Nov. 10, 1964 H. MUNRO 3,156,287

CONTROL MEANS FOR METAL FORMING APPARATUS

Filed Dec. 12, 1961 3 Sheets-Sheet 1

Fig. 1.

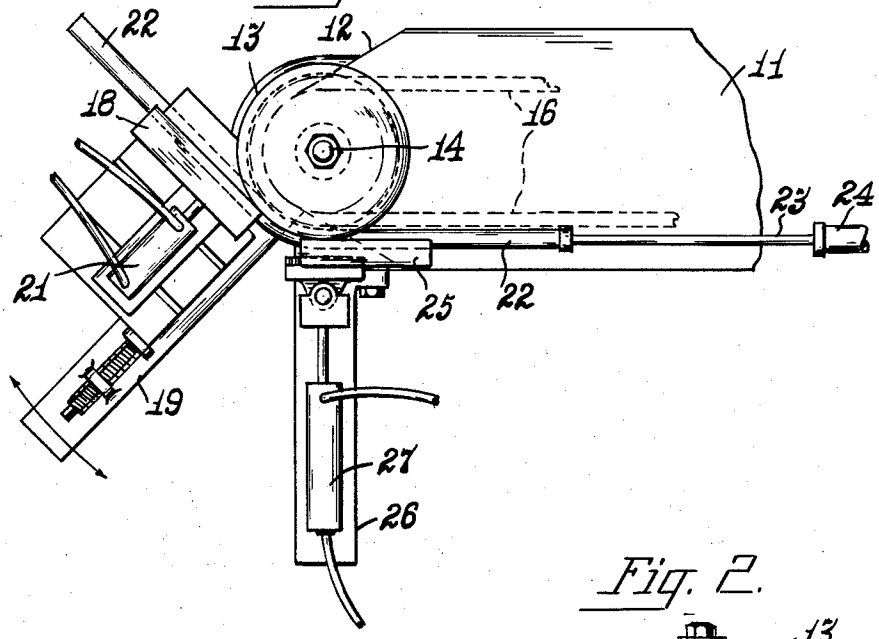


Fig. 2.

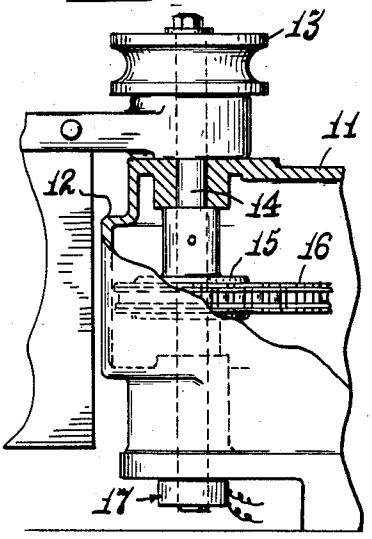
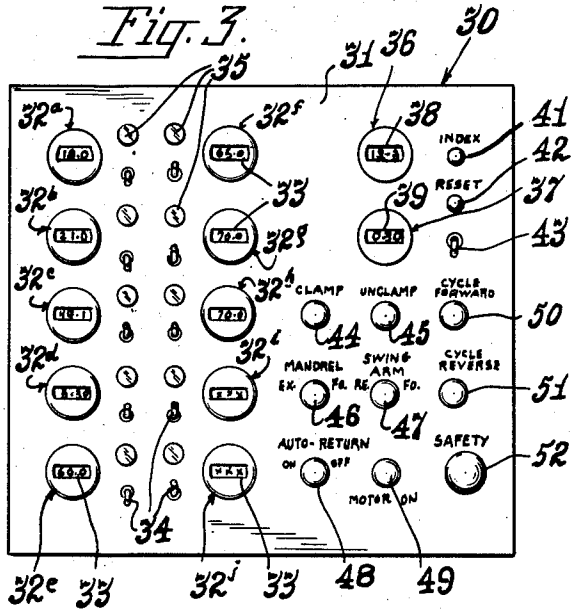


Fig. 3.



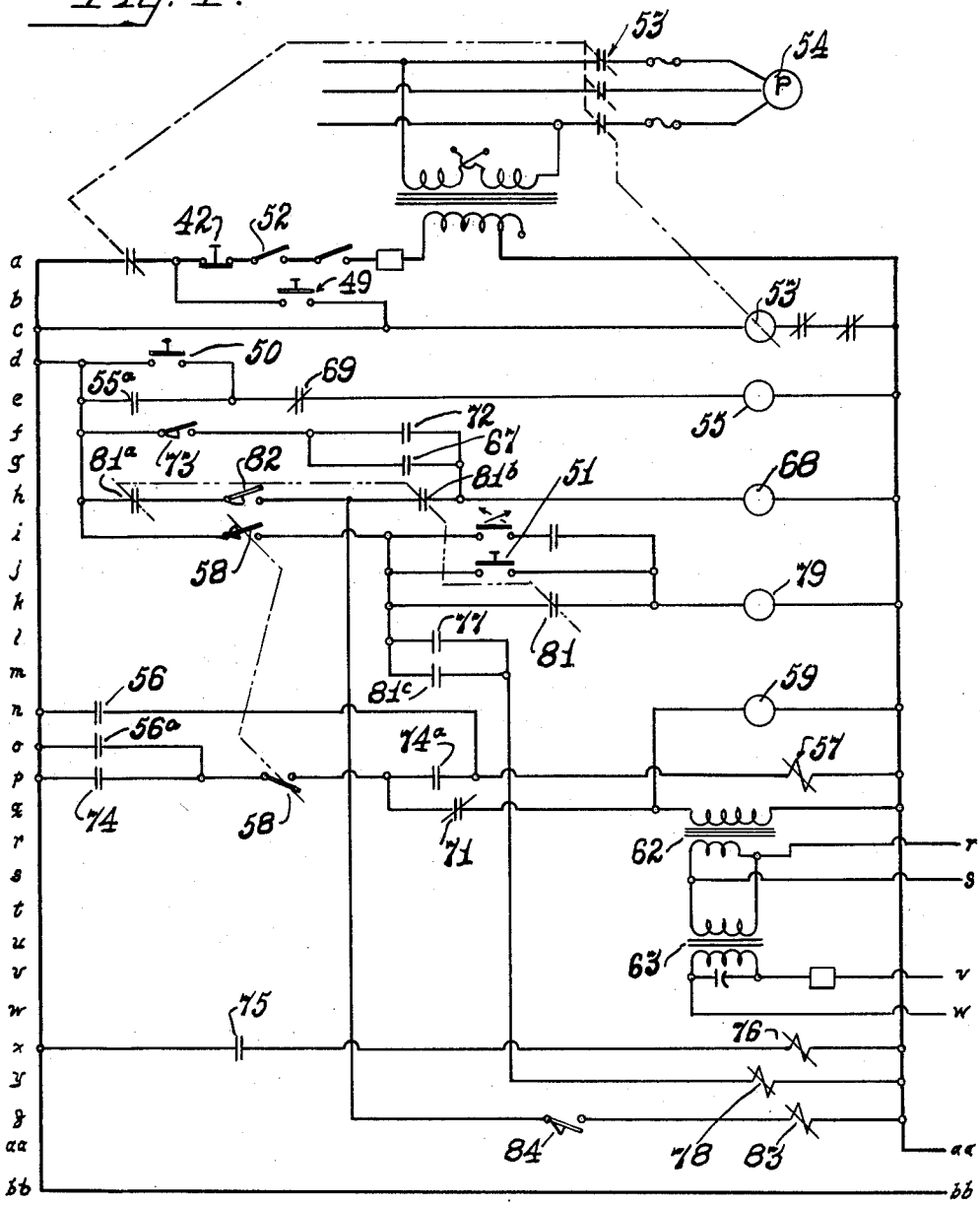
INVENTOR.
Harrison Munro.
BY
Charles H. Kinnan
Attorney

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CONTROL MEANS FOR METAL FORMING APPARATUS

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Fig. 4.



INVENTOR.
Harrison Munro.
BY Charles N. Redman
Attorney.

Nov. 10, 1964 H. MUNRO 3,156,287

CONTROL MEANS FOR METAL FORMING APPARATUS

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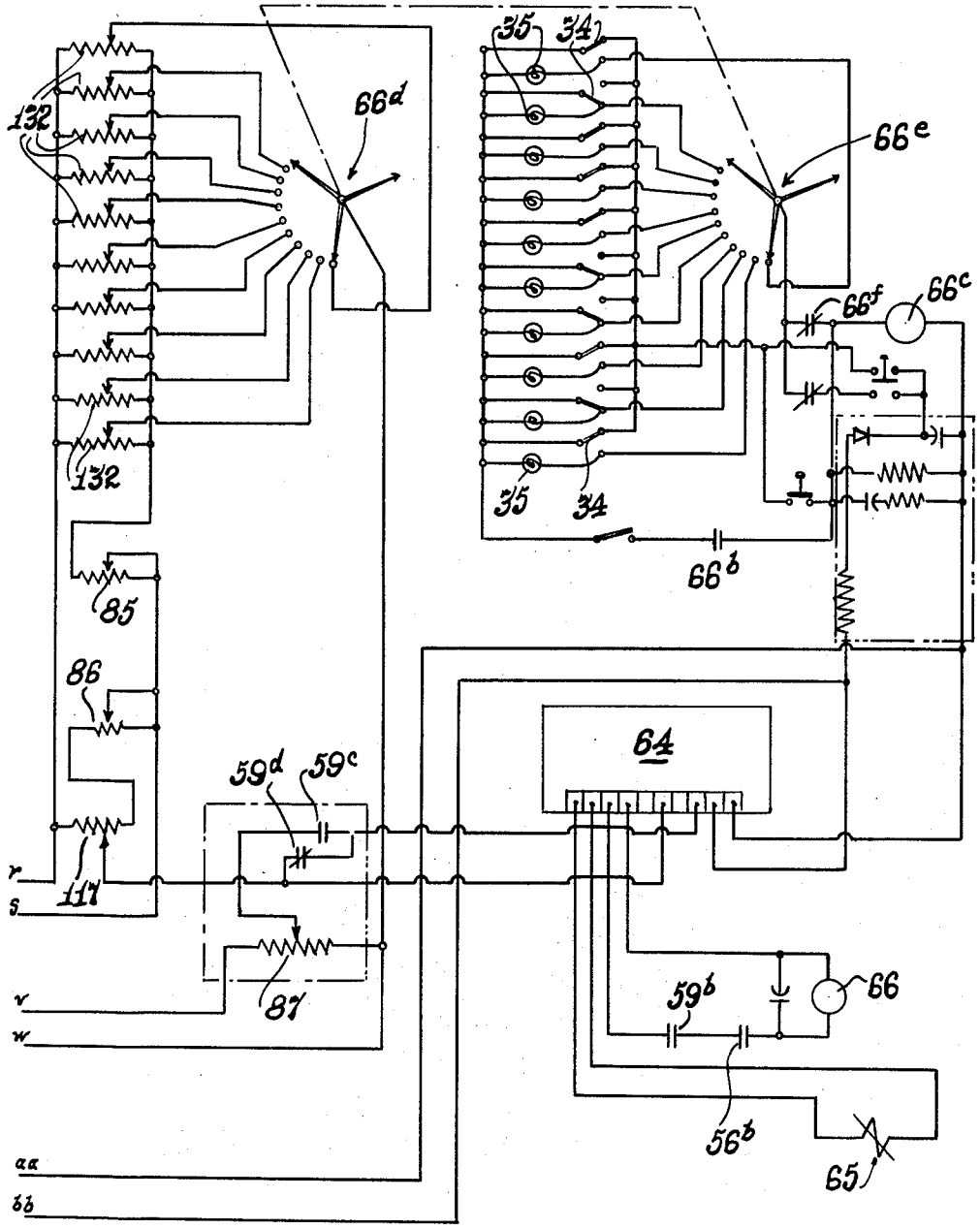


Fig. 4a.

INVENTOR.
Harrison Munro.
BY
Charles A. Redman
Attorney.

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3,156,287

CONTROL MEANS FOR METAL FORMING APPARATUS

Harrison Munro, Aurora, Ill., assignor to Pines Engineering Co., Inc., Aurora, Ill., a corporation of Illinois

Filed Dec. 12, 1961, Ser. No. 158,909
12 Claims. (Cl. 153—40)

The present invention relates to improvements in metal forming apparatus and is particularly concerned with the method of and means for programming metal forming operations of a nature wherein the spring-back characteristics of the workpiece enters into the operation.

Metal forming operations such as tube bending operations are performed in press and rotary bending machines. Insofar as the controls herein disclosed are concerned, the operations of these machines are essentially the same. For example, in rotary tube bending apparatus of the character disclosed herein, in an exemplary form, and by way of example, the tubing to be bent is positioned over a mandrel and is made to conform to the shape of a rotatable bending die by the operation of a pressure die. A clamp die is used to hold the end of the tubing in place against the bending die. The clamp die is carried on a swinging arm which is rotated about the axis of the bending die a distance required to perform the requisite bend in the tubing. As the bending die is carried around, the tubing is drawn along with it and the bending die defines the actual bending of the tubing. In press type benders, actual bending of the workpiece is effected by means of wing dies that carry the workpiece around the bending die carried on the end of a ram.

It will be appreciated that in bending operations, the wall of the tubing at the outside of the curve is subjected to a terrific tension and this tension increases as the radius of the bend is made smaller. As a result, there is a natural tendency for the tubing, upon being released at the completion of a bending operation, to spring back slightly and as a consequence it is difficult to hold the bend to its intended radius.

In known tube bending machines allowance is made in the rotation of the bending die to effect an overbend intended to compensate for the spring-back characteristics of the workpiece. However, in such known instances it is usually necessary to adjust each of the pre-set angles independently, or in some cases provision may be made to apply a constant degree of overbend to all of the pre-set angles. Constant control of the bend has proven to be unsatisfactory where precise bending is required primarily because such constant control fails to take into consideration the changes in the amount of spring back present when a given workpiece is bent to different angles or radii.

The present invention has as an advantage the provision of automatic means for effecting accurate and precise setting of the bending dies to cause them to function in a precise manner to effect the requisite amount of overbend in order to insure that the finished workpiece has the precise bend intended. The herein disclosed control apparatus also includes novel means that enables the operator to set-up the apparatus for programming a plurality of bends in sequence, which may be alike or which may vary according to the predetermined setting of the controls thereof. This is accomplished in the present instance, by associating with any tube bending apparatus of substantially conventional construction, a novel electronic control system that is operable to allow the bending apparatus to perform a single bending operation or a series of bending operations, selectively or automatically, for performing like or different bends in any selected sequence. The control system functions also to control operation of the bending mechanism with maximum accuracy through pre-setting of the control system to compensate for both constant and proportionate spring-back in the workpiece.

Such precision control is accomplished electrically, following initial determination of the potential spring-back through test bending of two like workpieces and transposing calculated error in the bends directly to compensating devices in the electronic control apparatus which then functions in combination with other control elements to affect machine operation in a manner to produce the required overbend for a given workpiece. The present invention has the additional advantage of adopting the bending apparatus for automatic programmed operation for feeding, clamping, bending and releasing workpieces successively fed thereto without readjustment of any of the controls or parts thereof, while insuring at all times that the repeated bends of the same intended angle are alike in every respect and respond to the required angle of bend.

The electronic bend control system herein disclosed includes a novel control panel which incorporates a plurality of individual control elements, hereinafter referred to as "angle dials," each of which is pre-set and is effective to cause operation of the bending apparatus for performing a predetermined bend in a workpiece fed thereinto. These angle dials are connected in the control circuit in a manner to be effective in a predetermined sequence but, if desired, any one or more of them may be cut out of the circuit without interrupting sequential operation of the angle dials left in the circuit. This control panel and the selective control of the effectiveness of any one or more of the angle dials and other controls therein allows more than one job to be programmed. It is therefore another advantage of this invention to provide novel means for programming the operation of a metal forming apparatus, which means is selectively actuable to perform one or more operations on the workpiece.

Other and more detailed advantages and objects of the invention will appear more fully as the description proceeds, reference being made to the accompanying drawings wherein a preferred exemplary embodiment of the invention is shown. It should be understood, however, that the drawings and description are illustrative only and should not be taken as limiting the invention except insofar as it is limited by the appended claims.

In the drawings:

FIG. 1 is a fragmentary plan view of an exemplary form of tube bending apparatus;

FIG. 2 is a fragmentary vertical sectional view, showing parts in elevation, of the swivel mounting for the secondary frame;

FIG. 3 is a plan view of an exemplary control panel; and,

FIGS. 4 and 4*a* are schematic views of the electric circuitry of the control apparatus.

Referring now in detail to the exemplary form of rotary bending machine shown in FIGS. 1 and 2, and selected for purposes of illustration, said machine includes a base frame 11, shown in part only, having a vertical journal housing or nose 12 at one end which mounts the tube bending assembly. As shown, said assembly includes a bending die 13, mounted firmly on the upper end of a vertical spindle 14 journalled in the nose housing 12. The spindle mounts a sprocket 15 over which a driven chain 16 is trained for imparting rotation to the spindle and bending die. Also mounted on spindle 14 is a control element generally indicated at 17, which in the present instance includes an angle feed-back potentiometer driven by a gear train from said spindle. The potentiometer is connected in the electric control circuit and functions for a purpose and in a manner all to be described presently.

The bending apparatus also includes a clamp die 18

mounted on the top of a secondary frame 19, hereinafter referred to as the swinging arm, extending radially from nose 12, and which is mounted on the spindle 14 so as to be rotatable therewith when said spindle is driven by operation of drive chain 16. Clamp die 18 is movable radially relative to bending die 13 by means of a cylinder-piston assembly 21. The clamp die functions to clamp a tube 22, to be bent, firmly against bending die 13. During a bending operation, a mandrel is frequently supported within the tube by mandrel rod 23 in order to support the outer wall of the tube and prevent excessive flattening. This mandrel may be extracted automatically at the end of the bending cycle by a suitable hydraulic cylinder 24.

A pressure die 25 is supported on a stationary frame 26 and mounted for reciprocation toward and away from bending die 13. A hydraulic piston-cylinder assembly 27 is provided for effecting such reciprocation and the pressure die functions to apply the necessary bending movement to the tube forcing it to conform to the curved section of bending die 13 as said die rotates during the bending operation. Pressure die 25 may be so mounted on its supporting assembly as to be free to advance with the tube thereby to minimize frictional effects on the tube. Both cylinder-piston assemblies 21 and 27 are connected to a suitable source of compressed fluid and the operation of the assemblies, as well as operation of mandrel rod 23, is controlled by the sequential operation of conventional hydraulic control valves (not shown). The drive for drive chain 16 is controlled through actuation of the novel electronic control mechanism to be described presently.

Operation of the apparatus, insofar as it has been described, is substantially as follows:

A length of tubing 22 to be bent is clamped firmly between bending die 13 and clamp die 18. Mandrel rod 23 is advanced into bending position and pressure die 25 is moved into tight engagement with the portion of the tubing to be bent. The secondary frame 19 is then rotated to bend the tubing around bending die 13. Such rotation continues until the desired angle of bend is accomplished whereupon the parts return to their initial positions for repeat operation after the tubing has been repositioned or replaced by another length of tubing.

As stated hereinabove, the material of the tubing has an inherent tendency to spring back when pressure thereon is relieved. Consequently, it is necessary, if accurate bending is to be accomplished, to provide means for overbending the tubing a precise amount to compensate for such spring back. Mere overbending at a constant degree is not sufficient, hence applicant has provided, by the herein disclosed control system, novel means functional in proportion to the percentage of overbend required to co-act with the constant degree overbend control to insure accuracy in the finished product. Before entering into a detailed discussion of the herein disclosed exemplary electrical system provided, not only to accomplish precision control of bending, but also to provide for automatic programming of a series of bends of like or different angles, any one or all of which may be selectively performed, reference is made to the novel exemplary control assembly 30 illustrated in FIG. 3.

The electric components of the control assembly preferably are enclosed within a substantially square shallow box-like structure (not shown) that may be mounted in any conveniently accessible position adjacent to the bending apparatus. The assembly includes a top panel 31 having a plurality of manually adjustable bend-control elements 32 (hereinafter termed angle dials) each including a precision signal potentiometer (not shown in this figure) having a 3-digit direct reading dial 33 thereon. In the present disclosure there are ten such angle dials, identified as 32*a* through 32*j*. The angle dials are each set in accordance with the angle of bends desired and their potentiometers are connected in an electric circuit to be described presently. Panel mounted on-off switches 34 and indicator lamps 35, are mounted on the panel, one each for each angle dial, the latter being operable to afford a visual signal when a specific angle dial is connected in the circuit.

The panel also mounts a pair of compensating potentiometers connected in said circuit (not shown in FIG. 3) having control dials 36, 37, each mounting a 3-digit direct reading dial 38, 39, respectively. The dials 36, 37, hereinafter termed compensation dials, are provided to permit dialing the critical "overbend" to allow for tube spring-back. One of these compensation dials 36, 37 is adjusted to cause a constant degree or overbend to be added to all pre-set angles whereas the other dial is adjusted to add a predetermined percentage of overbend to each angle. Thus the constant and percentage overbend cooperate to insure workpiece accuracy.

The purpose of providing a plurality of angle dials 32 and an on-off switch 34 for each is to allow more than one bend to be made in sequence in a workpiece and also to allow more than one job to be programmed in advance by switching only the desired potentiometers into the operating sequence. Thus, one may preset any one or more of the direct reading dials 33 and, during sequence operation, any one or more of the direct reading dials and their potentiometers, that may be cut out of the circuit by moving its switch 34 to "off" position, is passed over automatically. Accordingly, an operator can perform one or more bends of like or different pre-selected angles in a single work piece by manual or automatic operation.

Other components mounted on control panel 31 for ready accessibility by the operator are a manual index button 41, a sequence reset button 42, an automatic index toggle switch 43, and, in this instance, nine machine control buttons numbers 44 to 52, inclusive, operable manually to effect clamping, unclamping, mandrel withdrawal and advancing, swinging arm control, automatic return or reset button, motor start, cycle forward and reverse and safety button. It should be observed at this time that fewer or more angle dials 32 and control buttons may be used depending upon the specific type of machine to be controlled thereby.

In calculating the settings for the proportional and constant compensation dials 36, 37, it is assumed that spring-back in the material to be bent has the nature of a straight line function which can be expressed by the mathematical formula X plus NY; where X is the amount of constant compensation, Y is the percentage of proportional compensation, and N is the angle of the bend to be attained. Two test bends are made having different angles, and the resultant bends are carefully measured. The difference or error (E) between the actual bends and the angles set on the angle dials 32 used for test is carefully measured and, using the formula E equals X plus NY for the two bends, the results give the values of X and Y which may then be set into the proportionate and constant compensation potentiometer dials 36, 37 respectively, so that the compensation curve of the machine will closely approximate the true spring-back curve of the material being bent. Each time the tooling set-up or material changes, a new pair of test bends is made. However, additional test bends need not be made to accurately reproduce many different parts made from the same material with the same tooling set-up.

As an example of determination of the setting of the control dials 38, 39, the operator will make two test bends in tubing to be processed with the set angle (dials 32) of one bend twice that of the other, such as setting the angle of one at 90° and the other at 45°. The actual bends are then carefully measured, and if for example, the intended 90° bend measures 88.5° there is an error of 1.5°; and should the intended 45° bend measure 44.1°, there is an error of .9°. These error figures are then translated into readings that may be

applied directly to the two compensation control dials 36, 37 on control panel 31.

Thus, using the aforesaid figures in the formula above recited we have:

$$X=\frac{1.5-.9}{45}=\frac{.6}{45}=.0133\times 1000=13.3$$

and

$$Y=(2\times .9)-1.5=1.8-1.5=.3\times 10=3.0$$

The calculated reading 13.3 is applied to the proportionate direct reading dial 38, whereas the reading 3.0 is applied to the constant direct reading dial 39.

As will be more fully explained hereinafter, the proportionate and constant readings on direct reading dials 38–39 are electronically added to the dial readings of angle dials 32 which are set at the required angles to be performed. The resulting overbend will be such that when the workpiece is removed from the apparatus it will have an angle of bend equal to the input angle regardless of variation in tool set-up and metal.

The selective setting, operation and functions of the various controls on control panel 31 will best be understood from the following description of a normal operating cycle of the apparatus taken in cnjunction with reference to the control circuitry illustrated in FIGS. 4 and 4*a*.

After determining the angle of bends through adjustment of angle dials 32 and compensation dials 36, 37, making the tool set up, and positioning a length of tubing in the bending apparatus, the operator presses "start motor" button 49 (level *b*) on control panel 31 to energize motor starting coil 53 (level *c*) and start operation of a pump motor 54 for generating hydraulic pressure for operation of the various cylinder-piston assemblies in the apparatus.

The "cycle forward" button 50 (level *d*) is then depressed to energize a forward cycle relay 55 (level *e*). Energizing the coil of relay 55 closes relay contacts 55*a* (level *e*) creating a holding circuit to maintain energization of the coil of relay 55. Energizing coil 55 also closes relay contacts 56 (level *n*) energizing "clamp" solenoid 57 (level *p*) to actuate the hydraulic valve causing the clamp and pressure dies 18, 25, to advance against the workpiece. Energizing coil 55 also closes contacts 56*a* (level *o*) completing a circuit through switch 58 (level *p*), which is in closed position with the mandrel advanced, to energize a bend control relay coil 59 (level *n*) and also energize transformers 62 and 63 supplying reference voltage to a bridge network supplying an amplifier unit 64 (FIG. 4*a*).

The clamp die 18 and pressure die 25 now close against the tube and the valve controlling bending operation of the swinging arm 19 is energized by output from amplifier 64 and the swinging arm 19, carrying said clamp die 18, rotates to bend the trailing end of the tube around bending die 13. During rotation of said swinging arm, the angle feed back potentiometer 117 (FIG. 4*a*) of control element 17 is driven. When the electrical position of the angle feed back potentiometer 117 matches that of an angle setter potentiometer 132 (angle dials 32*a*–32*j*) that is at that time connected in the circuit, the bridge network is balanced and the input to amplifier 64 will reach a null, with its output now dropping to zero. When this occurs, a bend solenoid 65 (FIG. 4*a*) is de-energized. Simultaneously, a secondary output of the amplifier 64 energizes a coil 66 through contacts 59*b* which have been closed by energizing bend control relay 59 and contacts 56*b* which were closed by energizing forward control relay 55. Energizing coil 66 closes contacts 67 (level *g*) to supply current to the "unclamp relay" 68. Other contacts 66*b* on relay 66 complete the circuit to the actuating coil 66*c* of a stepping switch 66*d*–66*e*. Energizing coil 66*c* moves the ratchet pawl (not shown) of stepping switch 66*d*–66*e* so that when coil 66*c* is de-energized, as will be explained presently, the stepping switch will be advanced to the next position preparatory to making the next bend in sequence. Normally closed contacts 69 (level *e*) are opened by coil 68, deenergizing coil 55 (level *e*) and releasing all contacts previously actuated by this coil.

Normally closed contacts 71 (level *q*) are also opened by energizing of coil 68, and these contacts de-energize bend control relay coil 59 as well as reference voltage transformers 62 and 63. Contacts 59*c* and 59*d* (level *q*) are released by de-energizing coil 59 causing the input to amplifier 64 to be short circuited so that its output remains at zero. Simultaneously, the previously closed contacts 59*b* are released by de-energizing relay coil 59, and contacts 56*b* (level *w*—FIG. 4*a*) are released by de-energizing coil 55. Relay coil 66 is therefore de-energized, opening contacts 67 which have already been bypassed by contacts 72 (level *f*), and also opening contacts 66*b* de-energizing coil 66*c*. When coil 66*c* is de-energized, the spring-loaded ratchet causes stepper 66*d*–66*e* to be advanced to the next position.

If the next position of contact 66*e* on the stepper corresponds to a position in which a switch 34 is in the "off" position, a circuit will be immediately completed through the closed contacts of this switch through stepper 66*e*, through the closed contacts of some other switch 34 which is in its "on" position, and through interrupter contacts 66*f* to again energize coil 66*c*. When coil 66*c* is thus again energized, normally closed interrupter contacts 66*f* will be opened causing coil 66*c* to immediately again be de-energized. This causes the stepper 66*d*–66*e* to progress one additional step as coil 66*c* is de-energized. This sequence of energizing and de-energizing coil 66*c* is repeated at a very rapid rate until wiper 66*e* of the stepper arrives at some position in which the corresponding switch 34 is in the "on" position. When wiper 66*e* arrives in such a position, the circuit to coil 66*c* will no longer be completed except through one of the indicator lights 35. However, these indicator lights have such a high electrical resistance that they will light without passing sufficient current to actuate coil 66*c*. Thus, the position of stepper 66*d*–66*e*, and hence the angle setter pot 132 presently connected in the circuit will be indicated by the glowing lamp 35. Although any suitable stepping switch assembly may be used applicant has found that one known as Clare type 210 is very efficient in its function to index from one bend angle to the next as a multiple bend workpiece is formed.

When "unclamp" control relay coil 68 is energized, contact 72 (level *f*) creates a holding circuit for relay 68 to maintain it energized until switch 73 (level *f*) is opened upon opening movement of the pressure die slide 25. Contacts 74 and 74*a* (level *p*) maintain the "clamp" solenoid 57 energized while the mandrel is being extracted. Contact 75 (level *x*) energizes the "mandrel extract" solenoid 76 (level *x*) thus shifting the mandrel control valve into the extract position to pull the mandrel from the workpiece. When the mandrel is extracted, the switch 58 which has contacts at levels *i* and *p*, is actuated in this instance to open a circuit through switch contacts 58 at level *p* to de-energize the clamp circuit to solenoid 57 and to close a circuit at level *i* through a contact 77 (level *l*) to "unclamp" solenoid 78, the clamp control valve is thus shifted from "advance" to "retract" position and the clamp die 18 and pressure die 25 are retracted, releasing the workpiece. When the pressure die 25 is fully opened, "unclamp" switch 73 (level *f*) is opened, thus de-energizing relay coil 68 releasing all relay contacts previously actuated and stopping the machine cycle to permit removal of the workpiece.

At this time the operator presses the "cycle reverse" button 51 (level *j*) to close a circuit through the presently closed contact of limit switch 58 (level *i*) energizing coil 79 of the "reverse cycle" relay. Contacts 81 on

the "reverse cycle" relay are closed when relay coil 79 is energized, creating a holding circuit through the aforementioned contacts on limit switch 58. Relay 79 has contacts 81*a*, 81*b* at level *h* which are likewise closed to complete the circuit to relay 68 through the now closed normally open switch 82 (level *h*). Contacts 77 on relay 68 as well as contacts 81*c* on relay 79 again energize the "unclamp" solenoid 78. Contacts 81*c* (level *m*) maintain solenoid 78 (level *y*) energized after relay 68 has been de-energized as will be described presently.

An "arm return" solenoid 83 (level *z*) is energized by relay contact 81*a*, normally closed contacts on arm return limit switch 82 (level *h*), and presently closed normally open contacts on "unclamp" limit switch 84 (level *z*) and the swinging arm 19 returns to its initial or start position against actuating switch 82 to open same. When the circuit through switch 82 is interrupted and said relay 68 is de-energized, with the result that the "mandrel extract" solenoid 76 is de-energized also so as to allow the mandrel control valve (not shown) to shift back into mandrel advance position.

During the period of operation when the "unclamp" solenoid 78 is maintained energized through the closed switches 58 and relay contacts 81*c*, the hydraulic system pressure is maintained and the mandrel 23 moves forwardly to its advanced position. When reaching its forward position, the mandrel actuates dual switch 58 so as to de-energize the "reverse cycle" relay 79 and all solenoids previously energized. As a consequence, the hydraulic pressure system is vented and the clamp 18 and pressure die 25 are ready either for receiving another workpiece or for repositioning of the workpiece previously bent.

Although any conventional potentiometers 132 having high precision characteristics may be used, applicant has found that a potentiometer commercially known as "Model 205-Micropots" manufactured by Borg Equipment Co., is very efficient. As hereinabove stated, these potentiometers are each equipped in the present instance with a digital dial 33 which may correspond to those commercially known as "Microdials," and distributed by Borg Equipment Co. The feed-back potentiometer mounted in control unit 17 and driven by the spindle on the machine is a high precision one-turn potentiometer corresponding to "Model 400" manufactured by Spectrol Electronics Corp. The feed-back potentiometer is driven by a gear train having gain a ratio of 4 to 7 in order to provide 350° of potentiometer rotation to represent bender spindle rotation of 200°.

The potentiometers controlled by the proportionate and constant compensation potentiometer controls 36–38 and 37–39, respectively, are the same as those used for angle setting except for resistance value. In the instant disclosure, a ten ohm trimming potentiometer 85 similar to those manufactured by Bourns of Riverside, California, under the trademark "Trimpot" is installed in series with the voltage supply to the angle setter potentiometers 132 for calibration purposes. In the disclosed circuit the proportional compensation potentiometer 86, which is connected in series with the angle feed-back potentiometers 132, has a value of approximately $\frac{1}{10}$ the resistance of potentiometers 132.

Accordingly, adjustment of the potentiometer 86 will alter the total resistance of the angle feed-back potentiometer 132 in circuit with the result that the actual angle through which the spindle 14 will rotate will be increased or decreased proportionately before the system reaches a null. As stated, this variation is a proportional variation, that is, it will increase spindle rotation required to reach a null by an amount directly proportional to the setting of the effective angles setter dial 33.

Transformer 63 is provided with an isolated secondary winding to produce a voltage equal to a predetermined fixed portion, in this instance $\frac{1}{20}$, of the main reference circuit. It is this bias voltage that is applied across the

"constant" potentiometer 87 and a portion of this "bias" voltage is then applied in series with error signals applied to the input to amplifier 64. This voltage produces a fixed but adjustable offset to the set angle so that all angles set on the angle setter dials 33 are increased by a fixed amount.

Although the exemplary bend control apparatus and system herein disclosed is equipped with ten angle center potentiometers, it should be apparent that fewer or more potentiometers may be provided and that input may also be taken from other methods of numerical input presently in use, such as punched paper tape or cards fed through a reader or other translating equipment.

It should be understood further that when the herein disclosed control system is incorporated in a press type bending machine, in which the workpiece is formed between a ram-driven radiused die, and a pair of rotatable wing dies, the output signal from amplifier 64 is used to control movement of the ram while the angle feed back mechanism 17 is operably connected to one of the wing dies for operation in response to its movement.

From the foregoing description it is believed that the nature and advantages of my invention and the manner in which it is to be carried out will be readily apparent to those skilled in this art.

What I claim and desire to secure by Letters Patent of the United States is:

1. Control means for a tube bending machine of a type including a bending die and a clamp die rotatable with said bending die and means to rotate said dies and controlled by said control means, said control means comprising an electric circuit, a first variable resistor in said circuit, a plurality of second variable resistors arranged to be connected in a network with said first resistor, a relay in said circuit actuable to connect a selected second resistor in said circuit, a third and fourth variable resistor effective to vary the resistance of the selected second resistor, said resistors functioning when the electrical position of the first variable resistor matches the resistance of the selected second resistor, and means to actuate said relay for connecting a different second variable resistor in said circuit.

2. Control means for a tube bending machine including a bending die and a clamp die rotatable with the bending die, said control means including an electric circuit, a group of first control devices in said circuit selectively adjustable for varying the amount of rotation of the dies during successive bending operations, second control devices in said circuit selectively adjustable to increase the amount of rotation of the dies determined by the setting of said first control devices to effect overbending of the tube by an amount commensurate with the pre-determined spring-back characteristics of the tubing.

3. Control means for a bending machine including a bending die and a clamp die rotatable with said bending die, said means including a group of first control devices for selectively varying the amount of rotation of the dies during successive bending operations, a pair of second control devices for selectively increasing the amount of rotation of said dies determined by the setting of the first control devices to effect overbending of a workpiece by an amount commensurate with the pre-determined spring back characteristics of the workpiece.

4. In a bending machine, a pressure die, a bending die, a clamp die, means operable to move the pressure die into and out of workpiece holding positions, means operable to rotate the clamp die and bending die for bending a workpiece, control means for said operable means, said control means comprising an electric network including pre-set bend control potentiometers and a feed-back potentiometer, said feed-back potentiometer being adjustable in unison with rotation of the clamp and bending dies, and manually pre-set proportionate and constant compensation potentiometers connected in said network to all of said bend-control potentiometers to effect overbending of the

workpiece to a degree necessary to compensate for spring-back in the workpiece.

5. In a bending machine, a pressure die, a bending die, and a clamp die, means operable to move the pressure die into and out of workpiece holding positions, means operable to rotate the clamp die and bending die for bending a workpiece, control means for said operable means, said control means comprising an electric network including pre-set bend control potentiometers and a feed-back potentiometer, said feed-back potentiometer being connected to and adjustable during rotation of the clamp and bending dies, and manually pre-set proportionate and constant compensation potentiometers connected in said network to all of said bend control potentiometers to effect overbending of the workpiece to a degree necessary to compensate for spring-back in the workpiece.

6. In a tube bending machine, a bending die, pressure means adapted to grip a workpiece and hold it in position against said die, a rotatable clamp die, means operable to rotate the clamp die and bending die in unison, a plurality of control means separately operable to actuate said operable means to rotate said dies a predetermined distance for bending the workpiece around the bending die each time one of said control means is actuated, said control means including means effective to overbend the workpiece a distance sufficient to compensate for normal spring-back in the workpiece material, and means operable to effect selective operation of said control means.

7. Control means for a bending machine, said control means including a normally open main electric circuit, means actuable to close said circuit to supply reference voltage to a bridge network supplying an amplifier unit, holding relays in said circuit, an angle feed back potentiometer in said output circuit, a plurality of angle setter potentiometers selectively connected in the circuit of the angle feed-back potentiometer, said angle feed-back potentiometer being effective when its electrical position matches the electrical position of an angle setter potentiometer connected in said output circuit to balance the bridge-network and reduce the amplifier output to zero and stop die rotation, additional controls in said circuits effective when said output reaches zero to return all control elements to their initial positions, and a selector relay operable to connect other pre-selected angle setter potentiometers in the circuit.

8. Control means for a hydraulic tube bending machine of a type including a mandrel, a rotatable bending die, a tube holding die and a clamp die rotatable with the bending die, said control means including a normally open main electric circuit, switch means actuable to close said circuit to supply reference voltage to a bridge-network supplying an amplifier unit, holding relays in said circuit, an adjustable angle feed back potentiometer in said output circuit, a plurality of angle setter potentiometers selectively connected in the circuit of the angle feed back potentiometer, said angle feed back potentiometer being effective when its electrical position matches the electrical position of an angle setter potentiometer connected in said output circuit to balance the bridge network and reduce the amplifier output to zero, and a selector relay operable to connect other pre-selected angle setter potentiometers in the circuit.

9. Control means for a hydraulic tube bending machine of a type including a bending mechanism, said control means including a normally open main electric circuit including an amplifying unit, means actuable to close said circuit to supply reference voltage to a bridge network supplying said amplifier unit, a plurality of angle setter potentiometers selectively connected in the circuit of the angle feed back potentiometer, said angle feed back potentiometer being effective when its electrical position matches the electric position of an angle setter potentiometer connected in said output circuit to balance the bridge network and reduce the amplifier output to zero, and a selector relay operable to connect another pre-selected angle setter potentiometer in the circuit.

10. In a bending machine of a type including a mandrel, a bending die and a workpiece clamping die rotatable with the bending die, control means for said machine including a normally open main electrical circuit including an amplifier unit, a switch actuable to close said circuit and supply reference voltage to a bridge network supplying said amplifier unit the output of which actuates means to rotate the dies, holding relays in said circuit, an angle feed back potentiometer in said output circuit driven during rotation of the dies, a plurality of angle setter potentiometers adapted to be selectively connected with said angle feed back potentiometer, said angle feed back potentiometer being effective when its electrical position matches the electrical position of an angle setter potentiometer connected in said circuit to balance the bridge network and reduce the amplifier output to zero and stop rotation of the dies, and additional controls in said circuits effective to stop the operating cycle.

11. In a machine including apparatus for bending a workpiece, control means for said machine including a normally open main electric circuit including an amplifier unit, switch means actuable to close said circuit to actuate the machine and to supply reference voltage to a bridge network supplying the amplifier unit, the output of which actuates the workpiece bending apparatus, holding relays in said circuit, an angle feed back potentiometer in said output circuit driven during a bending operation, a plurality of angle setter potentiometers adapted to be selectively connected in said output circuit, said angle feed back potentiometer being effective when its electrical position matches the electrical position of a selected angle setter potentiometer connected in said output circuit to balance the bridge network and reduce the amplifier output to zero and stop the bending operation, and additional controls in said circuits effective when said output reaches zero to return all controlled elements to their initial positions and stop the machine cycle.

12. In a machine including apparatus for bending a workpiece, said control means including a normally open main electric circuit including an amplifier unit, switch means actuable to close said circuit and to supply reference voltage to a bridge network supplying the amplifier unit, the output of which actuates the workpiece bending apparatus, holding relays in said circuit, an angle feed back potentiometer in said output circuit driven during a bending operation, and a plurality of angle setter potentiometers adapted to be selectively connected in said output circuit, said angle feed back potentiometer being effective when its electrical position matches the electrical position of a selected angle setter potentiometer connected in said output circuit to balance the bridge network and reduce the amplifier output to zero and stop the bending operation.

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MICHAEL V. BRINDISI, *Primary Examiner.*

CHARLES W. LANHAM, *Examiner.*