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Fatigue Analysis of Acetylene converter reactor

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Abstract: *The structural integrity of mechanical components during several transients should be assured in the design stage. This requires a fatigue analysis including thermal and structural analysis. As an example, this study performs a fatigue analysis of the acetylene converter reactor during arbitrary transients. Using heat transfer coefficients determined based on the operating environments, a transient thermal analysis is performed and the results are applied to a finite element model along with the pressure to calculate the stresses. The total stress intensity range and cumulative fatigue usage factor are investigated to determine the adequacy of the design.*
Keywords: *Fatigue damage factor, FEM, Reactor Pressure Vessel, Smooth Bar Method.*

I. Introduction

An acetylene converter is a Catalytic reactor. The behavior of the catalyst in reactor is with high-pressure and temperature petrochemical processes. Acetylene is a byproduct of modern ethylene production processes, and it acts as a poison to the catalysts used for making polyethylene out of the ethylene product. Due to the above reasons, polymer-grade ethylene product should contain no more than 5 ppm of acetylene. [1]

There are many transients considered in the design stage. Their effect on the structural integrity should be addressed in the licensing documents in the form of a design report. Therefore in this study, an analysis procedure for fatigue analysis is suggested that includes thermal and structural analysis. For the transient thermal analysis, the thermal transient data are simplified to prepare a straightforward input deck. The most severe instances are found considering the total stress intensity range and the stress levels at those times are obtained along with the applied pressure [2]. These values are then used in a fatigue analysis to determine the final cumulative usage factor. Example analyses are performed for the acetylene converter reactor for arbitrary transients, and two acceptance criteria, the peak stress intensity and cumulative usage factor, are investigated.

II. Analysis

2.1 Finite element model

The acetylene converter reactor is considered in this study. It is made of ASME SA-516 Grade60 Class1 material. Flanges are not included in the model in this study, which should be investigated separately in detail.

Two finite element models are developed for a transient thermal analysis and a structural analysis using software. For the thermal analysis, 2-D thermal solid elements are used in the reactor vessel. This element can be used as an axisymmetric element with 2-D thermal conduction capability. It has eight nodes with a single degree of freedom, the temperature, at each node [3]. Six elements exist in the radial direction of the shell to represent the profile of the result in a manner suitable for generating sufficient information in the ensuing analysis.

For the structural analysis, 2-D structural solid elements are used, as shown in Figure 1. These types of elements are used for the 2-D modeling of solid structures. They can be used as axisymmetric elements [3]. An element in this case is defined as having eight nodes with two degrees of freedom for each node; these are the translations in the nodal x and y directions. Symmetric boundary conditions are imposed at the center nodes of the upper and lower heads. In addition, one node is fixed in all directions so as not to generate rigid body motion.

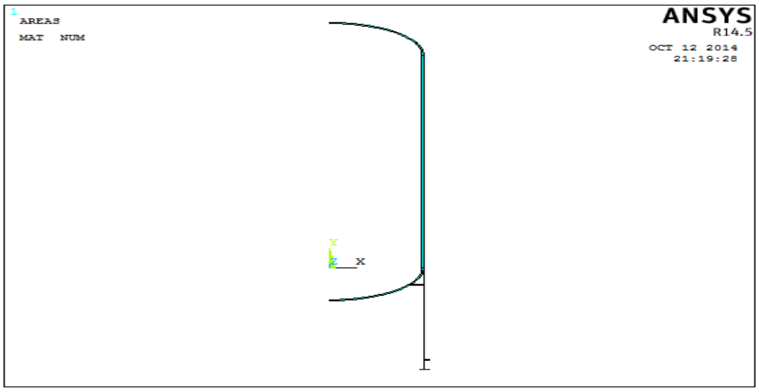

Fig. 1 Axisymmetric model of a reactor pressure vessel

2.2 Loading Cycle

Several transients are considered in this study, as start-up and regeneration. These are arbitrarily chosen for the fatigue analysis. The typical pressure and temperature history for the plant regeneration processes is shown in Figures 2.

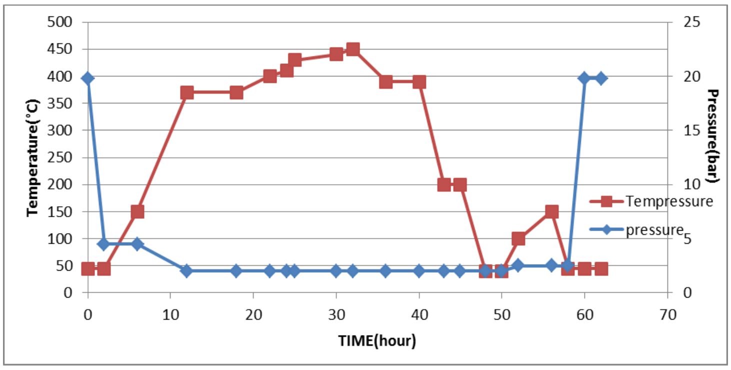

Fig. 2 Pressure and Temperature Histories of the Regeneration Process

2.3 Thermal analysis

To obtain the temperature distribution in the shell and head of the vessel and skirt, transient thermal analyses are performed for each transient defined previously. In this analysis, temperature versus time graph of reactor is given as temperature loading. As heat is transferred from solid structure into insulation and that heat is transferred from insulation to atmosphere by convection. Near a vessel skirt juncture, heat is transferred by radiation. Temperature Distribution near Skirt to Head Juncture is shown in figure 2.

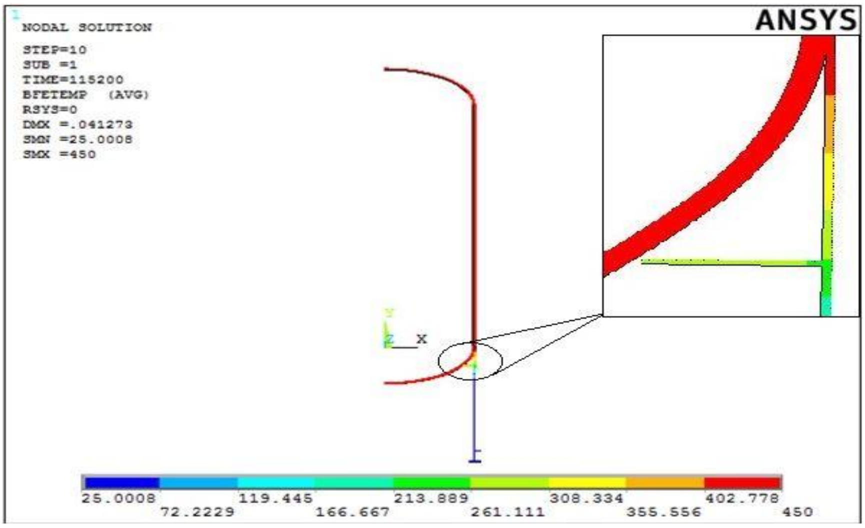

Fig. 2 Temperature Distribution near Skirt to Head Juncture

2.4 Stress analysis

In this analysis, for this model Pressure versus time graph is applied as pressure loading and temperatures from thermal analysis browsed for every sub –step. Model is designed in axisymmetric. Stress results are shown in figure 3. for regeneration cycle.

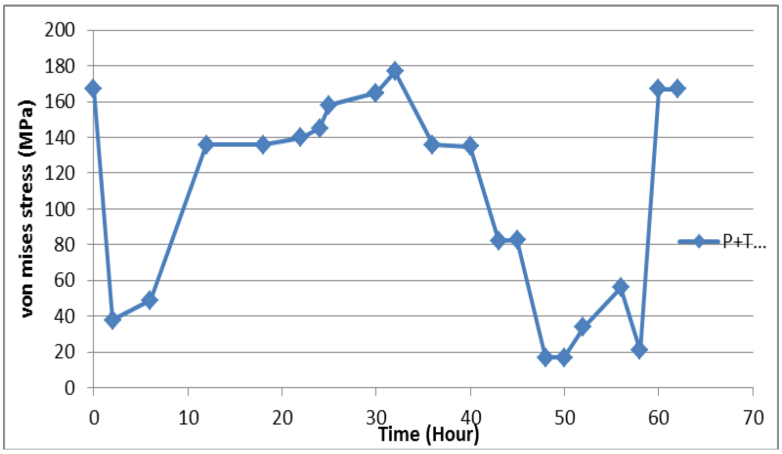

Fig. 3 Stress versus time plot

III. Fatigue Assessment

Cycle counting is used to summarize (an often lengthy process) irregular load-versus-time histories by providing the number of times cycles of various sizes that occur. The smooth bar method is used in this study. The total stress at each peak stress locations was read directly from the finite element output and is taken as the equivalent stress range $\Delta S_{p,k}$for the component [4].

3.1 The alternating stress

The effective alternating equivalent stress amplitude ($S_{a)}$ is calculated for the cycle using the equivalent stress range $\Delta S_{p,k}$for the component. The Poisson correction factor, $K_{v,k}$need not be used if the fatigue penalty factor, $K_{e,k}$, is used for the entire stress range (including $\Delta S_{LT,k}$)[5]. Hence the alternating stress is given by following equation

$$S_a = \frac{K_f * K_{e,k} * \Delta S_{p,k}}{2}$$

3.2 The permissible cycle

To calculate the permissible number of cycles, N_k, from the alternating equivalent stress computed, using the fatigue curves provided in Annex 3.F.[5]

The allowable number of cycles for each component is calculated using Equation (3.F.1)[5]

$$N = (10)^X$$

Where,

$$X = \frac{C_1 + C_3Y + C_5Y^2 + C_7Y^3 + C_9Y^4 + C_{11}Y^5}{1 + C_2Y + C_4Y^2 + C_6Y^3 + C_8Y^4 + C_{10}Y^5}$$

$$\mathrm{Y} = \left(\frac{S_a}{C_{us}}\right)\left(\frac{E_{FC}}{E_T}\right)$$

E_T= the material modulus of elasticity at the cycle temperature

E_{FC}= the modulus of elasticity used to establish the design fatigue curve

C_{US} = 6.894757 for units of stress in MPa. (Conversion factor)

For the vessel materials of construction, the coefficients C_i and the modulus$E_{FC}$are taken from the Smooth bar fatigue curve for carbon steel $\sigma_{uts} \leq$ 552 MPA are listed in table 3.F.1.[5]

Table 1 Allowable number of cycles, N_k

Component	Location	E_T(MPa)	E_{FC}(MPa)	$S_{alt,k}$(MPa)	X	N_k(cycle)
Skirt	Skirt ring at inside corner	190E03	195E03	106.2	5.414	2.59E05

3.3 Calculation the fatigue damage factor

The actual number of repetitions of the cycle is set to the cyclic life requirement provided in the User's Design Specification, 20000 cycles. The fatigue damage for the is then calculated by

$$D_{f,k} = \frac{n_k}{N_k} \leq 1$$

This result in calculated fatigue damage for limiting region (Skirt ring at inside corner) is 0.077. The fatigue damage is well below the allowable level of 1.0, satisfying the requirement.

IV. Conclusion

For a transient thermal analysis, the thermal transient data are simplified to prepare a simple input deck. The most severe instances are found considering the satisfaction of total stress intensity range, and the stress levels at those times are obtained along with the applied pressure. These values are then used in the fatigue analysis to determine the final fatigue damage factor.

Example analysis of the acetylene converter reactor is performed for postulated arbitrary transients and generating the following conclusions:

- The fatigue damage factor is well below the allowable level of 1.0
- The major contribution to the fatigue usage factor is temperature variations during transients.
- No effect of pressure loading on the fatigue factor arises inside of the vessel.
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