Introduction

One of the most important operations in hydrocarbon refining is a process known as fluidized catalytic cracking (FCC). A special type of slide valve controls the catalyst flows. Typically, these valves are installed in refractory lined piping approximately five feet in diameter and weigh 20,000 pounds. Operating temperatures inside the valve range from 900 to 1,400 °F. Occasionally, temperatures go as high as 1,800 °F for brief periods, called excursions, or short term upset conditions.

Catalyst control slide valves are designed for extended service life, with no unscheduled maintenance. Slide valve repairs and/or replacement requires shutting down the FCCU; and lost revenue from unscheduled down time and maintenance is exorbitant, totaling millions of dollars. In addition, cooling the FCCU equipment for access and heating back up to operating temperature adds days to the down time.

Challenge

Recently, a major Houston-based slide valve designer and manufacturer, Tapco International, approached one of Houston’s leading independent engineering firms, BES Engineering, with a new patented design. The Tapco BOLT-LESS (welded) valve design eliminated structural bolts in favor of an all-welded design. BES Engineering was asked to perform a stress analysis to determine the stresses due to steady-state and transient heat transfer, and to evaluate those stresses based on criteria for stress intensity, fatigue and creep-fatigue interaction.

The Tapco BOLT-LESS, or welded, slide valve will be used for introducing catalytic material in oil and petrochemical refineries.
demonstrated through analysis that the Tapco valve design exceeded the very stringent creep fatigue requirements."

The valve design, analyzed by BES, was constructed of carbon steel, stainless steel and refractory. The valve body was one-inch thick carbon steel. The designers and engineers were concerned most about thermal stress, fatigue, and creep fatigue interaction in the stainless steel internal support cone.

The bolts caused the biggest problems with the traditional slide control valves. The trade name of the new design specifically indicates that the bolts are gone. Dana E. Petroni, BES principal engineer, explains why:

"Over the years severe heat stresses build up in the valves. FCCU equipment cycles between 900 and 1,400 °F periodically, plus occasional excursions as high as 1,800 °F. At 1,800 °F, stainless steel’s load carrying capacity is compromised severely. Because of the accumulated heat stress, fatigue, and creep-fatigue, the bolts creep, eventually lose their pre-load, and can not maintain a tight seal."

Solution

The BES analysis focused on the connections of these components, namely those between the cone to body and the cone to orifice plate. The bimetallic welds of stainless to carbon steel and two bolt locations also were analyzed.

The work was done with ANSYS Professional from ANSYS Inc. of Canonsburg, Pa., U.S.A. At BES, ANSYS Professional was interfaced to the Pro/ENGINEER mechanical CAD system from Parametric Technology Corp., Waltham, Mass.

Modeling and Data Transfer Challenges

Modeling and data-transfer challenges confronted Gray and Petroni, as the work got under way. ANSYS Professional solved both issues. The modeling challenge was the need for second-order elements, specifically the iso-parametric and degenerated forms of the 20-node brick elements (SOLID95). With their characteristic mid-side nodes, these are usually more accurate than first-order elements when dealing with applications of stress.

"Both steady state and transient thermal analysis, including modeling the steel and the refractory, determines the temperature distribution within the valve," Petroni observes. "A linear stress analysis determines the stresses and strains within the valve due to the temperature gradients in addition to the mechanical loads."

"One big advantage with ANSYS over low-end analysis software packages is that ANSYS has second-order elements and the latter do not," Petroni pointed out. "Second-order elements are necessary for accurate results for this kind of problem due to model complexity requiring the use of degenerated brick elements in some regions. In fact," he added, "the ANSYS Help menu informs the user that tetrahedron forms of the first order brick elements (SOLID45) are not recommended for stress analysis."

The valve model used three-dimensional 20-node brick elements (SOLID95). The model also used degenerated versions of this element, 15-node prisms, 13-node pyramids and 10-node tetrahedrons. The data-transfer challenge was the need to transfer nodal temperatures to the stress model. A single model sufficed for both thermal and stress analyses but a modification was required between the analyses. There were 210,000 elements in the thermal model. The stress model required only the valve’s carbon and stainless steel elements. Without the refractory, the stress model was reduced to 125,000 elements.

"Because they have no stiffness, and therefore, no load carrying capacity, the refractory portion of the model was not needed in the stress analysis," Petroni explained. "Leaving any unneeded elements in an analysis extends run time and increases file size requirements. The ideal solution would be to deactivate, via a KILL command, the unneeded refractory elements. Unfortunately, ANSYS Professional does not have the KILL feature and physically removing these elements prevents the smooth transfer of nodal temperatures from the thermal analysis to the stress model."

The solution to the problem was to find a way to transfer nodal temperatures between the thermal and stress versions of the model without using a KILL feature. Petroni solved this with the ANSYS Parametric Design Language (APDL). Using APDL macros, nodal temperatures were transferred cleanly.
and quickly between the two versions of the model. Run times shrank and file size requirements were reduced for the stress model.

Starting at the Low End

Gray and Petroni did not start the valve analysis with ANSYS. Instead, they began with a 2-D axisymmetric model of the valve. This was done with a low-end, limited functionality finite element modeling and finite element analysis package (FEM/FEA).

“Proper design of valves is based on stress and distortion criteria,” Petroni explained. “The axisymmetric work showed that the stress criteria was satisfied. However, a 2-D axisymmetric model does not show how the displacement varies around the circumference of the orifice opening. This is due to non-axisymmetric features of the valve,” he continued, “and could change the stress results where the components are welded into place.

“The distortion criteria relates to the differences in vertical displacement in the orifice opening,” Petroni continued, “due to non-axisymmetric features of the valve. We needed to see the vertical displacement under the combination of mechanical and thermal load.”

A 3-D solid model is required, in order to accurately model the non-symmetric features. However, when the solid model was created using the low-end package, it was discovered that temperature dependent properties could not be inputted properly (in the new software version), and the transient thermal model would not run at all. Additionally, the stress runs for the steady state version took 40 hours to finish.

The decision was then made to re-build the 3-D model in ANSYS in order to obtain transient thermal results. Both steady state and transient thermal results were obtained and subsequent stress runs were made in order to verify the results obtained from the 2-D axisymmetric model.

Load Cases and Analysis Runs

BES studied a cold-wall type valve, so called because the valve body temperature is maintained under 650 °F by refractory. In the thermal analysis, five load cases were considered. The internal thermal load was applied as a convection boundary condition to the exposed refractory and stainless steel surfaces.

Four transient thermal analyses determined a temperature profile in the valve at any given time. These profiles, in turn, became the thermal loads for the stress analysis. To get the necessary stress results, mechanical loads were applied in combination with nodal temperatures.

The analyses were done with PCs using a 500MHz Intel Corp. Pentium III CPU and the Microsoft Corp. Windows NT operating system. “The result files for the stress analysis were 250 megabytes (MB) per load step and the database for the model was 400 MB,” said Petroni. “Time required to run the stress models was three hours per load step.” Petroni used the ANSYS pre-conditioned conjugent gradient (PCG) solver because it is much faster than frontal solvers sometimes used for these problems. “PCG is an iterative solver even though the analysis was linear and did not require stiffness iteration,” he noted.

“Frontal-type solvers require the formation of a triangularized stiffness matrix. The formation of this matrix typically represents about 90% of the run time,” Petroni said. “For a model of this size, the file size requirement for this matrix would be about 45 gigabytes (GB) – that exceeds the workstation’s capacity.”

These load steps would have taken 40 hours each to run on the low-end FEM/FEA pack-
age. Gray pointed out that low-end packages tend to “bog down” networks because their software is so much more I/O intensive than ANSYS.

Benefits

Had BES not moved to ANSYS Professional, meeting customer demands could have become very difficult with steadily increasing business loads. “The old software package would have been costing us 10% to 15% in simple efficiency, just in getting work out,” said Gray. “Efficiency is not a simple linear progression with run times because obviously, we would be doing other things while we were waiting for the runs. Still, that means we would not be able to get projects out the door if we had to rely on that software,” he added. “About 60% of the jobs we get in here are ‘on fire’.”

There is a four-fold difference in price between ANSYS Professional and the low-end package. Because of the big price differential, Gray and Petroni studied the return on investment (ROI) for ANSYS Professional:

Significant gains in efficiency. Says Petroni: “If we had to wait 40 hours for results with low-end packages, the issue is time wasted waiting for results. We can’t do anything on the model during a run, therefore, efficiency is lost due to stop-

pages. This is because low-end packages have limited solver options. ANSYS Professional gives you a wider choice of solver options.”

Credibility with customers. Said Gray: “The ANSYS reputation helps us gain business. Low-end packages have a reputation of being cheap and hard to use, deservedly so. Our long-term customers like the fact that we use ANSYS because it is thorough and we get their work done on time.”

In conclusion: The analysis verified and proved the Tapco BOLT-LESS (welded) valve design compared with previous “bolted” valve designs. The new design potentially saves clients hundreds of thousands of dollars, compared to the previous “bolted” valve designs, by eliminating unscheduled shutdowns and unexpected required maintenance.