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H. T. Hall

14,000 kg/cm²

PRODUCTION OF ULTRA-HIGH PRESSURES IN A DEVICE USING A CONICAL PISTON

L. F. Vereshchagin, A. I. Likhter, and V. I. Ivanov

In the production of high pressures a fluid is placed in a cylindrical opening drilled in a more or less thick steel block and the pressure in this liquid is usually produced by means of a piston that is cylindrical as well, to which is applied a compressive force by a hydraulic press. Through the action of the compressive force in the cylinder a nonuniform transverse deformation takes place, and the cylinder takes on a barrel shape. For this reason the diameter of the cylindrical piston must always be less than the internal diameter of the opening and it becomes necessary to use some method or other to seal the piston. More frequently a liner with an uncompensated surface is used of the type first developed by Bridgman [1]. Although in the development of various types of gaskets for moving pistons considerable ingenuity and labor have been expended, this part, to this day, turns out to be the most undependable part of high pressure equipment and is the most usual reason for various types of breakdown. The gasket operates well if the following conditons are observed: 1) sufficiently high pressure in the gasket, 2) sufficient length of gasket, and 3) sufficiently small gap between piston and opening. However, the first and second conditions lead to too great a loss in force due to friction. If, on the other hand, as the third condition requires, the initial gap between piston and opening is made too small, then when the pressure is raised it is possible for the piston to be scored in the opening. When it comes to pushing out a gasket that has become caught, or a scored piston, considerable effort is required, and it is frequently necessary to completely re-machine the piston and the cylinder. On the other hand, if the dimensions of the gasket and the friction are made as small as possible and the gap as large as possible, then it is possible for the fluid to break through the packing.

We have developed the first type of equipment to produce high pressure by the use of a conical piston which does not require any sealing gaskets. For this purpose we have used a system of cone and mandrel first used by Bridgman [2] to produce a supporting pressure. In pressing the cone into the lapped surface of the mandrel with a force T, the pressure produced on the contact surface and normal to it, $p = \frac{T}{\pi(a^2 - b^2)}$, where a is the larger and b is the smaller radius of the cone. In this case the friction of the cone in the mandrel, which lowers the effective pressure, is not taken into account. The friction may be determined if we measure the displacement of the cone in the mandrel while raising and reducing the pressure and assuming that in both cases the pressure is equal.

In Fig. 1 our installation for obtaining high pressures is shown. Here 1 is the cylinder block made of steel 40X, tempered and annealed up to a hardness of 40-42 on the Rockwell scale C; 2) a cone of soft steel with an internal diameter of 8 mm; 3) housing for electric lead-in. Part No. 4, with a channel for the introduction of the cable leading to the electric lead-in wire, serves to transmit the force developed by the press to cone 2. Cone 2 is carefully lapped to the conical hole of the cylinder block 1. Glycerin is poured into the bottom of the block—this is a liquid that is only slightly compressible and has considerable viscosity. The lower part of the opening in cone 2 is tinned and is filled with lead to a height of 1 cm from the bottom of the cone. The cone was inserted into the block and the excess of glycerin flowed out over the periphery of the cone. The cone was then removed, coated with graphite mixed with a small quanity of glycerin, and finally set in place. Into the cone opening slightly viscous petroleum ether was poured, and the electric lead-wire housing 3 was inserted. Lead 5 is located in the housing on a mica gasket and to this lead a manganin manometer 6 is soldered. After assembly the entire device was placed under a hydraulic press and was put under compression, the pressure p_2 inside the cone being measured by means of the manganin manometer as a function of the oil pressure P under the press piston. Then, after obtaining some maximum pressure the force developed by the press was reduced to zero. In this manner we obtained two curves similar to the ones shown in Fig. 2 where the first line corresponds to the rise, and the second to the lowering of the pressure.

When cone 2 (Fig. 1) is pressed into the cylinder block 1 normal pressure p_1 is developed over the surface of contact. Inasmuch as this pressure compresses the cone and stretches the cylinder block, the outside diameter of the cone is reduced by $\Delta_1 r$ and the inside diameter of the block increases by $\Delta_2 r$. The total $\Delta r = \Delta_1 r + \Delta_2 r$ and the cone is displaced into the interior of the cylinder block. The magnitude of the displacement $\Delta l = \frac{\Delta r}{\tan \alpha}$, where 2α is the angle at the apex of the cone. Because of this displacement of the cone, the volume of the internal space is reduced, and the pressure inside this volume is increased in accordance with the total compressibility of the materials filling the hollow space. To a first approximation we can consider that the internal pressure p_2 is the same in the entire volume and is measured by the manganin manometer 6 (Fig. 1). $\Delta_1 r$ and $\Delta_2 r$ may be computed by the formulas of the theory of elasticity [3] bearing in mind that in the for $\Delta_2 r$ we must substitute not only the external pressure p_1 but the internal pressure p_2 as well. For the purpose of the computation we can use a cylinder instead of the cone, since 2α is very small (4°).

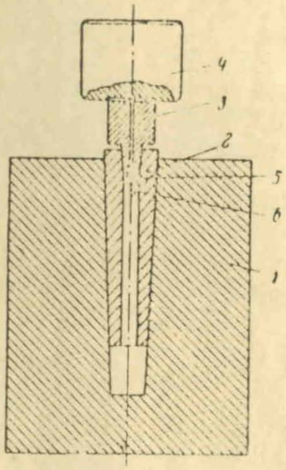

Fig. 1. Equipment for obtaining ultra-high pressures using a conical piston.

Substituting into the formula for the radial deformation the dimensions of the cone and the cylinder block, and considering $\frac{1}{m} = 0.3$, and $E = 2 \cdot 10^6$ kg/cm², we obtain

$$\Delta_1 r = 0.86 \cdot p_1 \cdot 10^{-6} \text{ cm},$$

$$\Delta_2 r = -(0.58 p_1 - 0.14 p_2) \cdot 10^{-6} \text{ cm},$$

$$\Delta r = \Delta_1 r + |\Delta_2 r| = (1.44 p_1 - 0.14 p_2) \cdot 10^{-6} \text{ cm}.$$

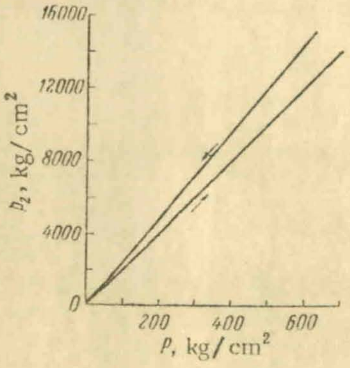

Fig. 2. Dependence of internal pressure p_2 on the oil pressure P in the press cylinder.

Let us carry out a detailed computation making use of the experimental data, curves for which are given in Fig. 2. In this experiment, into the 8 mm hole of the cone and above the lead plug, mercury was poured to the extent of 2.5 cc and above the mercury petroleum ether into which the manganin manometer was lowered. After raising and lowering the pressure and taking the equipment apart, it was found that the mercury, under pressure, went through the lead plug as though through a Jena glass filter and came through to the bottom of the cylinder block. At the same time the lead plug acquired a rotten structure, apparently due to amalgamation. In Fig. 2 the axis of ordinates gives the pressure p_2 measured with a manganin manometer and on the axis of abscissas the pressure P obtained under the press piston. Diameter of the piston was 135 mm, area $S = 143.3$ cm². For $p_2 = 12{,}000$ kg/cm² the pressure P, during the raising of pressure was equal to 606 kg/cm² and during lowering, 508 kg/cm². The actual force which the press developed for producing the internal pressure equal to 12,000 kg/cm² is

$$T = S \frac{P_{\text{Raise}} + P_{\text{lower}}}{2} = 143.4 \times 557 = 80 \text{ tons}$$

Of this force T, one part, T_2, is used to balance the pressure p_2 acting on the cross section of the cone, and the other part, T_1, produces the pressure p_1 on the periphery of the cone which assures the sealing of the equipment. $T_2 = Sp_2 \sim 43$ tons; therefore, $T_1 = 37$ tons. From this we find p_1 according to the formula $\frac{T_1}{\pi(a^2 - b^2)} =$ 14,400 kg/cm² (not taking friction into account). Substituting these quantities for p_1 and p_2 into the formula for Δr, we find that $\Delta r = 0.19$ mm, displacement $\Delta \ell = \frac{0.19}{\tan 2^\circ} = 5.43$ mm, corresponding to a change in volume of the internal space $\Delta v = 3.1 \cdot 0.543 = 1.68$ cc. This quantity Δv must be distributed among the materials that fill the internal space of the cone and the cylinder block in accordance with their compressibilities. The initial volume of the glycerin was 8.7 cc, mercury 2.5 cc, petroleum ether 1.3 cc, and lead 0.5 cc. The relative change in volume of these quantities $\frac{\Delta v}{v_0}$ at a pressure of 12,000 kg/cm² was respectively 0.134; 0.03433; 0.30 and 0.026. From these data the computed reduction in volume is equal to 1.66 cc, that is, it scarcely differs from the quantity Δv 1.68 cc found above. In view of the rough approximation used for this calculation such an excellent agreement must be considered fortuitous, but nevertheless this computation confirms the explanation, given by us above, for the action of the equipment and makes it possible to draw several conclusions. In order to obtain the highest possible pressures it is necessary to reduce the volume of the internal space to its limiting value and to keep the dimensions as small as possible. It is desirable to use liquids with the smallest possible compressibility. It is well known that of all the liquids the least compressible is glycerin. For this reason glycerin was chosen as the material to fill the internal space in the cylinder block. In choosing dimensions and working liquids it is necessary to be always sure, that p_1 is larger than p_2, otherwise the hermetic sealing will be destroyed, or else that the viscous flow of fluid past the gap be sufficiently small.

Some other experiments were carried out during which pressure p_2 up to 14,000 kg/cm² was obtained. By using one external supplementary stage the pressure developed in a system of the type described above can be raised up to 30,000 kg/cm². As is shown in the calculation that we have carried out, this equipment can be used to find the compressibility of liquids and solid bodies by comparing the results of measurements obtained on substances with known and unknown compressibilities. Moreover, it is possible to carry out investigations under such conditions where either the substances themselves or high temperatures can lead to the destruction of the sealing gaskets.

SUMMARY

1. A design of equipment has been developed for obtaining ultra-high pressures by means of a conical piston for which no sealing gaskets are required.

2. The operation of this equipment has been investigated both experimentally and theoretically.

3. Pressures up to 14,000 kg/cm² have been obtained.

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Laboratory for High Pressure Physics
Academy of Sciences, USSR