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Seals for Pressures to 10 000 Atmospheres*

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This note discusses the use of "armored" O-ring seals for the pressure range to 10 000 atmospheres. In addition, a simple high-pressure pump piston seal and a proprietary surface treatment to reduce liability of galling of steel parts are described.

THE seals whose description follows, were used with high-pressure equipment based on the unit used by Jacobs[1] at the University of Chicago Institute for the Study of Metals. Basically the equipment consists of a high-pressure pump capable of generating up to 3000 atmospheres pressure, operating on an intensifier to yield 10 000 atmospheres working pressure. The high-pressure bomb has been designed to accept a plug suitable for measurement of the pressure derivatives of elastic constants over the 10 000 atmosphere range.

For the first high-pressure work done in this laboratory, simple Buna-N O-rings were used as closure plug seals and as moving seals for the intensifier piston as described by A. W. Lawson.[2] A great deal of difficulty was experienced with extrusion of the O-ring past the piston, resulting in failure after one compression to 10 000 atmospheres in the case of the moving seals. In addition, the O-ring static seals extruded, jamming the closure plugs in place with subsequent galling of their contact surfaces. These problems were effectively cured by the use of an armor or anti extrusion piece in addition to the O-ring.

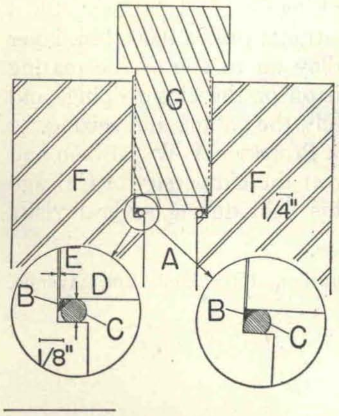

FIG. 1. Cross section of the high-pressure closure plug with armored O-ring seals. The inserts show the armor configuration before and after initial application of pressure to the system. *A*, the high-pressure region; *B*, machine steel armor ring; *C*, O-ring 7274 AN123872; *D*, O-ring squeeze; *E*, extrusion gap; *F*, bomb walls; *G*, closure plug.

Antiextrusion rings have been used before by Bridgman[3] and by Bowman *et al.*[4] but the geometry developed for the present work is simpler and has proven very effective. In addition, the problem of pinching off of the stem of a mushroom plug conventionally used is completely avoided using the present geometry because it is unnecessary to use a piston-mushroom plug combination to obtain an unsupported area configuration to effect the sealing action over the pressure range desired.

The geometry of these armor pieces is shown in Figs. 1 and 2 for the static and moving seal cases respectively. Referring to Fig. 1, one will notice that the armor ring is shaped so that initially there is a large "unsupported area," the entire region behind the armor ring. This geometry aids in obtaining an initial pressure seal. At high pressure the armor ring deforms and even begins to extrude into the extrusion gap. It is probably important that the initial squeeze on the O-ring be large enough that under hydrostatic compression to the highest pressures desired the O-ring does not shrink away from the walls of the cavity. One of these rings, made of mild steel, sealing a closure plug used in our measurements survived about seventy-five cycles to 10 000 atmospheres, with frequent removal and replacement of the plug, the seal remaining untouched. The static seal armor seems to need replacing only when the extrusion

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[1] I. S. Jacobs, Phys. Rev. **93**, 993 (1953).
[2] A. W. Lawson, Rev. Sci. Instr. **25**, 1136 (1954).
[3] P. W. Bridgman, *The Physics of High Pressures* (G. Bell and Sons, London, 1949), pp. 34, 39.
[4] Bowman, Cross, Johnson, Hill, and Ives, Rev. Sci. Instr. **27**, 550 (1956).

has become excessive. When it is desired to remove one of these seals, the frangible nature of the armor ring makes it a simple matter to extract it with a hook-shaped tool, no special extraction jig being necessary.

The seal used on the moving piston, and shown in Fig. 2, has been made with a phosphor bronze armor ring. Occasionally there has been a slight leak on the first few cycles up in pressure, but the ring seems to seat itself and to operate indefinitely thereafter. Two outstanding characteristics of the seal are its very low friction and its long life. One of the rings was used in our work for about one hundred cycles from 0 to 10 000 atmospheres, operating with a diametral piston clearance of 0.003 in., and was replaced then only because of

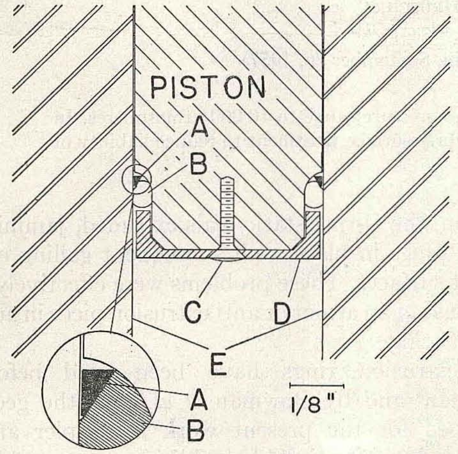

FIG. 2. Cross section of the high-pressure intensifier seal. The insert shows an enlarged cross section of the phosphor bronze armor ring. *A*, armor ring; *B*, O-ring AMS 7274 AN123861; *C*, 5–40 machine screw; *D*, filler piece to hold O-ring and armor in place during installation; *E*, walls of high-pressure cylinder.

a failure in another part of the equipment. Another ring was used with the same equipment on an autofrettage run in which the pressure was carried up to 16 000 atmospheres. After this run, the diametral clearance between piston and wall was found to be greater than 0.010 in. It should be mentioned at this point that the high-pressure fluid used for this work has been Octoil-S which was suggested to us by Dr. D. P. Johnson of the National Bureau of Standards because of its low pressure coefficient of viscosity. The excellent lubricating properties of this fluid have no doubt contributed to the success of the moving seal. Slight swelling of the Buna-N O-rings in the fluid does not seem to have an adverse effect on their performance.

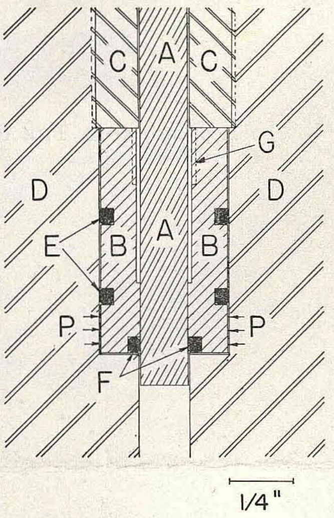

FIG. 3. Cross section of the high-pressure pump piston seal. *A*, reciprocating pump piston; *B*, phosphor bronze seal body; *C*, packing gland nut; *D*, body of pump; *E*, O-rings sealing outside of seal body, AN6227B-7; *F*, O-ring sealing between piston and inside of seal body, AN6227B-3; *G*, threaded portion to enable extraction of seal body; *P*, *P* indicates the re-entrant region of the seal body in which the seal is exposed to pump pressure on its outside but not on its inside surface.

The high-pressure pump piston seal is shown in Fig. 3. Essentially it is a hollow cylinder of phosphor bronze sealed with O-rings inside at the piston, and outside at the pump body. As shown in the figure, the seal is re-entrant. That is, up to the outside O-ring seal, it is exposed to hydrostatic pressure outside, but not inside because the piston seal occurs at the base of the cylinder. Thus, the cylinder will squeeze tightly around the piston, reducing to zero the extrusion clearance for the O-ring sealing the moving piston. This insures a long life for that O-ring, but requires a piston which is smooth and accurately cylindrical for satisfactory operation. The piston seal illustrated has been used to a pressure of about 1500 atmos for a year of steady research work with but one replacement of the O-rings, and has operated as high as 3000 atmos with no difficulties.

At the beginning of our high-pressure experience some difficulty was experienced due to galling and seizing of the intensifier piston on the cylinder wall, and of the closure plugs in the bomb. The piston is Solar steel hardened and drawn to 60 Rockwell "C"; plugs and bomb are SAE 4340 steel, 42 Rockwell "C." This problem was solved by making use of a treatment called "Electrolizing."[5] This treatment puts a 0.0002-in. layer of a dense low friction alloy on to one of the mating parts, in this case the piston or the closure plug, and seems to prevent completely the galling and seizing.

We should like to thank Professor A. W. Lawson and the staff of his laboratory at the University of Chicago for our initiation into this field during several visits there.

[5] The Electrolizing Corporation, 1505 East End Avenue, Chicago Heights, Illinois.