Stress In End Fitting Grayloc Connection Due To Flame Heating For Cap Screw Removal

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ABSTRACT

Stress analysis of fuel channel grayloc connection assembly due to the flame heating was performed to evaluate the acceptability of this method of cap screw removal on a contingency basis. In this calculation, the surface of end fitting at the grayloc connection is considered to be heated up from 70 ˚F to 1050 ˚F in 5 minutes.

The thermal and stress analyses were carried out by the finite element method (ANSYS) and sub-modeling near the high stress region for fatigue analysis and stress linearization. The analysis results show that stresses in area of the grayloc connection are higher than 3Sm, therefore some plastic deformation is expected. Since the flame heating is not a recurring event, the residual stress will relax over time. Therefore flame heating is considered as a stand alone ASME Code Level B transient with its stress range and fatigue usage limited according to NB-3223. The cumulative fatigue usage factor from the postulated five cycles of flame heating and the fatigue usage factor from the normal operating condition in Fuel Channel Design Manual (Reference 1) is 0.272.

It is concluded that from stress analysis point of view the flame heating at the rate and range mentioned above is an acceptable method for removal of cap screws.

INTRODUCTION

The torch heating of end fitting surface was usually applied to remove the grayloc bolts during maintenance process. As shown Figure 1, the torch flame heats front and side faces of end fitting. The heating rate is assumed to be such that the temperature heated surface rises from 70 °F (room temperature) to 1050 °F (mark crayon burning temperature) for 5 minutes. However reheating is usually done when the first screw is removed and the second/third screws can't be removed. Therefore the thermal transients are provided up to the second heating.

The thermal and the structural finite element models are constructed for the sequential thermal/thermal analyses. The two models are generally identical except their material properties.

Since cap screw removal during an outage in a depressurized state is a maintenance activity, ASME code rules does not apply. The thermal stresses developed as result of flame heating are secondary stresses and hence there is no pressure boundary integrity concern, rather it is like a Level B transient with fatigue being the concern. Since the flame heating is not a recurring event, the residual stress will relax over time. Therefore flame heating is considered as a stand alone Level B transient with its stress range and fatigue usage limited according to NB-3223.

MATERIAL PROPERTIES

The material properties of components (Figure 1) are as follows

- End fitting — 403 Stainless steel
- Feeder coupling hub — ASTM A-105
- Feeder coupling flange — SA-542 Cr-Mo steel
- Feeder coupling bolting — SA-637 Grade 718 Nickel alloy
- Sealing ring — 410 Stainless steel

The thermal conductivity between contact surfaces is assumed to be 2.9317×10^{-4} (Btu/sec·in^2 ˚F) and the natural heat convection coefficient is determined by assuming the horizontal cylinder as (Reference 2),

$$h = 0.27\left(\frac{\Delta T}{d}\right)^{1/4} \quad \text{(Btu/hr·ft}^2\ ˚\text{F). for laminar flow}$$

The outside diameter of end fitting is 6.6 inch and the temperature difference is assumed to be 600 ˚F. Then the convection coefficient is 3.0×10^{-6} (Btu/sec·in^2 ˚F).

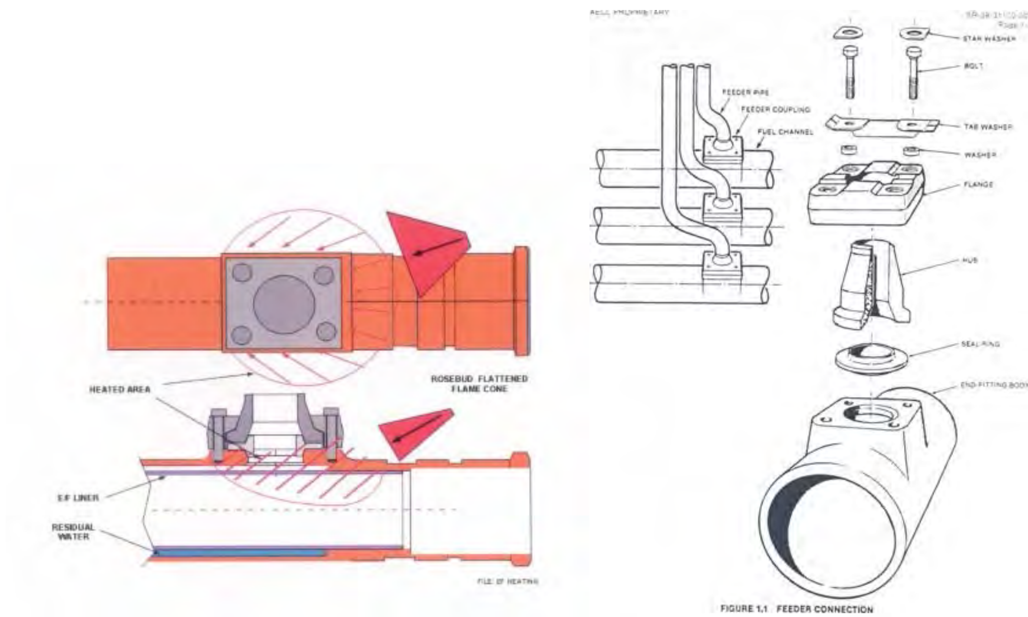

Figure 1 Torch Heating Face and Grayloc Assembly

LOAD

Grayloc assembly is subject to the thermal load and the pretension bolt load (25,000 lbf). However the end fitting is assumed to be practically empty and has no pressure. The following torch heating procedure is applied in the thermal analysis,

1. The front and two side faces of end fitting are heated from 70 ˚F to 1050 ˚F for 5 minutes (see Figure 2).
2. Natural heat convection to air (70˚F) for 15 minutes.
3. Heat up again to 1050 ˚F to remove other bolts.
4. Natural heat convection.

THERMAL AND STRESS ANALYSIS MODEL

The thermal and structural models are geometrically identical to map temperature properly. The element types for ANSYS are SOLID185 for structural model and SOLID70 for thermal model as shown in Figure 2, and the surface-to surface contact elements (CONTACT173/TARGET170) are applied to properly transmit loads/temperature through contact surfaces from the end fitting to flange. Pre-tension element is also used for the bolt pretension load.

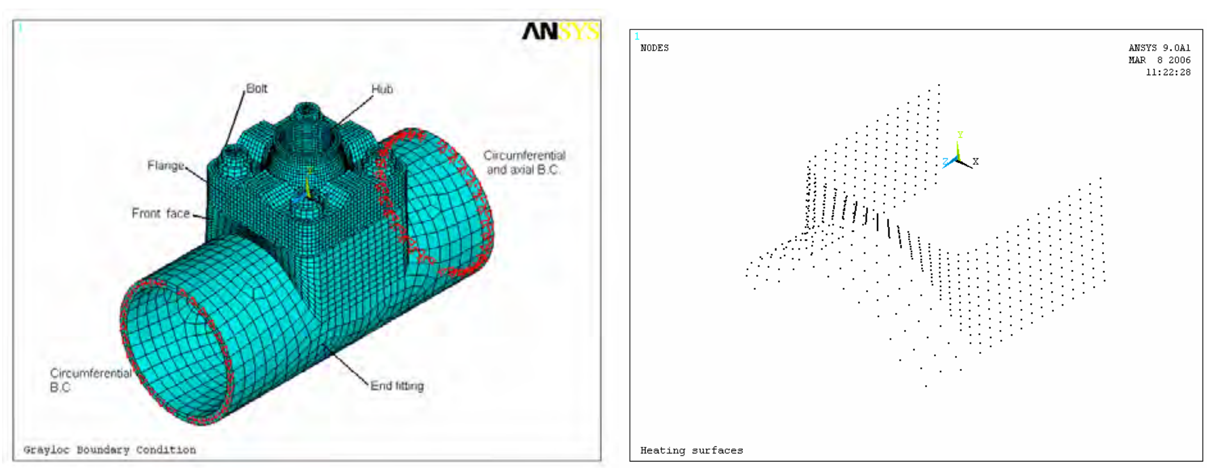

Figure 2 shows the grayloc assembly and the boundary conditions applied at the both ends of end-fitting.

Radial displacement is allowed at both ends of end fitting but the circumferential displacement is constrained. Axial constraint is applied any end, but the distance from grayloc to end fitting end is given such that the boundary condition does not affect to grayloc structural behavior.

DESCRIPTION OF RESULTS

The thermal analysis was carried out for the given flame heating procedure and the temperature distributions shown in Figure 3 are calculated, which shows that heat transfers to hub, sealing ring and flange through contact surfaces.

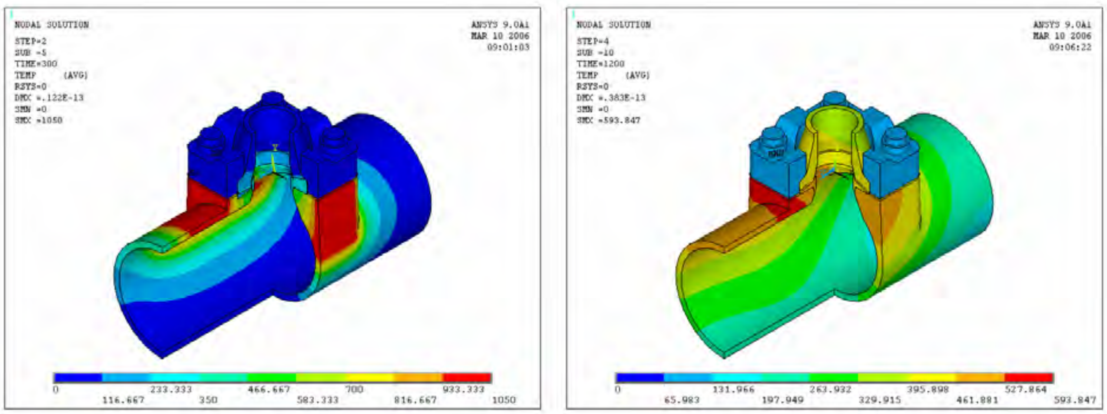

Figure 3 Temperature Distributions

The stress distributions of end fitting at the end of flame heating (300 sec) are shown in Figure 4. The stress contour of end fitting shows some regions (gray color) in which stress intensity is more than the yield strength (62,000 psi at 1100 F) of the end fitting material (SS 403). Therefore the grayloc assembly can be plastically deformed and the residual strains remain after heating.

Stress classification lines are set up as shown in Figure 4 and stress intensities are listed in Table 1. Stress intensities of lines 1, 3, 4 and 6 in hub are higher than its yield strength 17,900 psi. Stress intensity of line 13 below the end fitting side face is also higher than the yield strength 62,000 psi, but they are lower than 3 Sm (47,400 and 87,600 psi)..

The maximum stress intensity, which is the maximum stress intensity range for no initial stress, of end fitting from the original model is 141,467 psi, but the fillet was not precisely meshed and stress concentration can not be determined near weld. As a result, a sub model (Figure 5) having the fillet radius is constructed.

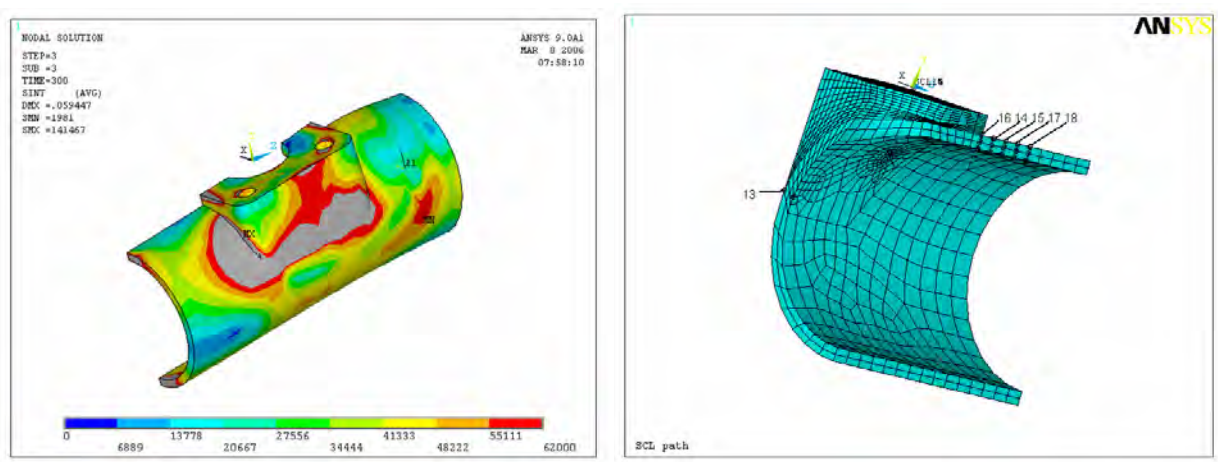

Figure 4 Stress distribution and stress classification lines

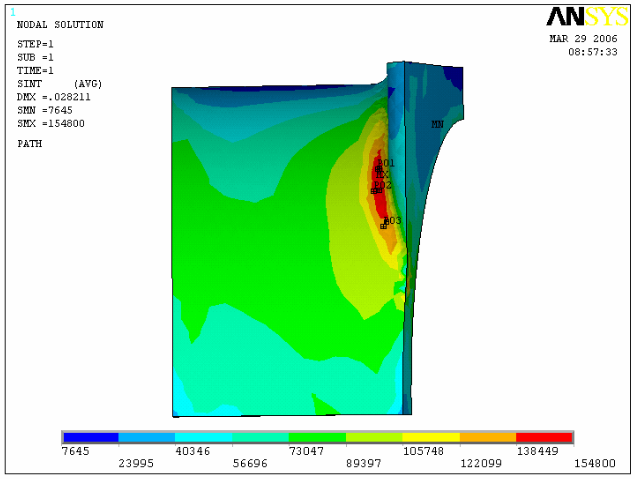

Figure 5 Stress distribution and stress classification lines of submodel

Figure 5 shows the stress contour which is almost same as that of the global original model, and the maximum total stress is 145,300 psi and the stress intensities (P+Q) of three stress classification lines are 121,600 psi, 102,500 psi and 93,750 psi, which exceed 3 Sm, therefore NB-3228.5 was applied for fatigue analysis, and the fatigue usage factor 0.102 is calculated for 150,000 psi , in which the used number of cycles for the flame heating is 5 and stress concentration factor 1.0 is applied.

In Reference 1, the cumulative fatigue usage factor of end fitting was 0.17. Then the cumulative fatigue usage factor including the additional 5 cycles of flame heating is 0.272.

Table 2 Stress Intensities of SCLs (Stress Classification Line)

Component		SCL	PL+PB+Q	(PL+PB+Q) / Sy
Hub	Sy =17,900 Sm=15,800	1	18,400	1.03
		2	11,300	0.63
		3	19,750	1.10
		4	22,930	1.28
		6	36,130	2.02
Flange	Sy =71,900 Sm=32,700	7	37,750	0.53
		8	43,060	0.60
		9	56,920	0.79
End Fitting	Sy=62,000 Sm=29,200	10	40,630	0.66
		11	41,870	0.68
		12	45,620	0.74
		13	63,380	1.02

Note * - Yield strengths (Sy) are at 1100 ˚F. Unit: psi

CONCLUSION

Thermal/stress analyses of grayloc assembly were carried out due to the flame heating. Even the flame heating is a maintenance activity, high stress is expected in grayloc assembly and influenced on its fatigue life.

REFERENCE

1. Design Manual of Fuel Channel Assembly
2. Holman, J.P., Heat Transfer, Third Ed., McGraw Hill, 1972 (see page 219).
3. ANSYS V9.0, User's Manual, Ansys Inc., 2005.
4. ASME Code, Section III, Subsection NB.