United States Patent

[11] **3,572,072**

[72] Inventors **Marvin L. Hundley; Edwin A. Till, Jr.; Buel O. Russell, Fort Worth, Tex.**

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[73] Assignee **said Hundley and said Russell assignors to Electro-Form, Inc. Fort Worth, Tex.**

Continuation-in-part of application Ser. No. 656,142, July 26, 1967, now abandoned.

[54] **ELECTROHYDRAULIC-FORMING SYSTEM**
22 Claims, 14 Drawing Figs.

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

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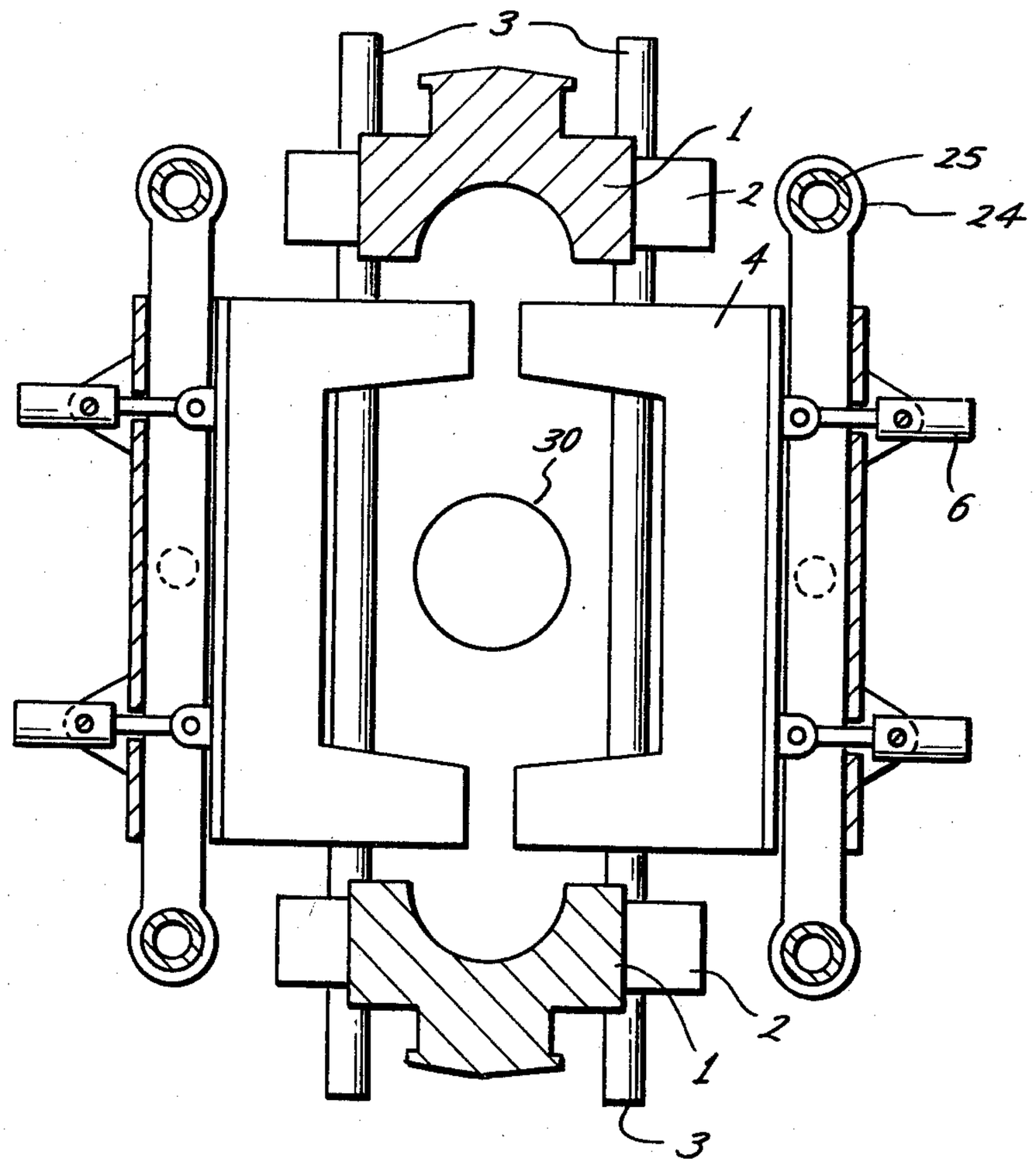
Primary Examiner—Richard J. Herbst
Attorney—Arnold, Roylance, Kruger & Durkee

ABSTRACT: Electroforming system including a tubular forming apparatus and a switch means for connecting an electrical power source to any one of a plurality of such forming apparatus. The forming apparatus includes two die portions which are wedgedly engaged by die support means to maintain the die portions in a closed position during the electroforming operation. End covers having novel seal means and electrodes are provided to enclose a workpiece within the die assembly. The switch means includes a first pair of conductive plates which is connected by coaxial cables to the power supply. A pair of plates is also provided for each forming apparatus and is connected by coaxial cables to the electrodes of the forming apparatus. The latter plates are movably mounted to abut the first pair of plates. A shorting bar is provided which abuts the first pair of plates when no plates are in an abutting position with the first two pairs.



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SHEET 1 OF 8

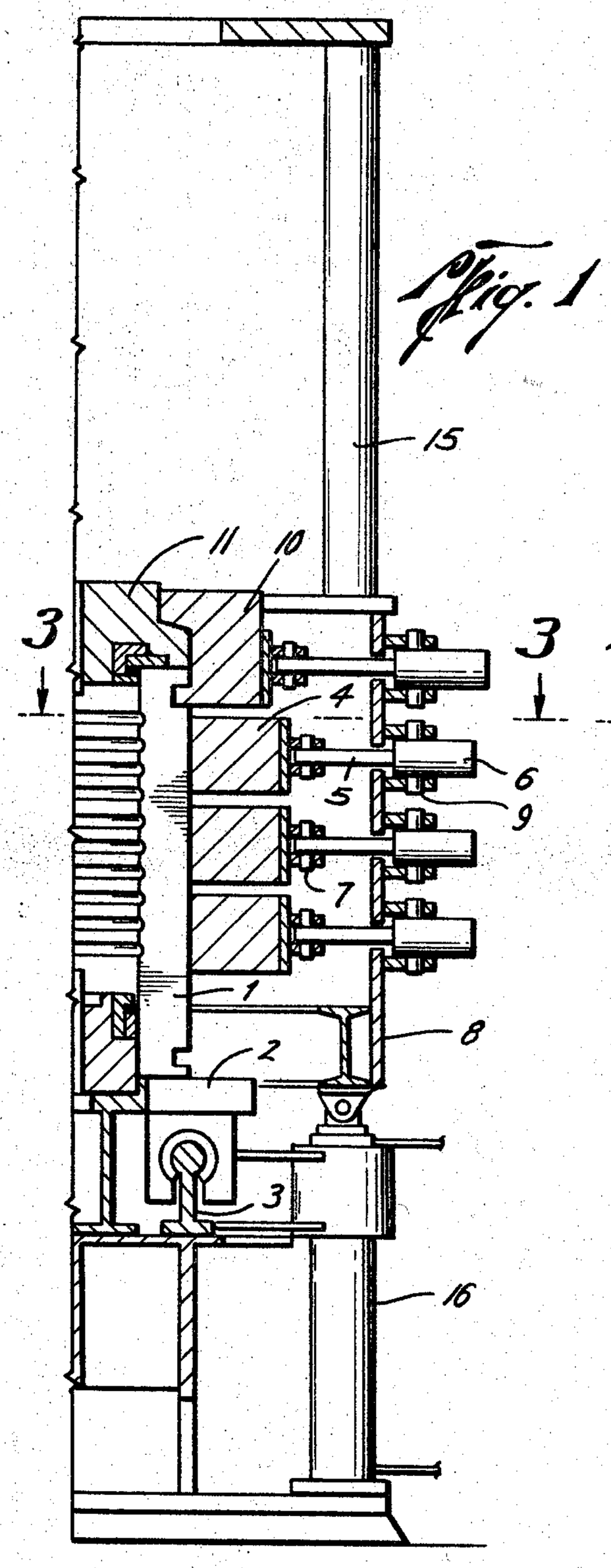


Fig. 1

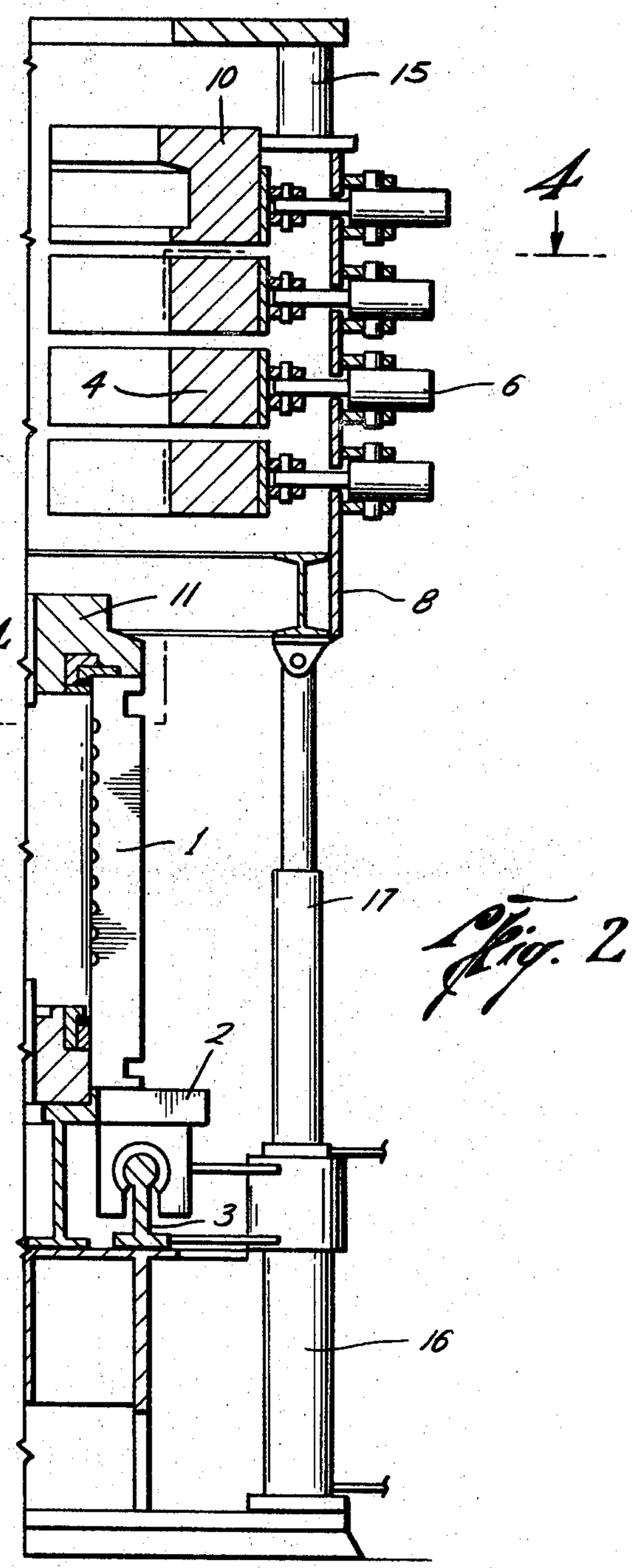


Fig. 2

INVENTORS
Marvin L. Hundley
Edwin A. Till, Jr.
Buel O. Russell

BY Arnold, Roylance, Kruger & Durkee
ATTORNEYS

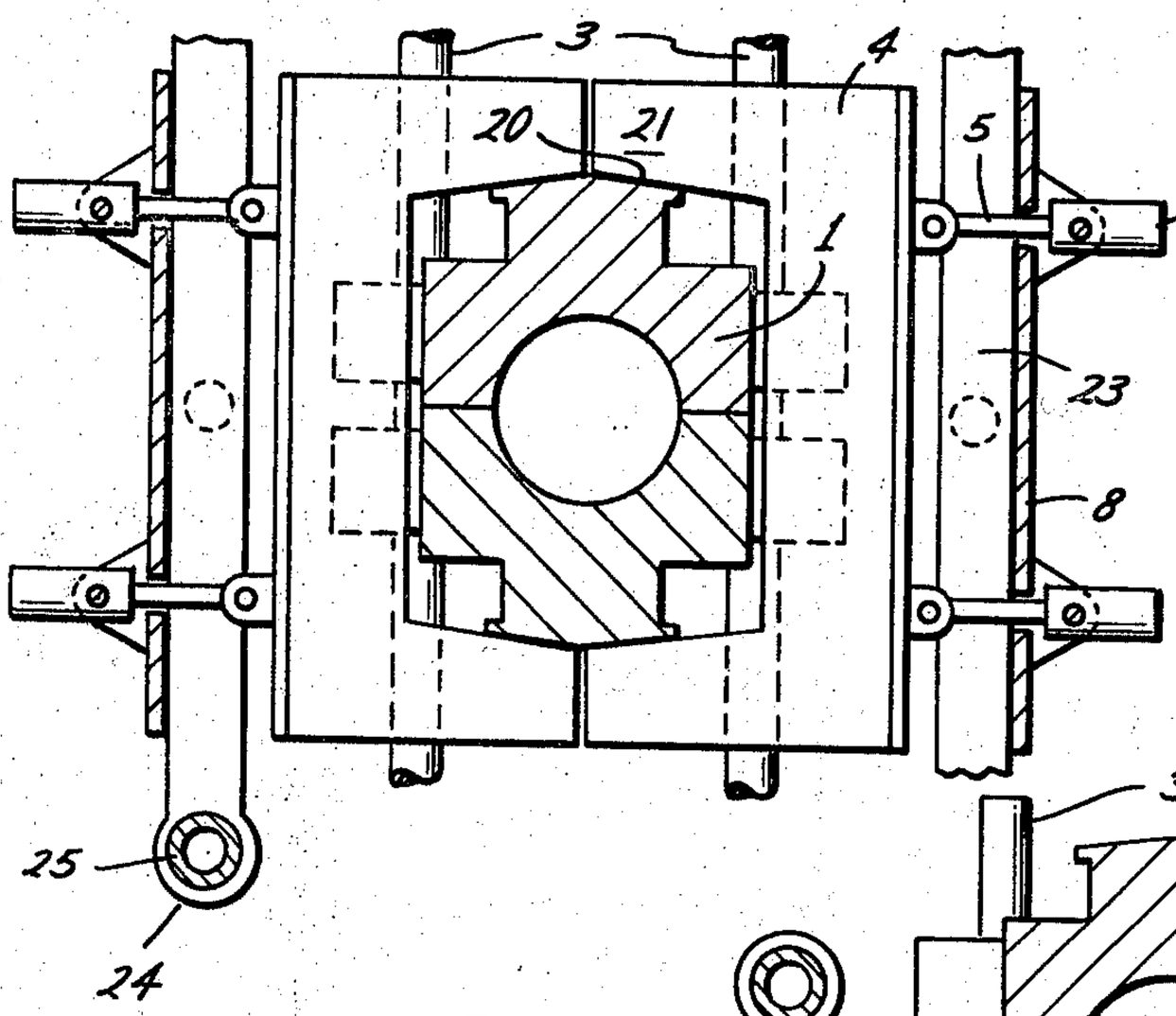


Fig. 3

Fig. 4

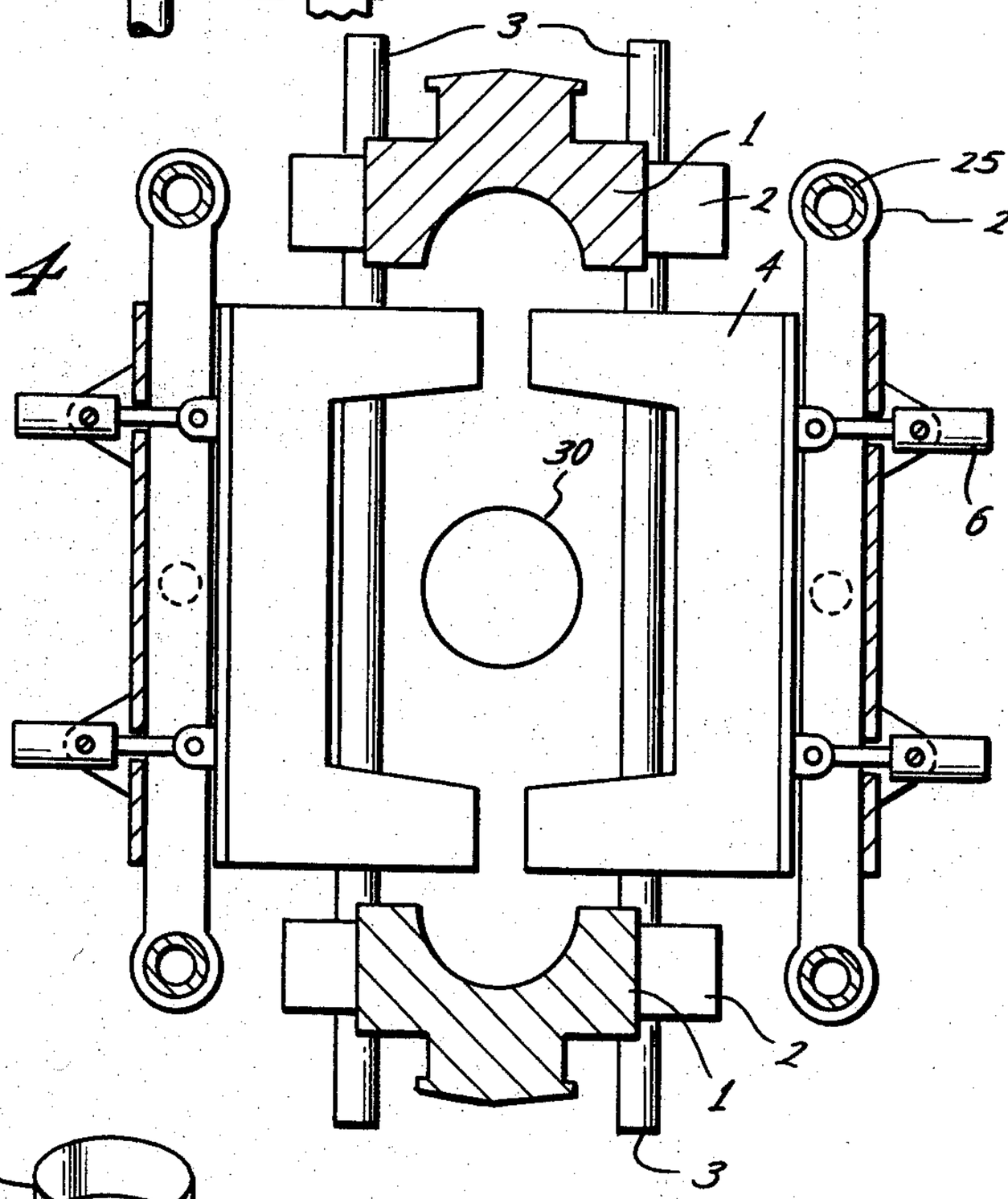
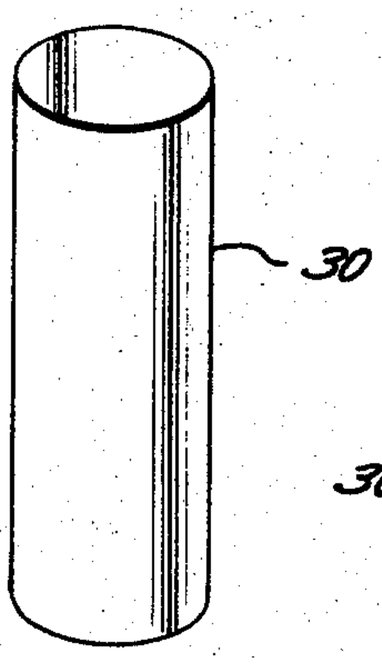


Fig. 5



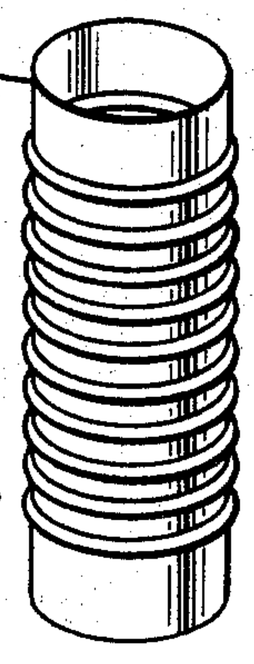
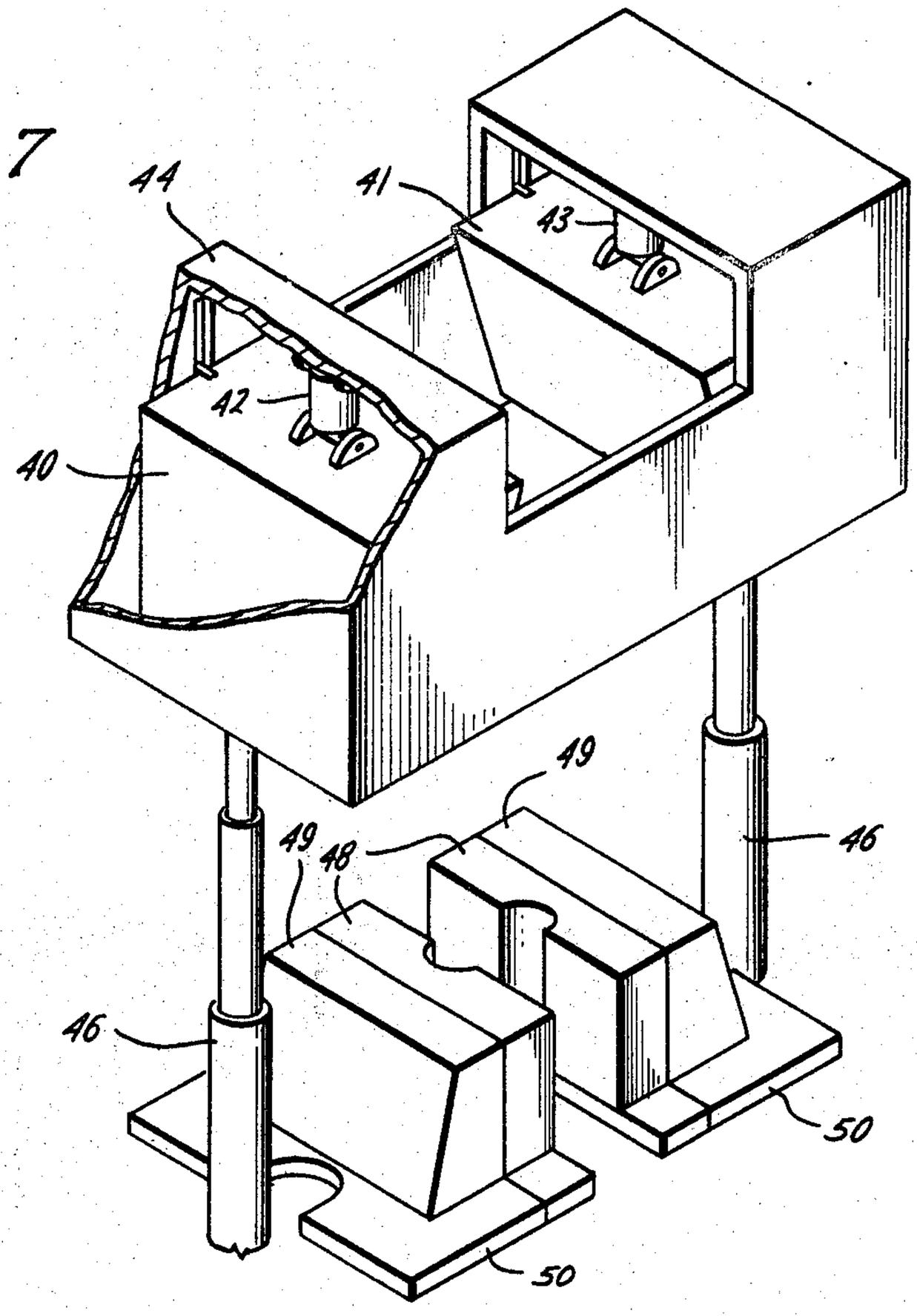


Fig. 6

INVENTORS
Marvin L. Hundley
Edwin A. Till, Jr.
Buel O. Russell

BY Arnold, Roylance, Kruger & Durkee
ATTORNEYS

Fig. 7



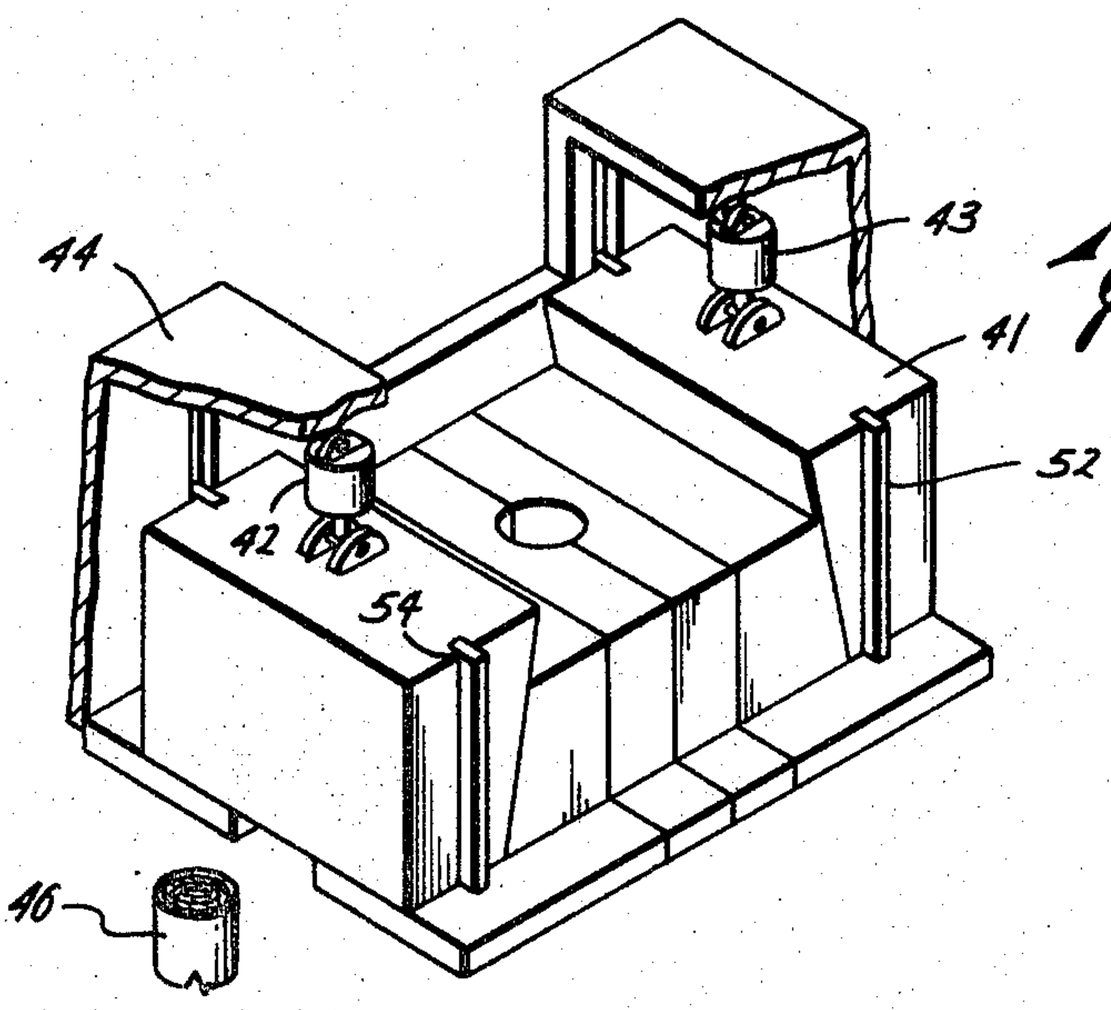
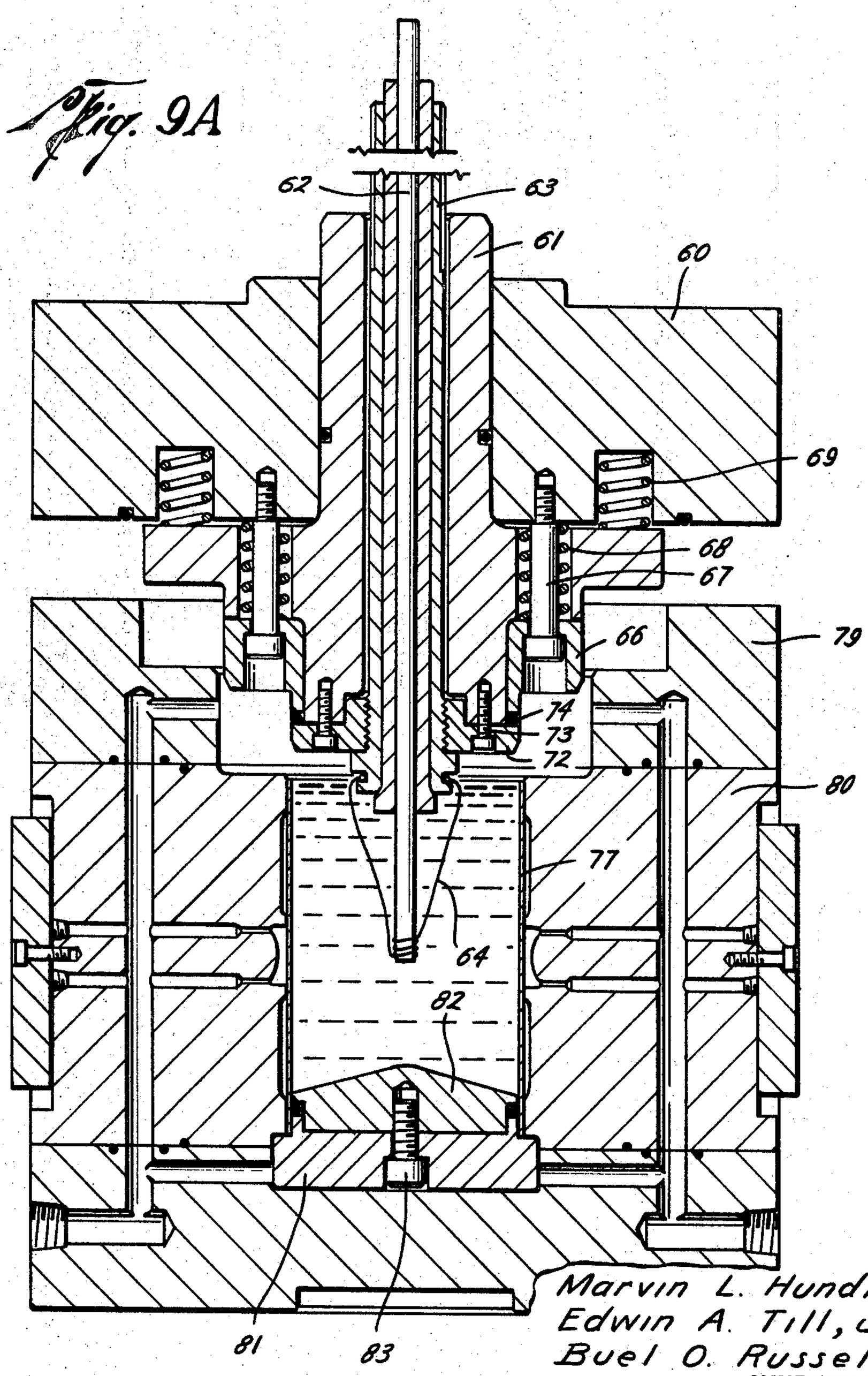


Fig. 8

Marvin L. Hundley
Edwin A. Till, Jr.
Buel O. Russell
INVENTORS

BY Arnold, Roylance, Kruger & Durkee
ATTORNEYS

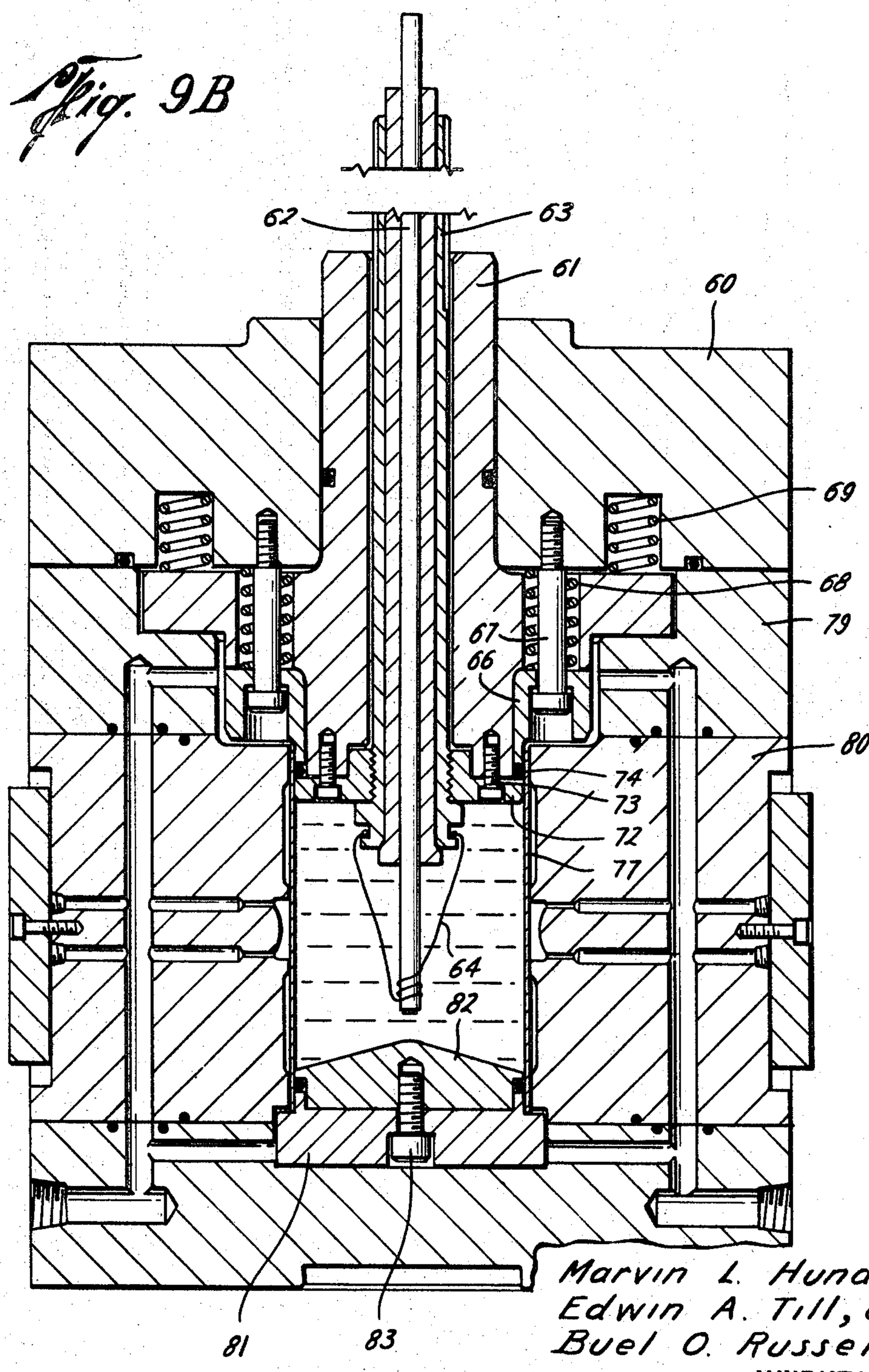
Fig. 9A



Marvin L. Hundley
Edwin A. Till, Jr.
Buel O. Russell
INVENTORS

BY Arnold, Roylance, Kruger & Durkee
ATTORNEYS

Fig. 9B



Marvin L. Hundley
Edwin A. Till, Jr.
Buel O. Russell
INVENTORS

BY Arnold, Roylance, Kruger & Durkee
ATTORNEYS

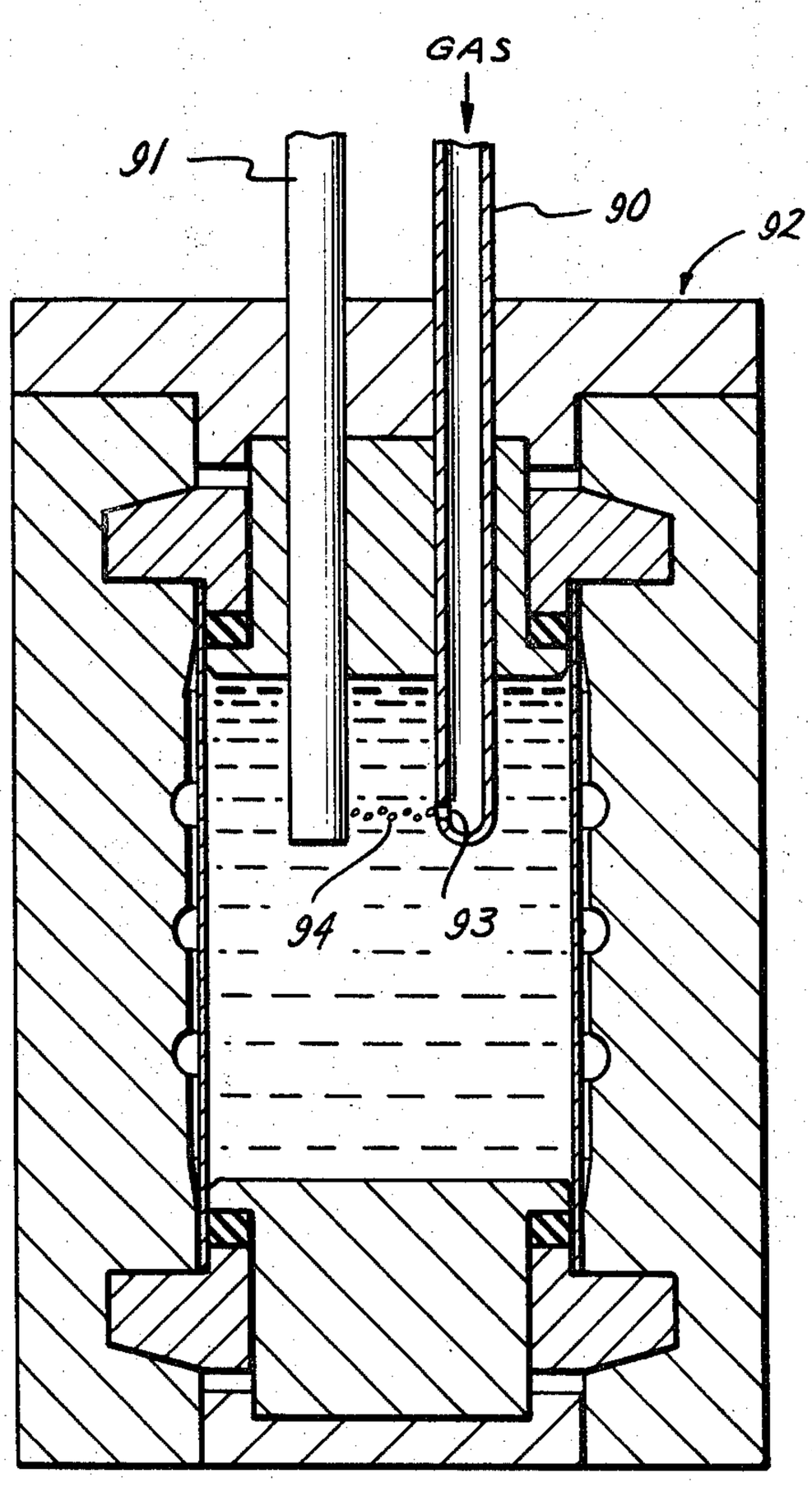


Fig. 10

INVENTORS
Marvin L. Hundley
Edwin A. Till, Jr.
Buel O. Russell

BY Arnold, Roylance, Kruger & Durkee
ATTORNEYS

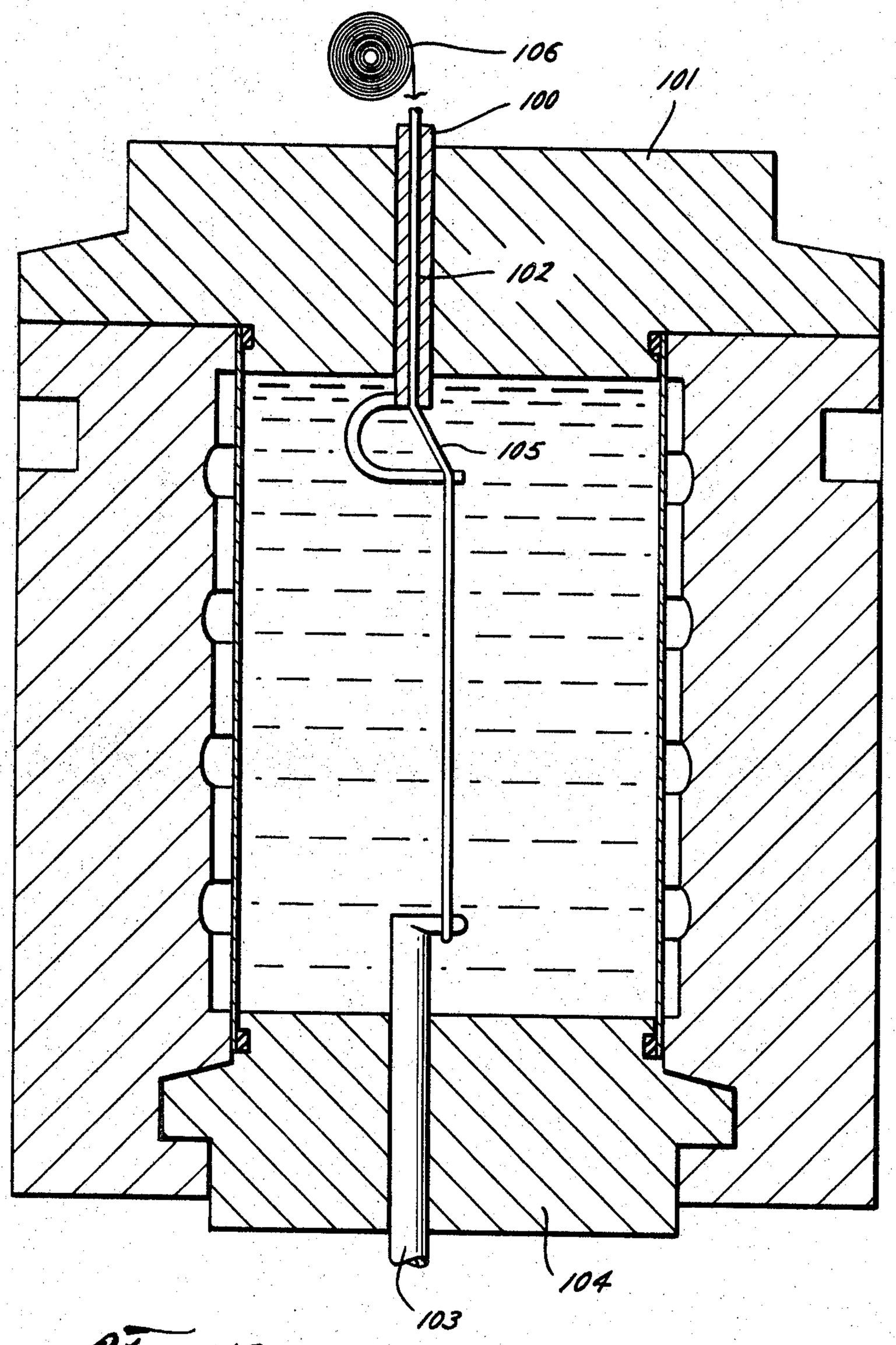


Fig. 10 B

Marvin L. Hundley
Edwin A. Till, Jr.
Buel O. Russell
INVENTORS

BY Arnold, Roylance, Kruger & Durkee
ATTORNEYS

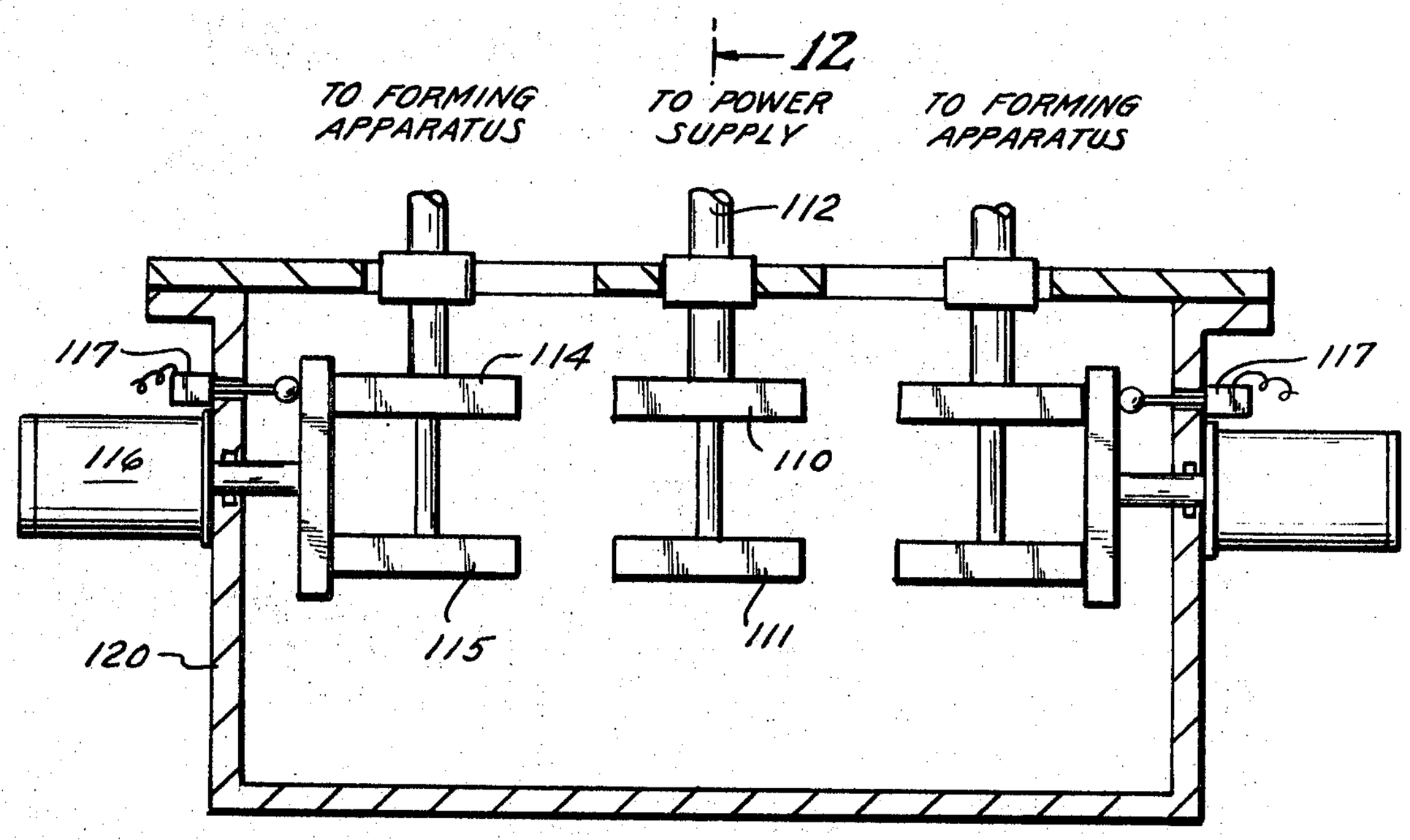


Fig. 11

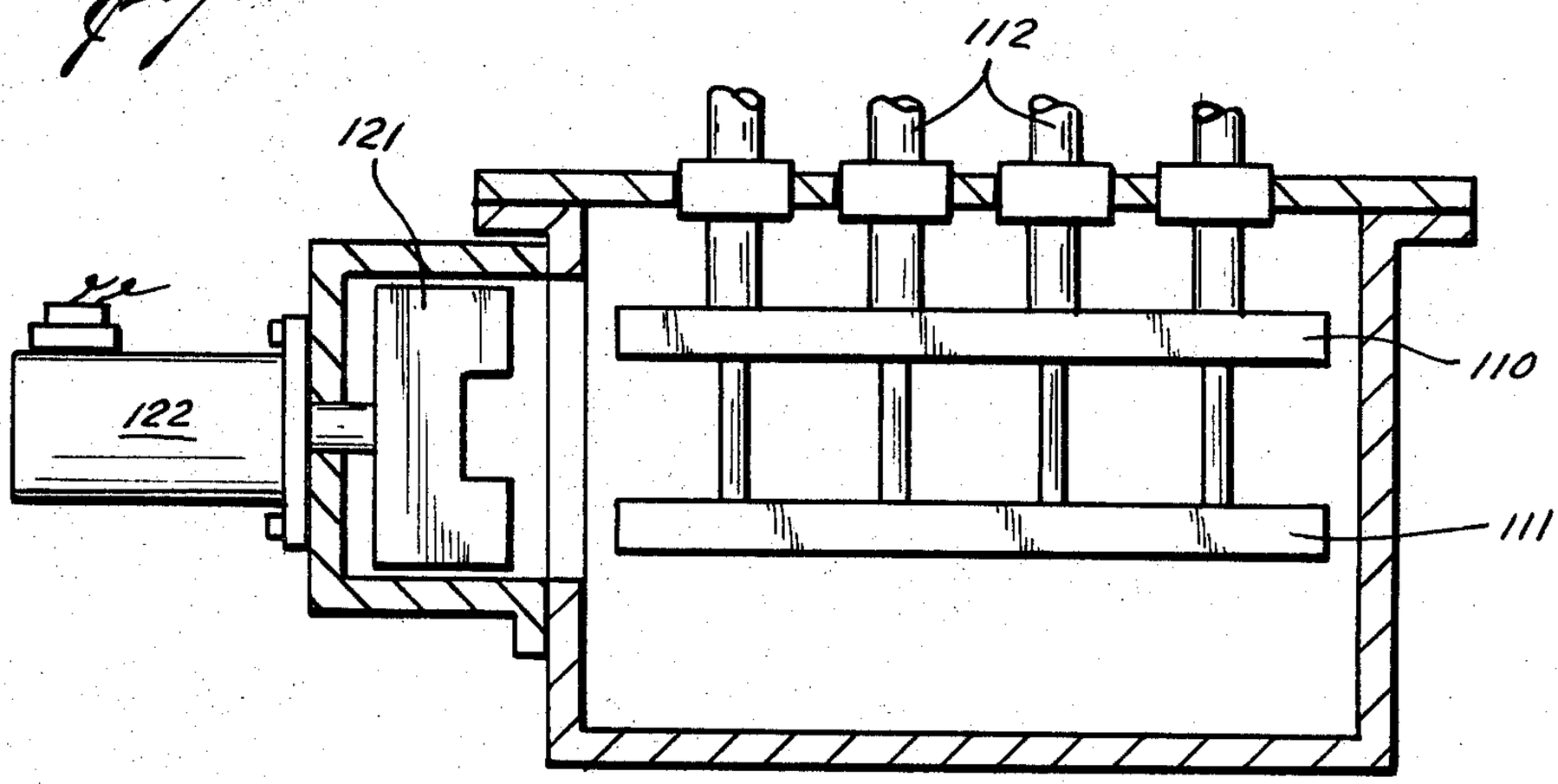


Fig. 12

INVENTORS
Marvin L. Hundley
Edwin A. Till, Jr.
Buel O. Russell

BY Arnold, Roylance, Kruger & Durkee
ATTORNEYS

ELECTROHYDRAULIC-FORMING SYSTEM

This application is a continuation-in-part of Ser. No. 656,142, filed Jul. 26, 1967, now abandoned.

BACKGROUND OF THE INVENTION

this invention relates to apparatus for shaping workpieces of deformable material. More specifically, the invention pertains to apparatus for shaping workpieces by electrohydraulic forming.

Electrohydraulic forming refers to a method of forming a workpiece by discharging electrical energy in a contained incompressible fluid medium. The shock wave developed by the discharge is transmitted by the fluid to a workpiece which is suitably enclosed in a forming die.

In a tubular forming apparatus, a tubular workpiece is enclosed in a die comprising two mating die halves. End members are positioned at either end of the die assembly to provide a sealed cavity within the workpiece which is filled with the incompressible fluid.

The die portions must be rigidly clamped to prevent separation thereof by the shock wave developed by the electrical discharge. However, because of the extremely high pressure developed by the electrical discharge, a suitable clamping means presents a major problem. Hydraulic cylinders will not absorb the high pressures without some movement, and rigid clamps present problems in alignment.

Another problem lies in providing an end member with a seal which will withstand the high pressure developed in the enclosed fluid by the electrical discharge.

The power source includes a DC voltage supply and a capacitor bank for storing a large electrical charge. Since the capacitor bank may operate several electroforming machines, it is desirable to provide a switching means suitable for transmitting the large charges of electricity to any one of several machines.

SUMMARY OF THE INVENTION

In accordance with this invention, an electrohydraulic forming system is provided which includes novel tubular forming apparatus and switch means for operating a plurality of such apparatus from one power source and capacitor bank.

The switch means includes two conductive plates which are electrically connected to the capacitor bank by suitable means such as coaxial cables. Two additional plates are provided for each forming apparatus and are electrically connected to the electrodes of the apparatus. The plates associated with each forming apparatus are movably mounted to abut the two plates connected to the capacitor bank. A shorting bar is provided which automatically abuts the first two plates when no other plates are in an abutting position with the two plates.

The forming apparatus includes two die halves which are maintained in a closed position by die holding members which wedgedly engage tapered contact surfaces on the exterior portions of the die halves. To aid in aligning the die-holding members in proper engagement with the die halves, each member and its actuating means is trunnion mounted.

The die end covers are provided with improved sealing means including an O-ring or other suitable preform seal and a compressor ring for forcing the O-ring in pressure contact with the workpiece. Electrodes mounted in the end covers are suitably positioned within the enclosure. A conductive path is provided between the electrodes by a means of a wire connected to the two electrodes or by a steam of conducting gas which is ejected by one electrode towards the other electrode.

The invention will be more fully understood from the following detailed description and appended claims when taken with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a quarter section of tubular forming apparatus in accordance with one embodiment of the invention with die-holding members in engagement with the die.

FIG. 2 is a quarter section of the tubular forming apparatus in FIG. 1 with the die-holding members disengaged and in a raised position.

FIG. 3 is a cross-sectional view taken along the line 3–3 of FIG. 1 and further illustrates the die-holding members engaging the die.

FIG. 4 is a cross-sectional view taken along the line 4–4 of FIG. 2 and further illustrates the die-holding members in the raised position and the die halves in an open position.

FIG. 5 is an isometric view of a typical workpiece prior to electroforming.

FIG. 6 is an isometric view of the workpiece in FIG. 5 after electroforming.

FIG. 7 is an isometric view of another embodiment of die-supporting means in a raised position and with the die halves in open position.

FIG. 8 is an isometric view of the die-supporting means of FIG. 7 in engagement with the closed die halves.

FIGS. 9*a* and 9*b* are cross-sectional views of the electrohydraulic-forming apparatus illustrating the sealing means and electrodes of the end covers with the die assembly in open and closed positions, respectively.

FIGS. 10*a* and 10*b* are cross-sectional views of the electrohydraulic-forming apparatus illustrating other electrode assemblies.

FIG. 11 is a cross-sectional view of electrical power switch means in accordance with the invention.

FIG. 12 is a cross-sectional view of the power switch means of FIG. 11 taken along the line 12–12 in FIG. 11.

In FIGS.1–4, like elements have the same reference numerals.

DESCRIPTION OF THE ILLUSTRATIVE EMBODIMENTS

Referring now to the drawings, and in particular to FIGS. 1 and 2, quarter section views of electro-forming apparatus in accordance with the invention are illustrated wherein the die clamp means includes a plurality of C-clamp members which wedgedly engage the die halves to maintain the die in a closed position during the electroforming operation. FIG. 1 shows the apparatus in a closed position. Die portion 1 is positioned on a support plate 2 which is slideably mounted on guide rail 3 of the apparatus pedestal. Die clamp members 4 are connected to pistons 5 of hydraulic cylinders 6. The pistons are connected to the clamp members by means of pin 7 and the cylinders are connected to a support plate 8 by means of pin 9. Die head clamp 10 engages the die head 11 and the die portion 1. When disengaged from the die, the die clamp members along with support plate 8 are movable along rod 15 by means of hydraulic cylinder 16 and piston 17 to a raised position as shown in FIG. 2. With the die clamps disengaged and in the raised position, the die halves 1 can be separated by moving support plate 2 along the guide rail 3, thereby allowing removal or insertion of the workpiece.

FIGS. 3 and 4 further illustrate the cooperative action of the die clamp members and the die portions. FIG. 3, a sectional view taken along the line 3–3 of FIG. 1, shows die halves 1 moved to a closed position along guide rails 3. The die portions are provided with tapered surfaces 20 which are wedgedly engaged by the arms 21 of the die clamp members 4. Hydraulic cylinders 6 which activate the die clamp members are trunnion mounted to support plate 8 and support member 23. Member 23 is provided with collars 24 and bushings 25 which move along guide rod 15 of FIG. 1.

FIG. 4 is a sectional view taken along line 4–4 of FIG. 2 and shows the die clamp members 4 disengaged from the die and in a raised position. After the die clamp members are raised above the die, the die halves can be parted by moving support plates 2 outwardly on guides 3.

In operation, a tubular work piece 30 is positioned as shown in FIG. 4 with the die portions in an open position. The die halves are then moved inwardly on guides 3 to a closed position. Die clamp members 4 are lowered by hydraulic cylinder

16 to the appropriate level, and hydraulic cylinders 6 move the die clamp members inwardly to engage the tapered contact surfaces of the die portions.

Since alignment of the die clamp members and the die is critical, the trunnion mounting of the die clamp members 4 and hydraulic cylinders 6 allow the die clamp members to move in a horizontal plane and effect proper alignment about the closed die portion. Further, the tapered contact surfaces of the die portions and the wedge engagement thereof by the arms of the die clamp members contribute to ease in engaging and disengaging the die clamp members and the die portions. It is to be noted that the forces generated by the electroforming operation are absorbed by the arms 21 of the die clamp members.

With the described C-clamp type of die clamp assembly, dies of differing axial length can be accommodated merely by adding more C-clamps or removing C-clamps. While the clamp 10 in FIGS. 1 and 2 has a different configuration than clamps 4, clamps 4 can be provided with inserts having horizontally oriented arms for mating with the tapered surface of the die head and the flange of the die, thus eliminating the need for the clamps 10.

FIG. 5 illustrates a workpiece 30 before the electroforming operation, and FIG. 6 is the workpiece after electroforming. The configuration of the workpiece in FIG. 6 is defined by the die.

FIG. 7 and FIG. 8 are isometric views of another embodiment of the die-clamping means. In this embodiment, wedge blocks 40 and 41 are trunnion mounted to hydraulic cylinders 42 and 43 which are trunnion mounted and supported by frame 44. The frame, along with the hydraulic cylinders and wedge blocks, is movable in a vertical direction by hydraulic cylinders 46. Die halves 48 are provided with backup blocks 49 which have tapered surfaces to accommodate the wedge members 40 and 41. The die halves and the backup blocks are mounted on horizontally movable support plates 50.

In operation, frame 44 is moved to the raised position by hydraulic cylinders 46, and the support plates 50 are moved to open the die halves, as shown in FIG. 7. After a workpiece is positioned between the die portions, the die is closed and frame 44 is lowered to a position around the dies. Wedge blocks 40 and 41 are then lowered by hydraulic cylinders 42 and 43 until the blocks engage the tapered surfaces of the backup blocks 49 as shown in FIG. 8.

FIGS. 9*a* and 9*b* are cross sections of the die assembly in open and closed positions, respectively, and illustrate the electrode assembly and sealing means for the work piece.

Referring to FIG. 9*a*, the upper seal assembly includes a die head 60 through which is slip fitted an insert 61 comprising an insulated inner electrode 62 and an outer electrode 63 which are electrically connected by means of wire 64. The insert is movably retained in die head 60 by means of an upper seal ring 66 which is fastened to the die head by means of bolts 67. Spring 68 biases seal ring 67 away from head 60 and spring 69 biases insert 61 away from head 60 when the die assembly is in the open position. Upper seal cap 72, which is fastened to insert 61 by means of bolt 73, supports O-ring preform seal 74. With the die assembly open, seal cap 72 is displaced away from seal ring 66 so that the preform seal 74 is not compressed.

In FIG. 9*a*, the upper seal assembly is lowered and seal cap 72, preform seal 74, and seal rings 66 enter the top of tubular workpiece 77. As the upper assembly is lowered, insert 61 contacts upper cap plate 79 which is mounted on die blocks 80. As die head 60 continues to lower, insert 61 slides upwardly in the die head thus moving seal cap 72 towards seal ring 66 and compressing perform seal 74. The compressed preform seal compressively engages the inside surface of the workpiece 77 forming a tight seal for the electroforming operation.

After the electroforming, upper seal assembly is easily removed since the seal is broken as soon as die head 60 is raised.

The lower seal is attached to the workpiece prior to insertion of the workpiece into the die halves. The assembly includes a seal plug base 81 and seal plug 82 which are held together by bolt 83. With the bolt unscrewed, the plug base and plug, along with O-ring preform seal 84, are inserted into the tubular workpiece 77. Thereafter, bolt 83 is tightened thus compressing the preform seal 84 and sealing the lower end of the workpiece.

After the workpiece is mounted in the die, filled with an incompressible fluid, and sealed, a vacuum system attached to port 87 is used to evacuate the space between the workpiece 77 and the die. Thereafter, the electroforming operation is performed by passing a large surge of electrical current through electrodes 62 and 63 which explodes wires 64. The resulting shock wave is transmitted by the fluid to the tubular workpiece.

FIG. 10*a* is an embodiment of the invention wherein the conducting path between the electrodes is provided by a stream of conducting gas rather than a wire. In this embodiment, a solid electrode 91 and a hollow electrode 90 are insulatingly mounted through the end cover shown generally as 92. To provide the electrical discharge between the electrodes, a stream of gas, such as neon, is passed through electrode 90 and out an aperture 93 in the electrode which directs the gas stream 94 towards the solid electrode 91. With this embodiment, several electrical discharges can be made without dismantling the die assembly between discharges as is required with a wire conductor. Using such a device electrodes can be spaced further apart than the gap a normal voltage would jump.

FIG. 10*b* is another embodiment of the invention wherein the conducting path is provided by a wire connecting electrodes in either end assembly. Hollow electrode 100 is insulatingly mounted through the top cover 101 with a wire 102 extending therethrough and conductively attached to electrode 103 mounted through the bottom cover 104. The end portion of the electrode 100 is curved, and the wire conductively engages the extremity of the curved end portion. Thus, while the electrical discharge disintegrates the wire portion between the electrodes, the portion 105 of the wire remains intact.

After the discharge and the die is opened, additional wire can be pulled from supply reel 106 through electrode 100 and again connected to electrode 103 for the next electrical discharge.

FIG. 11 and FIG. 12 are cross-sectional views of a power switch suitable for connecting a power supply and capacitor bank to one of several electrical-forming apparatus. A first pair of spaced parallel plates 110 and 111 are connected by suitable means such as coaxial cables 112 to the capacitor bank. A pair of movable plates are provided for each electroforming apparatus, such as plates 114 and 115. These plates are spaced in parallel alignment and are movable by means of solenoid 116 to abut plates 110 and 111. A trip switch 117 is provided with each pair of movable plates so that when the plates are not engaging plates 110 and 111 the trip switch is closed. To prevent damage to the contact surfaces of the plates when the large surges of current are passed therethrough, the plates are enclosed inside of housing 120 in either a vacuum or an atmosphere of inert gas.

FIG. 12 is a cross-sectional view of the power switch taken along the line 12–12 of FIG. 11 and further illustrates plates 110 and 111 and the plurality of coaxial cables 112 which connect the plates to the capacitor bank. As a safety measure to prevent an accumulation of electrical charge on plates 110 and 111 when no plates to the forming apparatus are engaging plates 110 and 111, a shorting bar assembly 121 is provided. A solenoid 122 is operatively connected with the trip switches 117 of FIG. 11 so that when all trip switches are closed, the solenoid is actuated and moves the shorting bar to engage plates 110 and 111. When any trip switch is released, the solenoid automatically retracts the shorting bar.

While the invention has been described with reference to specific embodiments, the description is illustrative and is not to be construed as limiting the scope of the invention. Various modifications and changes may occur to those skilled in the art without departing from the spirit and scope of the invention as defined by the appended claims.

We claim:

1. Electrohydraulic-forming apparatus comprising:
a pair of mating die portions for accommodating a tubular workpiece;
a lower seal assembly;
an upper seal assembly, said upper seal assembly including;
a. a die head;
b. an electrode insert slip mounted through said die head and including a flange portion spring biased away from said die head and movable towards said die head;
c. a seal ring adjacent to the circumference portion of said insert and said flange portion said seal ring being movably fastened to said insert;
d. a seal cap fastened to the bottom portion of said electrode insert;
e. a compressible seal supported by said seal cap and positioned between said seal cap and said seal ring; and
f. said seal ring and said seal cap compressing said preform seal when said die head is engaging said die.

2. Electrohydraulic-forming apparatus as defined by claim 1, wherein said upper seal assembly includes a first electrode insulatingly mounted therethrough and said lower seal assembly includes a second electrode mounted therethrough.

3. Electrohydraulic-forming apparatus as defined by claim 2 wherein said first electrode is hollow and includes a wire extending therethrough which electrically connects said first and second electrodes.

4. Electrohydraulic-forming apparatus as defined by claim 1 wherein said upper seal assembly includes two electrodes mounted therethrough, one of said electrodes being hollow and including an aperture for directing a gaseous stream towards the other electrode.

5. An electrohydraulic-forming apparatus comprising:
a die member including first and second mating die sections defining a die chamber for accommodating a tubular workpiece, said sections having opposed outer tapered surfaces defining angles which converge on opposed sides of said die member;
first and second die-clamping members disposed on opposite sides of said die member, said clamping members having opposed divergent inner faces disposed in fixed relation to each other and adapted to wedgedly engage the converging outer tapered surfaces of said sections to maintain said sections in a closed position;
actuator means to move said clamping members into and out of engagement with said die sections; and
connector means between said actuator means and said clamping members for permitting limited pivotal motion of said clamping members relative to said actuator means in the plane of movement of said clamping members.

6. The apparatus of claim 5 wherein said actuator means includes a hydraulic cylinder.

7. The apparatus of claim 6 including means for fixedly mounting said hydraulic cylinder for limited pivotal motion in the plane of movement of said clamping members.

8. The apparatus of claim 5 including:
frame means having vertical track members;
means mounting said clamping members and said actuator means on opposite sides of said die member for vertical movement on said vertical track member; and
means to move said clamping members and said actuator means vertically on said vertical track members from the region of said die member when said die member is in the open position.

9. The apparatus of claim 8 including; secondary frame means disposed for vertical movement on said vertical track members, said secondary frame means providing a support for said clamping members and said actuator means.

10. The apparatus of claim 9 wherein said actuator means includes a hydraulic cylinder which is trunnion mounted with respect to said secondary frame means.

11. The apparatus of claim 9 including means for removably securing a plurality of clamping members in said secondary frame means on opposite sides of said die member to accommodate die members of various size.

12. The apparatus of claim 5 including first and second end cover means for sealing a tubular workpiece in said die chamber and for providing a fluidtight seal with said mating pair of die sections.

13. The apparatus of claim 12 wherein one of said end covers includes a first electrode, and said second end cover includes a second electrode, said first and second electrodes extending into said chamber within said workpiece.

14. The apparatus of claim 13 including a wire disposed between said first electrode and said second electrode within said workpiece.

15. The apparatus of claim 12 including first and second electrode means extending into said die chamber through one of said end covers, said first and second electrode means being insulated from each other.

16. The apparatus of claim 15 wherein said first electrode extends axially into said die chamber and wherein said second electrode is disposed about the base of said first electrode, and further including a wire connecting said first electrode with said second electrode at at least two opposed points.

17. The apparatus of claim 12 including means for providing a fluidtight seal between said end cover means and the workpiece, said means including an annular preformed O-ring in said end cover means adapted to contact the inner periphery of said tubular workpiece and means to compress said O-ring to force the exterior surface of said O-ring into pressure contact with the workpiece.

18. An electrohydraulic-forming apparatus including:
frame means including horizontal and vertical track members;
a die member including two mating die sections defining a die chamber for accommodating a tubular workpiece, and said sections being movable between an open position and a closed position on said horizontal track members, said die sections having outer tapered surfaces defining angles converging on opposite sides of said die member;
first and second die-clamping members disposed on opposite sides of said die member, said clamping members having opposed divergent inner faces adapted to wedgedly engage the converging outer tapered surfaces of said die sections to maintain said mating die sections in closed position;
actuator means to move said clamping members into and out of engagement with the surfaces of said mating die sections; and
secondary frame means mounting suitable for removably mounting a plurality of said clamping members on each side of said die member for vertical movement on said vertical track from the region of said die member upon separation of said mating die sections.

19. The apparatus of claim 18 wherein said clamping members are trunnion mounted on said actuator means.

20. The apparatus of claim 19 wherein said actuator means includes a hydraulic cylinder and is trunnion mounted with respect to said secondary frame means.

21. The apparatus of claim 18 including:
a cover assembly movable in position to cover and seal at least one end of said die chamber comprising a first seal cap means having a portion adopted to enter a tubular workpiece within said chamber;
an annular compressible sealing means disposed around said first seal cap and disposed proximate the inner periphery of one end of said workpiece when said seal cap has entered said workpiece; and
die head means movable with respect to said seal cap to compress said sealing means against said first seal cap to

force said sealing means into pressure contact with the inner periphery of said workpiece.

22. The apparatus of claim 21 including spring-biasing means to bias said die head means away from said seal cap

means to avoid compressive force on said sealing means when said seal cap means is not within said workpiece in said die chamber.