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PRESSURE-MULTIPLYING APPARATUS

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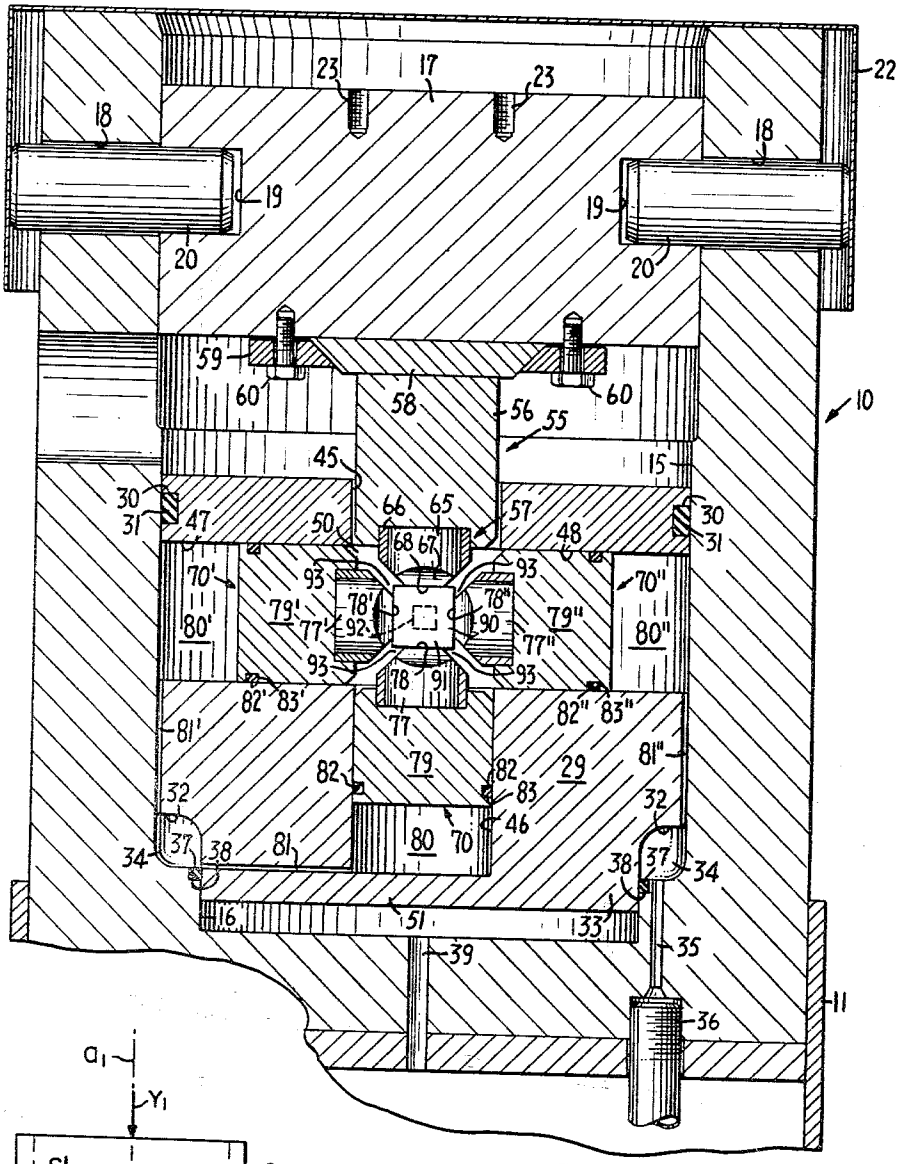


FIG. 1

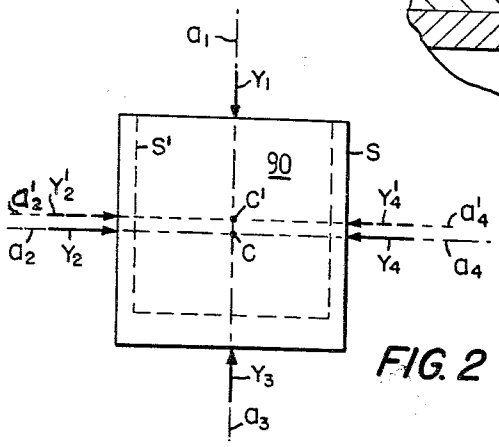


FIG. 2

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PRESSURE-MULTIPLYING APPARATUS

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This invention relates to pressure apparatus in which an object is compressed by an array of pressure-multiplying anvils disposed in three dimensions about the object. More particularly, this invention relates to improvements in pressure apparatus of such sort wherein the compression of the object takes place asymmetrically in the sense that the anvil forces on the object are a mixture of one or more active forces and one or more reactive forces induced by the active force or forces.

An apparatus for so compressing an object asymmetrically is disclosed in the article "Compact Multi-Anvil Wedge-Type High Pressure Apparatus" on pages 59–64 of the August 15, 1959 issue of the Journal of Research of the National Bureau of Standards. That apparatus comprises an upper vertical anvil and three lower anvils disposed in a tetrahedral configuration about a tetrahedral object such that each of the four anvils bears by its front face against a respective one of the four faces of the object. The rear face of the upper anvil abuts against the underneath of a movable upper platen of a conventional two-platen press.

Disposed on the lower stationary platen of such press in coaxial relation with the upper anvil is a hollow sleeve having an inner wall which is conically tapered to progressively reduce the inner diameter of the sleeve in the downward direction. The sleeve supports the three lower anvils by virtue of a bearing of the rear faces of those anvils against the inner conically tapered wall. Such wall has a slope steeper than that which would be required to produce a right angle relation between the wall and the axes of the lower anvils.

The mentioned object is comprised of a body of material to be subjected to pressure and of a tetrahedral casing for that body, the casing being constituted of a pressure-transmissive material such as pyrophyllite.

In operation, the movable upper platen of the press is advanced towards the stationary lower platen to drive the upper anvil downwardly. That downward driving causes the tetrahedral object to exert on each of the lower anvils a force transmitted to the conically-tapered inner sleeve wall against which the rear face of the lower anvil bears. Since such wall has a slope which is steeper than that which would render the wall exactly normal to the axes of the lower anvils, those anvils respond to the load thereon by sliding down along the wall. As the lower anvils so slide, the taper of the wall reacts like a wedge to advance the three lower anvils towards the center of the object simultaneously with the advancement then taking place of the upper anvils towards this same center. Hence, pressure is applied to the object in an "active" manner by the upper anvil and in a "reactive" manner by the three lower anvils. The applied pressure creates in the casing material of the object a pressure field which acts upon the central body of material in the object to subject that body to high pressure.

It might be noted that various types of apparatus which use the same wedging effect to compress an object are disclosed in co-pending application Serial No. 833,809, filed August 13, 1959, issued as Patent No. 3,105,994 for "Pressure Apparatus" and owned by the assignee of this application.

The apparatus described in the article is restricted to smaller ratings and is otherwise limited in application because of an inherent inability of its anvils to act uniformly

on the central object. Specifically, while no shear stress is produced on or in the object by the upper anvil, the friction between the sleeve wall and the rear faces of the lower anvils does develop a shear stress between the front face of each such anvil and the face contacted thereby of the object. Further, because the slope of the conically-tapered sleeve wall is necessarily steeper than that which would render the wall normal to the axes of the lower anvils, the reactive force exerted by the wall on each lower anvil is not in line with the axis of that anvil. Still further, because the lower anvils load the sleeve to produce an outward deformation of its wall at the places against which those anvils bear, the lower anvils do not advance as far as does the upper anvil towards the center of the object being compressed. Because of all the factors just mentioned, the apparatus which has been described is incapable of producing in the pressure transmissive casing of the object a hydrostatic pressure field which is truly uniform.

It is accordingly an object of this invention to provide apparatus which is free of the above noted disadvantages.

Another object of this invention is to provide apparatus in which an object is subjected to a compression which is asymmetric in the sense stated but in which the compression produces a uniform hydrostatic pressure field in the casing of the object.

These and other objects are realized according to the invention by providing a plurality of pressure-multiplying anvils which are arranged in three dimensions about a central cavity operably containing the object to be compressed, and which anvils are comprised of (*a*) a first anvil which is stationary relative to a reference point, and (*b*) a group of second anvils which are movable relative to that point. Also provided is means to subject the second anvils to forces in line with the axes thereof and to produce between all of the anvils a relative movement towards each other so as to compress the object.

When the object is so compressed by a first anvil which is stationary relative to a reference point and by second anvils which are movable relative to that point, during the compression the center of the object undergoes a shift in the direction of the axis of the first anvil relative to the initial positions of the axes of ones of the second anvils. According to the invention, however, the last named ones of said second anvils are floatingly supported in a manner whereby such anvils are unconstrained in respect to movement in the direction of shift except for the friction occurring between such anvils and the object against which those anvils press. Hence, such anvils are free to be moved and are moved by that friction to follow the shift. Therefore, the initial relative alignment of the axes of all anvils is maintained constant throughout the compression of the object. Because the alignment of the anvil axes so stays constant, the anvils are adapted by that feature and others to develop a uniform hydrostatic pressure field in the casing of the object being compressed.

For a better understanding of the invention, reference is made to the following description of an exemplary embodiment thereof and to the accompanying drawings wherein:

FIGURE 1 is a side elevation in cross section of the said embodiment, the cross section being taken in a vertical plane through the axis of the embodiment; and

FIG. 2 is a graphical diagram explanatory of the operation of the embodiment.

Referring now to FIG. 1, the reference numeral **10** designates a housing of circularly annular cross section in the horizontal plane. As shown, the housing **10** is mounted on a stand **11**. Formed within the housing is a hydraulic cylinder **15** having in its bottom a shallow well **16** of circular cross section in the horizontal plane

and of a diameter smaller than that of the cylinder proper.

The upper end of cylinder **15** is shown as being closed by a massive plug **17** inserted in the upper end of housing **10** and secured to the housing by eight equiangularly spaced closure pins **20** extending horizontal through holes **18** in the housing to be received in holes **19** in the side of the plug. Of those eight pins, two pins **20** are shown. The plug and pin assembly is capped by a safety shield **22** which precludes inadvertent removal of the pins. When access is desired to the interior of cylinder **15**, the shield **22** is removed, the closure pins are drawn out of the housing, and the plug **17** is then lifted out of the upper end of the housing. As an aid to such lifting, eye bolts (not shown) may be screwed into the threaded holes **23** formed in the top of the plug.

The closure means **17–22** is only one of many which can be used. As alternatives, the closure means may be a hinged fastenable cover or one of the closure arrangements disclosed in U.S. Patent 3,063,594 issued November 13, 1962 or the closure means disclosed in U.S. Patent 3,049,756 issued August 21, 1962.

Slidably received within cylinder **15** is a cylindrical piston **29** which carries in a groove **30** at its upper end a seal ring **31** in contact with the inner wall of the cylinder. The piston may be rotatable in cylinder **15** inasmuch as in operation the piston will become automatically adjusted to the angular position which is proper therefor. At a point above the cylinder bottom the piston is decreased in diameter to form an annular shoulder **32** and a stem **33** extending downward from the shoulder to be slidably received in the well **16** of the cylinder. Such construction of the piston produces in the cylinder an annular space **34** for receiving pressurized hydraulic fluid injected into the cylinder through a conduit **35** and through an inlet **36** providing a threaded connection for piping from a hydraulic pump (not shown). Fluid injected into that space is obstructed from leaking from space **34** into well **16** by a seal ring **37** extending around piston stem **33** and seated in an annular groove **38** formed in the side of the cylinder. In the event any fluid does leak past seal ring **35** into well **16**, pressure is prevented from building up in the well by a hole **39** through which the fluid is free to drain from the well to the exterior of the housing **10**.

The piston **29** has formed therein an upper vertical bore **45**, a lower vertical bore **46**, and four horizontal bores which are equiangularly spaced around the piston, and of which the bores **47** and **48** are shown. All six bores are cylindrical bores of equal diameter, and all six bores intersect at a central space **50** within the piston. The upper vertical bore **45** and the four horizontal circumferential bores extend from that space all the way through the piston. This is not true of the lower vertical bore **46** which terminates short of the piston bottom (i.e., the bottom of piston stem **33**) so as to have a wall portion **51** of the piston interposed between the lower end of such bore and the piston bottom.

For reasons later explained, the piston **29** is so constructed that pressurized fluid in annular space **34** acts upwardly on the piston over an effective cross sectional area (normal to the piston axis and mostly provided by the surface of shoulder **32**) which is substantially equal to the cross sectional area of the wall portion **51** which closes off the lower end of bore **46**.

The upper bore **45** provides a passage through the piston to its central space **50** for an upper anvil **55** referred to hereinafter as the "stationary" anvil because it is operably stationary relative to the housing **10** taken as a reference datum for movement. The principal parts of anvil **55** are a cylindrical backup member **56** and a pressure-multiplying tool **57** mounted by conventional fastening means (not shown) on the forward end of member **56**. The rear end of member **56** is secured to a mounting plate **58** having a conically tapered, downwardly-inwardly sloping, circumferential wall which is gripped by a matching, tapered, inner circumferential wall of an annular clamp ring **59** bolted by bolts **60** to the underside of plug **17**. By so mounting anvil **55** on plug **17**, the anvil has some freedom to rotate around its axis when the anvil is operably subjected to high pressure.

The tool **57** of anvil **58** is comprised of a tool head **65** having a tapered front end and a cylindrical shank, the latter being surrounded by a steel reinforcing ring **66**. The taper on head **65** is formed by four bevel faces of which face **67** is shown, and which render the front end of the head in the shape of a truncated square pyramid, the front face **68** of the head being accordingly a square planar face. Because that front face is substantially smaller in area than the rear face of head **65**, the head is adapted in a well known manner to "multiply" pressure in the sense that a pressure applied to the rear face thereof will be manifested as a substanitally greater pressure exerted by the front face of the head. Because the head is used as a pressure multiplier, it is constituted of sintered tungsten carbide or of a like material adapted to withstand without breakage the high stresses set up in the material as an incident to the pressure multiplication.

The stationary anvil **55** in bore **45** is one of an array of six anvils of which the other five are disposed in the five remaining bores of piston and are referred to hereinafter as "movable" anvils because they are movable relative to the reference datum provided by housing **10**. Of those five movable anvils, three are shown in FIG. 1, namely the anvil **70** in bore **46**, the anvil **70′** in bore **47** and the anvil **70″** in bore **48**. Since all five movable anvils are substantially identical in structure, only the anvil **70** will be described in detail, it being understood that, unless the context otherwise requires, the description is to be taken as applying also to the other four movable anvils, and that (as among anvils **70**, **70′**, **70″**) the same reference numerals with different prime suffixes are used to designate counterpart elements of the several anvils.

The anvil **70** is comprised at its forward end of a tool **77** whcih has a square planar front face **78**, and which in this respect and all others is a duplicate of the earlier described tool **57** for anvil **55**. The tool **77** is non-rotatably mounted by conventional fastening means (not shown) on the front end of a cylindrical ram **79** slidably received in the bore **46** and constrained from rotating therein by conventional keying means (not shown). As illustrated, the ram **79** is disposed in the forward end of bore **46** to provide in the bore behind the ram a chamber **80** for receiving hydraulic fluid. Such fluid may be injected into chamber **80** by way of a hole **81** extending through piston **29** between chamber **80** and the aforementioned annular space **34**. To obstruct leakage of fluid in chamber **80** past ram **79** and into the central space **50** of the piston, the ram **79** carries a sealing ring **82** in an annular groove **83** formed in the circumference of the ram.

Complementing the fluid passage **81**, there is formed in piston **29** a vertical groove **81′** by which hydraulic fluid may flow from space **34** to the chamber **80′** in horizontal bore **47**. Similar vertical grooves are formed in the piston to permit passage of fluid from space **34** to each of the other three horizontal bores.

The front faces of the one stationary anvil and the five movable anvils are disposed in relation to each other to define a central cubic cavity for containing the illustrated pressure-receiving assembly **90**. That assembly is comprised of an outer cubic casing **91** of a pressure-transmissive material (e.g. pyrophyllite) and an inner body **92** which is the material whose compression is ultimately desired, and which may be a charge for making synthetic diamonds, a workpiece to be subjected to high pressure, etc. As indicated by FIG. 1, the six planar square front faces of the six anvils each bear in centered relation against a respective one of the six outside faces of casing **91** but are somewhat smaller in size than those

casing faces. Such size difference causes the six anvils to be separated from each other by inter-anvil gaps 93 which permit relative movement between all the anvils in the direction toward each other.

The described apparatus is operated in the following manner. As a preliminary to a compressing action, the closure plug 17 is removed to thereby remove upper anvil 55 from bore 45. Next, the lower vertical anvil 70 and the four horizontal anvils are adjusted to a position at which their front faces make a cubic nest having a center point on the axis of anvil 70 and of proper size to permit a pressure-receiving assembly 93 to be slipped thereinto. The positioning of anvil 70 (which would ordinarily tend to fall of its own weight in bore 46) can be accomplished through the use of a hollow tube (not shown) having side perforations and having a threaded upper end received in a threaded hole in the bottom of ram 79 so that the tube props the anvil 70 up from the bottom of bore 46. The distance by which the tube so holds anvil 70 up in its bore is adjustable by the procedure of (*a*) drawing anvil 70 up through upper bore 45 to remove the anvil from piston 29, (*b*) turning the mentioned tube to vary the amount thereof threadedly engaged in the hole in the bottom of ram 79 until the free (bottom) end of the tube is a selected distance from the ram bottom and (*c*) reinserting the anvil 70 and attached tube in bore 46 and allowing the anvil to drop until the bottom of the tube strikes the bottom of the bore.

Inasmuch as there is some friction between the seal rings carried by the four horizontal anvils and the walls of the bores in which those anvils are received the horizontal anvils may be adjusted by a hand or by a hand tool (inserted through upper bore 45 into space 50) to positions suitable to form the mentioned nest. Alternatively auxiliary spring-actuated or hydraulically actuated devices (not shown) may be used to position the horizontal anvils (and, also, if desired, the vertical anvil 70).

Once the nest has been formed by the proper positioning of the front faces of the five lower anvils, a pressure-receiving assembly 90 is slipped into the cavity between those anvils. Next the upper open side of the cavity is closed by lowering the plug 17 to lower the attached stationary anvil 55 through bore 45 in piston 29 until the front face 68 of anvil 55 rests against the upper face of the assembly. The plug 17 is then anchored in place by insertion thereinto of the closure pins 20, the safety shield 22 is slipped over the outer ends of those pins, and the apparatus is now ready to operate.

Operation is initiated by injecting pressurized hydraulic fluid through inlet 36 and conduit 35 into the annular space 34 formed in cylinder 15 behind the annular shoulder 32 of piston 29. From that space, the pressurized fluid flows through horizontal passage 81 into chamber 80 behind anvil 70 to drive the front face 78 of that anvil against the pressure assembly 90 and to thereby force the assembly upwards against the front face 68 of the upper stationary anvil 55. At the same time, pressurized fluid flows from the annular space 34 through the vertical grooves leading upward therefrom (e.g. grooves 81′ and 81″) into the chambers at the radially outward ends of the four horizontal bores to there drive the four horizontal anvils forward in their bores so that the front faces of those anvils press against the assembly 90. In this manner, all six sides of the pressure-receiving assembly are simultaneously subjected to pressure from the front faces of the six anvils. Since the pressure of the fluid is ordinarily several thousand atmospheres and since, as described, the anvils have a pressure-multiplying effect, the pressure to which the assembly 90 is subjected is or may be on the order of many thousands of atmospheres.

In response to this great pressure, part of the pressure-transmissive material in casing 91 of assembly 90 is extruded into the inter-anvil gaps 93 to there form

gaskets which hold in the pressure developed in the main body of the casing, and which provide lateral support for the forward portions of the pressure-multiplying heads. The remainder of the pressure-transmissive material becomes plastic to have a hydrostatic pressure field created therein by the pressure applied thereto. Such field acts upon the central body 92 to produce the desired result of subjecting the material of that body to super high pressure.

In connection with the described operation, it is to be pointed out that the apparatus uses a hydrostatic pressure field developed in a pressurized medium to drive the anvils. In so doing the apparatus follows the teachings of U.S. Patent 3,044,113 issued July 17, 1962 and co-pending applications owned by the assignee of this application and identified as Serial No. 112,385 filed May 24, 1961, issued as Patent No. 3,091,804 and Serial No. 112,265 filed May 24, 1961 issued as Patent No. 3,093,862.

Referring now to FIG. 2, the lines a_1, a_2, a_3 and a_4 represent the initial positions of the axes of, respectively, the anvils 55, 70′, 70 and 70″. Those axes as initially positioned intersect at a point C which is the initial center of the pressure-receiving assembly 90. The outline of that assembly is represented by the solid line square *s* when the assembly is uncompressed and by the dotted line square *s′* when the assembly is compressed.

During compression, the pressurized hydraulic fluid in chamber 80 exerts on movable anvil 70 an upward active force Y_3 which is in line with the anvil's axis a_3, and which drives assembly 90 towards stationary anvil 55 to cause the latter anvil to subject the assembly 90 to a downward reactive force Y_1 in line with the axis a_1 of anvil 55 and equal in value to the active force Y_3. Thus, the pressure-receiving assembly 90 is vertically compressed by an active force from anvil 70 and by a reactive force from anvil 55.

Concurrently, the bodies of pressurized fluid in chambers 80′ and 80″ produce a rightward acting force Y_2 and a leftward acting force Y_4 on, respectively, the anvils 70′ and 70″ in the horizontal bores 47 and 48 of the piston 29. Each of the forces Y_2 and Y_4 is equal in value to the forces Y_3 and Y_1. Because the rear faces of anvils 70′ and 70″ on which the pressurized fluid acts are planar circular faces normal to and concentric with the axes of those anvils, the forces Y_2 and Y_4 are always directly in line with the axes of the anvil 70′ and 70″, respectively. The described inline relation is represented in FIG. 2 by the showing of the arrows designating the forces Y_2 and Y_4 as being respectively coincident with the lines a_3 and a_4. Because the last-named anvils are slidably received in the bores 47 and 48 of piston 29 which is maintained in constant axial alignment by housing 10, the walls of those bores maintain such anvils in a constant alignment relative to each other and to the anvil 70, and, moreover, preclude angular tilting of those anvils relative to the axis a_1 and anvil 55. Thus, the piston 29 and housing 10 serve as a guide means for the anvils 70, 70′ and 70″.

What has been said so far concerning horizontal anvils 70′ and 70″ applies also to the other two horizontal anvils which are not shown by FIG. 1. Therefore, the uncompressed assembly 90 (represented by square *s*) is subjected to six equal forces which are produced by the six anvils pressing on the assembly, and which are all active forces except for the one reactive force Y_1 from the stationary anvil 55.

The assembly when thus compressed is deformed so that its dimensions are reduced, such reduction being, represented in FIG. 2 by the smaller size of square *s′* than square *s*. Because the deformation in the vertical direction of assembly 90 is produced by the squeezing of the assembly between two anvils of which the upper is stationary and the lower is movable, the vertical deformation produces a shifting of the center of the assembly

along the axis a_1 of anvil **55** from the shown point C to a new point C' closer to the stationary anvil **55**. Thus the compression of the assembly produces an offsetting of the center thereof relative to the initial positions a_3 and a_4 of the axes of the shown horizontal anvils **70'** and **70''**, the same offsetting occurring relative to the initial positions of the axes of the two horizontal anvils which are not shown.

If the horizontal anvils were to be so constrained that their axes continued to be coincident with the initial positions thereof, the described shifting of the center of assembly **90** would produce an eccentric loading thereon by the horizontal anvils because the centerlines of action of those anvils would no longer pass through the center of the pressure-receiving assembly.

As a result, the horizontal anvils would create in the pressure-transmissive casing **91** of assembly **90** a hydrostatic pressure field which would be non-uniform. As another result, the shift in the course of its deforming of the whole casing **91** towards anvil **55** would develop on the horizontal anvils an upwardly directed friction force which would tend to jam those anvils in the piston bores in which those anvils are received.

In the present described apparatus, however, the eccentric loading of assembly **90** by the horizontal anvils and the jamming of those anvils in their bores are avoided in a manner as follows.

Referring to both FIGS. 1 and 2, when the pressurized fluid in chamber **80** exerts an upward pressure on the cross sectional area of the rear face of anvil **70**, the fluid also exerts a downward pressure of the same value over substantially the same cross sectional area on the wall portion **51** of piston **29** by which chamber **80** is bounded at its lower end. Therefore, the fluid in chamber **80** urges the piston **29** downward by a force Y_3' which is substantially equal to the upward force Y_3 exerted by the anvil **70** on the pressure-receiving assembly.

If the force Y_3' on piston **29** were not counteracted, that force would serve merely to drive the piston **29** downwardly in the cylinder **15**. It happens, however, that the downward force Y_3' on the piston is opposed by an upward force Y_3'' exerted on the piston in the annular space **34** within the cylinder **15**. The pressure of the fluid in that space is the same as the pressure of the fluid in chamber **80**. Also, the effective cross sectional area of the piston against which the fluid in space **34** acts upwardly is substantially equal to the cross sectional area of the wall portion **51** of the piston against which the fluid in chamber **80** acts downwardly. Therefore, the upward force Y_3'' on the piston is substantially equal to the downward force Y_3' thereon.

Because the piston **29** is so acted upon by downward and upward forces which are substantially equal in value, the piston is subjected to a net axial force which equal zero or is close to zero to thereby render the piston axially floating in the cylinder **15**. In other words, there is no significant constraint in the vertical direction on the motion of the piston within the cylinder.

Inasmuch as the piston is axially floating, and inasmuch as the piston provides the only contraint in the vertical direction for the horizontal anvils such as anvil **70'** and **70''**, those anvils are also floatingly supported, i.e. are unconstrained by their support (piston **29**) from vertical movement. The only constraint on the vertical movement of such anvils is the friction which is produced by the pressure contact of those anvils with assembly **90**, and which, in effect, couples the horizontal anvils to the assembly so as to move vertically therewith. The result is that, when the center of assembly **90** shifts, as described, from the point C to the point C', the mentioned friction causes the axes of such anvils to follow that shift so that those axes continue to pass through the center of pressure-receiving assembly. Such a following is represented in FIG. 2 by the dotted lines a_2' and a_4' which illustrate the positions of the axes of

anvils **70'** and **70''** after the assembly **90** has been compressively deformed.

The following matters should be noted in connection with the showing in FIG. 2 of the lines a_2' and a_4'. First, as stated, those liens pass through the center of the assembly when that center is at its new position C'. Further, the equal forces Y_2' and Y_4' by which the anvils **70'** and **70''** act on assembly **90** at or towards the end of compression are forces which continue to be directly in line with the axes of such anvils when those axes are at their new positions a_3' and a_4'. Still further, because the horizontal anvils are received in bores in a piston which is constrained by the wall of cylinder **15** from being tilted relative to the axis a_1 of the stationary anvil **55**, the axes of the horizontal anvils when in their new positions a_2' and a_4' continue to make the same angle with axis a_1 as they did when in their initial positions a_2 and a_4.

Thus, in the described apparatus, all of the horizontal anvils are driven inwardly against the assembly **90** by forces which continuously act in line with the axes of such anvils while, simultaneously, those anvils are supported in a vertically unconstrained manner so that the friction contact thereof with the assembly causes those anvils to follow the vertical shift in the center of the assembly towards the stationary upper anvil **55**. Because the horizontal anvils so follow the vertical shift in the center of assembly **90**, eccentric loading of that assembly by those anvils is avoided, wherefore the anvil pressure produces a uniform hydrostatic field in the casing **91** of the assembly. The piston follows any vertical shift undergone by the horizontal anvils so that the upward movement of such anvils does not produce any binding of those anvils in their bores. Because of the described construction of the apparatus, each of the anvils which bears on assembly **90** moves equally towards the center point of the assembly when that center point is considered as the reference point for anvil movement.

As earlier explained, the floating positioning of piston **29** in cylinder **15** is the result of substantially equal forces exerted by the pressurized fluid downwards on the piston over a cross sectional area of its wall portion **51** and upwards on the piston over an effective cross sectional area above the annular space **34**. If those two cross sectional areas are exactly equal, theoretically the net vertical force on the piston will be zero. As a matter of practice, however, the weight of the piston produces an additional downward force thereon, and, also, the piston is subjected to some drag by the contact of its seal ring **31** with the inner wall of the cylinder . To compensate for those weight and drag forces, the cross sectional area of the piston which is effectively subjected to upward force by the fluid in space **34** can be made larger than the cross sectional area of the wall portion **51**.

The above described embodiment being exemplary only, it will be understood that the omissions therefrom, additions thereto and modifications thereof can be made without departing from the spirit of the invention, and that the invention extends to embodiments differing in form and/or detail from that specifically described. Thus, for example, the described apparatus can be modified to compress a tetrahedral pressure-receiving assembly by (*a*) replacing the vertical bore **46** in the piston and the four horizontal bores therein by three bores which are each at 120° to the vertical bore **45** and which are equiangularly spaced around the piston, (*b*) modifying the stationary anvil and the movable anvils to each have a triangular front face, and (*c*) maintaining the feature described for the cubic apparatus of having the effective cross sectional area of the piston on which the fluid acts upwardly of the same or slightly greater value than the cross sectional area of each of the broes of the piston in which the movable anvils are received. It can be shown that an apparatus of such tetrahedral configuration will operate in the manner previously described so that the

pressure-receiving assembly will be equally compressed by all anvils, each of those anvils will be subjected to a driving force in line with the axis thereof (the force on the assembly from one anvil being reactive and those from the others being active), and the piston will be floating to permit the movable anvils in the lower bores to follow in an unconstrained manner the vertical shift of the assembly towards the upper stationary anvil.

Accordingly, the invention is not to be considered as limited save as is consonant with the recitals of the following claims.

I claim:

1. Apparatus comprising, means forming a hydraulic cylinder, a piston disposed in said cylinder and having formed therein a central space and a plurality of bores which extend in three dimensions from said space through said piston, and which include a first bore and second bores, said first bore extending axially into said piston from the front end thereof, a plurality of pressure-multiplying anvils comprised of a first stationary anvil operably received in said first bore and of second movable anvils respectively received in slidable relation in said second bores, and means to produce by pressurized hydraulic fluid a driving of said second anvils along the axes of said second bores towards said space and an accompanying movement of said piston in said cylinder and the second anvils contained thereby towards said first anvil so as to compress by all said anvils an object contained in said space.

2. Apparatus as in claim 1 in which said anvils and corresponding bores are six in number and are disposed in pairs along three axis at right angles to each other.

3. Apparatus comprising, means forming a hydraulic cylinder, a piston disposed in said cylinder and having formed therein a central space and a plurality of bores which extend in three dimension from said space through said piston, and which include a first bore and second bores, said first bore extending axially into said piston from the front end thereof and at least one of said second bores being at an angle of more than 90° to said first bore, a plurality of pressure-multiplying anvils comprised of a first stationary anvil operably received in said first bore and second movable anvils respectively received in slidable relation in said second bores, means to inject pressurized hydraulic fluid in said second bores behind said second anvils to drive them along the axes of said second bores towards said space so as to compress an object contained therein between said second anvils and first anvil, and means to subject said piston to axial forces from said fluid which are substantially equal and opposite so as to render said piston axially floating in said cylinder.

4. Apparatus comprising, means forming a hydraulic cylinder, a piston disposed in said cylinder and having formed therein a central space and a plurality of bores which extend in three dimensions from said space through said piston, and which include a first bore and second bores, said first bore txending axially into said piston from

the front end thereof and at least one second bore being at an angle of more than 90° to said first bore, a plurality of pressure-multiplying anvils comprised of a first stationary anvil operably received in said first bore and second movable anvils respectively received in slidable relation in said second bores, means to inject pressurized hydraulic fluid in said cylinder behind said piston to urge it forwardly, and means by which said fluid flows from behind said piston into said second bores to urge said piston rearwardly in substantially equal opposition to said forward urging and to drive said second anvils along the axes of said second bores towards said space so as to compress an object contained therein between said second anvils and said fisrt anvil.

5. Apparatus comprising, a housing containing a hydraulic cylinder having a reduced diameter well in its bottom, a piston having a main portion slidably received in said cylinder and a reduced diameter stem portion fitted in said well, said piston having formed therein a central space and a plurality of bores extending in thre dimensions from said space through said piston and comprised of a first bore and second bores, said first bore extending axially into said piston from the front thereof, at least one of said second bores being at an angle of more than 90° to said first bore, and none of said second bores having an opening into said well, a plurality of pressure-multiplying anvils comprised of a first stationary anvil operably received in said first bore and second movable anvils respectively received in slidable relation in said second bores, means to inject pressurized hydraulic fluid behind the annular region of said piston between the main portion thereof and the reduced diameter stem portion thereof so as to urge said piston forwardly, seal means obstructing the entry of said fluid into said well, and means enabling flow of said injected fluid into said second bores behind said second anvils to drive them along the afes of said second bores towards said space so as to compress an object contained therein between said second anvils and said first anvil.

6. Apparatus as in claim 5 in which said fluid in said second bores urges said piston rearwardly over substantially the same effective cross sectional area as that over which said fluid acts in said annular region to urge said piston forwardly so as to render said piston axially floating in said cylinder.

7. Apparatus as in claim 5 in which closure means at the forward end of said housing permits selective opening and closing of the housing at that end, and in which said first anvil is mounted on and projects inwardly from said closure means.

References Cited by the Examiner

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WILLIAM J. STEPHENSON, *Primary Examiner.*

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,169,273 February 16, 1965

Jacob Brayman

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 3, line 6, for "horizontal" read -- horizontally --; column 8, line 5, for "liens" read -- lines --; line 71, for "broes" read -- bores --; column 9, line 32, for "axis" read -- axes --; line 36, for "dimension" read -- dimensions --; line 57, for "txending" read -- extending --; column 10, line 20, for "thre" read -- three --; line 37, for "afes" read -- axes --.

Signed and sealed this 10th day of August 1965.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents