Serge Staroselsky, CCC, alongside Gioacchino Mugnieco and Salvatore Avarino, ENI Versalis, as well as Roberto G. Presenti and Jan Van Bauwel, Nalco Champion, present a case study where a turbo train performance monitoring system optimised a charge gas compressor in an ethylene plant.

OPTIMISING PERFORMANCE

Accurate compressor performance monitoring is playing an increasingly important role in optimising production and maintenance activities. A recently completed case study at the ENI Versalis ethylene production facility in Priolo, Sicily offers unique insights into the real time detection of performance degradation, as well as compressor performance restoration, of a charge gas compressor (CGC) in an olefins plant.

In November 2017, turbomachinery experts from CCC and Versalis customised CCC's Total Train Performance Advisor$^{\text{TM}}$(TTPA) to serve as an onsite Performance Monitoring System (PMS), which included CCC's Compressor Performance Advisor$^{\text{TM}}$ (CPA), Turbine Performance Advisor$^{\text{TM}}$ (TPA), and intercooler monitor. The TTPA effectively diagnosed compressor fouling from polymerisation in two of the five compressor stages. The performance degradation caused by the fouling had created significant economic impact, increasing steam consumption and reducing throughput.

To financially justify addressing this situation, the team calculated the associated costs of the increased steam consumption and decreased efficiency, which led to supplementary collaboration with Nalco Champion, whose EC3144A anti-foulant solution was implemented in March 2018. Over a period of several weeks, the compressor's efficiency was restored to an optimal range, and ENI realised record production at lower operating costs.

In examining this collaboration, this article will explore the relevant calculations, as well as system optimisations and integrations within the plant distributed control system (DCS) and historian, which afforded operations personnel enhanced key performance indicator (KPI) monitoring and improved the planning and execution of corrective actions.

System description

The CGC at ENI Versalis Priolo is composed of five compression stages driven by an extraction steam turbine,

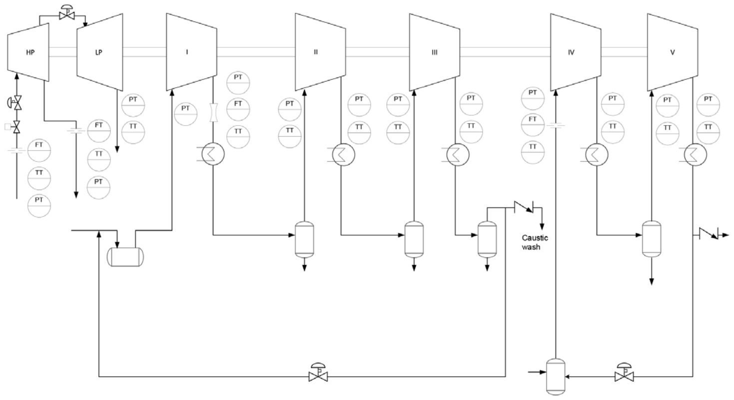

Figure 1. Five-stage charge gas compressor PFD at ENI Versalis Priolo.

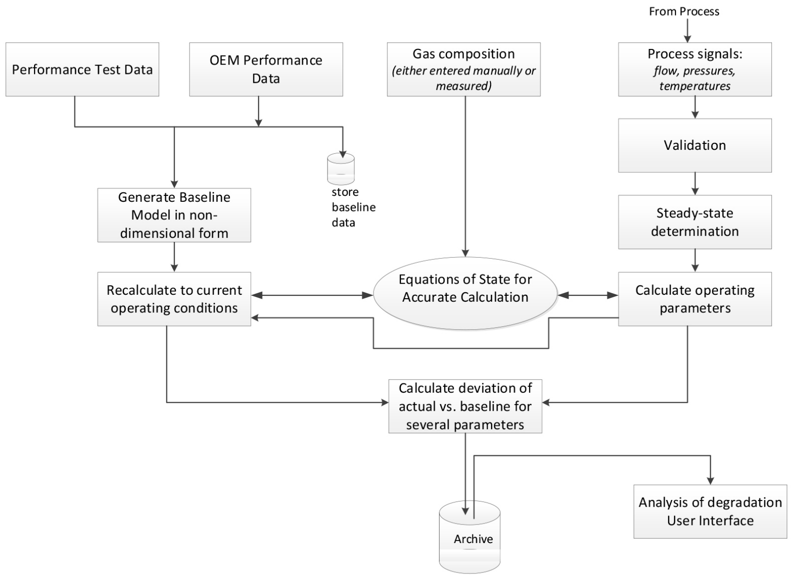

Figure 2. CPA simplified schematic.

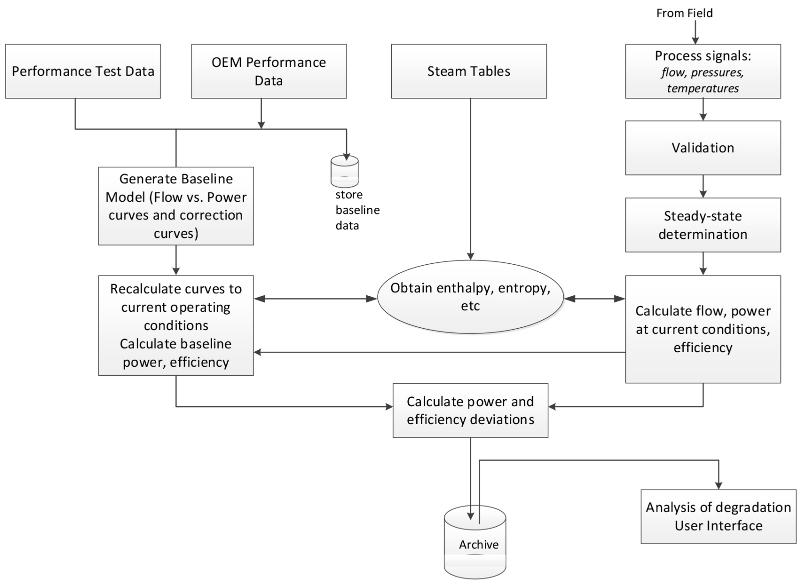

Figure 3. TPA simplified schematic.

and a simplified process flow diagram (PFD) (Figure 1). Charge gas compressor fouling is a well-known issue, including fouling mechanisms such as radical polymerisation, Diels-Alder condensation, and thermal degradation due to coke. These processes are highly dependent on temperature and can result in coke-like deposits in the compressor, associated equipment, and adjacent piping and intercoolers.

This can lead to severe decreases in compression process efficiency and intercooler heat transfer coefficients, as well as steam turbine efficiency, which can be directly affected by boiler feedwater quality and steam contamination. The performance monitoring system (PMS) identifies these fouling processes and evaluates severity by calculating the equivalent costs of increased energy consumption, providing justification for timely maintenance operations. Efficiency degradations in ENI's CGC stages two and three required extra power consumption of approximately 2 MW to compensate for reduced throughput, with an economic impact of more than €2 million.

Performance monitoring system

The PMS conducts a real time comparison of the actual compressor, intercooler, and turbine performance parameters to their baseline equipment values, which are most often obtained from the original equipment manufacturer (OEM) data or field experimental characteristics. The baseline efficiency of the compressor changes as a function of the operating parameters and gas composition, while turbine efficiency calculations depend on steam conditions, rotating speed, and flow. Therefore, accurate estimation of the baseline performance, which covers a wide range of conditions, plays an important role in identifying degradation.

The CPA calculates process gas properties using the Benedict-Webb-Rubin-Starling (BWRS) equations of state (Figure 2). For this project, the consulting team manually entered gas composition into CPA for each section, though communication link can be used for automatically updating gas composition when such information is available. The TPA estimates turbine isentropic efficiency utilising built-in steam tables for enthalpy and entropy as functions of temperature and pressure (Figure 3).

These calculation methods help avoid nuisance detection of degradation, and calculations only occur with valid data collected during steady-state conditions. The main calculation results are communicated to the plant historian, and the system archives input and output parameters, preserving graphical data history.

Operator and engineering interface

At Priolo, the PMS was installed as part of the software package delivered with the turbomachinery control system (TCS). During the TCS engineering phase, numerous computations were performed, including surge line and extraction map calculations, which reduced the overall configuration effort required for control and monitoring functions, and provided input validation for measurements connected to the TCS. For operators, viewing the compressor and operating points on their respective performance maps offers significant benefits and the PMS enhances this through improved calculation accuracy and additional baseline models for identifying degradation.

In addition to estimating efficiencies, the CPA estimates discharge pressure, discharge temperature, polytropic head, and power consumption baseline values for the existing inlet conditions. Knowledge of baseline parameters can assist in identifying drifting measurements – if a monitored parameter exceeds deviation threshold, the CPA provides an alarm.

The compressor map graphic in Figure 4 shows the actual surge and control lines, as read from the antisurge controller, superimposed on the OEM characteristics (blue curves). The green performance characteristic is the estimated baseline curve, corresponding to the current suction conditions and rotating speed. The blue dot is the current operating point – under ideal circumstances, it would be located on the yellow line. The extraction turbine map in Figure 5 shows the actual operating point on the baseline extraction map.

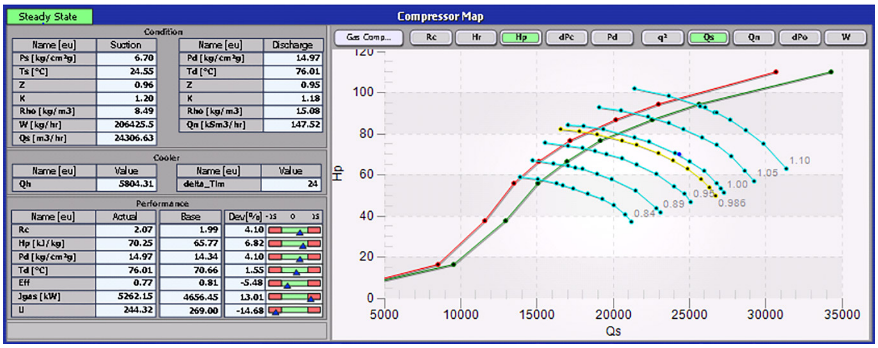

Figure 4. CPA typical operator and engineering interface screen.

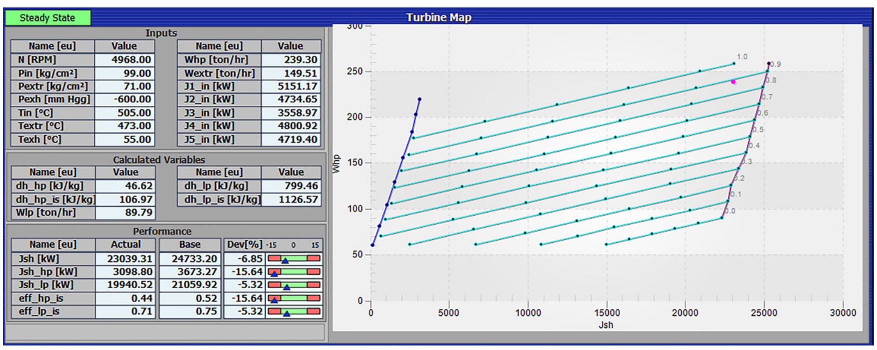

Figure 5. Extraction turbine map.

The baseline map is dynamic, with adjustments based on steam inlet and outlet conditions.

Compressor performance calculations

The CPA follows the ASME PTC-10 methodology when constructing a performance model. Differences between static and stagnation pressure are neglected, and CPA obtains gas properties from BWRS equations of state. For a single section adiabatic compression, the compressor characteristics are approximated as below, and this non-dimensional parameter set allows for proper mapping of the compressor baseline curve and the actual operating point at varying compressor operating conditions:

$$\psi = f_1(\phi, Ma_N)$$

$$\eta_p = f_2(\phi, Ma_N)$$

Where:

ϕ (phi) – flow coefficient.

ψ (psi) – head coefficient.

η_p – polytropic efficiency.

Ma_N – rotational Mach number.

f_1, f_2 – piecewise, continuous functions for approximating compressor performance.

Turbine calculations

The TPA calculates the steam flow, shaft power, and isentropic efficiency of the steam turbine, and estimates deviation from the baseline performance. It provides a graphical interface with real time plotting of baseline steam flow (W) vs shaft power (Jsh) curve, compensated for the existing steam conditions and the current operating point.

The TPA displays multiple curves for extraction machines, each corresponding to a given extraction flow. When the conditions in turbine exhaust are below the saturation line, it estimates efficiency based upon consumed power, which can be calculated from the driven load parameters, such as a compressor or a generator. It provides means of correcting baseline data centred on rotating speed, steam flow, and steam pressure and temperature.

Intercooler calculations

The intercooler performance advisor calculates and monitors the deviation of the actual heat transfer coefficient from the nominal, and as the cooler fouling increases, its heat transfer coefficient reduces, resulting in additional compression work:

$$d_U = \frac{U_{act}}{U_{base}}$$

Where:

U_{base} – overall heat transfer coefficient of the exchanger for baseline conditions.

U_{act} – overall heat transfer coefficient of the exchanger for actual conditions.

Integration with plant historian and plant KPI dashboards

The TTPA calculates variables, and deviation alarms are passed to the DCS via Modbus communication, which was preferred over object linking and embedding for process control (OPC) communication due to an existing link. The data was then integrated into the plant historian and represented into the plant KPI dashboards that allow operation management to have a simple synopsis of the machinery performance (Figure 6).

Instrumentation requirements

The PMS was designed to perform calculations for each compressor section, and reliable measurements for calculations were captured throughout the engineering phase. As only the first and fourth stages had flow measuring devices installed, and the flow was approximated through each section by subtracting or adding the liquid flow from the inter-stage knock-out drums, the PMS was allowed to work with a reduced set of flow elements.

Efficiency recovery

Two observations were made indicating fouling of the compressor: decline of efficiency in stage two (Figure 6A), and high vibrations in stage three (Figure 6D), which led to Nalco Champion's involvement in March 2018. To cope with these problems, avoid further increasing operational costs, and prevent an unplanned shutdown, Nalco Champion initiated its multi-component EC3144A anti-foulant programme in both stages. This resulted in a quick recovery of the efficiency on stage two (Figure 6B), a reduction of vibrations on stage three (Figure 6D), and additional efficiency increase in stage three as well (Figure 6C).

Conclusion

Performance monitoring systems create opportunities for accurate analysis, which allow for the design, development, and implementation of optimisation solutions that are custom designed for each unique situation. Specifically, this article has focused on the performance-monitoring calculations of a case study where a PMS was integrated with a client's plant DCS and historian, which offered operating personnel easy access to KPIs, such as throughput deviation and steam consumption.

The implementation of these systems often features standard software products optimised by knowledgeable experts before integration with plant systems to ensure technical solutions work in the targeted operations environments. The method and tools are easily repeatable. This collaborative solution resulted in actual savings of approximately €3.9 million, providing a significant return on investment far past simply fixing the compressor fouling issue.

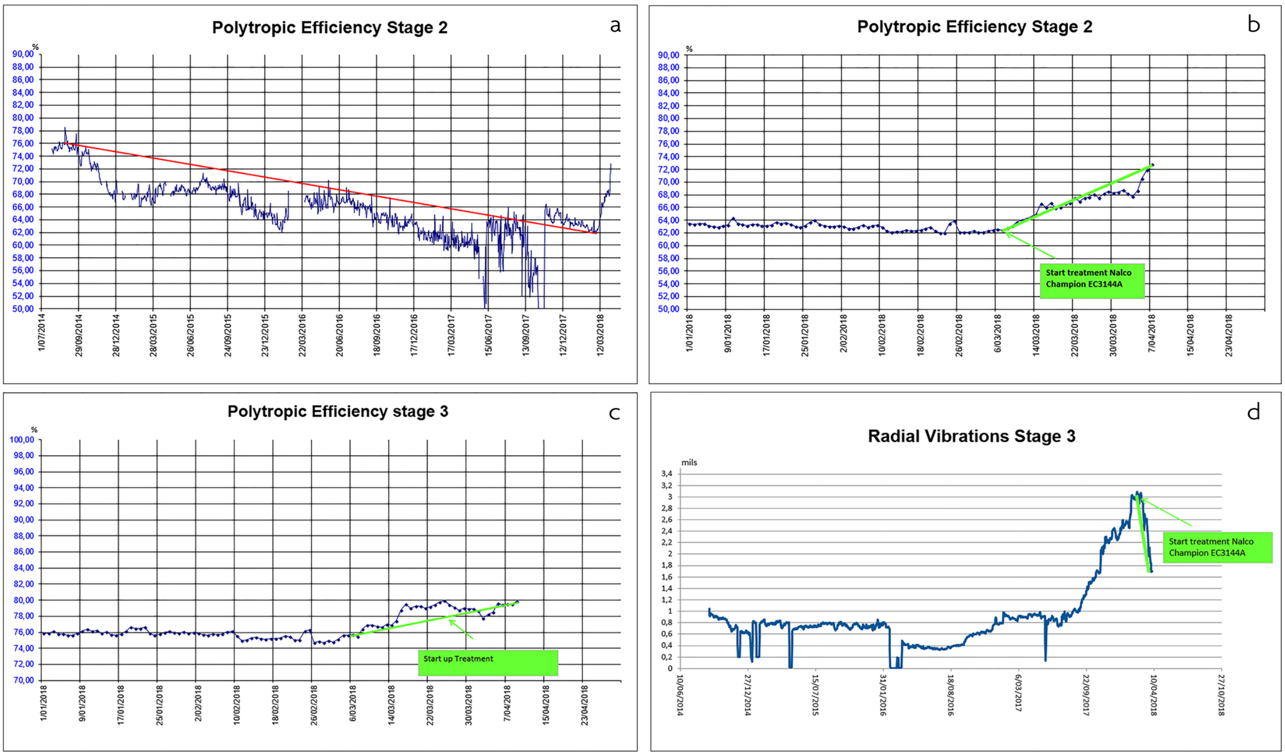

Figure 6. A and B illustrate stage two efficiency reduction before treatment/efficiency recovery after treatment, while C and D present stage three efficiency increase after treatment/vibration decrease after treatment. (A) Over 14% efficiency decline stage two. (B) Over 10% efficiency recovery stage two. (C) Over 4% efficiency recovery stage three. (D) Vibration decrease stage three.