Compressors

Aligning centrifugal compressor test data

Conditions during centrifugal compressor testing at the customer's facility can be different from those defined in the machine's data sheets. However, numerical analysis software CMap by IPC can align performance predictions under test with those provided by OEMs and field measurement.

One of the primary tasks in manufacturing a centrifugal compressor is the shop testing. Compressor tests, often performed at OEM facilities, are usually to validate the performance as stated by the OEM in the machinery specification sheets.

The importance of this phase is proved in almost all cases, by the fact that the project quality requirements includes a witnessed test, to be executed in order to assure that the manufacturer's predictions meet the specification (design) performance.

Shop testing for centrifugal compressors is then a quite delicate task. For example, it may happen that inlet conditions, during the test, are different from specification conditions defined in the machine's data sheets.

Sometimes the need for a different inlet pressure and temperature may occur, sometimes the test could require a gas different from the one specified in the data sheet; 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 Type 1 Test for a test with the same specification gas and specification conditions, and Type 2 test for a test with different gas and/or inlet conditions.

In cases where inlet conditions during the test are different from those in the specifications, the OEM usually provides the compressor performance maps adjusted to test conditions in order to superimpose them on the performance measured during the test.

Similar consideration also applies 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. Also, in certain circumstances, inlet conditions may vary in an unpredictable way. In these cases, the availability of computational tools for the prediction of compressor performance in under changed (off-design) inlet conditions may be a valuable help.

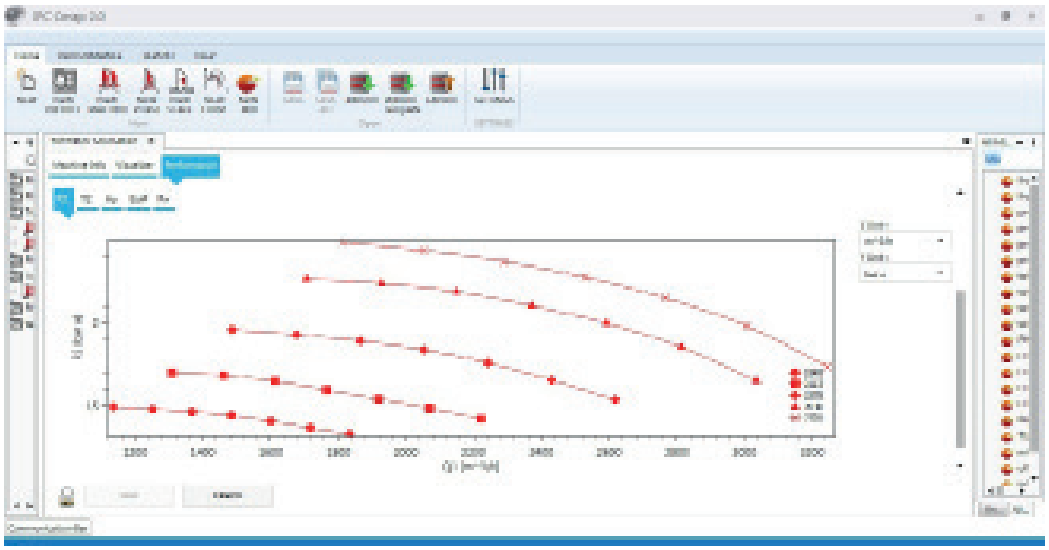


Fig.1. Screen shot of Cmap.

Type 2 test

This paper aims to show the results of a numerical simulation of centrifugal compressor test performance in accordance with a Type 2 test, with test gas different from the specification gas, where the test gas is R134a. The input for this analysis consists in the compressor performance maps provided by the OEM in specification conditions i.e. with a specification gas, in the case of a hydrocarbon.

A numerical analysis is executed, using IPC software CMap, in order to predict the compressor performance when running in test conditions with a test gas. The analysis produces a performance map referenced to specific test conditions with a R134a refrigerant (simulated test map). The simulated map (predicted performance adjusted to the test gas R134a) may be used as reference for a comparison with the test performance measured during the shop test.

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 specification/ test conditions. 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 head coefficient, flow coefficient and Mach number must be conserved primarily; additional conditions requested include the machine Reynolds number and the machine 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 requirement to test the centrifugal compressor at the same speed as the OEM's predicted performance in specification conditions and allow, within a certain range, to test with gas mixes different from the design one.

In this paper the test performance has been predicted considering Freon R134a as test gas. This is a typical gas used in many performance tests.

Simulation

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

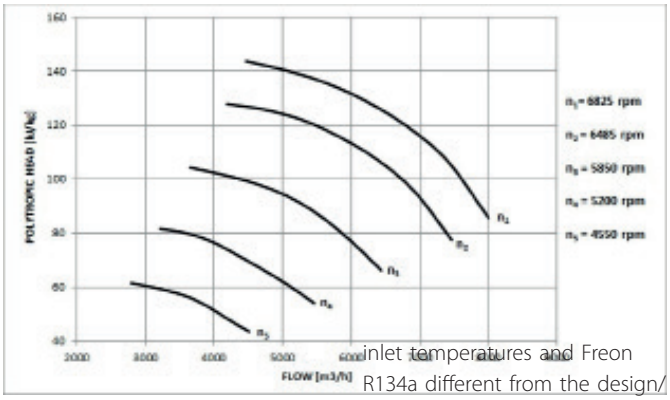


Figure 2. Discharge pressure in specification condition.

CMap allows the compressor performance prediction using different equations of state (EOS) depending on the gas mix considered in the calculation. For a hydrocarbon gas mixture Lee-Kesler or PR EOS can be used. For Freon R134a the MBWR EOS will be selected to determine the thermodynamic properties of the operating fluid.

After this first calculation step it will be possible to compare the predicted tested performances to the actual tested performances.

Starting from the centrifugal compressor performance map in specification conditions, the tested performance curves have been calculated using the software Cmap. Figure 2 shows the predicted tested performances curves obtained with the software Cmap.

Possible applications

As stated before, the first application of this method is to compare the test predicted maps with 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. Thanks to the software, this operation is quick and straightforward. Obtained predicted maps can be easily superimposed to measured test maps. This comparison will allow a check on the capability of the machine to match the specified conditions.

The proposed method can be profitably used to also predict the centrifugal compressor's overall performances when running with operative inlet conditions different from the specification ones. This may be the case of a compressor running in operative conditions different from specification ones. In this case the proposed method will allow one to predict the expected compressor performance when running in actual inlet conditions.

The availability of predicted performance (i.e. design performance adjusted to actual operative conditions) will also allow a new kind of diagnostic capabilities from the possibility of comparing actual performance to expected ones. A deviation of the measured (actual) performance from the expected (adjusted) ones, beyond a certain threshold, may be read as a first indication of some of phenomena or problem affecting the machine and causing its operative parameters to deviate

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 • Temperature : 50°C	• Pressure : 1 bar a • Temperature : 35°C

Table 1. Inlet condition of predicted performance and inlet condition of tested performance.

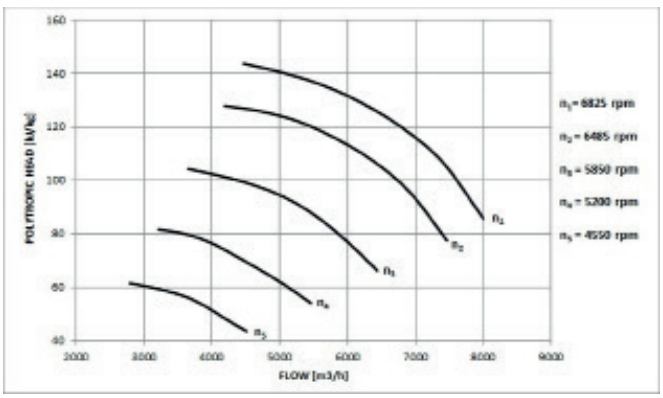


Figure 3. Polytropic head in Specification condition.

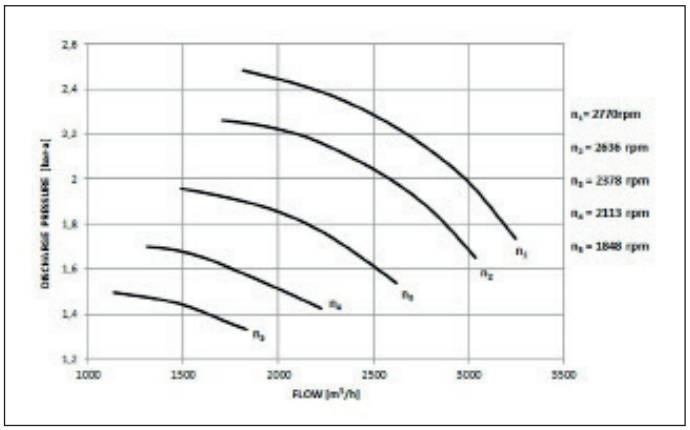


Fig. 4. Discharge pressure in test condition (with Freon R134a).

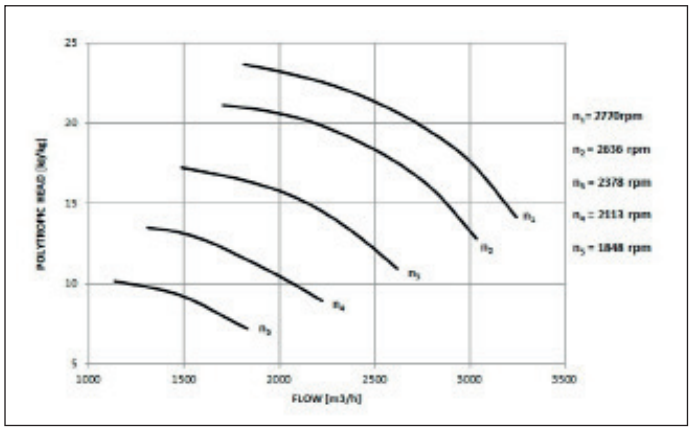


Fig. 5. Polytropic head in test condition (with Freon R134a).

When implemented in IPC monitoring systems, CMap software is able to store automatically data and to provide a real time indication of the compressor efficiency and a comparison with expected ones. The detection of a deviation of actual efficiency form the expected efficiency (i.e. design adjusted in actual condition) is an indicator of the health status of the compressor.

This feature permits the continuous indication of how much the machine's behaviour is aligned with design expectations. These evaluations can be used to see historical trends and to build pictures of the status during operation. Collected data will be useful to support decision making on predictive maintenance activities plans an operations.

Another important application of this method is the use of CMap software for prediction of modification of surge points in actual operative conditions, with different inlet pressure and temperatures, different operative gas. This method, called SPS, is suited to the protection of heavy duty, heavy pressure centrifugal compressors, especially when working under time-varying inlet conditions.

The availability of such advanced compressor protection, increases the level of machinery protection and avoids potential critical failures due to the catastrophic effect of the compressor surge. Also the dangerous effect of possible surging of short duration, but with repetitive occurrence, whose cumulative action may cause an important reduction of the machine lifetime if not detected from the compressor protection system.

Methods proposed and described in this paper can allow:

- predict the tested performances of a centrifugal compressor with Freon R134a as inlet gas.
- predict the performances of a centrifugal compressor under varying thermodynamic conditions of the inlet gas. The prediction of compressor performances is accurate even at high pressures, where the ideal gas theory commonly used introduces considerable errors.
- analyze the performance of the compressor during operation and compare them with those expected provided by the manufacturer.
- have useful indications on the health of the compressor (diagnostics) based on the capability to analyze the performances and efficiency of the machine in a simple and immediate way.
- implement advanced method for antisurge protection SPS
- CMap may be used as third party software for validation of compressor test performance during OEM shop test.
- the methods and software tools have been validated against much compressor technical data, and against all available scientific papers on thermodynamic gas theories developed in the hydrocarbons research field.

Conclusion

Experiences with real machinery showed that compressor performance prediction obtained with Cmap software are in good alignment with OEM predictions and field measurement. In those cases where deviation had been detected, Cmap allowed the identification of compressor anomalies, giving useful quantitative indication for possible corrective action ●

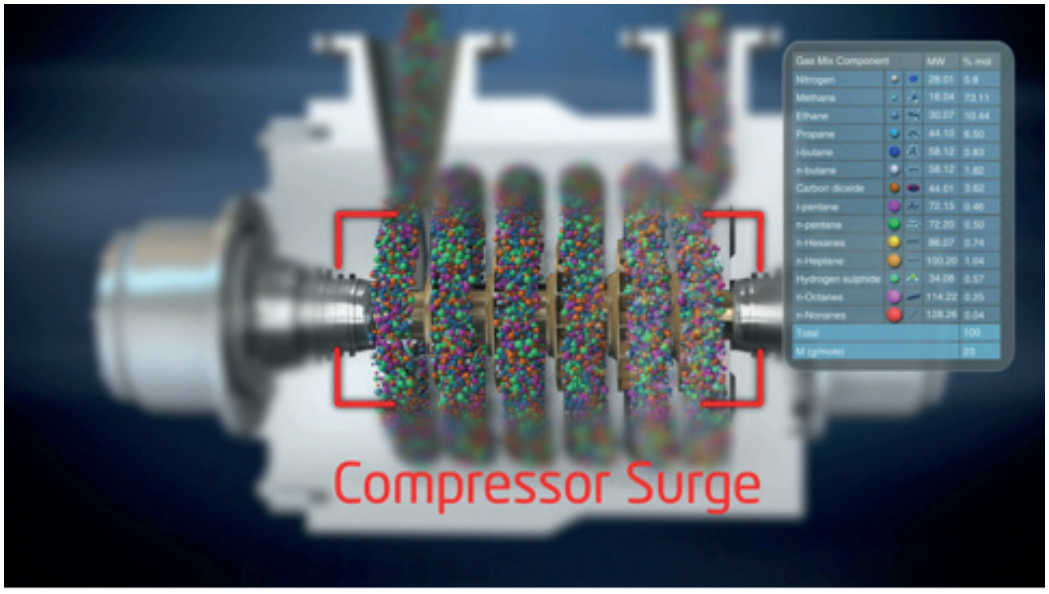


Fig. 6. Compressor surge in actual operative conditions.

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