ANALYSIS OF SEVERAL HIGH-PRESSURE CONTAINER DESIGN CONCEPTS

INTRODUCTION

This design analysis is part of a research program to develop the manufacturing capabilities of the hydrostatic extrusion process. An important component of the extrusion equipment is the pressure container. The purpose of this design study was to determine the maximum pressure capability of several containers at the fluid pressures expected in advanced hydrostatic forming processes. Containment of bore fluid pressures up to 450,000 psi at room temperature and at temperatures of 500 F and 1000 F was considered. The results of the study also pertain to other applications, besides hydrostatic extrusion, where such pressures are encountered.

A summary report of the important results of this study has already been given as part of the last interim progress report (Report IV for 1 September 1964-30 November 1965). The present report gives a complete and detailed description of the analysis including a comprehensive presentation of results.

SCOPE OF ANALYSIS

The purpose of this study is to determine the maximum pressure capability of several designs of vessels for containing fluids at the pressures encountered in hydrostatic extrusion and other hydrostatic forming processes. Containment of bore fluid pressures up to 450,000 psi at room temperature and at temperatures of 500 F and 1000 F is considered.

The operating cycle of these high-pressure containers consists of application of the pressure needed for extrusion or forming, followed by a decrease in the pressure to zero. To be useful in production, the high-pressure containers must withstand a large number of such operating cycles. Therefore, fatigue strength of component materials must be an important design consideration. However, consideration of fatigue strength appears to be lacking in design analyses heretofore. The general method of design analysis has been to use a safety factor on the yield pressure. As the design pressures have been steadily increased, material limitations have necessitated lower factors of safety, sometimes less than 1.1. Consequently, fatigue failures are being experienced. Because of the extreme operating pressures being considered for hydrostatic extrusion and other forming operations (up to about 450,000 psi), it was essential that the various container design concepts be analyzed and compared on the basis of a fatigue criterion.

In order to estimate the pressure capability of each container, stress analyses are conducted. Only stresses due to the bore pressure and shrink-fit assembly are analyzed; no thermal gradients are assumed present. However, the effect of temperature change (from operating temperature to room temperature) upon the prestress (residual stresses) is included in the analyses. Excessive residual stresses may result because of differences in thermal expansion of the component parts of each container.

Four types of pressure vessel designs were analyzed in detail. These are:

(1) Multi-ring container,
(2) Ring-segment container,
(3) Ring-fluid-segment container, and
(4) Pin-segment container.

The four cylindrical containers are shown in Figure 7. A wire-wrapped (strip-wound) vessel and a controlled fluid-fill, cylindrical-layered container were also considered, but only briefly.

The multi-ring container was one of the first design modifications of the monoblock thick-walled cylinder*. An initial compressive stress at the bore is achieved by shrink-fit assembly of successive cylinders each manufactured to provide an interference fit with its mating cylinder. The multi-ring container has been analyzed on the basis of static shear strength by Manning[4, 5, 6].

The ring-segment container with one outer ring was patented by Poulter[7] in 1951. One intent of this design is to reduce the pressure acting upon the outer ring by using a segmented cylinder to redistribute the pressure at a larger diameter. However, the inner cylinder is always subject to the bore pressure. The external diameter of the vessel necessarily increases with increasing segment size.

The ring-fluid-segment container makes use of the fluid-pressure support principle. This container is essentially constructed of two parts. The inner part is a ring-segment-type container with one outer ring, but with a fluid support pressure, p_3, as shown in Figure 8(c). The outer part is a multi-ring container subject to an internal pressure, p_3, the support pressure for the inner part. The advantage of this design is that the fluid pressure (p_3) provides a compressive hoop stress at the bore which counteracts the tensile hoop stress resulting from the bore pressure, p. Theoretically, p_3 can be changed in proportion to the change in bore pressure in order to reduce the bore stress over an entire cycle of bore pressure. This variation of p_3 with the bore pressure is assumed in the analysis.

The origin of the ring-fluid-segment concept is not clear. Ballhausen[8] patented an approach of this sort in 1963. Another application of the same principle was patented by G. Gerard and J. Brayman[9], also in 1963. A similar design, but with additional features, was reported by F. J. Fuchs[10] in 1965.

The pin-segment design is an approach proposed by Zeitlin, Brayman, and Boggio[11]. Like the ring-segment container this vessel also uses segments to reduce the pressure that must be carried by the external support. Unlike the ring-segment container, the pin-segment container has segmented disks (thin plates) rather than segmented cylinders. Also, the external supporting members in this case are pins rather than an external ring. The pins carry the reaction to the bore pressure predominantly in shear.

All four containers have one thing in common: the liner is subject to the full bore pressure. The four containers differ in the manner and in the amount they constrain the liner.

*The monoblock thick-wall cylinder is the simplest type of pressure container. However, for the very high pressure levels considered in this study it is a relatively inefficient design.