Jan. 12, 1971 H. MUNRO ET AL 3,553,989

TUBE BENDER WITH INCREMENTAL TUBE MEASUREMENT

Filed April 23, 1968 2 Sheets-Sheet 1

Fig. 1

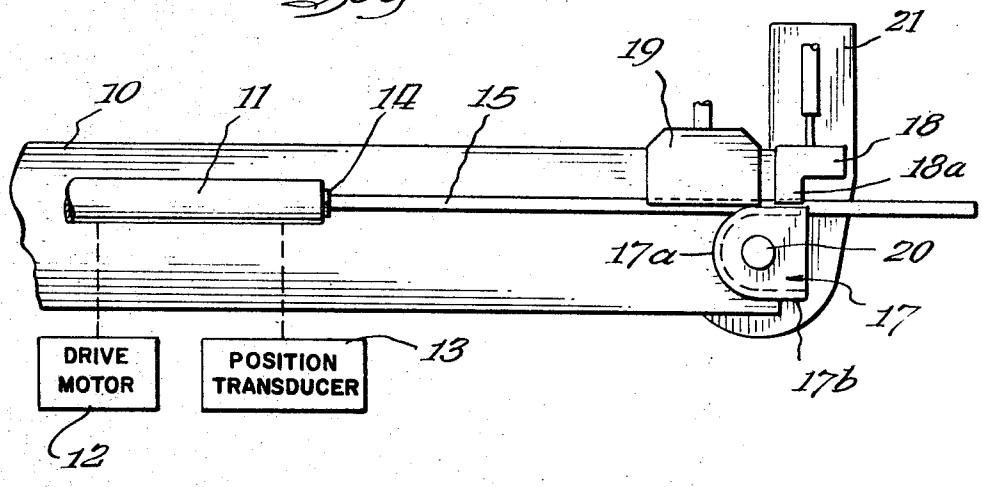


Fig. 2

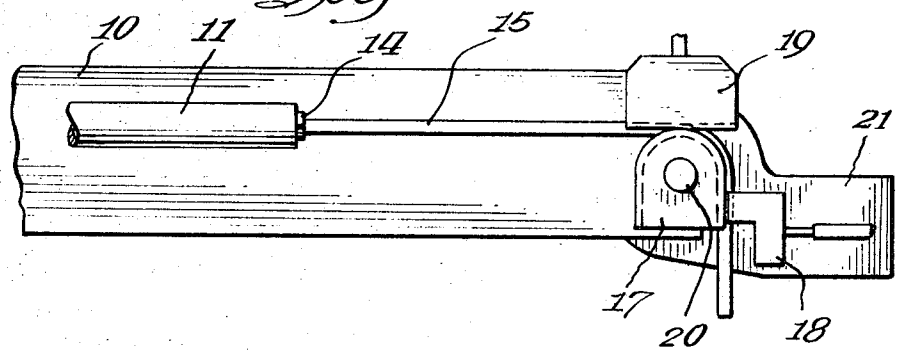
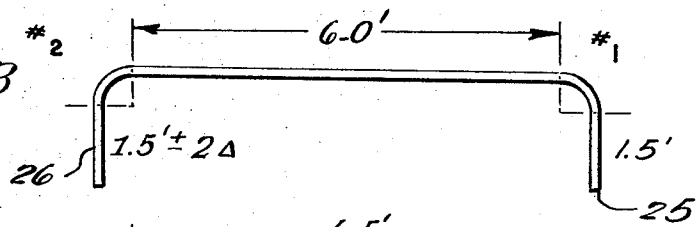


Fig. 3
PRIOR ART



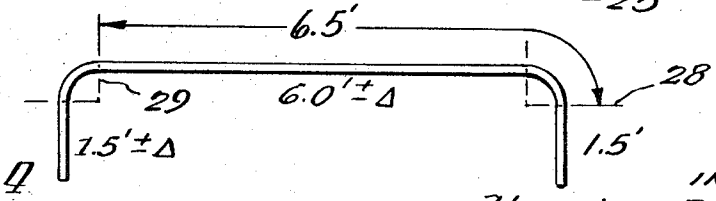


Fig. 4

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TUBE BENDER WITH INCREMENTAL TUBE MEASUREMENT

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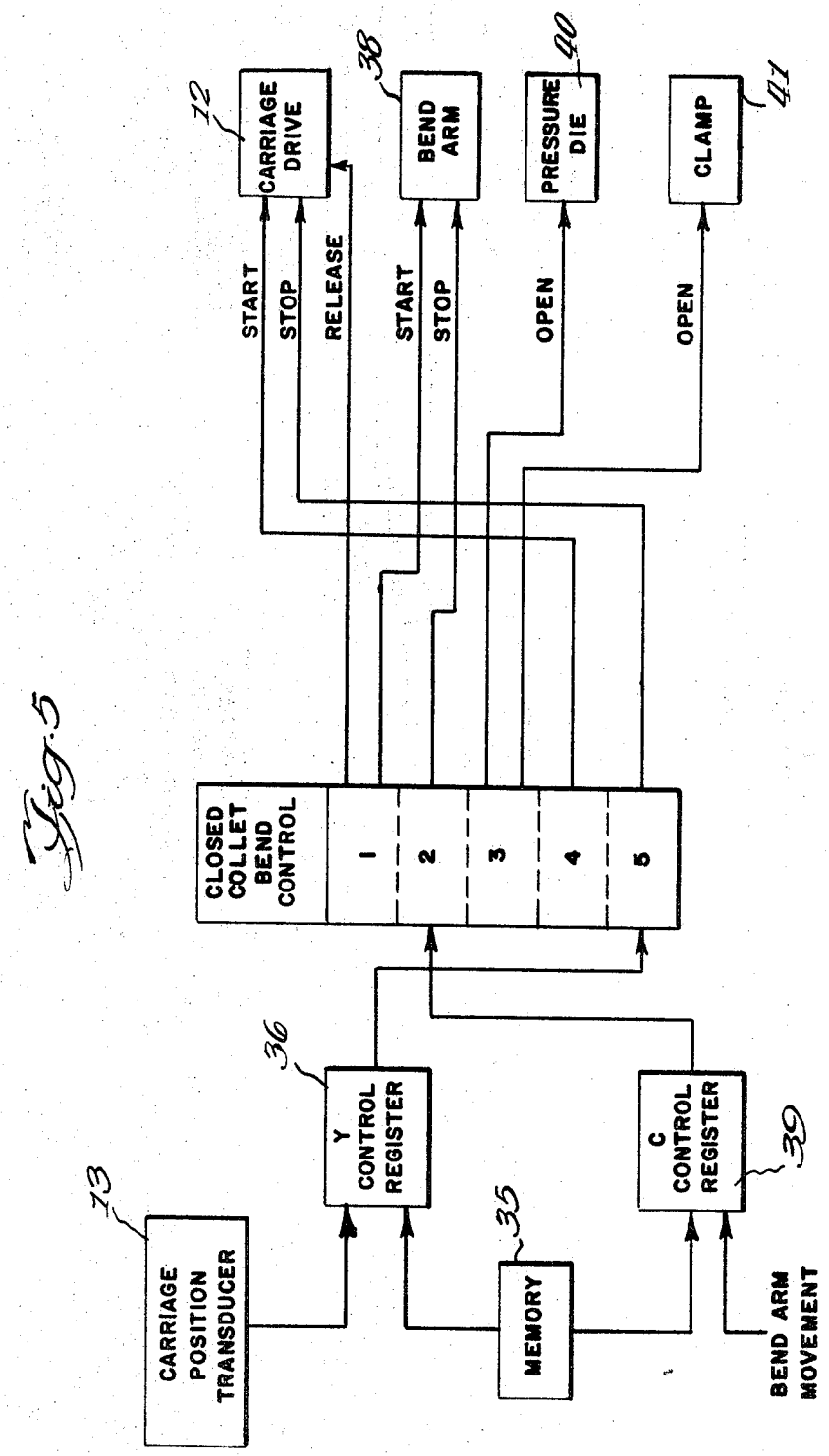


Fig. 5

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TUBE BENDER WITH INCREMENTAL TUBE MEASUREMENT

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ABSTRACT OF THE DISCLOSURE

A numerically controlled tube bender in which each bend is incrementally programed in terms of the distance between starting points of successive bends, the plane and the angle of the bends. The length of tube used in making each bend, which varies with tube characteristics, is subtracted from the programed dimension between the bend starting points and the distance between the end of the first bend and the start of the second bend is adjusted accordingly.

This invention relates to a numerically controlled tube bender with an incremental control program and automatic compensation for variation in the length of tube used in forming a bend.

In a rotary tube bender, for example, a tube is bent around a bending die, generally of circular configuration. The tube is deformed or stretched during the bending operation and the length of the tube used varies depending on the physical dimensions and characteristics of the tube. For example, the amount of elongation in forming a given bend varies with such factors as tube diameter, wall thickness, elasticity and temper of the material, and the like. The dimensions of the tube are known and can be taken into account in setting up the bending program. However, the temper and other physical characteristics may vary from tube to tube and cannot be anticipated in the program.

In an automatic tube bender each bend is specified in terms of its position along the length of the tube, the plane of the bend and the angle of the bend. It is preferable to program the bender for incremental operation in which the location of each bend is specified by the dimension between the starting point of the bend and the end point of the preceding bend. This dimension is readily available from a part drawing and can be incorporated directly in the control program without complicated calculations. However, variations which occur in the overall dimension of the ben tube as a result of difference in the deformation or stretch at each bend can exceed the dimensional tolerance for the part.

These variations can be compensated, at least in part, by programing the control for the bend spacing dimension to include the length of the bend, i.e., the programed dimension is from the start of one bend to the start of the next bend rather than the straight tube length between bends. The length of tube used in making the first bend is then deducted from the programed dimension to determine the distance to move for the next bend. In this way each bend and succeeding straight section have the correct total length.

One feature of the invention is that the bender has a carriage travel control including means determining the length of tube consumed in making the first bend, means for subtracting such length from the programed incremental bend position information and further means for advancing the carriage from the finish point of the first bend a distance corresponding to the difference, to reach the starting point for the second bend.

Another feature is that the tube bender has a carriage which holds the tube and in which the tube is fixed during the bend, together with means for measuring the carriage movement to determine the length of tube consumed in making the bend.

Yet another feature is that drive means for the carriage includes a servo drive motor and means are provided for energizing the motor to apply a forward torque to allow the carriage to move with the tube during formation of the bend.

And another feature is that the control includes a carriage control register with means for storing the incremental bend position information and responsive to a carriage position transducer to subtract carriage movement information from the programmed incremental bend location information.

Further features and advantages of the invention will readily be apparent from the following specification and from the drawings, in which:

FIG. 1 is a fragmentary diagrammatic plan view of a rotary tube bender at the start of a bend;

FIG. 2 is a fragmentary diagrammatic plan view of the bender at the end of a bend;

FIGS. 3 and 4 are diagrams of formed tubes with dimensions illustrating the operation of the invention; and

FIG. 5 is a functional block diagram of the portion of the bender control system which forms a part of the invention.

In the drawings and in the following description there is disclosed only so much of the bending machine and the control as is directly pertinent to the invention. Suitable apparatus for the other elements of the system are known and need not be described in detail here.

The bending machine has a base **10** on which a carriage **11** is mounted for longitudinal and rotary movement. A servo drive motor **12** powers the carriage while a carriage position transducer **13** provides position information to hte control. Carriage **11** includes a tube holding collet **14** which may be clamped on or released from the tube **15**, as desired.

Bending tools include a rotary bending die **17**, a tube clamp **18** and a pressure die **19**. Bending die **17** has a grove (not shown) in the side wall thereof with a depth slightly less than the radius of tube **15**. The bending die has a semicircular peripheral portion **17***a* at the left end and a straight-sided section **17***b* at the right end; and is rotatable about shaft **20** which is concentric with semicircular end portion **17***a*. Clamp **18** has an end face **18***a*, also provided with a tube receiving groove, which holds the tube **15** against the straight-sided section **17***b* of the bending die. The clamp is movable toward and away from the bending die by a drive means (not shown). Bending die **17** and clamp **18** rotate together, and with bending arm **21**, in forming a bend. Pressure die **19** has a tube receiving groove (not shown) in the face thereof and is movable toward and away from bending die **17** by a suitable drive means (not shown).

At the start of a bend, pressure die **19** is adjacent clamp **18** and during the bending operation, as the bending die rotates, the pressure die moves with the tube, holding the tube in the groove of the bending die and preventing it from bowing outwardly as a result of the bending force applied. When a bend is completed, the clamp **18** and pressure die **19** are retracted and the bending arm **21**, with the bending die **19** and clamp returned to the starting position. Tube **15** is then advanced to the point at which the next bend starts, by carriage **11**.

If the next bend is to be in a plane different from that of the first bend, the carriage **11** is rotated to locate tube **15** properly with respect to the plane of the bending die before the clamp **18** and pressure die **19** are closed.

Normally where the control is programed for incremental operation (i.e., for a carriage movement from the end of one bend to the start of another) collet **14** is opened or released and the carriage **11** is stationary during the bend. A length of tube sufficient to make the bend is pulled from the carriage during the bending operation. At the end of the bend, the collet closes and the carriage effects the programed translation of the tube to the next bend point. With the control described herein, the collet remains closed and the carriage moves forwardly as the tube is wrapped around bending die **17**.

During the bending operation, the forces applied to the tube tend to elongate it. The degree of elongation depends on several factors, including tube diameter, wall thickness, tensile strength and elasticity of material, its temper and the like. Physical characteristics of the material may vary from tube to tube, depending upon the homogeneity of the alloy, its treatment and other factors.

With a basic form of incrementally programed control, differences in tube elongation in forming the bends are ignored. The bender is controlled to provide a fixed distance between the end of one bend and the start of the succeeding bend, regardless of the amount of tube consumed in each bend. If the total length of the part is critical, a straight tube slightly longer than that which will be necessary can be used and the end cut off to fit after the bends are made. This is wasteful of material and requires an extra operation.

The diagram of FIG. 3 illustrates the problem encountered with an incremental bending program. A twelve foot tube is bent into a simple U-shape. Assuming that the starting point of FIG. 3 is at tube end **25**, the first motion programed is a carriage movement of 1.5 feet. Ninety degree bend No. **1** is then formed. From the end point of bend No. **1**, a longitudinal movement of the carriage of 6.0 feet is made to the starting point of bend No. **2**. A second 90° bend results in a U-shaped tubing configuration as shown. If the tube bends each use 0.5 feet, as contemplated by the program, the final end portion **26** has a length of 1.5 feet. However, if there are deviations in the amount of tube used in forming the bends, section **26** may have a dimension of 1.5 feet$\pm 2\Delta$ (where Δ is the deviation which may occur in one bend).

In accordance with the present invention, the formation of the tube is programed on a modified incremental basis, as illustrated in FIG. 4. Here, the programed carriage movement, is the dimension between the starting points of succeeding bends. Thus, the total length of tube used between point **28** (the start of bend No. **1**) and point **29** (the start of bend No. **2**) is fixed. Any variation in the length of tube used in forming bend No. **1** is compensated for by changing the length of the following straight section. In a tube having several bends the cumulative error resulting from variations in tubing characteristics is minimized.

In a straight incremental control, the programed information for each bend includes the bend location, as indicated by the distance from the end point of the preceding bend to the starting point of the next bend, the bend plane and the bend angle. In operation, the carriage moves the tube to the point at which the bend is to be made and rotates it to the appropriate point. Clamp **18** and pressure die **19** close, collet **14** opens and the bend is formed. The collet then closes, the pressure die and clamp open and carriage **11** moves the tube forward the incremental distance to the next point at which a bend is to be formed.

In the system disclosed herein, the programed information for the tube bend location is the dimension from the start of one bend to the starting point of the next bend. During the bending operation, collet **14** remains closed and the carriage moves forwardly as tube **15** is wrapped around the bending die. The length of tube consumed in making the bend is measured by position transducer **13** and is deducted from the total distance between bend

starts. Following release of the tube by the clamp **18** and pressure die **19**, carriage **11** moves the tube forwardly the remaining distance to the point at which the next bend starts. During the bending operation, servo drive motor **12** for the carriage is energized sufficiently to release the carriage to move with the tube **15** as bending die **17** turns.

The relevant portions of the control are illustrated diagrammatically in FIG. 5.

A memory **35** or other source of program information is connected with a carriage or *y*-axis control register **36**. Information regarding carriage movement **13** is also connected with the *y*-axis control register from position transducer **13**. At the start of the bending operation, the first section of the bend control provides a release signal to carriage servo drive motor **12** to permit carriage movement and a start signal to bend arm drive means **38**. A bend or *c*-axis control register **39** compares the bend arm movement with programed instructions from memory **35** and when the arm has turned through the appropriate angle, actuates the second section of the control to stop rotation of the bend arm **21**. During formation of the bend, the carriage **11** moves forwardly as the tube **15** is wrapped around the bending die **17**. The resulting movement information from transducer **13** is subtracted from the programed dimension in *y*-control register. At the end of the bending operation, section **3** of the control actuates pressure die drive means **40** and clamp drive means **41** to open both the pressure die and clamp. Section **4** of the control then starts carriage drive servo motor **12** which advances tube **15**, as the bending die is returned to its starting position (the control for this last action is not illustrated). Forward movement of the carriage is detected by transducer **13** and compared with the command information in *y*-control register, which is the difference between the programed dimension and the length of tube used in making the bend. When the carriage is moved forward the difference distance, section **5** of the control stops the carriage and the machine is ready to perform the next bending operation.

While we have shown and described certain embodiments of our invention, it is to be understood that it is capable of many modifications. Changes, therefore, in the construction and arrangement may be made without departing from the spirit and scope of the invention as disclosed in the appended claims.

We claim:

1. In a numerically controlled tube bender having tube bending means, a tube holding carriage movable to position a tube with respect to said bending means for formation of a bend having a starting point and a finish point, starting at a specific point located along said tube and a control for operating the bender in accordance with a program for forming a plurality of discrete bends having dimensional information including the starting point location of a second bend relative to the starting point location of a first bend, a carriage travel control, comprising:

means for determining the length of tube actually consumed between the starting point and finish point in making the first bend;

means for subtracting the length of tube actually consumed from the programed dimensional information relating the starting points of the first and second bends;

means for advancing the carriage from the finish point of the first bend a distance corresponding to the difference between the programed dimensional information relating the starting points and the length of tube actually consumed, to reach the starting point for the second bend.

2. The tube bender of claim **1** in which the tube is fixed with the carriage during the bend and including

means for measuring carriage movement to determine the length of tube consumed in making the bend.

3. The tube bender of claim 2 having carriage drive means and means operative during operation of the bending means to release said carriage from restraint by the carriage drive means.

4. The tube bender of claim 3 in which the carriage drive means includes a servo drive motor, and having means for energizing the motor at a release level during operation of the bending means.

5. The tube bender of claim 2 in which the carriage position transducer has an output which is subtracted from the programed starting points information.

6. The tube bender of claim 5 having a carriage control register with means for storing the starting points information and responsive to said carriage position

transducer to subtract carriage movement information from the programed starting points information.

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U.S. Cl. X.R.

72—11, 149, 159, 293, 319