CENTRIFUGAL COMPRESSOR SIMULATION OF PERFORMANCE TEST WITH FREON R134A

BY MASSIMILIANO DI FEBO AND PASQUALE PAGANINI

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INTRODUCTION

One of the primary tasks during the manufacturing process of a centrifugal compressor is shop testing. Compressor testing, usually performed at original equipment manufacturer (OEM) facilities, are generally performed to validate the performance as stated by the OEM in the machinery specification sheets.

Centrifugal compressor shop testing represents one of the main steps in the machine manufacturing process. The importance of this phase is to make sure, in almost all cases, the project quality requirements includes a witnessed test, to be executed so that the manufacturer predictions meet the specification (design) performance.

Shop testing for centrifugal compressors is a quite delicate task. Sometimes, inlet conditions during the test are different from specification conditions defined in the machine's data sheets.

Occasionally, the need for different inlet pressures and temperatures may occur; 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 PTC 10 (Performance Test Code on Compressors and Exhausters) standard identifies these possible different test cases and refers to the Type 1 test for testing with the same specification gas and specification conditions, and the Type 2 test for testing with a different gas and/or inlet conditions.[1]

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

Similar consideration may apply to field testing where the inlet conditions, at test time, 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 time in unpredictable ways. In these cases, the availability of computational tools for the prediction of compressor performance under changed (off-design) inlet conditions may be of valuable help.

PURPOSE AND METHOD DESCRIPTION

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

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

The main parameters used to assess the performance of a centrifugal compressor were flow, head, power absorbed, and efficiency.

Some additional conditions are needed to allow a significant

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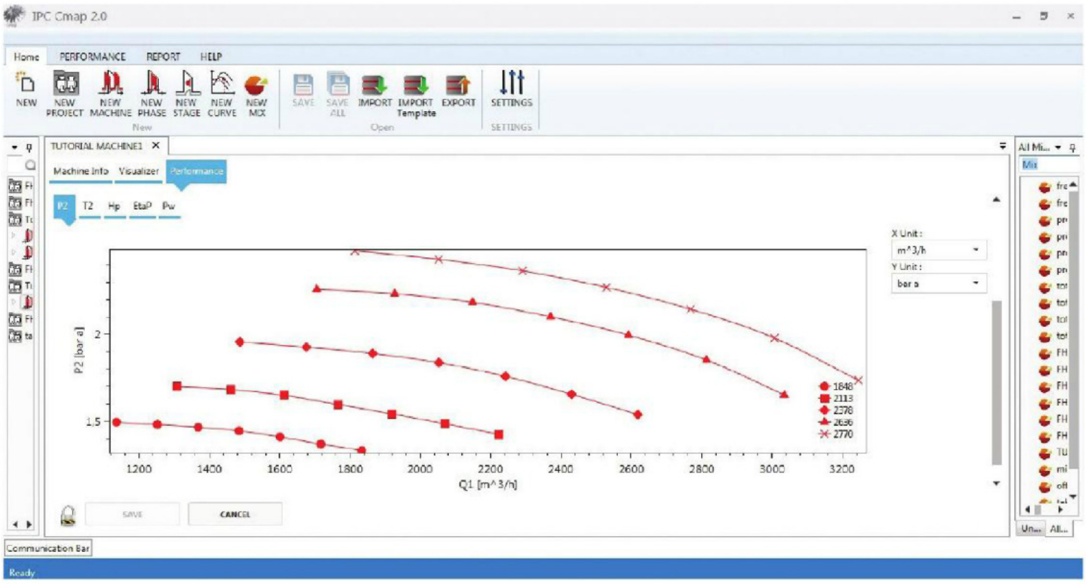

Figure 1: Screen Shot Of The CMap Software

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 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.

(1) $\Phi = \frac{Q_1}{\frac{\pi}{4}D^2u^2}$ Flow Coefficient

(2) $\Psi = \frac{gH_p}{u^2}$ Head Coefficient

(3) $Mu = \frac{u}{\sqrt{kZRT}}$ Mach Number

(4) $Re = \frac{\rho ub}{\mu}$ 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-predicted performance in specification conditions and allow, within a certain range, a test with gas mixes different from the design one.

In this paper, the test performance was predicted considering Freon R134a as the test gas. R134a is, in fact, a typical gas used in many performance tests.

SIMULATION

As said, 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 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 1).

Specification Inlet Conditions	Test Inlet Conditions
Gas Mixture 80.51% Methane 1.46% Nitrogen 14.69% Ethane 3.19% Propane 0.07% I-butane 0.08% N-butane	Gas Mixture 100% R134a
Pressure: 40.2 bara (583 psi) Temperature: 50°C (122°F)	Pressure: 1 bara (14.5 psi) Temperature: 35°C (95°F)

Table 1. Inlet Condition Of Predicted Performance And Inlet Condition Of Tested Performance

CMap performs the compressor performance prediction using different equations of state (EOS) depending on the gas mix considered in the calculation. For the hydrocarbon gas mixture, Lee-Kesler or Peng-Robinson EOS can be used. For Freon R134a, the modified Benedict-Webb-Rubin (MBWR) EOS was selected to determine the thermodynamic properties of the operating fluid.

After this first calculation step, it will be possible to proceed to the comparison of 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.

Figures 2 through 5 show the predicted tested performance curves obtained with the software CMap.

METHOD: POSSIBLE APPLICATIONS

As stated at the beginning of this paper, a first application mode of this method consists in the execution of a comparison of the test-predicted maps to the measured test performance. Using the CMap software, the OEM specification (design) maps are, in fact, quickly adjusted to the test conditions

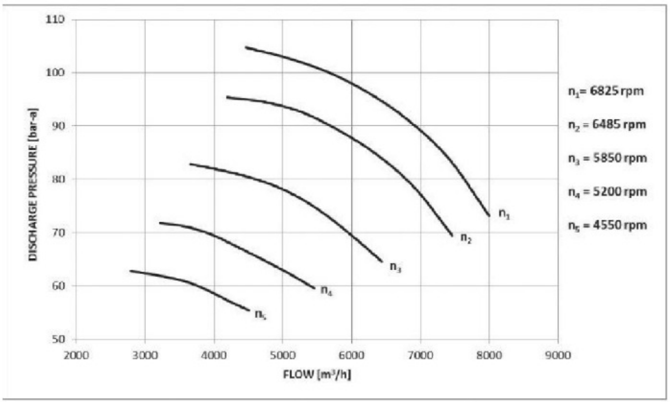

Figure 2: Discharge Pressure In The Specification Condition

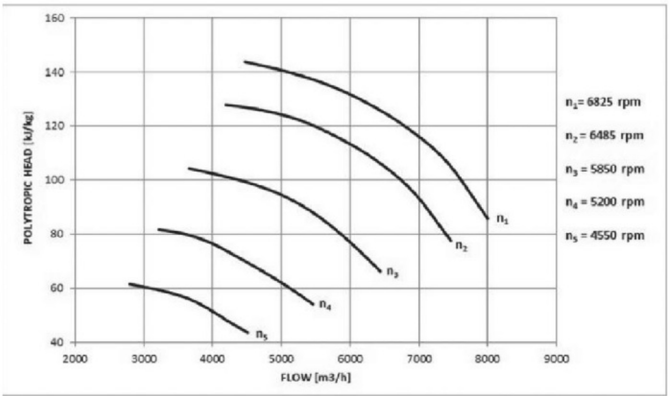

Figure 3: Polytropic Head In The Specification Condition

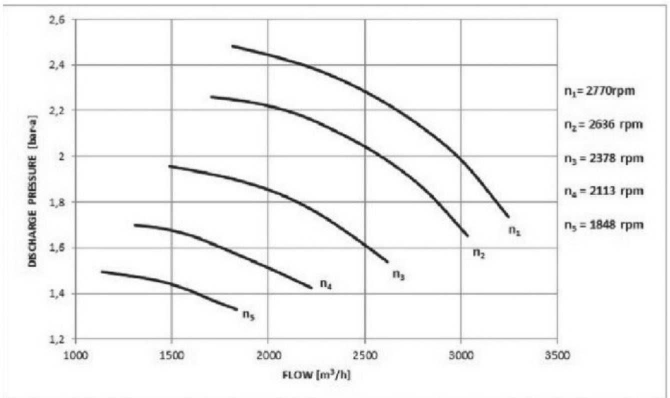

Figure 4: Discharge Pressure In The Test Condition (With Freon R134a)

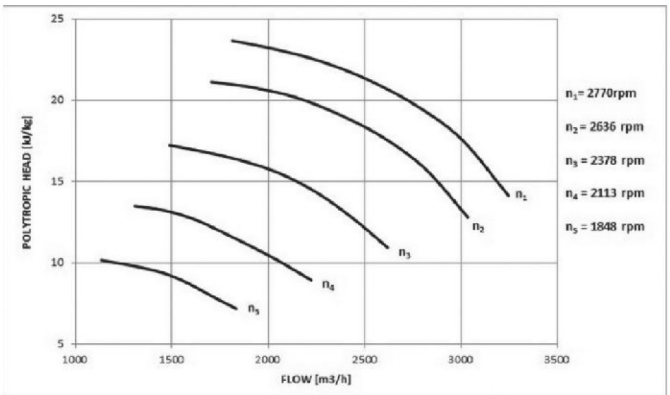

Figure 5: Polytropic Head In The Test Condition (With Freon R134a)

with a test gas and different inlet pressure and temperature. Obtained predicted maps can easily be superimposed to the measured test maps. This comparison will allow the machine to match the specified conditions.

The proposed method also can be profitably used to predict the centrifugal compressor overall performances when running with operative inlet conditions different from specification ones. This may be the case of a compressor running in operative conditions different from specification ones. In this case, the proposed method can 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 allow new kinds of diagnostic capabilities arising from the possibility of comparing actual performances to expected ones. A deviation of the measured (actual) performance from the expected (adjusted) ones, beyond a certain threeshold, may be read as a first indication of some phenomena or problem affecting the machine and causing its operative parameters to deviate from expected values.

When implemented in IPC monitoring systems, CMap software is able to store data automatically and to provide a realtime indication of the compressor efficiency and comparison with expected ones. The detection of a deviation of actual efficiency from the expected efficiency (i.e., design adjusted in ac-

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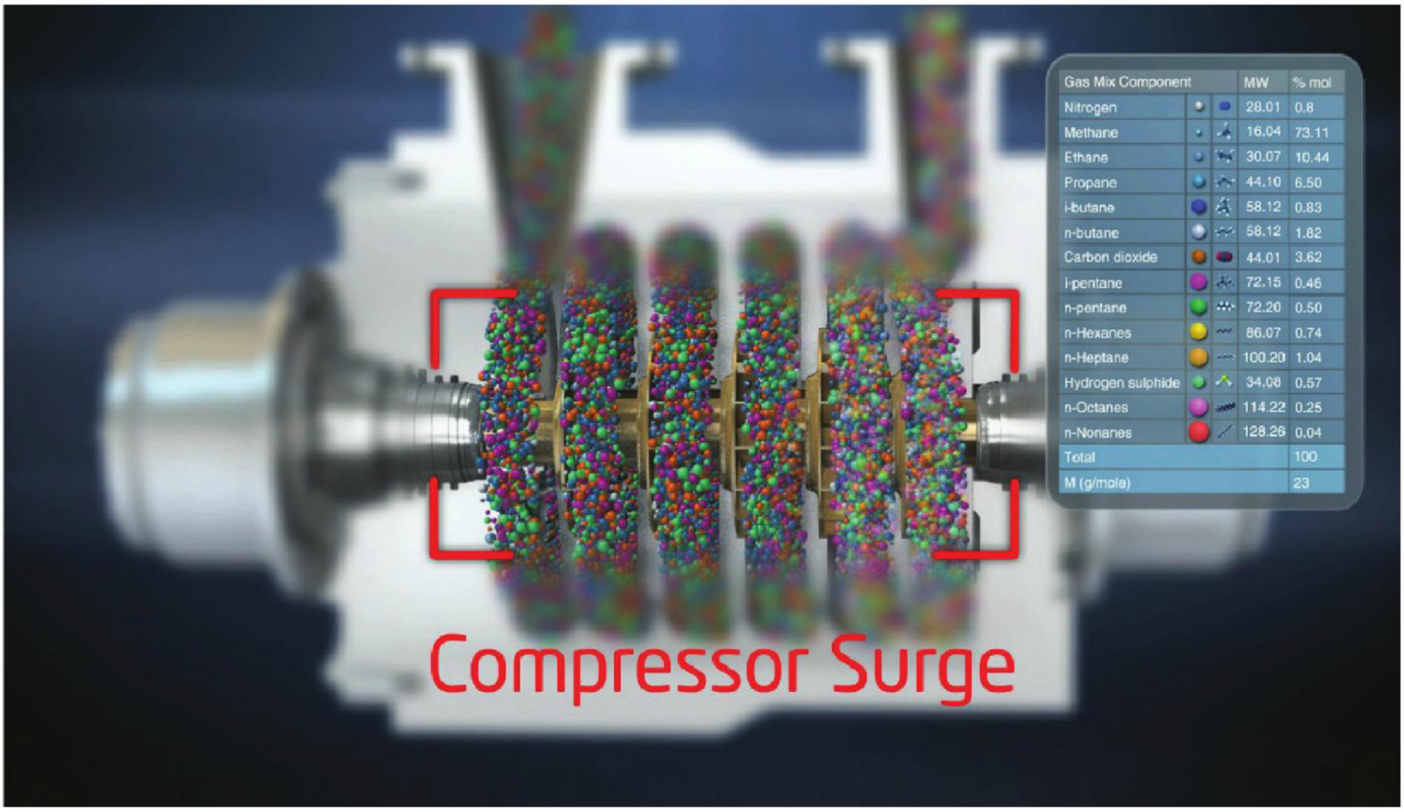

Figure 6: Compressor Surge In Actual Operative Conditions

tual condition) is a meaningful indicator of compressor health status. This is a powerfull feature that permits continuous indication about how much the machine behavior is aligned with design expectations. These evaluations can be used for historical trends and to build pictures of the machine's status along the operation period. Collected data will be useful to support decision making on predictive maintenance activity plans and operations.

Another important application of the presented method is the use of CMap software for the prediction of modification of surge points in actual operative conditions (Figure 6), with different inlet pressures and temperatures and different operative gases. This method is called SPS, which is under IPC patent. This method is well suited for protection of heavy-duty, heavy-pressure centrifugal compressors, especially when working under time-varying inlet conditions.

Availability of these kinds of advanced protection features increases the level of machinery protection and allows potential critical failures to be avoided that might be caused by catastrophic effects of the compressor surge as well as the dangerous effects of possible surging events of short duration but with repetitive occurrence, whose cumulative action may cause an important reduction of the machine's lifetime if not detected from the compressor protection system.

CONCLUSIONS

Experiences with real machinery showed that compressor performance predictions obtained with CMap software are in very good alignment with OEM predictions and field measurements. In those cases where deviation was detected, CMap identified compressor anomalies, giving useful quantitative indications for possible corrective actions.

Methods proposed and described in this paper allow the following:

- Prediction of tested performances of a centrifugal compressor with Freon R134a as the inlet gas.
- Prediction of 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.
- Analysis of the performance of the compressor during operation to compare them with those expected provided by the manufacturer.
- Useful indications on the health of the compressor (diagnostics) based on the capability to analyze the performances and efficiencies of the machine in a simple and immediate way.
- CMap may be used as a third-party software to validate compressor test performance during the OEM shop test.
- The methods and software tools have been validated through many compressor technical data and all the available scientific papers on thermodynamic gas theories developed in the hydrocarbons research field.

REFERENCE

[1]ASME PTC 10-1997 (Rev. 2014), "Performance Test Code on Compressors and Exhausters" (New York, NY: American Society of Mechanical Engineers [ASME], 2014).