United States Patent

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[54] **ELECTROHYDRAULIC TRANSDUCERS**
7 Claims, 7 Drawing Figs.

[52] **U.S. Cl.** **72/56,** 72/63
[51] **Int. Cl.** **B21d 26/12**
[50] **Field of Search** ..... 72/56, 63; 29/421 E; 340/12 R

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ABSTRACT: This disclosure relates to electrohydraulic transducers of the type where electrical energy is discharged across a gap between a pair of electrodes to create a shock wave which expands a flexible chamber to urge a tubular workpiece telescopically externally thereof into conformity with a mold cavity, and includes an internal cage structure for supporting the chamber and at least one of the electrodes, and means for clamping the tubular workpiece at a predetermined position relative to the cavity prior to a forming operation.

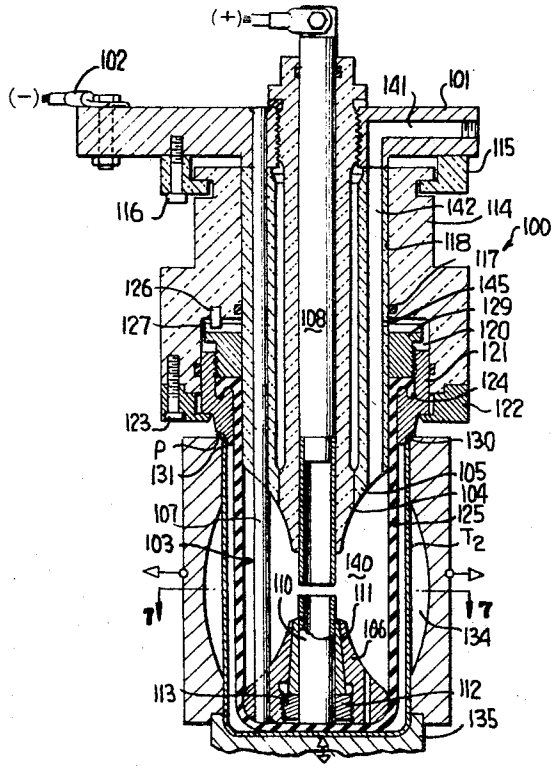


FIG.1

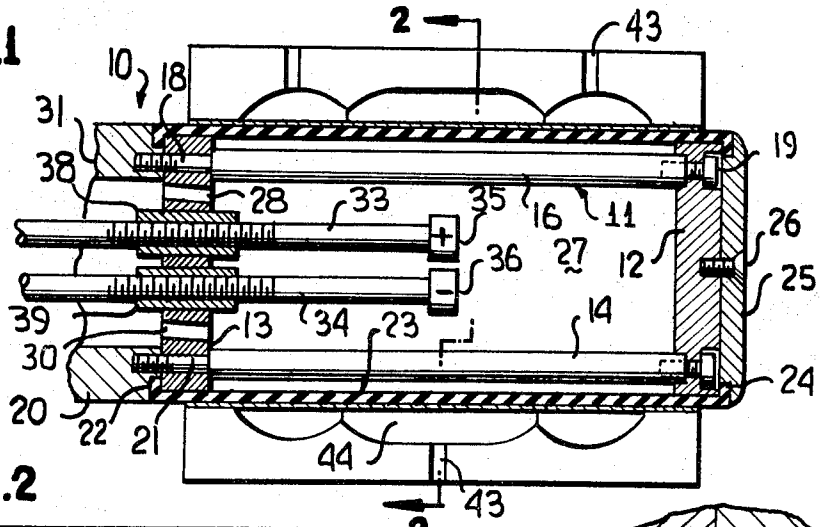
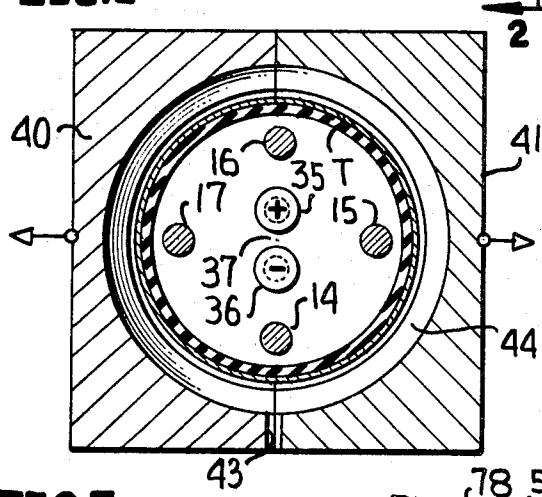


FIG.2



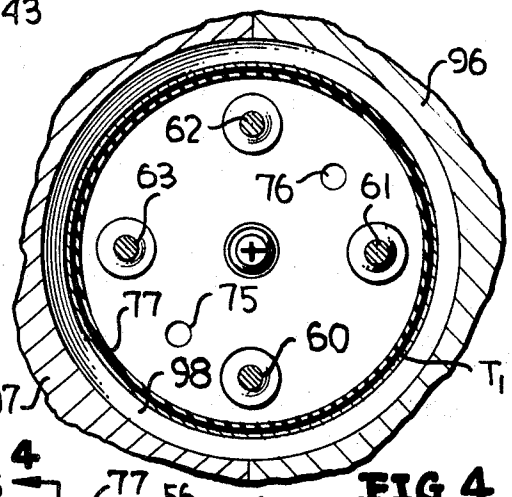
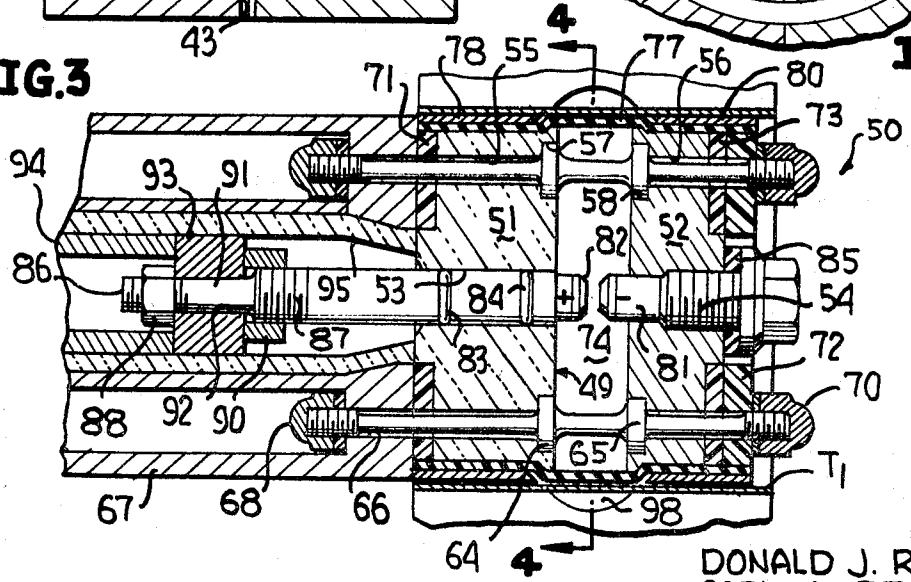


FIG.4

FIG.3



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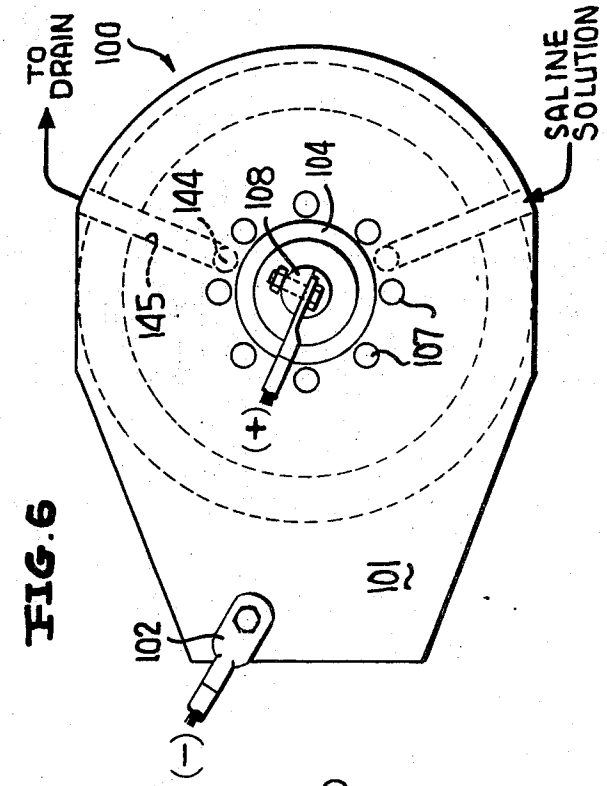


FIG.6

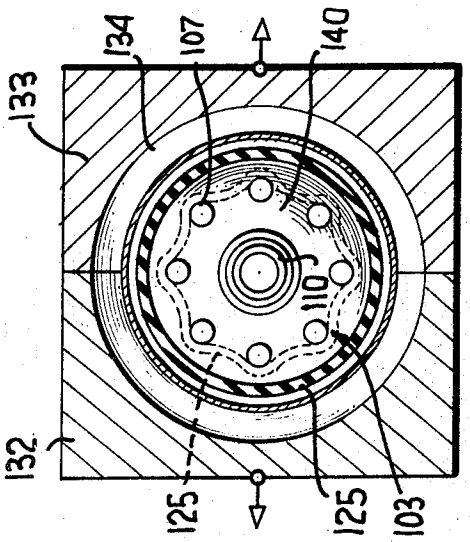


FIG.7

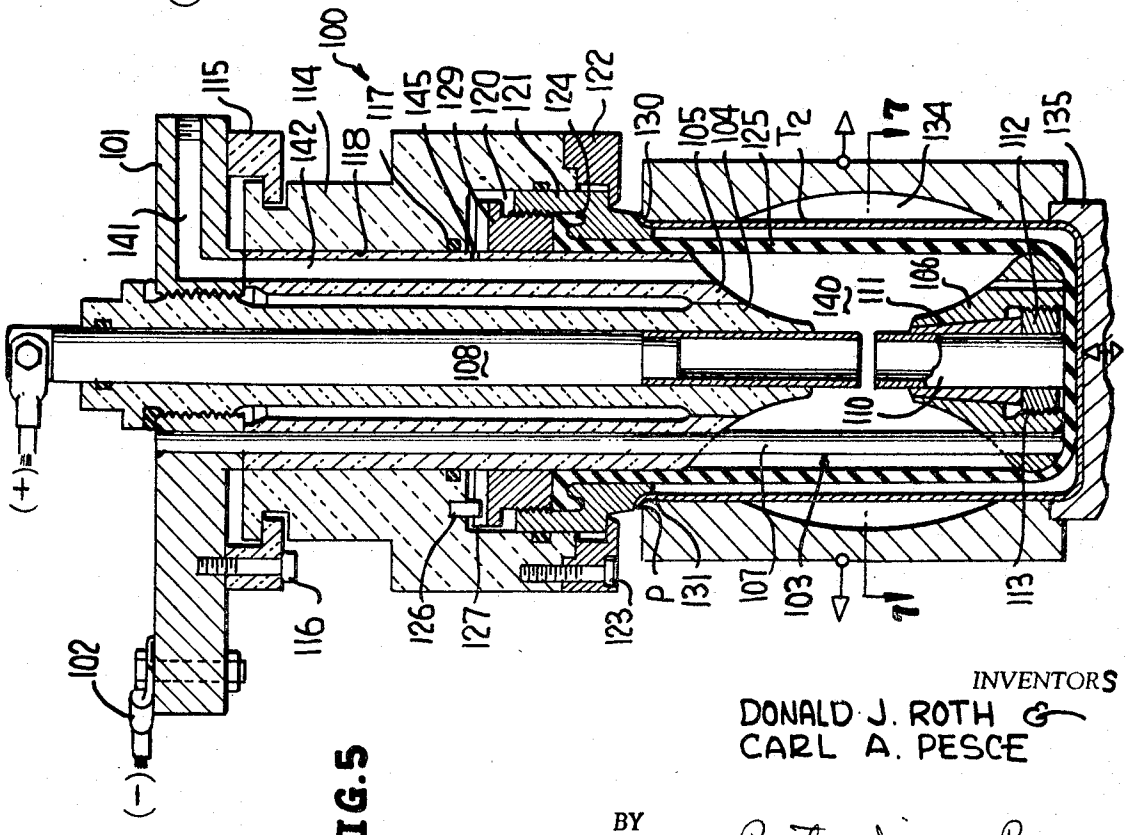


FIG.5

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ELECTROHYDRAULIC TRANSDUCERS

A primary object of this invention is to provide a novel electrohydraulic transducer which includes a flexible chamber surrounding a rigid cage carrying a plurality of electrodes, means are provided for introducing a fluid medium into the chamber, and means for discharging electrical energy across the electrode-electrode gap whereupon the resultant electrohydraulic effect produces a momentary shock wave which expands the chamber radially outwardly and forces a tubular workpiece in a similar direction into conformity with a mold cavity.

A further object of this invention is to provide a novel transducer of the type heretofore described wherein means are provided for clamping a bottom wall of the tubular element between the chamber means and an exterior supporting element, as well as for clamping an opposite peripheral edge portion of the tubular element to achieve reformed tubular elements of uniform axial length.

A further object of this invention is to provide a novel electrohydraulic transducer of the type heretofore described wherein means are provided for increasing the clamping forces of the peripheral edge portion clamping means in proportion to an increase in pressure internally of the chamber.

Still another object of this invention is to provide a novel electrohydraulic transducer as heretofore set forth wherein the electrodes are positioned in either axially opposed or spaced-parallel relationship, and in each case means are provided for adjusting the electrode-electrode gap therebetween to compensate for erosion caused by electrical discharge.

With the above and other objects in view that will hereinafter appear, the nature of the invention will be more clearly understood by reference to the following detailed description, the appended claims subject matter, and the several views illustrated in the accompanying drawings.

In the drawings:

FIG. 1 is a fragmentary axial sectional view taken through an electrohydraulic transducer of this invention, and illustrates a rigid cage surrounded by a flexible baglike element defining a chamber, and a pair of parallel electrodes positioned within the chamber.

FIG. 2 is a cross-sectional view taken generally along line 2–2 of FIG. 1, and illustrates a manner in which a pair of split molds are closed about the transducer prior to the operation thereof.

FIG. 3 is a fragmentary sectional view of another electrohydraulic transducer constructed in accordance with this invention, and illustrates another cage which supports a pair of axially opposed electrodes interiorly of a fluid medium chamber.

FIG. 4 is a fragmentary sectional view taken generally along line 4–4 of FIG. 3, and illustrates a split mold positioned in external telescopic relationship to the transducer prior to the operation thereof.

FIG. 5 is a longitudinal sectional view taken through another transducer of this invention, and illustrates another cage and chamber construction, as well as means for clamping a free peripheral edge portion of a tubular workpiece relative to a split mold and means for increasing the clamping force in proportion to an increase in the pressure of a fluid medium introduced into the chamber.

FIG. 6 is a top plan view of the transducer of FIG. 5, and illustrates electrical connections and hydraulic passages thereof.

FIG. 7 is a cross-sectional view taken generally along line 7–7 of FIG. 5, and illustrates the closed position of a split mold relative to the transducer prior to the operation of the latter.

Referring first to FIGS. 1 and 2 of the drawings a novel electrohydraulic transducer constructed in accordance with this invention is generally designated by the reference numeral 10 and includes a internal cage structure 11 defined by a pair of circular-spaced platelike members 12, 13. The plate 12 is

secured to one of four supporting rods 14 through 17 by identical bolts 19. Opposite end portions 18 of each of the rods 14 through 17 are reduced and threadably secured to a rigid tubular support 20 after being telescopically directed through bores 21 of the member 13.

Prior to securing the rods 14 through 17 in the position shown in FIG. 1 a radially inwardly directed flange 22 of a flexible tubular sleeve 23 is positioned as shown in FIG. 1 whereupon the tightening of the rods 14 through 17 clamps the flange 22 between the rigid support 20 and the member 13. The opposite end of the flexible tube 23 is likewise provided with a radially inwardly directed flange 24 which is clamped in position between the member 22 and a plate 25 by one or more screws 26. The members 12, 13 and the flexible element 23 thereby define a chamber 27 into which a fluid medium, such as a low (4 percent) concentrate salt solution, may be introduced through a port 28 and removed through a port 30. The port 28 is coupled by a conduit 31 to a pump 32 for not only filling the chamber 27 but pressurizing the fluid medium to between 600—800 p.s.i. incident to the performance of a reforming operation under the influence of an electrical energy discharge, which will be described more fully hereinafter.

A pair of electrodes 33, 34 are positioned internally of the chamber 27 in generally spaced-parallel relationship and terminate at cylindrical end portions 35, 36 between which is established an electrode-electrode gap 37. Threaded portions (unnumbered) of the electrodes 33, 34 permit the electrodes to be rotated to position the opposed peripheral surfaces of the end portions 35, 36 in predetermined spaced relationship to each other. The rotatable mounting of electrodes 33, 34 thereby permit the gap 37 to be adjusted simply be rotating either or both electrodes which additionally compensates for the erosion of the end portions 35, 36 during to continuous electrical discharges thereacross. The rotation of the electrodes 33, 34 also permits the axial position of the end portions 35, 36 to be adjusted relative to the chamber 27, and the parallel disposition of the electrodes also presents a low inductance path for the discharge of electrical energy which in turn allows a more efficient transfer of the energy from electrical to mechanical. The threaded end portions of electrodes 33, 34 are received in internally threaded insulators 38, 39 respectively.

The transducer 10 is operated by first placing a tubular element T into external telescopic relationship to the chamber 27 and closing thereabout a pair of mold bodies 40, 41 as best shown in FIG. 2. The mold bodies 40, 41 preferably include vent openings 43 which open into a cavity 44 defined by the mold bodies 40, 41.

When thus positioned the pump 42 is energized by a suitable motor (not shown) to conduct the fluid medium (not shown) into the chamber 27 through the conduit 31 and the port 28. At this time a valve (not shown) in a conduit (also not shown) connected to the port 30 is closed. As the pressure of the fluid medium in the chamber 27 increases the flexible tubular element 23 expands radially outwardly and contours the tubular element T to the general configuration of the cavity 44. After a predetermined pressure has been reached (600—800 p.s.i.) a suitable switch is closed to discharge electrical energy stored in a capacitor or an inductor through the electrodes 33, 34 and across the gap 37. This discharge creates a rapidly extending plasma bubble at the gap 37 and the interaction of the bubble and the incompressible fluid medium causes a mechanical shock wave to be formed which moves radially outwardly through the fluid medium and the flexible element 23 to expand the tubular element T into intimate conformity with the cavity 44.

Reference is now made to FIGS. 3 and 4 of the drawings which illustrate another electrohydraulic transducer 50 which includes an internally generally rigid cage 49 defined by a pair of spaced platelike members 51, 52 which include respectively axial bores 53, 54 and a plurality of identical circumferential bores 55, 56 which are respectively counterbored at 57, 58.

A plurality of identical supporting rods **60** through **63** having enlarged flange portions **64**, **65** are positioned relative to the bores **55**, **56**, and the counterbores **57**, **58** in the manner clearly illustrated in FIG. **3**. The left-handmost end portions of the rods **60** through **63** pass through bores **66** of a rigid supporting member **67**, and are secured in position by identical nuts **68**. The opposite end portions of the rods **60** through **63** are also threaded and are secured in position by a plurality of identical nuts **70**. Suitable annular sealing means **71** through **73** are provided for preventing the escape of a fluid medium (not shown) from a chamber **74** into which it is introduced and removed by ports **75**, **76** in the member **51** and corresponding bores in the support member **57** which are coupled by conduits (not shown) to suitable pumps.

The chamber **74** is peripherally closed by a flexible member **77** which is secured in exterior encircling relationship to the chamber **74** by a pair of exterior clamping bands **78**, **80**.

An electrode **81** is positioned in the bore **54** and projects into the chamber **74** in coaxial relationship to an electrode **82** projecting outwardly of the bore **53**. A pair of O-ring seals **83**, **84** and a washer **85** prevent fluid medium in the chamber **74** from escaping outwardly thereof between the electrodes **81**, **82** and the bores **54**, **53**, respectively.

The electrodes **81**, **82** are mounted for axial adjustment relative to each other to adjust the size of the electrode-electrode gap (unnumbered). The adjusting means is defined by a pair of threaded portions **86**, **87** of the electrode **82** upon which are received nuts **88**, **90** respectively. A reduced end portion **91** of electrode **82** is slidably received in a bore **92** of a cap **93** welded or otherwise secured to a tubular member **94** of the stationary support member **67**.

In order to adjust the electrode-electrode gap the member **94** is slid to the left and outwardly of a tubular insulator **95** after which the nut **88** and the nut **90** are appropriately rotated to increase or decrease the length of the electrode projecting beyond the right-handmost face of the cap **93**. Thereafter the tube **94** is reinserted into the tubular insulator **95** and the electrode is repositioned as shown with the only change being that of the electrode-electrode gap.

The transducer **50** is operated in conjunction with a pair of mold bodies **96**, **97** of a split mold which define a tubular cavity **98** to which is conformed a tubular workpiece or element T_1 upon the operation of the transducer **50** in the manner heretofore described relative to the transducer **10**.

Reference is now made to FIGS. **5** through **7** of the drawings which illustrate another electrohydraulic transducer **100** which includes an upper stationary electrically conductive supporting plate **101** to which is connected a conductor **102**. The plate **101** forms a support for a cage **103** defined by a pair of annular insulating members **104**, **105** spaced from a member **106** by a plurality of electrically conductive rods **107** which at opposite ends thereof are welded to the plate **101** and to the member **106**. Electrode **108** is positioned within the tubular member **104** and is positioned in coaxial relationship to an electrode **110** which is connected to the member **106** by a tapered annular clamping plug **111** and a nut **112** threadably secured to an internally threaded recess **113**.

The annular member **105** is received in a housing **114** which is clamped to the undersurface of the plate **101** by a split ring **115** add a plurality of bolts **116**. A seal **117** is positioned between the exterior of the annular member **105** and a bore **118** to prevent fluid seepage.

The lower end portion of the housing **114** includes a fluid chamber **120** in which is slidably mounted an annular piston **121** which is illustrated in its lowermost position by means of an annular flange **122** secured to the housing **114** by bolts **123**. An upper peripheral portion **124** of a flexible baglike element **125** is clamped to the piston **121** by means of an annular nut **129** which is threadably secured to the piston **121** and is prevented from inadvertent unthreading during the operation of the transducer **100** by means of a pin **126** which projects into an upwardly opening groove **127** of the nut **129**. The function of the piston **121** is a clamp a peripheral edge portion P of a tubular element T_2, such as a can body, between an annular clamping surface **130** of the piston **121** and an opposing clamping surface **131** of a pair of mold bodies **132**, **133** defining a cavity **134** therebetween.

A lower open end portion of the cavity **134** is closed by a circular plate **135** which is reciprocated by conventional means (not shown) in the direction of the unnumbered double-headed arrow associated therewith. The plate **135** is shown in its uppermost position at which a bottom wall (unnumbered) of the tubular element T_2 is clamped between the upwardly directed force of the plate **135** which is resisted by the rigidity of the cage **103** and the lowermost surface of the member **106**.

A fluid medium, such as low concentrate saline solution, is introduced into a chamber **140** of the transducer **100** through a passage **141** in the plate **101** and a passage **142** in the annular member **105**. A port **143** places the port **142** in fluid communication with the chamber **120** for applying the necessary force to move the piston **121** downwardly to apply clamping pressure between the surfaces **130**, **131**.

A passage **144** (FIG. **6**) in the annular member **105** and a bore **145** permit the chamber **140** to be drained in the manner heretofore described relative to the transducer **10** of FIG. **1**.

Assuming that the mold bodies **132**, **133** have been moved in the direction of the unnumbered headed arrows associated therewith and that the plate **135** has been moved downwardly, an operation of the transducer is initiated by first positioning the tubular workpiece or element T_2 upon the upper surface of the plate **135** and moving the same upwardly until the peripheral edge portion T of the workpiece contacts and seats against the clamping surface **130** of the piston **121** which at this time is positioned slightly more upwardly from that shown in FIG. **5** with the bottom surface of the groove in contact with the end face of the pin **126**. In this position the bottom wall of the tubular element T_2 is clamped in a predetermined position as established by the clamping action between the cage **103** and the plate **135**.

The mold bodies **132**, **133** are then closed in a conventional manner during which time the clamping surface **131** is brought into underlying contact with the exterior surface of the peripheral edge portion P.

The fluid medium is then introduced into the chamber **140** through the passage **141** and the passage **142** which not only causes the chamber **140** to fill, but also the chamber **120**. The fluid medium in the chamber is then progressively increased in pressure by conventional means (not shown) during which time the baglike element **125** is progressively expanded radially outwardly and eventually conforms the tubular element T_2 to the general configuration of the cavity **134**. During this progressive increase in the pressure of the fluid medium the clamping force between the surfaces **130**, **131** is increased because a like pressure is established in the chamber **120** via the port **143**. Thus, irrespective of the pressure within the chamber **140** the peripheral edge portion P is securely clamped at a desired predetermined position. Due to this clamping and the clamping action between the member **106** and the plate **135** the axial height of each finally reformed tubular element is substantially identical and is not foreshortened, as would occur if the peripheral edge portion P were not clamped whereupon the expansion of the tubular element would draw the peripheral edge P axially downwardly thereby resulting in workpieces of indiscriminate heights.

After the fluid medium in the chamber **140** has been increased to a predetermined amount between, for example, 600 to 800 p.s.i., energy stored in a capacitor or an inductor is transferred by the closing of a switch (not shown) to the electrodes **108**, **110**, it being noted in this regard that each of the components **101**, **107**, **106**, and **112** are constructed from electrically conductive material. The discharge of the electrical energy between the electrodes **108**, **110** creates a bubble in a manner heretofore described which forces the tubular element T_2 into intimate contact with the cavity **134**, thereby completing the reforming operation.

The fluid medium is then purged from the chamber **140** through the passages **144, 145** which creates a partial vacuum sufficient to lift the piston **121** to release the clamping force between the surfaces **130, 131**. The baglike element **125** is thereby also collapsed against the supporting rods **107**, as shown in phantom outline in FIG. **7**, whereby upon the opening of the split molds **132, 133**, downward movement of the plate **135** permits the reformed tubular element T_2 to be readily withdrawn downwardly and subsequently discharged.

While preferred forms and arrangement of parts have been shown in illustrating the invention, it is to be clearly understood that various changes in details and arrangement of parts may be made without departing from the spirit and scope of the invention as defined in the appended claimed subject matter.

We claim:

1. An electrohydraulic transducer comprising flexible chamber means about which a tubular element is adapted to be exteriorly telescopically positioned, means for introducing a fluid medium into said chamber means, means for supporting a pair of electrodes in said chamber means whereby upon the discharge of electrical energy across said electrodes the resultant electrohydraulic effect produces a momentary hydraulic shock wave which expands said chamber means and forces said tubular element radially outwardly thereby reforming the initial configuration thereof, clamping surface means interiorly contacting a free peripheral edge portion of the tubular element, clamping surface means exteriorly contacting said free peripheral edge portion, means for relatively moving said clamping surface means toward each other to clamp the free peripheral edge portion of the tubular element therebetween thereby clampingly positioning the tubular element at a predetermined position relative to said chamber means, relatively rigid cage structure means disposed partially interiorly of said chamber means, a fluid cylinder carried by said cage structure means, a piston of said fluid cylinder having a surface portion defining said interior clamping surface means, and means for introducing fluid into said fluid cylinder for moving said piston between clamping and unclamping positions relative to said exterior clamping surface means.

2. The electrohydraulic transducer as defined in claim **1** wherein said piston is of an annular configuration and is in exterior telescopic relationship to said chamber means.

3. The electrohydraulic transducer as defined in claim **2** wherein said chamber means is a flexible baglike element having a closed end, one of said pair of members is supported at said closed end by said supporting means, and one of said electrodes is carried by said one member.

4. An electrohydraulic transducer comprising flexible chamber means about which a tubular element is adapted to be exteriorly telescopically positioned, means for introducing a fluid medium into said chamber means, means other than said flexible chamber means for clamping the tubular element at a predetermined position relative to said chamber means, and means for increasing the force of said clamping means in proportion to an increase in pressure of said fluid means in said chamber means.

5. The electrohydraulic transducer as defined in claim **4** including means for supporting a pair of electrodes in said chamber means whereby upon the discharge of electrical energy across said electrodes the resultant electrohydraulic effect produces a momentary shock wave which expands said chamber means and forces said tubular element radially outwardly thereby reforming the initial configuration thereof.

6. The electrohydraulic transducer as defined in claim **4** wherein said clamping means includes piston means exteriorly of said chamber means, and said force-increasing means is a fluid circuit placing said piston in fluid communication with said chamber means.

7. The electrohydraulic transducer as defined in claim **4** wherein said clamping means includes a piston axially movable in a fluid cylinder, said piston having a surface portion defining a surface for clamping against a free inner peripheral surface of said tubular element, and said force-increasing means includes means for introducing fluid into said fluid cylinder for moving said piston between clamping and unclamping positions relative to an exterior clamping surface.