STAINLESS STEEL PRODUCTS
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GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

SUMMARY REPORT

(Including Design Analysis)

FACILITY FORM 602

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NASA Specification 60B24450

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SUMMARY REPORT – Bellows Tunnel Fuel Tank

This Summary Report is being submitted in compliance with the requirements of Contract NAS5297 and will summarize the findings made during the performance of this contract.

During the production of this Assembly Number 3303324, Procurement Specification Number 60B24450, only two significant improvements were found necessary, one being the addition of a pneumatic leak test as part of the acceptance testing, the other being the deletion of the aluminum foil wrapping of the assembly for shipment. It was found necessary to add a pneumatic leak check of 7.5 $\pm$2.5 psig to the acceptance testing of the assembly when a leak in a unit was detected during the installation at the George C. Marshall Space Flight Center, Huntsville, Alabama. The leak occurred in the neck of the convolutions in the straight section that attaches to the flange. No official reports or photographs of the failure were received by Stainless Steel Products, therefore a complete description and analysis of the defect cannot be given. It is recommended on assemblies or systems that require only a low pressure hydrostatic test the addition of pneumatic leak test to the specification requirement, since a low pressure hydrostatic test is less likely to detect the pressure of a very minute defect.

The problems created by the use of aluminum foil wrap in the packaging operation were discovered when units taken from storage were contaminated by a black substance later determined to be aluminum oxide. The use of a aluminum foil is required by Paragraph 3.2.11 of MSFC-Spec-164, consequently it is recommended for long-time storage items requiring cleaning and packaging, an alternate wrapping material which does not create a serious electrolytic action caused by greatly dissimilar metals, should be added to the specification.

A number of minor problems appeared during the execution of the manufacturing process required by this contract, however, the resolution of these problems were handled with relative simplicity in an expeditious manner.

As expected on an assembly of this type the real difficulties were encountered during the performance of the Qualification Testing. Although the problems were mainly related to the extraneous equipment used to simulate nominal vehicle installation during the testing of this tunnel bellows assembly, it is being reported because of its significance.

While angulating the assembly $\pm$1.5° from nominal in accordance with the requirements of the vibration test (Para. 4.3.4.2.d.1) an interference was

~~detected between the inside of~~ the convolutions of the bellows section and the outside of the aluminum tunnel which during installation passes through the tunnel bellows assembly. To eliminate this interference condition, it required that the bellows inside diameter be increased to allow more clearance in the installed condition. A retest of the re-designed bellows proved that this improvement solved the clearance problem.

Further qualification test difficulties were experienced during the axial cycling test with respect to the operation of the Teflon Fuel Tank Tunnel Bearing (60B24504), the Fuel Tank Upper Tunnel (60B24419), and the Fuel Tank Bellows Assembly (60B24450). When the temperature of the test set-up was brought to (-)130°F it was discovered that the teflon bearing contracted more rapidly than the aluminum tunnel, causing the bearing to grip the tunnel and prevent a smooth operation of the assembly. At this time, a consultation between the Boeing Engineering representatives and the Stainless Steel Products representative decided that the design of the bearing and tunnel was inadequate for the type of motion during the low temperature service and a temporary change was made to the bearing to aid in the development of a design improvement.

Boeing Field Engineering decided at this time to split the ring so that it could not grip the tunnel during operation. This was done immediately and the re-wroked bearing was assembled back into the test assembly and the test was again started. At this time the bearing did not grip the tunnel, however the clearance caused by the more rapid contraction of the bearing away from the Type 347 stainless steel seal flange allowed the bearing to move back and forth with the tunnel and create a "slapping" action of the bearing against the seal flange. A second consultation determined that a more extensive re-design would be required and testing was temporarily suspended.

On receipt of E.O. 303 to Specification 60B24450, Stainless Steel Products modified the seal flange of the tunnel bellows assembly by the drilling of 16 holes and tapping them for helicoil insertion around the spherical bearing surface. While this work was being performed, Marshall Space Flight Center modified the bearing by cutting it into four sections and drilling holes which facilitated the attachment of the four sections to the spherical surface of the seal flange.

The modified bearing was assembled into the tunnel bellows and the Qualification Testing was again performed, this time without difficulty. All future assemblies were manufactured in the same way as the qualified unit which included E.O.1, E.O. 301, 302, and 303.

DESIGN ANALYSIS

Buckling from External Pressure

When a bellows is pressurized externally, it buckles in the same manner as a thin cylinder. Therefore from

$$P_{cr} = \frac{2E}{(1-\nu^2)}\left[\frac{t_{eb}}{\bar{D}}^3\right]$$

Where E = Youngs Modulus = 29,000,000

ν = Poisson's Ratio = .34

$$\bar{D} = \left(\frac{O.D.^2 + I.D.^2}{2}\right)^{1/2} = \left(\frac{29.9^2 + 27.45}{2}\right)^{1/2}$$

$\bar{D}$ = 28.62 inches dia.

$$t_{eb}^3 = \frac{2t\,N_p h^3}{\text{Pitch}} = \frac{2 \times .025 \times 1 \times 1.225^3}{.666}$$

$$t_{eb}^3 = .138$$

$$P_{cr} = \frac{2 \times 29{,}000{,}000 \times .138}{(1-.34^2) \times 28.62}$$

$$P_{cr} = 386 \text{ psig}$$

The critical failure point because of the external loading, will be the end convolution on either end of the bellows due to the carry-back end moment of the neck attachment to the end flanges. This condition will cause a reduction of collapsing pressure of 70% resulting in an actual pressure of 120 psig (determined from previous test data).

Collapsing characteristic of the bellows necks or end attachment sleeves has been maintained by capping the bellows necks over the end attachment flanges thus allowing the end flanges to support the imposed load.

In this configuration the bellows fatigue characteristics will be as follows:

Motion stress $\sigma M = \dfrac{41400 \times 10 \quad \times tXST}{N_c\ h^2}$ (assuming complete elastic characteristics for each of calculations)

$$\sigma M = \frac{41.4 \times 10^6 \times .025 \times 4}{1.225^2 \times 30} = \underline{91,960 \text{ lbs/sq.in.}}$$

From the Cycle Life Curve it is clearly indicated that the required motions are well within the capabilities of this bellows.

$$\text{Spring Rate } Z_a = \frac{N_p \times Ks\ 33.6 \times 10^6 \times D_i \times t^3}{N_c\ h^3}$$

$$Z_a = \frac{1 \times 1 \times 33.6 \times 10^6 \times 27.45 \times .025^3}{30 \times 1.225^3}$$

$$\text{Spring Rate } Z_a = \underline{261 \text{ lbs/in.}}$$

Thickness required to prevent deformation of convolution sidewall:

$$t = \sqrt{\frac{P \times h^2}{2 \times 120,000}}$$

$$t = \sqrt{\frac{55 \times 1.225^2}{2 \times 120,000}}$$

$$t = .01855 \text{ inches}$$

The preceding calculations are based upon formulae from Mechanical Design of Stainless Steel Bellows, Stainless Steel Products, Inc., and show that the bellows design conforms with all the requirements contained in Boeing Specification 60B24450. Since a similar unit was qualified for the Marshall Space Flight Center, it can be stated that all preceding calculations have been verified by testing.