Green Machine

One of the biggest challenges in designing reciprocating compressors is understanding the complex operation of reed valves that open and close as they deform under loads generated by fluid flowing through the compressor. Tecumseh engineers used ANSYS multiphysics capabilities to design a new compressor that consumes less power and produces less noise in under half the time required to design the previous product.

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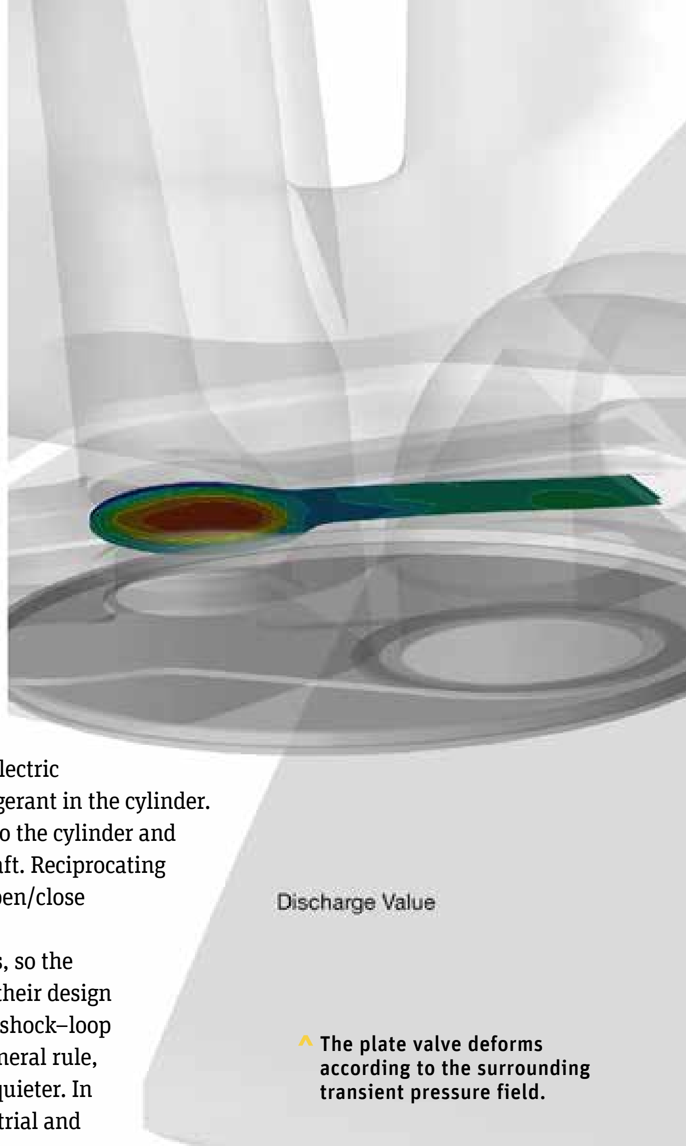

^ The plate valve deforms according to the surrounding transient pressure field.

Reciprocating compressors use a piston and cylinder, similar to an internal combustion engine, to move heat from a refrigerator's interior to the exterior. While an internal combustion engine burns fuel in the cylinder to move the piston and turn a crankshaft, a reciprocating compressor uses an electric motor to turn a crankshaft that moves the piston to compress refrigerant in the cylinder. In an internal combustion engine, valves that open to deliver fuel to the cylinder and allow exhaust gases to escape are mechanically driven by a camshaft. Reciprocating compressors, on the other hand, typically use reed valves whose open/close movements are driven by fluid flowing through the compressor.

Much of a typical compressor's losses occur around these valves, so the compressor's energy efficiency and noise levels largely depend on their design and operation, as well as on the suction muffler (suction side) and shock–loop system (discharge side), which are used to attenuate noise. As a general rule, restricting flow reduces a compressor's efficiency while making it quieter. In the past, designing a new reciprocating compressor was largely by trial and

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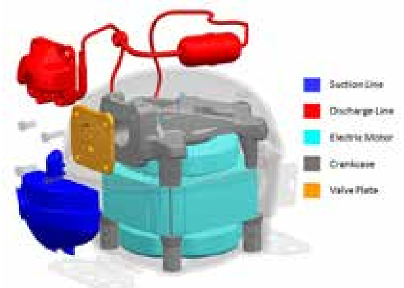
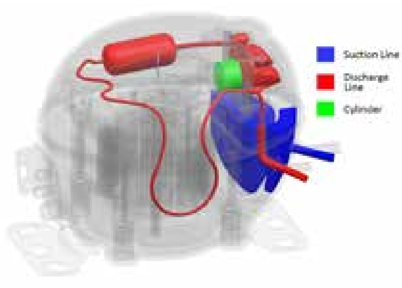
error. It required building and testing dozens of prototypes, and it took four to five years to complete. In designing a new TA² family of compressors, Tecumseh engineers took only 18 months using ANSYS multiphysics simulation, a reduction of over 60 percent in time to market. They achieved a 1.5 percent increase in energy efficiency — a gain that if applied across all of the refrigerators in Brazil would save enough electricity to power the homes of a city of almost 1 million inhabitants. Furthermore, noise was reduced by 3 dB, cutting the noise level in half. It is the same result as if two compressors were running and one was shut off.



^ Diagram of compressor parts



^ Fluid volume of compressor

DIFFICULT DESIGN CHALLENGE

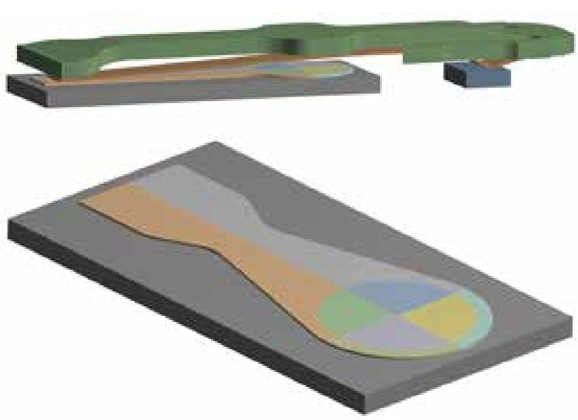
In a gasoline-fired engine, the valves are controlled mechanically, so their position at any point in the machine cycle is always known. However, for reciprocating compressors, the valves are controlled by pressure differences, and a fluid–structure interaction (FSI) simulation is needed during design to determine their position. The cycle begins when the electric motor moves the piston to enlarge the compression chamber, thus reducing its pressure. The pressure difference between the compression chamber and ambient pressure deforms the suction valve, which causes refrigerant to be sucked into the cylinder. When the piston reverses direction and increases the pressure in the chamber, the discharge valve opens to dispense pressurized refrigerant.

Tecumseh management tasked the engineering team with developing a replacement for the company’s TA family of compressors that delivered higher energy-efficiency and lower noise at a lower cost. Reducing the cost of the compressor required using a less expensive and less efficient electric motor, so it was even more critical to increase compressor efficiency. Meeting these conflicting objectives within a tight time frame required the engineering team to develop a complete software prototype of the compressor, incorporating both mechanical components and fluid flow.

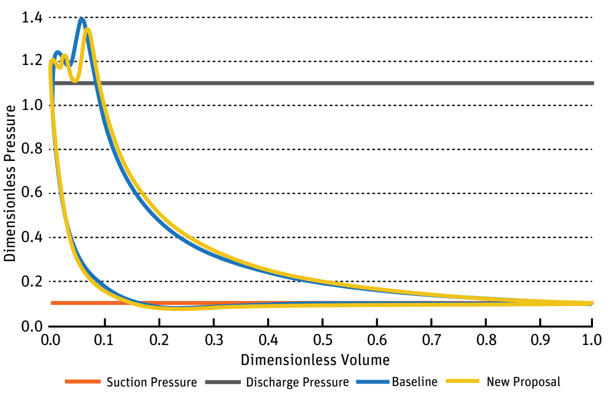
SETTING UP A MULTIPHYSICS SIMULATION

Tecumseh engineers selected ANSYS Mechanical finite element analysis software and ANSYS CFX computational fluid dynamics (CFD) software because these tools can easily be connected within the ANSYS Workbench environment to simulate FSI. They created both solid and fluid geometries in the ANSYS DesignModeler pre-processor, and used Workbench to automatically mesh components and define physical models and boundary conditions. Moving meshes represented the movement of the cylinder and the valves. Using the Workbench project schematic, engineers easily connected the output of each tool to the boundary conditions of the other to simulate FSI.

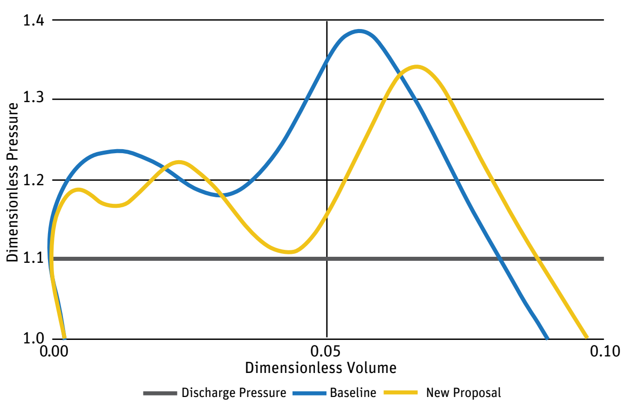
Pressure–volume diagrams generated by the simulation, which track cylinder pressure against cylinder volume over the operating cycle of the compressor, were extremely useful. The area near the top of the chart, where cylinder pressure exceeds discharge pressure, quantifies discharge losses. The area under the suction pressure line, where cylinder pressure is less than suction pressure, indicates suction losses. Suction losses are caused primarily by pressure drop across the suction port when the suction valve opens and closes. Discharge losses are caused by pressure drop across the discharge port.


^ Structural model of valve plate

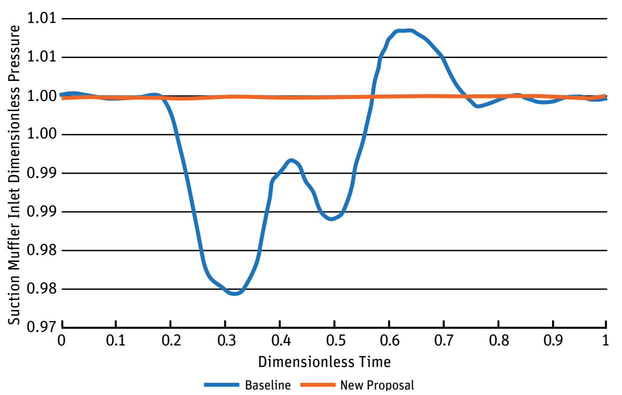
"*Multiphysics simulation* makes it possible for Tecumseh to resolve conflicting requirements while bringing *products to market* faster than ever before."



^ Pressure-volume chart quantifies losses on suction and discharge sides of compressor.



^ Discharge losses were reduced in the new design (blue) versus the previous generation (yellow).



^ Pressure–time history shows cyclical pressure variations that cause noise.

The simulation provided time histories of pressure at suction and discharge ports. Because noise is caused mainly by pressure fluctuations around the suction and discharge valves that exit the refrigerator cabinet, these time histories provided valuable information. Guided by the simulation results, Tecumseh engineers manually iterated the design of plate valves and other components, substantially increasing efficiency and reducing the noise the compressor generated. Since the suction side generates the majority of noise, engineers designed a more elaborate suction muffler. This new muffler necessarily had higher losses, but these were more than offset by improvements in the suction valve's efficiency.

A reciprocating compressor's efficiency is measured by a coefficient of performance (COP), which is the amount of work it performs in moving heat out of the refrigerator's interior, in watts, divided by its power consumption, also in watts. By simulating many different designs, Tecumseh engineers were able to make trade-offs that achieved the optimal combination of increased efficiency and reduced compressor noise. The resulting COP improvement of 1.5 percent is a major enhancement for a mature product, providing Tecumseh with a substantial competitive advantage.

The new compressor's noise levels were also substantially reduced. After the design was completed, Tecumseh engineers used ANSYS ACT Acoustics (available from the ANSYS App Store) to simulate the noise levels on the suction side of the old and new designs. The results showed an improvement on the suction muffler performance around 20 dB at most frequencies. Tecumseh engineers also performed a modal analysis of the compressor housing using ANSYS Mechanical, and, based on these results, they modified its design to reduce its response at the compressor's operating frequency, providing further noise reductions.

The appliance industry continues to demand reciprocating compressors with higher energy-efficiency and lower noise at a competitive price. Multiphysics simulation makes it possible for Tecumseh to resolve these conflicting requirements while bringing products to market faster than ever before. ∧

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