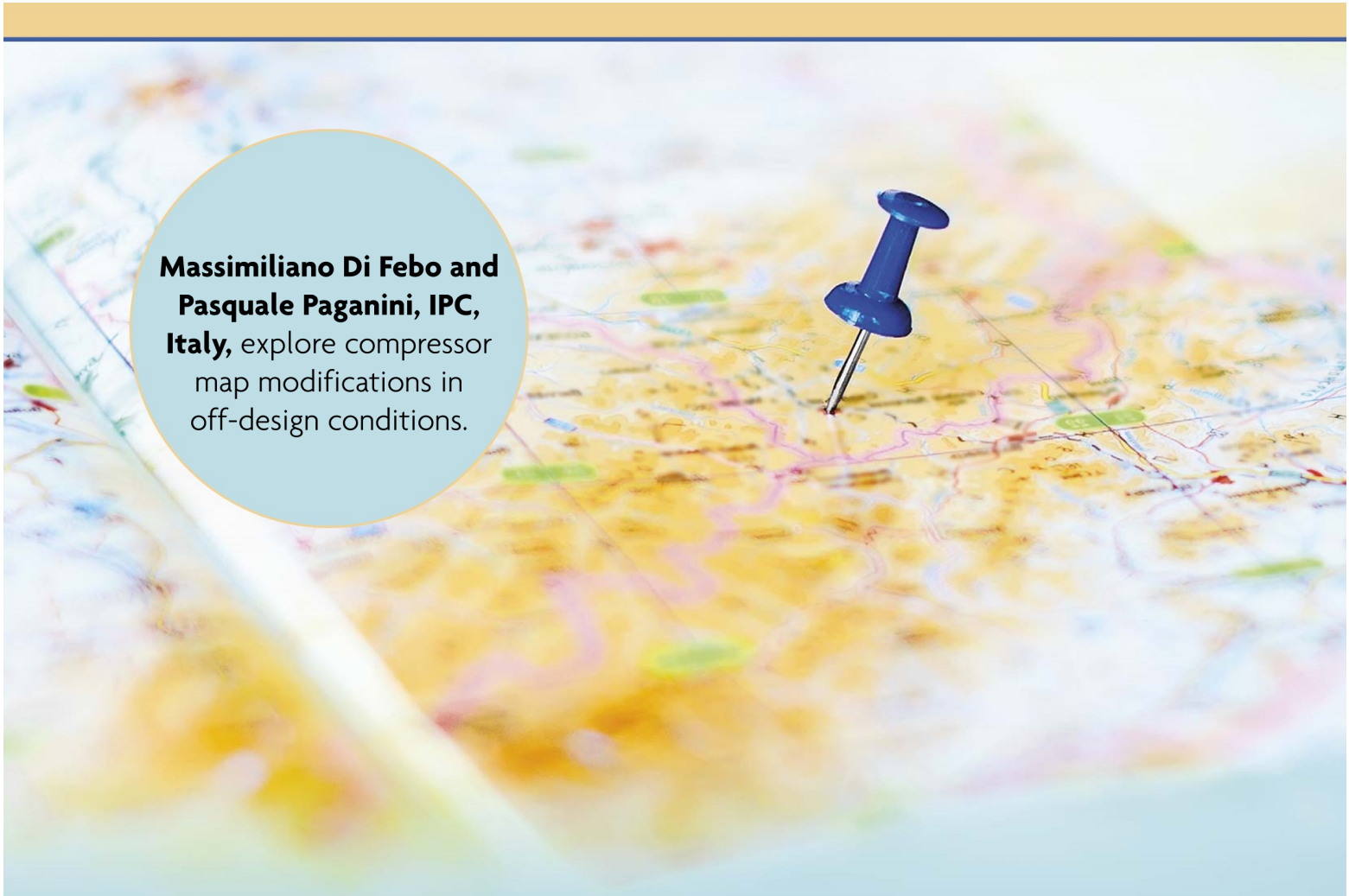


Massimiliano Di Febo and Pasquale Paganini, IPC, Italy, explore compressor map modifications in off-design conditions.

MAPPING OUT THE POSSIBILITIES

Centrifugal compressors are a vital component of process plants and their availability is often critical for plant output and overall profitability. Therefore, the evaluation of machine performance is of primary significance, particularly in order to understand how well the machine is running in off-design conditions and how much it is deviating from expected performances.

The performance of centrifugal compressors depends on inlet operative conditions, i.e. gas mix composition, inlet pressure and temperature. Inlet conditions can be subject to change during operations, which may necessitate the compressor to operate with different inlet conditions than those that were considered during the design stage. Therefore, approaches that attempt to evaluate machine conditions based on the assessment of compressor performance will need to make a prediction based on the current inlet conditions. In order to accomplish this specific task, an adequate computational model should be used, which embeds and couples both compressor aeromechanics and compressed gas thermodynamic models.

Compressor performance

Compressor performance is usually represented in graphs of discharge pressures, discharge temperatures, polytropic heads, efficiencies and absorbed power. These are plotted with their corresponding running speeds against the actual flow and related to the same reference inlet conditions.

Table 1. Design inlet conditions

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

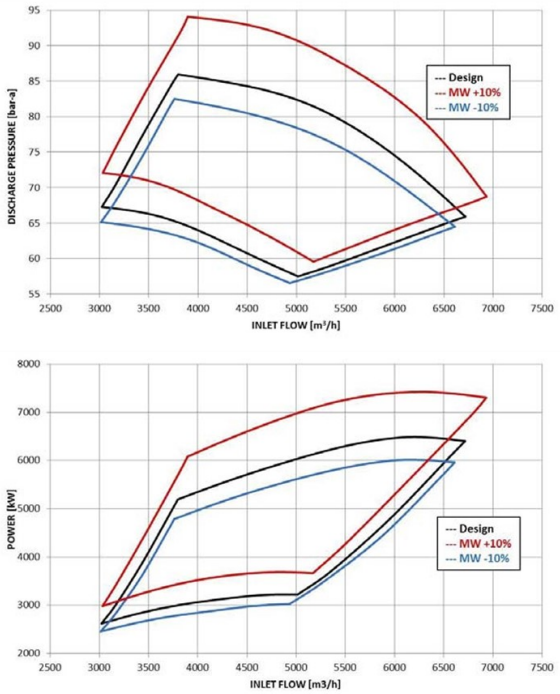


Figure 1. Map modification for gas mix composition variation (discharge pressure vs inlet flow; power shaft vs inlet flow).

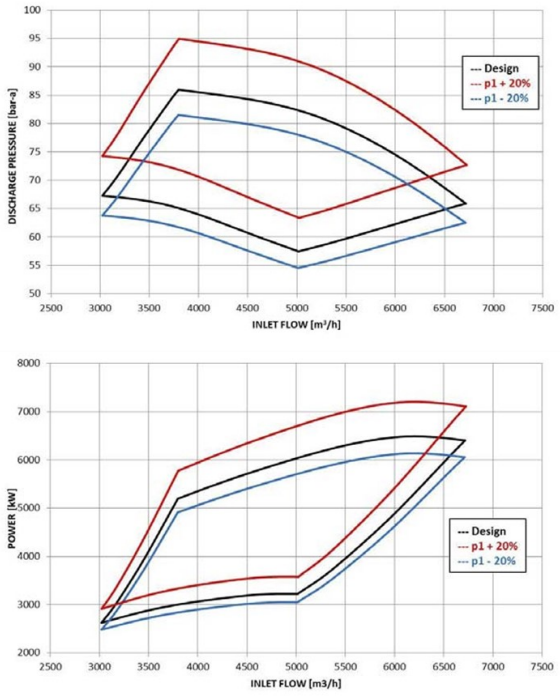


Figure 2. Map modification for inlet pressure variation (discharge pressure vs inlet flow; power shaft vs inlet flow).

A group of these plots are called performance maps. Commonly, original equipment manufacturers (OEMs) provide compressor performance maps for one or more specific design inlet condition.

During operational time, however, field inlet conditions can differ from the specification conditions indicated in the machine data sheets. In these situations, it is necessary to adjust the design performance map to operating conditions in order to assess the compressor performance.

This article will present how the compressor performance maps vary with regards to changes in the inlet conditions and will briefly describe the best method of how to apply them. These inlet conditions shall be referred to as off-design conditions to distinguish them from the reference conditions. Modified performance maps shall be obtained through a numerical analysis.

All numerical evaluations to be discussed were developed using the CMap software. CMap embeds the most recent thermodynamic theories and machine aeromechanical models, and works according to the prescriptions of the ASME PTC10 (Performance Test Code on Compressors and Exhausters) standard.

Brief method description

Using a centrifugal compressor performance map, the relevant gas mix composition and thermodynamic conditions, the software can perform full automated calculations to produce predictive compressor performance maps for off-design conditions.

Calculating the off-design performance requires the ability to extract invariant information that describes the compressor's behaviour. This information is then used to rebuild and predict the performance under new inlet conditions. CMap is sensitive to inlet pressure and temperatures, as well as each component of the gas mix. As such, it can map variations in a single mix component and its possible effect on compressor performance.

The software rules out approximation and guesswork, resulting in a computational tool that can predict the machine performance with high accuracy over a large range of operational conditions, across most major compressors.

Calculation cases

Under operating conditions, the inlet pressure, inlet temperature and gas mix composition can vary simultaneously, consequently affecting the compressor performance. In order to provide information on the various possible performance modifications, four different variation cases of the inlet parameter will be considered:

- Gas mix composition variation.
- Inlet pressure variation.
- Inlet temperature variation.
- Simultaneous variation of inlet parameter.

Analysis developed with CMap makes it possible to create performance maps that can consider these

off-design conditions. The maps can then be used to highlight the compressor's new operating range (e.g. new surge line, new stall line). Table 1 presents the set of

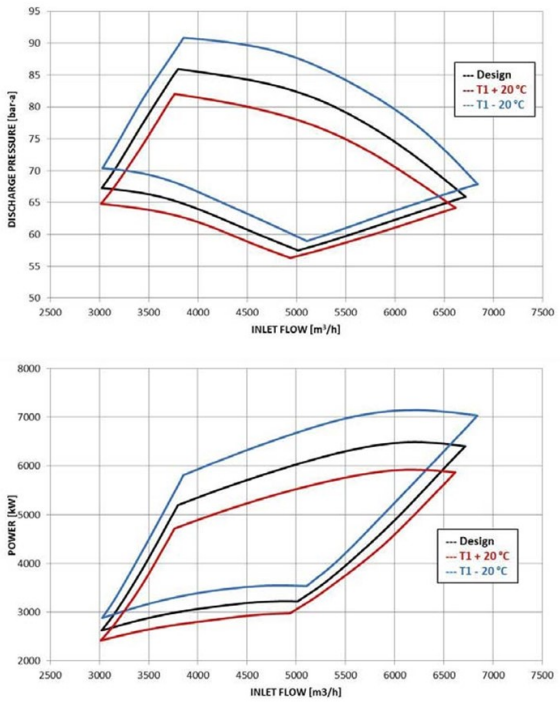


Figure 3. Map modification for inlet temperature variation (discharge pressure vs inlet flow; power shaft vs inlet flow).

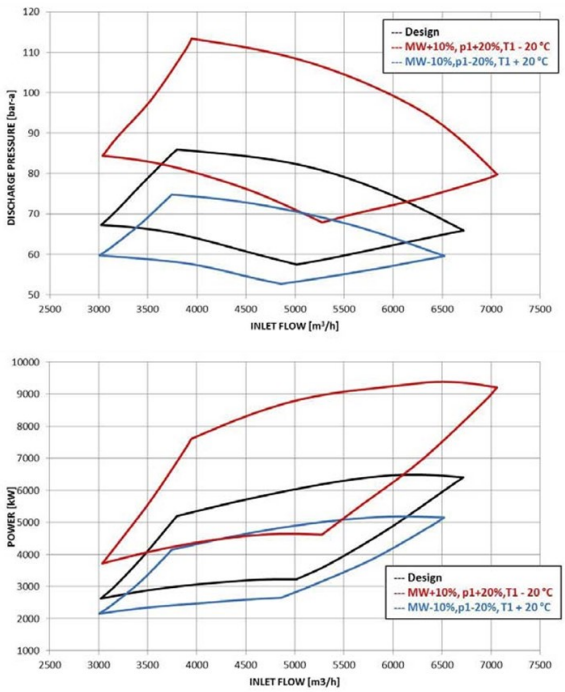


Figure 4. Map modification for inlet parameter variation (discharge pressure vs inlet flow; power shaft vs inlet flow)

design inlet conditions on which the case analysis of this article will be based.

Following a numerical analysis, the initial (design) maps and the modified (off-design) maps are superimposed on a single graph in order to allow an immediate comparison of the performance changes.

Gas mix composition variation

As the gas mix composition changes it can cause the molecular weight to fluctuate between +10% and -10%. Figure 1 shows how the software maps these potential changes and demonstrates how they would impact compressor performance.

Inlet pressure variation

Similarly, Figure 2 shows how the software maps inlet pressure changes of between +20% and -20% and the effect this has on compressor performance.

Inlet temperature variation

Figure 3 also highlights how the software maps off-design conditions, presenting how changes in inlet temperature of between +20°C and -20°C can impact the compressor performance.

Simultaneous variation of inlet parameters

Finally, Figure 4 maps the impact of simultaneous changes in the inlet pressure, inlet temperature and gas mix composition (inlet pressure ±20%, inlet temperature ±20°C and MW ±10%).

It is important to note the shift of the surge line and the stonewall as well as the change of the slope curve displayed in each of the four case study Figures.

Conclusion

The numerical analysis demonstrated in this article illustrates how it is possible to accurately determine the centrifugal compressor performance under varying inlet conditions, using advanced computational tools such as CMap.

The calculations generated by the CMap software have been validated over a large range of compressors from the main centrifugal compressor OEMs.

These experiences with real machinery showed that compressor performance predictions obtained with the software are in alignment with OEM predictions and field measurement for machines in good conditions.

Overall, advanced computational tools can help predict the performances of a centrifugal compressor in off-design conditions and present them in computational maps. These predictions are accurate even at high pressures.

Furthermore, it is possible to predict how surge points in operating conditions can vary with different inlet pressures, temperatures, and gas mix composition, as well as advise how best to implement advanced protection against these surges. Finally, the software allows the implementation of advanced diagnostic systems in order to analyse machine performance in operational time and

shaft vs inlet flow).

identify possible problem areas in the future.