

June 29, 1965

J. BASSET

3,191,383

TWO STAGE FLUID COMPRESSING DEVICES

Filed June 20, 1962

3 Sheets-Sheet 1

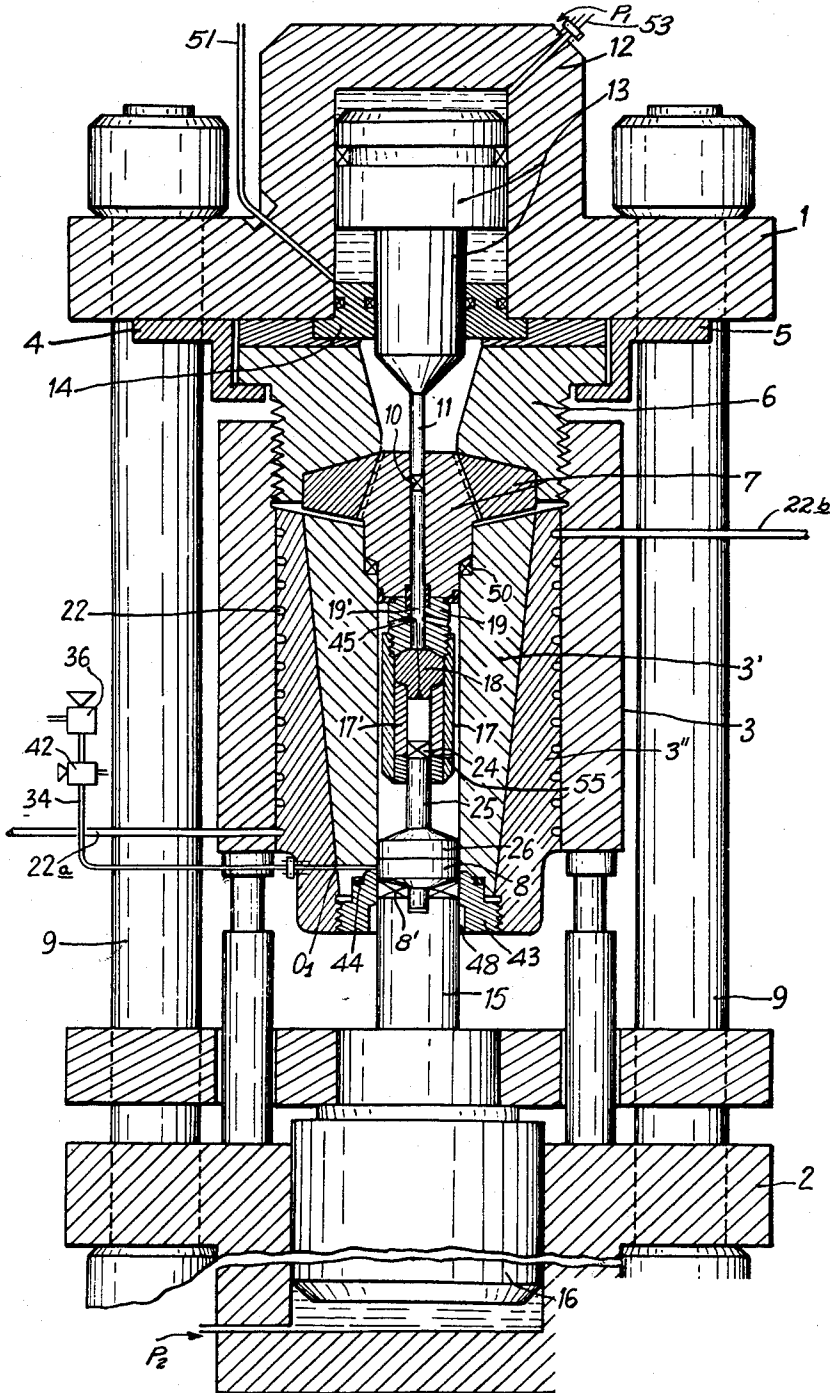


Fig. 1

June 29, 1965

J. BASSET

3,191,383

TWO STAGE FLUID COMPRESSING DEVICES

Filed June 20, 1962

3 Sheets-Sheet 2

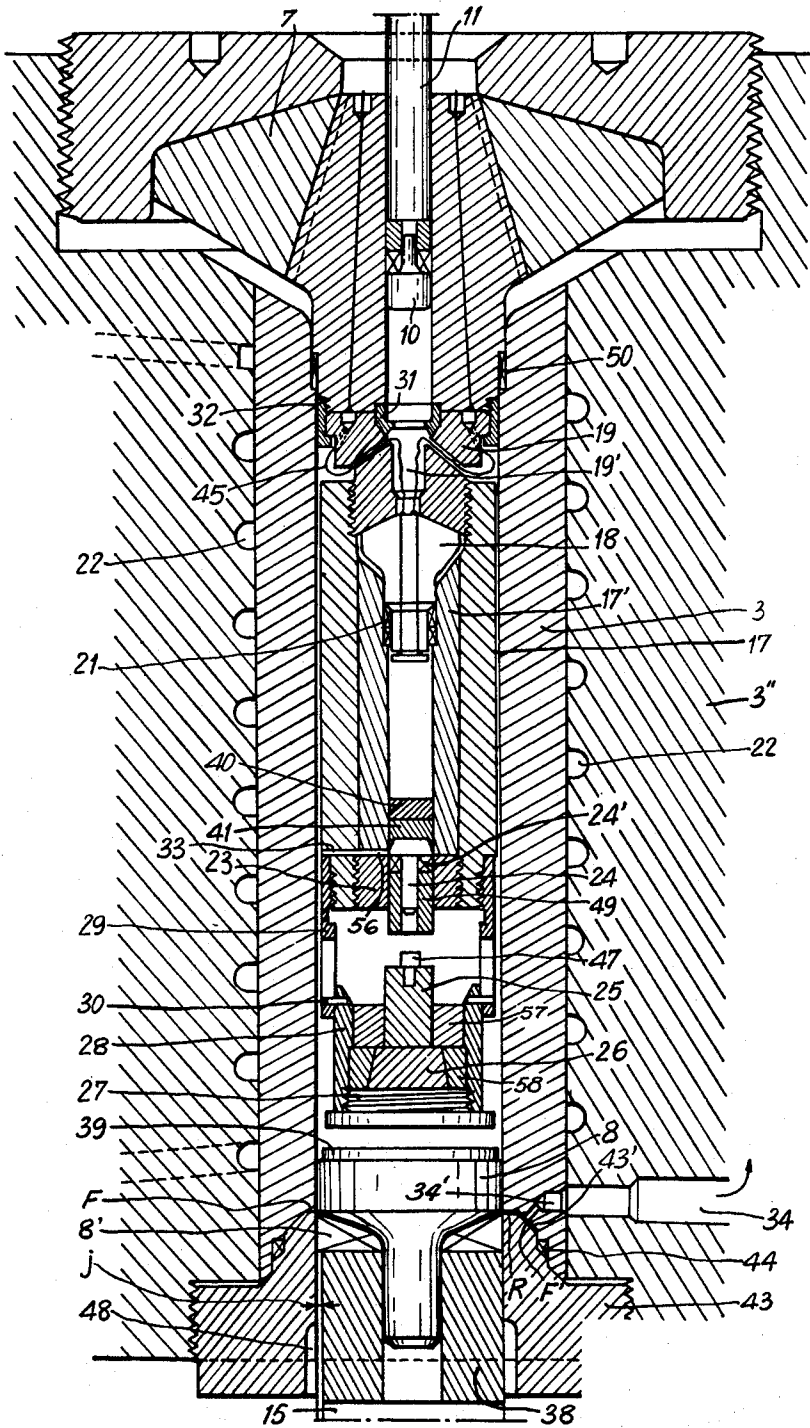


Fig. 2

June 29, 1965

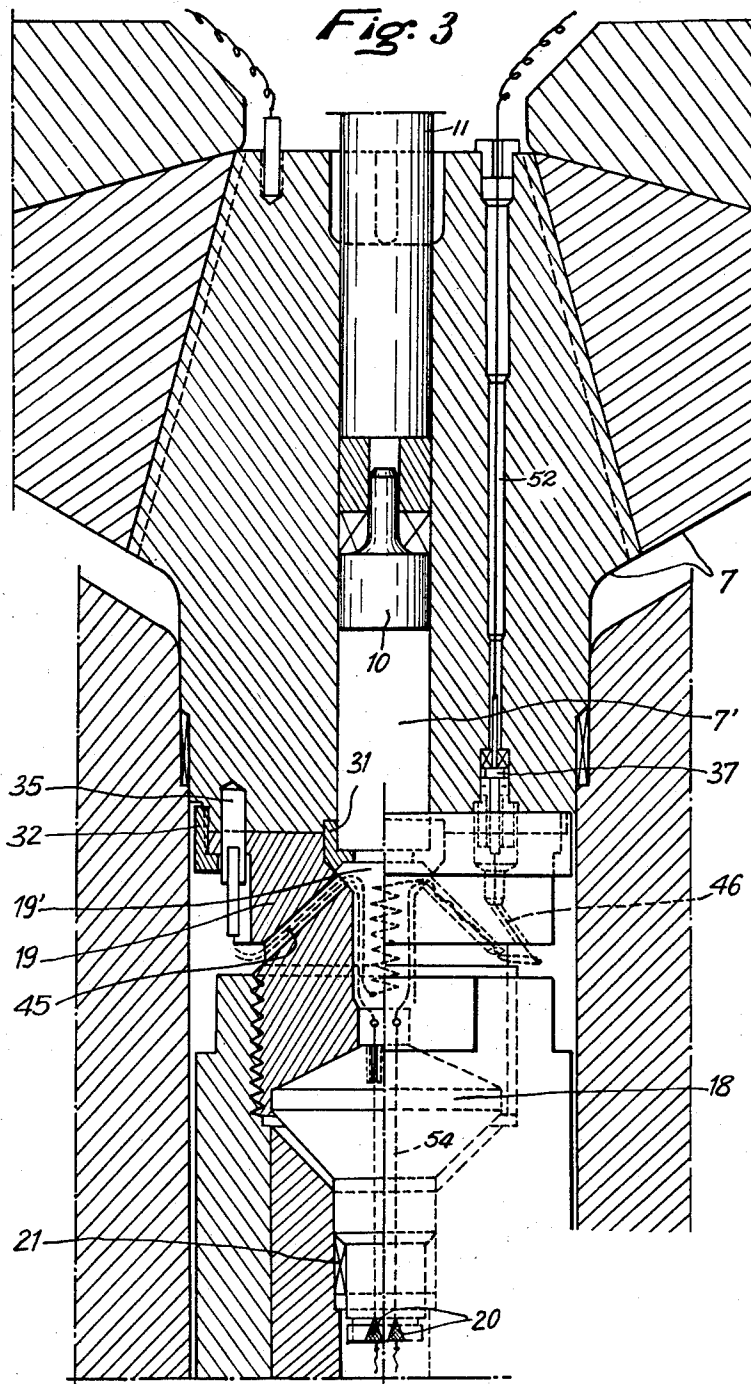
J. BASSET

3,191,383

TWO STAGE FLUID COMPRESSING DEVICES

Filed June 20, 1962

3 Sheets-Sheet 3



1

2

3,191,383
TWO STAGE FLUID COMPRESSING DEVICES
Jacques Basset, 8 Rue Troyon, Sevres, France
Filed June 20, 1962, Ser. No. 203,920
Claims priority, application France, July 8, 1961,
867,387, Patent 1,329,584
4 Claims. (Cl. 60—54.5)

This invention relates generally to two-stage fluid compressing devices, and more particularly is directed to fluid compressing devices of the type in which a structure defining an inner chamber is contained within an outer chamber so as to be subjected to a basic pressure in the outer chamber and thereby permit the production of a high pressure in the inner chamber with reduced stressing of the structure defining the latter.

The existing two-stage fluid compressing devices are disadvantageous in that the inner chambers thereof can only be of small volume and there is no possibility of feeding electrical energy into the inner chambers for the performance of electromagnetic operations therein. Further, the existing devices of the described character do not permit the independent control of the pressures developed in the inner and outer chambers.

Accordingly, it is an object of this invention to provide two-stage fluid compressing devices which avoid the above disadvantages of existing devices and are capable of producing very high pressures, of the order of several ten thousand atmospheres in true fluids having low viscosity, whether in the form of gases or liquids.

According to an aspect of the invention, there is provided an outer cylinder defining an outer chamber closed at one end and open at the other end and an inner cylinder defining an inner chamber and housed entirely and coaxially within the outer cylinder, with one end of the inner cylinder being closed and rigidly secured to the closed end of the outer cylinder and with the other end of the inner cylinder opening into the outer chamber and being spaced axially inward from the open end of the outer cylinder. The inner cylinder is furthermore provided with a transverse port located near its open end for communicating the inner chamber with the outer chamber. The fluid compressing device further comprises an inner piston slidable through the open end of the inner cylinder, means for feeding a precompressed fluid and opening into the outer cylinder at a point near the open end of the latter and an outer piston slidable through the open end of the outer cylinder and facing the outer end of the inner piston. The device is controlled by hydraulically actuated means adapted to urge the outer piston axially into the outer cylinder so as to successively close the means feeding the precompressed fluid, further compress the precompressed fluid in the inner and outer chambers and finally urge the inner piston into the inner cylinder to make the inner piston close the transverse port connecting the two chambers and thereafter compress the fluid isolated in the inner chamber to a pressure rising considerably above that prevailing in the outer chamber.

Very high pressures, for example, as high as 65,000 atmospheres, can be attained in the above device embodying the invention while electromagnetic operations may be performed inside the inner chamber which may even be equipped with an electric furnace. This becomes possible by reason of the fact that the wall of the inner cylinder is subjected only to the difference between the high basic pressure in the outer chamber, say 20,000 atmospheres, and the very high pressure in the inner chamber, say 60,000 atmospheres. Further, the cylinders may be merely formed of annealed steel.

Other features of the devices embodying the invention permit adjustment of the pressure at which the inner

piston providing the very high compression begins operating, separation of the fraction of fluid compressed in the inner cylinder from that which is subjected to the basic pressure in the outer cylinder, and maintenance of the fluid contained in the inner chamber at a temperature such that it cannot become solid under the highest pressures obtained.

The above, and other objects, advantages and features of the invention will be apparent in the following detailed description of illustrative embodiments which is to be read in connection with the accompanying drawings, wherein:

FIG. 1 is an axial sectional view which is partly diagrammatic and shows an embodiment of this invention;

FIG. 2 is an axial sectional view of a modification of the two compression chambers on a larger scale; and

FIG. 3 is a further enlarged, fragmentary sectional view showing the arrangement of electrical conductors in the upper portion of the device.

Referring to FIG. 1 in detail, it will be seen that the device embodying this invention, as there shown, generally comprises an outer cylinder 3 located between plates 1 and 2 constituting parts of coaxial hydraulic presses P_1 and P_2 and being rigidly connected to each other, for instance through the uprights 9, or other suitable connecting frame. An inner or hypercompression cylinder 17 is positioned inside a liner or body 3' within the outer cylinder 3. The cylinder 17 forms the second compression stage of the apparatus.

The pressure P within the inner hypercompression cylinder 17 is produced by a piston 24 which is acted upon by a piston rod 25.

The liner or body 3' within outer cylinder 3 is of high strength steel and over said body are fitted at raised temperature one or more successive coaxial hoops 3'', so as to give the compound tube thus constituted, a maximum resistance against internal pressure by reason of the production of negative preliminary stresses inside the body 3'.

The outer cylinder 3 is closed at one end by a stationary plug 7 having a very high mechanical resistance, and which is also constituted by a hooped body. The plug 7 is secured in position by a head 6, while the other end of cylinder 3 slidably receives a movable piston 8. The plug 7 and piston 8 are fitted with suitable fluidtight packings of a conventional type. The movable piston 8 is adapted to be shifted by the piston rod 15 sliding inside the cylinder 3 and actuated in its turn by the piston 16 of the lower hydraulic press P_2 .

The outer cylinder 3 is rigidly connected with the plate 1, for instance by clamping members 4 and 5 which are bolted to the plate 1 and which engage the head 6 securing the plug 7 closing the outer cylinder 3. The size and shape of the head 6 are selected so as to transmit the thrust exerted by the pressure against the plug 7 to the press plate 1 while reducing to a minimum the stresses per unit of surface to which the bearings are subjected.

It will be noted that, since the thrust exerted on the plug 7 is transmitted by the head 6 to the plate 1 of the upper press, the thread through which the head 6 is engaged with the outer cylinder 3 is subjected only to the reaction due to the basic pressure P_s acting on the annular surface registering with the packing 50 having a reduced cross-section.

The plug 7 (FIG. 3) further has a number of axial passageways 52 through which extend electrical conductors provided for the feed of current as may be required by electrical operations to be performed in the inner chamber defined by the inner cylinder 17. A central axial bore 7' of the plug 7 slidably receives a movable auxiliary piston 10 adapted to be shifted by a plunger 11 secured to the plunger piston 13 of the upper hydraulic press P_1 .

The piston 13 includes two sections of different diam-

3

eters, and its larger diameter section slides inside the cylinder 12 of the upper press P_1 while its smaller diameter section slides inside a stationary annular member 14 closing the lower end of cylinder 12. The piston 13 is raised by supplying liquid under pressure through the pipe 51 opening into the annular space between the annular closing member 14 and the larger diameter section of the piston 13. The piston 13 is urged downwardly by liquid under pressure supplied to the upper end of cylinder 12 through a pipe 53. The plunger 11 and piston 10 are intended for the adjustment and maintenance of the basic pressure P_s at a constant value inside the outer cylinder.

In the device shown on FIG. 1, the gaseous or liquid fluid to be compressed is admitted to the outer chamber defined by cylinder 3 through small ports passing through the liner 3' and leading to pipes 34 by way of bores O_1 formed in the hoop or hoops surrounding liner or body 3'.

I may also resort to the slightly modified arrangement illustrated in FIG. 2. In this latter case, an annular member 43 is screwed into the lower end of the inner hoop 3'' of the outer cylinder 3 and has the same inner diameter as the body or liner 3' of the outer cylinder. Said annular member 43 engages through its upper cylindrical-frustoconical section the body 3' of the outer cylinder 3 and clamps in position an annular packing 44 housed inside said body 3'. The upper flat end F of the member 43 which engages the flat bottom of the recess housing said member inside the body 3' has radial grooves R, and a slight clearance 43' of 0.05 to 0.1 mm. is provided between the cooperating frustoconical surfaces F' of the member 43 and of the body 3'. The gases or liquids may reach the inside of the outer cylinder 3 through a conduit 34 passing through the hoop or hoops 3'' and leading to a bore or a system of bores 34' formed in the body 3' and opening into the annular clearance 43'. The grooves R in orifice F of member 43 allow the fluids to enter the chamber of cylinder 3 from the clearance 43'. It should also be noted that longitudinal grooves 48 the edges of which are cut obliquely, are formed in the lower end portion of the annular member 43 for reasons which will appear hereinafter.

The separation of the fluid contained in the compression chamber of the outer cylinder 3 from that contained in the means feeding the fluid in a precompressed condition is performed as follows:

When the piston rod 15 urged upwards by the plunger piston 16 of the lower hydraulic press enters the outer cylinder 3, the piston 8 and its fluidtight packings 8' pass in front of the admission ports O_1 or the grooves R for the gases or liquids and, since said ports or grooves have a very reduced size in the vicinity of the inner surface of the outer cylinder the passage of the piston 8 is performed without destroying or detrimentally affecting the packings. The fluid contained inside the outer cylinder 3 is thus isolated. It will be noted furthermore that a valve 36 (FIG. 1) fitted in the pipe 34 feeding fluid into the outer cylinder 3 allows separating from the external fluid feeding means the preliminary compression system of the outer cylinder 3 just before the passage of the fluidtight packings of the piston 8 in front of the fluid feeding ports or grooves.

With the embodiment of FIG. 2, after the fluidtight packings 8' of the piston 8 have passed across the grooves R, the small amount of fluid contained between the valve 36 and the grooves R is exhausted through the clearance J (FIG. 2) formed between the piston rod 15, the bearing ring 38 and the inner surface of cylinder 3. Said fluid may furthermore be recovered by means of an auxiliary system. When the fluid is fed into the cylinder 3 through ports located at the lower end thereof very high basic pressures, for example, about 20,000 atmospheres, can be employed as the walls of the outer cylinder 3 are not provided with any lateral ports in the portions which are subjected to the very high pressures.

4

The high compression cylinder 17 or second compression stage (FIGS. 2 and 3), is designed as follows:

The cylinder 17 is constituted by a thick-walled tube of high strength steel or sintered carbides with a body or liner 17' surrounded by one or more hoops fitted in succession inside each other to increase the resistance of the compound tube against internal pressure by producing preliminary compression stresses.

Experience shows that for pressures within the inner cylinder 17 that do not exceed 60,000 atmospheres, and a basic pressure approximating 20,000 atmospheres, the use of sintered carbides which are expensive and difficult to machine, is not essential for the cylinder 17.

The cylinder 17 is closed at one end by a stationary plug 18, and at its other end slidably receives the piston 24 provided with fluidtight packings and which may be displaced by the plunger 25.

The plug 18 engages a head 19 secured to the plug 7 by a retaining ring 32 screwed on the latter. The plug 18 may be in the form of a one-piece block made for instance of high speed tungsten steel for pressures which do not rise above 50,000 atmospheres, or else it may be constituted by a hooped body for higher pressures.

The plug 18 (FIG. 3) has one or more fluidtight passageways 54 for current conductors connected to electrodes 20 (FIG. 3) which may be constituted for instance by cones made of a hard conductive material such as a high speed tungsten steel or a steel having a very high resistance such as 35NCD16. The conical electrodes 20 preferably have a cone angle between 6 and 30° and are insulated in a convention manner.

It should be noted that when the cones are subjected to pressure, they are automatically wedged in position. However, before the action of pressure is felt, a preliminary clamping is applied thereto in order to achieve a contact as perfect as possible between the cones and the mating surfaces of plug 18.

The fluidtightness round the actual plug 18 is ensured by a compound packing 21.

All the conductors passing out of the plug 18 enter a central recess 19' formed in the head 19 to make possible relative rotation of the head 19, if required, with reference to the plug 18 during the mounting and the dismantling of the arrangement. Through transverse passageways 45 opening into the central recess 19' in the head 19, the conductors extend out of the head and then pass through openings 46 leading to the housings for the said electrodes in the stationary plug 7 of the outer cylinder. It should be noted that the passageways 45 (FIG. 3) also provide a connection between the axial bore 7' and the outer cylinder chamber in which the basic pressure prevails.

The cylinder 17 is provided with means for admitting the fluid adjacent the end opposed to the stationary plug 18. Such means for admitting the fluid is designed to effect the separation of the fluid contained inside the cylinder 17 from that contained in the compression chamber of the outer cylinder 3.

As shown on FIG. 1, the means for admitting the fluid into the chamber defined by cylinder 17 may be constituted merely by an opening 55 located at the lower end of the cylinder 17 and terminating with a section having a very small diameter adjacent the inner wall surface of the cylinder 17.

Alternatively, in the modification illustrated in FIG. 2, a head 23 may be screwed into the lower end portion of cylinder 17 so as to seat against the lower end of the insert or body 17'.

A small diameter radial perforation 33 passing through the cylinder 17 leads to a point in the vicinity of the contact surfaces between the body or insert 17' and the head 23.

Small, narrow grooves 56 of a depth of 0.1 to 0.2 mm. are provided in the surface of the head 23 in contact with the body 17' and communicate with the radial perfora-

tions 33 to provide the passageway for admitting fluid from the outer chamber defined by cylinder 3 into the inner chamber defined by cylinder 17.

The plunger piston 25 made of very hard material (such as 35NC-D16 steel treated to resist 190 kg. high speed tungsten steel, cobalt or sintered carbides) and, in the embodiment of FIG. 2, is surrounded at its lower end with one or more steel hoops 57. It rests on a base 26 made of a hard material which may be the same as that used for the plunger piston 25.

The base 26 is also surrounded by a hoop 53 and has a conical shape with a bottom cross-section larger than that of the plunger piston, so as to distribute the thrust exerted on the piston 25 over a maximum area. The base 26 rests in turn on a stepped base 27 of a very hard steel having a high resistance. Said base 27 has a maximum diameter which approximates the inner diameter of the liner 3' of cylinder 3 and is adapted to come into contact with the movable plug 8 and to distribute, over the entire upper surface of the head of the plug 8, the thrust transmitted by the base 26.

A sleeve 28 made of steel or bronze of a grade having a high mechanical resistance, is screwed on the base 27 to position the piston 25 and the bases 26 and 27. The sleeve 28 may slide inside a slideway 29 made of steel in which it is properly centered. Said slideway 29 is in turn secured to and centered on the lower end portion of the cylinder 17. Studs 30 project from the sleeve 28 and are slidable in axial slots formed in the slideway 29 for guiding the movements of the piston 25 and of the bases 26 and 27, and for preventing separation of piston 25 and bases 26 and 27 from the cylinder 17.

It will be noted that the extent of travel of the piston 25 depends on the height of the slideway 29.

A removable centering stud 47 is secured to the upper end surface of the plunger piston 25 and adapted to engage a corresponding recess defined at the lower end of a sleeve 49 (FIG. 2) forming part of piston 24 to achieve better centering of the whole arrangement when the plunger piston 25 acts against the sleeve 49 of piston 24 and continues its movement so as to slidably enter the lower end of liner 17'.

The previously assembled cylinder 17 is mounted on the plug 7 of the outer cylinder 3 through the ring 32 which is fitted over the head 19 before the latter is screwed into the upper end portion of cylinder 17. The centering of the cylinder 17 with reference to the plug 7 is further ensured by a ring 31. A stud 35 (FIG. 3) which serves as an electrical grounding member angularly positions the head 19 with reference to the plug 7. It will be noted that the head 19 is provided, if required, with housings for the terminals 37 on the plug 7, so that it is possible to position simultaneously the plug 7 and the inner cylinder assembly within the outer cylinder 3.

When it is desired to heat the inside of the cylinder 17 so as to prevent any solidification of the fluid therein when the pressure rises, it is possible to apply the heat to the outer cylinder 3 for transmission to the inner cylinder 17. Such heating may be applied by outwardly arranged electric heating elements (not shown) forming a sleeve round the outer cylinder 3, or else by means of a water-jacket (not shown) fitted around the outer cylinder 3.

Alternatively, as shown on the drawings, a hot gas or liquid may be circulated within the walls of the outer cylinder 3, for example, inside a helical groove 22 provided for this purpose along the inner or outer surface of the first hoop 3'. The helical groove begins and terminates in two annular grooves located respectively in the vicinity of the opposite ends of the body 3' of the outer cylinder, and conduits 22a and 22b (FIG. 1) are connected to said grooves, so as to serve respectively for the entrance and for the exhaust of the fluid. It will be noted that the above described arrangement may serve as well as for cooling the cooperating chambers 3 and 17.

It is also possible to provide means for direct heating of the inner cylinder 17 for instance, by enclosing the latter in a heat-insulating sleeve carrying electric resistances or else by housing cylindrical heating elements in vertical bores formed in the wall of the inner cylinder 17.

The heating of the compression chamber of the inner cylinder 17 may also be effected by means of electric resistances located therein and fed through the conductors extending through the plugs 13 and 7.

The two last mentioned heating systems are chiefly applicable to large-sized apparatus of which the plugs can be equipped with current-feeding means transmitting enough electric energy into the heating elements, and also allow the use of a sufficient number of thermocouples.

All the above-disclosed heating means are provided with suitable adjusting or controlling means.

Assuming that the fluid to be compressed is gaseous, a two-stage fluid compressing device as described hereinabove is operated as follows:

During initial filling of the device with previously compressed gas, the movable piston 10 and the plunger piston 11 are located entirely inside the plug 7, that is towards the vicinity of the end of their stroke, while the piston rod or plunger 15 is in its lowermost position, and the movable piston 8 is also in its lowermost position so that the fluidtight packings 8' of the plug 8 lie underneath the corresponding admission ports O₁ or R for the fluid. The piston rod 25 and the piston 24 are also in their lowermost positions with the fluidtight packings for the plug 24 lying below the port 33 or grooves 55 through which the gas is admitted to inner cylinder 17. Under such conditions, the chambers of the outer and inner cylinders 3 and 17 are filled with a gas under a pressure generally above 1,000 atmospheres which is supplied through the pipe 34 to enter cylinder 3 at ports O₁ or R and to pass from cylinder 3 into cylinder 17 through ports 33 or 56.

The valve 36 is closed to separate the device from the source of the compressed gases as soon as the desired initial pressure is reached in cylinders 3 and 17.

It will be noted that during the rise in pressure to a preliminary or initial value inside the cylinders 3 and 17, the pressure rises also inside the cylinders of the lower and upper hydraulic presses P₂ and P₁ which causes the pistons 13 and 16 and also the movable pistons 24 and 8 to move by reason of the compressibility of the liquid contained in said press cylinders. The pistons 13 and 16 are then caused to remain in the desired position by introducing liquid under pressure into the corresponding press cylinders.

Once the filling with a precompressed gas has been completed and the valve 36 has been closed, the piston rod 15 and the piston 8 are urged upwardly by the piston 16 of the lower hydraulic press and slidably engage the inside of the outer cylinder. At the same time, the piston 10 is held substantially in the same position by introducing liquid under pressure inside the cylinder 12 of the upper press.

At a predetermined position of the piston 8, the fluidtight packings 8' of the piston 8 pass in front of the feed ports O₁ or R, to isolate the latter from the interior of cylinder 3. When the packings have actually passed beyond said ports, the fluid contained in the pipe 34 is exhausted through the clearance J (FIG. 2) extending between the piston rod 15 and the inner wall surface of the cylinder 3.

As the pressure continues rising, the movable piston 8 engages the base 27 so that the piston plunger 25 begins moving and consequently said plunger engages the movable piston 24 which is displaced upwardly in the inner cylinder 17. As long as the fluidtight packings 24' of the movable piston 24 have not passed beyond the fluid admission ports 33 or 56, the pressure P is the same inside the two chambers defined by cylinders 3 and 17. Said

pressure P depends on the original filling pressure provided for the system, on the compressibility of the compressed fluid, on the rate of filling of solid materials in the compression chambers of the cylinders 3 and 17. Thus, for initial positions which are identical for the pistons 15 and 25 and for the same initial pressure P , different values are obtained for the pressure P in the two chambers for identical strokes executed by the pistons.

Taking into account the experimental arrangements which it may be necessary to house in the inner chamber of the device, it is possible to act easily on the coefficients of filling by fitting small blocks of steel 39, 40 and 41 (FIG. 2) inside the cylinders 3 and 17.

The lower hydraulic press then continues acting and the pistons 15 and 25 continue rising so that the fluidtight packings 24' of the movable piston 24 are made to pass in front of the ports 33 or 56. From this moment onwards and for equal strokes of the piston rod 15 and the piston 25 which are practically rigid with each other, the relative reductions in volume dv/v of the fluids contained in the compression chambers of cylinders 3 and 17 are no longer the same and the pressures within said chambers are no longer equal.

If, for equal strokes h of the pistons 8 and 24, the ratio dv/v relating to the fluid contained in the chamber of cylinder 17 is higher than that corresponding to the chamber of cylinder 3, the pressure P_1 in the cylinder 17 rises more speedily and is always higher than the pressure P_2 prevailing in the cylinder 3, so long as the piston 11 remains stationary.

The ratio P_1/P_2 defines the supporting action of the hydrostatic basic pressure on the walls of the cylinder 17 and its auxiliaries such as plug 18, cylinder head 19 and the like.

When the pressure P_1 continues rising and the piston 24 continues its movement, it is possible to act on the ratio P_1/P_2 by shifting the piston 10 and piston rod 11 inside the plug 7. If the cross-section of the piston 10 is sufficiently large and its range of movement is sufficiently great, it is apparent that it is possible for instance to keep the ratio P_1/P_2 at a constant value or else to keep the pressure P_2 constant when it has reached a predetermined value.

The pressure P_1 having reached the desired value and the operations having been executed as required within the cylinder 17, the release in pressure is achieved by reversing the procedure described above for providing the rise in pressure.

Upon passage of the fluidtight packings 24' of the piston 24 below the ports 33 or 56, connection is in principle restored between the compression chambers defined by cylinders 17 and 3 and normally the piston 24 is stopped in its downward travel and no longer follows the movement of piston 25. However, if the ports 33 or 56 are accidentally clogged by waste material from the fluidtight packings, the piston 24 continues its downward movement into the head 23 and there is the danger that, when the packings of 24 are about to pass out of the cylinder 17, there will be a sudden expansion of the gases contained in the cylinder 17 leading to destruction of the packings and other serious damage. In order to avoid such damage, mortises or grooves are provided longitudinally inside the cylinder head 23, and when the fluidtight packings of the movable piston 24 reach the level of said mortises, the packings are partly destroyed, and the gases are exhausted without any risk of damage to the apparatus.

As the piston rod 15 continues its downward movement, the piston plunger 25 and its bases 26 and 27 reach their final position, as determined by guide 29, and are separated from the movable piston 8.

When the fluidtight packings of the piston 8 have passed in front of the gas feeding ports O_1 or grooves R , the gases contained in the two cylinders 17 and 3 may enter the pipe 34 and be exhausted through the pressure reducing valve 42.

In the event that the gas admitting ports R or O_1 are accidentally clogged, a safety system including mortises or grooves 48 provided longitudinally in the inner wall surface of the lower cylinder head 43 allows gradual or non-explosive exhausting of the gases.

Auxiliary means may be provided in the apparatus for effecting the electric measurement of the pressure inside the cylinders 3 and 17. Such measurement may be effected by means of manganine gauges fed through the terminals of the plugs 7 and 18 and located in the central recess 19' of head 19 and on the plug 18.

As concerns the heating of the hypercompression chamber in cylinder 17 by any of the previously described means, it should be noted that, if the whole apparatus is heated before the rise in pressure is performed, the resultant pressure is the same as when starting at room temperature, but if the whole apparatus is heated when a high pressure has already been reached, there is obtained a general increase in pressure.

If interiorly disposed resistances are caused to heat the chamber of cylinder 17 before the device operates to cause hypercompressing of gas trapped in cylinder 17, and after stabilization of the temperature of the different parts, the result obtained is the same as if no heating had been applied.

If the heating is performed by means of heating resistances located inside the compression chamber of cylinder 17 when the pressure therein has already reached a high value, said pressure rises with the temperature so that the ratio P_1/P_2 is modified and consequently it is necessary to act on the piston 11 so as to keep the ratio P_1/P_2 at the desired value.

Although illustrative embodiments of the invention have been described in detail herein with reference to the accompanying drawings, it is to be understood that the invention is not limited to those precise embodiments, and that various changes and modifications may be effected therein by one skilled in the art without departing from the scope or spirit of the invention, except as defined in the appended claims.

What I claim is:

1. A two-stage fluid compressing device comprising an outer cylinder defining an outer chamber and being closed at one end and open axially at the other end, an inner cylinder defining an inner chamber and being housed entirely and coaxially within said outer cylinder, one end of said inner cylinder being closed and rigidly secured to the closed end of said outer cylinder and the other end of said inner cylinder opening axially into said outer chamber and being spaced axially inward from said open end of said outer cylinder, said inner cylinder further having a transverse port extending therethrough adjacent said other end of the inner cylinder for communicating the inner chamber with the outer chamber, an inner piston slidable in said inner cylinder through said other end of the latter, means for feeding a precompressed fluid into said outer chamber and including means defining an entry port at a point near the open end of said outer cylinder, an outer piston slidable in said outer cylinder through said open end of the latter and facing the outer end of the inner piston, and hydraulically actuated means operative to urge said outer piston axially into said outer cylinder for successively closing said entry port of the means feeding precompressed fluid, compressing the precompressed fluid trapped in the outer and inner chambers by closing of the entry port and then urging the inner piston axially into the inner cylinder so that said inner piston initially closes said transverse port of the inner cylinder for isolating said inner chamber from said outer chamber and thereafter compresses the fluid in the inner chamber to a pressure rising considerably above that prevailing in the outer chamber.

2. A two-stage fluid compressing device as in claim 1; wherein said means defining an entry port at a point near the open end of the outer cylinder includes an annular member screwed into said open end of the outer

cylinder and having the same inner diameter as the latter so that the inner surface of said annular member constitutes a continuation of the inner surface of said outer cylinder, said inner surface of the annular member being spaced axially from said inner surface of the outer cylinder to define a clearance therebetween, and said outer cylinder has a channel extending therethrough and opening into said clearance for conducting the precompressed fluid to the latter.

3. A two-stage fluid compressing device comprising an outer cylinder defining an outer chamber, a plug closing one end of said cylinder and having a portion extending axially into said outer chamber, said plug having an axial bore opening outside said outer cylinder and said portion of the plug having a channel therein opening into said bore and said outer chamber, the end of said outer cylinder remote from said plug being axially open, an inner cylinder defining an inner chamber and being housed entirely and coaxially within said outer cylinder, one end of said inner cylinder being closed and rigidly secured to said plug closing one end of said outer cylinder and the other end of said inner cylinder opening axially into said outer chamber and being spaced axially inward from said open end of said outer cylinder, said inner cylinder further having a transverse port extending therethrough adjacent said other end of the inner cylinder for communicating the inner chamber with the outer chamber, an inner piston slidable in said inner cylinder through said other end of the latter, means for feeding a precompressed fluid into said outer chamber and including means defining an entry port at a point near the open end of said outer cylinder, an outer piston slidable in said outer cylinder through said open end of the latter and facing the outer end of the inner piston, and hydraulically actuated means operative to urge said outer piston axially into said outer cylinder for successively closing said entry port of the means

feeding precompressed fluid, compressing the precompressed fluid trapped in the outer and inner chambers by closing of the entry port and then urging the inner piston axially into the inner cylinder so that said inner piston initially closes said transverse port of the inner cylinder for isolating said inner chamber from said outer chamber and thereafter compresses the fluid in the inner chamber to a pressure rising considerably above that prevailing in the outer chamber, an auxiliary piston slidable in said bore of the plug, and auxiliary hydraulically actuated means operative to adjustably urge said auxiliary piston in said bore toward said channel for adjustably varying the relationship between the presses in said inner and outer chambers.

4. A two-stage fluid comprising device as in claim 3; further comprising electrically operated means within said inner chamber, and conducting means for feeding electrical energy to said electrically operated means, said conducting means extending through said channel of the plug and through the closed end of said inner cylinder.

References Cited by the Examiner

UNITED STATES PATENTS

1,970,999	8/34	Ferris et al.	60—54.5
2,324,149	7/43	Gray	60—54.5
2,357,632	9/44	Cornelius	60—54.5
2,452,292	10/48	Cousino	60—54.5
2,601,761	7/52	Fouron et al.	60—54.5 X
2,867,088	1/59	Kux	60—54.5
2,915,878	12/59	Hramoff	60—54.5
2,990,687	7/61	McCrea	60—54.5
3,038,313	6/62	Trythall	60—54.5

JULIUS E. WEST, *Primary Examiner*.

ROBERT R. BUNEVICH, *Examiner*.