KNIGHTHAWK TECH NOTES

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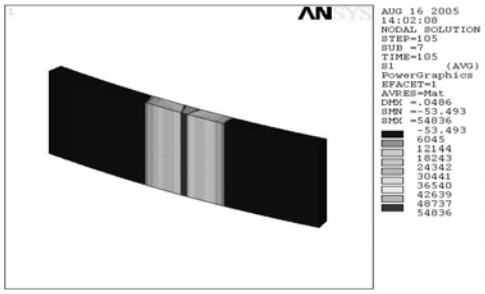
December, 2005 ***Issue 05.02***

"Residual Stress—It's Everywhere"

Your reactor has just failed and once again you are in another meeting where the focus is on a weld. You have just heard from your welding experts that the welds in your reactor were found to be good and the welding procedures were done in accordance with the specifications. The pressure vessel experts say that the design is good and there are no indications of process problems. Metallurgists speculate on all sorts of theories on what could be the cause. In any case, it has failed and you really don't have a good explanation. All you really know, is that it has always failed in the weld area and the operation is a critical high pressure high temperature reactor. You also observed that cracking always appears on one spot on the reactor. How do you find the answer?

Residual weld stress is always a concern for static and rotating equipment. The welding operation can be perfect, including any subsequent stress relieving, but there is always residual stress unless the specimen is heat treated with processes such as solution annealing, which typically cannot be done in place. The efforts also affect the original heat treatment in the parent metal. One way of looking at the problem is the incorporation of a non-linear plastic analysis. Numerical techniques have been developed and validated to look at the residual strain that is left from the welding operation. To accomplish this, the weld is modeled as it is actually made from cold to hot, including the molten aspect of the problem. It is highly non linear and requires knowledge



of the welding operation and residual effects. These numerical techniques have been validated by research work at national laboratories and universities. The model involves a transient heat transfer that serves as the heat load for the transient plastic structural models. These models can establish accurate strain in the heat effected zone and can be evaluated along with the normal process load.

In applications that experience low cycle thermal fatigue or stress rupture conditions, these models can provide insight on the failure and provide a methodology for strategically locating welds in reactors. The general methodology is as follows:

1. Develop and research material properties for the non-linear analysis.
2. Perform the transient heat transfer analysis.
3. Execute a non-linear plastic structural model involving phase change.
4. Incorporate stress relieving as necessary.
5. Execute the problem with the initial strain from the welding operation
6. Perform a Code Assessment.
7. Evaluate the results with and without the residual strain for comparison.

These techniques have proven to be useful in critical applications where materials are pushed to the limits in both rotating and static equipment. Like always, all work should be evaluated and approved by a professional engineer competent in this specialty area.

Cliff's Notes:

KHE is an excellent resource when evaluating residual weld stress in static and rotating equipment. We have developed and executed complex non-linear plastic problems for industry in many applications. In addition, we have conducted research in residual weld stress areas for major corporations.

KnightHawk is wrapping up an exciting 2005 and we are looking forward to 2006. In November we are happy to welcome Ed Silver, PE to our staff as Process Group Leader. Ed's 35 year career spans from production to engineering. Ed will focus heavily on the process analysis and in particular process troubleshooting and performance analysis of static and rotating equipment.

Most of all I would like to wish everyone a Merry Christmas and Happy New Year. We thank you for all you business and wish you all the very best.

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KnightHawk Project Update

- Critical Pipe Stress – Crack Gas – Petrochemical
- Structural Dynamics – Acoustic – Nuclear
- Level 3 Reactor Fit For Service – Petrochemical
- Level 3 Waste Heat Boiler Fit For Service – Petrochemical
- Rotordynamics – Motor Compressor Train – Refinery
- Turbine Generator Wreck – Power
- Polymer Gear Pump Failure Analysis – Petrochemical
- Tower Tray Analysis – Petrochemical
- Polymer Heat Exchanger – Petrochemical
- Boiler Failure – Power
- Structural Dynamics – Off Shore
- Residual Weld Stress – Non-linear Plastic Analysis - Petrochemical
- Waste Heat Boiler Failure Analysis and Redesign - Petrochemical
- Emergency Hot Tap – Level III Analysis - Petrochemical
- Valve Design Troubleshooting – Off Shore
- Waste Heat Boiler Failure Analysis – Petrochemical
- Process Transients Field Data Acquisition – Petrochemical
- Reactor Design Optimization – FEA - Petrochemical
- Steam line fluid dynamics —CFD—Nuclear
- Vibration Screw Compressor - Petrochemical
- High Pressure Flange Design Riser – FEA – Off Shore
- Ethylene Crack Gas Cooler – Fit For Service – Petrochemical
- Heat Exchanger Vibration – Petrochemical
- Structural Vibration – Petrochemical
- 100 MW Gas Turbine Failure – Power
- 150 MW Gas Turbine Failure – Power
- Nonlinear Membrane Bladder – Nonlinear FEA – Equipment Mfg
- Compressor Vibration Study - Petrochemical
- Gasifier Reactor Redesign – Petrochemicals
- Steam Turbine Failure - Power
- Boiler Failure analysis – Petrochemical
- Non Linear FEA - Petrochemical
- Structural Dynamics – Rotating Equipment – Petrochemical