Bearing Area Code Documentation

LRI - Engine - Analysis

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Process:

Bearing Stress:

When calculating the necessary thickness of a submerged nozzle, we must take into account both shear and bearing stresses. However, in most cases, the bearing stress will be far greater than the shear stress and much more likely to cause failure. From figure 1 we can see that the nozzle is held in place by a retaining ring whose contact area with the nozzle is defined as the bearing area.

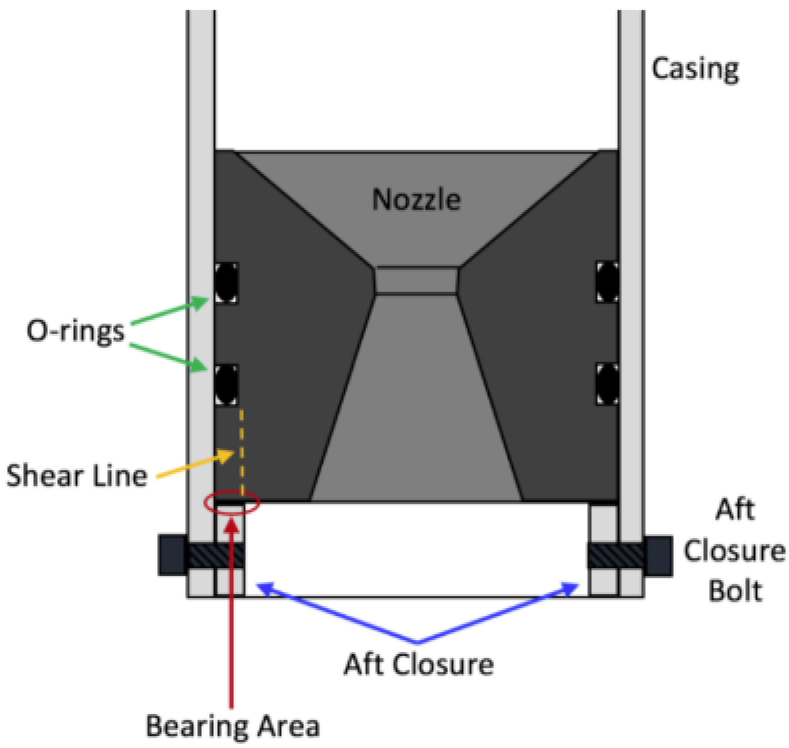

Figure 1. Cross-section of a submerged nozzle with a bolted aft closure, showing the bearing area and shear line.

This means our bearing area can be defined as

$$A_{bearing} = \pi(D_{o,\,closure} - t_{closure}) \times t_{closure} \tag{1}$$

Where $D_{o,\ closure}$ is the outer diameter of the closure and $t_{closure}$ is the thickness of the retaining ring. Therefore, the bearing stress on the nozzle is

$$\sigma_{bearing} = \frac{\frac{\pi}{4} D_{o,\, closure}^{\ 2} \times MEOP}{A_{bearing}} \tag{2}$$

where $MEOP$ is the maximum expected operating pressure, and the safety factor for our graphite nozzle is

$$SF_{bearing} = \frac{\sigma_{bearing,\, yield,\, graphite}}{\sigma_{bearing}} \tag{3}$$

where $\sigma_{bearing,\, yield,\, graphite}$ is the bearing yield strength of graphite.

Shear Stress:

In addition to bearing stress, submerged nozzles also have shear stress along the shear line shown in figure 1. Depending on the thickness of the graphite, the shear line may go from the end of the nozzle to the last O-ring groove, or it may go farther towards the diverging section of the nozzle. The shear area can be found regardless as

$$A_{shear} = \pi \times D_{i,\, closure} \times L \tag{4}$$

where L is the length of the shear line mentioned above. The shear stress is then

$$\sigma_{shear} = \frac{\frac{\pi}{4} D_{o,\, closure}^{\ 2} \times MEOP}{A_{shear}} \tag{5}$$

and the safety factor is

$$SF_{shear} = \frac{\sigma_{shear,\, graphite}}{\sigma_{shear}} \tag{6}$$

where $\sigma_{shear,\, graphite}$ is the maximum shear strength of graphite and σ_{shear} is the shear stress experienced by the nozzle.

Implementation:

In practice, this script intakes a nozzle contour and assumes that the retaining ring will be in contact from the very edge of the nozzle to the casing. It then graphs the thickness of the retaining ring against bearing and shear safety factor. Note that as the thickness of the retaining ring increases, this also implies that the thickness of the material around the nozzle also increases. The script also intakes the last O-ring groove size and position for (4) as well as MEOP for (2) and (5). The compressive strength of graphite is assumed to be 345 MPa and the tensile strength is 76 MPa. The bearing strength is assumed to be approximately equal to the compressive strength, and the tensile strength is assumed to be 1/10 of the compressive strength. The code then loops through (1)-(6) for thicknesses between 0-20mm and saves the safety factors in arrays, plotting them against the thickness values at the end. For a conservative estimate, the shear line length is assumed to be the length from the end of the nozzle to the last O-ring groove only until the ring thickness surpasses 1.5 times the O-ring groove thickness, at which point the shear length is from the end of the nozzle to the point on the converging section of nozzle where the same radius is reached.

Note: In google colab, in order to access the csv contour file, you must upload it to the local directory of the colab file. Click on the file icon on the left side, click the file upload button, and upload the csv to the main directory. If the file does not end up in this location, the reference will cause an error.

References:

1. Sennot, Austin & Sharp, Charles. *How to Design Pressure Vessels, Propellant Tanks,and Rocket Motor Casings.* (2023). https://static1.squarespace.com/static/60d8d9b060e90a67c5c69db4/t/62997fbfa1150834ce0a9556/1654226881895/how+to+design+pressure+vessels,+propellant+tanks,+and+rocket+motor+casings.pdf