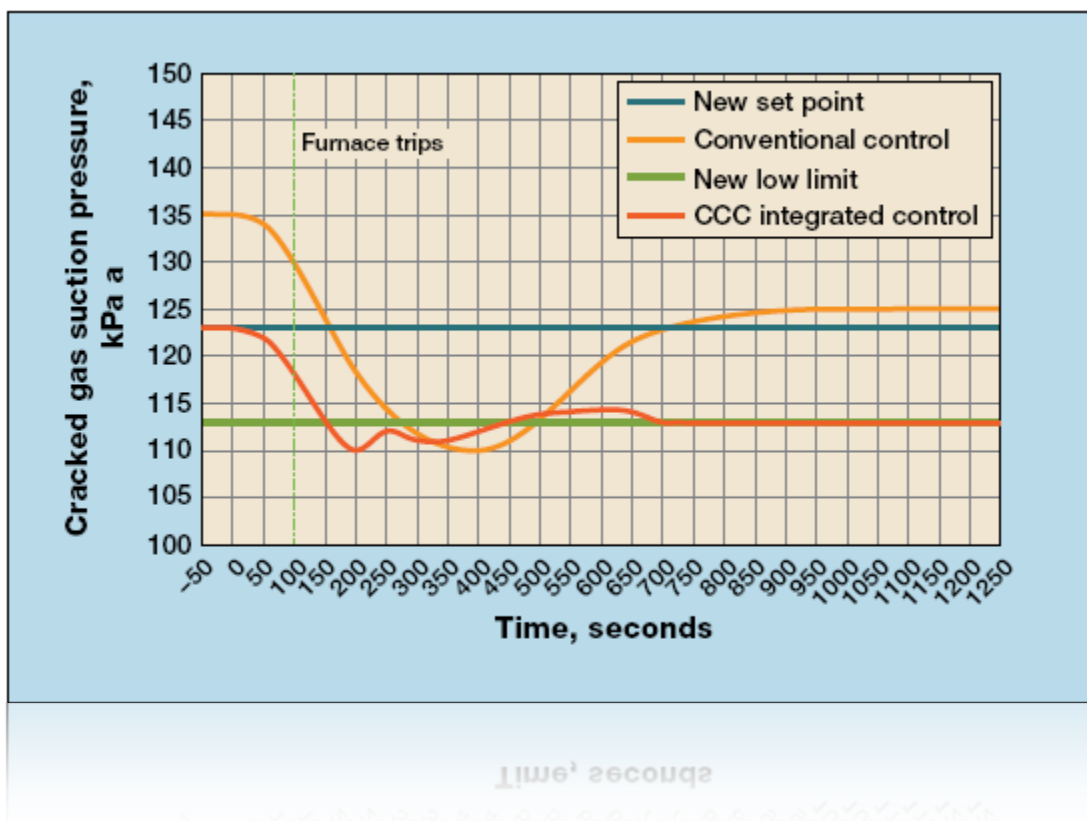# Advanced Turbomachinery Controls Improve Ethylene Plant Yield

Publish Date: Q3 2015
Author: Medhat Zaghloul

Advanced integrated turbomachinery controls can significantly alleviate the suction pressure dip of a cracked gas compressor, leading to considerable yield improvements.

Ethylene Plant yield is a function of pyrolysis furnace backpressure, among other factors. The mechanism to keep the furnaces backpressure at a certain value is the suction pressure to speed cascade control loop on the cracked gas compressor.

The schematic arrangement of the gas path from the furnaces to the compressor may be represented as follows:
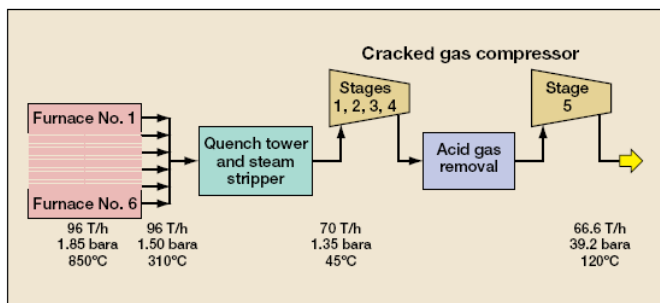

Figure 1 Schematic arrangement of pyrolysis furnaces and cracked gas compressor

In the above Fig. 1, the design pressures, temperatures and flow rates of the gas path are depicted for a 300,000 MT/Y Ethylene Plant, in a simplified manner. Any particular plant may have slight differences.

In every plant, the selected cracked gas compressor suction pressure set-point value is determined to ensure that, in the event of a single or multiple furnace trip events, the suction pressure does not dip low enough to sub-atmospheric values, thereby creating the risk of sucking in air with the process gas, which could create an explosive mixture.

The cracked gas compressor is a multi-section centrifugal compressor, with 4 or 5 stages of compression required to bring the cracked gas pressure up to the desired value of approx. 40 bara. The cracked gas compressor is usually driven by an extraction type steam turbine, using high pressure live steam and extracting steam to the plant's medium pressure steam network, as well as condensing the remaining steam that is used in the turbine low pressure compartment.

Caustic wash is usually installed between the 3rd and 4th (or 4th and 5th) stages to remove any trace quantities of acid gas (H2S) present in the cracked gas.

As the cracked gas that enters the compressor is saturated with steam, condensate removal is required after each stage's discharge cooler and prior to introducing the gas to the succeeding stage of compression.

Typically, the first group of compressor stages (upstream of the caustic wash) is protected against surging by a single antisurge valve, while the stage (or stages) downstream of the caustic wash section is (are) protected by another antisurge valve.

In the event of a furnace trip, a significant portion of the cracked gas available from the furnaces drops almost instantaneously.

A suction pressure controller uses the cracked gas compressor 1st stage suction drum pressure as its process variable (PV), compares it to the configured set-point (SP), and the resulting error used to generate a PID response to modulate the speed set-point of the steam turbine driver, between its control range of Minimum Governor to Maximum Governor values.

The actual modulation of the live steam valve (V1 valve) is done by a Speed Governor, cascaded with the cracked gas suction pressure controller. The modulation of the live steam valve, for those plants that have an extraction turbine driver, needs to be closely coordinated with the turbine's extraction (V2) valve.

In the event of a furnace trip, a significant portion of the cracked gas available from the furnaces drops almost instantaneously. In this example we will consider 16.7% of the plant's rated capacity (assuming that normally there are 6 furnaces in service).
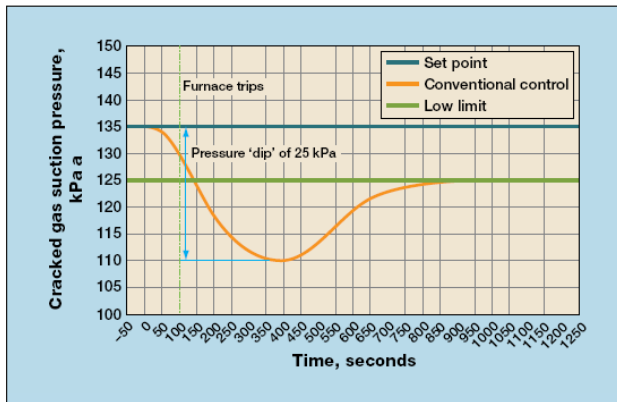
Figure 2 Conventional controls dynamic behaviour for a furnace trip event

The cracked gas pressure at the compressor's suction drum will also start to drop precipitously after the time delay caused by the process volume of the process equipment between the furnace outlets and the compressor's suction drum.

Several factors will influence the value of the minimum suction pressure value reached during the furnace trip event. These include:

- The volume (capacity) of the process equipment between the furnaces outlet and the cracked gas compressor suction drum,
- The tuning of the compressor suction pressure controller, and
- The speed of response (quality) of turbine speed control.

The volume of the process equipment in question is not a factor that can be influenced by better control strategies. However, the other two factors are influenced by better control strategies. Of those, the quality of the turbine speed control is more important, since it is the "inner" loop of the pressure-to-speed control cascade arrangement.

The turbine speed control could be based on a mechanical-hydraulic governor, or a more modern digital governor. In either case the extraction control mechanism usually presents control challenges to the turbine speed control loop.

Take the example of an older control system where the speed governor is a mechanical-hydraulic device using the flywheel principle and is linked to the extraction

valve actuator with a mechanical linkage. This type of older system would introduce significant oscillations in the speed control whenever there is a change in speed or extraction demands, which, in order to produce a smoother response would require considerable dampening of the control responses, rendering the overall speed control response quite sluggish.

While the most sophisticated dedicated digital control hardware and software algorithms available in the market greatly improve the speed control response, there is still a minimum time constant achievable in terms of the speed control of an extraction type turbine.

Advanced and integrated turbomachinery controls can significantly alleviate the suction pressure dip

One of the most important rules of controls implementation is that the "outer" loop of a cascade control arrangement (in this case the pressure controller) must be tuned at least 5 times slower than the time constant of the "inner" loop.

Thus, it is fair to conclude that even with the best dedicated digital speed control hardware, and the best speed-extraction control algorithms, there is still going to be a somewhat sluggish to very sluggish suction pressure control time response in any ethylene plant.

It was perceived that in order to deal with the suction pressure "collapse" that would accompany a furnace trip (or multiple furnaces tripping) , and prevent the pressure dip from becoming sub-atmospheric, that a low suction pressure limiting loop needs to be implemented, in tandem with the normally sluggish suction pressure control loop.

This limiting loop would be tuned to be faster that the principle pressure control loop, but would require a set-point value that was offset from the "main" suction pressure controllers.

For many years this was considered the "state-of-the-art" for setting up the cracked gas suction pressure control set-point value.

When a time recording is made of the behavior of such a "state-of-the-art" control arrangement is made, the result could look something like this:

With advanced control algorithms that incorporate the full integration of all the compressor's turbo-machinery controls functions, such as antisurge, performance, speed and extraction controls, into one dedicated high-speed controls platform, it is possible to improve on the pressure dynamic behavior time trend that is shown in the above Fig. 2.

Modern state-of-the-art surge control systems, needed and implemented to protect the charge gas compressor from surging and its associated mechanical damage to the machine, require that the installed antisurge valves have sufficient capacity to handle full recycle operation of the compressor train. In addition these antisurge valve actuators are required to have exemplary stroking characteristics, in terms of stroking speed and freedom of stroking from overshoot in both directions of actuator travel.

Thus it is possible to utilize recycle gas flow from the low pressure antisurge valve back into the cracked gas compressor suction drum to help recover the suction pressure for a furnace trip event.

When the suction pressure drops below the low suction pressure limit, a fast limiting control response can be used to temporarily open the low pressure antisurge valve, in addition to lowering the speed of the turbine.

It should be noted that while the low pressure antisurge valve is providing recycle flow back to the cracked gas compressor suction drum – for the express purpose of preventing the suction pressure collapse in the event of a furnace trip, the high pressure stages of the cracked gas compressor could be starved of flow sufficiently to require partial recycle as well. It would this be helpful if the high pressure antisurge controller could open the high pressure antisurge valve in an

anticipatory manner, using loop decoupling techniques between the two antisurge controllers of the cracked gas compressor.

As may be seen from the comparison of the conventional controls vs. the advanced integrated controls in dealing with a furnace trip event, the pressure dip recorded was only 12.5 kPa.

There are two possible control algorithm strategies to implement this enhanced control function of using the antisurge valve to prevent suction pressure collapse in the charge gas compressor during a furnace trip event:

- Use a conventional limiting function entirely within the antisurge controller, i.e. when the 1st stage suction pressure of the cracked gas compressor drops below a pre-configured fixed value, then open the antisurge valve appropriately, or

- Set up a "Pressure Override Function" within the suction pressure controller that transmits a control response to open the LP antisurge valve of the cracked gas compressor when the 1st stage suction pressure drops below a configurable offset of the suction pressure set-point assigned value.

The latter approach may provide an ever better overall recovery of the suction pressure due to its "limiting threshold" being an offset to the suction pressure set-point, rather than an absolute pressure value.

In either case, it should be possible to drop the assigned set-point value of the cracked gas compressor suction pressure controller by a significant amount. For the purpose of illustration in this article, let us assume that it may be reduced by approx. 12.5 kPa, down to 122.5 kPa, instead of the 135 kPa that was possible with the conventional control system.

This reduction in the cracked gas suction pressure set-point value should translate into a proportional reduction in the furnaces outlet pressure, which, for our typical process illustrated in Fig. 1 would be a drop from 185 kPa to 172.5 kPa.

Based on the data provided in Fig. 5, the corresponding improvement in Ethylene Yield could be as high as 1.05% (from 25.6% to 26.15%).

For the 96 T/h of feedstock processed in the furnaces (again referring to Fig. 1), this would correspond to an increase of Ethylene production of approx. 1.01 T/h of Ethylene or 8,730 T/year with a market value of approx. 10 million dollars.

It should be pointed out, however, that the slightly lower suction pressure set-point value for the cracked gas compressor would require approx. 2.86 ~ 3.00% more power generated by the compressor's steam turbine driver, which does impose a slight energy penalty (less than 300 ~ 400 K$/year) compared to the potential extra revenue, due to the improved Ethylene Yield.
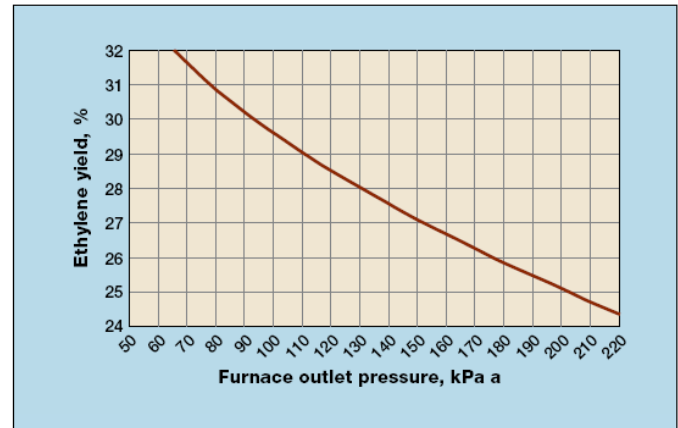

Figure 5 Furnace outlet pressure vs ethylene yield
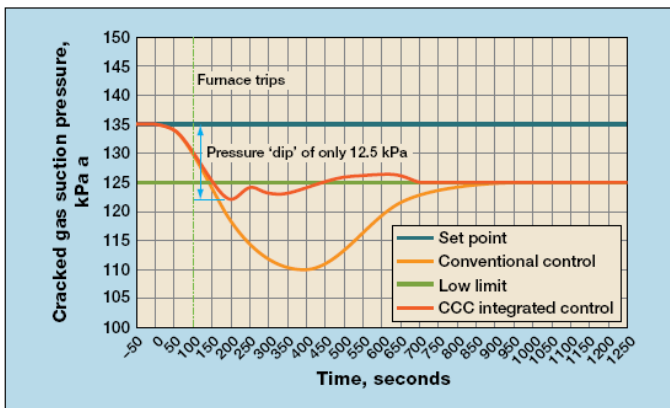Source: Petrochemical Processes by A Chauvel & G Lefebvre

Figure 3 Conventional controls vs advanced integrated controls dynamic behaviour for a furnace trip event
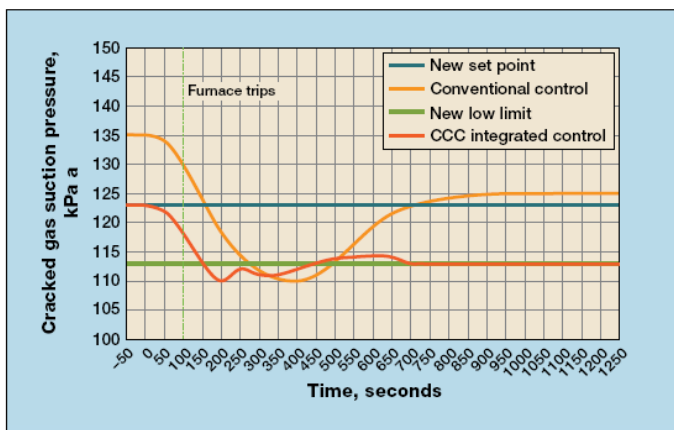

Figure 4 The suction pressure set-point may be reduced with advanced integrated controls without increasing the risk of a compressor trip during a furnace trip event

Conclusion

For many years, the suction pressure set-point of the cracked gas compressor represented a constraint that plant operations consider inviolate. However advanced and integrated turbomachinery controls can significantly alleviate the suction pressure dip as a consequence of single or multiple furnace trips, thus allowing the charge gas compressor "normal" suction pressure setting to be significantly lower than with conventional control systems.

This in turn can lead to considerable yield improvements in the concerned plant, with the potential revenue increase in the many millions of dollars.

Further reading

1. Narayanan K., Ramakrishnan S., Maximizing ethylene plant production with CCC's Advanced Turbomachinery Constraint Control System, Compressor Controls Corporation, 2005.

2. Chauvel A., Lefebvre G., Petrochemical Processes.

About The Author:

Medhat Zaghloul is CCC's Regional Technology Manager for the Europe, Middle East and Africa Regions with Compressor Controls Corporation (CCC), based in the Abu Dhabi Office. Medhat joined CCC in 1993 and has over 38 years of experience in the oil and gas industry with 15 years specific to the instrumentation and controls for the petrochemical industry. He is responsible for the development of technical solutions and control applications and providing technical guidance and support. Mr. Zaghloul holds a B.Sc. in Electrical Engineering from the Cairo Institute of Technology in Egypt (now Helwan University).

Advanced Turbomachinery
Controls Improve Ethylene Plant
Yield | v3 | 09/24
© 2024 Honeywell International Inc.

Honeywell

CCC