APPARATUS AND METHOD FOR COMPACTING PARTICULATE MATERIALS


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Primary Examiner—J. Howard Flint, Jr.
Attorney, Agent, or Firm—Barnes, Kisselle, Raisch & Choate

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 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
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 these 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 8 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 connected 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 compaction 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 to 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 accumulator 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 moveable 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 moveable, 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 ad-
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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