CENTRIFUGAL COMPRESSOR PERFORMANCE MONITORING SYSTEM

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ABOUT THE AUTHORS

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INTRODUCTION

Condition And Preventive Maintenance

Centrifugal compressors represent a vital component within process plants. Assuring safe and optimal operative conditions for compressors is often understood as a primary goal for the process plant maintenance management teams. In the course of the last decade, the approach to process plant machinery maintenance has changed radically. The initial, corrective approach, with repair interventions after the failures, has been followed by the preventive approach, with parts replaced at fixed work hours. This last approach represents a considerable improvement, especially for important machines, but it has not been considered optimal since it requires the execution of maintenance interventions and parts replacement even in the absence of failure signals, producing consequent unnecessary associated costs. An optimal method should then be able to signal when the component is approaching a critical status and provide a notification with enough advance notice to organize the necessary logistics and resources for the maintenance interventions.

Actual Trends And Compressor Predictive Maintenance

For most common centrifugal machines, the predictive techniques commonly implemented today are connected to the vibrational conditions and, in general, to mechanical indicators (mainly bearing vibrations and temperatures). Furthermore, there are a certain number of cases in which defects may have a subtle appearance, as, for example, the situations in which a degradation of the machine appears without being accompanied by mechanical signals. In such cases, the machine performance deficiency gets worse and progressively starts to affect the plant performance without triggering mechanical indicator alerts. In these situations, the problem source continues to operate inside the machine, until it appears, accompanied by mechanical indicators. A typical case of this subtle behavior is fouling, which introduces a progressive loss in performance and efficiency, in the absence of mechanical indicators. Another aspect connected to the reading on vibration is that the measurement can change with the machine operational point while the threshold remains fixed. These considerations highlight the importance of machinery performance analysis. The underlaying machine modeling paradigm is called "digital twin" within the overall industry digitization trend. The quantitative approach at the base of this method may allow the connection to artificial intelligence (AI) solutions. Machine capability to deliver expected performance is a root signal of machine health, and lack of performance is the earliest external indicator of the presence of some problem. For compressors, the calculation of expected

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performance requires a sophisticated approach involving an aeromechanical machine model and gas thermodynamics and, consequently, the use of adequate calculation tools.

New Generation Monitoring Systems,
The Proactive Approach

The next generation of machinery monitoring systems should embed the capability to dynamically evaluate the machine performance according to effective operative conditions, where “dynamically” indicates that the limits should be adjusted to the machine’s actual operative condition. Also, these systems should be able to anticipate the problem, shifting the focus from the failure effect to the failure cause and providing possible indications about the time scale in which the problem is expected to develop. This is known as the proactive approach and represents the effort to push the preventive maintenance philosophy to its inherent limits. Actual process computers offer all the computational capability required for the implementation of an accurate, model-based performance monitoring method, bringing the traditional predictive systems into the proactive maintenance dimension. Advanced diagnostic capabilities arise from the coupling of machine performance analysis capability with the predictive methods based on analysis of mechanical parameters (vibrational, thermal, and tribological), thus not replacing but embedding and extending the previous systems’ capabilities.

Performance-Based Diagnostic
Method And Definitions

At the core of a performance monitoring system should be the capability to compare the actual performance to some reference value. To be significant, this reference value should represent the optimal machine performance. Therefore, design performance or as-tested performance may be used as a valid reference point. At this point, more details become necessary. In fact, while the measurement of actual performances is quite straightforward, the evaluation of the design performance may be quite complex. In the case of centrifugal compressors, to perform a comparison between homogeneous values, the design performance needs to be adjusted to actual operative conditions. This adjustment step is not trivial and, as such, requires the availability of adequate computing tools. To find the cause of the dependency of compressor performance from the gas mix composition and operative inlet conditions, a more complex aeromechanic and thermodynamic machine is necessary to get precise numerical results and allow a correct comparison to field-measured parameters.

Today, thanks to the diffusion of more powerful computational tools and machinery performance prediction software (such as CMap software for centrifugal compressors performance), these complex machine modeling capabilities are available in the market and allow diagnostic strategies to be implemented based on performance analysis (Figure 1).

Performance evaluation within machinery maintenance signals the irreversible step from qualitative evaluation to numerical and model-based methods, allowing machine maintenance to be aligned with other departments like engineering and operations. This process of integration is sometime called “performance productive maintenance,” revealing a larger view of the plant’s productiveness. The starting point of the method is the availability of a centrifugal compressor performance curve, the relevant gas mix composition, and thermodynamic conditions (pressure and temperature). Having this input data available, the software (powered by CMap) will perform all complex calculations in a fully automated way and will produce the expected compressor performances for inlet pressures, inlet temperatures, and gas mix compositions different for design/reference ones. By modeling the centrifugal compressor, it is possible to obtain a valid comparison term for the evaluation of compressor performance in actual condi-

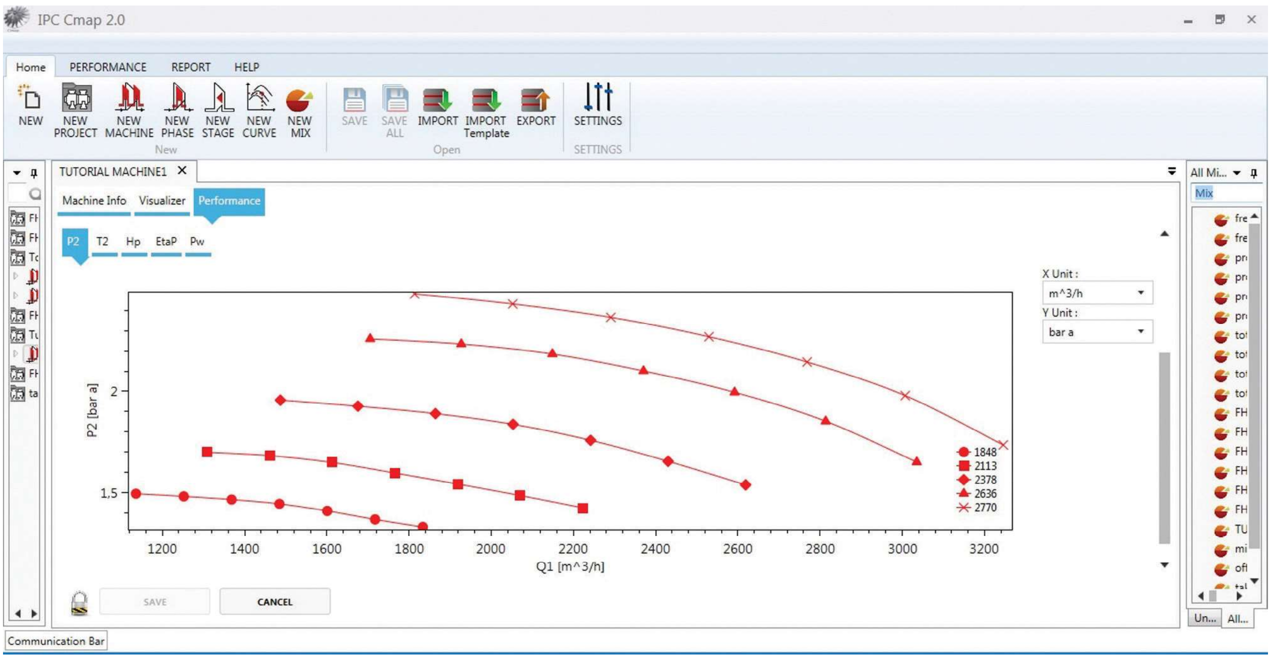

Figure 1. Screen Shot Of CMap

tions, referred to as expected performance. The method is compliant with the ASME PTC 10 (Performance Test Code on Compressors and Exhausters) standard.

System configuration parameters include the following:

- Compressor map in reference condition at variable speeds
- Inlet reference condition, i.e., inlet pressure, inlet temperature, and gas mix composition
- Selected equation of state for gas property calculation
- Measured parameters (actual) used as inputs include suction pressure, suction temperature, discharge pressure, discharge temperature, suction flow, running speed, and gas mixture

The system will provide calculated expected values, which is the compressor performance curve at the actual speed and inlet condition.

Once these performance values are obtained, it is possible to compare the actual values to the expected ones. The difference among these values, or "performance deviations," are indicators of how much the compressor behavior deviates from the normal/optimal behavior.

A value, in whatever operative condition, will be "normal" when its deviation is zero. Deviation zero consequently represents an operative status in which the machine is operating just as expected according to reference (or design) value. In the underlying hypothesis, the design performance is relative to an optimal (as new) machine condition or any way represents the reference term for any evaluation. Interestingly, these parameters may also be trended in time. The change in time of a deviation parameter shall represent a measure of how quickly the observed performance moves away from its "normal" value. When a performance deviation becomes irreversible in time, it is possible to say that the machine suffered a performance degradation. A stable degradation is a sign of a defect, non-critical and compatible with machine operations, which affects mainly performance. Degradations that increase in time are critical failures and will lead to critical events if not interrupted. Time trends of performance deviations, deviation rates, and degradations will provide a very powerful indication of the machine's health status and may be used in conjunction with mechanical indicators, with specific diagnostic logics to address possible failure causes. An application of these concepts has been implemented in IPC Compressor Monitoring systems. These systems are focused to continuous monitoring and a continuous evaluation of the machine performance, deviation, and degradation based on the comparison to performance expected according to original equipment manufacturer (OEM) data. This quantitative performance evaluation approach allows implementation of maintenance strategies optimizing schedules of interventions for maximum production and minimum costs.

CASE STUDY

The compressor under study was running for most of its operational time under off-design inlet conditions. A

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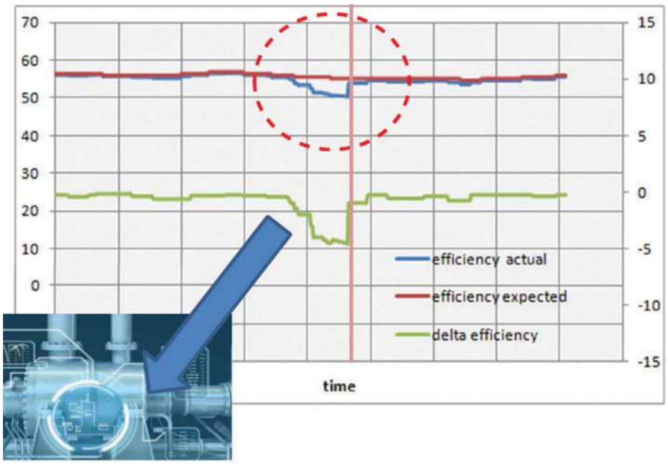

Figure 2. Time Trend Efficiency

performance-based monitoring system was implemented. The system included a calculation server devoted to run the machine model (CMap software) to obtain the expected or "normal" performance in actual (off-design) conditions. PC/PLC-based architecture allowed the machinery panel to predict machinery behavior according to OEM expectations, and this information was used to continuously evaluate the machine's health status. Automated application of CMap provided a continuous monitoring of the machine's performance and therefore exerted an automated surveillance and diagnostic. Also, the compressor protection from surge was updated automatically and continuously to actual inlet conditions to overcome the limitations of actual systems. The availability of expected performance data allowed the comparison to measured field values and evaluation of performance deviation and degradation. Figure 2 shows a comparison of the actual efficiency to expected efficiency in actual conditions. As previously mentioned, this parameter is a powerful indicator of compressor operative conditions and health status: eventual deviation between expected and actual parameters is an indicator of the occurrence of malfunctions.

The same trends are available for discharge pressure, discharge temperature, polytropic head, and power. Machine performance analysis coupled with mechanical indicators allowed, through specific logics, to generate some diagnostic advice regarding the nature of the failure, addressing the user toward some main defect areas such as mechanical, wear/fouling, and instrumentation. Machinery monitoring systems shall be the next generation of machinery surveillance systems. This quantitative performance evaluation approach allows predictive maintenance strategies to be implemented, optimizing schedules of interventions for maximum production and minimum costs. The proposed method could provide benefits, especially for centrifugal compressors that work in high- and very high-pressure ranges and under rapidly time-varying process conditions.

CONCLUSIONS

Methods proposed and described in this paper allow the prediction of the performances of a centrifugal compressor in an off-design condition. The prediction of compressor performances is accurate even at high pressures, where the ideal gas theory commonly used introduces considerable errors, has 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, and supports decisions and planning of predictive maintenance and activities. The described methods have allowed more accurate surveillance of the machines and detection of failure indicators. The availability of a real-time machine model continuously predicting the expected performance has also been used to detect possible anomalies in instrumentation readings, especially concerning the measurement of suction flow, which, as known, may be affected by problems and introduce consequent errors. When such error conditions are detected, the calculated expected flow may be used temporarily to replace the measured one, allowing the system to continue to run without interruption while replacing or repairing the faulty transmitter.

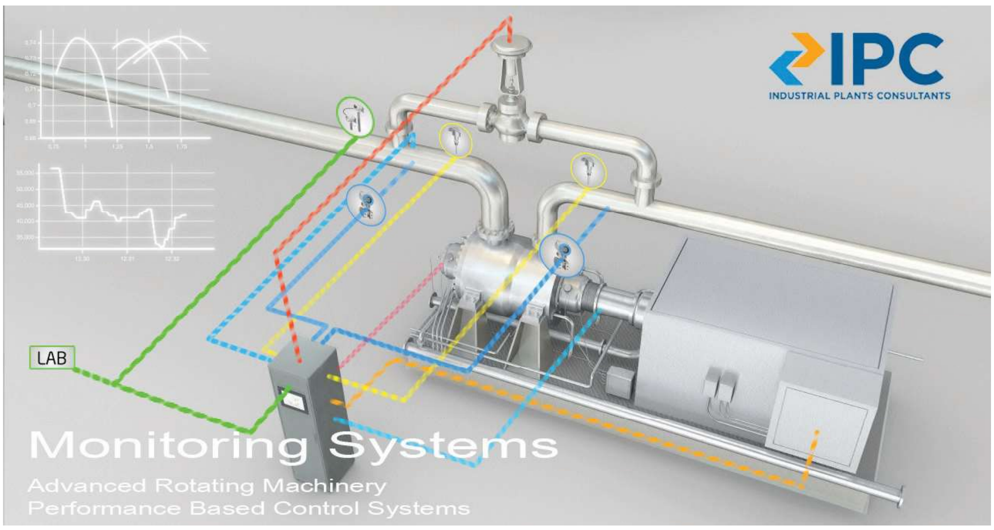

Figure 3. Layout Of Monitoring System