COMPRESSOR MAPS MODIFICATION IN OFF-DESIGN CONDITIONS

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INTRODUCTION

Centrifugal compressors are a vital component within process plants. Availability of these machines is often critical for plant output and its overall profitability. In this perspective, the capability to evaluate machine performance assumes a primary significance; so, the capability to understand how good the machine is running in an off-design condition and how much it is deviating from expected performances becomes important.

As known, centrifugal compressor performance depends on inlet operative conditions, i.e., gas mix composition and inlet pressure and temperature. In general, inlet conditions may be subject to changes during operational time, and these changes may cause significant distance and inlet condition changes that were not considered at the design stage. Therefore, every approach attempting to evaluate the machine conditions based on the assessment of compressor performance will necessarily require the capability to predict, every time, the compressor performance with current inlet conditions. To accomplish this specific task, an adequate computational model shall be used, embedding and coupling both compressor aeromechanics and compressed gas thermodynamic models.

COMPRESSOR PERFORMANCE

Usually, compressor performances are described in terms of graphs of discharge pressures, discharge temperatures, polytropic heads, efficiencies, and absorbed power, which are plotted for differed running speeds against the actual flow and related to the same reference inlet conditions.

A group of plots is usually called a performance map. According to common practices for the process industry, original equipment manufacturers (OEMs) provide compressor performance maps for one or more specific design inlet conditions (Figure 1).

As anticipated, it may happen that during operational time, field inlet

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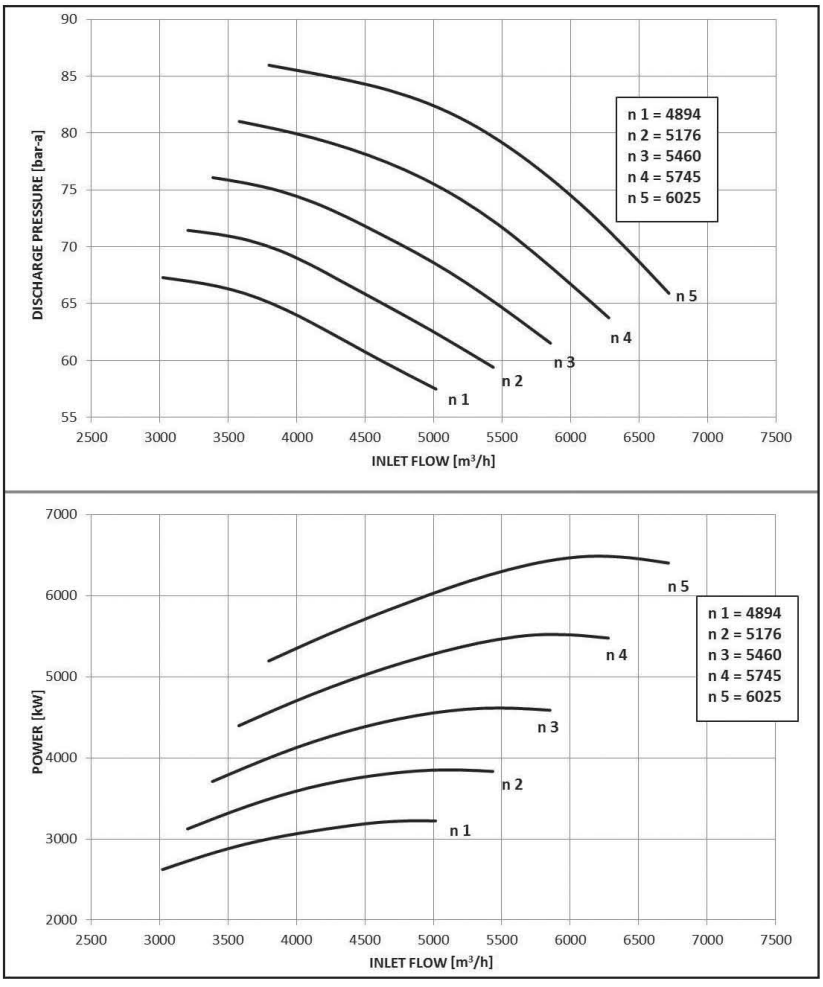


Figure 1: Performance Map

conditions are different from specification conditions (indicated in the machine data sheets). This may happen for several reasons, such as the long time interval occurring from the design stage to the operational phase or the cause of process inherent behavior, just to mention some. In these situations, to assess the compressor performance, it will be necessary to adjust the design performance map to operative conditions.

The main purpose of this paper was to present how the compressor performance maps change according to changes of inlet conditions. In the following, these inlet conditions shall be referred as off-design condition just to distinguish it from the reference conditions. Modified performance maps shall be obtained through a numerical analysis. The applied method shall be described here in brief.

All numerical evaluations reported in this paper have been developed using CMap software. CMap embeds the most recent thermodynamic theories and machine aeromechanical models and works according to the ASME PTC10 (Performance Test Code on Compressors and Exhausters) standard.[1]

BRIEF METHOD DESCRIPTION

The starting point of the method is the availability of a centrifugal compressor performance map, the relevant gas mix composition, and thermodynamic conditions (pressure and temperature). With these inputs available, the software will perform the complex calculations and produce the predicted compressor performances maps for off-design conditions (Figure 2).

Calculation of off-design performance requires the capability to extract the invariant information that describes the compressor behavior. This information is then used to rebuild and predict the performance under the new inlet conditions. Necessary calculations couple intimately the compressor aeromechanic and the thermodynamic of real gas mixtures. CMap is, in effect, sensitive to inlet pressure and temperatures, but also to each component of the gas mix, so that a variation of a single mix component is potentially able to manifest its effects.

In CMap, no approximation is used. The gas mix is not described simply by its molecular weight, and the thermodynamic gas behavior is predicted with equations of state (EOS). The result is a unique computational tool with the capability of predicting machine performance with very high accuracy over a large range of operational conditions and with validity covering practically all the major commercial compressors.

CALCULATION CASES

Under real operative conditions, it may happen also that the inlet pressure, inlet temperature, and gas mix compositions vary simultaneously, affecting compressor performance. To provide information on the various possible performance modifications, in this paper, four variations of the inlet parameter have been considered:

- Gas mix composition variation
- Inlet pressure variation
- Inlet temperature variation
- Simultaneous variation of inlet parameters

The analysis developed with CMap allowed performance maps in these off-design conditions to be obtained. From the off-design maps, it is possible to highlight the compressor's new operating range (new surge line, new stall line).

In Table 1, the considered design inlet conditions are shown. Figure 3 depicts the gas mix composition.

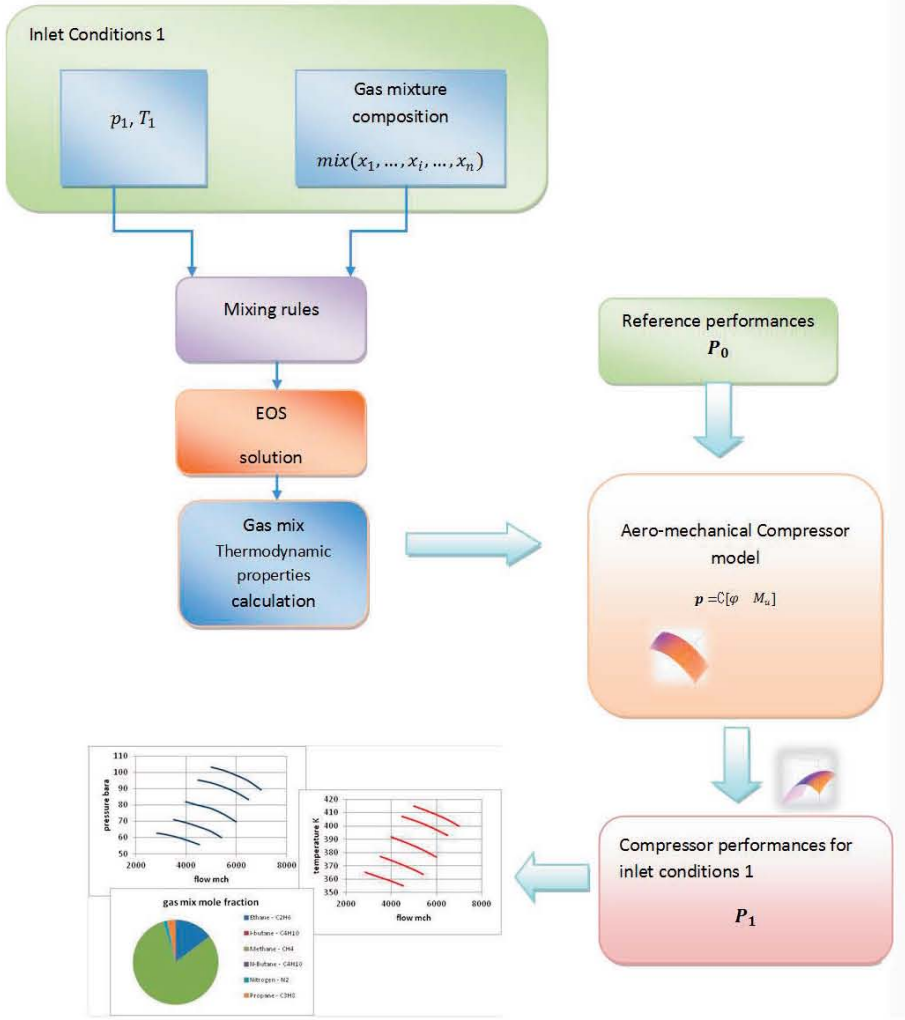


Figure 2: How CMap Works

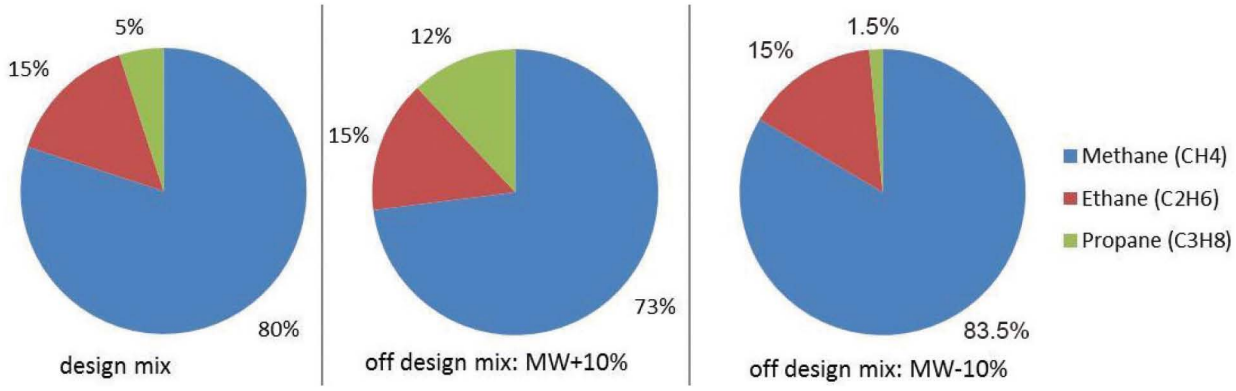


Figure 3: Gas Mix Composition

Hydrocarbon mix MW [kg/kmole]	19.55
Inlet pressure [bar a]	40.2
Inlet temperature [°C]	50

Table 1. Design Inlet Conditions

Gas Mix Composition Variation

In this case, the gas mix composition was changed such that the molecular weight varied between 10 and –10%. Figure 4 shows how the maps change (discharge pressure vs. inlet flow, power shaft vs. inlet flow) by varying the gas mix composition.

Inlet Pressure Variation

In this case, the inlet pressure was changed between 20 and –20% of the design condition. Figure 5 shows how the maps change (discharge pressure vs. inlet flow, power shaft vs. inlet flow) by varying the inlet pressure.

Inlet Temperature Variation

In this case, the inlet temperature was changed between 20 and –20°C (60 and –4°F) of the design condition. Figure 6 shows how the maps change (discharge pressure vs. inlet flow, power shaft vs. inlet flow) by varying the inlet temperature.

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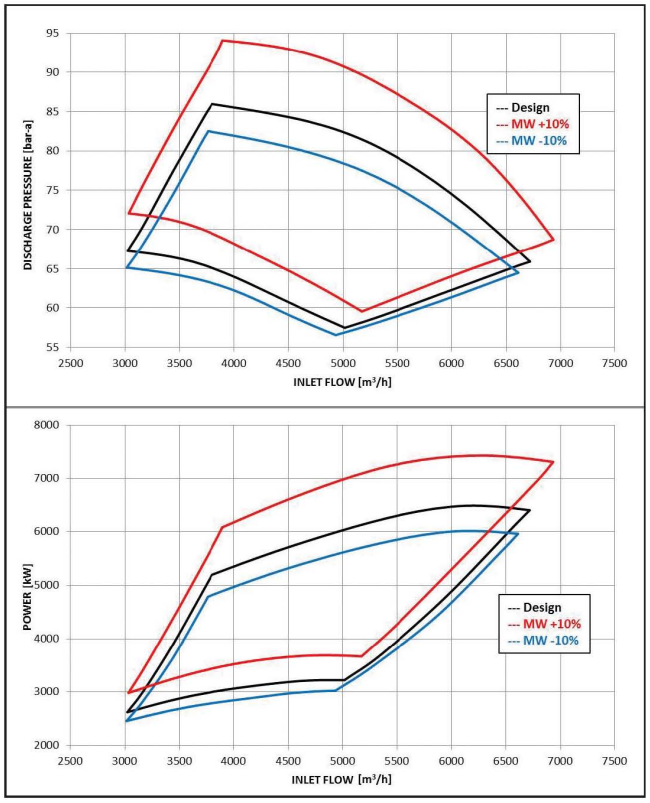


Figure 4: Map Modified For Gas Mix Composition Variation

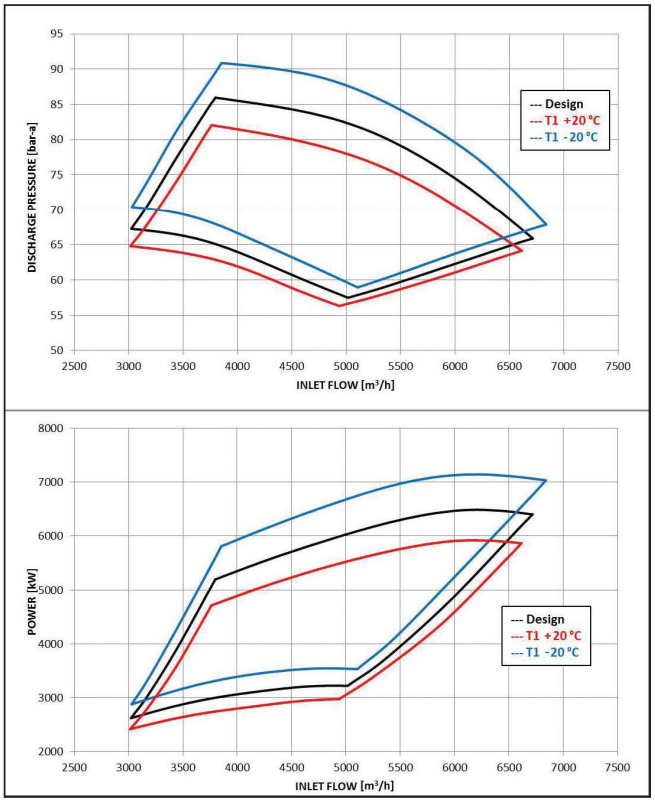


Figure 6: Map Modified For Inlet Temperature Variation

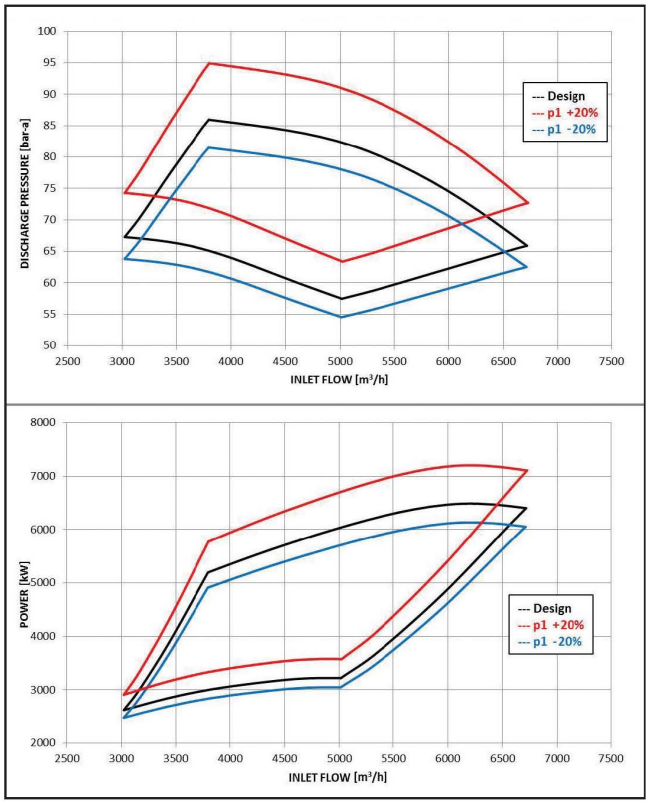


Figure 5: Map Modified For Inlet Pressure Variation

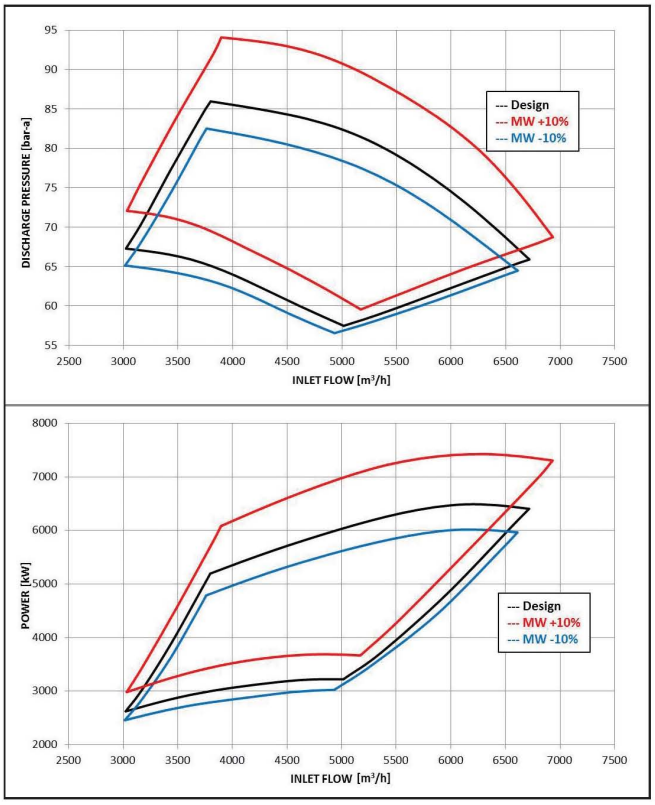


Figure 7: Map Modified For Inlet Parameter Variation

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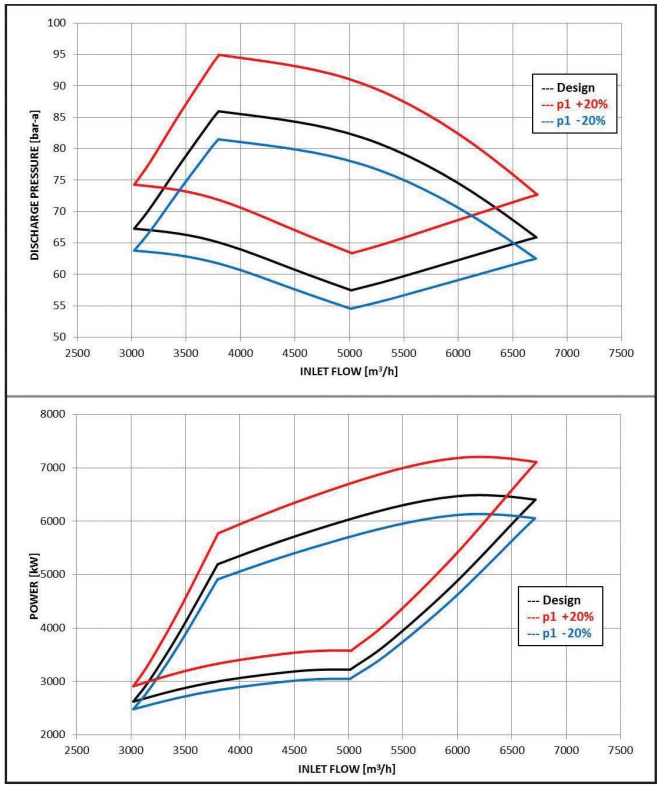


Figure 8: Screen Shot Of CMap2.0

Simultaneous Variation Of Inlet Parameters

In this case, the inlet pressure, inlet temperature, and gas mix composition are changed simultaneously (inlet pressure: ±20%, inlet temperature: ±20°C, and MW ±10%). Figure 7 shows how the maps changed (discharge pressure vs. inlet flow, power shaft vs. inlet flow) by simultaneously varying the inlet parameter.

The curves in Figures 4 through 7 display the shift of the surge line, the shift of the stonewall, and the change of the slope curve. Figure 8 shows a screen shot of the CMap.

CONCLUSIONS

The numerical analysis presented in this paper illustrates how it is possible, using advanced computational tools such as CMap, to determine accurately the centrifugal compressor performance under varying inlet conditions. The calculation method, implemented in CMap software, has been proven and validated over a large range of compressors from centrifugal compressor OEMs.

Experiences with real machinery showed that compressor performance prediction obtained using CMap software are in very good alignment with OEM predictions and field measurement for machines in good conditions.

Methods proposed and described in this paper allowed the following:

- Prediction of a centrifugal compressor performance map in off-design conditions — The prediction of compressor performance is accurate even at high pressures, in which the ideal gas theory commonly used introduces a considerable amount of errors.
- Prediction of the modification of surge points in actual operative conditions, with different inlet pressures and temperatures, different operative gases, and the implementation of advanced protection from surge.
- Implementation of an advanced diagnostic system able to analyze machine performance in operational time and identification of possible problem areas.

ABOUT THE AUTHORS

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REFERENCES

[1]ASME PTC 10-1997, "Performance Test Code on Compressors and Exhausters" (New York, NY: ASME, 1997).