Sept. 20, 1966   R. FELTS   3,273,365

METHOD AND APPARATUS FOR FORMING METAL

Filed May 14, 1963   3 Sheets-Sheet 1

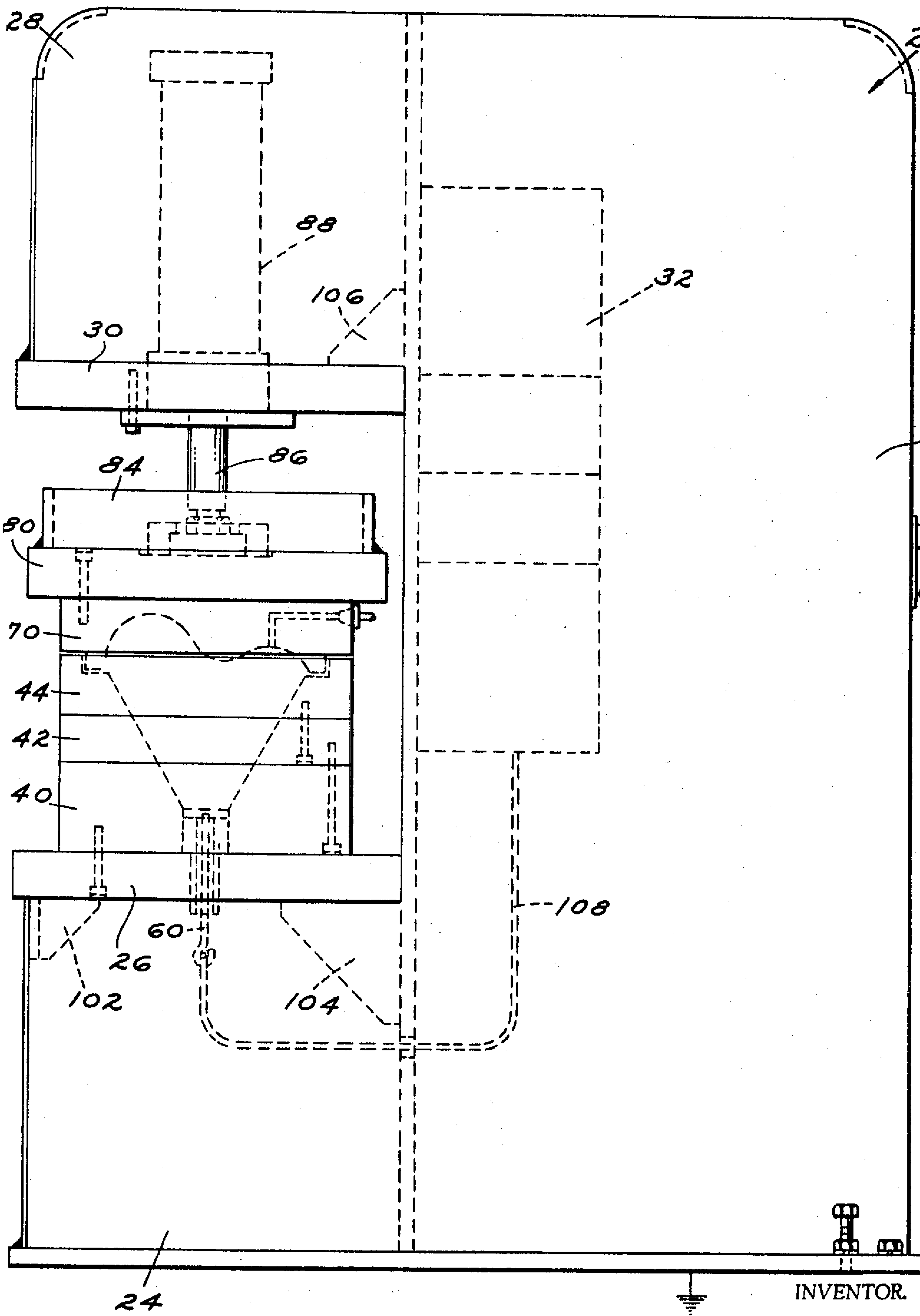

FIG. 1

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FIG. 2

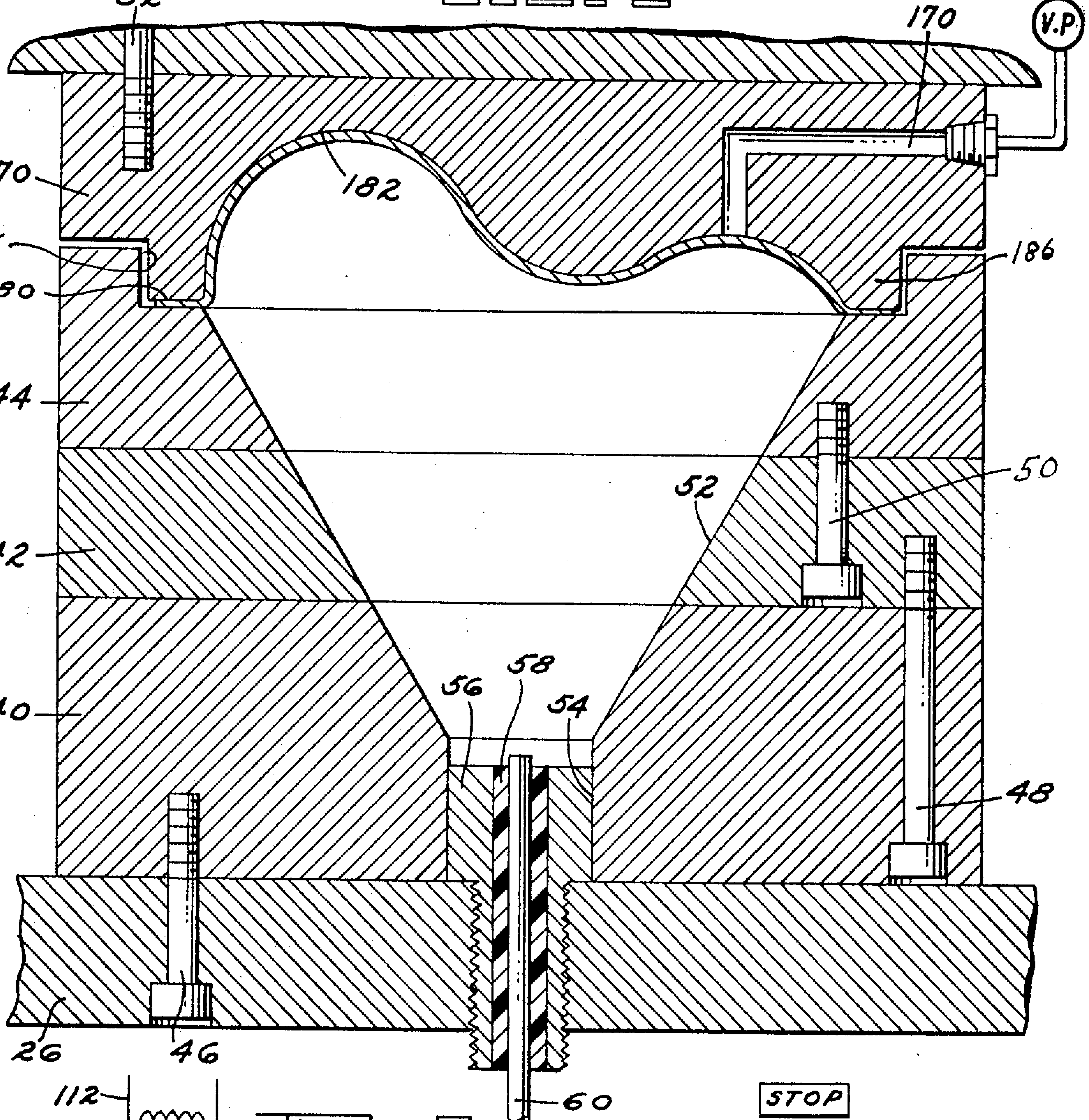
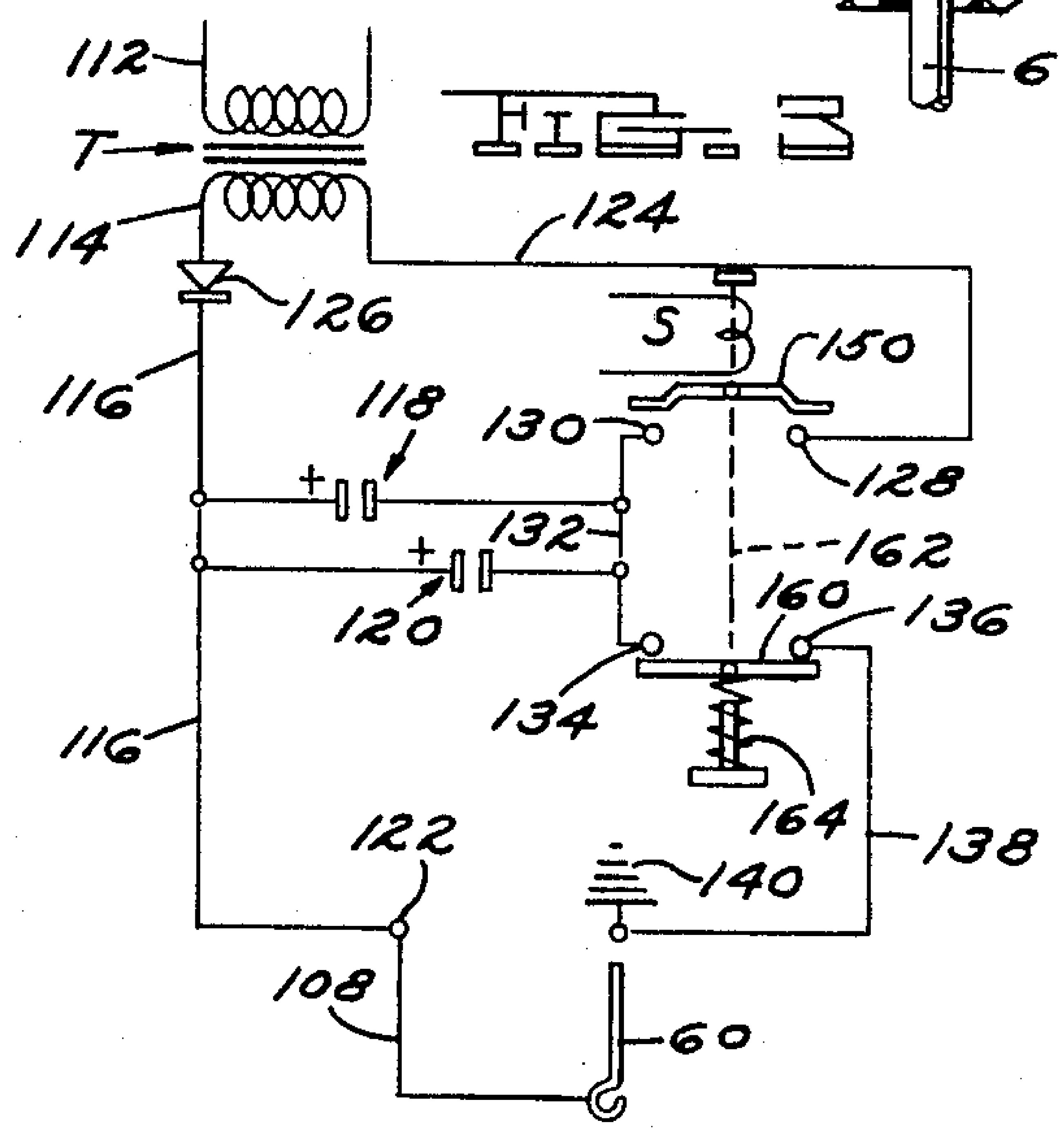


FIG. 3



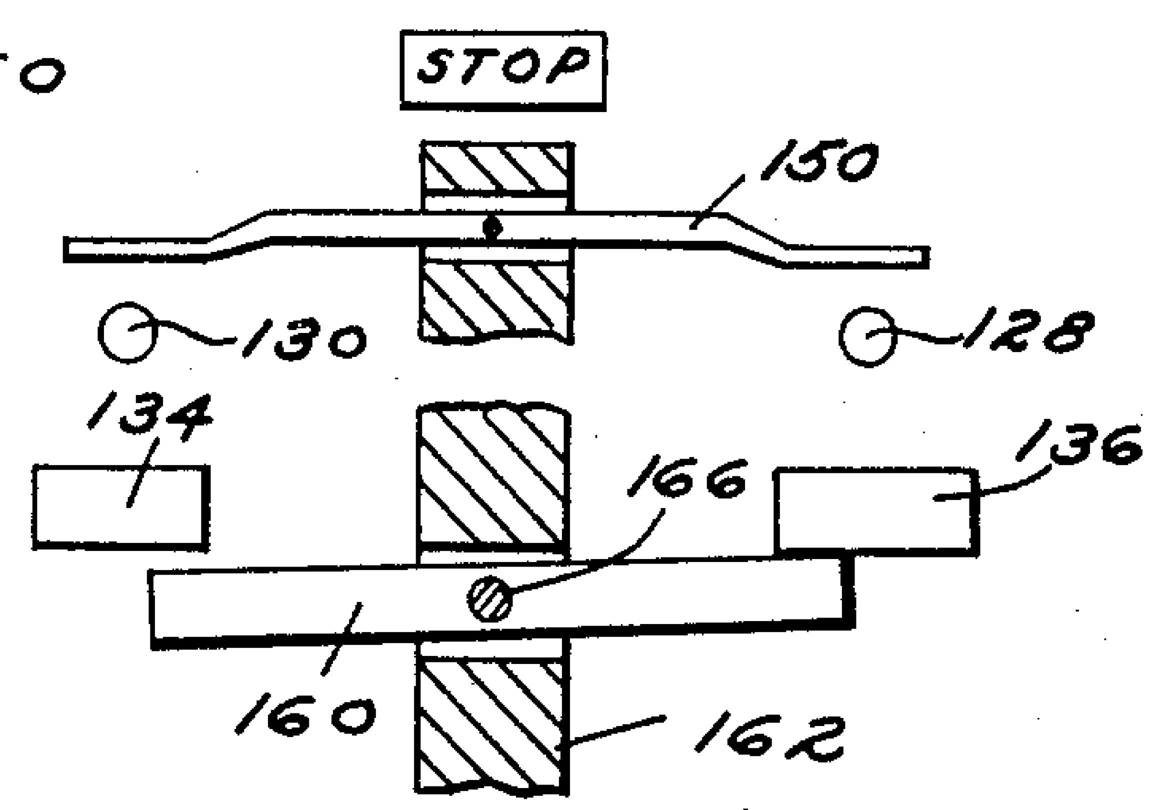


FIG. 4

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FIG. 5

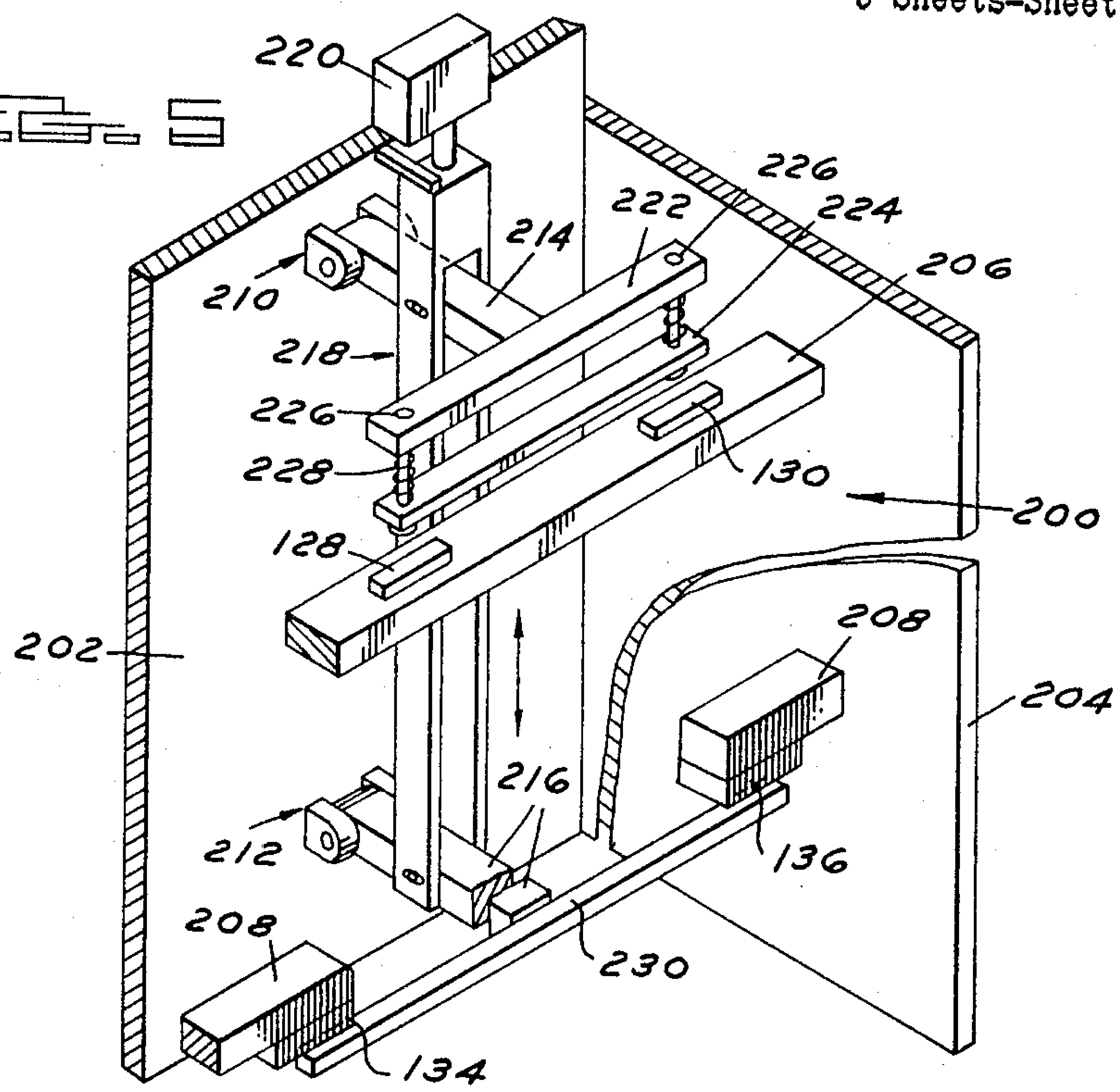
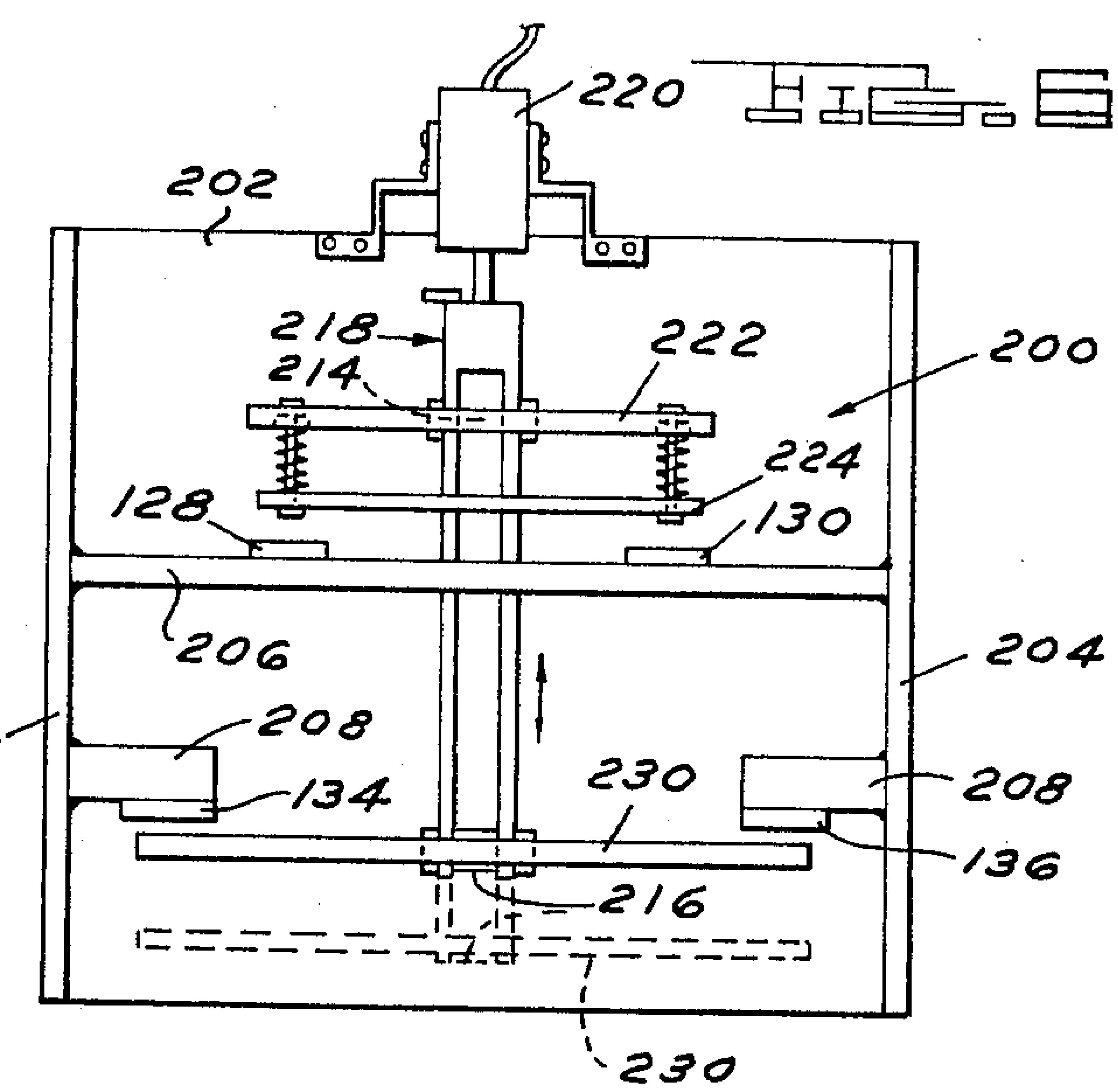


FIG. 6



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3,273,365
Patented Sept. 20, 1966

3,273,365
METHOD AND APPARATUS FOR FORMING METAL

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Filed May 14, 1963, Ser. No. 280,265
9 Claims. (Cl. 72—56)

This invention relates to a method and apparatus for the forming of metal by the electro-hydraulic effect.

Generally speaking, the electro-hydraulic effect is a force which has been known for quite some time. The process is sometimes referred to as high-energy-rate metal forming by electro-hydraulic force.

The history of metal forming, of course, is an old one which started with the use of the manual hammer and moved to the mechanical press and subsequently to presses operated by hydraulics and even by the explosion forces of material such as gases or dynamite.

Another effort to form metals has been by the use of rubber or flexible diaphragms which are placed against the metal in a cavity and subjected to very high hydraulic pressures. For the exertion of extremely high pressures in devices of this kind, it has been necessary to build extremely heavy and strong presses and even with these massive structures the maintenance of the high pressures and the frequent application of the stresses involved has caused a breakdown of the materials as a result of metal fatigue or over-stressing.

It is an object of the present invention to utilize the electro-hydraulic effect in metal forming in a machine with a very small structural mass. Extremely high pressures can be applied and excellent results obtained in the forming, for example, of sheet metal.

The electro-hydraulic effect may be defined briefly as the creation of transient high pressure by means of a submerged electrical discharge.

It is an object of the present invention to provide an improved machine for the utilization of the electro-hydraulic effect, such machine being adaptable to various production uses with varying die cavities and the like and said machine being very easily controlled for varying forces which are required as well as different areas of application of pressure.

Another object of the invention is a machine design which is not subject to extreme shock forces for each impulse which will tend to destroy the machine, the design being such that the machine can absorb these shocks in a unique manner.

Another feature of the invention is an electrical circuit and switch control which produces a suitable electrical discharge without the usual destructive effect on the capacitor portion of the circuit which commonly results from the sudden discharges of high energy circuits.

It is a further object to provide a machine utilizing the electro-hydraulic forces which can be used in production with a rapid operation as distinguished from some high pressure units which have necessitated very slow action due to the nature of the force being used.

A further object is a unique design for confining the liquid which forms the force transmittal medium.

Other objects and features of the invention relating to details of construction and operation, as well as to the method of forming metal, will be apparent in the following description and claims.

Drawings accompany the disclosure and the various views thereof may be briefly described as:

FIGURE 1, a side elevation of a machine shown in part diagrammatically for accomplishing the formation of metal parts utilizing the method and principles thereby disclosed.

FIGURE 2, a vertical section of a die bed for use in the machine of FIGURE 1.

FIGURE 3, a diagram of an electric circuit for use in the machine.

FIGURE 4, an illustration of the switch contact means for releasing the capacitance charge to the discharge point.

FIGURE 5, a perspective view of a modified switch mechanism.

FIGURE 6, a face view of the modified switch mechanism.

A brief discussion of the application of the electro-hydraulic effect may be helpful in the introduction of this disclosure. This electro-hydraulic effect is the direct creation of hydraulic pressure for a very short period of time by means of electricity. There are no intermediate devices such as motors or pumps to create the hydraulic pressure. By passing a very high electrical charge through a submerged gap or through a resistance element, the electrical energy is rapidly converted into hydraulic energy. The time sequence takes place in less than 400 micro-seconds. The electro-hydraulic effect is sometimes referred to as an electrical, high-energy-rate technique. The term "high-energy-rate" stems from the fact that when a capacitor bank is charged to high voltage and this stored energy released quickly into a suitable load circuit, energy is released at explosive or near explosive rates. If the load circuit takes the form of a well-designed transducer and the transducer is positioned below the surface of water or some other fluid, a complete series of events will take place.

One outcome of these events is a hydraulic pressure pulse that may reach well over 100,000 lbs. per square inch, with a wave form and duration that may be controlled by choice of circuit parameters.

One example of an electrical module for this type of circuit rated at 30,000 joules (or watt-seconds) will store 20,000 volts in a 150 micro-farad capacitor bank. This energy is sufficient to form sheet metal parts up to about 20″ in diameter. Larger parts may be formed by the use of additional storage modules to the machine or additional slots as required.

With respect to the structure of the machine and the relationship to the source of energy, it has been commonly supposed that the die must be under water or other suitable fluid. The work can be accomplished in an open or closed tank, but it has been discovered that metal may be formed by simply exposing one side of the top surface of a liquid body in which the electrode is immersed. It is preferable to evacuate the die cavity to avoid the build-up of pressure in the trapped air behind the part. This trapped air would perhaps cause spring back and also the very rapid compression of the air may raise the temperature of the air to the point that it would melt or burn the metal of the blank. A vacuum of about 29″ of mercury will usually accomplish the necessary results. The process to date has been successful in the forming of metal all the way from 3″ in diameter to 48″ in diameter. Metal thicknesses from .003″ to 1″ have been formed and a wide variety of die materials has been found suitable ranging from plaster to tool steel.

Referring to the drawings:

In FIGURE 1, a machine is shown wherein a C-shaped housing **20** generally has a vertical pedestal **22**, a bottom base unit **24** having a bed plate **26**, a top overhang section **28** having a top supporting plate **30**. In dotted lines in FIGURE 1 is shown a control and capacitance section **32** wherein there are mounted the various capacitance units and a switch and various other controls that might be desirable in connection with the use of the machine.

On the bed plate 26 is a pressure core unit formed of solid metal plates 40, 42 and 44 each resting on the other and bolted together by suitable bolts 46, 48 and 50. A conical recess 52 is formed in the plates having a cylindrical recess 54 at the bottom of plate 40 for receiving a spark conductor holder 56 which is threadingly engaged with the plate 26.

The spark unit 56 is a solid piece of iron having a core 58 of any dielectric material such as polyethylene or a spiral fiberglass insulation material referred to as Melamine. Within the core is an iron or copper conductor rod 60.

This conductor may also be a co-axial cable (known as RG 2-21-U) but it is preferred that the device shown in the drawings be used since the machine can be grounded and the spark transferred directly to the grounded metal portions. Note that with the machine at ground potential and the capacitors inside the machine structure, no dangerous voltages are developed in exposed areas. Well-known circuitry will insure that the machine cannot be charged until the top movable plate is lowered to its operative position. Suitable interlock switches can accomplish this.

The taper in the plates 40, 42 and 44 has an included angle of about 60° although this included angle may vary considerably without affecting the results. If it is desired to make a square part rather than a circular part, an adaptor plate can be provided at the top of the conical recess to blend from the circular conical recess to a square opening. On the top of the plate 44 is a die recess plate 70 mounted directly on a head plate 80 with suitable bolts 82. Head plate 80 is reinforced by a secondary head plate 84 and is attached to a rod 86 extending from a piston (not shown) in a cylinder 88 in head 28. Suitable hydraulic or pneumatic pressure is furnished in the cylinder under standard controls to effect lifting of the head plates 80 and 84 together with the die cavity plate 70 when desired.

The machine is formed of suitable weldment construction, the various portions 20, 24 and 28 being constructed to carry the loads to which the machine is subjected. A door controlled by a handle 100 on the rear of the machine admits access to the electrical units stored therein. Plate 26 is supported by the walls of the portion 28 in addition to gusset portions 102 and 104. The head plate 30 is supported by the walls of the portion 20 and in addition by gusset portions 106. The capacitance units 32 (shown diagrammatically) are connected by a suitable conductor 108 to the spark rod 60.

As indicated above, the inertia of the parts surrounding the pressure chamber is utilized to absorb a considerable portion of the shock of the pressure wave. Thus, the piston 86 is primarily provided to lift and lower the plate 70 rather than exert any pressure on the plate in resistance to the shock wave. The plate 40, for example, can be 4" thick; plates 42 and 44, 2" thick; plate 70, 3" thick, and, similarly, plate 80 is 2" thick and plate 84, 3". Thus, these plates being of solid metal, except for the cavities formed therein, considerable inertia is available to resist the pressure shock which is of very short duration. The machine frames are, therefore, not subject to the racking and destructive loads that might otherwise be exerted on them if there was an attempt to positively lock the clamp plate 70 in place mechanically or even by hydraulic pressure.

In FIGURE 3, a circuit is shown for the basic control of the device. A transformer T has an input side 112 connected to a 110 or 220 volt, 60 cycle, single-phase power source. The output coil 114 can develop up to 20,000 volts. One side of the secondary portion of the transformer in line 116 leads to capacitance units 118 and 120 through rectifier 126, and, as previously indicated, any number of capacitance units can be inserted at this point in the circuit. Line 116 continues around to a pole 122 connected to the conductor 108 leading to

the electrode 60. The other side of the secondary 114, through a line 124, leads to a pole point 128. An opposed pole point 130 is connected to a line 132 which joins the capacitance units 118 and 120 and terminates at a pole point 134 opposite a pole point 136 which connects through line 138 to a machine ground 140. This is the circuit used in connection with the particular electrode shown in FIGURE 2 where the spark jumps from the electrode rod 60 to the metal surrounding the insulated sleeve 58 which is the machine frame itself. Lines 116 and 138 can also connect to opposite sides of a co-axial cable so that the spark jumps from one portion of the cable to the other.

Charging and firing switches of the circuit are operated conjointly for purposes of safety. A connecting bar 150 overlies the poles 128 and 130 and a connecting bar 160 overlies the poles 134 and 136. A suitable solenoid S operates a shaft 162 to control the position of the bars 150 and 160. A spring return 164 can be utilized if desired. The circuit for the control of a solenoid S can be a standard circuit with suitable timing as desired.

The vertical control bar 162 (FIGURE 4) is preferably a shaft of non-conductive material which has a fairly high degree of mechanical strength. The switch for charging the capacitance units is a spanning leaf of spring conductive material which, when lowered, will contact the poles 128 and 130 simultaneously. The cross bar 160 which can be referred to as a crow bar type of switch is simply a bar of conductive metal shown in FIGURE 4 mounted on a pivot 166 passing through the shaft 162. The pole pieces 134 and 136 are about the same size and consistency of the cross bar 160. These can be formed of conductive metal which in actual size is a rod or a bar of brass or iron about ½ to ⅝" in cross section. The switch is so designed that there is about 2½ or 3" gap maintained between the parts when open. Thus, when switch 150, for example, is closed with each end in contact with the pole pieces 128, 130, the bar 160 will be 2 to 3" from the poles 134, 136 and similarly when the bar 160 is in the "up" position the bar 150 will be a similar distance from the poles 128, 130.

It will be noted that the bar 160 has a limited pivot motion on the pin 166, but the pin 166 is so located that both ends of the bar 160 cannot contact the poles 134 and 136 simultaneously. Thus, when discharge of the capacitance occurs, it will take place through the gap at either pole piece 134, 136 or both but bar 160 will never contact these pole pieces simultaneously.

In the operation of the device, the current from the transformer T passes through the leaf conductor 150 so that capacitance units 118 and 120 are charged to the fullest extent. When it is desirable to "shoot" the device, the energy in solenoid S, which has held switch 150 in position, is released and the spring 164 moves the shaft 162 upwardly. As the bar 160 approaches the poles 134, 136, there will be a spark jump as previously described which discharges the capacitance units through the rod 60 to the ground 140. The exact effect at the switch is not known, but it is thought that the double gap cuts down on the ringing frequency and thus steepens the initial impulse while lengthening the life of the capacitors by preventing the voltage resurge which might otherwise occur in a solid impact contact.

Thus, the charging circuit is always disconnected before the gap at pole pieces 134, 136 is closed by the cross bar switch 160 to the degree that the capacitance can discharge. The speed of operation of the shaft 162 is not critical or important because regardless of its speed, it is impossible to approach the speed of transfer of the electricity at the gap which is 186,000 miles per second. Thus, this tremendous force is released. In a machine which has a capacitance unit totaling 150 micro-farads, energy to the extent of 30,000 joules can be developed and release an equivalent of 21,000 foot pounds of work. This could be the equivalent of about a 500 ton press.

When the die cavity **70** is in use, it is desirable to have a passage **170** to permit a vacuum pump to be attached to withdraw the air from the cavity just prior to the release of energy into the body of water which lies in the conical recess **52**. The plate **180** to be formed is placed over the cavity **52** and the margins are held between the plate **44** and the plate **70**. When the discharge switch bar **160** is brought into position, the energy from the spark gap between the rod **60** and the metal of the machine will cause a tremendous charge of energy into the body of water which exerts its force upwardly as shown in FIGURE 2 to move the metal up into the die cavity **182**. It is desirable that around the top of the recess **52** an annular inset recess **184** be provided to receive an annular portion **186** of the die block **70**. This provides a liquid seal between the parts and improves the effectiveness of the die. As soon as the electrical energy has been discharged, the piston rod **86** can be lifted to separate the die parts and release the formed part. These cycles can be repeated very rapidly to produce the results sought.

In FIGURE 5, a modified switch structure is shown wherein a switch compartment **200** has a rear wall **202** and side walls **204**. A bar **206** between the side walls supports the spaced contacts **128, 130** of the circuit in FIGURE 3, while cantilever bars **208** on opposed walls **204** support the spaced contacts **134, 136** of the circuit. On the rear wall **202** are vertically spaced clevis mounts **210** and **212** which pivotally mount switch support bars **214** and **216** each pivotally connected to a bifurcate vertical actuator bar **218** suspended below the armature of a solenoid **220** suitably mounted on the back plate **202**.

On the support bar **214** is a cross arm **222** which resiliently supports a conductive cross connector arm **224** (**150** in FIGURE 3) through pins **226** and compression springs **228**. On support bar **216** is a conductive cross arm **230** which is mechanically limited by the upward travel of bar **218** so that a separation of approximately ⅛" is maintained between the cross arm **230** and the contacts **134, 136**. The stroke of the armature of solenoid **220** is preferably great enough in relation to the length of lever arms **214, 216** that the conductive cross arms **224** and **230** are moved a substantial distance from their respective contacts when in off position. In practice, this is preferably about 4 or 5 inches.

The gaps at the respective ends of bar **230**, which are never closed, are provided to prevent erosion or accidental welding of the contacts. This switch as well as the switch shown in FIGURES 3 and 4 prevents so-called "ringing" or oscillation in the circuit upon discharge of the capacitors. The spring mounting of conductive arm **224** assures positive non-arcing contact when the armature of solenoid **220** moves down to connect contacts **128, 130**.

I claim:

1. In a device for forming material of the type utilizing a liquid chamber, a confined forming cavity and an electrode in said chamber for carrying a charge of high potential to said chamber and a high capacitance circuit adapted to be discharged to said electrode, an improved switch for controlling the charge and discharge of a high potential capacitance which comprises:

(a) spaced first contact members for a charging switch,

(b) means for supporting said spaced contact members in spaced relation,

(c) spaced second contact members for a discharge switch,

(d) means for mounting said second contact in spaced relation to each other and to said first contact members,

(e) a first conductive bar mounted to contact simultaneously said first contact members and span the distance therebetween to provide a conductive connection,

(f) a second conductive bar movable into proximity to said second contact members without contacting either member to provide a capacitance discharge path,

(g) means for mounting said conductive bars comprising:

(h) a plurality of arms on spaced mounting means having said conductive bar mounted respectively thereon,

(i) an actuator arm associated with each of said arms wherein movement of said actuator shifts said arms relative to said contact members, said arms being so positioned relative to said contact members that movement of one of said conductive bars to a position adjacent its respective contact members shifts the other of said bars a material distance away from its respective contact members wherein only one pair of said contact members may be electrically associated at any one time, and

(j) means for operating said actuator bar.

2. A device as defined in claim **1** in which said first conductive bar for spanning the contacts for the charging switch is resiliently mounted on its support to allow resilient pressure to be applied against said conductive bar when in contact with its respective contact members.

3. A device as defined in claim **1** in which the arms for mounting said conductive bars are shiftable to move said bars laterally in a direction substantially normal to the line between said first contact members and substantially normal to the line between said second contact members.

4. A device as defined in claim **1** in which the arms for mounting said conductive bars are pivoted at a proximal end at spaced points on a common mounting panel, the bars being mounted adjacent the digital end of said arms and normal to said arms, and the actuator arm is pivotally connected to said bar carrying arms and shiftable lineally to pivot said bar carrying arms to the respective switch positions.

5. An apparatus for the shaping of sheet material to conform to the surface of a preformed die utilizing a fluid force as the forming medium which comprises:

(a) an open-topped, solid-wall vessel having a liquid retaining chamber in the form of an inverted cone to retain a body of liquid with the surface thereof directly adjacent the top of the vessel,

(b) peripheral means at the top of said vessel to support the edges of a work sheet to be formed in a position overlying the surface of a body of liquid in said vessel,

(c) electrode means to form a spark gap substantially at the bottom and apex of the inverted conical chamber,

(d) a die plate having a shaped die surface to overlie the surface of a body of liquid in said chamber in work-forming position and to overlie peripheral areas of said vessel to seal said vessel around said chamber, the periphery of the vessel being provided with an annular recess directly adjacent the top of the chamber therein, and

(e) an annular portion on the bottom face of said die plate positioned and shaped to insert into said annular recess to contact and clamp a sheet to be formed and to cooperate with said annular recess to effect a seal between said vessel and said die plate.

6. An apparatus for the shaping of sheet material to conform to the surface of a preformed die utilizing a fluid force as the forming medium which comprises:

(a) an open-topped, solid-wall vessel having a liquid retaining chamber in the form of an inverted cone to retain a body of liquid with the surface thereof directly adjacent the top of the vessel,

(b) peripheral means at the top of said vessel to support the edges of a work sheet to be formed in a position overlying the surface of a body of liquid in said vessel,

(c) electrode means to form a spark gap substantially at the bottom and apex of the inverted conical chamber,

(d) a die plate having a shaped die surface to overlie the surface of a body of liquid in said chamber in work-forming position and to overlie peripheral areas of said vessel to seal said vessel around said chamber, the wall of said vessel being formed of conductive material whereby it may be incorporated in a discharge circuit, and said electrode means being positioned within the said inverted conical recess spaced from said wall of said vessel, and

(e) a high capacitance circuit including said vessel and said electrode to form a discharge gap in the circuit to create an impact force from said vessel chamber toward said die plate.

7. An apparatus for the shaping of sheet material to conform to the surface of a preformed die utilizing a fluid force as the forming medium which comprises:

(a) an open-topped, solid-wall vessel having a liquid retaining chamber in the form of an inverted cone to retain a body of liquid with the surface thereof directly adjacent the top of the vessel,

(b) peripheral means at the top of said vessel to support the edges of a work sheet to be formed in a position overlying the surface of a body of liquid in said vessel,

(c) electrode means to form a spark gap substantially at the bottom and apex of the inverted conical chamber,

(d) a die plate having a shaped die surface to overlie the surface of a body of liquid in said chamber in work-forming position and to overlie peripheral areas of said vessel to seal said vessel around said chamber, the wall of said vessel being formed of conductive material whereby it is incorporated in a discharge circuit, and said electrode means being positioned within the said inverted conical recess spaced from the wall of said vessel,

(e) means to insulate said electrode electrically from said vessel and serving to seal the bottom of the chamber in said vessel to retain liquid therein, and

(f) a high capacitance circuit including said vessel and said electrode to form a discharge gap in the circuit to create an impact force from said vessel chamber toward said die plate.

8. An apparatus for the shaping of sheet material to conform to the surface of a preformed die utilizing a fluid force as the forming medium which comprises:

(a) an open-topped, solid-wall vessel having a liquid retaining chamber in the form of an inverted cone to retain a body of liquid with the surface thereof directly adjacent the top of the vessel,

(b) peripheral means at the top of said vessel to support the edges of a work sheet to be formed in a position overlying the surface of a body of liquid in said vessel,

(c) electrode means to form a spark gap substantially at the bottom and apex of the inverted conical chamber,

(d) a die plate having a shaped die surface to overlie the surface of a body of liquid in said chamber in work-forming position and to overlie peripheral areas of said vessel to seal said vessel around said chamber, and

(e) means associated with said die plate to lower and lift said plate relative to said vessel toward and away from a sealing position atop said vessel, said die plate being of such massive structure as to resist movement by fluid forming forces in said chamber and being unrestrained when in work-forming position by said means to lower and lift said plate.

9. An apparatus as defined in claim **6** in which there is provided:

(a) a double pole switch for charging and discharging in said capacitance circuit comprising two pairs of opposed poles in a circuit,

(b) means for spanning one pair of poles for directing charging energy to said capacitance, means for spanning the other pair of poles for discharging said capacitance, and

(c) means for actuating and controlling said spanning means wherein the spanning means for discharging the capacitance is positioned in its motion relative to its respective poles to permit a proximal position for said spanning means relative to said poles and to create a capacitance discharge gap without full contact of both poles with said spanning means and thus prevent current oscillation in the circuit.

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