Engineering Notes

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6-ft-diam Metallic Diaphragm for Fluid Storage and Positive Expulsion Systems

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RELIABLE, lightweight, metallic positive expulsion diaphragms with multicycle capability have been demonstrated in diameters from 6 in. to 33 in. for cryogenic and other fluid service.[1–3] This Note discusses the design, fabrication and testing of a 6-ft-diam diaphragm made of a thin, one-piece stainless steel hemispherical shell reinforced by stainless steel hoop wires (Fig. 1) that are attached to it by brazing. The hoop reinforcement prevents random buckling and controls the diaphragm rolling mode during reversal and fluid expulsion.† Although developed for cryogenic fluids, the diaphragm materials utilized make it also suitable for a wide range of storable propellants. When such a hoop-reinforced diaphragm is housed inside a tank (Fig. 2) and fluid is stored on the concave side of the diaphragm, the application of a pressure on the convex side of the diaphragm that exceeds the fluid pressure by a few psi will cause the diaphragm to invert at its apex and pass through successive positions (Figs. 2 and 3b) until the diaphragm is completely inverted and the fluid is expelled. Controlled rim-rolling deformation modes. wherein the diaphragm begins to invert at its rim (Fig. 3a) and combination rim-and-apex-rolling modes can also be achieved.

The diaphragm shell is kept thin to reduce bending strain and to lower the diaphragm actuation pressure differential (ΔP) during reversal. The sizing and spacing of the hoop reinforcement has been discussed.[1] A 25-mil-thick shell and $\frac{5}{16}$-in.-diam reinforcing wires with 1.6-in. spacing were employed for the 6-ft-diam diaphragm. Annealed austenitic stainless steel and copper braze material were selected for their elongation, compatibility, and ready fabrication properties. The shell and reinforcing wires were made from AISI 321 and AISI 308 stainless steels, respectively.

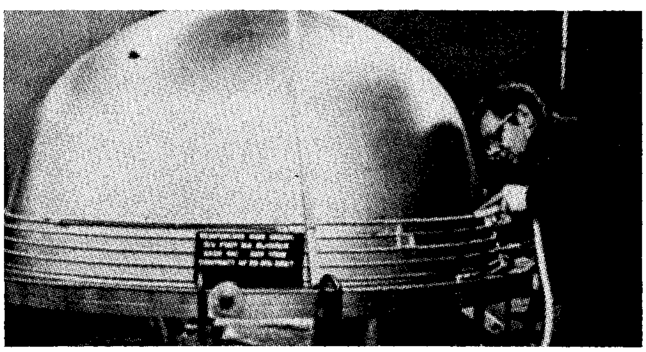

Fig. 1 Tack welding wires to 72-in. diaphragm shell.

Fabrication

The starting sheet material is formed into the final prescribed shell shape and thickness by hydraulic pressure after a succession of forming passes and intermediate anneals. The precise final shape is achieved by use of a sizing die. Several important differences between this process and conventional forming techniques contributed to the success achieved. First, the edge of the sheet (and subsequent shell) is restrained to be at a specified diameter throughout the forming process, and thus the boundary conditions at the edge are always known. This eliminates problems due to clamping pressure, sealing, friction, thin-out, etc., common to those fabrication methods which allow the edge to move inwards during forming. Second, the starting sheet has a prescribed tapered thickness variation. This prevents thin-out and overstraining and permits close control of shell thickness and shape. The starting sheet taper thickness variation (determined by means of test-verified plasticity theory) is selected to give the prescribed final shell thickness and contour after a specified number of forming passes and intermediate anneals. Finally, the tooling is simple and not particularly sensitive to size increases. This eliminates press capacity or other tooling size or capacity problems and leads to reduced fabrication cost. Fabrication started with procurement of 96-in. × 96-in., 0.05-in.-thick, sandwich-pack-rolled and annealed 321 stainless steel sheet from U. S. Steel Corp. Sheet taper grinding was done by Mill Polishing Corp., Delair, N. J. A two-step taper was used. The outer edge was maintained at 30-mil thickness.

Edge retaining rings were welded to the trimmed, tapered circular starting sheet, which was then clamped between a forming ring and the flange of a head closure and hydraulically

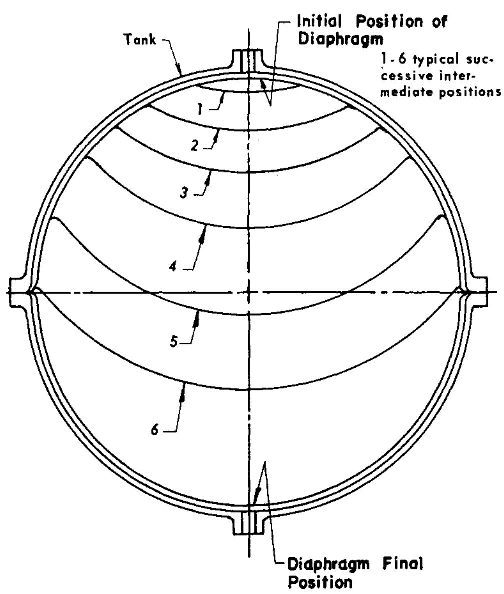

Fig. 2 Diaphragm reversal apex roll mode.

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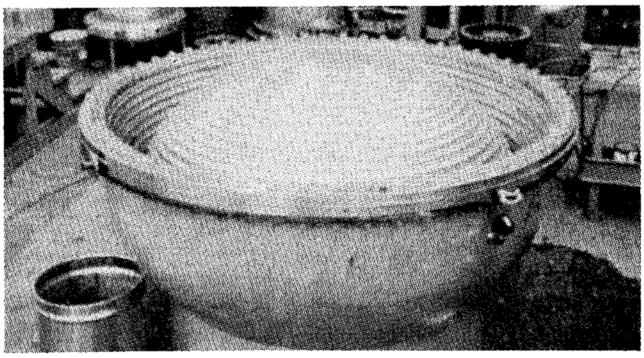

Fig. 3a 6-ft-diam diaphragm second reversal (rim roll mode).

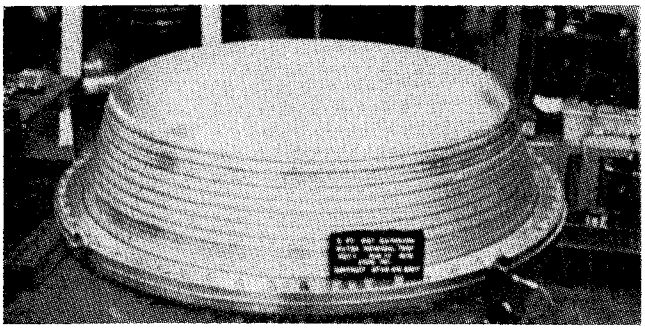

Fig. 3b 6-ft-diam diaphragm first reversal (apex roll mode).

formed (bulged) into a preform stage (Fig. 4a) using intermediate anneals between forming passes. Then hydraulic pressure was applied in the final sizing die (Fig. 4b) using several passes and intermediate anneals. This die consisted of a removable plastic liner mounted in the water reversal test rig and machined to final inside contour. A flanged hemispherical head closure was used for clamping the shell preform in the forming tool and permitting the die to be pressurized.

Fig. 4a Free-form bulging—first pass.

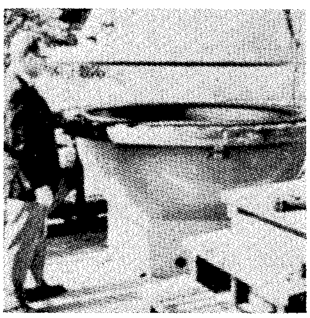

Fig. 4b Assembly of bulged shell into final sizing die.

The conical transition region in the shell equator area (Fig. 1) minimizes strain and reinforcing wire interference problems during diaphragm reversal. The shell thickness was controlled at 25 ± 1.5 mil, while the 6-ft nominal diameter shell shape was well within the ±0.06-in. tolerance target on diameter.

The reinforcing wires were tack-welded to the shell (Fig. 1) and then permanently attached by furnace brazing, the tack welds functioning as the brazing fixture. The brazing material was applied as copper plating on the wires prior to their tacking to the shell. This procedure offers the potential for significant improvement in brazing technology for diaphragm construction, since the braze material is applied in a controlled manner with minimum labor. Brazing was accomplished by Wall Colmonoy Corp. in the same 100-in.-i.d. vacuum furnace that was used to anneal the diaphragm shells during forming.

Inspection of the completed diaphragm assembly at Arde after brazing revealed brazing voids in several wires and shell leaks at three tack-weld regions. The brazing voids were repaired by silver solder, and the shell leaks were repaired utilizing welding or silver soldering techniques developed and verified in the previous 23-in. diaphragm program.[1] The defects were relatively few considering that this was the first diaphragm of such a large size to be fabricated and that hand assembly techniques with minimal tooling were used.

The fabrication problems were brought about primarily by the relative stiffness of the $\frac{5}{16}$-in.-diam wire compared to the large-diameter, thin shell making fit-up and application of proper clamping pressure needed for tack-welding difficult. It is anticipated that these problems will be eliminated through improved fabrication processing and tooling as was done for the smaller diaphragms.[1–3]

Testing

For a reversal test, the diaphragm is clamped between the flanges of a hemispherical closure and loose circular rings by bolts, and "O" rings are used as seals. Water, under pressure, introduced on the convex side of the diaphragm, actuates the diaphragm and reverses it (turns it completely inside out upon itself about the loose circular ring).

The first reversal was a well-controlled, rim-roll mode with the diaphragm rolling through the wires, one-by-one in sequence from the first wire at the rim to the last wire at the apex (Fig. 3a). Structural performance (reversal mode and actuation pressure levels) were according to design predictions. Actuation pressures varied from about 1 psid start at the rim to approximately 4.5 psid at the apex. Toward the end of reversal 1, a small leak opened up in a shell weld repair area. Testing was continued until the reversal was complete. The leak was repaired and reversal testing was continued subsequently as a further check of diaphragm structural performance. The diaphragm was completely reversed 3 more times with no further leakage. Diaphragm reversal modes were as well controlled as the first reversal. The condition and appearance of the diaphragm after these reversal tests was excellent. Figure 3b shows the diaphragm during the second reversal.

Conclusion

Ring-reinforced diaphragm scale-up has now been demonstrated in the range of $\frac{1}{2}$- to 6-ft diam. The metallic shell fabrication method utilized hydraulic forming coupled with plasticity theory and relatively simple tooling. However, use of better tooling and improved fabrication processing (particularly for tack welding the reinforcing wires to the diaphragm shell) are indicated.

Use of copper plating to apply braze material to parts joined by furnace brazing gives precise control of the amount and distribution of braze material and simplified its application.

References

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[2] "Development of Gold Brazing Technique and Design and Supply of 18" Diameter Positive Expulsion Tank Assembly," Rept. 56001-2, Feb. 1969, Jet Propulsion Lab. Contract 951898, NAS 7-100, Arde Inc., Mahwah, N. J.

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Liquid Fluorine Feed System Component Design Criteria

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FORMULATION of the basic design criteria for flight-weight fluorine feed systems began in 1965,[1] and the valve-related technology included evaluation of existing valves, and testing of two reworked off-the-shelf valves. In a continuation program,[2] conceptual design studies were directed toward a shutoff valve optimized for service with oxidizers containing liquid fluorine (LF_2). The latest effort included the design and fabrication of two test valves, with LF_2 tests of 250 cycles for one and 840 cycles for the other, which demonstrated the accuracy and utility of the criteria. Fabrication and acceptance testing was subcontracted to the Systems Division of Parker Hannifin, Los Angeles.

High reactivity of liquid fluorine requires specific consideration for specific design areas. A material in a fluorine environment must not exceed its ignition temperature, Table 1. Because the mass of material (available heat sink) in flightweight components is small, materials with a relatively high heat-transfer coefficient are needed for fluorine service. For critical component areas near high heat sources, the common stainless steels and Monels are less desirable than nickel, Inconel, copper, and aluminum.[3]

Table 1 Ignition temperatures of selected metals in fluorine

Metal	Melting point, °F	Average ignition temperature, °F	% maximum variation from average
Aluminum	1200	1382[a]	—
Copper	1980	1277	8.0
Iron	2780	1242	0.8
Molybdenum	4740	378	8.3
Monel	2400	755	12
Nickel	2620	2091	6
302 Stainless steel	2570	1259	13
Tungsten	6170	496	18

[a] An average of four tests gave an ignition temperature greater than melting point of aluminum.

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Use of metal gaskets and seals rather than plastic materials such as Teflon, Kel F, etc., is recommended. Because no compatible lubricant is available for assembling the metal parts, no seal configuration should be used which requires a turning motion that might cause galling. A plating of soft gold, copper, or silver on one of the surfaces should be specified to accommodate some sliding motion. Nonsliding seals such as bellows, diaphragms, etc., are recommended for all components where relative motion occurs between two parts. All parts are designed so that all surfaces can be cleaned and inspected easily. A one-piece design without cavities is preferred. A cavity should be sealed by welding or brazing, and a 100% x-ray inspection specified to ensure the quality of welds. Dye penetrants should not be used, because they cannot be completely removed by normal cleaning procedures, and the residue may cause a reaction with fluorine.

Corrosive effects of LF_2 on the common structural materials do not normally present a problem. The anhydrous form of the common impurity HF does not produce high rates of corrosion, but aqueous HF is very corrosive; great care must be taken to prevent moisture from entering the fluorine system. It is recommended that no subcomponent be prepassivated as there is no way to prevent the fluoride film from absorbing atmosphere moisture before installation into the system.

Valve Design and Test Results

Valve design objectives and specifications are shown in Table 2. For preliminary helium leak testing, a leak rate of 10^{-8} lb/sec of *G*He at −320°F was selected (on the basis of experience) as equivalent to the 10^{-7} lb/sec fluorine leakage requirement. The basic 2-in. valve configuration (Fig. 1) consists of a 90° offset poppet design weighing ~10 lb. The valve body is an Inconel 718 weld assembly made of two lathe-turned subcomponents. The surfaces that mate with the static seals must be free of porosity and have a surface finish of 16 μin. AA maximum. The static seals are of two functional types: those directly exposed to F_2 during normal

Table 2 Valve design objectives and specifications

	NAS3-11195	NAS3-12029
Fluid	LF_2, *LOX*, *FLOX* (MIL-P-27401)	Same
Temperature (fluid)	−320°F	Same
Fluid pressure, oxidizer	100 psig max. operating	Same
	250 psig proof	Same
	375 psig burst	Same
Actuation, helium	500 psig max. operating	500 psig operating
	600 psig proof	750 psig proof .
	750 psig burst	1125 psig burst
Flow rate	90 gpm	60 gpm
Pressure differential at rated flow	10 psig max.	5 psig max.
	5 psig target	
Line size	2-in. i.d.	Same
Leakage rate		
A) Propellant to actuator	0 SCIM He	Same
B) Main seat internal leakage	10^{-6} PPS F_2	10^{-7} PPS F_2
Actuation time (maximum)	75 msec	Same
Fail safe	Closed	Same