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Peterson

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[54] **APPARATUS AND METHOD FOR COMPACTING PARTICULATE MATERIALS**

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[52] **U.S. Cl.** **264/40;** 264/297; 264/334; 425/78; 425/149; 425/344; 264/111

[51] **Int. Cl.** **B30b 11/02**

[58] **Field of Search** 264/111, 40, 297, 334; 425/78, 135, 149, 344

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[57] **ABSTRACT**

Power in a plurality of die cavities is compacted by a corresponding plurality of punches on a head, each punch being connected with a piston in a hydraulic cylinder on the head. The cylinders communicate with each other and with a hydraulic accumulator cylinder which permits the punches individually to shift axially and compensate for cavity-to-cavity variations in the amount of powder fill. When the head moves beyond the range in which compensation occurs, a piston in the accumulator bottoms out to build equal pressure in the cylinders to transmit uniform compacting force to the punches.

14 Claims, 7 Drawing Figures

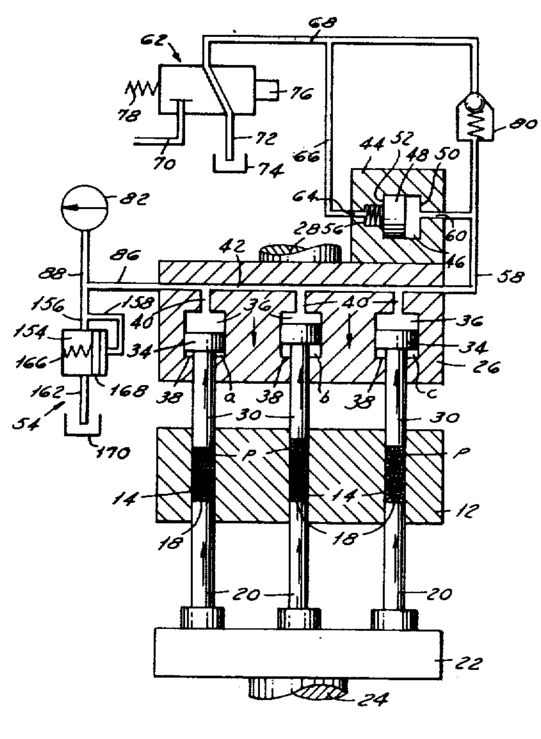


FIG. 2

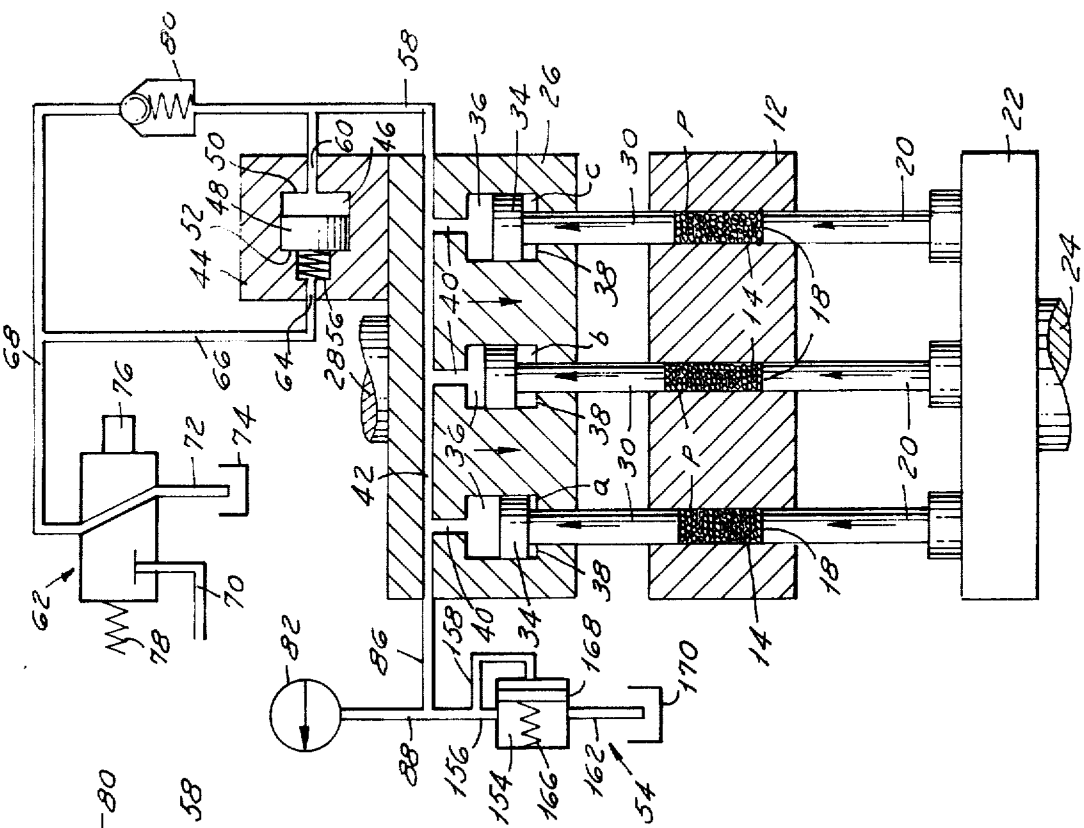


FIG. 1

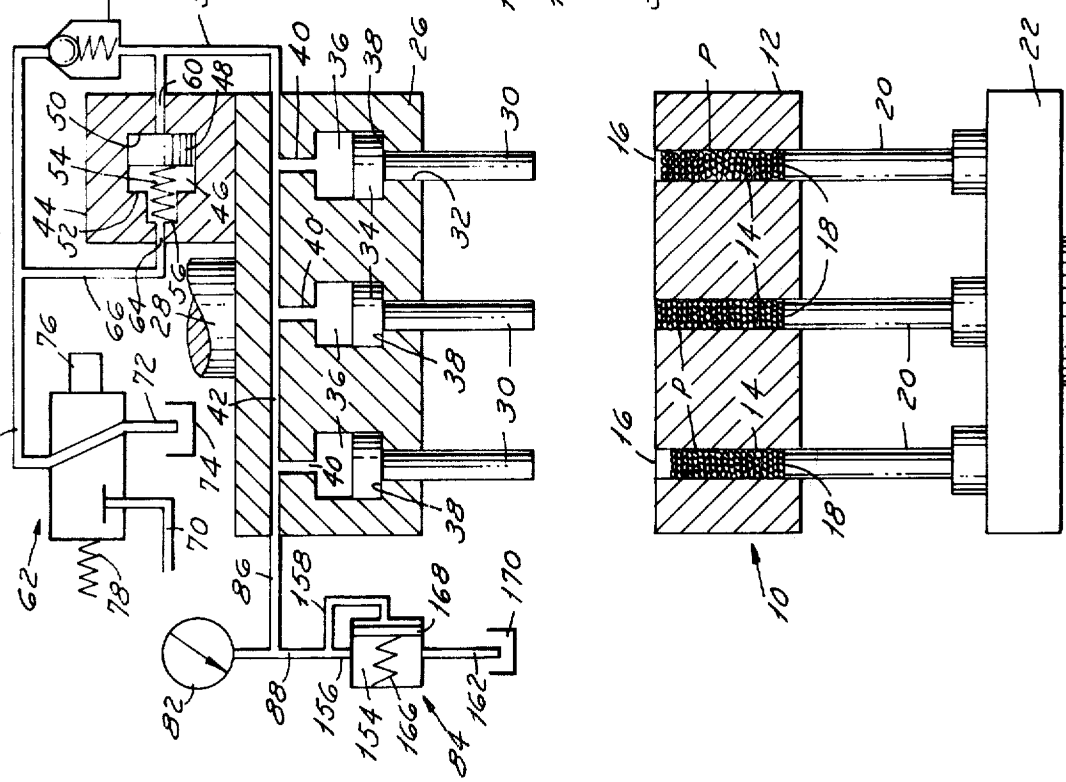


FIG.4

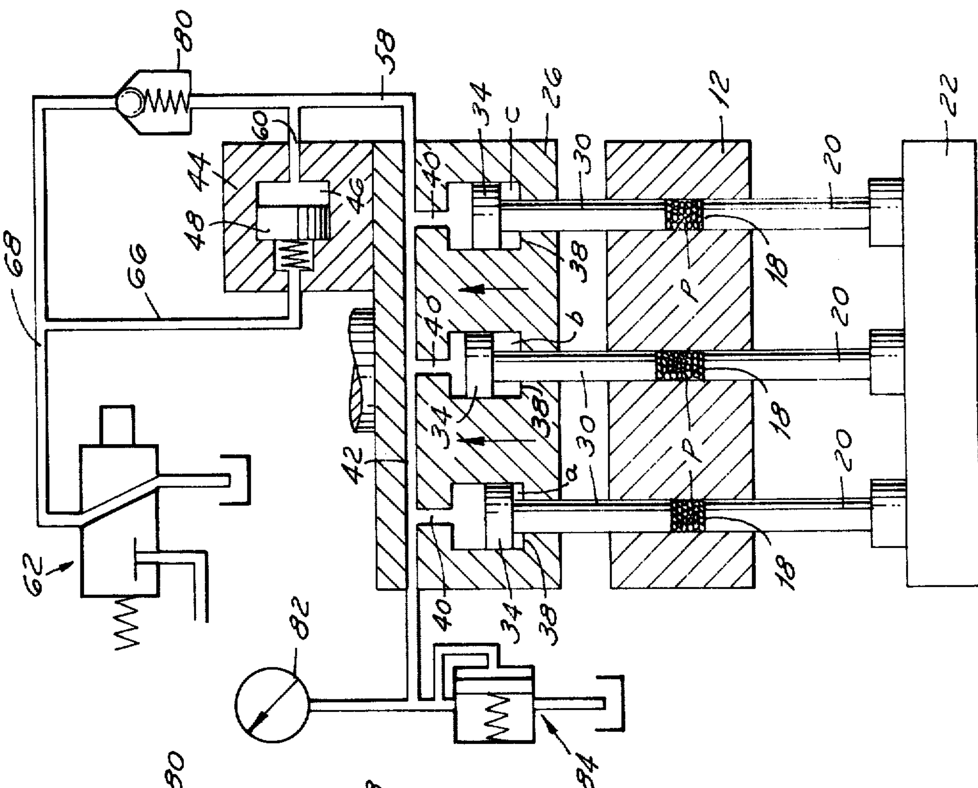
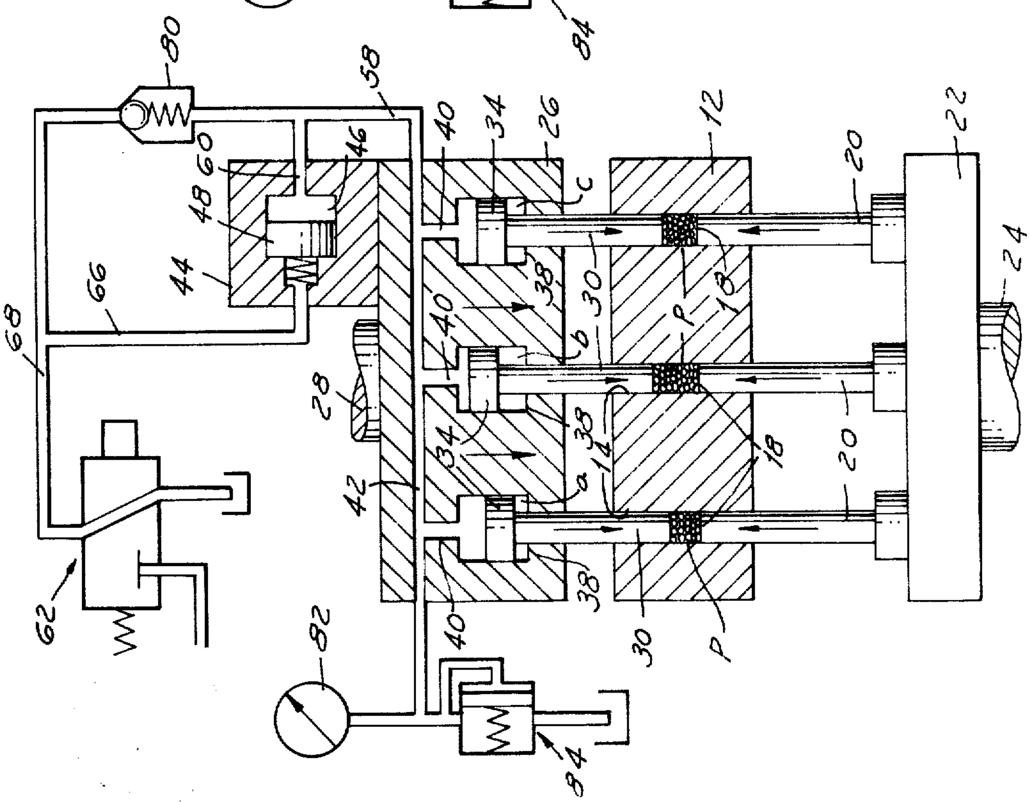

80
58
26
12
22
60
34
c
30
20
44
46
40
48
38
24
66
68
P
18
40
b
20
34
38
30
18
42
a
P
20
62
40
34
38
18
82
84

FIG.3


80
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P
82
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FIG.6

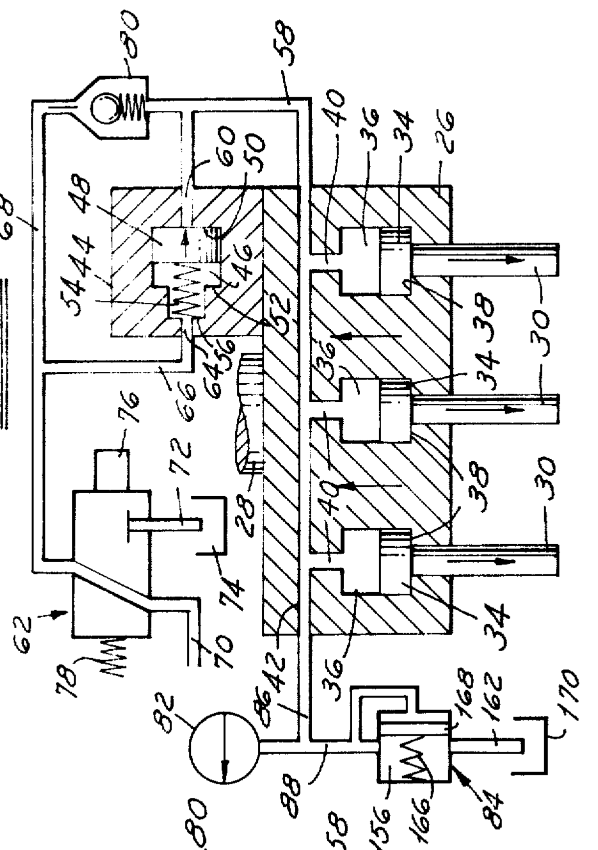
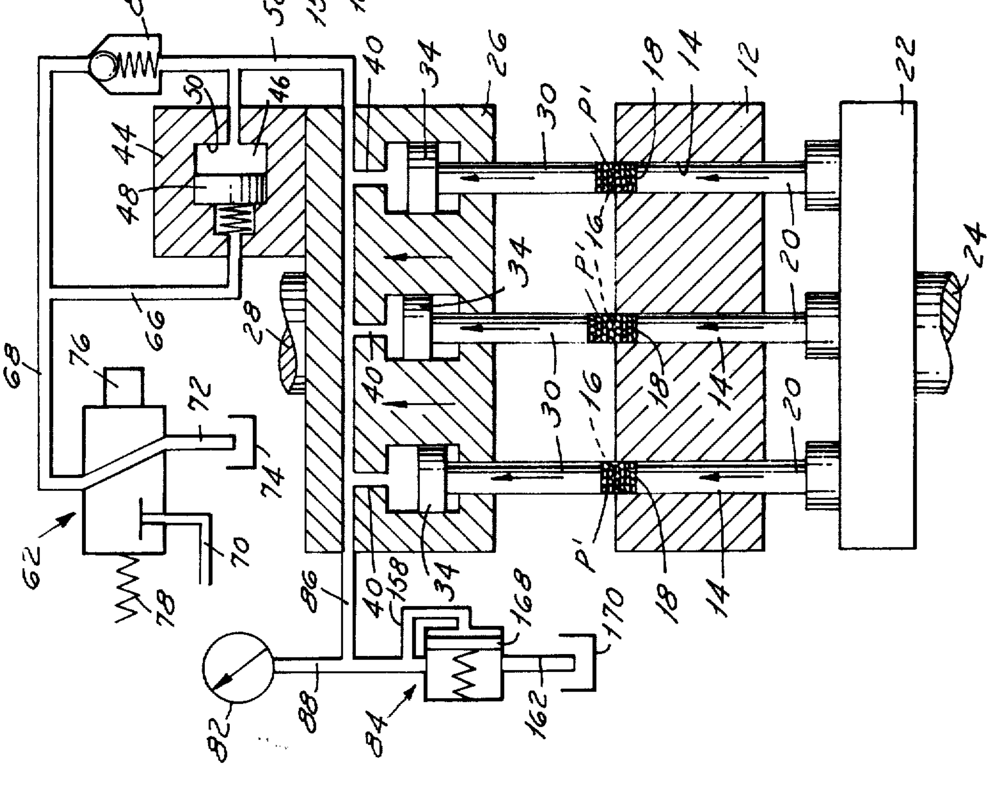


FIG.5



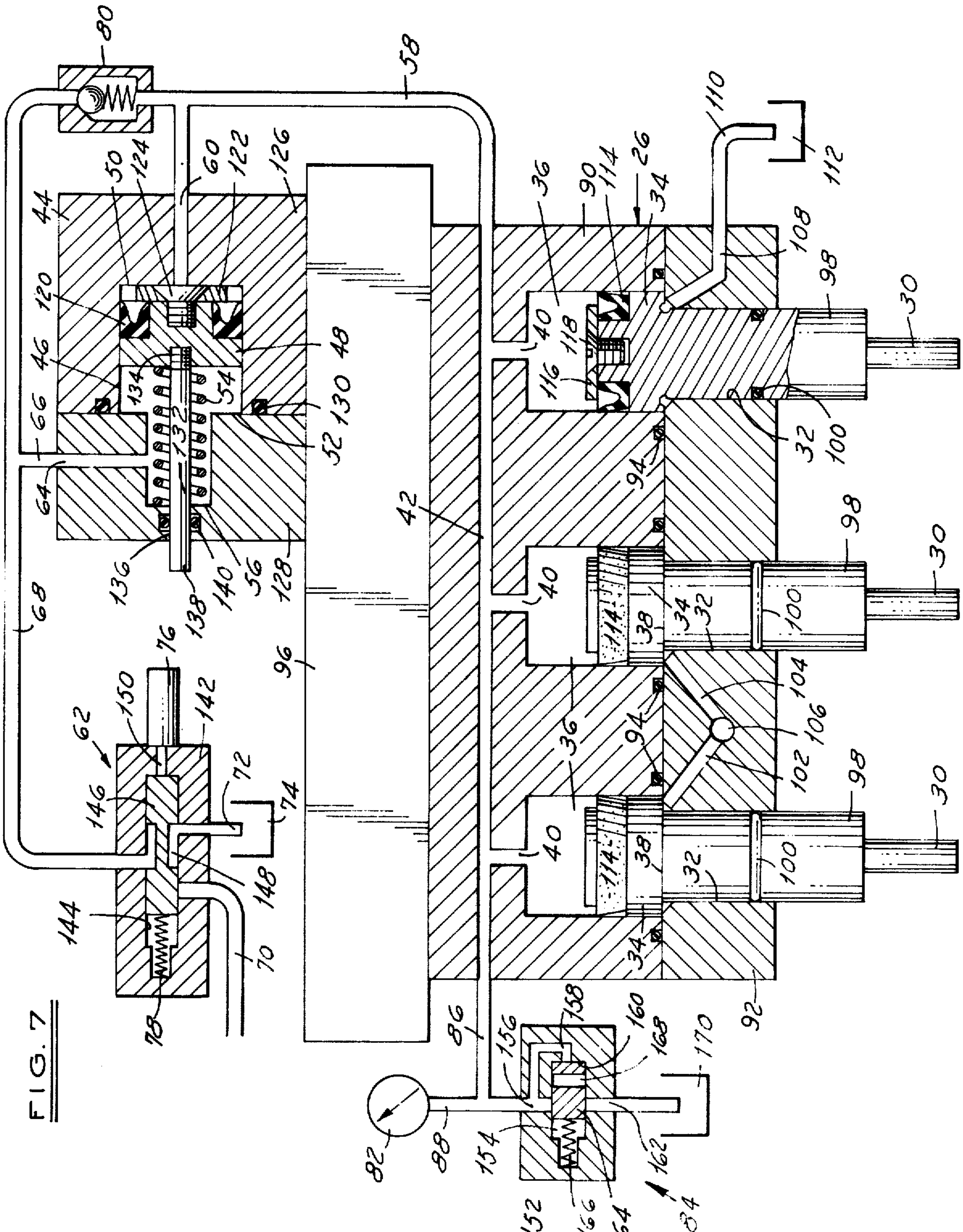


FIG. 7

APPARATUS AND METHOD FOR COMPACTING PARTICULATE MATERIALS

This invention relates to presses of the type used to compact particulate materials or powders to form retaining condition. Typical materials with which such presses are used are powdered metals, ceramics and tungsten carbide.

The usual requirements for such compacted materials are uniform density, dimensions which are accurate within specified tolerances, and freedom from internal and external defects — such as laminations, cracks, end capping and chipped edges. These requirements are difficult to meet because of such factors as poor flowability of the powder, air entrapped therein and problems in controlling the rate of compaction at various locations within a body of the powder.

Some powders have peculiar characteristics which compound the difficulties in obtaining an acceptable product. Notable among these is uranium-dioxide powder which is compacted to cylindrical pellets for use as fuel in nuclear reactors. This material has unusually poor flowability and frequently has an unusual amount of entrapped air. It is made in relatively small batches which vary in physical characteristics from one to another. The material is extremely expensive so that any appreciable percentage of defective pellets is unacceptable. Finally, these pellets are made in vast numbers and at very high production rates.

One result of the poor flowability and relatively fluffy nature of uranium-dioxide powder is that it is difficult to fill a die cavity each time with exactly the same quantity of the powder. This is particularly troublesome when a plural cavity press is being used since it is difficult to apply uniform compacting pressures to columns of the powder varying in height from cavity to cavity. Moreover, when the pellet is decompressed following compaction, the pellet is unusually susceptible to formation of internal defects because of expansion of the entrapped air. Uranium-dioxide is selected for illustration of the invention because it involves not only problems common to the compacting powders in general, but additional problems as well.

The object of the present invention is to provide a relatively simple, inexpensive press structure which is improved to overcome the problems arising from the above-discussed factors. In the drawings:

FIGS. 1 through 6 are diagrammatic sectional views illustrating successive steps in a cycle of operation of a press embodying the present invention;

FIG. 7 is an enlarged scale diagrammatic sectional view illustrating a compensator and accumulator feature of the invention.

Shown in the drawings is a conventional hydraulic press **10** of the opposed ram type on which is mounted a stationary die plate **12** which defines a plurality of die cavities **14**, each having an open upper end **16**. Each die cavity has a bottom wall **18** which is formed by the upper surface of a punch **20**. Punches **29** are mounted on a lower platen **22** which is driven by a powered ram **24** for moving punches **20** vertically in die cavities **14**. The speed of the ram and the pressure exerted by the ram at various portions of the compacting cycle are regulated by conventional hydraulic controls on the control circuit of the press.

Press **10** has a head **26** which is supported on an upper platen above die plate **12** by a ram **28** which is power driven in a manner similar to ram **24** to move the head downwardly in closing movement relative to plate **12** and upwardly in reacting movement relative thereto. The control circuit of the press is adapted to adjustably regulate the speed of and force on each ram independently by such means as pressure and flow control valves. However, since the press controls themselves are conventional and form no part of the present invention, a detailed description thereof is unnecessary. Head **26** carries a plurality of compacting punches **30** each aligned with a die cavity **14**. Each punch **30** passes slidably through an opening **32** in head **26** and terminates at its upper end in an enlarged head **34** forming a piston in a hydraulic cylinder **36** in the head. In the upward retracted position of head **26** (FIGS. **1** and **6**) each piston **34** is supported by the bottom end wall **38** of its respective cylinder **36**.

Cylinders **36** communicate with each other hydraulically through ports **40** and a passageway **42** in head **26**. Mounted on head **26** is a body **44** which defines an internal hydraulic accumulator cylinder **46** having a piston **48** therein. Cylinder **46** has an end wall **50** and an opposite end wall **52**, a central portion of which is recessed to receive a compressed spring **54** and to provide a seat **56** therefor. Spring **54** engages piston **48** and urges the piston toward end wall **50**. Passageway **42** communicates hydraulically with cylinder **46** through a conduit **58** and a port **60** in body **44**. Thus, cylinders **36** are in hydraulic communication with cylinder **46** as well as with each other.

A valve **62** is hydraulically connected with cylinder **46** at the side of piston **48**, opposite from port **60** by means of a port **64** connected with valve **62** by conduits **66, 68**. Valve **62** has an inlet **70** connected with a source of hydraulic fluid under relatively low pressure (not shown) and has an outlet **72** connected to a drain **74**.

Valve **62** is actuated by a solenoid **76** for interconnecting conduit **68** and inlet **70** and is returnable by a spring **78** to disconnect conduit **68** from inlet **70** and connect it with outlet **72**. Conduits **58, 68** are interconnected through a check valve **80** which permits a flow of fluid from conduit **68** into conduit **58** but prevents the flow of fluid in the opposite direction.

Passageway **42** is hydraulically connecteed with a pressure gauge **82** and a pressure relief valve **84** through conduits **86, 88**. Thus, when valves **80, 84** are closed, a closed fluid circuit is established between cylinders **36** and accumulator cylinder **46**, the pressure being the same throughout the circuit.

As shown in greater detail in FIG. **7**, head **26** comprises body **90** to which a retainer plate **92** is secured by such means as bolting (not shown). O-rings **94** are interposed between the body and retainer plate. Body **90** defines cylinders **36**, ports **40** and passageway **42**. Body **90** forms part of a platen **96** to which ram **28** is secured.

Retainer plate **92** defines the openings through which enlarged portions **98** of punches **30** slidably extend. O-rings **100** are interposed between enlargements **98** and openings **32**. Plate **92** forms the bottom walls **38** of cylinders **36** and is also bored to form a system of passageways **102, 104, 106, 108** which communicate with the lower ends of cylinders **36** and with an outlet **110** into a drain **112**. Each piston **34** is provided with a high pressure seal **114** secured thereto as by a retaining washer **116** and a screw **118**. Seals **114** slidably engage the walls of cylinders **36**.

Accumulator body **44** may be mounted on platen **96** or may be machined as part of head **26** and/or platen **96**. Accumulator piston **48** has a high pressure seal **120** secured thereto by a retaining washer **122** and a screw **124**. Accumulator body **44** comprises two sections **126**, 128 secured together by such means as bolting (not shown). Section **126** defines cylinder **46**, end walls **50** and **52** thereof and port **60**. Section **128** forms the recess for spring **54**, spring seat **56** and port **64**. An O-ring **130** is provided between sections **126, 128.**

A rod **132** is threaded to piston **48** at **134**. This rod extends through the interior of spring **54**, projects slidably through an opening **136** in body section **128** and has an end portion **138** disposed outside of the accumulator body. An O-ring **140** is provided between the rod **132** and body section **128.**

Valve **62** has a body **142** forming an internal cylinder **144** within which a spool **146** is slidable. Spool **146** has an annular groove **148** which interconnects conduit **68** with outlet **72** in one position and interconnects conduit **68** with inlet **70** in another position. When outlet **72** is connected with conduit **68,** inlet **70** is cut off from communication therewith and vice versa. The valve spool is moved in one direction by plunger **150** of solenoid **76** and is returned in the other direction by spring **78.**

Pressure relief valve **84** has a body **152** which defines an internal cylinder **154** having a side port **156** connected with conduit **88** and a shunt passageway **158** which opens into an end **160** of the cylinder. The cylinder has a side outlet port **162** aligned with port **156.** A piston **164** in the cylinder is urged against cylinder end **160** by a spring **166** to close shunt passageway **158.** In this position piston **164** isolates port **156** from port **162** to contain fluid under pressure in the system comprised of cylinders **36, 46** and the various interconnecting ports and passageways.

The stress of spring **166** is adjustable to maintain piston **164** in this position until hydraulic pressure in such system exceeds a predetermined selected pressure, whereupon that pressure forces piston **164** to the left as FIG. **7** is viewed to align a port **168** therein with ports **156, 162** which permits fluid to pass out of the system through outlet **162** into drain **170** until the pressure lowers again to the predetermined maximum. At that time spring **166** returns piston **164** to the right, removing port **168** from registry between ports **156** and **162** to again close the system. The maximum pressures to which rams **24, 28** are subjected are controlled by relief valves in the press control circuit. Relief valve **84** is provided as a precaution in the event of a malfunction of the press controls. Valve **84** is set to open at a pressure slightly in excess of the relief valves in the press circuit.

In use, at the beginning of a cycle of operation press **10** is in the condition illustrated in FIG. **1.** Lower punches **20** are in a downward position so that their upper end surfaces **18** are positioned in lower portions of die cavities **14.** Each cavity **14** has been filled or partially so with a quantity of powder P to be compacted. As a practical matter the quantity of powder frequently varies from cavity to cavity, as shown in exaggerated form in FIG. **1** for purposes of illustration. Valve solenoid **76** is in de-energized condition and valve **62** is in the position of FIGS. **1** and **7** wherein the portion of accumulator cylinder **46** to the left of piston **48** is in communication with drain outlet **72** and inlet **70** is cut off from communication with the hydraulic compensator system.

Suitable conventional controls on the press are now actuated to cause the various components of press **10** to function in the manner and sequence described below.

Ram **28** is actuated to lower head **26** so that punches **30** enter the upper ends **16** of die cavities **14** and begin to compact powder P. The individual punches encounter different degrees of initial resistance when there are varying amounts of powder in the individual die cavities. Since the powder levels in the cavities are assumed to be different, each punch moves upwardly with respect to head **26** a distance which is commensurate to the resistance which it has encountered and thereby forces its respective piston **34** upwardly a like distance in cylinder **36.** This retrograde movement is represented by arrows on punches **30** in FIG. **2.**

Upward movement of pistons **34** displaces hydraulic fluid from cylinders **36** through ports **40,** passageway **42,** conduit **58,** port **60** and into accumulator cylinder **46.** The pressures generated or applied at each of the pistons are identical. Accumulator piston **48** is forced to the left as the drawings are viewed until it bottoms against end wall **52** of cylinder **46.** This movement of piston **48** displaces hydraulic fluid from the left portion of cylinder **46** and through port **64,** conduits **66, 68** and outlet **72** into drain **74.** By the time that piston **48** has bottomed against end wall **52** the relative movement of pistons **34** to compensate for the different amounts of powders in cavities **14** has been completed and identical low pressures are applied to all pistons. The various distances through which punches **30** and their pistons **34** have shifted are represented at *a, b* and *c* in FIGS. **2** through **4.**

As head **26** continues downwardly, the hydraulic pressure increases uniformly on the tops of pistons **34** since cylinders **36** are in hydraulic communication with each other and with the now entirely filled accumulator. Since no further retrograde movement of punches **30** and pistons **34** is possible, the full force of head **26** is now transmitted to pistons **34** and the punches through the hydraulic fluid in cylinders **36.**

When piston **48** bottoms against cylinder wall **52** the pressure in the compensator system immediately begins to increase. At this point a limit switch (not shown) is tripped by the upper platen which directs a signal to the lower ram **24** controls in the press circuit. Ram **24** is thus actuated to raise platen **22** at a controlled rate for driving lower punches **20** upwardly into die cavities **14** as represented in FIG. **2.** Downward movement of head **26** and upper punches **30** and upward movement of lower punches **20** is continued until the desired maximum compacting pressure (for example, 10,000 p.s.i.) has been attained and powder P has been compacted to form retaining condition. The press is now in the condition illustrated in FIG. **3.**

During the compaction procedure the hydraulic fluid in cylinders **36, 46** and interconnecting circuitry is actually slightly compressed. After compaction has been completed, ram **28** is actuated by a pressure switch in the press control circuit to reduce partially the downward force on head **26.** This reduces the pressure in the compensator system to a predetermined low value (such as 3,000 p.s.i.). During this pressure reduction the hydraulic fluid expands slightly, forcing head **26** upwardly relative to punches **30** as represented by the arrows in FIG. **4** while maintaining punches **30** in forcible engagement against the upper ends of the compacted powder. This slight upward movement of the head relative to punches **30** is permitted by spaced *a*, *b* and *c* between the bottoms of pistons **34** and the lower end walls **38** of cylinders **36** which developed during the compensating movement of the pistons prior to compaction.

This decompression and expansion of the hydraulic fluid serves a very useful purpose in that it facilitates an initial relatively gradual reduction of the force applied by punches **20, 30** on the opposite ends of the compacted material, which in turn facilitates a relatively gradual decompression of the compacted material itself. This initial decompression prevents sudden recovery expansion of the powder itself and sudden expansion of air entrapped within the compacted powder and, thus, tends to prevent the formation of internal faults in the compacted material such as cracks, laminations and end caps.

The compacting force of punches **20, 30** on powder P is exerted in an axial direction. However, this force tends to displace powder P radially against the walls of die cavities **14**. The powder is thus compressed both axially and radially. Consequently, during the decompression step discussed above the compacted powder decompresses both axially and radially.

During the decompression step, a substantial upward thrust on ram **24** is maintained with the result that during the decompression step or immediately upon its conclusion the force differential between the upper and lower punches begins to move the compacted material (now pellets P') together with punches **30** upwardly in die cavities **14**. During this movement the upper and lower punches are maintained in pressure contact with the upper and lower ends of pellets P'.

As this movement continues the pellets gradually emerge through the open upper ends **16** of die cavities **14** and entrapped air in the pellets escapes progressively and gradually as the pellets emerge. This step is illustrated in FIG. **5**. Ultimately, pellets p'are completely ejected through cavity ends **16** (FIG. **6**) and ram **24** is actuated to halt upward movement of lower punches **20**. Head **26** continues upwardly thereby disengaging upper punches **30** from the pellets and removing the forcible contact of the upper and lower punches against the pellets. Head **26** continues upwardly to its initial position of FIGS. **1** and **6** at which time upper ram **28** halts movement of head **26**. After pellets P' have been removed from the work area, ram **24** and punches **20** are retracted downwardly to the starting position of FIG. **1**.

During the decompression step and the upward movement of the pellets prior to their reaching open ends **16** there is some escape of trapped air from the pellets along the side walls of die cavities **14**. However, the pellets and punches fit relatively closely within the die cavities and it is believed that most of the escape of trapped air occurs gradually as the upper ends of the pellets move upwardly out of the ends **16** of the die cavities.

After head **26** has returned to its upward retracted position, solenoid **76** is energized to shift valve spool **146** leftward as FIG. **7** is viewed to connect hydraulic inlet **70** with conduit **68** and disconnect conduit **68** from outlet **72**. Accumulator cylinder **46** is thereby pressurized to move piston **48** to the right as the drawings are viewed (under the assistance of spring **55** and/or rod **132**), thereby emptying the accumulator and returning pistons **34** and punches **30** to their downward bottoming position. After the accumulator has been emptied, pressure in cylinder **46** and conduit **68** builds to that of the supply pressure at inlet **70**. If there has been any loss of fluid from the system downstream of the accumulator (through the seals, for example), check valve **80** opens under this pressure differential to replenish the supply of fluid to the closed circuit. Thereafter the check valve closes.

Solenoid **76** is now de-energized and spring **78** returns valve spool **146** to the right, cutting off inlet **70** from conduit **68** and, through conduit **68**, connecting the left end of accumulator cylinder **46** with drain outlet **72**. Spring **54** in accumulator cylinder **46** holds piston **48** against the right end wall **50** of the accumulator cylinder and the press is now in its initial condition of FIG. **1** ready for operation in a subsequent cycle in the manner described above.

Portion **138** of piston rod **132** which projects exteriorly of accumulator body **44** (FIG. **7**) provides a visual indication of the position of accumulator piston **48** and, in some circumstances, may be used as a manual plunger for returning piston **48** to its initial position against end wall **50**.

Inevitably, during the compacting procedure there is some leakage of hydraulic fluid past seals **114** on pistons **34**. This leakage is utilized as a lubricant between pistons **34** and cylinders **36** and between enlargements **98** of punches **30** and openings **32** within which they move. Passageways **102, 104, 106, 108** in retainer plate **92** are used to drain accumulations of the leakage into outlet **110** and drain **112**.

Check valve **80** and high pressure seals **114, 120** serve to isolate the circuitry between compensator cylinders **36** and accumulator piston **48** during the compaction cycle. Check valve **80** opens only to permit replenishment of fluid into the circuitry between compacting cycles. Gauge **82** shows the pressure in the compensator/accumulator system at various stages in cycle of operation of the press.

At the beginning of a cycle of operation the pressure in the compensator/accumulator circuit is nominally zero, being only that which is created by the force of spring **54** on piston **48**, and typically this force is about 10 pounds.

Accumulator **46, 48** is mounted as close as is practical to compensator cylinders **36** to minimize pressure losses in the system and, for this purpose, it is preferable to mount the accumulator on head **26** as shown or to form it as part of head **26** and/or platen **96**.

The accumulator is shown as comprising a cylinder **46** and piston **48** therein, but broadly this accumulator is an expansible chamber having a predetermined maximum volume and other types of expansible chambers could be used.

In the typical press according to the present invention, cylinders **36, 46** have a diameter of about one inch and punches **20, 30** have a diameter of about one-quarter inch. The compacting stroke of punches **30** is about one-half inch. The travel of accumulator piston **48** is correlated to permit a retrograde compensating stroke of pistons **34** which is about one-quarter of the compacting stroke of punches **30**. Depending upon the powder used and the degree of compaction desired, the press rams can be controlled to produce maximum pressure on the top sides of pistons **34** (FIG. **3**) of from about 3,000 p.s.i. to about 10,000 p.s.i. and a back pressure during decompression and ejection (FIGS. **4** and **5**) of from about 500 p.s.i. to about 3,000 p.s.i. The pressure developed by the hydraulic source which supplies oil to the system through valve **62** can be in the range of about 250 p.s.i. to 500 p.s.i.

Press **10** is illustrated as having three die cavities **14** and as being of the opposed ram type with the compensator system (pistons **34**, cylinders **36** and accumulator body **44**) mounted on the upper platen. However, the invention is not limited to this specific arrangement; for example, the compensator system could be mounted on both platens or the lower platen. Likewise, the lower platen could be stationary and die plate **12** could be ram operated to apply compaction force to the lower ends of the pellets being formed. The number and shape of the cavities can also be varied. Such modifications would require corresponding, readily apparent modifications in the compensator system and the press control circuit. Depending on the shape of the pellet or part being pressed, the cavities may be other than cylindrical.

A typical press in accordance with the invention is capable of satisfactory operation at rates up to about 75 cycles per minute and at such rates produces pellets of uranium-dioxide which are of acceptable quality and at acceptably low percentages of defective pellets.

I claim:

1. In an apparatus for forming powder material into pellets which are uniformly compacted to substantially the same density, which comprises, a die having a plurality of through cavities therein in which powder is adapted to be compacted to form said pellets, a head having a plurality of punches thereon aligned one with each of said cavities, the leading end of each punch being adapted to be advanced into one end of its respective cavity to compact the powder therein, said head having a plurality of hydraulic cylinders therein, a piston axially slidable in each cylinder and operatively connected to the opposite end of a respective punch, means defining an accumulator chamber having a pressure responsive member therein movable to expand the chamber to a predetermined maximum size, means forming a closed hydraulic fluid circuit between said accumulator chamber and said cylinders so that the fluid pressures in said cylinders are substantially identical, a second plurality of punches for closing the other ends of said cavities, said last-mentioned punches being mounted on a common support which is movable relative to said die, means for moving said head and die relatively toward each other to interengage the leading ends of the punches on the head with the powder column in each cavity to thereby compact said powder, the length of each cylinder being greater than the required stroke of the piston therein to produce the powder compaction desired, said maximum size of said accumulating chamber being related to the cumulative sizes of said cylinders and the full compacting stroke of said punches such that, when said cavities are filled to slightly different levels and the head is initially relatively moved to engage the punches thereon with the powder, the punches retract different distances upon encountering the resistance of the respective powder columns and the powder is subjected to an initial low compression of substantially the same magnitude in each of said cavities before said accumulator is expanded to said maximum size and upon further relative movement of said head toward said die to produce said full compacting stroke of said punches and pistons, said accumulator chamber is expanded to said maximum size and the compacting force on the powder is increased to identical high values in each cavity and is directly proportional to the pressure produced in said closed fluid circuit by reason of said further movement of said head relative to said die and means for relatively moving said head, support and die for ejecting the compressed pellets axially from the cavities while both sets of punches remain in pressure contact with the opposite ends of the pellets.

2. The apparatus called for in claim **1** including means for moving said support relative to said die upon said further relative movement of said head for causing the second set of punches to positively displace powder at said opposite ends of said powder columns in a compacting direction relative to the cavities.

3. The apparatus called for in claim **2** wherein said cavities are of uniform cylindrical shape and the leading ends of said two sets of punches correspond in size and shape with the cross section of the cavities.

4. The apparatus called for in claim **3** wherein the means for relatively moving said head, support and die comprise at least two hydraulically actuated rams.

5. The apparatus called for in claim **4** wherein said two rams are opposed, one being connected to said head and the other to said support.

6. The apparatus called for in claim **3** including a source of hydraulic fluid connected with said closed circuit for replenishing the same.

7. The apparatus called for in claim **3** wherein said accumulating chamber comprises a cylinder having a piston movable axially therein, said accumulator cylinder having one end thereof in said closed fluid circuit, the opposite end of the accumulator cylinder having a stop therein for limiting the extent of axial movement of the piston therein in one direction to thereby define said maximum size of the accumulator chamber.

8. The apparatus called for in claim **7** including means biasing said accumulator piston toward said one end of the accumulator cylinder to thereby permit the flow of fluid from said punch cylinders into said accumulator cylinder upon retraction movement of the punch pistons.

9. The apparatus called for in claim **3** wherein said accumulator chamber is mounted on said head.

10. The apparatus called for in claim **3** wherein said die is mounted in a fixed position on said press between said head and support and said head and support are movable toward and away from said die.

11. The method of compacting powder in a plurality of open ended die cavities to simultaneously form a plurality of compacted pellets by applying opposed forces to two sets of axially opposed punches extending into the cavities of a die from the opposite ends thereof, at least one set of said punches being mounted on a head, said head and die being relatively movable, each punch of one set being operably connected with an individual piston movable axially within a hydraulic cylinder on said head, said cylinders being in common fluid communication, which comprises, applying a force to produce relative movement of said head and die so that each punch on the head approaches the adjacent end of the powder column in its respective cavity while the punches of the other set are positioned to engage the opposite ends of the powder columns; permitting each piston to retract slightly in its respective cylinder in response to its respective punch encountering the resistance of the adjacent end of the powder column by displacing hydraulic fluid from each cylinder into an expandable fluid chamber connected in closed circuit with said cylinders; causing said chamber to expand so as to receive said fluid from said cylinders; while continuing the application of said force, arresting expansion of said chamber before any of said retracting pistons bottom in their respective cylinders to thereby apply substantially equal relatively low pressures on all of said pistons; increasing said force to continue the relative movement of the head and die until the fluid pressure in said cylinders rises to a predetermined high value which corresponds to the desired compacting force exerted by the punches on the columns of powder to thereby form said pellets, said fluid being compressible responsive to pressure at said high value; relieving said force to reduce the pressure in said cylinders to a positive value sufficiently below said high pressure to thereby permit substantial decompression of said fluid so that the expansion thereof causes the pistons to advance relative to their cylinders; retaining both sets of punches in pressure contact with the opposite ends of the pellets by the application of a differential force thereto to cause the punches to move in the same direction relative to the die to eject the pellets axially from the cavities; and thereafter moving one set of said punches relative to the other to permit extraction of the pellets from therebetween.

12. The method called for in claim **11** including the step of relatively moving the second set of punches and the die when said force is increased to positively displace the powder at said opposite ends of the columns in a compacting direction relative to the cavities.

13. The method called for in claim **11** wherein said force is relieved as described to an extent that the pressure obtaining in said cylinders is at a value intermediate said low and high pressures.

14. The method called for in claim **13** wherein said low pressure is in the range between 250 and 500 p.s.i., said high pressure is in the range between 1,000 and 10,000 p.s.i. and said intermediate pressure is in the range between 500 and 3,000 p.s.i.

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