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Keywords: Femap, NX Nastran, hydroelectric, thrust collar, thrust bearing, fracture mechanics, thermal loading, static analysis, stress analysis

Main Graphic:

Caption: Hydroelectric Dam Thrust Collar stress, Weld and Fatigue Analysis

Case Study Section: FEA | Stress and Deflection

HYDROELECTRIC DAM THRUST COLLAR STRESS, WELD AND FATIGUE ANALYSIS

Analysis Type: Static Stress Analysis

During the inspection of a thrust bearing at a hydroelectric dam, cracks were observed at the welds of the gussets of the thrust collar. This instigated the inspection of other thrust collars at the facility and similar cracks were noted in each of the thrust collars. It was clear that analysis was necessary to determine the root cause of the cracking in the collars.

No preparation of the gussets or weld penetration is assumed. That is, the load is transferred entirely through the fillet welds. Figure 2 shows how the FEA model was constructed by showing a cutaway of the gusset/bottom plate intersection. The free face of at the bottom of the gusset can be seen because the mesh of the two components is not merged.

The first step was to investigate a variety of load cases to determine the most likely culprits. Excessive interference fit between the shaft and the collar was analyzed using surface-to-surface contact. Dead weight and thrust loads were analyzed using rigid body element (RBEs) and body acceleration loads. Disassembly loads were applied using convective heat transfer. After all loads were analyzed and post-processed, the most likely causes of cracking were investigated further.

To simulate the heating load induced by the torches used during disassembly, a transient thermal analysis was done using convective heat transfer. Although temperatures and film coefficients for the torch could be approximated, the disassembly load cases proved to be scenarios of high interest and a more detailed approach was required. A physical test was performed on thrust collar with the same torch that was used during disassembly; temperatures were recovered using a thermal camera. The physical test was replicated with an FE model and convective heating was applied to the model with a range of both temperatures and film coefficients. The data from the FE model was plotted with the data from the physical testing to determine the combination of film coefficient and temperature that would best simulate the torch heating (see Figure 5).

Through this assortment of modeling and analysis techniques, the root cause of the cracking was determined. This allowed the hydroelectric dam engineers to establish a safe and effective disassembly technique for future thrust bearing designs.

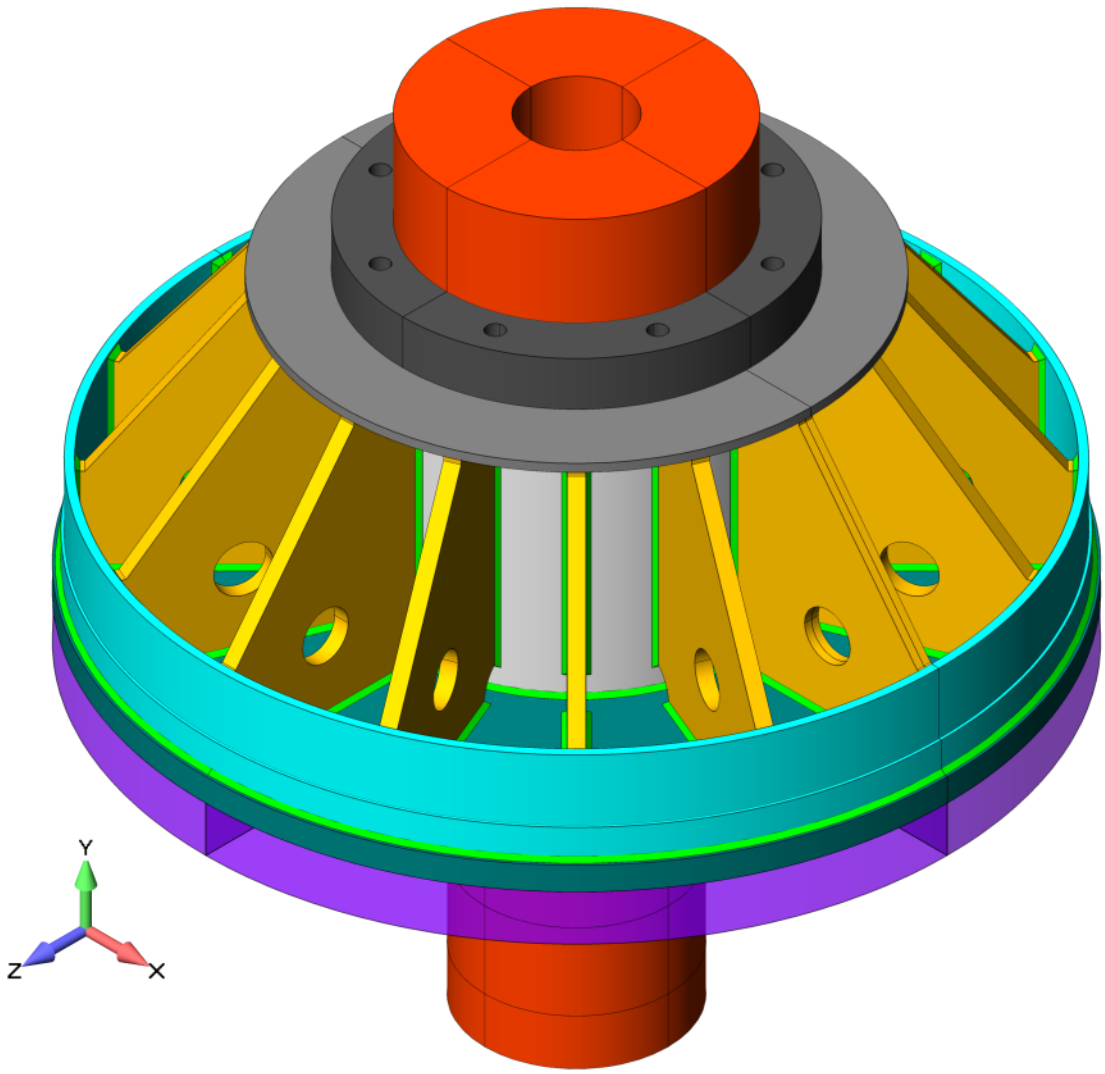

Figure 1: The FE model of the complete thrust collar assembly

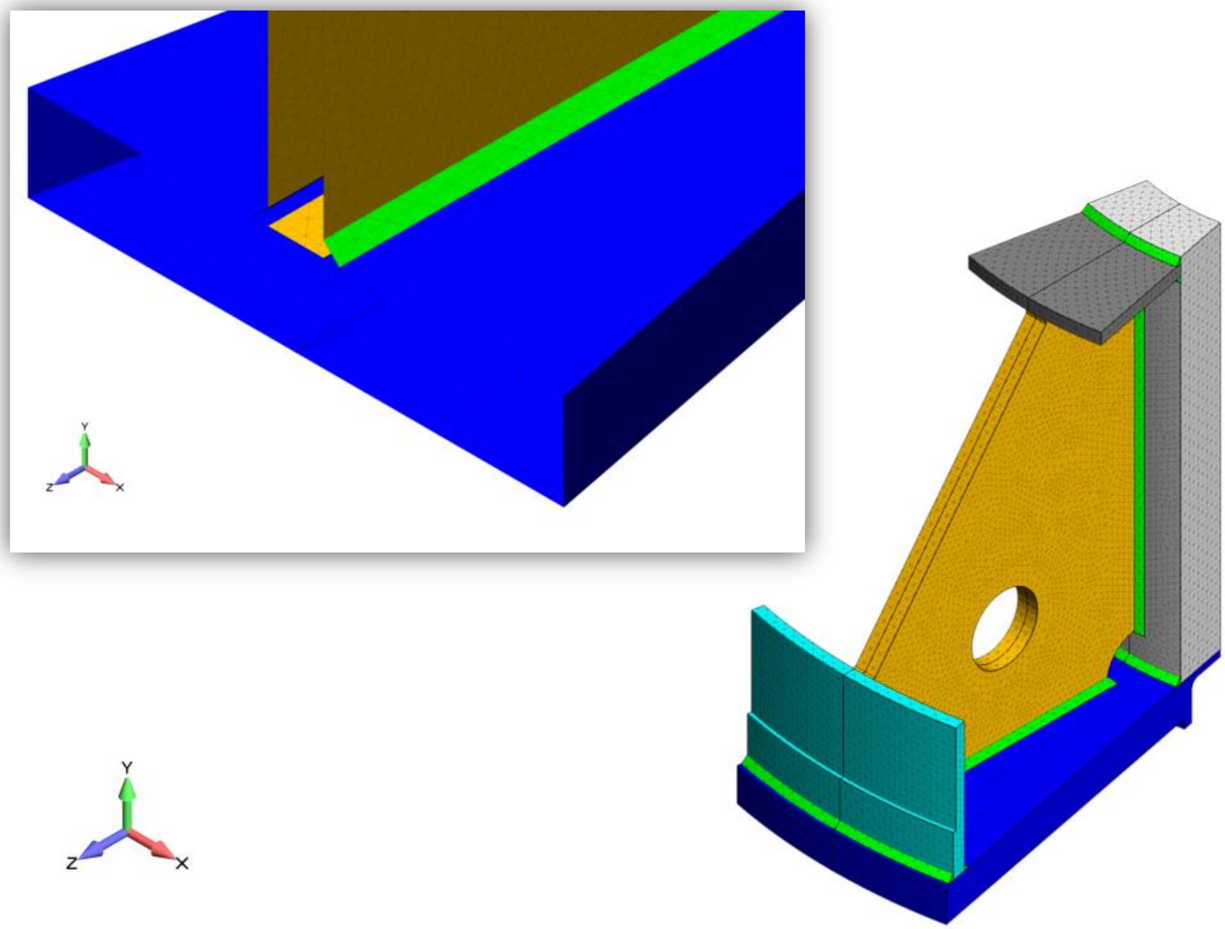

Figure 2: FEA model showing the idealizing of the fillet welds as chamfers

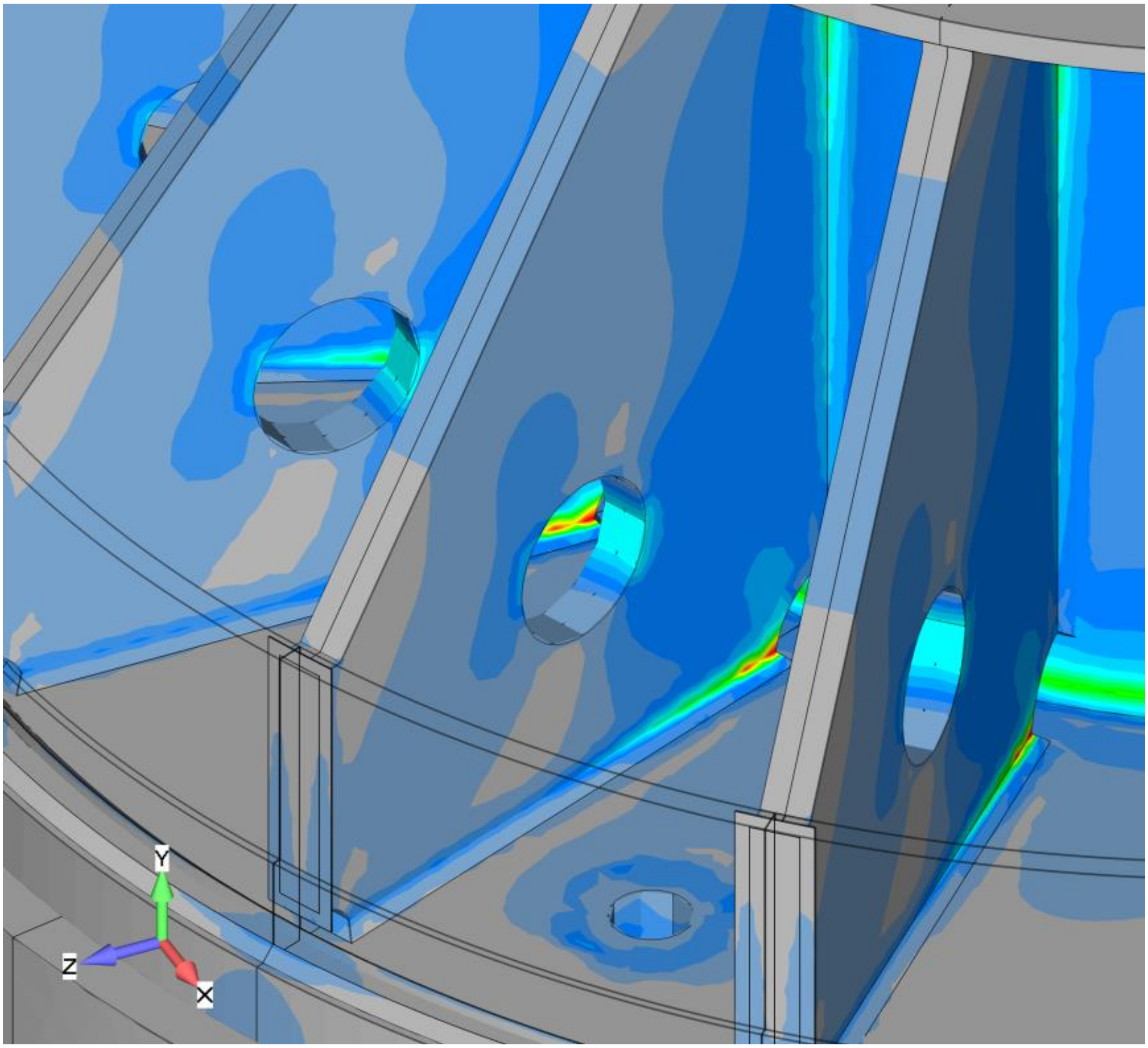

Figure 3: Stress contour of gusset weld region with the outer ring graphically suppressed.

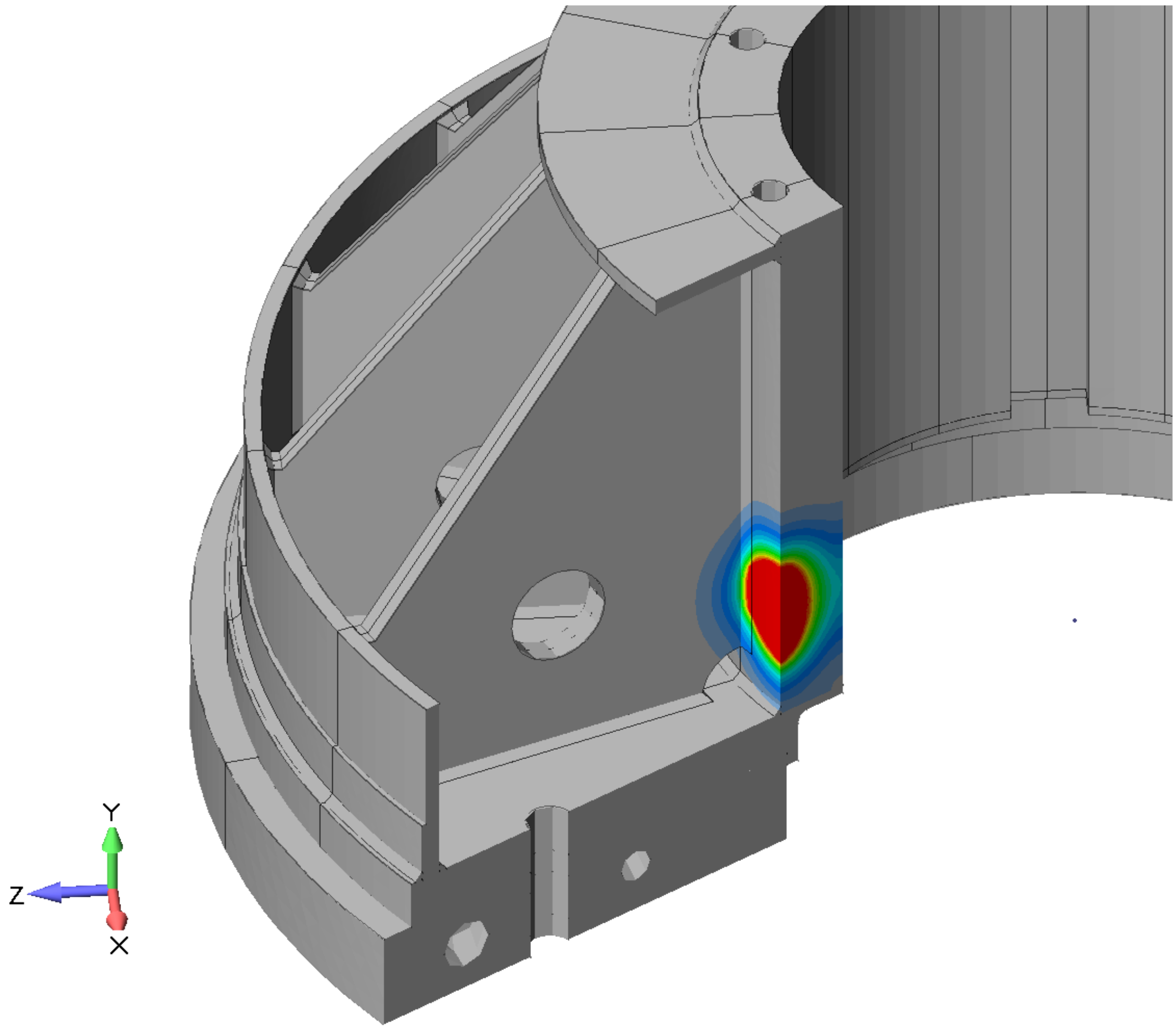

Figure 4: A section-cut showing temperature results at five minutes into heating.

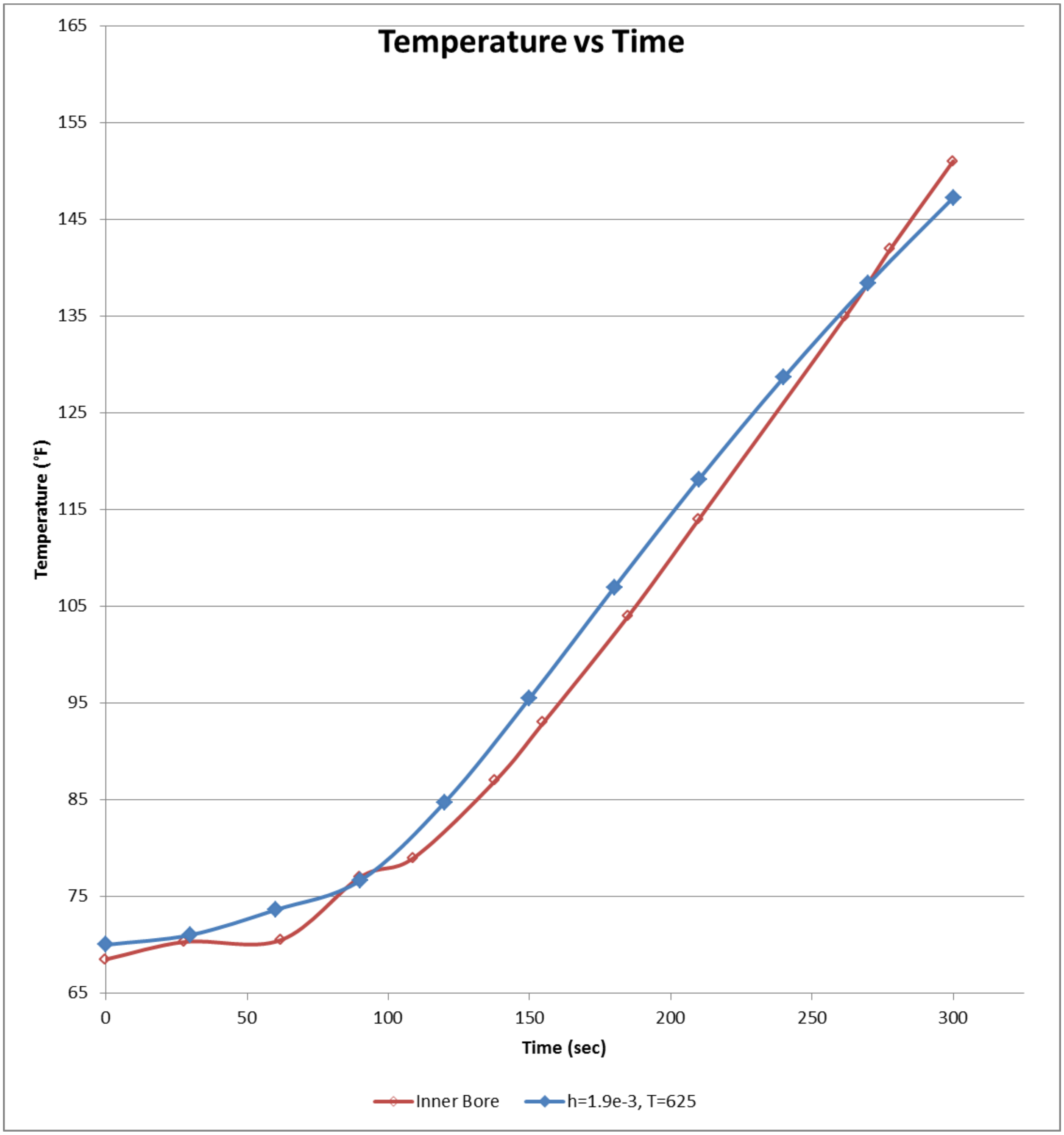

Figure 5: Temperature vs Time plots of the physical test data and the FE model

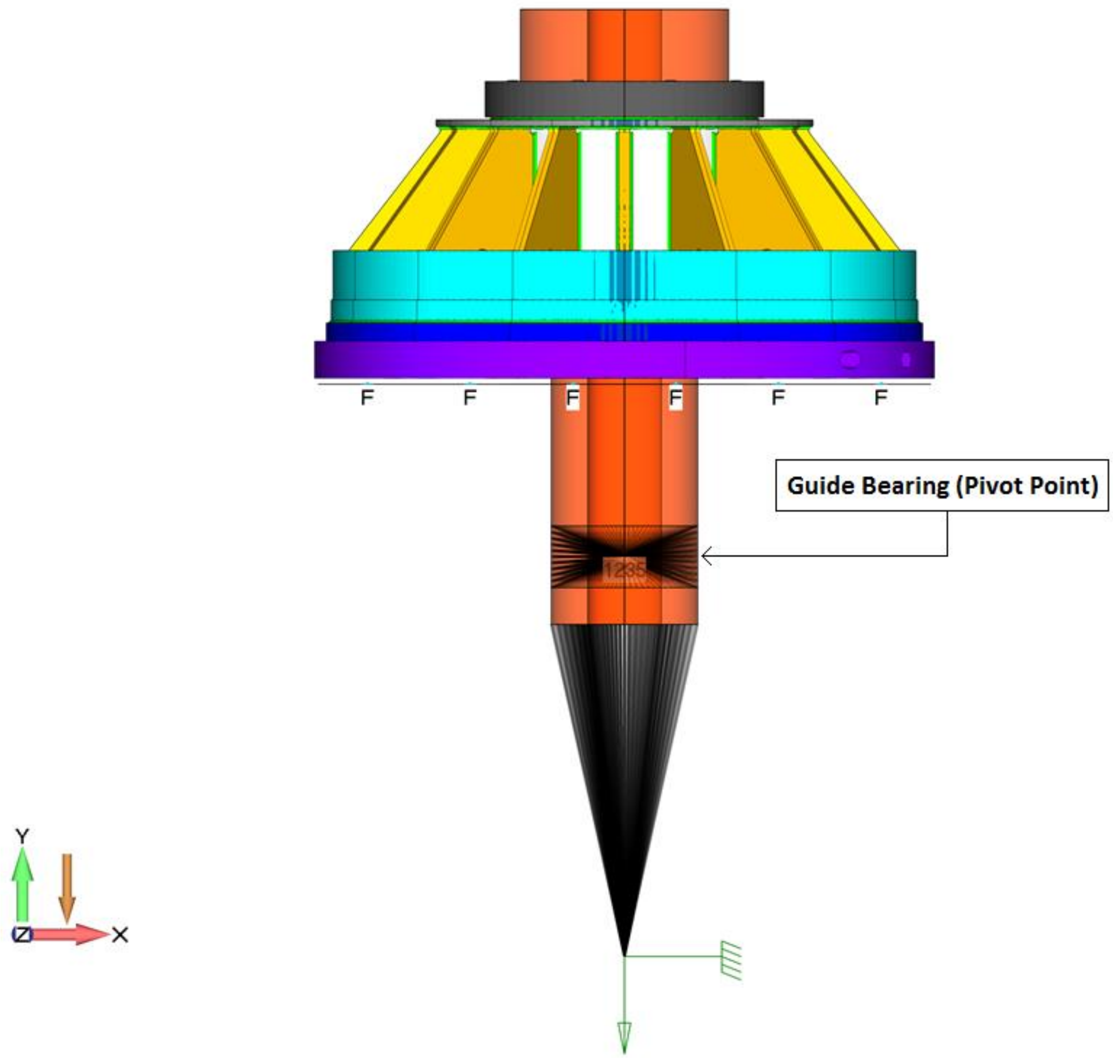

Figure 6: One of the more complex load cases was that for shaft mis-alignment of the thrust collar

In addition to the load cases and combinations described in the SOW, the FEA model was used to investigate the effects of a misaligned shaft. As measured in year xxxx, the shaft varied from its vertical axis by 0.xxx" per foot. The goal of this load case is to conservatively envelope any stresses that might result from misalignment.

The assumptions are:

1.) The thrust runner support is rigid. Any compliance of the thrust shoes, spring bed or foundation is neglected.
2.) The guide bearings are rigid. This assumption means the guide bearings will maintain the shaft in its misaligned position as it rotates.
3.) The thrust collar is level. It is possible that the entire system could be adjusted to match the misalignment of the shaft to mitigate any problems. This analysis assumes a level thrust collar

and therefore, a misalignment delta of 0.xxx” per foot is experienced between the thrust collar and the shaft with every rotation.

To apply this condition to the model, a rigid element (RBE2) was connected to the bottom surface of the FE shaft model for the displacement application. The guide bearing acts as a pivot point and a displacement of 0.0xxxx” was enforced at the independent node of the RBE2. This node is xx” below the center of the guide bearing. This load case is shown graphically in **Error! Reference source not found.**.

$$\frac{xx\ inches}{12\ {}^{inches}/_{foot}} * 0.00xx\ {}^{inches}/_{foot} = 0.xxx\ inches$$

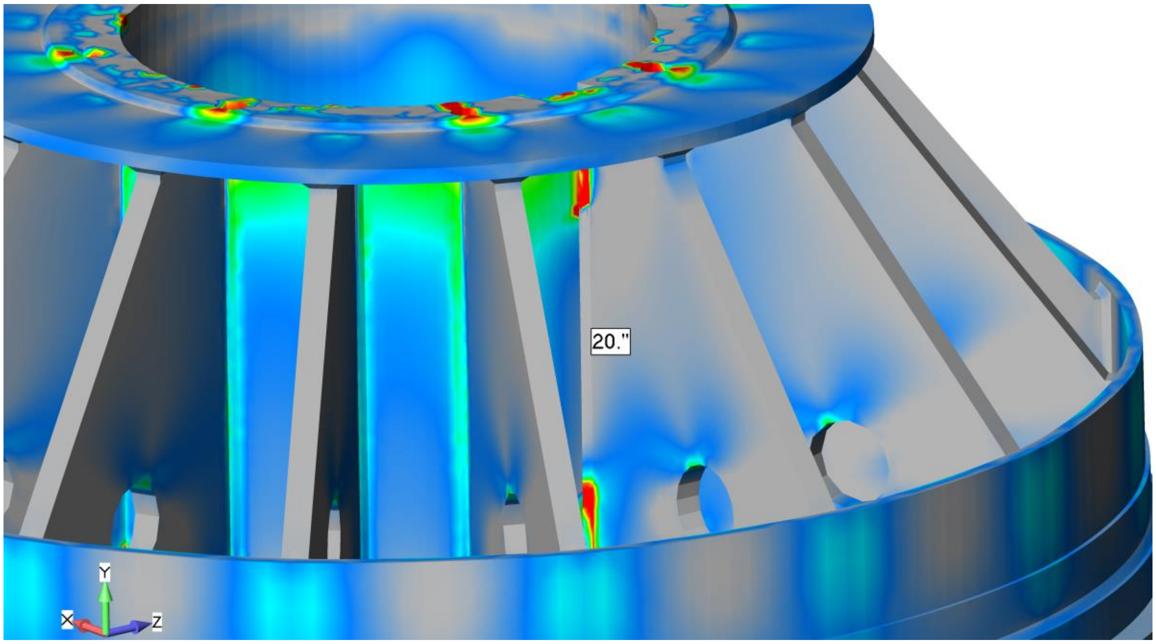

Figure 7: The crack was located in the gusset adjacent to the hub's thrust keyway

Fracture Mechanics and LEFM for Crack Prediction

A crack, 20" long was inserted between the gusset and the hub of the thrust collar. Figure 7 shows the crack inserted into the gusset. The crack runs completely across the gusset at the top and the bottom. The free space between the upper and bottom cracks or the length of the crack is 20".

The stress intensity factor (K_I) was calculated by taking the crack opening displacement at the quarter-node location of the 20-node brick elements using for the crack tip modeling. Details on this procedure can be found in a paper by Laird and Epstein, "Fracture Mechanics and Finite Element Analysis", ASME Magazine, Nov. 1992.

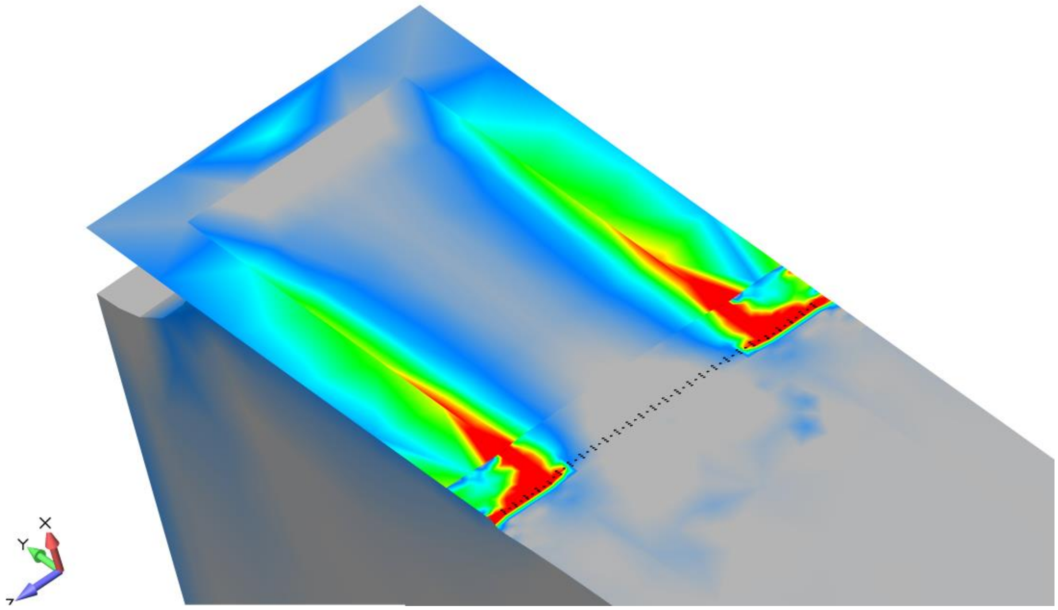

Figure 8: Stresses in the region of the crack tip (upper section of hub)

Figure 8 shows the stresses in the crack section near the upper end of the gusset/hub. Only one end of the crack was modeled for K_I calculation due to the complexity of the modeling technique and the expectation that the K_I would be quite low and therefore, would negate the need for further investigation.

HDR-0813-01 Fracture Mechanics Worksheet

For FEA, we can use this simple formula:

$$K_{I\_FEA} = \frac{E \cdot \Delta y_{qpn}}{4\left(1-\nu^2\right)} \cdot \sqrt{\frac{2\pi}{r_{qpn}}}$$

$$E := 290000000 \cdot \frac{lbf}{in^2} \qquad \nu := 0.3$$

$r_{qpn} := 0.025 \cdot in$ $\qquad \Delta y_{qpn} :=$ [redacted] $\cdot in$

$K_{I\_FEA} := \frac{E \cdot \Delta y_{qpn}}{4\left(1-\nu^2\right)} \cdot \sqrt{\frac{2\pi}{r_{qpn}}} =$ [redacted] $\cdot ksi \cdot \sqrt{in}$

Figure 9: Calculation of K_I based on the QPN method

As given in the calculations within Figure 9 , the K_I = XX ksi√in. This is a nominal value from K_I calculations all along the crack front.

The stress intensity factor calculation is given in Figure 9 as copied out of a MathCAD worksheet, where *E* is the modulus of elasticity, Δy_{qpn} is the displacement of the quarter-point node (qpn) in the direction normal to the crack plane, ν is Poisson's ratio, and r_{qpn} is the distance from the crack tip to this QPN.