

COOL CUSTOMER

Design optimization demonstrates the ability to reduce engineering time and increase fatigue life of refrigerant lines on a new generation of scroll chillers.

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Preventing fatigue failure of copper refrigerant lines that connect compressors to condenser coils is a critical aspect of designing a new scroll compressor chiller configuration. Traditionally, R&D teams use a combination of physical testing and conventional finite element analysis to qualify the lines, especially to identify and correct resonances that could cause a reliability problem. But this approach is too slow to address chiller designs that have more than 100 refrigerant-line configurations. Trane has developed a new automated workflow capable of developing robust designs. The methodology combines design of experiments, response surface modeling and numerical optimization algorithms to configure refrigerant lines to minimize stress at running speed. The automated workflow uses ANSYS software combined with Optimus parametric optimization tools to evaluate 10 design alternatives and tune the refrigerant line geometry until operating stresses are below the endurance limit — all in the time once required to analyze just one design.

Trane is the world's leading producer of commercial and light commercial scroll air-cooled chillers that are used for air conditioning, process cooling, refrigeration, dehumidification and other applications. The company's line of chillers includes single-scroll compressor configurations under 15 tons



▲ Trane chiller

up to tandem compressors over 60 tons. The refrigerant lines are sized to survive long periods of near-continuous operation in an environment that teems with strong vibrations generated by compressor cycling. Lines that are configured with a resonant frequency away from the operating frequency of the compressor have a substantially longer fatigue life. Each line's resonant frequencies depend on the details of its geometry, such as overall length, bends and bend radii. The geometry of each line is, in turn, constrained

by the need to avoid obstructions, such as equipment and other lines.

EXISTING MANUAL PROCESS

The refrigerant lines for scroll chillers are designed using a combination of finite element analysis and physical testing. Dynamic finite element analysis is performed to predict the amount of stress generated by a unit of motion. Then the compressor is run to determine the maximum motion actually experienced by the line. These tests are time consuming

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because they have to be run at a wide range of speeds under several configurations to be certain of exciting all of the resonances in each line at its peak. The motion observed in the test is used to scale up the stress seen at unity motion to predict actual stress on the line.

If the stress exceeds the fatigue limit, then the line has to be redesigned. The general approach is to reduce resonant frequency of a refrigerant line by increasing its mass and reducing stiffness. Likewise, to increase resonant frequency, the team reduces the mass and increases the line's stiffness. Each time the design is changed, a new analysis iteration is performed. This is a tedious process; traditionally, it relied heavily on the experience of the engineer.

NEW-GENERATION CHILLER INCREASES DESIGN CHALLENGE

Creating a newer generation of scroll chiller that delivers higher performance while greatly increasing the number of configurations creates a major challenge. Current traditional analysis methods

would greatly increase the amount of physical testing required and lengthen the product introduction schedule. Trane looked into developing an alternative approach: utilizing an optimization tool to automate a simulation workflow that evaluates potential resonance issues and iterates toward the most favorable lower-stress solution.

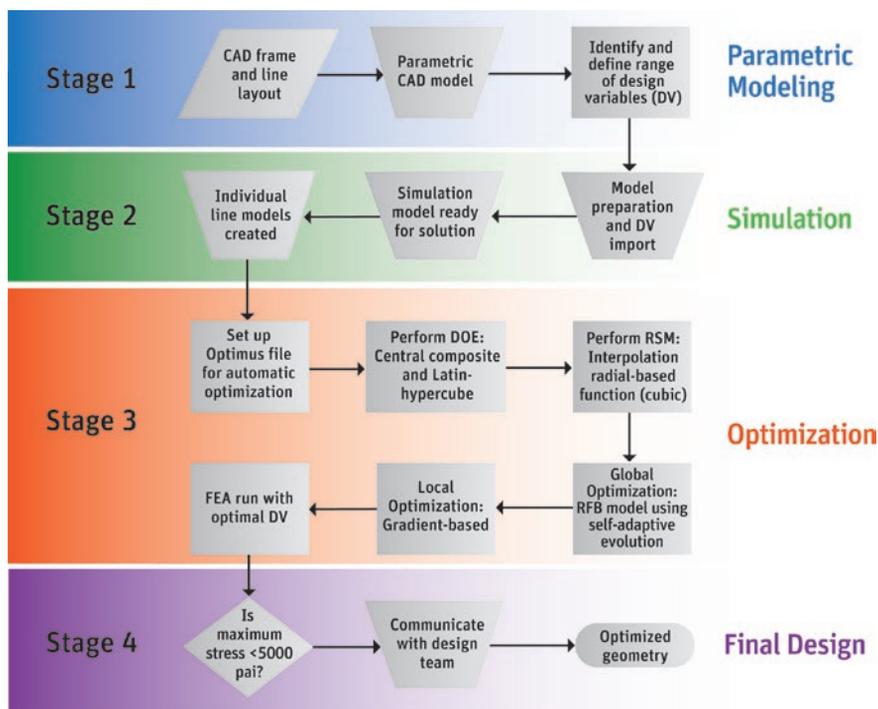
Trane worked with Optimus® from Noesis Solutions, a process integration and design optimization solution that bundles a collection of design exploration and numerical optimization methods. Optimus is tightly integrated with ANSYS Workbench, enabling the user to directly interact with Workbench design parameters and analysis results. Rather than manually defining substitution and extraction rules of design parameters and analysis results, the user simply drags and drops the Workbench icon into Optimus' graphic workflow editor. By visually formalizing the refrigerant lines simulation process in the workflow editor, Optimus establishes direct and automatic interfacing with ANSYS Workbench.



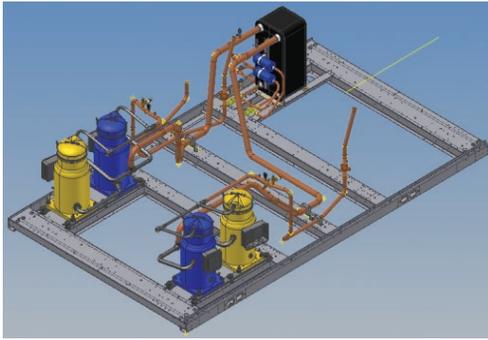
▲ Typical refrigerant lines



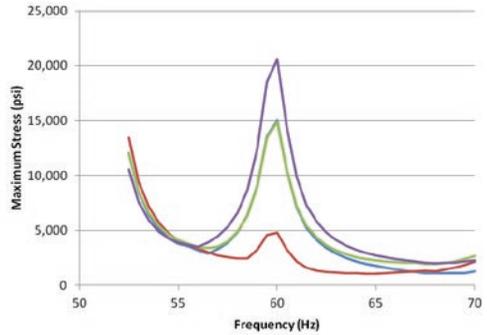
▲ Example of fatigue failure



▲ Line geometry optimization process



▲ CAD geometry of compressor frame with lines



▲ Maximum stress from four load cases

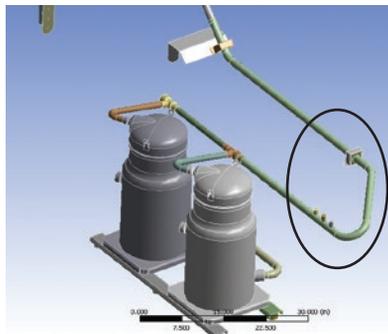
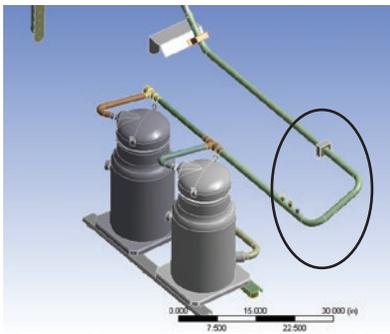
Trane engineers built a CAD model of a tandem scroll compressor and refrigerant line layout, which they imported into ANSYS Workbench. They defined and parameterized the relevant design variables of the refrigerant lines and identified feasible ranges for each variable. Then the team used the Optimus workflow engine that automatically drives the design exploration and optimization process.

AUTOMATING THE SIMULATION WORKFLOW

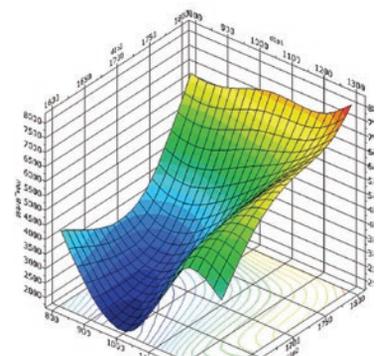
The simulation process starts with meshing the model and setting up boundary conditions. These tandem compressors are designed so they don't exceed a certain vibratory motion. Trane engineers used structural dynamics to determine the amount of motion generated by a small unity force, then they back-calculated the amount of force required to produce the maximum possible motion in a single compressor. The two compressors each can generate this force in different phases relative to each other. Trane engineers considered four load cases based on 0, 90, 180 and 270 degrees phase lag between the two compressors. For example, with 0 degree phase lag, the two compressors both exert maximum force in the same direction. Engineers used ANSYS Mechanical to conduct harmonic force response analysis and employed APDL command snippets to extract the maximum equivalent stress at each load, frequency and phase angle.

Then the engineers used Optimus to perform design of experiments (DOE) on the simulation workflow to explore the design space with minimum computational effort. A response surface fitted to the data points revealed by the DOE serves as a reliable metamodel to efficiently identify the global optimum for the refrigerant lines configuration under investigation. Performing design optimization directly on the metamodel eliminates the need to rerun additional ANSYS Workbench simulation iterations, saving substantial amounts of time. Subsequently, a local gradient-based optimization is carried out by rerunning the harmonic force response analysis in the area of the global optimum. Optimus' automated workflow execution results in an optimized set of refrigerant lines design variables, ensuring that the local operating alternating stress remains below 5,000 psi.

The increasing complexity of new-generation chiller design created challenges for Trane engineers in ensuring robust design of refrigerant lines. Trane is now ready to address this challenge with an Optimus-driven optimization process including engineering simulation from ANSYS that substantially reduces stress in each line while also ensuring conformance to geometric and functional specifications. The future process has the ability to reduce line stress, which will make Trane scroll compressor refrigerant lines more robust while reducing time to market and freeing engineering effort for more proactive tasks. ▲



▲ Original design (left) and optimized design (right)



▲ Response surface map for two design variables