CONTROL SYSTEM OPTIMIZATION

BY MASSIMILIANO DI FEBO AND PASQUALE PAGANINI

ABOUT THE AUTHORS

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INTRODUCTION

Control systems are the brain of the process plant. Their importance is well recognized, and, for this reason, the design and implementation of plant control systems are considered from the first design stage until the final startup stage. Medium and large plants may include many different process areas with different kinds of machines. Each one of the involved processes may require special attention and precautions to render the best outputs and contribute to maximizing the overall plant performance. Despite their importance, it often happens that the plant control system may not be fully optimized.

In this paper we'll restrict the focus to centrifugal compressor plants, introducing some main concepts applicable to the compression station control system. Furthermore, a case history is presented about the optimization applied by the IPC team on the plant control system. This paper will provide some interesting evaluations of benefits and estimations of the environmental impact.

COMPRESSION STATION CONTROL SYSTEMS ELEMENTS

Each compression station includes a station control system. This system comprises all the devices devoted to managing, controlling, and protecting all the plant physical assets, including machinery, piping, drivers, instrumentation, auxiliaries, etc.

Controlling a compression station requires some main tasks: assuring adequate machinery protection and plant stability, meaning that the main plant parameters should be fluctuating, during operational time, within the expected operative range. Plant stability is the result of the effective control system capability to coordinate all machinery and devices during the operational time. Plant stability allows unwanted phenomena to be avoided, such as recycles and shutdowns.

INSTRUMENTATION

API standard 617 provides detailed indications about the compressor instrumentation.[1] Onboard equipment should include vibration and temperature probes. Sensors are normally located in proximity of rotor bearings where vibration and temperature readings are taken and compared to alarms and trips. Field instrumentation assures that the machine will not operate outside the permitted range. Not only machinery but also process items (headers, scrubber, coolers, etc.) are often equipped with sensors to detect potentially anomalous or even dangerous conditions. Instrumentation represents the base layer of the control system upon which all logic and control actions are based.

CONTROL TASKS

One of the main tasks is the "load control." This task provides maintenance of a mass balance between the gas incoming into the station and the gas outgoing. Apparently, this may appear as a simple task. The reality is more complex, and many problems are normally faced, especially when the station has a less simple architecture such as stations with more compression trains in parallel. The load control is usually carried out by acting on the speed of the driving motor (frequently a gas turbine for turbo-compressors), or by acting on the "throttle" valve in the case of constant speed drivers (frequently asynchronous motors for motor-compressors). It should be noted that the load control has the suction header pressure as process parameter. But, the same suction pressure affects the flow in the anti-surge valve, which is controlled by the anti-surge controller. If these two control actions should occur at the same time, they would influence each other, and the station could be destabilized by persistent oscillations potentially triggering recycles and shutdowns.

The situation is complicated by the fact that, in some circumstances, the anti-surge valves are used for the load control and therefore adequate strategies are needed to accommodate these events, always assuring an overall station stability.

Other factors must also be considered for the purpose of

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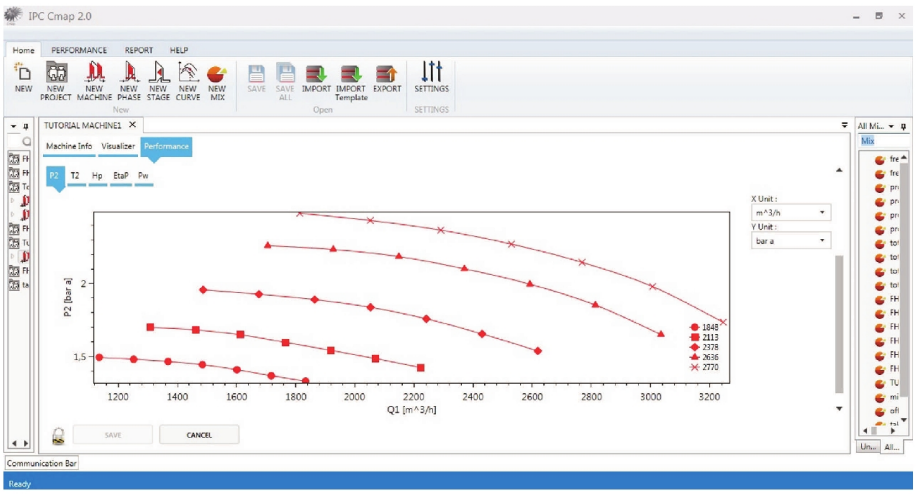


Figure 1. CMap Screen Shot

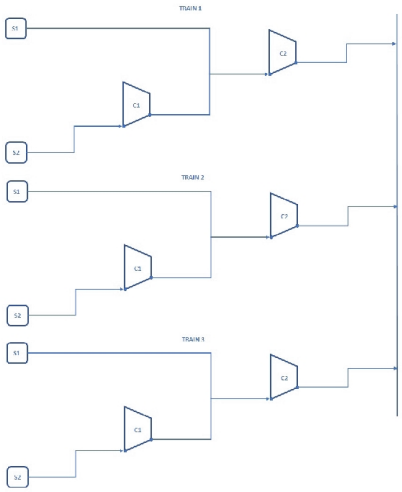


Figure 2. Plant Layout

system stability, such as the closing speed of the anti-surge valve, when and under which conditions the anti-surge valve closure should be permitted, how to manage the single compressor recycle when working in a compression train, how to manage more trains in parallel, how to manage a compressor ramp up into the parallel, and so on.

These considerations show how delicate and important the compression station control system duty is, and how it may require a high level of sophistication in case of non-trivial plant configurations.

DANGEROUS OPERATIVE CONDITIONS

Surge

Among critical operative conditions the surge deserves special mention. In a very quick inversion of the flow inside the compressor, surge happens when the characteristic curve becomes unstable, i.e., when the derivative of the discharge pressure vs. the flow approaches zero. Surge has a very destructive nature – the inversion of the flow causes high vibrations and violent axial displacements that

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overload the bearings. During the surge cycles the gas may achieve very high temperatures, causing damage to the compressor parts.

Most of the time the actual operative conditions are different from design conditions; consequently, the identification of the compressor surge point becomes complicated because it requires the adjustment of the compressor performance curves at the actual off-design conditions. While this capability is provided by IPC software CMap, traditional systems are often still based on approximated methods that when implemented, results tend to be quite conservative and set the protection thresholds quite far from the surge point. This often causes the compressor to enter the recycle condition even when not strictly necessary.

While this approach focuses on machine safety, it causes a higher impact on financial and environmental points of view. In fact, during operational time, plant instabilities may trigger protection actions. The effect is that the compressor goes off-line and the gas coming into the station is inevitably burned in the flare.

Recycles And Shutdowns

Recycles and shutdowns also deserve a short explanation since they both have a critical impact on plant productivity. Shutdowns are critical events that require the machine to be stopped immediately. This usually happens when some of the critical operative parameters exceed alarm values hitting the trip point. Of course, shutdowns represent lost revenue for lost production during time intervals necessary to reset the system and restart.

Recycling is the recirculation of the compressed gas back from the machinery discharge to the suction side. The recycling of a centrifugal compressor is most often due to the triggering of the anti-surge valve emergency opening. This protection action is actuated by the control system when the operative flow becomes very near to the surge point (normally 1.03 of surge flow).

Also, recycles have a great impact on the overall station productiveness since they require system reset, though compressors are not stopped. System reset requires human intervention for acknowledgment and problem understanding and is therefore time-consuming. The first step in recycling is to enter the machine into protection mode (anti-surge emergency opening). The machine must remain in this status until operator acknowledgment. The second step is when the machine recovers its load. Also, recycles represent a loss of production because the gas continues to be flared until the completed machine reloading, causing a neat loss of gas production, a loss of energy for unnecessary compression power, a carbon dioxide (CO_2) equivalent impact for this wasted energy, and a very high impact for the CO_2 injected in the atmosphere.

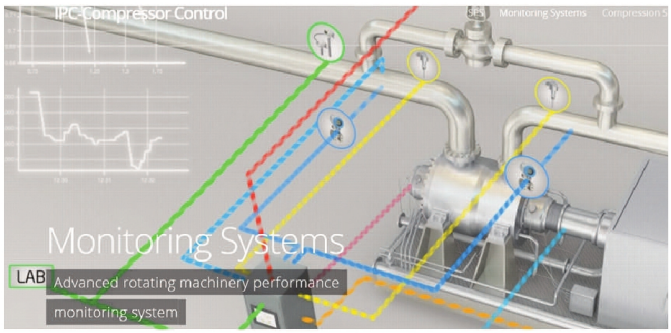


Figure 3. Layout Control System

CASE HISTORY

The compression station was made up of three independent compression trains (independent gas sources), with each train including two compressors in series. Each train was driven by a single, fixed-speed electrical driver. Each single compressor was equipped with its own anti-surge valve.

Before the beginning of the plant optimization project, the compression plant was affected by a high number of critical events, mainly recycles and shutdowns.

After an observation period dedicated to understanding the problems and behavior of the system, the IPC team proposed the following directives:

- Evaluation of the compressor performance, through the comparison of the operational values to the original equipment manufacturer (OEM) expected performance
- Observation of the plant dynamical behavior and understanding the interconnection of the plant parameters' fluctuations with the machine operative performance
- Execution of a detailed analysis of all the involved control system tasks and design of control task modifications aimed to reduce or minimize the appearance of critical events

The first directive was applied using the available field measurement data and that of the capabilities of CMap software for the prediction of centrifugal compressor performance.

CMap contributed largely to identifying compressor performance non-conformity and then updating control system settings for the effective compressor operative conditions. The flexibility, reliability, and quickness of the software obtained a better picture of the overall system operational status.

Cooperation with the field supervising personnel helped to understand the observed dynamics and infer the dependencies of causes and effects. Work was also necessary to get into the existing control task and design and implement necessary software modifications. An increased stability grade for the compression station was obtained, reducing the number of recycles and shutdowns to a few events per year.

FINANCIAL AND ENVIRONMENTAL IMPACT OF THE OPTIMIZATIONS

Before the launch of the optimization project, the plant was affected by an average of one recycle per day, per train, with a duration of about half an hour per recycle.

In these transients each compression train was recycling about 40,000 kg/h (88,185 lb/h), with the overall station flaring about 72,000 kg/day (158,733 lb/day). The estimated loss for flared gas was about 4.6 million Euros ($5.1 million USD) per year, including loss of production and cost for energy spent on recycles.

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During recycles the trains were wasting about 3 MW with an estimated loss of about a quarter of million Euro ($577,135 USD) per year due to unnecessary adsorbed electrical power.

The total loss was about 4.9 million Euros ($5.4 million USD) per year.

From an environmental point of view, the situation was even worse. The CO_2 equivalent introduced in the atmosphere for the unnecessary recycling power was about 1160 tons per year, while the CO_2 flared was about 70,400 tons per year. The CO_2 equivalent for heat wasted by flaring was about 13,500 tons per year.

THE IMPACT

This amount of CO_2 would be equivalent to the amount of CO_2 produced in a year by 42,720 passenger cars. Another interesting comparison: about 18 medium-sized wind turbines (2.2 MW) would be necessary to avoid that amount of CO_2 into the atmosphere, with a cost of about 40 million Euro ($44.3 million USD).

Financial Impact	Euro (millions)
Loss of production	4.6
Lost energy for compression	0.2
Overall loss per year	4.9
Environmental Impact	Tons of CO_2
CO_2 equivalent for recycle power	1161.2
CO_2 in atomsphere from flare	70,488
CO_2 equivalent for wasted heat	13,591.40
Overall CO_2 impact	85,204.60
Equivalences	
Number of passenger cars per year that produce the same amount of CO_2	42,720
Number of 2.2-MW wind turbines needed to save the same amount of CO_2	18
Cost	36.0 million Euros

CONCLUSIONS

The adoption of advanced strategies for the machinery monitoring and station control systems represents, from the financial point of view, a justified investment.

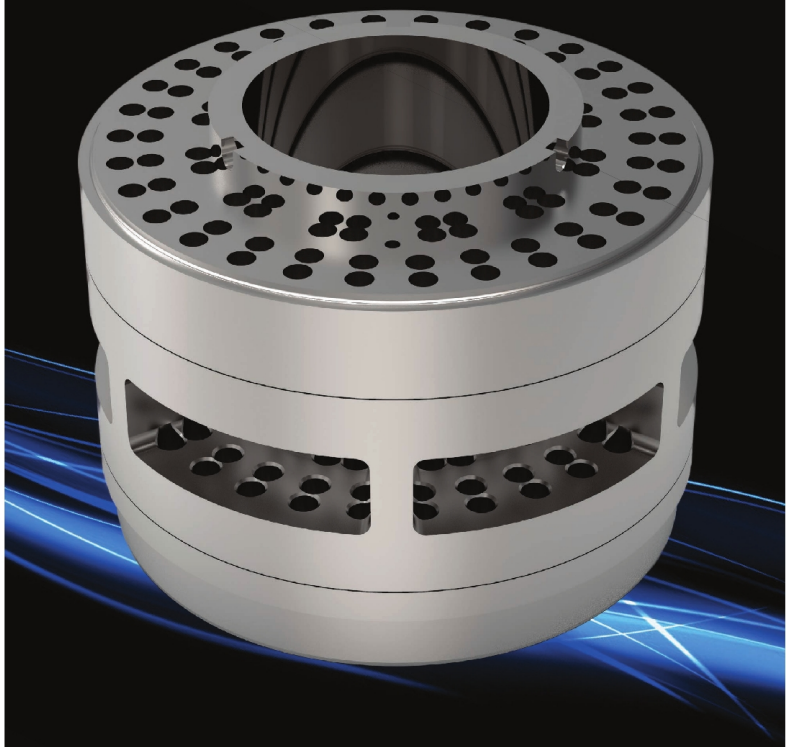
From the environmental point of view, benefits are more than evident. The gas industry, beyond financial goals, bears the moral responsibility for environmental compliance.

Knowledge of compression systems, application experience, and the support of specialty machinery software tools such as CMap should be considered valid support in the achievement of not only economic benefits but also environmental goals and responsibilities.

REFERENCE

[1]API 617, "Axial and Centrifugal Compressors and Expander-Compressors" (Washington, DC: American Petroleum Institute, 2014).

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