have been sufficient. (It is also possible that the tooling could be designed to eliminate the need for any hold-down force at all.) Next, fluid is added to the liner bore. The stem or ram is forced down against the fluid to build up sufficient pressure to extrude the billet through the die. For long, small-diameter billets for which the die contact area is small, a guide is used on the back end of the billet to prevent it from tilting.

Pressure Control and Measurement

The fluid in the bore of the container was pressurized by axial movement of the stem shown in Figure 5. The stem was secured in a tapered clamp ring which in turn was located in tooling fixed to the top platen of the 700-ton press. Precise axial alignment of the stem with the bore was readily achieved by adjusting screws in the stem-support tooling.

The fluid pressure for room-temperature trials was measured by a manganin coil attached to the bottom of the stem as shown in Figure 6. (A strain-gage transducer described below, was designed for operation at elevated temperatures.) The manganin coil has a resistance of 120 ohms and its resistance change with pressure was calibrated by the vendor to be 1.65×10^{-7} ohm/ohm/psi. A Moseley X-Y plotter (Model 135) is used to measure the resistance change of the "active" coil against a "compensating" manganin coil of 120 ohms at ambient conditions. The recorder produces a chart which shows the fluid pressure against stem travel. An additional check on pressures is given by the stem pressure which is greater than the fluid pressure by an amount proportional to the frictional losses between the stem seal and the container wall. Several measures of stem pressure were available. Two such measures were (1) a load cell between the stem and the pressure plate and (2) a hydraulic-line pressure gage which gives the oil pressure on the main ram of the 700-ton press. Stem pressure from either of these devices was continually recorded on one channel of a 2-channel recorder (Brush Mark 842, Model No. 13-6624-00).

High-Pressure Strain-Gage Transducer

The high-pressure strain-gage transducer described here was conceived for use in measuring fluid pressures in warm hydrostatic extrusion because the manganin gage could not be used much above room temperature. As depicted in Figure 7[3,4] the temperature coefficient of resistivity of manganin has a zero slope at approximately room temperature, but at higher and lower temperatures the resistivity gradient becomes steep. This leads to considerable errors when the manganin gage is used much above or below room temperature. Also the pressure coefficient of resistivity also changes with temperature and this would introduce still more error.

The strain-gage high-pressure transducer in its final evolved stage is illustrated in Figure 8 along with the shrink-fit bushing and the stem. The operation of this transducer is somewhat similar to one Bridgman[5] once used. The cap was designed to withstand the external pressure while the strain gages sensed this pressure internally.

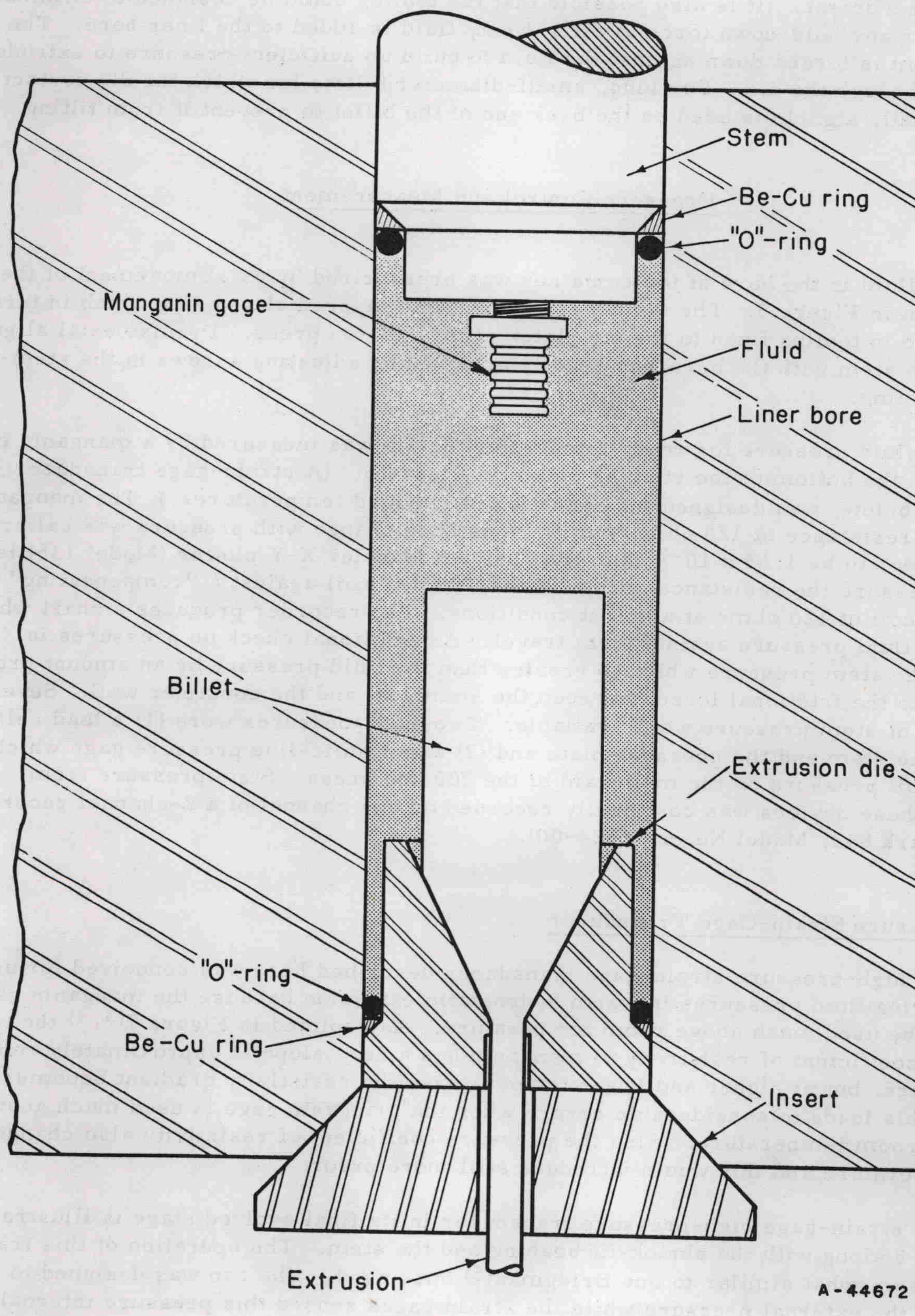

FIGURE 6. DETAILS OF HYDROSTATIC EXTRUSION PROCESS SHOWING THE STEM AND DIE SEAL METHODS, AND PARTIALLY EXTRUDED BILLET