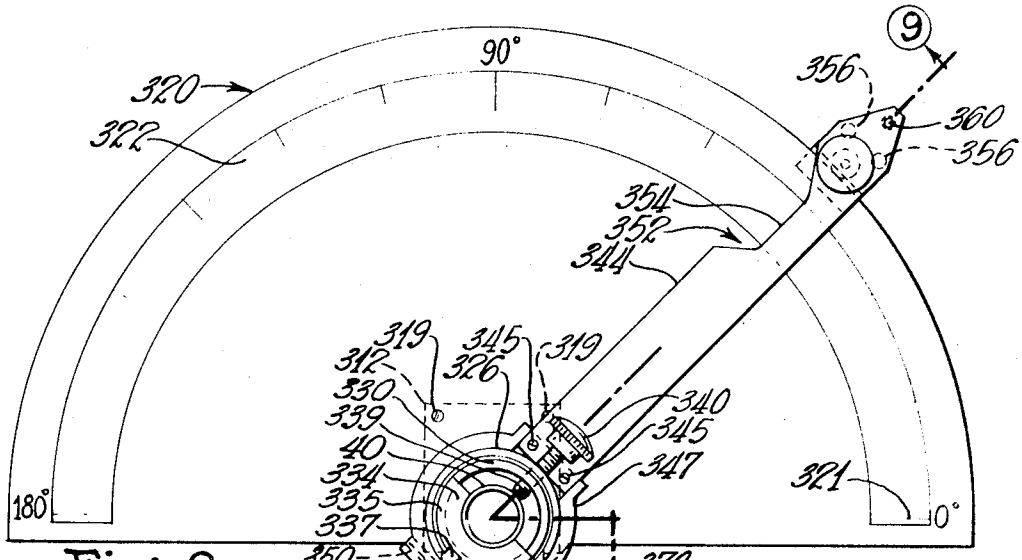


Fig. 8

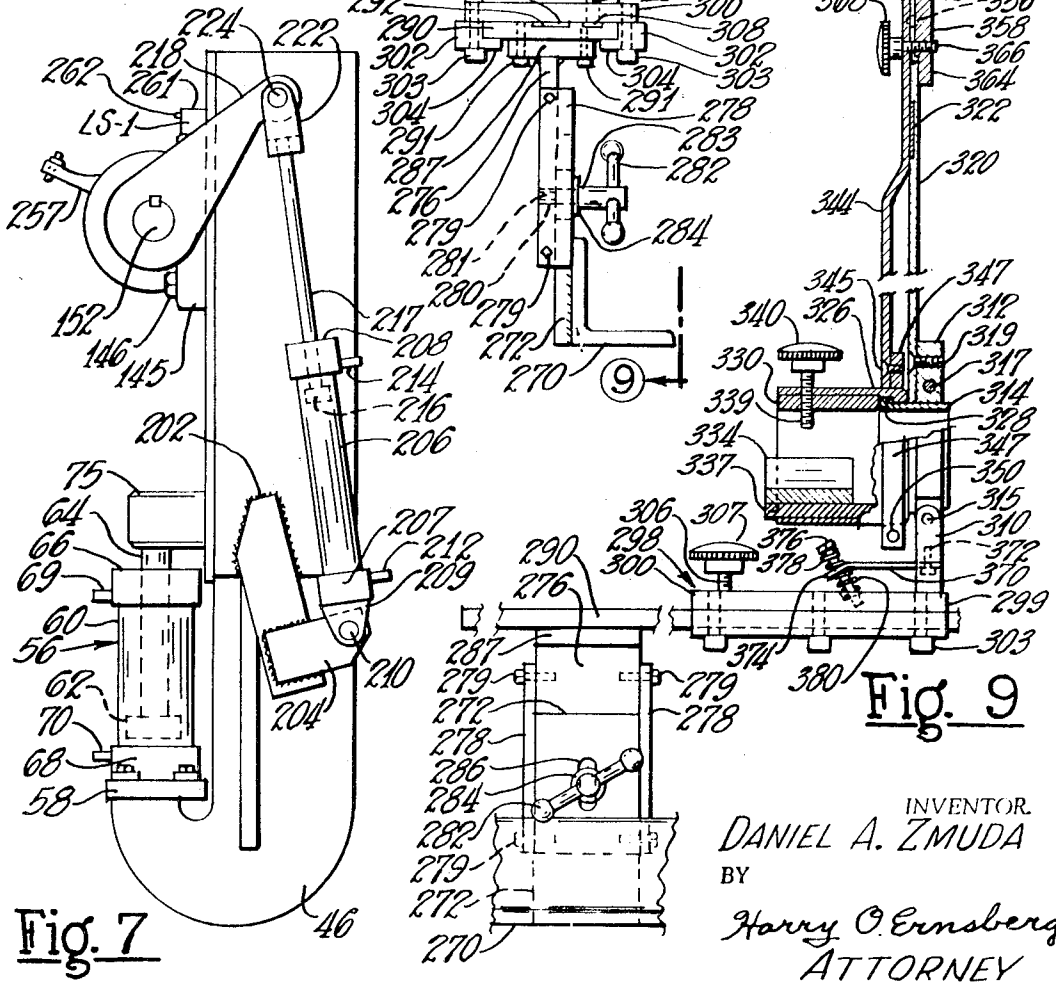


Fig. 9

Fig. 7

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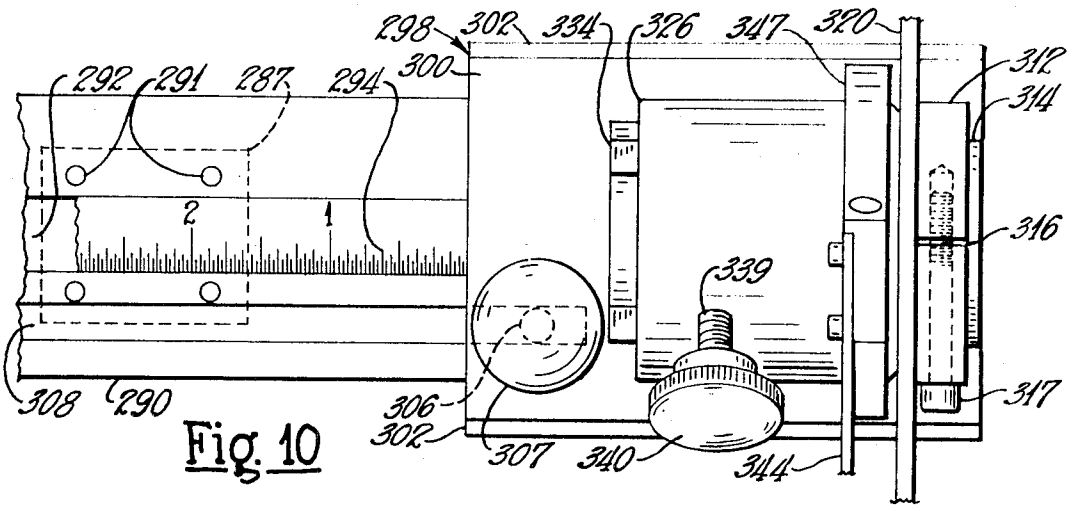


Fig. 10

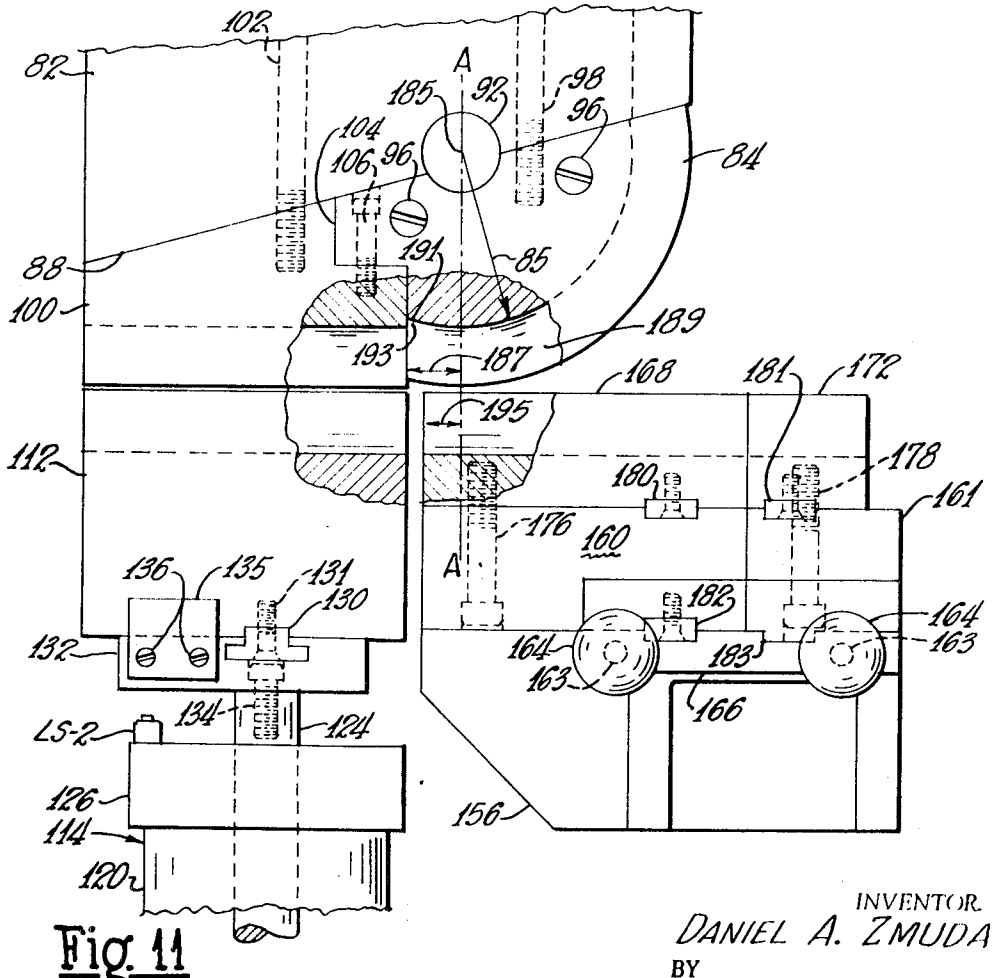


Fig. 11

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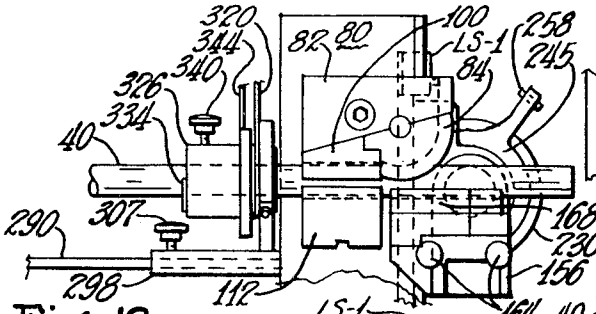


Fig. 12

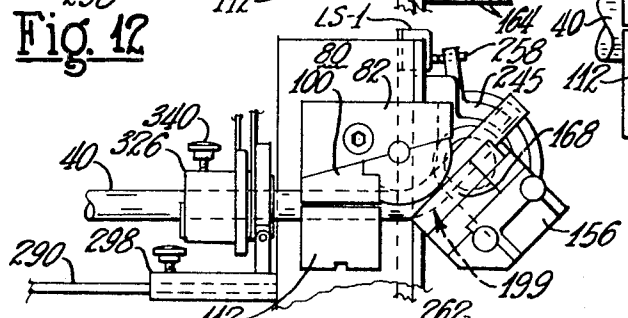


Fig. 14

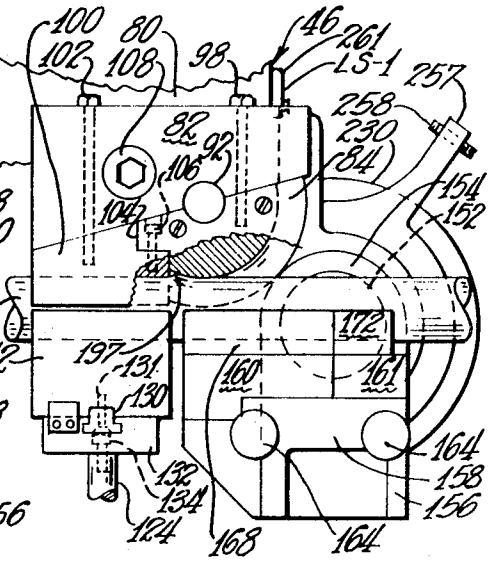


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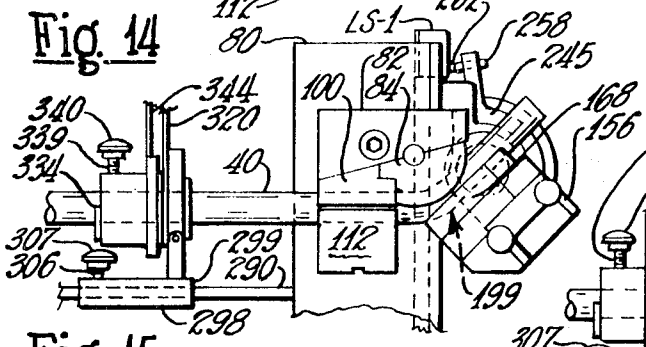


Fig. 15

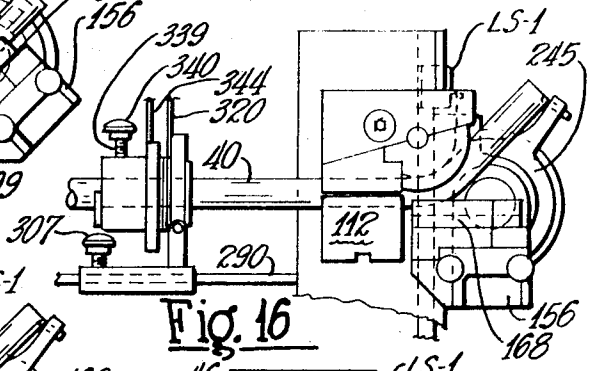


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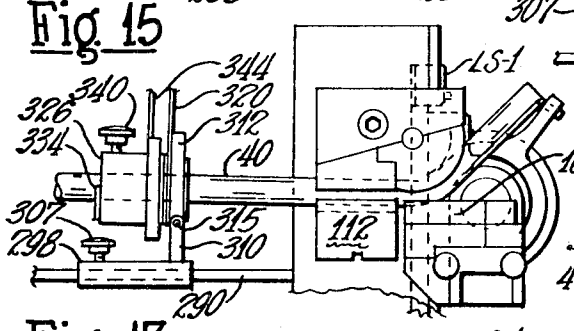


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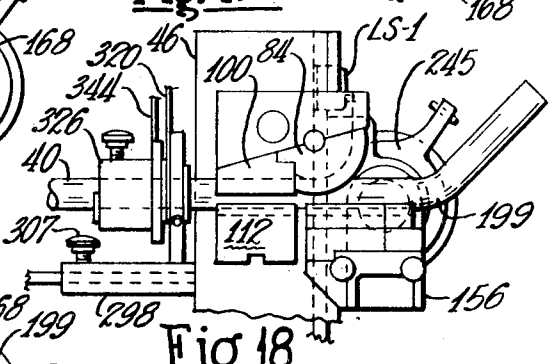


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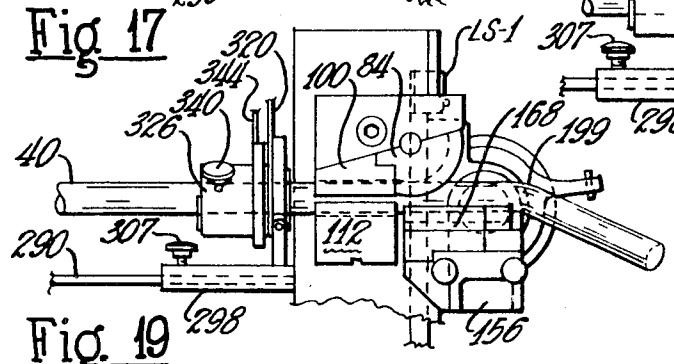


Fig. 19

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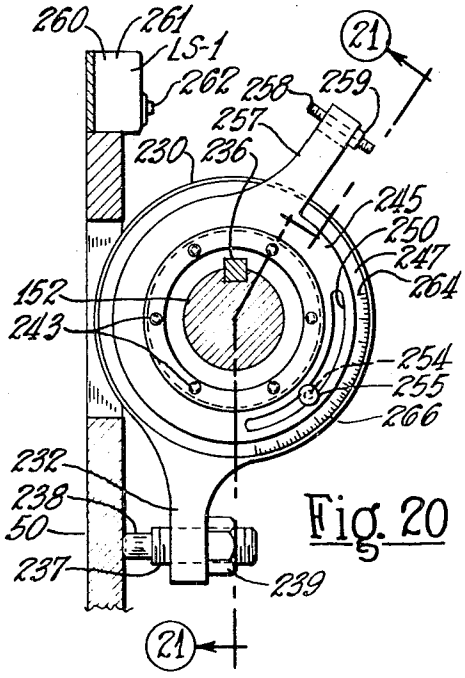


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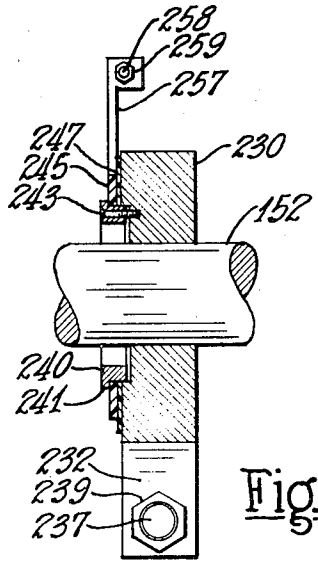


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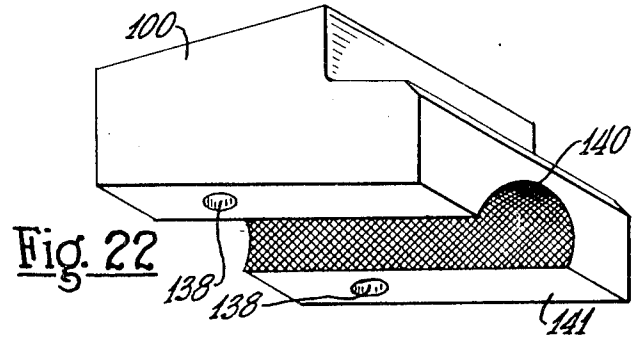


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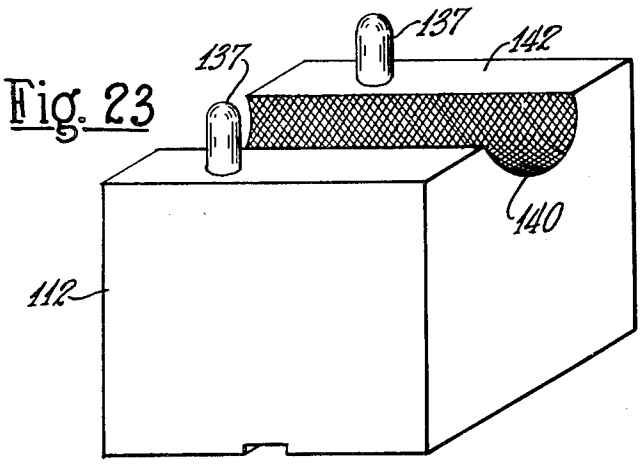


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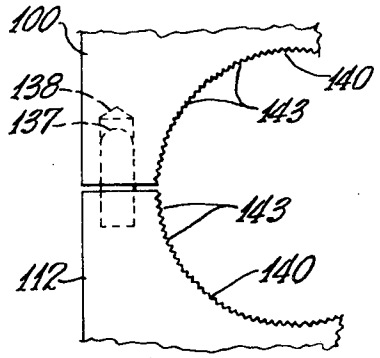


Fig. 24

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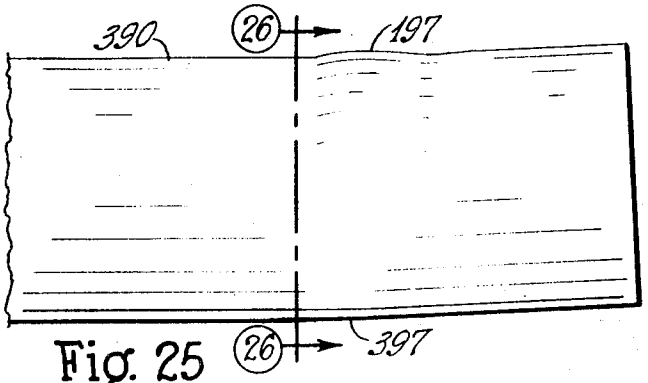


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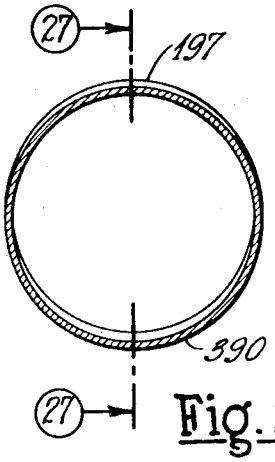


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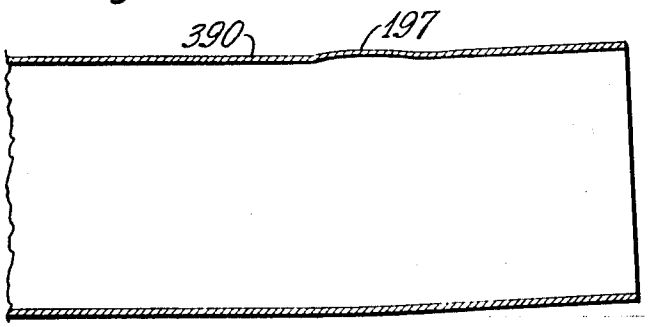


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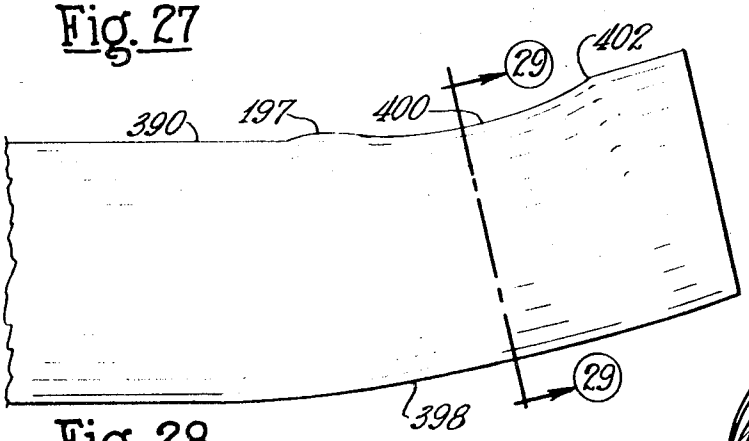


Fig. 28

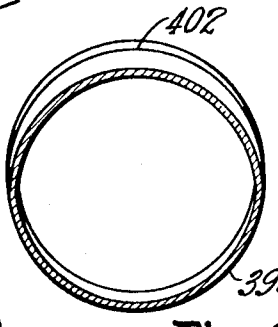


Fig. 29

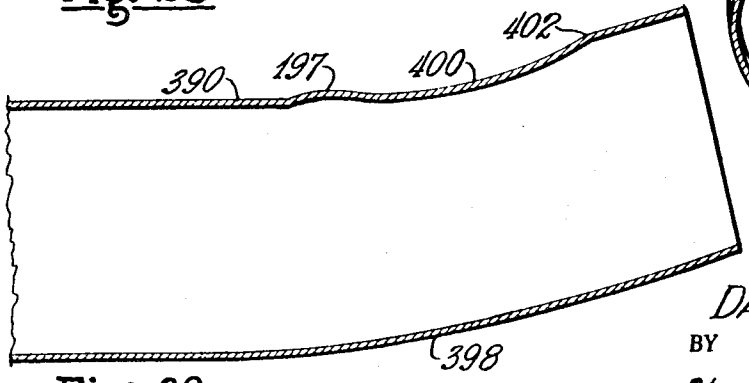


Fig. 30

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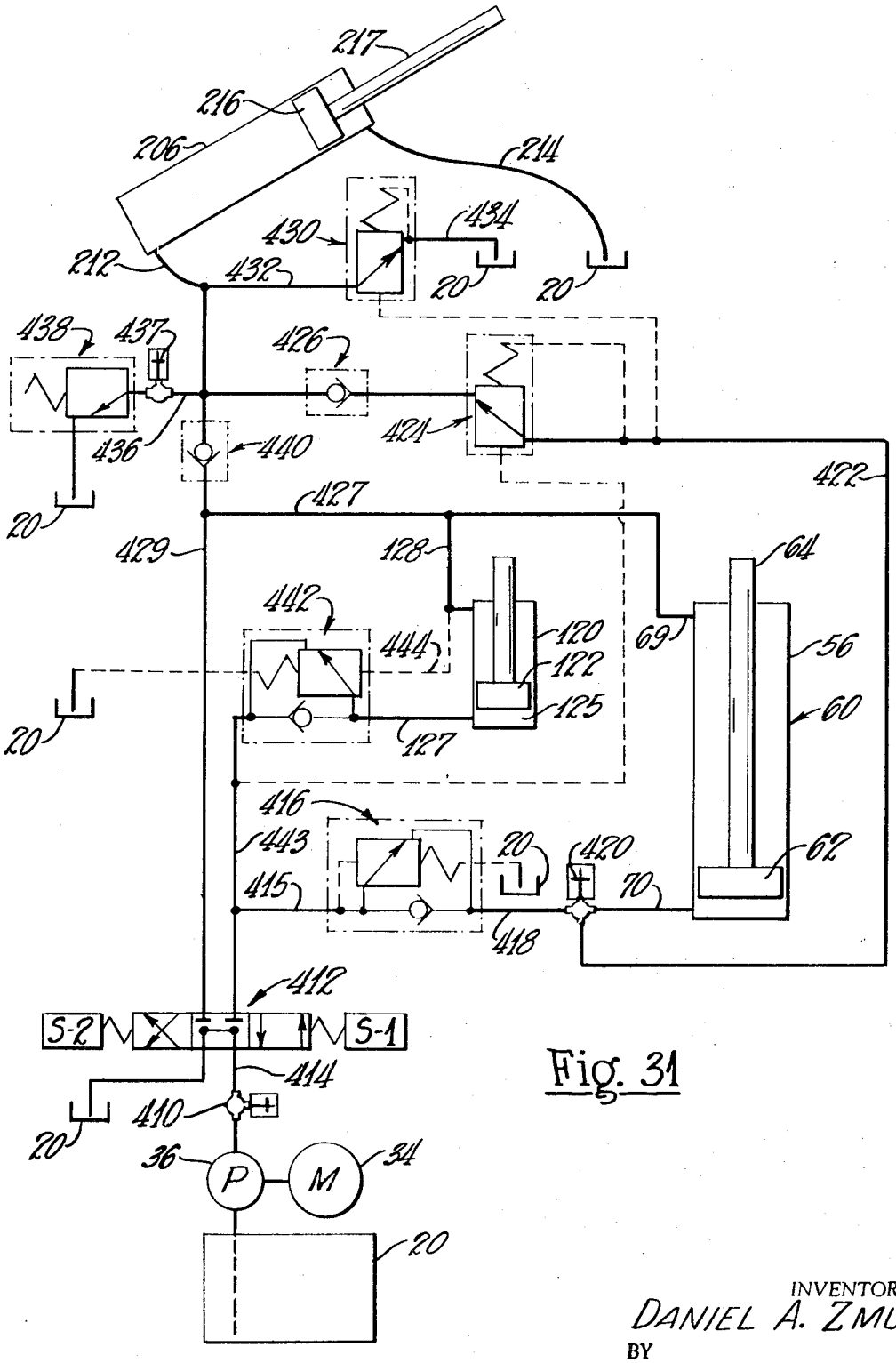


Fig. 31

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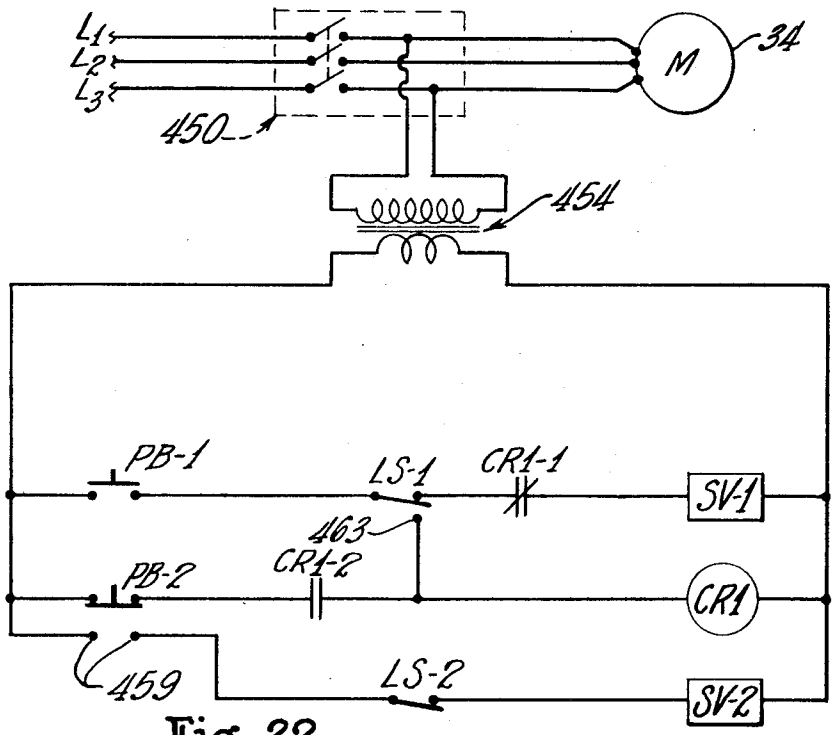


Fig. 32

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METHOD AND APPARATUS FOR BENDING TUBING

This application is a division of my copending application Ser. No. 736,317, filed June 12, 1968; U.S. Pat. No. 3,557,586.

This invention relates to a method of and apparatus for bending tubing or tubular stock and the like and more especially to a method of and apparatus for forming or impressing successive bends in exhaust pipe and during repositioning of the tubing and the performance of successive bending operations of maintaining positive control of the position of the pipe or tubular stock to assure accurate orientation of the bends in the formed tubing or exhaust pipe.

The frame or chassis construction of an automotive vehicle, and particularly automobiles of recent years having comparatively low silhouettes, embodies many cross frame members and struts in order to provide necessary strength characteristics. In order to convey the exhaust gases from the engine for discharge at the rear of the vehicle it becomes necessary to impress or form many bends of various depths and angularities in exhaust pipes or tail pipes in order to avoid interference with the vehicle frame members or struts. Exhaust pipes are usually several feet in length and must be fashioned with many bends and at varying depths and degrees of angularity. In the production of quantities of a pipe having a particular number and pattern of bends, comparatively large presses are employed equipped with a reciprocable bending die cooperating with movable bending shoes or wing dies, the reciprocating die in cooperation with the wing dies forming a bend in a pipe or tube, both regions of the pipe adjacent the bend being moved concomitantly from an initial position during a bending operation. A tube bending press of this general character is illustrated in U.S. Pat. No. 2,887,141. In order to produce successive bends in a tube on a press of this character, adjustable stops spaced from the press are arranged to be successively engaged by an end of the tube in order that the pipe or tubing embody a particular pattern of bends.

Whenever the press is adjusted to produce a pipe having a different pattern of bends therein, all of the stops must be adjusted and depth of bend abutments adjusted by the use of a master pipe or tube desired to be duplicated. By reason of the comparatively large number of models and types of automotive vehicles, each requires a pipe having a particular number and orientation of bends in order to be properly assembled with a chassis frame of a vehicle. As exhaust pipes and tail pipes are fashioned of steel, they are subjected to severe weather conditions and deterioration is comparatively rapid, usually necessitating frequent replacement. As it is uneconomical for a manufacturer of exhaust pipes to adjust or set up a press for a small number of pipes, it is a usual practice for a manufacturer of exhaust pipes and tail pipes to produce a substantial number of identical bent pipes at one setting of the press and stops or abutments. The bent pipes are then stored until sold to customers desiring the exhaust pipe or tail pipe for a particular model automobile. By reason of the large number of pipes that a manufacturer is required to carry in stock, the storage of the pipes may require several acres of covered storage space and necessitate complex inventory control, rendering the system very costly. Furthermore, distributor outlets must carry a substantial inventory of bent pipes for various models of automobiles in order to supply garages and service establishments when a particular bent pipe is needed for replacement.

Endeavors have been made to develop a method and apparatus whereby a length of tubing or pipe could be employed to effect the formation or impression of the required number of bends the proper depth and angularity to replace a particular pipe but up to the present time there has been no satisfactory method or apparatus of a character which would enable the fashioning of the proper bends in a length of pipe to duplicate a pipe for replacement without the use of highly skilled labor and at a high cost and which would not be competitive with pipes bent or fashioned in the manner hereinabove described.

The invention embraces a method of forming successive bends in a pipe, tubular member or tubular stock wherein the tubular member or tubular stock is controlled through each step of a series of method steps whereby each of the bends may be formed of desired depth and angularity and the proper distances between successive bends is assured so that the bent pipe or tubular member will accurately conform to the requirements of a particular installation where the pipe or tubular member is used.

Another object of the invention resides in a method of forming a bend in metal tubing or stock involving the steps of effecting initial flow or displacement of the metal at a local region adjacent the zone of initiation or start of the formation of a bend immediately followed by a bending operation whereby movement of the metal by the displacement step is continued in the bend formation whereby a smooth contour bend is attained.

Another object of the invention is the provision of a method of forming successive bends in straight metal tubing or tubular stock to fashion an exhaust pipe or tail pipe for an automotive installation wherein the bends are of a character to minimize reduction in cross sectional area of the pipe at the bends without the use of a mandrel.

Another object of the invention resides in a method of establishing a bend in a comparatively thin-walled metal tube wherein the metal of the tube adjacent the starting region of a bend is subjected to forces prior to a bending operation to cause initial movement or flow of the metal of a character enabling the formation of a bend without appreciably thinning the wall of the tube or collapsing the metal at the bend whereby a bend is formed of smooth contour and without effecting reduction in the strength characteristics of the metal at the region of the bend.

Another object of the invention embraces a method wherein a straight length of thin-walled metal tube, such as tubing used for exhaust pipes and tail pipes of exhaust gas systems, is successively advanced as successive bends are formed in the pipe wherein a region of the tube adjacent a bend to be formed is clamped or secured in a manner wherein stretching of the metal is held to a minimum and the bending forces applied to the tube in a manner to effect bends of different depths and wherein the tube throughout the formation of successive bends is controlled by positive means whereby the bends are accurately formed with the desired spacing between adjacent bends so that the tube configuration accurately conforms to a desired pattern of bends to assure proper installation in the position of use of the bent tube.

Another object of the invention resides in a method of forming successive bends in a rectilinear or straight length of thin-walled metal tube wherein the straight length portion is positively held in a fixed position during a bending operation and, during each advancing movement of the tube to the bending station the tube is secured against rotation, and pursuant to each advancing movement the tube is rotated by controlled means to assure accurate and proper angularity of a bend with respect to an adjacent bend and the depth of a bend controlled by adjustable means effective to interrupt movement of the bending instrumentality to attain the desired depth for each successive bend.

Another object of the invention embraces a method involving a pressure actuated instrumentality for forming a bend in tubular stock and utilizing counteracting forces in a manner whereby a bend is fashioned with a minimum of bending forces.

Another object of the invention resides in a method of forming successive bends in a straight tube disposed to accommodate the bent region of the tube without the necessity of providing a floor pit or a special clearance space for the bent pipe.

Another object of the invention embraces an apparatus or instrumentality for impressing or forming successive bends in a length of metal tubing wherein positive control is exercised of the positioning and advancing movements of the tubing in

the performance of successive bending operations to attain a finished configurated tube with successive bends of desired spacing, angularity and depth.

Another object of the invention is the provision of a bending apparatus of comparatively small and compact construction for bending thin-walled tubing such as tubing for exhaust pipes and tail pipes wherein a single bending shoe or member is employed for forming successive bends, the apparatus being of a character wherein the successive bends of substantially any depth or angularity may be formed without interference.

Another object of the invention resides in a pipe bending apparatus of comparatively small compact construction which is readily portable equipped with control devices and instrumentation rendering it adaptable for forming successive bends in a straight length of pipe wherein the bends may be of different spacing, of different depths and of different angularities enabling the production of an exhaust pipe or tail pipe particularly for replacement which accurately conforms to the original thereby assuring a proper replacement installation.

Another object of the invention resides in a portable bending apparatus for forming successive bends in a pipe whereby an unskilled operator, given the parameters for the finished bent pipe, is enabled to rapidly and accurately form a replacement exhaust pipe or tail pipe.

Another object of the invention resides in an apparatus for bending thin-walled metal tubing embodying a single bending member or wing die which is movable about a relatively fixed matrix in forming a bend and wherein the tubing adjacent the region of a bend is securely held or clamped to prevent distortion or stretching of the tubing other than at the region of the tubing in which a bend is being formed.

Another object of the invention resides in a bending apparatus embodying a single bending instrumentality for bending tubing about a relatively fixed matrix, and clamping or securing the tubing in a manner whereby the application of force to the bending instrumentality effects initial lateral displacement or distortion of the tubing at a localized region to thereby engender preliminary flow of the metal of the tube at the start of a bending operation on the tubing.

Another object is the provision of a tube bending apparatus disposed in one angular position to accommodate the pipe with a plurality of bends with ample clearance space rendering unnecessary a pit or excavation below floor level and the apparatus further arranged at a forward angle or inclination to facilitate more convenient operational access for the operator.

Another object is the provision of a small and compact bending apparatus for bending tubular stock wherein the clamping and bending components are readily interchangeable to accommodate tubular stock of various diameters.

A further object of the invention resides in a metal tube configurated with a circular cylindrical portion and an arcuately shaped portion with a region of the metal joining the portions displaced laterally and outwardly of the circular cylindrical portion.

Further objects and advantages are within the scope of this invention such as relate to the arrangement, operation and function of the related elements of the structure, to various details of construction and to combinations of parts, elements per se, and to numerous other features as will be apparent from a consideration of the specification and drawing of a form of the invention, which may be preferred, in which:

FIG. 1 is a front elevational view illustrating an embodiment of the tube bending apparatus of the invention;

FIG. 2 is an elevational view of the right-hand side of the apparatus shown in FIG. 1;

FIG. 3 is an elevational view of the left-hand side of the apparatus shown in FIG. 1;

FIG. 4 is an enlarged side view of a portion of the apparatus illustrated in FIG. 2;

FIG. 5 is a front elevational view of the apparatus shown in FIG. 4;

FIG. 6 is a top plan view of the apparatus illustrated in FIG. 4;

FIG. 7 is a rear view of the apparatus illustrated in FIG. 4;

FIG. 8 is an elevational view taken on the line 8—8 of FIG. 1;

FIG. 9 is a detail view, partly in section, the view being taken substantially on the line 9—9 of FIG. 8;

FIG. 10 is a plan view of the apparatus shown in FIG. 9;

FIG. 11 is an enlarged front view of the tube clamping and tube bending components of the apparatus;

FIG. 12 is a front elevational view similar to FIG. 11 illustrating the tube advancing carriage and the position of a tube in clamped position preparatory to making a bend in the tube;

FIG. 13 is an enlarged view of a portion of the apparatus shown in FIG. 12 illustrating the initial step of engaging the bending shoe with the tube to effect cold flow of the metal of the tube preparatory to a bending operation;

FIG. 14 illustrates the position of the tube bending shoe at the completion of a bend in the tube;

FIG. 15 illustrates a subsequent step of repositioning the carriage at the completion of a bend in the tube;

FIG. 16 illustrates the withdrawn position of the bending shoe after the completion of a bend shown in FIG. 15;

FIG. 17 illustrates the withdrawn position of the bending shoe and the tube clamping means in tube release position;

FIG. 18 illustrates the tube advanced by the carriage to a position for a subsequent bending operation;

FIG. 19 illustrates the tube rotated through a desired angle at which a subsequent bend is to be formed;

FIG. 20 is an enlarged detailed sectional view of the mechanism for determining the depth of bend in a tube, the view being taken substantially on the line 20—20 of FIG. 4;

FIG. 21 is a sectional view taken substantially on the line 21—21 of FIG. 20;

FIG. 22 is an isometric view of the stationary tube clamp section;

FIG. 23 is an isometric view of the movable tube clamp section;

FIG. 24 is an enlarged fragmentary end view of portions of the tube clamp sections illustrating the roughened tube engaging surfaces;

FIG. 25 is a side elevational view of a portion of a tube illustrating the shape of the tube established by initial cold flow of the metal of the tube preparatory to forming a bend;

FIG. 26 is a transverse sectional view through the tube, the view being taken substantially on the line 26—26 of FIG. 25;

FIG. 27 is a longitudinal sectional view through the tube, the view being taken on the section line 27—27 of FIG. 26;

FIG. 28 is an elevational view of a portion of a tube illustrating a completed bend;

FIG. 29 is a transverse sectional view taken substantially on the line 29—29 of FIG. 28;

FIG. 30 is a longitudinal sectional view of the bent tube illustrated in FIG. 28;

FIG. 31 is a schematic diagram of the hydraulic circuits and actuators for the tube bending apparatus, and

FIG. 32 is a schematic electric circuit diagram of the controls for the hydraulic actuators of the apparatus.

While the method of and apparatus for bending pipe are especially usable for impressing or forming a plurality of successive bends in a metal pipe or tube employed as a component in an exhaust gas system for an internal combustion engine, it is to be understood that the method and apparatus of the invention may be employed for bending pipe or tubular stock into various contours and configurations for any purpose where it is desired to utilize bent tubing or pipe.

The bending apparatus of the invention may be supported by any suitable frame means and in the embodiment illustrated, the tube bending apparatus is supported by a frame component preferably mounted on caster wheels for portability, or the frame may be directly mounted on a floor or other support. Referring to the drawings and initially to FIGS. 1 through 7, in the embodiment illustrated, the frame constituting the mounting means or support for the bending apparatus is inclusive of a base frame structure 10 comprising spaced parallel side members 11 preferably of L-shaped cross section joined by end members 12 of L-shaped cross section, the end

members being abutted against and welded to the side members **11** to form a generally rectangular support means.

The base frame **10** is equipped with conventional caster wheels **14** rendering the apparatus readily portable. The parallel side members **11** are joined by transversely extending struts or braces **16** and **17** preferably of L-shaped cross section and having their respective ends welded to the side members **11**. Extending between the transverse member **16** and the end member **12** are transversely spaced members **18**, shown in FIGS. **1** and **3**, the ends of the strips being welded respectively to the member **16** and the adjacent end member **12**.

The strips **18** provide a support for a tank or reservoir **20** containing fluid such as oil for operating the actuators to carry out or perform the method steps in bending pipe or tubing. Mounted upon the base construction **10** is a pair of triangularly shaped frame components **22** and **24**.

As shown in FIGS. **1** and **2**, each triangularly shaped structure includes a horizontal bar **26** preferably of L-shaped cross section, an upwardly extending member **28** which is slightly inclined from a perpendicular position as shown in FIG. **1**, and a second angularly disposed member **30**.

The lower end of the members **28** and **30** are welded to the respective ends of the horizontal member **26** in each of the frame constructions **22** and **24**. The upper end of each of the angularly disposed strut members **30** is welded as at **31** to the adjacent member **28**. Also mounted upon cross members of the base structure **10** is a motor **34** which drives a hydraulic pump **36**, the motor and pump unit being preferably mounted upon a sub-base **38** carried by and secured to the main base frame **10**.

The apparatus of the invention for impressing successive bends in tubing, tubular stock or pipe **40** is of the character whereby the operative components for forming bends in a tube or pipe **40** are so fashioned and coordinated as to provide a modular unit adapted to be mounted upon the frame structure hereinbefore described or which may be mounted or supported on frame structure of other configuration. The modular unit **44** is inclusive of a main frame member **46** which may be of cast metal and upon which is mounted the tube clamping and bending apparatus.

In the embodiment illustrated, a tube clamping means, a tube bending means and reactive force means for the tube bending means are hydraulically operated, the hydraulic actuators being supported upon the frame member **46**.

The member **46** is fashioned with lengthwise arranged parallel recesses **48** in which is slidably mounted a slide, plate or ram member **50**, the member **50** being disposed between the side walls of the recesses **48**. Plates **52** are secured by screws **54** to the portions of member **46** adjacent the recesses whereby the slide or member **50** is guided by the ways provided by the recesses **48** and the plates **52**.

A hydraulic actuator **56** is provided for reciprocating the slide or member **50** and components carried thereby. The member **46** is fashioned or configurated with an anvil portion or pad **58** upon which is mounted the hydraulic cylinder **60** of actuator **56**. Reciprocably disposed in the cylinder **60** is a piston **62** mounted on the end of a rod **64**, the latter extending exteriorly of the cylinder. The cylinder is provided with upper and lower heads **66** and **68**, tubes **69** and **70** being connected respectively with the heads for conveying fluid such as oil for actuating the piston **62**, the cylinder head **68** being fixedly secured to the pad **58** by bolts **72**.

Secured to the slide or member **50** by screws **74** is a transversely projecting member **75** having a portion **76** adjacent the end of the piston rod **64**. The end of the rod **64** abuts the lower surface of the portion **76**. The upper end of the rod **64** is bored and threaded to receive a securing bolt **78**, the head **79** of the screw being disposed in a counterbore **77** provided in the portion **76**. The upper end of the rod **64** abutting the portion **76** of member **75** effects the transmission of fluid force against the piston **62** directly through member **75** to reciprocate the slide **50** for performing tube bending operations.

As shown particularly in FIGS. **5**, **6** and **11**, there is secured to the upper end portion **80** of the frame member **46** an abutment block **82** which forms a bolster member providing support for the stationary die or matrix **84** about which a tube is to be bent in performing bending operations. The abutment or bolster block **82** is welded to the portion **80** of member **46** as indicated at **86**. The abutment block **82** is fashioned with its lower surface **88** at an angle with respect to the longitudinal axis of the frame member **46**.

The stationary die **84** is provided with an angularly arranged surface which mates with and abuts against the surface **88** as shown in FIG. **5**. A dowel **92** is pressed into a bore formed in the upper portion **80** of member **46**, the abutment block **82** and the die **84** each being formed with a portion of a circular cylindrical configuration engaging the dowel **92** for positively positioning the die **84** with respect to the abutment block **82**. The die **84** is secured to a ledge or pad portion **94** of the abutment block **82** by means of screws **96**, shown in FIGS. **5** and **11**. The die **84** is secured to the bolster or backing member by means of a bolt **98**, shown in FIGS. **5** and **11**.

Clamp means is provided for securely holding a tube adjacent a region to be bent during a bending operation. The clamp means includes a stationary section **100** shown in FIGS. **5** and **11**, which abuts against the angular surface **88** of the abutment block **82** and is secured to the block **82** by a bolt **102**.

The upper section **100** of the tube clamping means is fashioned with a recess to accommodate a projection **104** on the stationary die **84** and the overlapping portions of the section **100** and stationary die **84** are provided with aligned openings to receive a securing bolt **106**.

The abutment block **82** and the portion **80** of member **46** are provided with aligned threaded openings to receive a threaded member **108** as a further anchoring means for the abutment block **82** in addition to the welding **86**. The tube clamping means includes a relatively movable section **112**, the tube clamping sections being particularly shown in detail in FIGS. **22** and **23**. A hydraulic actuator **114** is provided for actuating the movable tube clamping section **112**, the actuating means being shown in FIGS. **1**, **2**, **4** and **5**.

Welded or otherwise secured to the member **46** are brackets or bracket means **116** upon which is mounted a platform or support member **118**. Mounted on the support member **118** is a hydraulic cylinder **120** in which is reciprocably mounted a piston **122** secured on a piston rod **124**, the cylinder being provided with end heads **125** and **126** equipped with fluid conveying tubes **127** and **128** to facilitate fluid flow into and out of the cylinder **120** for actuating the piston **122**. The means connecting the piston rod **124** with the clamping shoe **112** is particularly illustrated in FIG. **11**.

The clamping shoe **112** is provided with a transversely extending T-shaped key **130** secured to the clamping shoe **112** by a screw **131**. A member **132** disposed beneath the shoe **112** is equipped with a T-shaped slot accommodating the key **130**, this means providing for slidable assembly of the member **132** with the clamping shoe **112**. The end of the piston rod **124** abuts the lower surface of member **132**, the latter being secured to the piston rod by a bolt **134**. The tube clamping die **112** is secured against transverse movement by a plate **135** removably secured to the member **132** on the piston rod **124** by screws **136**, the plate engaging the outer surface of the clamping die. The tube clamping die sections **100** and **112** are shown respectively in FIGS. **22** and **23**.

As shown in FIGS. **22** and **23**, the upper clamp section **100** is fashioned with bores **138** and the section **112** provided with dowel pins **137** which extend into the bores **138** to properly align the clamping sections. The stationary tube clamping member **100** and the movable clamping member **112** are removably supported so that clamping members for use with various sizes of tube or pipe may be interchanged.

A feature of the tube bending apparatus is the method of clamping the tube preparatory to and during a tube bending operation. As shown in FIGS. **22** and **23**, each of the mating

clamp sections **100** and **112** is formed with a semicylindrical recess **140**, the recesses being fashioned as a cylindrical bore when the sections are mated with their surfaces **141** and **142** in engaging relation. The interior surface of each semicylindrical recess **140** is fashioned with a diamond-shaped internal knurled pattern or configuration.

The diamond-shaped pattern in the pipe clamping areas or surfaces provide a plurality of closely spaced minute projections **143** of pyramidal shape shown in FIG. **24**, the apices of the projections extending radially toward the longitudinal axis of the recesses **140** when the sections **100** and **112** are in engaging relation. When the clamp sections **100** and **112** are in tube engaging position, as shown in FIG. **24**, and pressure exerted on the section **112** against a tube, the apices or points provided by the internal diamond-shaped knurling slightly indent the exterior surface of the tube being clamped to thereby positively prevent endwise movement of the rectilinear portion of the tube during a bending operation.

The tube bending shoe or bending die means, also referred to as a wing die, is supported upon a journally mounted crank member or crankshaft carried by the reciprocable slide **50**. As shown in FIGS. **2**, **4** and **6**, bearing members **144** and **145** are secured to the reciprocable slide **50** by bolts **146**. The member **144** is equipped with a bushing or bearing sleeve **148** and the bearing member **145** equipped with a bearing sleeve or bushing **150**. Journaled in the bearing bushings **148** and **150** is a shaft or member **152**. Integral with one end of the shaft **152** is an L-shaped portion or crank **154**, the forward extending portion **156** of the crank having a platform portion **158** which supports the tube bending instrumentality, bending die or bending shoe construction.

The platform **158** supports bolster or spacer blocks **160** and **161** as shown in FIGS. **4**, **5** and **11**. Mounted upon the spacer block **160** is a tube bending body, shoe, wiper or bending die **168**. The rear surfaces of the spacer blocks seat against a ledge **165** formed on the crank member **154**. Disposed at the frontal face of the spacer blocks is a plate **166** having openings accommodating locking screws **163** having plastic manipulating heads **164**.

The bending shoe or wing die **168**, mounted on the spacer block **160**, is fashioned with a semicylindrical recess or configuration **170** to accommodate the lower half of a tube or pipe **40** during a bending operation. The bending die **168** is supplemented by a short length bending die section **172**, also having a semicylindrical recess **170**, mounted upon the short length spacer block **161** as shown in FIG. **11**. The bending shoe **168** is secured to the spacer block **160** by a screw **176** and the supplemental bending shoe section **172** secured to the short length spacer **161** by a screw **178**. Keys **180** and **181** position the bending shoes **168** and **172** with respect to the spacer blocks **160** and **161**.

A key **182** positions the spacer block **160** with respect to the ledge **156** of the crank member **154**. A tongue or key portion **183** on the supplemental spacer block **161** fits in a key way in the upper surface of the ledge **156** to position the block **161** with respect to the ledge. By tightening the screws **163**, the plate **166** is brought into snug engagement with the frontal surfaces of the spacer blocks **160** and **161** to hold the blocks and the bending shoes **168** and **172** in fixed relation on the ledge portion **156** of the crank **154**.

The spacer blocks **160** and **161** are made removable in order to utilize bending shoes for pipes of different diameters, each pipe requiring a particular thickness of spacer blocks **160** and **161**. The bending shoe construction or wing die section **168** is used in conjunction with the supplemental or short length bending shoe section **172** in impressing usual type bends in pipe or tubular stock.

In instances where successive bends are close together and project in different directions radially from the axis of the rectilinear tube stock, the supplemental bending shoe section **172** of the bending shoe construction and the spacer block **161** may be quickly and easily removed by backing off the clamping screws **163**. Thus successive bends in close relation may be fashioned by the bending shoe section or die **168** by temporarily removing the short length bending shoe section **172**. The die section **172** should normally be used in forming bends particularly those which are of substantial depth, the supplemental die **172** providing additional surface area of the bending shoe construction for engagement with the tube or pipe being bent. The bending shoes or dies **168** and **172** are preferably made of brass to assure long life.

As shown in FIG. **11**, there is an important relationship between the center **185** of the generatrix of the root or bottom of the curve or radius **85** of the semicircular recess **189** of the stationary die **84**, the bending shoe **168** and the clamping die **100**.

As shown in FIG. **11**, a plane A—A, normal to the axis of a tube in clamped position between the clamping dies **100** and **112** and passing through the center of curvature of the die **84** is about three-fourths of an inch from the end of the clamping die **100**. This distance is indicated by the line **187**. The radius or generatrix **85** of the root or bottom of the semicircular recess or groove **189** in the curved die **84** is continued to the left of the plane A—A as viewed in FIG. **11** at the region **191** forming a generally triangular space or pocket **193** as particularly shown in FIG. **11**.

The adjacent end region of the bending shoe **168** preferably extends toward the clamping die **100**, an approximate distance to the left of the plane A—A indicated by the line **195** which overlaps a portion of the space **193**, the extending portion indicated at **195** of the bending shoe **168** being of assistance in forcing metal of the tube or pipe to be bent into the triangular pocket or space **193**.

The purpose of the space or recess **193** is to provide a region into which the metal of the tube or pipe is initially moved or cold flowed upon initial engagement of the bending shoe or wing die **168** with the tube, this condition being shown in FIG. **13**, the displaced or laterally moved metal of the tube being indicated at **197** in FIGS. **13** and **25** through **30**. The metal at the region **197** is forced into the generally triangular space **193** upon upward movement and engagement of the bending shoe **168** with the tube or pipe to be bent.

The pressure or force of initial engagement of the bending shoe **168** with the pipe initiates or starts lateral movement or flow of the metal of the pipe into the space **193** before the start of a bending movement of the bending shoe **168**.

The preforming or initial movement of the metal into the space **193** at this localized region before a bend is initiated is important in the formation of a bend as such initial flow or movement of the metal of the tube at the region of the start of a bend has already begun. Concomitantly with the establishment of initial flow of the metal into the space **193**, continued upward pressure of the bending shoe **168** starts the formation of a bend, the bending shoe **168** rotating about the axis of the crankshaft **152**.

As the crankshaft **152** is journaled on the slide **50**, upward movement of the slide **50** effects a wrapping or wiping of the bending shoe **168** about the periphery of the fixed bending die or matrix **84** to form a bend in the pipe **40** as shown in FIG. **14**. The preflowing of the metal into the space **193** is effective in fashioning a smooth bend in the pipe or tube **40** without any wrinkles or any collapsing of the tube at the interior radius of the bend. It is believed that certain novel factors are operative in forming a smooth bend.

The clamping jaws **100** and **112** exert a gripping force on the pipe or tube **40** to an extent that during the forcing of the metal of the tube into the space **193** and during the succeeding bending operation the region of the pipe held by the clamping jaws **100** and **112** is not appreciably stretched so that during bending, the metal is flowed around the semicircular configuration of the stationary bending die **84**.

The forcing of the metal of the tube into the space **193** provides the raised or laterally extending portion **197** of the tube disposed in the space **193**, and this portion **197** of the tube provides an anchor means which is effective to resist stretching of the region of the tube gripped by the clamping means **100** and **112** during the formation of a bend.

To insure the proper bending of the tube or pipe by the wrapping action or bending action of the movable bending shoe or body **168** about the tube in bending the tube around the stationary die **84**, it is necessary to provide the wiping shoe **168** with a backing pressure or reaction force during rotational movement of the bending shoe **168**. The backing pressure should be substantially constant during a bending operation and of substantially lesser pressure than the pressure exerted on the bending shoe in a pipe bending direction.

In the embodiment illustrated, the backing force or pressure is provided by hydraulic pressure in a cylinder in conjunction with a pressure relief means to meter or bleed liquid out of the cylinder to maintain substantially constant the reaction or backing pressure resisting rotation of the bending shoe **168**. An arrangement for accomplishing this function is illustrated in FIGS. **2**, **3**, **4**, **6** and **7**. As shown in FIG. **7**, a member **202** is welded or otherwise secured to the main frame member **46**, the member **202** supporting a bracket or abutment **204** welded thereto.

A cylinder **206** is provided with end heads **207** and **208**, the end head **207** being fashioned with a clevis or bifurcated portion **209** which straddles the bracket **204**. The clevis portion **209** and the bracket **204** are provided with aligned openings accommodating a pivot pin **210**. The heads **207** and **208** are provided respectively with liquid conveying tubes **212** and **214** for conveying liquid into and out of the ends of the cylinder **206**. Reciprocably disposed within the cylinder **206** is a piston **216** mounted on a piston rod **217** which extends through the end head **208**.

Fixedly keyed onto an end region of the shaft **152** is an arm or member **218**, to the distal end region of which is welded a plate **220**. Mounted upon the upper end of the rod **217** is a clevis **222** which straddles the arm **218** and the plate **220**. The arm **218**, plate **220** and clevis **222** are provided with aligned openings to accommodate a pivot pin **224**.

Through this arrangement liquid, in the cylinder **206** resists rotation of the tube bending shoe **168** in a tube bending direction. As hereinafter described the flow of liquid from cylinder **206** is metered or controlled by a pressure relief valve so as to maintain sufficient and constant backing pressure on the shaft **152** resisting but not preventing rotation of the bending shoe **168**.

A method and means are provided for regulating or adjusting the angular extent or depth of a bend being formed in a tube or pipe. One form of arrangement for accomplishing this function is shown in FIGS. **1**, **2**, **5**, **6**, **7**, and **12** through **21**.

The arrangement is inclusive of an adjustable protractor associated with and adjustable relative to the shaft **152**. Mounted upon and rotatable with the shaft **152** is a member **230** fashioned with an arm or projection **232**, shown in FIGS. **20** and **21**. The member **230** is fixed to the shaft **152** by a key **236** to rotate with the shaft.

The arm **232** is provided with a threaded bore to receive a threaded member **237** having an abutment portion **238** and provided with a nut **239**. As shown in FIG. **20**, the abutment **238** engages the slide **50** limiting rotation of the shaft **152** and determining a nonbending position of the bending shoe or wing die **168**.

As shown in FIGS. **20** and **21**, there is mounted on member **230** an annulus or ring **240** having a flange **241**, the ring **240** being secured to member **230** by a plurality of circumferentially spaced screws **243**. Mounted on the exterior periphery of the ring **240** for rotative adjustment relative to the member **230** is a member **245** which is preferably fashioned of molded resinous material such as Lucite. Cemented to member **245** is a protractor scale **247** whereby members **245** and **247** rotate as a unit relative to the ring **240** and member **230**, a flange **241** on the ring **240** preventing lateral displacement of members **245** and **247**.

As shown in FIG. **20** the members **245** and **247** are fashioned with registering arcuately shaped slots **250**, the curvature of the slots **250** being concentric with the axis of shaft **152**. The member **230** is fashioned with a threaded bore accommodating a locking screw **254** having a knurled head **255**.

The screw **254** may be manipulated so that when released, the members **245** and **247** may be rotated relative to member **230** and, upon tightening the screw **254** the members **245** and **247** will be locked to and rotatable with the member **230**.

During the formation of a bend the shaft **152** is rotated and member **245** is rotated therewith. Mounted on a projection **257** of the member **245** is an adjustable abutment screw **258** which may be locked in adjusted position by a nut **259**. As shown in FIG. **20**, a housing **260** is secured to the slide **50**, the housing **260** enclosing a limit switch LS–1. The switch LS–1 is inclusive of a movable switch plunger **262**. As hereinafter described, the limit switch LS–1 is in circuit with a solenoid of a four-way valve arranged to direct fluid into the hydraulic actuator **56** for the bending shoe **168**.

During the formation of a bend, the members **230** and **245** are rotated in a counterclockwise direction, as viewed in FIG. **20**, and when the abutment screw **258** engages the plunger **262** of the limit switch LS–1, a second solenoid of the four-way valve is actuated to interrupt the movement of the bending shoe, this arrangement determining the depth of bend formed in a tube. By adjusting the member **245** with respect to the member **230** bends of various depths may be formed in the pipe or tubing.

The member **247** is calibrated with indicia **264** indicating degrees of angular adjustment of the member **245** with respect to the member **230**. The member **230** is fashioned with a zero angle index line **266** with which the protractor graduations cooperate to determine the angularity of a bend to be made in the pipe or tube.

In forming a bend, the member **245** is preadjusted to the particular angularity of the bend desired in the pipe or tube. A bend is fashioned by wrapping or forming the adjacent portion of a tube or pipe about the stationary die **84** by the wing die or wiper shoe **168**, and the forming operation continues until the abutment screw **258** engages the plunger **262** of limit switch **261** and terminate the bending cycle. Where successive bends of different angularities are to be formed, the operator, after each bend, releases the locking screw **254** and readjusts the member **245** to the angularity desired and draws up the screw **254** to lock the member **245** to the member **230**, thereby predetermining the angularity or depth for the next succeeding bend to be made.

The apparatus is inclusive of means for maintaining accurate and positive control of the position of the pipe and for indexing the length of pipe between successive bends whereby the finished pipe will accurately conform in shape to a predetermined configuration or shape. The control means is inclusive of an arrangement for clamping the pipe to prevent uncontrolled movement thereof, means for controllably rotating the pipe to predetermine the direction of angularity of a bend to be formed in a pipe, and means for advancing the pipe through a predetermined distance to position the pipe preparatory to the formation of a bend.

Referring to FIGS. **1**, **3**, **8** and **9**, a member **270** is secured to the frame **46** by welding, the member **270** being preferably of L-shaped cross section as shown in FIG. **3**. Welded to the L-shaped member **270** is an upwardly extending member or plate **272**.

Mounted for slidable movement vertically and disposed contiguous with the plate **272** is an adjustable slide or plate **276**. Disposed at the edges of the plate **276** are members or guides **278** fastened to plate **276** by screws **279**.

As shown in FIGS. **8** and **9** the members **278** are parallel and the plate **276** is slidable vertically between members **278**. The plate **276** is fashioned with a threaded opening **280** to accommodate a threaded locking member or screw **281** to which is secured a manipulating handle **282**, the manipulating portion of the handle having a shoulder **283** engaging a washer **284**. The plate **272** is fashioned with a slot **286**, the side walls of the slot being parallel with the edge plates **278**. By manipulating the handle **282**, the plate **276** may be adjusted vertically relative to the plate **272** and the plate **276** locked in adjusted position by the screw **281**.

Welded to the upper end of the plate **276** is a platform member **287**. Supported upon the platform **287** is a longitudinally extending member, carriage support or track **290**. The carriage support **290** is secured to the platform member **287** by screws **291**. As shown in FIG. **10**, the upper surface of member **290** is fashioned with a longitudinal recess **292** extending lengthwise in which is disposed a strip of metal or plastic **294** bearing graduations or indicia which may be in inches or other means for indicating the relative position of a carriage.

Slidably supported upon the member or track **290** is a carriage **298**. The carriage is inclusive of a flat plate **300** extending lengthwise of the track or member **290**. Disposed at the lengthwise edge regions of the plate **300** are parallel members **302** secured to the plate by screws **303**. The members **302** have projections **304** underlying the edge regions of the plate **290**, the members providing ways whereby the carriage **298** is slidable lengthwise of the track member **290**. The plate **300** is provided with a threaded bore accommodating a screw **306** having a plastic manipulating head **307** shown in FIGS. **8**, **9** and **10**.

As shown in FIGS. **8** and **10**, the upper surface of member **290** is fashioned with a longitudinal shallow recess **308**, the locking screw **306** being aligned with the groove or recess **308**. When it is desired to lock the carriage to the track **290**, the screw **306** is drawn up to engage with the bottom of the recess **308**. Fixedly secured to the carriage **298** is a U-shaped bracket **310** and mounted between the furcations of the bracket **310** is a member **312** which has a central bore accommodating a tubular sleeve or bushing **314**, shown in FIG. **9**.

The upper portion of the member **312** is split as at **316**, shown in FIG. **10**, and a bolt **317** is employed to clamp the member **312** tightly to the sleeve **314**. The member **312** is pivotally supported upon the U-shaped bracket **310** by a bolt of shaft **315**. Secured to member **312** by screws **319** is a protractor or semicircularly shaped member **320** which has a scale **322** graduated in degrees, the scale illustrated being graduated for 180°.

Means is provided for rotating the tube or tubular stock **40** to predetermine the radial angularity of a bend with respect to the angularity of the preceding bend. Journally supported upon the sleeve or bushing **314** is a hollow cylindrical member **326**, shown in FIG. **9**. The cylindrical member **326** has a portion engaging over a flange **328** on the sleeve **314**. Snugly fitted within the sleeve or cylindrical member **326** is a ring or cylindrical member **330** engaging the flange **328** whereby the cylindrical member **326** is rotatable relative to the sleeve **314** but is secured against endwise movement by the ring **330**.

The inside diameter of the sleeve **314** and the ring **330** is such as to accommodate the tubing or tubular stock of largest diameter to be bent by the bending apparatus. Removable means is provided for insertion in the ring **330** to accommodate tubular stock of different diameters, said means cooperating with a locking element to lock the tubing or tubular stock in a position with the axis of the tubing or tubular stock coincident with the axis of the sleeve or bushing **314**. As shown in FIG. **8**, there is disposed within the ring **330** a semicylindrically shaped sleeve or member **334** having an interior diameter of a dimension to fit a particular diameter of tube.

The semicylindrical member **334** has a flange **335** which is notched to accommodate a projection **337** on the ring **330** so as to position the member **334** against rotational movement in the ring **330**.

The cylindrical member **326** and the ring **330** are fashioned with registering threaded openings to receive a locking screw **339** equipped with a plastic manipulating knob **340**. As shown in FIG. **8**, the screw **339** may be drawn into locking engagement with the tube **40** which is centered and supported by the bushing member **334**.

When a different size of tubing or pipe is to be accommodated, the bushing **334** is removed and a similar bushing of different internal diameter inserted in the ring **330** so that the axis of the tube or pipe will be coincident with the axis of the cylindrical sleeve **314**.

A lever or arm **344** is provided which cooperates with the protractor member **320** and the rotatable sleeve or bushing **326** for rotating the tubing or pipe to predetermine the angularity of a bend to be formed in respect of the relative position of a preceding bend in the tubing or pipe. This arrangement is illustrated in FIGS. **1** through **3**, **8** and **9**. The lever or arm **344** is secured by screws **345** to an annular or ring-shaped member **347**.

The annularly shaped member **347** is split as at **348**, the two boss portions adjacent the split or kerf **348** fashioned on the ring **347** accommodating a bolt **350** for clamping the annular member **347** to the sleeve **326** whereby movement of the arm **344** rotates the sleeve **326**. The lever or arm **344** is fashioned with a recess **352** providing an index surface **354** preferably at the central longitudinal axis of the lever **344**, the surface **354** providing a movable index for cooperation with the degree indicia **322** on the protractor member **320**.

Means is provided readily for securing or locking the lever **344** in adjusted position relative to the protractor member **320**. The upper end region of the lever **344** is fashioned with two shallow recesses to accommodate spherical members or balls **356**. Disposed adjacent the upper end region of the lever **344** is a plate or member **358**, the plate having detents to accommodate the balls **356**, as shown in FIG. **9**. The balls **356** provide a fulcrum means to accommodate slight rocking or tilting movement of the plate **358** with respect to the lever **344**.

The upper extremity of the lever or arm **344** is provided with a threaded bore accommodating a threaded member or screw **360**, the member **360** extending through an unthreaded bore in the plate **358**. The screw **360** is provided with a knurled head **362**, an expensive coil spring **363** being disposed between the plate **358** and the knurled head **362**. A portion **364** of the plate **358** overlaps and is contiguous with the peripheral arcuate region of the protractor member **320**, as shown in FIG. **9**. A locking screw **366** extends through an opening in the lever **344** into a threaded bore in the plate **358**, the screw **366** being equipped with a plastic manipulating knob **368**.

By releasing the locking screw **366**, the spring **363** swings the plate **358** about the fulcrum means provided by the balls **356** to release the lever **344** from locking engagement with the protractor member **320** to facilitate rotation of the lever **344** with respect to the protractor member **320** and thereby rotate the tube or pipe **40** which is locked to the sleeve **326** by the locking screw **339**. The method steps performed by the arrangement shown in FIGS. **8** and **9** will be hereinafter described.

As shown in FIG. **9**, an arm **370** is secured to the lower portion of the member **312** by screws **372**. The angularly disposed end region **374** of arm **370** is bored to accommodate a bolt **376** which is threaded into an opening in the plate **300** of the carriage. Disposed between the head of the bolt and the portion **374** is a coil spring **378** and disposed between the plate **300** and the portion **374** is a coil spring or other resilient member **380**. The member **380** may be semi-hard rubber.

The coil springs **378** and **380** provide a resilient cushioning means for the member **312**, the protractor member **320**, the sleeve **326** and the lever **344** and associated components. In the event that the pipe **40** tends to stick or adhere to the clamping dies **100** and **112** and requires manually applied lateral force or impact to loosen it, the assembly comprising member **312**, sleeves **314** and **326**, bushing **334** and associated components is arranged for slight pivotal movement about the pivot pin **315** as restricted by the resilient means **378** and **380** to prevent damage to these components without disturbing the locking of the pipe **40** by the screw **339** so that there is no loss of control of the position of the pipe **40**.

The method and apparatus of the invention are particularly adaptable for impressing successive bends in pipe, tubing or tubular stock for use as exhaust pipe for the exhaust system of

an automotive engine. Where the pipe or tubing is for fashioning exhaust pipes for exhaust systems for various types of internal combustion engines, different diameters of stock may be used as, for example, 1¾ inch diameter, 2 inch diameter, 2¼ inch diameter and other sizes where required.

As shown in FIG. **1**, a length of pipe, tubing or tubular stock **40** is normally rectilinear as shown at the left-hand side of the bending apparatus, as viewed in FIG. **1**, the portion of the pipe at the right-hand side of the apparatus having been formed into bends identified at **391, 392, 393** and **394**. Tubular stock of any length may be used and bends of various depths and angularities may be formed with different distances between successive bends.

FIGS. **25** through **30** illustrate actual contours or configurations of a metal tube in initiating and completing a bend in the tube. The portion of the tube **40**, shown in FIG. **25** illustrates at **197** the lateral displacement, distortion or cold flow of the metal at a localized region of the tube effected by initial engagement of the bending shoe **168** with the tube which forces the metal, shown at **197** in FIG. **13** into the space **193** shown in FIG. **11**. FIGS. **26** and **27** illustrate the cross sectional shape of the tube portion shown in FIG. **22**.

Thus, the metal **197** at a localized region of the tubing is caused to move or flow immediately preceding or concomitantly with the start of a bending operation which movement or flow of the metal is continued without interruption by rotation of the bending shoe **168**. The rectilinear portion of the tube **40** at the left of the displaced metal **197** is tightly clamped by the clamping dies or jaws **100** and **112**.

The force or impact of the bending shoe or wing die **168** engaging the region **397** of the tube diametrically opposite the region of the displaced portion **197** causes a slight upward inclination of the unclamped portion of the pipe or tube **40** at the right of the displaced metal **197** so that flow or movement of the metal at both regions **197** and **397** has begun at the start of bending operation.

The initial movement or cold flowing of the metal at the region of the start of a bend is an important factor in successfully impressing a bend in the pipe or tubing without collapsing of the metal at the bend so that a smooth bending contour is attained.

FIGS. **28** through **30** illustrate the contour of a completed bend in the pipe or tubing **40**, the bend being of lesser depth than that shown in FIGS. **14** through **19**. During a bending operation the wiper shoe or wing die **168** engages the region **398** of the tube and as the bending shoe rotates, it forces the upper region **400** of the tube into the curvature of the stationary matrix or die **84** to form the bend in the pipe. The completion of the bend is at the region **402** at which zone rotation of the bending shoe **168** has been interrupted.

It should be noted that the diameter of the pipe at the region of the bend **400** is slightly reduced due to the stretching of the metal by the action of the bending shoe on the region **398**. As the rectilinear portion of the pipe **40** is tightly gripped between the clamping dies or jaws **100** and **112**, shown in FIGS. **22** and **23**, there is no appreciable stretching of the metal of the tube contained within the clamping dies **100** and **112**.

From FIGS. **28** through **30** it will be seen that the bend is of smooth contour without any wrinkles. The bending is accomplished without the use of a mandrel with only a very small reduction in the cross sectional area of the pipe at the bend **400** as compared with the cross sectional area of the rectilinear portion of the pipe **40**. Thus a novel configuration of metal tube is produced embodying a circular cylindrical portion and an arcuately shaped portion with a region of the metal of the tube joining the portions displaced laterally and outwardly of the circular cylindrical portion.

FIG. **31** is a schematic diagram of the hydraulic lines, actuators, sequence valves and other operating components of the hydraulic system for effecting tube clamping and tube bending operations. The oil reservoir or oil supply tank **20** is illustrated schematically at several points in FIG. **31** to simplify the diagram. The hydraulic system includes, in addition to the oil supply tank or reservoir **20**, a motor **34** driving a hydraulic or oil pump **36** for developing fluid pressure. A pressure gauge **410** may be intercalated with the outlet line of the pump **36**.

A conventional Vickers solenoid-operated four-way valve **412** is connected with the metering valve by a fluid line **414**. A fluid line **415** is connected with the four-way valve **412** and a first sequence valve **416**. A fluid line **418** is connected with the sequence valve **416** and a pressure gauge **420**, the latter being connected by a line **70** with the lower end of the cylinder **60** of the actuator **56** which actuates the bending shoes **168** and **172**.

The fluid line **418** is connected by a fluid line **422** through a second sequence valve **424** and check valve **426** and fluid line **212** with the lower end of the cushion or reaction cylinder **206**, the other end of the cylinder **206** having an outlet or return fluid line **214** to the oil supply **20**. A third sequence valve **430** controls hydraulic reaction pressure on the piston **216** which relieves the pressure above a predetermined value whereby the oil flows out of the cylinder **206** to the reservoir **20** through the fluid lines **432** and **434**.

The fluid pressure line **436** has a pressure relief valve **438** which is set to normally relieve the pressure when the pressure reaches a predetermined value in the fluid line **436**. A pressure gauge **437** is intercalated in the fluid line **436**. A check valve **440** is connected in the fluid line **436** as shown. Fluid is supplied to a fourth sequence valve **422** through a fluid line **443** and from the sequence valve **442** to the lower end **125** of the clamping cylinder **120** through a fluid line **127** beneath the piston **122**.

The upper end of the cylinder **120** has an outlet line **128** for returning fluid from the upper end of the clamping cylinder to the oil supply **20**. The piston in the clamp cylinder **120** is released by flow of oil through line **444** through the sequence valve **442** into the upper end of the cylinder. The operation of the hydraulic actuated mechanisms will be hereinafter explained in describing the operation of clamping a pipe and performing a bend in the pipe.

The electrical control circuit is illustrated in FIG. **32**. The circuit includes a conventional starter **450** enclosed in a cabinet **461**, shown in FIGS. **1** and **3**, controlled by "start" and "stop" buttons or plungers **457**, the starter being connected with current supply conductors L1, L2 and L3. The oil pump driving motor **34** is connected with and energized by the starter. A transformer **454**, contained in a housing **462** shown in FIGS. **1** through **3**, is supplied with current through the starter, the transformer reducing the voltage for the components of the control circuit. PB–1 is a push button switch for initiating the operation of a bend. LS–1 is a limit switch **261** which limits the depth of a bend.

SV–1 is a first operative position of the four-way valve **412** when the solenoid S–1 of the valve is energized, and SV–2 is the operative position of the four-way valve **412** when the second solenoid S–2 is energized. PB–2 is a push button switch movable to a position to energize the solenoid S–2 to effect return movement of the bending shoe **168** to its initial position. CR–1 is a control relay enclosed in a cabinet **465**, shown in FIGS. **1** and **2**, the relay having contacts CR1–1 and CR1–2, the purpose of same being hereinafter explained in connection with the operation of the apparatus. LS–2 indicates a limit switch shown in FIG. **11**, which is actuated by the movable clamping die in retracted position to de-energize the solenoid S–2 of the four-way valve **412** to condition the hydraulic system for a succeeding bending operation.

The operation of the apparatus and steps in the method of clamping and forming a bend in a tube or pipe and the steps of advancing and positioning the tube or pipe are as follows: assuming that the apparatus is in position to receive and accommodate a rectilinear length of tube or tubular stock **40** the operative components of the bending apparatus are in the following positions: the bending shoe or wing die **168** is at its lowermost position shown in FIGS. **1** and **12**, that is, its most remote position from the stationary bending die **84**, the

clamping die **112** is in its lowermost position remote from the stationary clamping die **100**, as shown in FIG. **12**, and the tube **40** extends through the bushing **314** of the carriage **290** and is in unclamped condition.

A portion of the tube **40** extends beyond the region of the bending die **168**, an amount dependent upon the length of unbent tube to be provided in advance of the first bend. With the tube **40** in this position in which to perform a first bend the motor **34** is energized through the starter **450**, the motor driving the hydraulic pump **36** to establish hydraulic pressure for operating the hydraulic actuators.

The operator then releases the locking screw **254**, shown in FIG. **20**, associated with the protractor member **245** and rotates the member **245** relative to the member **230** to bring a particular angle graduation on the protractor scale **247** in registration with the index line **256**. The locking screw **254** is then drawn up to securely hold the member **245** to the member **230**. Thus if the angle of bend to be formed is 25°, the member **247** is adjusted to such position.

The operator then depresses the push button switch PB–1 (see FIGS. **1** and **32**) which energizes solenoid S–1 of the four-way valve **412**. Oil under pressure from the pump **36** flows through lines **414** and **443**, through the sequence valve **442** to the lower end **125** of the clamping cylinder **120**, and exerts pressure upwardly against the piston **122** to securely clamp the tube between the clamping dies **100** and **112**, the components at this stage being at the positions shown in FIG. **12**.

When the movable clamping jaw **112** is in tube-clamping position, the clamping cylinder **120** cannot accommodate more oil and hence the oil pressure rises and sequence valve **416** is piloted at the pressure value for which the sequence valve **416** is set or adjusted. The sequence valve **416** then directs oil under pressure through oil line **418** through the tube **70** into the bending cylinder **60** beneath the piston **62**. At the same time, oil flows through line **422** through the sequence valve **424** past the check valve **426** and through line **212** into the reaction or cushioning cylinder **206**.

The piston **62** moves upwardly in the cylinder **60**, moving the slide **50** upwardly to engage the movable bending die or shoe **168** with the tube **40**. The engagement of the bending die **168** with the tube **40** under fluid pressure on the piston in cylinder **60** effects initial flow, movement or displacement of the metal into the space **193**, shown in FIG. **11**, the metal being bulged or forced into the space **193** to form the raised region **197**, shown in FIGS. **13** and **25** through **30**.

The piston **62**, under fluid pressure, continues upward movement of the slide **50** causing the rotation or wiping of the bending die or wing die **168** around the stationary die or matrix **84** to effect a bend **199** in the tube or pipe **40**, as shown in FIG. **14** the action of wiping the bending die **168** around the stationary die **84** rotating the shaft **152** as it moves upwardly with the slide **50**.

During upward movement of the piston **62**, the oil above the piston in the cylinder **60** flows through the fluid lines **427** and **429** into the oil supply tank **20**. The relative rotation of shaft **152** causes rotation of the arm **218** which produces a mechanical force driving piston **216** in a return or downward direction, as viewed in FIG. **7**, in the reaction or cushion cylinder **206**, forcing oil at the opposite side of the piston through the line **212** and relief valve **438** to the oil supply. The relief valve **438** may be set to open at a predetermined pressure in the cushion cylinder **206**, the relief pressure setting being less than the force acting on the piston **62** in forming a bend in the pipe. As oil is forced from the lower end of cylinder **206**, as viewed in FIG. **7**, oil is sucked from the oil supply **20** through the fluid line **214** into the upper end head **208** of the cylinder thus avoiding a formation of a vacuum above the piston **216**.

The higher force acting on the piston **62** is sufficient to effect a bending of the tube and, as the bending action progresses, the hydraulic pressure acting on the piston progressively increases as the stresses resisting bending increase.

When the increasing pressure approaches the pressure setting of the sequence valve **416**, sequence valve **424** is depiloted but oil flow continues. The pressure increase continues until sequence valve **430** is piloted. Pressure on the piston **122** of the clamp cylinder becomes equal to the setting of the sequence valve **416** or the pressure on the piston **62**, whichever is the highest.

If the pressure on the piston **62** exceeds the pressure setting of sequence valve **430**, this sequence valve permits flow of oil from the cushion or reaction cylinder **206** through the fluid line **434** into the reservoir or oil supply **20** bypassing the relief valve **438**, and the pressure then existent on opposite sides of the piston **216** of the reaction cylinder is greatly reduced as the bend nears completion.

At the completion of a bend, viz the position of the components shown in FIG. **14**, the tube clamp **112** is in tube clamping position and the bending die **168** is in bend-completion position. The operator holds the switch PB–1 in contact-engaging position throughout a tube bending operation. The bend is completed when the abutment screw **258** on the protractor **245** has been moved by rotation of the shaft **152** to engage the plunger of the limit switch LS–1 as in FIG. **14**, the limit switch LS–1 being then engaged with a contact **463**, shown in the circuit diagram (FIG. **32**). Actuation of limit switch LS–1 opens the normally closed contacts of the relay CR1–1 and closes the normally open contacts CR1–2.

This action de-energizes solenoid S–1 of the four-way valve **412** so that the valve is centered, directing oil flow into the supply tank. The operator then manipulates the screw **340** to release the shoe **334** from engagement with the tube **40** and manipulates the screw **366**, shown in FIGS. **8** and **9**, to release the lever or arm **344** from frictional engagement with the stationary protractor **320** and swings or rotates the arm **344** into registry with the zero line **321** or the 180° line depending upon the direction of angularity of the bend to be formed relative to the angularity of the bend that has just been formed. The sleeve, **326** secured to the arm by member **347**, is rotated with the arm. With the arm **344** in a 0° position or in the 180° position, the operator manipulates the knob **366** to tightly engage the arm **344** to the protractor **320**. The operator then manipulates the knob **307** of the locking screw **306** to release the carriage **298** from the track **290**. The operator then moves or slides the carriage **298** in a left-hand direction, as viewed in FIG. **15**, a distance equal to the distance between the bend **199** which has just been completed and the next succeeding bend to be formed in the tube **40**.

The linear distance that the carriage **298** is moved is determined by the graduations on the scale **294**, shown in FIG. **10**, which is supported in the recess **292** in the carriage supporting track **290**. Thus, the carriage is moved until the end face or surface **299** is in registration with the desired graduation of the scale or indexing medium **294**. The other end face of the carriage **298** may, if desired, be used as an index in repositioning the carriage.

The carriage **298** and components associated therewith are shown in a readjusted or indexed position in FIG. **15**. The knob **340** is then rotated to lock the screw **339** and the semicircular shoe **334** in tight engagement with the tube **40**, and the screw **306** drawn up by manipulating the knob **307** to lock the carriage to the track **290**.

The operator then actuates the switch PB–2, shown in FIGS. **1**, **3** and **32**, into engagement with contacts **459**, shown in FIG. **32**, to complete an energizing circuit through the solenoids S–2 of the four-way valve **412**, shown in FIG. **31**, this circuit being energized as long as the operator manually holds the switch PB–2 across the contacts **459**. Oil under pressure from the pump **36** is now directed through the four-way valve through lines **429**, **427** and **69** into the cylinder **60** at the opposite side of the piston **62** to move the piston downwardly in the cylinder **60** which moves the slide **50** downwardly, effecting rotation of the shaft **152** and retracting the bending die **168** to the position shown in FIG. **16**.

At the same time oil flows through the line **429** through check valve **440** and tube **212** into the opposite end of the reaction cylinder **206** which moves the piston **216** upwardly as viewed in FIG. **7**, which forces the oil in cylinder **206** at the opposite side of the piston through the line **214** into the oil supply or tank **20**. FIG. **16** illustrates the bending shoe or die **168** in fully retracted position with the clamping die **112** still in tube clamping position.

As the piston is retracted the oil beneath the piston flows through line **418**, sequence valve **416** and fluid line **415**, through the four-way valve **412** into the oil supply **20**.

When the cylinder **60** is filled with oil under pressure above the piston **62**, the piston reaches the bottom of its stroke and pressure builds up in the fluid line **427**, piloting the sequence valve **442** whereby oil flows through the line **128** to the upper end of the clamping cylinder **120** exerting downward pressure upon the piston **122** and oil below the piston returned through the sequence valve **442** to the oil supply **20**.

Through this action the tube clamp **112** is withdrawn from clamping engagement with the tube **40**, as shown in FIG. **17**. The clamp **112** is retracted through a distance until the limit switch LS–2, shown in FIG. **11**, is engaged by the member **132** attached to the clamping die **112**, the limit switch automatically interrupting the circuit through the solenoid S–2, shown in FIG. **31**, centering the valve **412** to interrupt oil flow in the event that the operator has not manually released the push button switch PB–2 from engagement with contacts **459**, and direct oil through valve **412** to the supply.

While both the bending shoe **168** and the clamping die **112** are disengaged from the tube **40**, the tube **40** is locked to the member **326** so that the tube is held against relative movement. With the tube locked to the member **326**, the carriage **298** carrying the protractor **320**, lever **344** and member **326** is advanced as a unit until the carriage abuts the frame **46**, as shown in FIG. **18**. This movement advances the tube **40** to the position shown in FIG. **18** but without any relative rotation of the tube having taken place.

With the tube and carriage in the position shown in FIG. **18** and the carriage secured to the track **290** by the clamping knob **307**, the operator manipulates the knob **368** to release the arm **344** for movement relative to the protractor **320**. The operator then rotates the arm and tube **344**, sleeve **326**, clamping shoe **334** and tube **40** through an angular distance equal to the angular distance for the next bend to be formed in the tube with respect to the preceding bend. After this action has been completed the arm **344** is locked to the protractor **320** at the desired angle by manipulating the lock screw knob **368**.

Through the operations described, the tube is repositioned, as shown in FIG. **19**, through a linear distance at which a succeeding bend is to be formed and the tube rotated to provide the desired radial angularity for the bend with respect to the tube axis. The tube **40** is in a position for the operator to close the switch PB–1 to initiate the above described sequence of operations in forming the next succeeding bend. The series of method steps or operations is carried out for each succeeding bend until all of the bends desired in the pipe have been formed.

Thus, an operator, having the specifications of the angularities of the bends, the depth at which each bend is to be formed and the distance between successive bends, is enabled to accurately form a tube or pipe to the desired shape or configuration. The configuration of the pipe may be made to accurately conform to the specifications because the tube is always under positive control whenever the tube is advanced or rotated preparatory to a bending operation.

The hydraulic control components are compactly mounted upon a panel **468**, shown in FIG. **1**, on which is mounted the four-way valve **412**, the relief valve **438** and the sequence valves **416**, **424**, **430** and **442**. The check valves and pressure gauges are associated with the components mounted on the panel **468**.

The method and arrangement facilitates the formation of a bend in a pipe at substantially lower hydraulic pressures than has heretofore been possible. The following is exemplary of pressures that may be satisfactorily utilized in forming bends. The cross sectional area of the piston **122** in the clamp cylinder **120** may be about 5 square inches and the sequence valve may be set to release at about 200 pounds pressure per square inch. Thus, the resultant force actuating the movable clamping die **112** is about 1,000 pounds.

The area of the piston **62** in the cylinder **60** of the bending shoe actuator **56** may be about 12½square inches. The sequence valve **416** may be set to release at about 900 pounds pressure per square inch. Thus, the resultant force acting on the piston **62** is about 11,000 pounds. The area of the piston **216** in the reaction or cushioning cylinder **206** may be about 3 square inches and the relief valve **438** may be set to release at a pressure of about 800 pounds per square inch. Thus the reaction force on the piston **216** is about 2,400 pounds.

These exemplary pressures and forces have been found satisfactory in bending tubular stock or tubing for exhaust pipes in the range of 1½inch diameter to 2½inches in diameter. It is to be understood that the sequence valves may be set to release at lower or higher pressures and the diameters of the cylinders of the hydraulic actuators may be modified to change the effective forces on the clamping die **112**, the bending shoes **168** and **172** and on the piston of the reaction or cushioning cylinder **206**.

The bending apparatus is adapted to perform bending operations upon tubes or pipes of different diameters. When it is desired to accommodate the apparatus to a different size of pipe, the components shown in FIG. **11** including the stationary bending die or matrix **84**, the clamping shoes **100** and **112**, the spacer blocks **160**, **161** and the bending die, wing die or wiper shoe sections **168** and **172** are replaced with components of dimensions to fit different size tubes or pipes. In addition, the locking shoe **334**, shown in FIG. **8**, is replaced by a locking shoe of a different size to accommodate the pipe.

The auxiliary or supplemental bending die or wiper shoe section **172** is normally utilized in association with the bending die or wiper shoe section **168** in order to provide additional surface area for engagement with the tube or pipe during a bending operation. In instances where the distance between successive bends is short, the auxiliary or supplemental bending shoe section **172** may be readily removed to facilitate forming a succeeding bend.

Where different sizes of tube or pipe are to be bent, an auxiliary or supplemental bending shoe section **172** is provided of the same cross sectional shape as the bending shoe section **168**. The spacer blocks **160**, **161** and the die **112** for different sizes of tube are of different thicknesses to accommodate the different sizes of tube.

FIGS. **1**, **2** and **3** illustrate the bending apparatus wherein the apparatus is arranged at two different angles in different planes. In FIG. **1** it will be noted that the rectilinear axis of the tube **40** is at an angle of about 15° with respect to the floor surface F and the axis of the bending apparatus is therefore at about 15° with respect to a vertical axis. Exhaust pipes for vehicle installation are usually several feet in length being upwards of 12 feet or more in length for some vehicles.

A substantial number of bends is required in most exhaust pipe constructions in order to avoid interference with structural components or frame members of a vehicle, and such bends are at varying angles and of varying depths. By inclining the axis of the tube **40**, as shown in FIG. **1**, the various successive bends may be impressed in the tube or pipe without the right-hand end of the tube impinging or engaging the floor. Through this angular arrangement of the bending apparatus, it is unnecessary to provide a pit or excavation to accommodate the bent pipe.

As shown in FIGS. **2** and **3**, the bending module or unit is arranged in an angular position, being inclined forwardly at about 45° with respect to the floor F. This facilitates the use of the machine by the operator and provides for easy access to

the controls. While the angularities for the bending apparatus above described have been found preferable, it is to be understood that these angularities may be varied depending upon the place of use of the apparatus.

It should be further noted that the components of the bending apparatus are mounted on a single frame component **46** so that the module provided by the assembly on the frame component **46** may be mounted in other positions or may be mounted in a suspended position if desired. This versatility of position is possible as the hydraulic connections between the oil pump and the components of the module may be flexible whereby the reservoir or tank **20**, motor **34** and the oil pump **36** may be in positions other than those illustrated herein.

In the event that the pipe tends to stick or adhere to the knurled surface of one or the other of the clamping dies **100** and **112** upon release of the clamping die **112**, it may be necessary to effect complete disengagement of the pipe by striking the pipe with an instrument, such as a hammer. By supporting the member **312** and sleeve **326** and associated components upon the trunnion **315**, the slight tilting of the pipe in loosening the same will not damage the sleeve **326** and will not effect release of the tube locking screw **339**. This slight tilting of the tube in loosening the same is illustrated in FIG. **17**.

It will be apparent that applicant's method of bending metal tubing is inclusive of the steps of restraining the tubing against longitudinal movement preparatory to forming a bend in the tubing and exerting a force laterally against the tubing at a localized region adjacent the tube restraining means to effect initial cold flow or displacement of the metal at the localized region. Bending of the pipe is performed by continuing the application of lateral force against the tubing at a zone adjacent the displaced metal, the bending shoe wiping the tubing about the stationary matrix **84** in an arcuate configuration to form a bend. The stretching of the metal of the clamped portion of the tube during bending is inappreciable, and stretching of the metal is further restrained by the displaced metal anchored in the pocket or zone **193**. It is to be understood that the configuration of the pocket or space **193** may be modified in lieu of the curved portion of the matrix at the left side of the plane A—A, shown in FIG. **11**. For example, the matrix **84** at the left-hand side of the plane A—A, as viewed in FIG. **11**, may be formed with a notch providing a rectangular space into which the metal may be displaced to form the configuration **197** in FIG. **13**.

It is to be understood that while the embodiment of the apparatus illustrated is particularly adapted for forming successive bends in tubular stock, tubing or pipe utilized with internal combustion exhaust systems of automotive vehicles, the bending apparatus is adaptable for bending tubing or tubular stock for other uses.

It is apparent that, within the scope of the invention, modifications and different arrangements may be made other than as herein disclosed, and the present disclosure is illustrative merely, the invention comprehending all variations thereof.

I claim:

1. The method of bending metal tubing of substantially circular cross section including restraining the tubing against lengthwise movement, exerting lateral force on the tubing at a localized region to initiate cold flow of the metal of the tubing at said localized region, and applying force against the tubing adjacent the localized region to bend a portion of the tubing into an arcuate configuration while maintaining the bent portion of the tubing of substantially circular cross section.

2. The method of bending metal tubing of substantially circular cross section including restraining longitudinal movement of the tubing, applying force laterally against the tubing at a localized region to effect relative movement of the metal of the tubing outwardly at said localized region, and continuing the application of force against a portion of the tubing adjacent the localized region to form said portion into an arcuate configuration while maintaining the portion of arcuate configuration of substantially circular cross section.

3. The method of bending metal tubing of substantially circular cross section including clamping the tubing, exerting force against the tubing at a localized region to effect lateral and outward displacement of the metal of the tubing at said localized region, and applying force against the tubing adjacent the localized region to bend a portion of the tubing into an arcuate configuration while maintaining the bent portion of substantially circular cross section.

4. The method of working metal tubing including the steps of restraining the tubing against longitudinal movement, exerting force laterally against the tubing at a localized region to distort the metal outwardly and thereby initiate cold flow of the metal of the tubing at the localized region, applying force against the tubing adjacent the distorted metal at the localized region forming a bend in the tubing, engaging a locking surface with the tubing at a region spaced from the bend, releasing the tubing from the influence of the laterally directed and tubing restraining forces, advancing the tubing and locking surface longitudinally in the direction of the bend through a predetermined distance, and rotating the tubing while engaged by the locking surface to predetermine the angular position of the bend to be formed relative to the angularity of the formed bend.

5. The method of bending metal tubing of substantially circular cross section including the steps of disposing a length of tubing between clamping surfaces, engaging the surfaces with the tubing, moving a body into engagement with a localized region of the tubing, displacing metal of the tubing laterally and outwardly at the said region by the moving body and thereby initiate flow of the metal prior to a bending operation, rotating the body engaged with the tubing to form a bend in the tubing while maintaining the bent portion of substantially circular cross section, resisting rotational movement of the body by forces sufficient to maintain the body in engagement with the tubing during the formation of a bend, and limiting rotational movement of the body when a bend of desired depth has been formed.

6. The method according to claim **5** including the steps of gripping the tubing to a carriage at a region spaced from the clamping surfaces, retracting the body from engagement with the tubing upon completion of the formation of a bend, releasing the clamping surfaces, and advancing the carriage and gripped tubing to dispose the tubing in a position preparatory to forming a succeeding bend in the tubing.

7. The method according to claim **5** including the steps of gripping the tubing to a carriage at a region spaced from the clamping surfaces, retracting the body from engagement with the tubing upon completion of the formation of a bend, releasing the clamping surfaces, advancing the carriage and the gripped tubing to dispose the tubing in a position preparatory to forming a succeeding bend, and rotating the tubing to an extent predetermining the angularity for a bend to be formed with respect to the formed bend.

8. The method of working metal tubing including restraining the tubing against longitudinal movement, exerting forces laterally against the tubing to distort the metal outwardly to initiate cold flow of the metal of the tubing and form a bend in the tubing, engaging a locking surface with the tubing at a region spaced from the bend, releasing the tubing from the influence of the laterally directed and tubing restraining forces, advancing the tubing and locking surface longitudinally in the direction of the bend through a predetermined distance, and rotating the tubing by the locking surface to predetermine the angular position of the bend to be formed relative to the angularity of the formed bend.

9. The method of working metal tubing of substantially circular cross section including clamping the tubing, initiating cold flow of the metal of the tubing by distorting the metal in a lateral and outward direction at a localized region, and bending the tubing adjacent the localized region of the tubing while maintaining the bent portion if the tubing of substantially circular cross section.

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