fitted into the cup with the bridge lead wires passing through it into the axial bore in the stem. A seal of epoxy adhesive was made where the lead wires leave the bushing to prevent moisture and other foreign substances from entering the cup.

Calibration of the transducer was accomplished by calibrating it against a manganin gage at room temperature in the hydrostatic-extrusion tooling and under the conditions it was to be used. After the initial calibration producing a scaling of 20 microinches/ksi, a one to one correspondence (45 degree plot on an X-Y recorder with both axes scaled in pressure) was obtained between the strain-gage transducer and the manganin gage in further tests. The accuracy and repeatability of calibration was in the order of 1 percent.

The high-pressure transducer performed quite well in many trials at room temperature and at 400-500 F. However, two adverse effects were noted when operating at the elevated temperatures. The first was a slight drift of the instrument zero point while the second was a transient in the zero point of the transducer.

The zero shift was produced by an unbalancing of the bridge due to uneven resistance variations with temperature in each leg either in the strain gages or the connecting lead wires. By soaking the cap in the hot fluid for a few seconds before pressurizing, it was possible to reestablish electrical balance in the strain bridge. Balanced conditions then remained stable throughout the trial. The transient thermal strain which occurred at the zero point, due to the high temperature gradient in the cap, was virtually eliminated by the soaking technique described above.

Toward the end of the experimental trials at 400-500 F, the electrical terminals in the gage failed. In the remaining elevated temperature trials, stem pressure readings were used as a guide to fluid pressures. Gage failure was due to exposure to temperatures above 500 F when the hot fluid burned occasionally. The temperature limitation of the electrical materials used in the transducer was 550 F. For future trials at 500 F, it is recommended that electrical materials capable of higher temperatures than the existing limit of 550 F be used.

Sealing Arrangements

Room Temperature

The sealing method used in the room-temperature trials for the die and stem is illustrated on a die in Figure 9a. This arrangement, used for most of the program, consisted of a beryllium-copper (98Cu-1.8Be-0.2Co) ring of triangular cross section in conjunction with a standard Buna N rubber O-ring. Toward the end of the program, an alternative system of sealing the die was evaluated. This advanced seal arrange ment shown in Figure 9b consisted of a single rubber O-ring located at the base of the die. This arrangement is similar in principle to that used at the ASEA High Pressure Laboratory in Sweden. The advancement was essentially an economic one since sealing was never a problem with the previous arrangement. The new arrangement eliminated the need for a metallic seal ring and reduced the die-machining costs somewhat. A major advantage of the improved design is that it allows larger diameter billets to be extruded than with the original design for a given bore size. In the original design, it would have been necessary to have a two-piece die to accommodate large diameters. Sealing with the improved design was achieved in all the trials in which it was evaluated and at pressures up to 250,000 psi

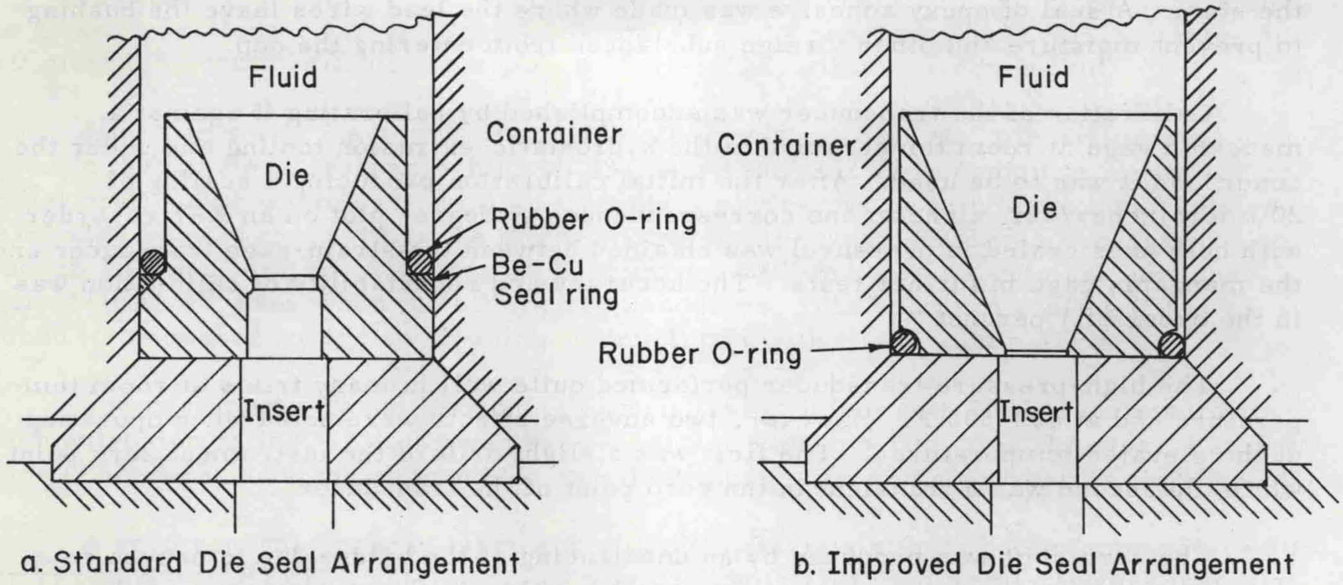

FIGURE 9. DIE SEAL ARRANGEMENTS EVALUATED IN HYDROSTATIC EXTRUSION

In view of the very few difficulties encountered with the stem seal design, its use was continued throughout the program. During the program, however, other stem seal designs have been reported such as a U-ring used at ASEA (Robertfors, Sweden) and a rubber O-ring/metal seal ring located in the linear bore as used at Western Electric (Princeton) and ASEA. These designs would be considered for use in future tooling.

Temperature Range of 400-500 F

In the design of a stem to incorporate a high-temperature, high-pressure gage, the stem-seal angle (Figure 10) was increased to 65 degrees from 45 degrees with the design used at room temperature, with the aim of reducing the stem pressure by decreasing the friction between seal and container. The modification was made as a result of the stem-seal experience of Fuchs(6) with this design. In room-temperature calibration trials, it was found that the stem pressure/fluid pressure difference was reduced by approximately 25 percent when using the 65 degree stem-seal angle.

During the warm trials, three O-ring arrangements were used in the investigation as a result of leakage problems. Three combinations were used:

(1) A single PTFE O-ring
(2) A PTFE O-ring plus a Buna-N rubber O-ring
(3) Two PTFE O-rings.

With the single PTFE O-ring, fluid leaks were frequent. The other two O-ring arrangements successfully contained fluids at pressures up to about 220,000 psi. In none of the arrangements, however, were the rings reusable because of distortion or breakage.