United States Patent [19]

Stuart

[11] **3,902,344**

[45] **Sept. 2, 1975**

[54] **TUBE BENDING METHOD**

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[73] Assignee: **Rollmet, Inc.,** Santa Ana, Calif.

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[52] **U.S. Cl.** **72/128;** 72/342; 72/369

[51] **Int. Cl.²** **B21D 7/16**

[58] **Field of Search** 72/128, 369, 342

[56] **References Cited**

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Primary Examiner—Lowell A. Larson

Attorney, Agent, or Firm—Knobbe, Martens, Olson, Hubbard & Bear

[57] **ABSTRACT**

Large diameter thin-walled pipe is bent by a ram pushing the pipe forward axially and a bending arm forcing the forward end of the pipe to follow a curved path. A heater mounted in a plane passing through the center of the bend heats the pipe in a narrow bending zone to a temperature substantially reducing the yield strength of the metal. Heat input and cooling are adjusted around the periphery of the bend to provide uniform temperatures irrespective of changes in pipe wall thickness resulting from the bending. The flexure axis of the bend may be moved inward or outward along the bend radius by pulling or retarding with the pivotal bending means, or may be fixed by providing relatively cool spots in the heated band at the desired location of the flexure axis. Guide means are provided which may pre-deform the pipe laterally to compensate for lateral deformation during bending or may prevent deformation during bending. The portion to be bent may have a different diameter or thickness to compensate for changes in dimensions resulting from bending.

3 Claims, 14 Drawing Figures

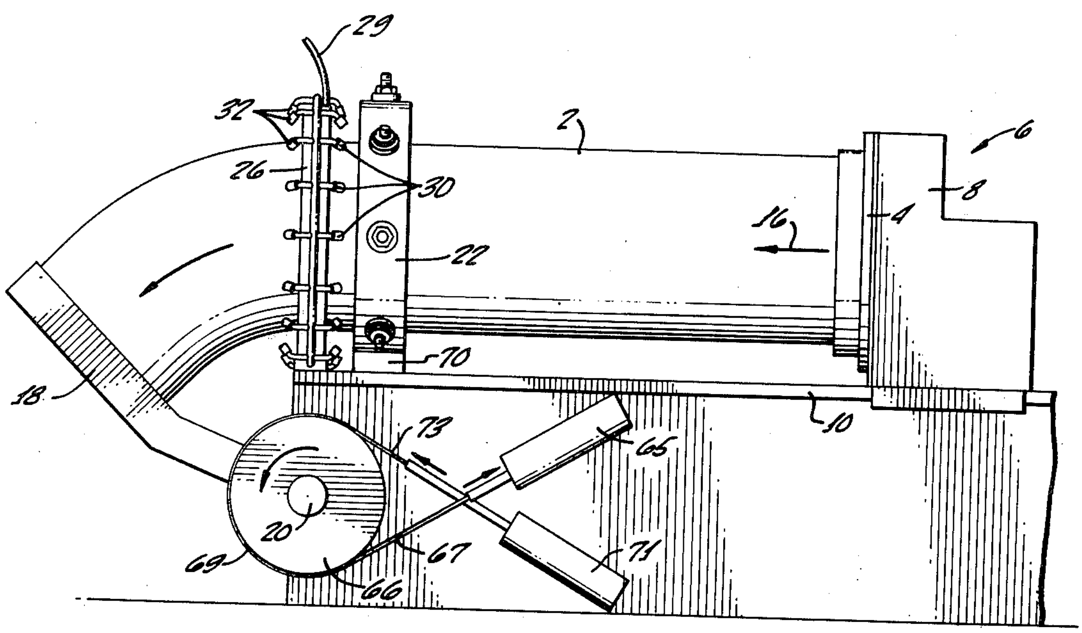

FIG. 1

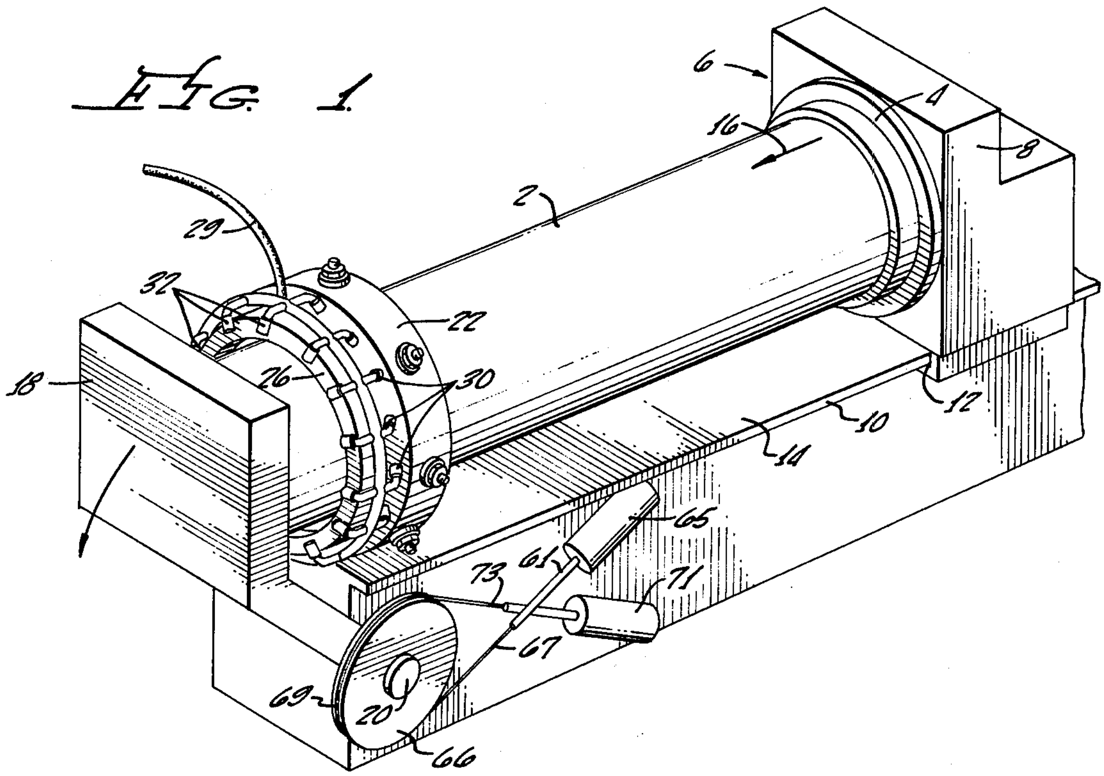
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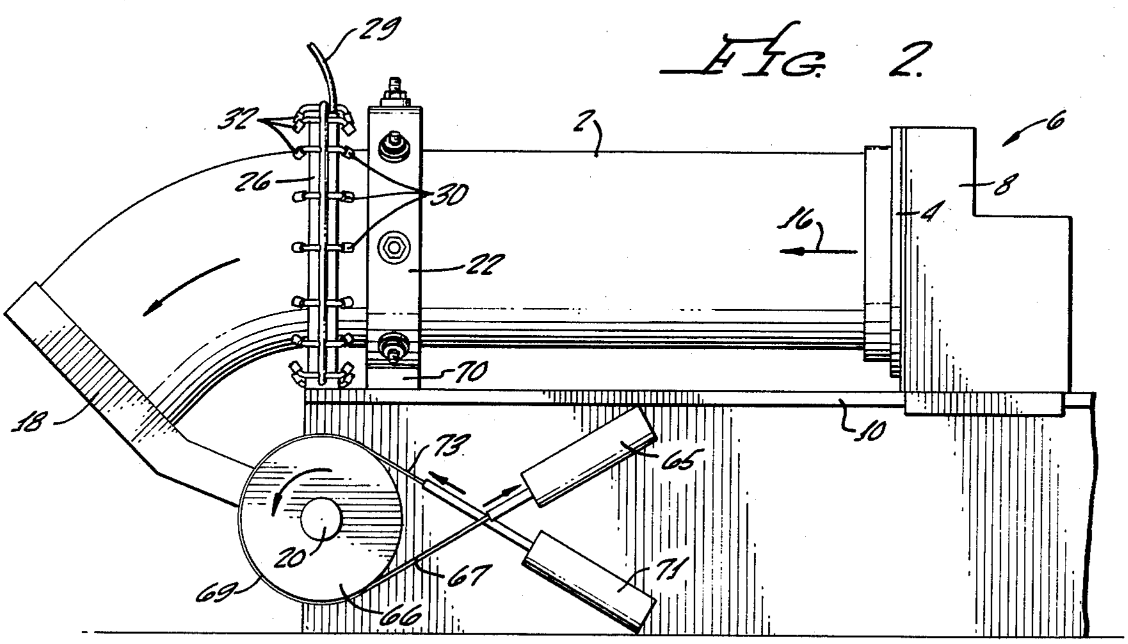
FIG. 2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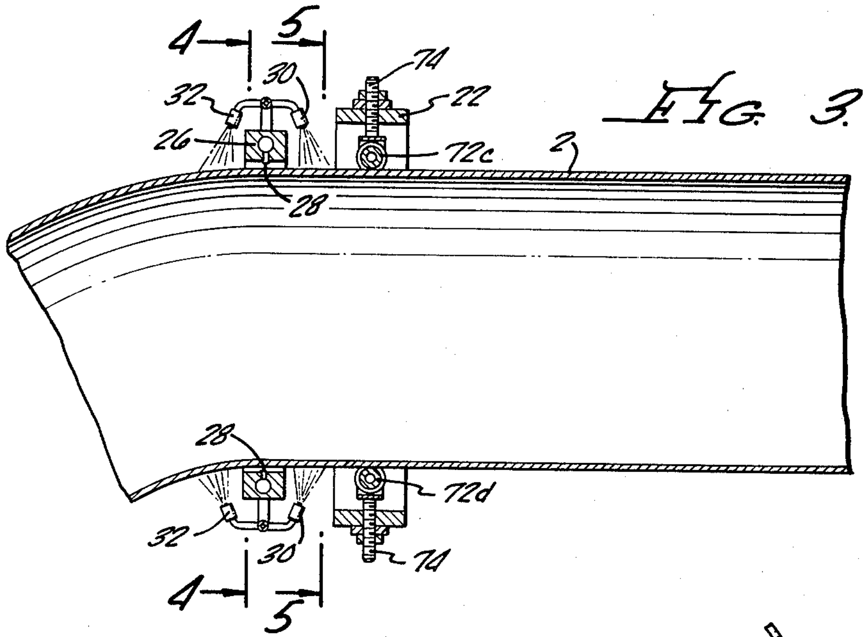


FIG. 3.

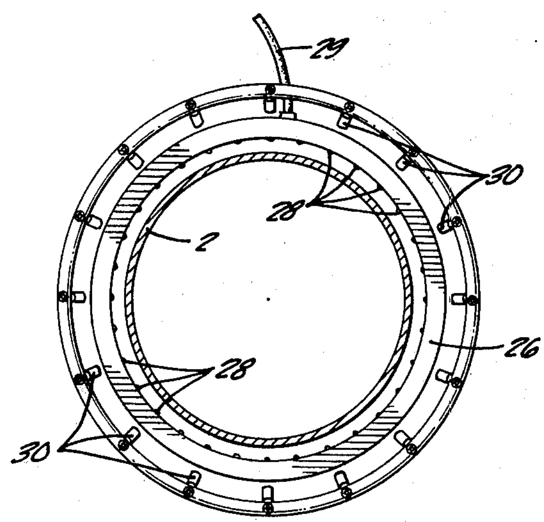


FIG. 4.

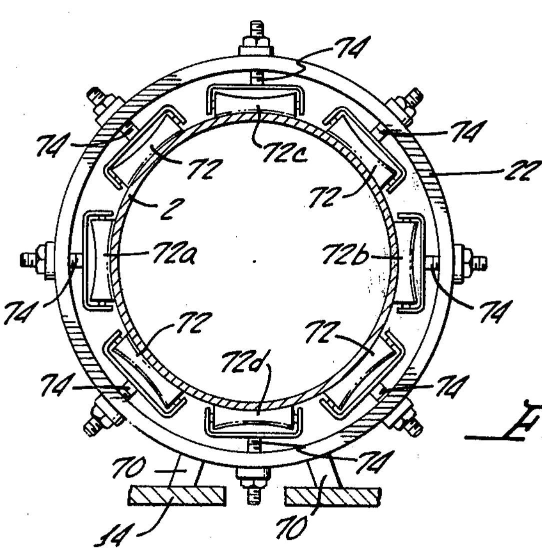


FIG. 5.

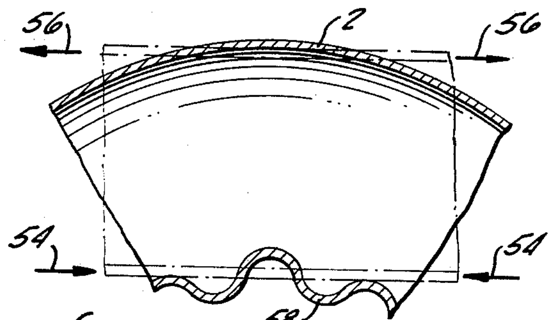


FIG. 6.

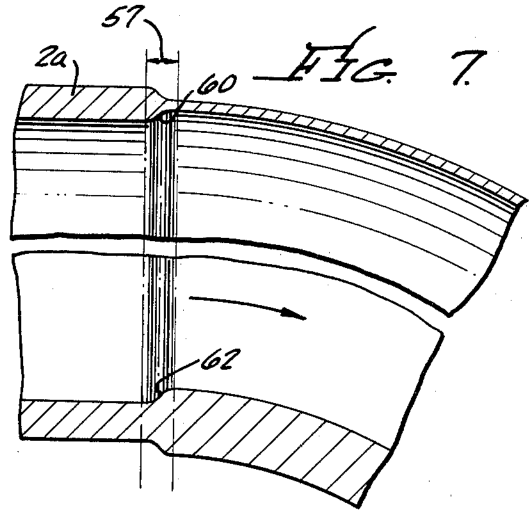


FIG. 7.

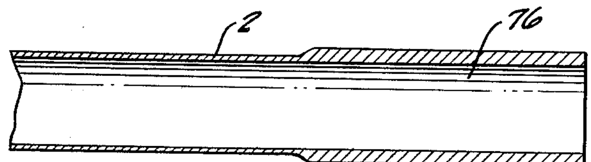


FIG. 8.

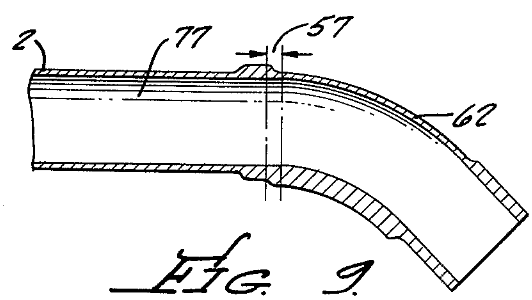


FIG. 9.

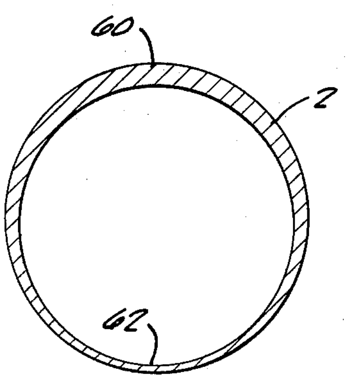


FIG. 10.

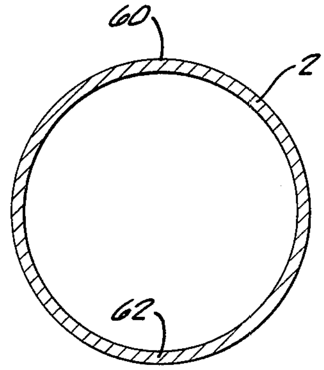
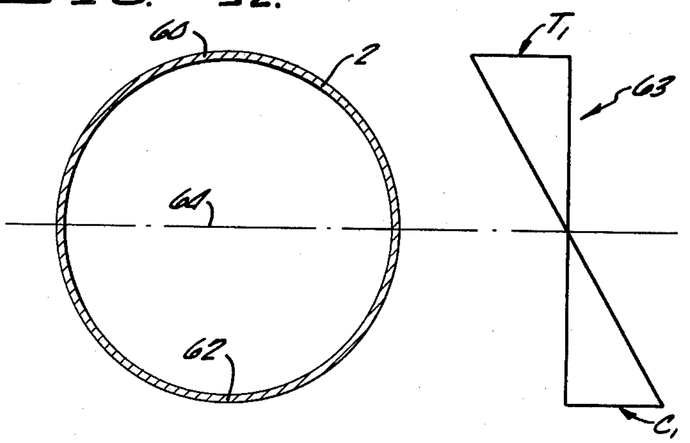


FIG. 11.

FIG. 12.



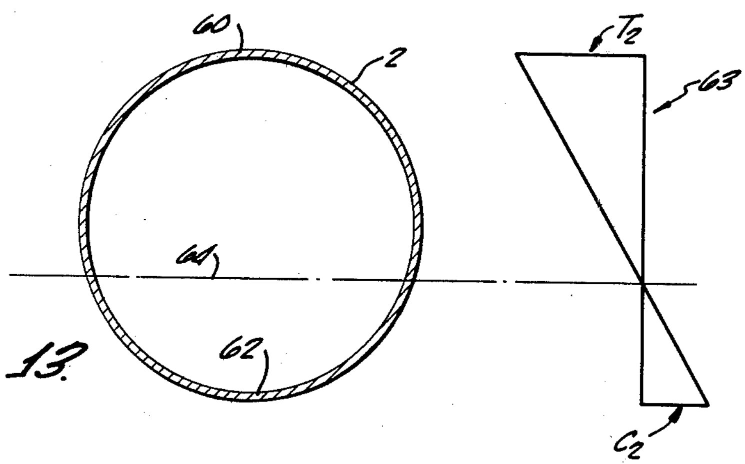


FIG. 13.

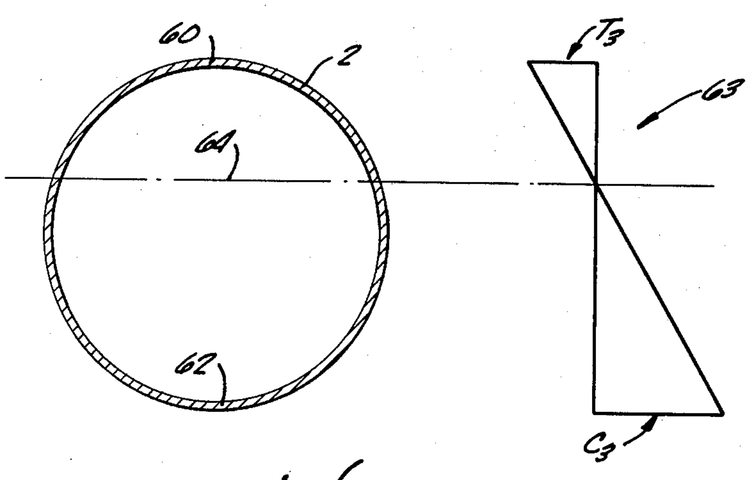


FIG. 14.

TUBE BENDING METHOD

SUMMARY OF THE INVENTION

This invention relates to the forming of bends in large diameter pipe having relatively thin walls. This application is related to my copending application for "Method and Apparatus for Bending Pipe," Ser. No. 447,886, filed Mar. 4, 1974, and the apparatus and method disclosed herein may also incorporate the features disclosed in that application.

Forming bends in thin-walled tubing or pipes has been a very difficult procedure because the walls tend to buckle or wrinkle on the inside of the bend when subjected to the substantial stress required for bending. This tendency is stronger, the thinner the wall thickness in relation to the diameter of the pipe. Prior art commercial techniques often supported the pipe internally or externally to resist buckling. That requires tooling which is extremely costly for large diameter pipe. In addition, the problem of extracting the finished part from the tooling seriously limits the complexity of the bends that can be formed.

It is known that pipe can be bent by pushing it along its axis from one end while guiding the leading end about a radius. However, such a technique is completely unsatisfactory for thin-walled pipe because the compressive stress on the inside of the bend exceeds the column strength of the pipe wall, and buckling results. U.S. Pat. No. 785,083, issued to Brinkman describes such a proceduring using a wide heat zone to reduce bending forces.

In order to overcome buckling, a narrow heat zone must be employed as described by Hirayama et al in U.S. Pat. No. 3,368,377. The narrowness of the heated zone is of paramount importance as it is a result of this narrowness that the pipe is prevented from wrinkling or buckling. The principle involved is that a column compressed at either end will thicken rather than buckle if the thickness of the column is more than about one half of its length. The metal at the inside of the bend in the hot zone may be regarded as a short column under compression. Since bending occurs only in the heated zone, in this analogy the length of the column corresponds to the width of the heat zone and the thickness of the column corresponds to the wall thickness.

The width of zone which may be permitted without buckling is dependent on the wall thickness of the pipe and to a lesser degree on the diameter of the pipe. For a pipe of exceptionally thin wall in relation to its diameter, the heated zone should be as narrow as twice the wall thickness. For thicker walls, or smaller diameters, the zone may widen somewhat. In the case of thick-walled pipes and solid bars the tendency toward buckling is so limited that little attention need be paid to the width of the heat zone. In these cases heat is used merely to reduce the bending forces. In general, the zone should be as hot as possible without microstructural deterioration of the metal.

A number of problems can arise when bending pipe heated in a narrow band in accordance with prior art practices. For example, the pipe at the inside portion of the bend thickens under compression as the bend is made, while the outside portion thins under tension, resulting in nonuniform wall thickness in the bent form if uniform blank material is used. Accordingly, a uniformly distributed heat source tends to overheat the thinner portions while underheating the thicker portions. Applicant overcomes this problem by applying greater or less heat or cooling around the periphery of the bend depending on the local wall thickness.

Further, prior art processes provide no means for controlling or adjusting the amount of stretching or compression caused during bending. The bending moment causes compression in the inside or crotch of the bend, and stretching in the outside of the bend. In some applications the range of possible bends will be limited by the tendency to form wrinkles in the areas in compression. In others the range will be limited by the inability of the metal to stretch without cracking in the stretched area of the bend. In accordance with one aspect of this invention the axial force applied by the ram pushing the pipe is complemented by a second axial force applied to the pipe through the pivotal arm. This complementary force may either assist or oppose the forward motion of the pipe through the heated zone. In the first case, the pipe is stretched along the arc of the bend, reducing the tendency toward buckling in the bend crotch. In the second case, the pipe is compressed along the arc of the bend and the amount of stretching and the tendency to crack is reduced.

In the prior art the final bend wall thickness is predetermined by the bend geometry and the starting wall thickness. By means of the complementary force, in conjunction with the ram, the final wall thickness may be increased or reduced.

In addition, the location of the flexure axis may be controlled in accordance with this invention by designing the heating means so as to provide relatively cool spots in the heated annular band on opposite sides of the pipe at the desired location of the axis. As the cooler portion will not bend under the load causing bending in the heated portion, compression will result below the cool spots and stretching above.

In accordance with another aspect of this invention, problems with deformation of the pipe during bending are eliminated. Preferably, this is accomplished by guide rollers bearing on the pipe upstream of the heated zone. In accordance with one embodiment, the rollers pre-deform the pipe to compensate for the subsequent deformation during bending. In accordance with another embodiment, the rollers confine the pipe dimensionally so as to prevent deformation.

Further in accordance with this invention, the portion of the pipe to be bent may, for example, be prethickened in the portion to form the outside of the bend and prethinned in the portion to form the crotch of the bend so as to compensate for the thinning and thickening which occurs in bending. The diameter may also be preadjusted to compensate for dimensional changes which occur during bending; all with the end result of a bend portion having a diameter and wall thickness substantially the same as the straight portions.

These and further features of this invention will be apparent from the following description of a preferred embodiment of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of an apparatus constructed in accordance with this invention;

FIG. 2 is a side elevation of the apparatus of FIG. 1 showing a pipe in the process of being bent;

FIG. 3 is a partial longitudinal section through the pipe and the apparatus;

FIG. 4 is a section taken generally along lines 4—4 of FIG. 3;

FIG. 5 is a section taken generally along lines 5—5 of FIG. 4;

FIG. 6 is a schematic section illustrating the forces buckling a pipe in prior art processes;

FIG. 7 is a schematic section illustrating the dimensional effect of bending a pipe in accordance with this invention;

FIG. 8 is a longitudinal section through a portion of a modified form of pipe prior to bending;

FIG. 9 is a longitudinal section through the pipe portion of FIG. 8, after bending;

FIG. 10 is a cross-section through a portion of a modified form of pipe prior to bending;

FIG. 11 is a cross-section through the pipe portion of FIG. 10, after bending;

FIG. 12 is a schematic representation of a pipe cross-section and a strain diagram showing the flexure axis approximately in the center of the pipe;

FIG. 13 is a schematic representation like FIG. 12, but showing the flexure axis lowered; and

FIG. 14 is a schematic representation like FIG. 12, but showing the flexure axis raised.

DESCRIPTION OF EXEMPLARY EMBODIMENT

Referring to FIGS. 1 and 2, a pipe 2 in which a bend is to be formed is shown in position on the apparatus of this invention. By way of example, a typical pipe would be of 304 stainless steel of an overall diameter of about 16 inches and having a wall thickness of about ⅜ inch. The trailing end of the pipe is received in a collar 4 which is mounted on a ram 6. The ram includes a slide 8 mounted by suitable guides such as the illustrated flange 10 and groove 12 for sliding movement along a base 14. Suitable power means such as a hydraulic or pneumatic cylinder (not shown) is attached to the slide 8 for pushing the pipe 2 axially in the direction of the arrow 16.

A bending arm 18 is removably but rigidly connected to the forward end of the pipe 2 so that the forward end of the pipe and the bending arm move as a unit. The bending arm is pivotally mounted on the base 14, for example by a shaft 20, for pivotal movement about the shaft 20 which is the desired center of curvature of the bend.

A ring 22 including roller type guides surrounds the pipe to guide the pipe in its movement forward, and for deformation control as will be described below.

A heater ring 26 is mounted so as to be disposed around the pipe in a plane perpendicular to the longitudinal axis of the pipe and passing through the axis of bending 20. The heater ring may either be a gas burner as illustrated or an induction heater. If a gas burner is used, it is preferred to also provide an internal burner ring as described in my copending application, Ser. No. 447,886, filed Mar. 4, 1974, referred to above. The internal burner has been omitted in these drawings in order to simplify the disclosure.

Referring to FIGS. 3 and 4, the exemplary burner ring has a plurality of jets 28 connected to a gas supply line 29 and disposed around the circumference of the pipe 2 so as to heat the pipe to a temperature at which its yield strength is substantially reduced. For steel this preferably is a temperature in the range of about 1,600°F. to 2,000°F., and preferably about 1,800°F. The range of temperatures could be broader, but there is no significant change in the yield strength at temperatures below 1,200°F., and metallurgical deterioration begins at temperatures in excess of 2,200°F.

A pair of quench rings 30, 32 are also disposed around the pipe 2 on opposite sides of the burner ring 26. Each quench ring includes a set of jets; those of the first ring 30 being directed slightly forward of the burner ring and those of the second ring 32 being directed slightly rearward of the burner ring. The quench ring jets are connected to a source of coolant such as air, or preferably water, or a combination of the two, to cool the pipe 2 forward and rearward of the burner 26 and restrict the heated zone to a narrow band.

In operation, the ram 6 is urged forward by its power source to move the pipe 2 longitudinally of its axis in the direction of the arrow 16. Since the forward end of the pipe can move forward only arcuately with the bending arm 18, the path of the forward end of the pipe necessarily is through an arc having its center of curvature at the axis 20 of the bending arm. Accordingly, a torque or bending moment is applied to the pipe 2 tending to bend the pipe about the axis 20.

Referring now to FIG. 6, which is a schematic longitudinal section through a portion of a representative pipe 2, it will be evident that the bending moment applied to the pipe applies compressive forces 54 to the inside portion of the bend and tensile forces 56 to the outside portion of the bend. The compressive forces tend to shorten the pipe on the inside portion of the bend and the tensile forces tend to lengthen the pipe on the outside portion of the bend from its initial shape as shown in the dashed lines.

If the thickness of the pipe wall is relatively small in relation to the diameter of the pipe as is the case with the pipes for which this invention finds it primary application, the compressive forces 54 generated on the inside of the bend in order to cause bending at normal temperatures tend to form buckles or wrinkles 58 in the metal. This tendency is stronger the thinner the wall thickness in relation to the diameter of the pipe, and makes impractical the bending of large diameter thin-walled pipe. It is for that reason that the narrow heat zone is used.

The burners 26, 34 are designed to generate sufficient heat to raise the temperature of the pipe 2 in the narrow heated zone to above a preselected temperature at which the yield strength is substantially reduced, e.g. 1,800°F. With the reduced yield strength, the required bending moment, and therefore the resulting compressive stress is less.

A constant preselected pressure is kept on the ram 6 which is sufficient to cause bending stresses in the pipe 2 equal to the yield strength of the metal at the preselected temperature. Since longitudinal movement of the pipe can occur only as the pipe bends, the pipe does not move until the temperature in the heated zone reaches the preselected temperature. At that time the compression and tension in the heated zone equals or exceeds the yield strength of the metal and the metal begins to bend, thereby permitting the pipe 2 to advance under pressure of the ram 6. As the pipe advances, new cold metal is brought into the heated zone and the bending process continues when the new portion is heated to the appropriate temperature. The temperature of the heated zone is not controlled directly, but is controlled by the ram pressure setting. The temperature increases until the metal yields, under the applied force of the ram **6.** As the pipe **2** bends, it passes slowly through the burners **26, 34** and hot metal is displaced by cold metal. The speed with which the new metal is heated to the forming temperature, which controls the rate of advance of the pipe **2,** is dependent on the amount of excess heat available. Thus, the apparatus is self-regulating in that no movement will occur until the desired temperature is achieved since no bending will occur until the metal's yield strength is reached.

The bend resulting from this invention is typified by FIG. **7** which shows a straight pipe portion **2***a* having uniform wall thickness entering the heated zone **57.** In the heated zone, the bending moment causes stress exceeding the yield strength of the metal. Accordingly, the wall portion at the outside of the bend abruptly thins at **60** and the wall portion at the inside of the bend abruptly thickens at **62.**

The thicker wall portions dissipate more heat than the thinner portions. Thus, if heat and cooling are applied uniformly around the circumference of the pipe **2,** and on either side of the burner, the thicker portions generally will not attain the desired temperatures, while the thinner portions will be overheated. Accordingly, the amount of heating or cooling applied preferably is not uniform around the circumference and on either side of the burner.

The amount of heat dissipated in the metal is strongly dependent on the proximity of the cooling jets to the heat source. The closer the jets the greater the heat dissipation, and vice versa. Thus, the unequal heat dissipation resulting from dimensional changes may be compensated for by moving the quench sprays closer or further from the heat ring.

Alternatively, nonuniform heat input around the pipe periphery may be accomplished. For example, with a gas burner heater, the gas jets may be larger or more closely spaced at the crotch than at the outside of the bend. With an induction heater the heater may be spaced further from the pipe at the outside of the bend than at the crotch, or a nonuniform lamination density may be used.

In some instances, for example where composite material is used, the temperature may deliberately be made nonuniform to suit the properties of each material, by employing the above methods.

Referring now to FIG. **12,** a schematic strain diagram **63** represents the strain in the wall of pipe **2** in the heated bending zone. This strain varies substantially linearly from maximum stretching T_1 at the top **60** to maximum compression C_1 at the bottom **62** with the flexure axis **64** (at the point where the strain is zero) occurring approximately midway. If wrinkling is likely to occur, it may be desirable to lower the flexure axis **64** as shown in FIG. **13** so that the maximum compression C_2 is less than the compression C_1. In that instance the maximum stretching T_2 will be greater than T_1, but that may be acceptable, or even desirable with some pipe dimensions or materials.

Similarly if cracking is likely to occur it may be desirable to raise the flexure axis **64** as shown in FIG. **14.** Accordingly, the maximum stretching T_3 will be less than the stretching T_1 although there will be a related increase in the maximum compression C_3 over C_1.

Such variation of the flexure axis may, for example, be accomplished with a hydraulic or pneumatic cylinder and pulley as shown in FIGS. **1** and **2.** A pulley **66** is mounted on the axis **20** and fixed for movement with the arm **18.** A first cylinder **65** is suitably mounted on the base **14** and has its piston rod **61** connected to a wire rope **67** which extends partially around the pulley **66** in a clockwise direction and is suitably fastened to the pulley, for example at **69.** A second cylinder **71** is similarly mounted on the base and connected to a wire rope **73** which extends counterclockwise partially around the pulley **66** and is connected at **69,** for example.

To lower the flexure axis the cylinder **65** is actuated to pull the bending arm **18** thereby applying added tension to the pipe. To raise the flexure axis the cylinder **71** is activated to resist forward pivoting of the arm **18** thereby applying additional compression to the pipe. In either event the amount of force applied by the cylinder will determine the distance the flexure axis is raised or lowered.

Further, the location of the flexure axis may be controlled to some extent by designing the heater so as to provide relatively cooler spots in the annular heated band on opposite sides of the pipe at the desired location of the flexure axis. The cooler spots will have a higher yield point and therefore will serve as a pivotal point about which the pipe will bend. That is, portions above the cooler spots, in orientation of the exemplary configuration, will expand and therefore be in tension, whereas portions below the cooler spots will contract and therefore be in compression.

In order to achieve the cooler spots, the gas burner can be designed to have no jets at the desired flexure axis location, or the induction heater can be designed to have breaks in its arc at those locations, or the quench rings can be arranged to provide added coolant directly on those spots.

In some instances the bending of the pipe may cause lateral deformation, that is the pipe may increase in diameter in its dimension perpendicular to the plane of the bend, and decrease in diameter in its dimension in the plane of the bend. This can be prevented with the guide **22** shown in FIGS. **1** and **5.** The guide includes a ring **22** suitably supported from the base **14** by brackets **70** to surround the pipe **2.** A plurality of rollers **72** are mounted on the ring and extend radially inwardly toward the pipe. Each roller is mounted on a threaded stud **74** which provided for independent adjustment of the radial distance from the center of the ring to each roller. The rollers are adjusted to contact the periphery of the pipe and guide it in its forward movement. Further, the rollers can be adjusted to put sufficient radial pressure on the pipe to constrain it against lateral deformation. Alternatively, the side rollers **72***a* and **72***b* can be adjusted inward to a spacing less than the norml outside diameter of the pipe and the top roller **72***c* and bottom roller **72***d* adjusted outward to a spacing greater than the normal outside diameter of the pipe to predeform the pipe sufficiently to allow for the deformation which will take place in bending, thereby resulting in a bend portion of the diameter and shape desired.

As shown in exaggerated form in FIGS. **8** and **9,** in some instances the pipe **2** to be bent may first be thickened in the area to be bent **76.** Thus, when the pipe is bent the outside portion of the bend **62** will have a wall thickness equal to that of the straight pipe portion **77.** This is desirable where specifications require a minimum wall thickness.

As shown in FIG. **10**, in some instances the pipe **2** to be bent may first be made eccentric with thin wall in the area to become the bend crotch **62**, and with thick wall in the outer bend region **60**. Thus, as shown in FIG. **11**, the eccentricity may be designed so that the bent pipe will have uniform wall thickness equal to that of the straight pipe portion. This is desirable where specifications require a uniform wall thickness.

Further, the pipe to be bent may first be expanded in diameter in the area to be bent. This can be designed to result in an inside pipe diameter in the bent portion equal to that in the straight portion.

What is claimed is:

1. A device for bending pipe comprising:

means for advancing a pipe past a heating station;

heating means at the heating station for heating a narrow annular band of the pipe to a temperature sufficient to substantially reduce its yield point;

means for applying a bending moment to the heated portion of the pipe;

means varying the heat around the periphery of the band;

said heating means including cooling means for cooling the pipe forward and rearward of said heating means to confine the heated area to a narrow band; and

said means varying the heat comprising means varying the spacing between said forward and rearward cooling means around the periphery.

2. A device for bending pipe comprising:

means for advancing a pipe past a heating station;

heating means at the heating station for heating a narrow annular band of the pipe to a temperature sufficient to substantially reduce its yield point;

means for applying a bending moment to the heated portion of the pipe; and

said heating means including means for interrupting the annular heated band of pipe by cooler portions on opposite sides of the pipe at opposite ends of the desired flexure axis to control location of the flexure axis.

3. A method of bending a thin-walled pipe of large diameter comprising:

heating a narrow band of the pipe to a temperature substantially reducing its yield point;

applying a bending moment to the pipe portion in the narrow band;

progressively moving the narrow band along the pipe as the portion in the band bends; and

providing relatively cool spots in said band on opposite ends of the desired flexure axis.

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