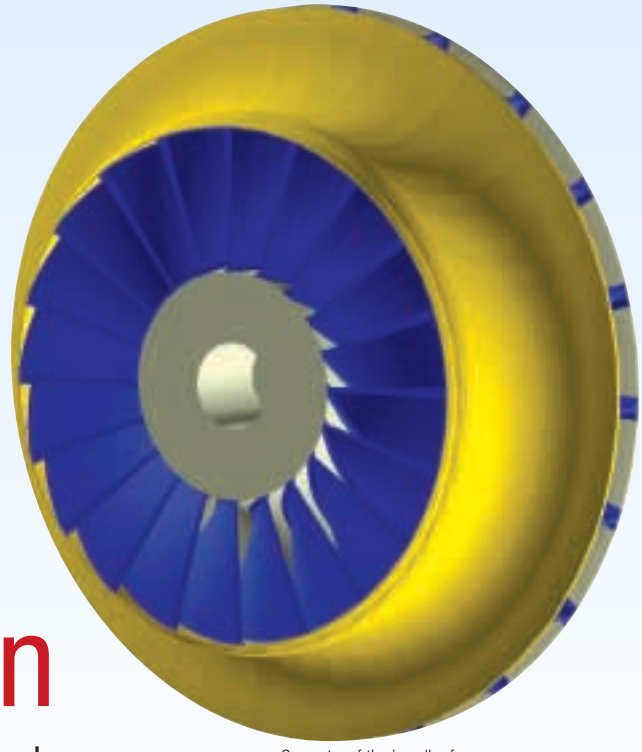

Geometry of the impeller for an expansion turbine

High-Speed Product Design

Integrated software facilitates design and development of expansion turbines to avoid failure.

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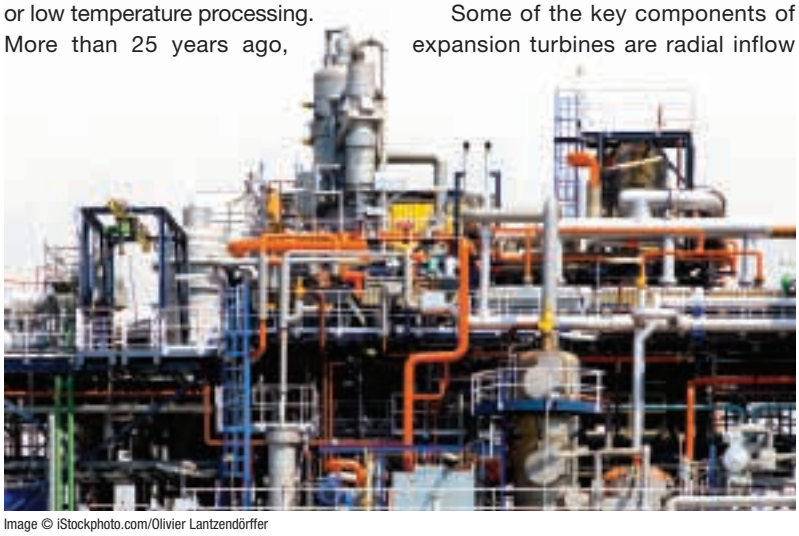
The air separation industry relies on efficient and reliable turbomachinery to create the highest performance air separation plants possible. Key to this industry are expansion turbines — centrifugal or axial flow turbines that expand a high-pressure gas to reduce the gas temperature and produce work. The turbines are widely used for industrial applications that require fluid cooling or low temperature processing.

More than 25 years ago, Praxair, Inc., of New York, U.S.A., a leading supplier of atmospheric, process and specialty gases, created an in-house turbomachinery group that specializes in cryogenic expansion turbines. For the last two decades, Praxair turbine design engineers have been using the suite of finite element analysis (FEA) products from ANSYS as their mechanical simulation software packages of choice.

Some of the key components of expansion turbines are radial inflow turbine impellers, which operate at very high rotational speeds. Impeller aerodynamic performance and reliability depend in part upon the impeller blade shape and thickness. In addition to steady-state centrifugal pressure and thermal loads, dynamic stresses arising from upstream flow nozzle pressure fields can cause impeller fatigue failure. The ability to accurately and quickly predict stress, deflection and the modal characteristics of an impeller allows Praxair's turbomachinery designers to develop an impeller that provides maximum aerodynamic performance without sacrificing reliability.



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Praxair engineers use the design analysis package BladePro-CF™ from Impact Technologies, together with mechanical simulation software from ANSYS, to perform steady-state stress analysis, modal analysis (natural frequency and mode shape), harmonic forced response analyses and fatigue life calculations. BladePro-CF is fully integrated with some FEA products from ANSYS (such as ANSYS

Multiphysics, ANSYS Mechanical and ANSYS Structural licenses), making the coordinated use of products relatively simple.

In order to assess an impeller's margin against fatigue failure, engineers use a combination of steady-state and dynamic stresses. The use of Campbell and interference diagrams, as well as animated mode shapes from BladePro-CF, allows engineers to visualize the potentially dangerous interactions of various impeller mode shapes and sources of excitation.

An analysis begins when Praxair engineers import basic impeller geometry data into BladePro-CF. They attach boundary conditions and select materials within BladePro-CF prior to creating the 3-D ANSYS model for simulation. Next, they apply pressure profiles, temperature profiles and the centrifugal load, and the mechanical software from ANSYS calculates the static stress throughout the impeller. Once the static stress analysis is complete, engineers examine plots of displacement, von Mises equivalent stress (for crack initiation) and maximum principal stresses (for crack propagation).

The use of a sound mesh topology and a high-density hexahedron-based mesh in the blades and shroud are crucial to accurate frequency prediction for the large number of modes of interest. For Praxair's shrouded impellers, more than 100 modes of vibration are present, ranging from zero rotations per minute (rpm) to the highest frequency of interest. A very accurate representation of stiffness and mass is required to produce sufficiently accurate predictions. The BladePro-CF program pre-selects master degrees of freedom and then allows the Praxair engineers to modify these.

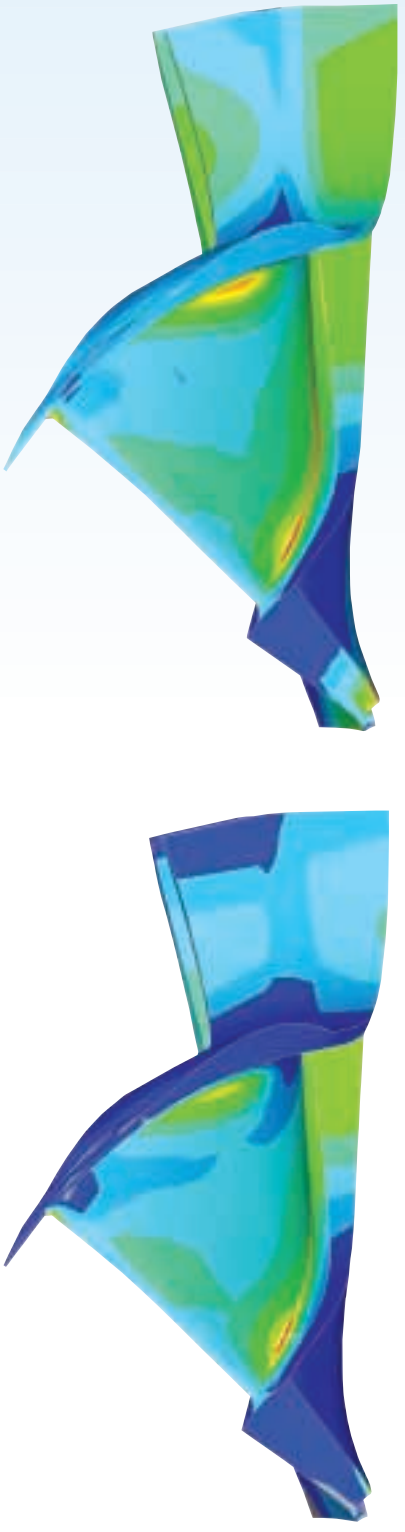
The FEA simulation then calculates the natural frequencies and mode shapes at either zero rpm or a defined speed that would include stress stiffening effects. The back-substitution files are saved for any subsequent harmonic forced response analysis. For radial inlet turbine impellers, it is important to identify diametral and circular mode shapes that are critical in assessing the likelihood of dangerous resonance conditions — as not all modes can be excited or are of equal importance.

Engineers next use dynamic forced harmonic response analysis to calculate the dynamic stresses. At this step, a Goodman diagram (available in BladePro-CF) is invaluable, as it provides a graphic display of the combinations of static and dynamic stresses for the entire impeller. The diagram allows a viewer to visually compare the combined stresses with the material's allowable limits. Once the critical locations are identified, engineers utilize the local strain module of BladePro-CF to calculate the time to crack initiation for each location; this value combined with the duty cycle of the compressor is then used to predict fatigue life.

The Praxair engineering team was able to pinpoint a weakness in an older impeller that experienced a fatigue failure by looking at a Campbell diagram. In so doing, they easily determined that vibration-based failure could be avoided by changing the number of nozzles, or guide vanes, that direct flow to the impeller blades. The analysis portion of this investigation took less than a day, compared with multiple days without the use of BladePro-CF and simulation. Impeller failures can cost from $50,000 to $100,000, making the avoidance of these situations of great interest to both the manufacturer and end users.

The combination of BladePro-CF and FEA products from ANSYS allows Praxair engineers to easily and accurately determine the quality of their turbomachine impeller designs by providing an appropriate margin against fatigue damage. Using this approach, they can effectively and quickly predict and examine in detail the vibration-related parameters that could affect the reliability and life of their designs. ■

BladePro-CF is a trademark of Impact Technologies, LLC., an ANSYS, Inc. partner.



ANSYS Mechanical simulation results showing maximum principal (top) and radial (bottom) stress distributions for one impeller design. Red indicates area of high stress.