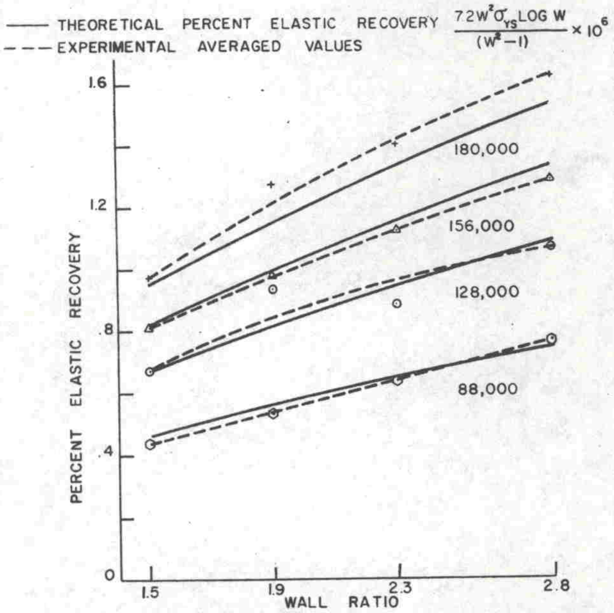

Fig. 7—Percent elastic recovery at the bore vs. wall ratio

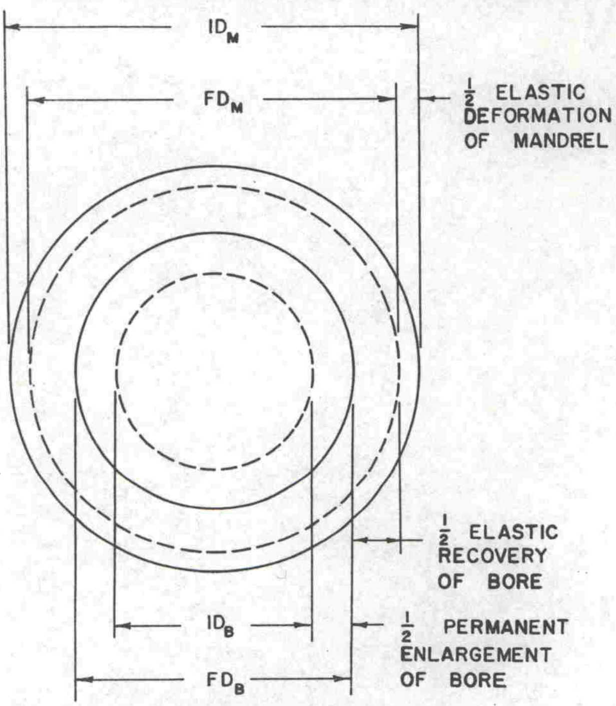

Fig. 8—Schematic diagram of bore and mandrel surface deformations

less the residual strain is the elastic recovery at the exterior surface. It may also be determined if the cylinder walls have been completely yielded by comparing the peak strain with that calculated from Hookes' law. An example of over yielding and under yielding is indicated in this figure by the 1.52 and 0.51% bore enlargements respectively.

Elastic recovery is defined in percent as:

$$\% \text{ E.R.} = \frac{(ID_m - FD_b)}{ID_b} \times 100 \quad \text{(2A)}$$

Elastic recovery at the bore plotted as a function of wall ratio is shown in Fig. 7 where each experimental point is the average value for all cylinders at a given wall ratio and yield strength regardless of percent enlargement. The data indicated a slight trend for an increase in elastic recovery with an increase in percent enlargement for a given yield strength and wall ratio; however, the spread at any point was less than $\pm 0.1\%$. This substantiated the same observation made with the outside-surface measurements. The variation of elastic recovery with percent enlargement appeared to be random with no determinable correlation from one wall ratio to another. The $\pm 0.1\%$ spread in elastic recovery seemed to have no practical significance for the bore diameters of these tests since machining inaccuracies produced greater variations in the final bore dimensions than did the elastic-recovery variation.

Elastic recovery was also observed to vary along the cylinder length, being larger at the mid-length than at the ends. The lower values at the ends are attributed to an observed longitudinal displacement of metal out of the bore as the mandrel passed. However, the center 2 in. of the 5-in. cylinder possessed a constant value of elastic recovery where the least longitudinal flow was expected. This physical phenomenon again revealed no end effects at the mid-length position.

The elastic recovery as defined in eqs (2) is composed of two factors: (*a*) the elastic compression of the mandrel due to radial pressure exerted by the specimen, and (*b*) the elastic recovery of the specimen after the mandrel has passed. The magnitude of these two factors may be computed from the Lamé equations for thick-walled cylinders with the following assumptions:

(1) The pressure existing between the mandrel and the specimen is equal to the internal hydrostatic pressure required to completely yield the specimen. This pressure is given in the form of eq (1). The value of K depends on the theory of plasticity which is used. Tresca's maximum shear criterion gives a value of $K = 1$, and the Von Mises criterion gives a value of $K = 1.15$. Extensive experimental work in hydrostatic autofrettage of miniature cylinders shows a value of $K = 1.08$ for the type of steel used in these tests.

(2) The mandrel may be considered as a solid circular cylinder under radial hydrostatic pressure only. The effect of longitudinal loading on the mandrel may be neglected.

(3) Both mandrel and cylinder are steel with a Poisson's ratio (μ) of 0.3 and an elastic modulus (E) of 30×10^6 psi.

Figure 8 illustrates a superposition of the elastic and plastic deformations of the mandrel and cylinder during the swaging operation. This relates and clarifies eqs (2) and (3).

By definition (Fig. 8),

$$\% \text{ elastic recovery (E.R.)} = \frac{\Delta D_m + \Delta D_b}{ID_b} \times 100 \quad \text{(2B)}$$