https://ntrs.nasa.gov/search.jsp?R=20030065882 2020-03-28T18:42:34+00:00Z

EVALUATION OF THE SPHERICAL FLANGE CONCEPT FOR A ROCKET ENGINE

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Abstract

Due to the inherent tolerance variability of hardware, flange misalignments occur during installation of mating components for a liquid propellant rocket engine. Flange misalignments include axial, lateral, and angular offsets. If these misalignments are high, they can impart significant loads into the two mating components. These significant loads can then be a driver in the design of the propellant ducts. Such was the case for the Rocketdyne RS-83 engine design for the Space Launch Initiative Program. To address this flange misalignment issue, Marshall Space Flight Center joined with Rocketdyne to develop and test a spherical flange system that allows for misalignment, yet reduces loads imparted, and at the same time provides sufficient sealing against leakage. The flange design was tested to evaluate and compare performance parameters such as misalignment and leakage. The environmental conditions ranged from –100 to +400 degrees Fahrenheit (°F) with 1000 to 4000 pounds per square inch gage (psig) pressure. The desirable design features will be extracted and synthesized into a new flange design concept. This paper will address the spherical flange design and the test results.

Background

The Space Launch Initiative Program (SLI) provided the opportunity for several competing engine concepts to identify and provide risk reduction strategy's for the technological improvement of next generation main propulsion engines. Among these candidate concepts was Rocketdyne's RS-83 liquid hydrogen (LH2)/liquid oxygen (LOX) engine configuration (see Figure 1). The turbopumps were tightly packaged around the main combustion chamber resulting in short ducts of relatively complex geometry. The engine concept was a fuel rich staged combustion engine that utilized a single preburner to drive both high pressure LH2 and LOX turbopumps. A hot gas crossover duct connected the LH2 turbopump hot gas discharge with the LOX turbopump hot gas inlet. Flexible bellows were not used on the crossover duct to eliminate potential failure modes and reduce inspection requirements. The hot gas temperatures inside the crossover duct were maintained such that active cooling of the lines and ducts was not required. This hot gas crossover duct utilized an 8-inch internal diameter (ID) spherical flange design located at the LH2 turbopump hot gas discharge flange.

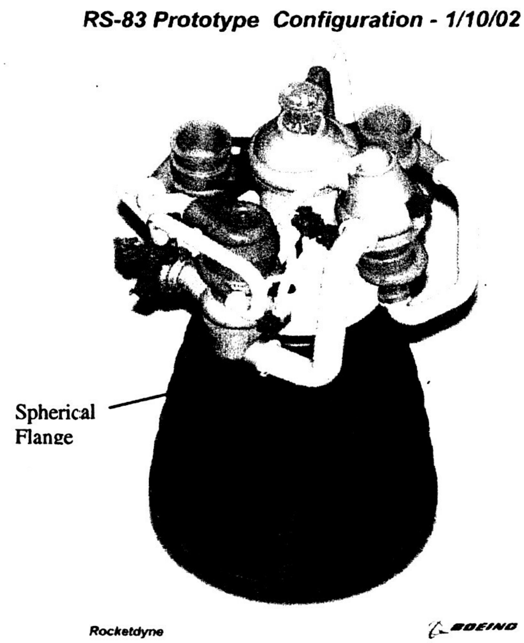

Figure 1

The spherical joint was required to accommodate the misalignment of the high pressure turbopumps relative to one another and the inherent tolerance stack up of the components affecting the hot gas crossover duct. The application of a spherical joint design on a reusable manned flight engine raised concerns because little is known in the U.S. rocket engine community about the design, ability to seal, affect on system flow, durability, and reliability.

Rocketdyne and Marshall Space Flight Center previously collaborated on a design for a 4 inch ID Inconel 718 spherical flange and seal setup for cryogenic application at 2000 psig pressure. The spherical contact surface is on a 5-inch radius (see Figure 2). The seal design was performed by Hydrodyne and based upon an existing Rocketdyne NAflex seal design. The spherical flange seal is a pressure assisted metal seal (Inconel 718) with a Teflon coating.

Zero Degree Misalignment
Torque 160 ft-lb.

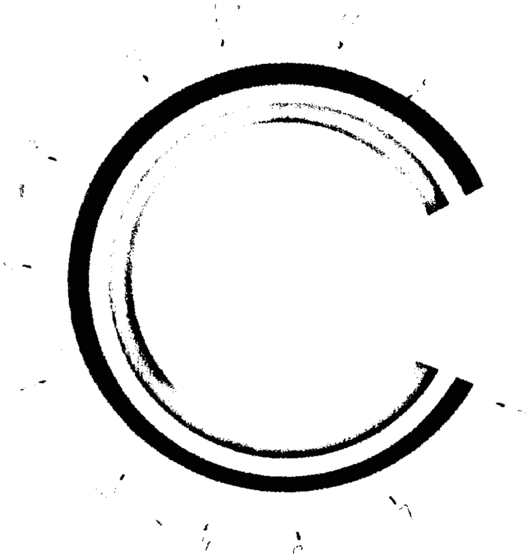

Figure 4

The image of Figure 4 shows the contact region of the spherical flange halves. The white gap between the two circles is the seal gland region.

1 Degree Misalignment
Torque 160 ft-lb.

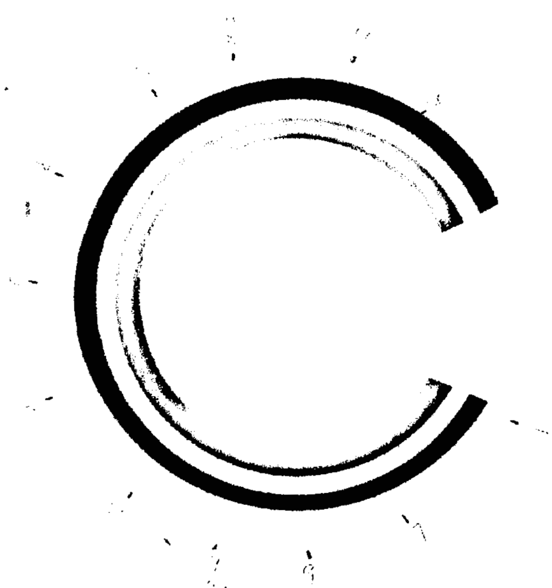

Figure 5

2 Degree Misalignment
Torque 160 ft-lb.
Figure 6

The results of the Fuji paper tests indicate the contact region made between the flange halves was subject to "flange roll". Flange roll is caused by the applied moment due to bolt torque. This torque induced flange distortion causes the inside heal of the flange to not make full contact. This phenomenon was verified by performing subsequent Fuji paper tests at bolt torques of 50, 80, 100, and 150 ft-lb. The visual indication of flange roll begins between 80 to 100 ft-lb bolt torque.

Zero Degree Misalignment
80 ft-lb Bolt Torque

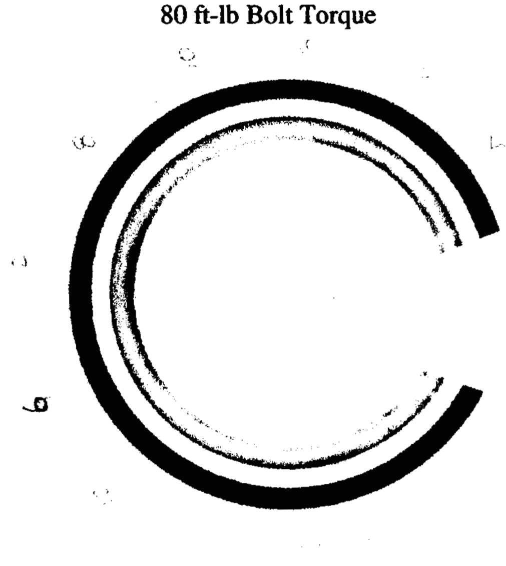

Figure 7
Zero Degree Misalignment

100 ft-lb Bolt Torque

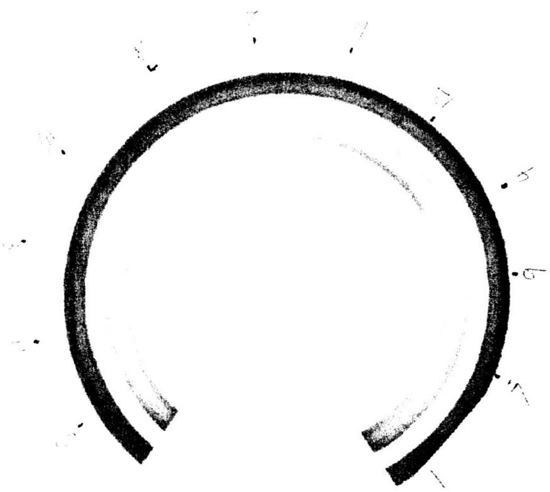

Figure 8

Thermal Leakage Testing

The flange design was tested to evaluate and compare performance parameters such as misalignment and leakage. The environmental conditions ranged from –100 to +400 degrees Fahrenheit (^{o}F) and with 1000 to 4000 pounds per square inch gage (psig) pressure. The spherical flange half containing the seal grove was modified with an intentional groove flaw to insure leakage measurements were obtained for the seal only. This flaw made any leak protection from metal to metal contact of the spherical surfaces impossible. The assembly and testing of the spherical flange hardware was performed at building 4656 in the Component Development Area (CDA) of MSFC. A thermal chamber was used to maintain environmental temperature and band heaters were used to facilitate the direct heating of the flange assembly (see Figure 9).

Flange Assembly

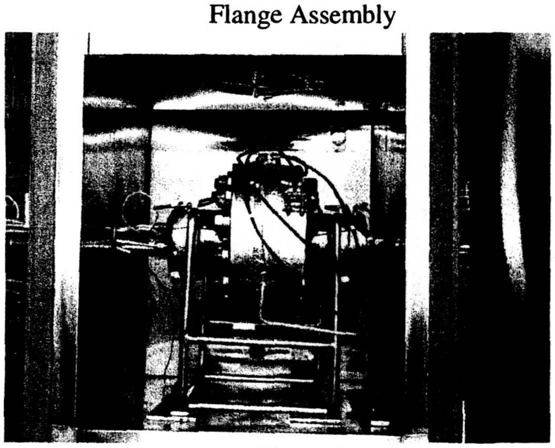

Figure 9

The flange joint was sealed using thermal tape and a helium mass spectrometer was connected to measure leak rate. The test matrix data for the spherical flange was then obtained at misalignment angles of zero, 1, and 2 degrees. (Note: A new seal was installed for each misalignment angle.) The thermal leakage test matrices had no measured leak rate greater than 2.0 x 10^{-6} SCCS helium.

Test Matrix

Temp (Deg F) (+/- 10)	Pressure (psig) (+/- 100)
Ambient (65)	40 (+/- 5 psig)
	1500
	3000
	4000
-50	40 (+/- 5 psig)
	1500
	3000
	4000
-100	40 (+/- 5 psig)
	1500
	3000
	4000
0	40 (+/- 5 psig)
	1500
	3000
	4000
ambient	40 (+/- 5 psig)
	1500
	3000
	4000
100	40 (+/- 5 psig)
	1500
	3000
	4000
200	40 (+/- 5 psig)
	1500
	3000
	4000
300	40 (+/- 5 psig)
	1500
	3000
	4000
400	40 (+/- 5 psig)
	1500
	3000
	4000

Table 1

Following the completion of thermal leakage test matrix, the seal and flanges were visually inspected. The Teflon coating on the seal was worn off exposing the inconel base metal at the contact point of the seal to flanges (see Figure 10).

Magnified Seal (100X)

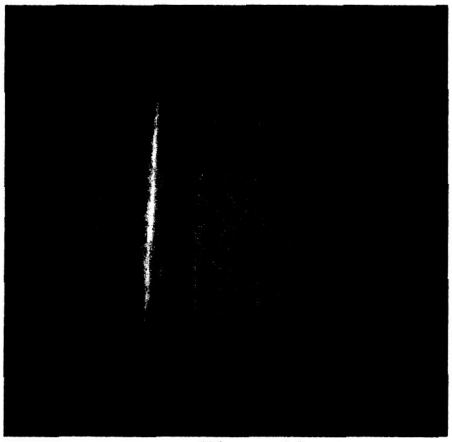

Figure 10

The flange surface was marked with what appeared to be residue rings at the contact point of the seal to flanges (see Figure 11).

Residue Ring

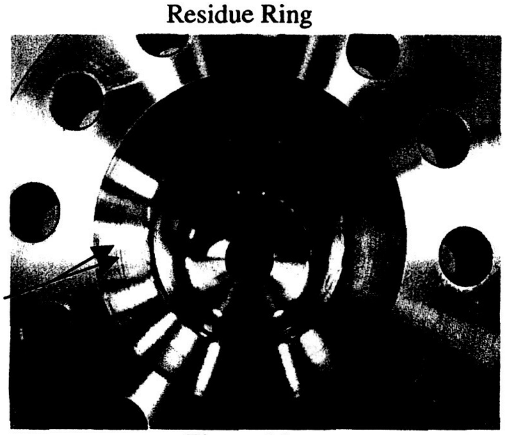

Figure 11

The surface marks on the spherical flange were analyzed using the profilometer, which had been calibrated to remove the surface curvature. The results indicated the surface marks caused by fretting to be a depth of 0.08 thousands of an inch (mils) from the average surface. This had essentially no effect on the surface finish value. The bars on the profilometer graph represent the region corresponding to the surface mark.

Profilometer Data

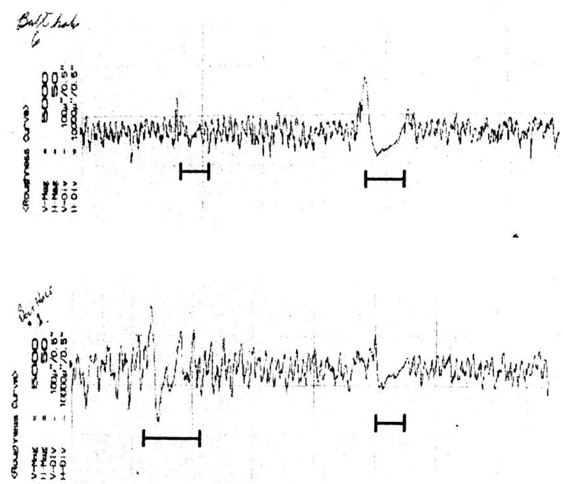

Chart 1

Conclusion

The spherical flange sealing capability at elevated temperature and pressure was demonstrated with a Teflon coated seal that was designed for cryogenic application. A silver plated seal would have been desirable for high temperature testing. However, program schedule and fabrication leadtime constraints prohibited the procurement of a new high temperature seal from Hydrodyne. The flange "roll" effect was identified when a bolt torque of 80 ft-lbs was applied to the fasteners. For a flight weight flange, the "roll" effect would initiate at a lower torque value for this type of design. The concerns of the "roll" effect are flange distortion, which might result in the loss of seal preload and induced stress on the duct due to the applied torque of the fasteners. A "Johnson Flange" type limiter that prevents going beyond the designed angular position is a design option for addressing the flange "roll" issue. Further testing to demonstrate sealing capability under applied external load and/or vibration are required to fully address the application of this type of spherical flange. However, the sealing capability at high pressure and temperature has been demonstrated.