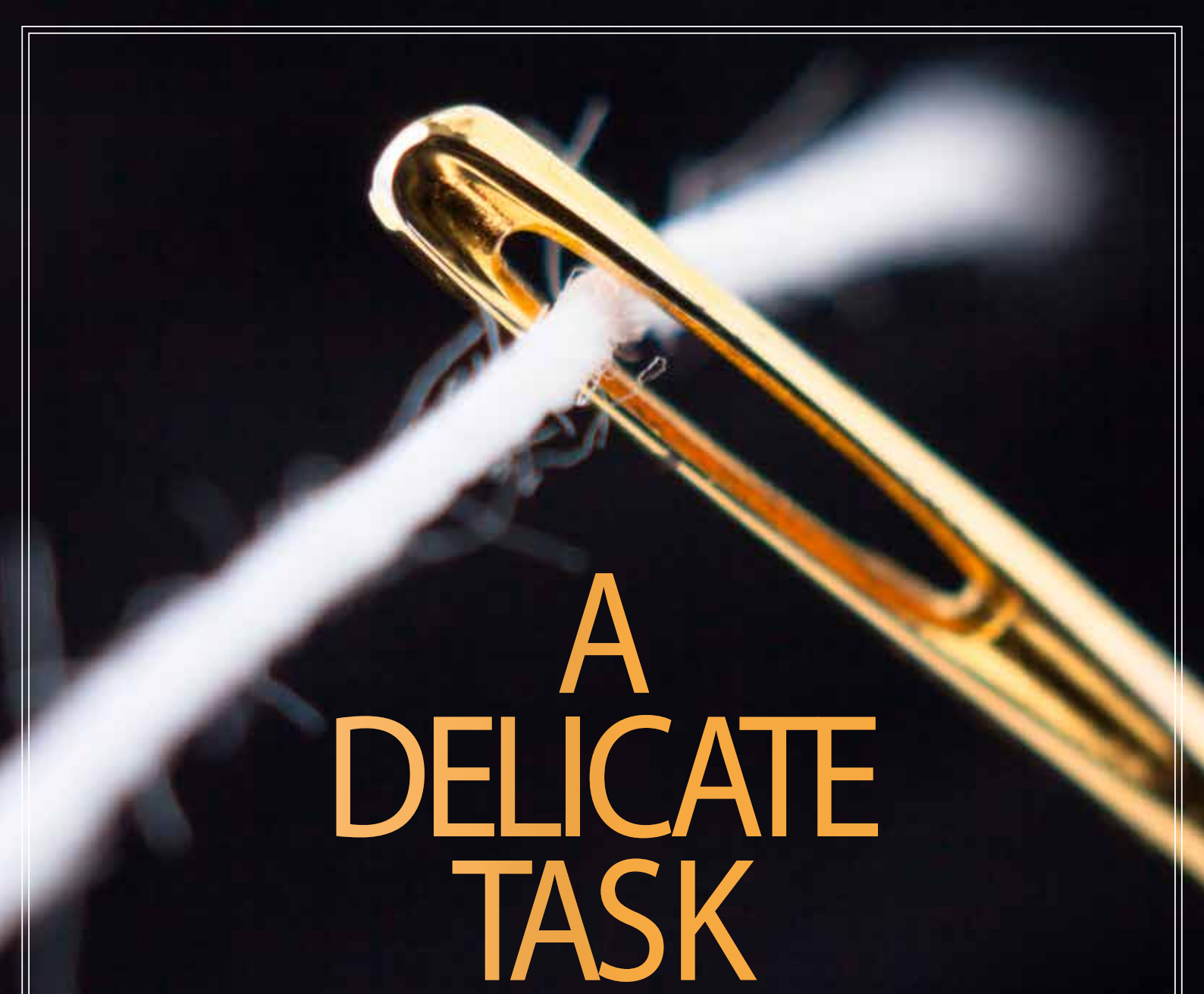


A DELICATE TASK

Massimiliano Di Febo and Pasquale Paganini, IPC, Italy,
discuss how advanced software can assist operators in achieving highly accurate compressor performance predictions.

One of the primary tasks during the manufacturing of a centrifugal compressor is the shop testing. Compressor testing is usually performed at the original equipment manufacturer's (OEM) facilities and is, in general, performed with the purpose of validating the performance that has been stated by the OEM in the machinery specification sheets.

Centrifugal compressor shop tests represent one of the main stages in the machine manufacturing process. The importance of this phase is also attested by the fact that, in almost all cases, the project quality requirements include a witnessed test, which is executed in order to ensure that the manufacturer's predictions meet the specification (design) performance.

Shop testing for centrifugal compressors can be a delicate task. In general, it may be that inlet conditions during the test are different from the specification conditions defined in the machine's data sheets.

Sometimes the need for different inlet pressure and temperature may occur, or the test could require a gas different from the one specified in the data sheet; or, in some cases, both conditions may turn up simultaneously. The ASME PTC10 (Performance Test Code on Compressors and Exhausters) Standard identifies these possible different test cases and refers to the Type1 Test (Type1) to test the same specification gas and specification conditions, and Type2 Test (Type2) to test with different gas and/or inlet conditions.

In the cases where inlet conditions during the test are different from the ones recalled in the specifications, the OEM provides compressor performance maps, adjusted to test conditions, in order to superimpose that onto the performance measured during the test.

Similar considerations may also apply to field testing, where the inlet conditions at the time of the test may not be under full control, and may represent an independent

variable for the test process. Furthermore, in certain circumstances, inlet conditions may vary in time in unpredictable ways. In these last cases, in particular, the availability of computational tools, which predict compressor performance under changed (off-design) inlet conditions, may be of great value.

Purpose and method description

This article aims to present the results of a numerical simulation of a centrifugal compressor's performance, in accordance with a Type2 test, with test gas differing from specification gas (where the test gas is Freon R134a [2134a]). The input for this analysis consists of compressor performance maps, provided by the OEM in specification conditions, i.e., with a specification gas (in the case study considered, the gas process is a hydrocarbon).

A numerical analysis is executed using the IPC software called CMap, in order to predict the compressor's performance when running it in test conditions with a test gas. The output of this analysis is a performance map referenced to specific test conditions with an R134a refrigerant (simulated test map). The obtained simulated map (with predicted performance adjusted to accommodate for the test gas R134a) may then be used as a reference for a comparison to the test performance that was measured during the shop test.

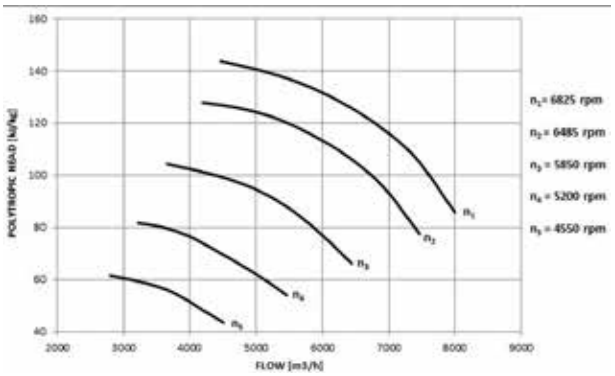


Figure 1. Discharge pressure in specification conditions.

Table 1. Inlet conditions

Specification inlet conditions	Test inlet conditions
Gas mixture: • Methane: 80.51% • Nitrogen: 1.46% • Ethane: 14.69% • Propane: 3.19% • I-butane: 0.07% • N-butane: 0.08%	Gas mixture • R134a: 100%
Pressure: 40.2 bar_a	Pressure: 1 bar_a
Temperature: 50°C	Temperature: 35°C

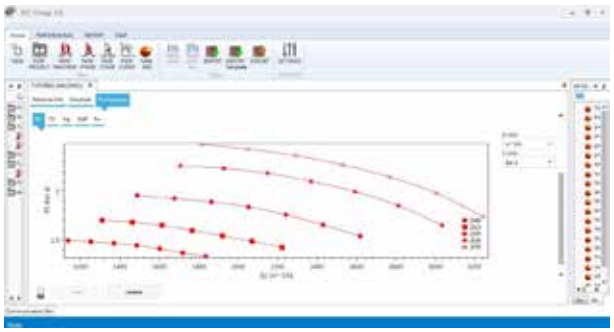


Figure 2. Screenshot of Cmap software.

The main parameters used to assess the performance of a centrifugal compressor are:

- Flow.
- Head.
- Power absorbed.
- Efficiency.

Some additional conditions are needed to allow a significant comparison of these parameters in the two different referenced conditions (specifications/test). From a fluid dynamic point of view, a strict similarity of flow at each performance point is necessary in order to compare the predicted performance with the tested performance. For this reason, the non-dimensional parameters, such as head coefficient, flow coefficient and Mach number, must be conserved primarily (some additional conditions are requested: the machine's Reynolds number, Mach number and volume ratio).

$$\varphi = \frac{Q_1}{\frac{\pi}{4} D^2 u^2}$$ Flow coefficient.

$$\Psi = \frac{g H_p}{u^2}$$ Head coefficient.

$$\mathrm{Mu} = \frac{u}{\sqrt{kzRT}}$$ Mach number.

$$\mathrm{Re} = \frac{\rho u b}{\mu}$$ Reynolds number.

This equality of non-dimensional parameters among test and specification conditions eliminates the need to test the centrifugal compressor at the same speed as the OEM predicted performance in specification conditions, and allows, within a certain range, to test with gas mixes different from the design one.

In this article, the test performance has been predicted considering that R134a will be used as a test gas. R134a is, in fact, a typical gas used in many performance tests.

Simulation

As mentioned above, the starting point is the availability of an OEM centrifugal compressor performance curve in specification conditions, along with a relevant gas mix composition and thermodynamic conditions (pressure and temperature). With this input data available, the CMap software will perform all complex calculations in a fully automated fashion and will produce the predicted compressor performances for test inlet pressures, inlet temperatures and Freon R134a that are different to the design/reference ones.

CMap conducts the compressor performance prediction using different equations of state (EOS) depending on which gas mix is considered in the

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calculation. For a hydrocarbon gas mixture, the Lee-Kesler (LK) or Peng-Robinson (PR) EOS can be used. For Freon R134a, the modified Benedict-Webb-Rubin (mBWR) EOS is selected in order to determine the thermodynamic properties of the operating fluid. After the first calculation step it will then be possible to proceed to the comparison of the predicted tested performances to the actual tested performances. Table 1 shows the inlet condition of predicted performance and inlet condition of tested performance.

Starting from the centrifugal compressor performance map in specification conditions, the tested performance curves have been calculated using Cmap. Figure 1 shows the predicted tested performance curves obtained with Cmap.

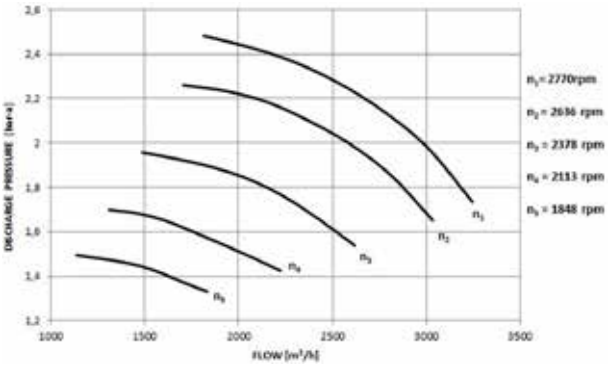


Figure 4. Discharge pressure in test conditions (with Freon R134a).

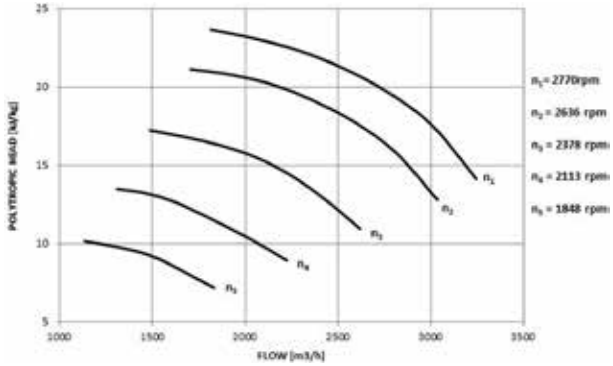


Figure 5. Polytropic head in test condition (with Freon R134a).

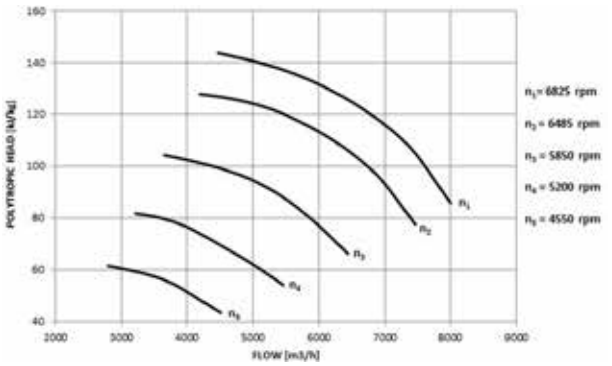


Figure 3. Polytropic head in specification conditions.

Possible applications of the method

As stated at the beginning of this article, the first application of this method involves the comparison of the test predicted maps to the measured test performance. Using the CMap software, the OEM specification (design) maps are quickly adjusted to the test conditions with a test gas and different inlet pressure and temperature. Due to the software, this operation is quick and straightforward to achieve. Obtained predicted maps can be easily superimposed onto measured test maps, allowing one to check the capacity of the machine according to the specified conditions.

The proposed method can be profitably used to predict the centrifugal compressor's overall performance when running with operating conditions other than those specified. This may be the case for a compressor running in operative conditions that are different from the specification ones. In this case, the proposed method can predict the expected performance of the compressor when run in real input conditions. The availability of expected performance (that is to say, the design performance adjusted to the actual operating conditions) will also allow for a new type of diagnostic capability, arising from the ability to compare actual performance to what is expected. A deviation of the measured (actual) performance from the expected (adjusted) ones, beyond a certain threshold, can be read as an indication of some of the phenomena or problems affecting the compressor and causing its operating parameters to deviate from expected values.

When implemented in IPC monitoring systems, CMap software can automatically store data and provide a real time indication of compressor efficiency and comparison with expected ones. The detection of a deviation of actual efficiency from the expected efficiency (i.e., design adjusted in actual condition) is a meaningful indicator of compressor health. This is a powerful feature that permits a continuous indication of how much of the machine's behaviour is alligned with design expectations. These evaluations can then be used to build historical trends and pictures of the machine status throughout the operation period. Collected data is useful to support decision making on predictive maintenance activities, plans and operations.

Another important application of the presented method is the use of CMap software for the prediction and modification of surge points during operating conditions, with different inlet pressure, temperature and operative gas. This method is called SPS® – an IPC patent. This method is particularly well suited for the protection of heavy duty, high pressure centrifugal compressors, especially ones working under time-varying inlet conditions.

The availability of such advanced compressor protection features increases the level of machinery protection and avoids potential critical failures due to a compressor surge, as well as the dangerous effect of possible repetitive short duration surging events, whose cumulative action may cause a significant reduction of the machine lifetime if not detected by the compressor protection system.

Conclusion

Experiences with real machinery demonstrated that a compressor performance prediction obtained with Cmap software aligns with OEM predictions and field measurements. In those cases where deviation had been detected, Cmap identified compressor anomalies, providing useful quantitative indication suggestions for possible corrective action.

The methods proposed and described in this article allow one to:

- Predict the tested performance of a centrifugal compressor with Freon R134a as the inlet gas.
- Predict the performance of a centrifugal compressor under varying thermodynamic conditions of the inlet gas. The prediction of compressor performance is accurate, even at high pressures, whereas the ideal gas theory, commonly used, introduces considerable errors.
- Analyse the performance of the compressor during operation and compare it to the expectations provided by the manufacturer.
- Obtain useful indications regarding the health of the compressor (diagnostics), based on the capability to analyse the performances and efficiency of the machine in a simple and immediate way.
- Implement advanced methods for antisurge protection, SPS.
- CMap may be used as a third-party software for validation of the compressor test performance during an OEM shop test.
- Observe how the methods and software tools have been validated against compressor technical data, then vs all the available scientific papers on thermodynamic gas theories developed in the hydrocarbon research field.

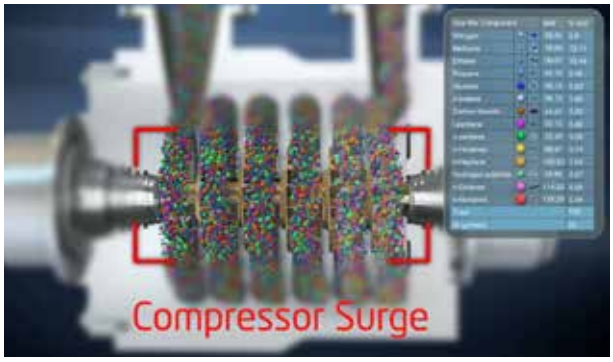


Figure 6. Compressor surge in actual operative conditions.

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