Concepts NREC Helps DTI Stay Cool on New Axial Compressor

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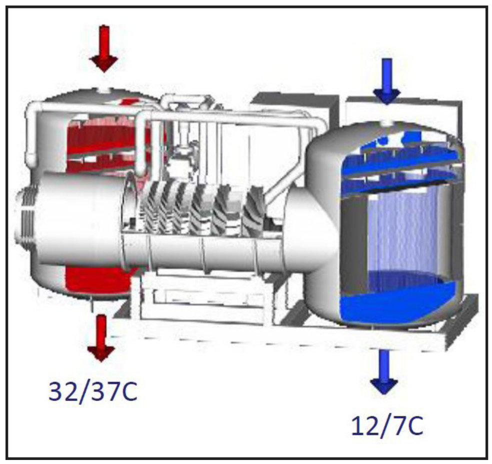
The Danish Technological Institute (DTI) has employed Concepts NREC's (*CN) Agile Engineering Design System®* to create a new type of axial compressor for manufacturers of commercial chillers under pressure to reduce their dependency on artificial refrigerants.

Industrial refrigeration, such as that deployed in commercial chiller technology, is largely dependent upon NH_3 (ammonia) refrigerants or synthetic HFCs (hydrofluorocarbons). The latter were adopted in the 1990s as the widescale replacements for CFCs (chlorofluorocarbons) such as Freon-12. Although HFCs do not harm the ozone layer if they are free from chlorine or bromine, their atmospheric concentrations are increasing rapidly, causing international concern about a different process: greenhouse gas global warming.

Tasked with developing a solution, the Danish Technological Institute, a self-owned, 1000-strong, not-for-profit institution, aims to develop, apply, and disseminate research and technologically based knowledge for both national and international industry. One of its many departments is Energy and Climate, which, in turn, is comprised of many sub-business areas such as refrigeration and heat pump technology.



New type of Axial Compressor with water as refrigerant.

"The need for a natural alternative to synthetic refrigerants was clear as far back as the mid-1990s, and water was considered by far the best contender," states Hans Madsbøll, a project manager in the DTI's Energy and Climate business unit. "With water there is no global warming effect, and it is inexpensive and easily available. Furthermore, it is non-toxic, non-flammable, and is not subject to breakdown. However, the use of water would require the development of new, highly efficient and cost-effective axial compressors."

To help optimize the process of identifying the required turbocompressors for commercially competitive chiller units using water as refrigerant, DTI's survey of experts in turbomachinery led them to Concepts NREC.

CN supported a feasibility study performed by DTI and Sabroe, which was recently acquired by Johnson Controls. The study investigated several options for centrifugal, mixed-flow, and axial compressors using a wide range of performance and manufacturing parameters. Ongoing feasibility studies, scaled tests, and prototyping were used to assess factors such as size, materials, performance, cost, flexibility, and scalability.

Axial-type compressors were deemed preferable for the project to best suit volume flows of 30-200 m^3/s and pressure ratios of 1:4-8. The principle of an axial compressor stage is that the rotors give the vapor high velocity, and hence, dynamic pressure, after which the stationary stator blades slow the vapor again, converting velocity into pressure.

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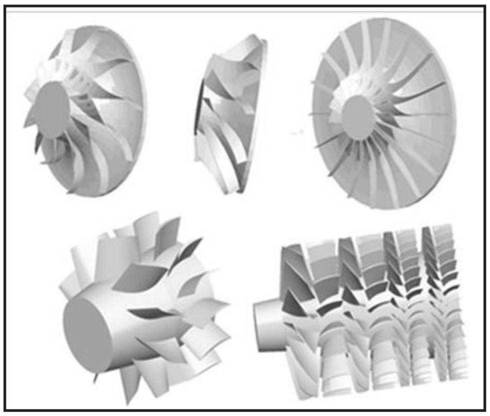
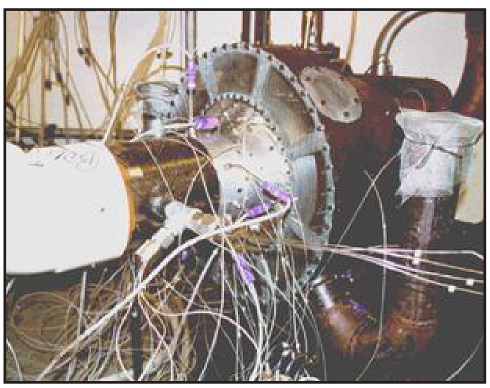
After initial discussions, DTI invested in *CN*'s ***Agile Engineering Design System®***, exploiting the AXIAL™ code for preliminary design and the AxCent® code for detailed design work, along with Pushbutton CFD® and the former AXISTRESS™.



The multistage axial compressor (bottom, right) was deemed the most promising following DTI's evaluation in collaboration with CN.



Axial compressor being tested at low Reynolds number in CN test facility.

"Although the aim was to create two different-sized axial compressors - for 0.8 and 1.8 MW chiller cooling capacities – between 50 and 100 different configurations were up for consideration at the project's outset," says Madsbøll. "At the first stage of development, *CN* helped provide the meanline data for a dozen preferred configurations that were subsequently tested; from there on, we continued alone using *CN*'s CAE/CAM software."

CN made the first meanline design of the compressor, designed the first stage in detail, and did the performance test of the first stage in a scaled version of approximately 1:6. The test (performed with air) took place at *CN*, with the objective to meet both the relative Mach number and Reynolds number of the real design, where the media is low-pressure water vapor. One of the *CN* test rigs was modified with closed loop piping in order to keep air at the appropriate vacuum conditions to meet the Reynolds number.

The results and feedback were used to influence the design specifications of the system, and the final full-scale tests were performed by DTI with additional stakeholder interest from Kobe Steel, Ltd. (Kobelco™) of Japan, in collaboration with four Japanese power companies. Utilizing *CN* software throughout, the axial compressor designs were optimized stage-by-stage. Continuous compressor and chiller tests were conducted, along with the prototype testing onsite at Kobe Steel.

Performance was measured using a large number of pressure and temperature sensors inside the compressor. The data were then compared to the detailed 3D CFD flow calculations from AxCent® and AXIAL™'s 1D meanline predictions.

In conjunction with *CN*'s software results, these tests helped refine the design of blade shapes. Here, independent technical areas such as compressor aerodynamic optimization, selection of material and production method, optimization of stress level and natural frequencies, rotordynamics, and bearing specifications had to be reconciled. This was further complicated by the fact that an axial compressor has many variables that are important to both the aerodynamic and mechanical design, such as the number of stages, rotational speed, diameter, blade count/profile/height/length ratio, front/exit thrust area, blade angle, and blade camber and thickness. Also important are hub radius and curvature, and tip clearance and structure.

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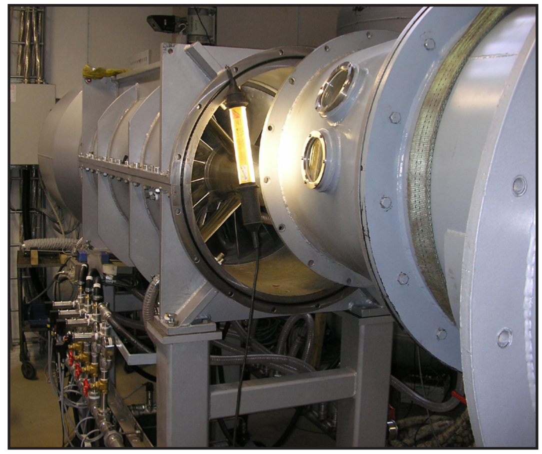
"The identification and selection of these variables affects the total pressure ratio, efficiency, relative Mach number, and various types of losses," explains Madsbøll. "The actual design procedure was structured as a number of iterations where the design was improved and optimized gradually by adjusting the geometry of the previous designs."



The smallest compressor has a capacity of 800 kW at 7°C.

AxCent® proved particularly valuable here, as it includes several options for real-time interactive flow analysis, including full 3D CFD with an advanced full Navier-Stokes solver for comprehensive evaluation.

"The blade designs are now finalized and are currently with the industrial partners for commercialization within the coming 18 months," states Madsbøll. "This is why we can't elaborate too much more. However, I can say that the benefits of using *CN* software have been pivotal to the success of the project. For instance, aside from being ultra-compact, the blades have been designed in such a way that they are relatively inexpensive to machine – much more so than conventional alternatives. Furthermore, the chiller system operating in a vacuum is very efficient and loses only 1-2% of its total energy consumption. Competing systems typically have losses in the range of 5-10%."

Ultimately, two sizes of a patented compressor were developed. The largest, with a capacity of approximately 100 m^3/s, corresponds to a chiller capacity of around 1.8 MW at 7°C. The smaller compressor has a volume flow of approximately 40 m^3/s, corresponding to an approximate cooling capacity of 800 kW.

This project represents the first time an axial compressor, specifically for chiller applications in industrial refrigeration, has been developed from scratch. Used in combination with an optimized version of a direct contact heat exchanger, the design is set to provide a commercial breakthrough in the use of water as a refrigerant. Production rights are shared between Kobe Steel Ltd. and Johnson Controls Denmark.

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