Brüel & Kjær Vibro

Application Note

Ethylene Plant
Machine Condition and Performance Monitoring

The critical compressor trains in an ethylene plant can result in millions in lost production as a result of unnecessary downtime and inefficient operation. Brüel & Kjær Vibro provides a monitoring solution for not only protecting these machines, but also improving their reliability, availability and operating efficiency.

Ethylene production plant

There is a world-wide insatiable demand for ethylene – making it the highest volume petrochemical commodity in the world. World production has tripled since 1980 but margins are dropping and plants are running at over 90% nameplate capacity. There is little room for unplanned downtime. To remain competitive, it is necessary to operate efficiently and reliably with minimal downtime.

Critical machines and maintenance issues

The most critical machines in the ethylene plant are:≠

- Crack gas compressor
- C2 (ethylene) and C3 (propane) refrigeration compressors
- Steam turbine prime movers

The crack gas compressor is the primary constraint for production. Production losses for a shutdown can cost over €750 000/day. Moreover, plant startup after a trip requires extra manpower with greater safety risks. There is also increased flaring with more pollution during a start-up.

Figure 1 Typical crack gas compressor (Mitsubishi)

In addition to downtime, there can also be production losses due to the crack gas compressor operating inefficiently over a long period of time. This can be due to leaking inter-stage seals or compressor free-radical polymer fouling on the compressor blades and diffuser (typically the 2nd, 3rd and 4th stages, see Fig. 2). If unchecked, fouling limits throughput and can cost millions every year. It reduces thermodynamic efficiency, increases the steam turbine steam rate and requires a maximum governor valve opening. The maximum continuous speed is no longer sustainable in the presence of severe fouling. It also directly affects the process by increasing suction pressure, discharge temperature and intercooler pressure-drop.

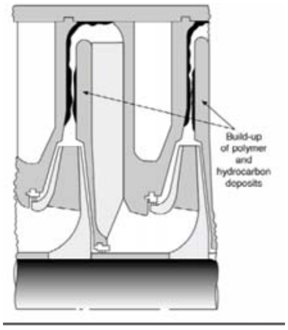


Figure 2 Crack gas compressor fouling

As the spot prices for different feedstocks change, some plants are forced to use the most economical feedstock available at the time. This means the loading and fouling is different on the crack gas compressors for the different feedstocks. This subsequently makes it even more difficult to effectively plan interval maintenance ahead of time.

The refrigeration compressors operate with cleaner gasses but they also have their own fair share of problems. Trips can be caused by a number of factors such as compressor surge, high liquid level, low discharge pressure, high discharge temperature, and overspeed.

The highly exothermic process of ethylene production requires the use of backpressure or condensing steam turbines with admissions and extractions. Fouling can make it difficult to maintain speed at maximum steam flow, or may require operation with HP and LP valves fully open and increased backpressure from the LP turbine.

Monitoring Strategy

The combined condition and performance monitoring strategy of a typical crack gas compressor train is shown in Fig. 3 (performance monitoring) and Fig.4 (vibration monitoring). Because of the varying operating conditions found in an ethylene plant (e.g. changing feedstocks), an adaptive monitoring strategy is needed. This will distinguish between signal changes due to changing process conditions and those due to developing machine faults. It is also important to graphically correlate process parameters together with the performance and vibration values to better understand the fault mechanisms and to fine-tune the adaptive monitoring strategy.

Performance Monitoring

The thermodynamic parameters shown in Table 2 are used to detect and diagnose fouling or erosion of impellers and diffusers, leaky seals, surge and stonewalling. These are calculated using the inputs shown in Fig. 2 and Table 1. The process parameters are measured by sensors that are normally OEM installed on the machines, and are cost-effectively imported from the distributed control system (DCS) to the monitoring system. The Lee-Kessler method is used for calculating the real gas mixture properties. The proper setup of the calculations depends on customer-supplied information such as “as built” baseline performance curves, process equipment (inter-cooling, bleeds, admissions, etc.) and an accurate determination of the gas composition.

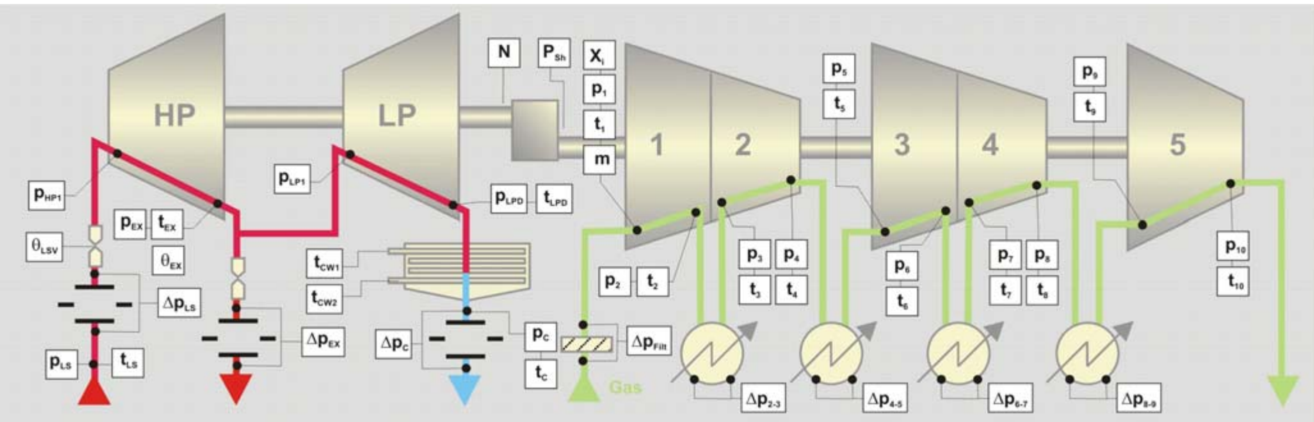


Figure 3 Input process parameters needed for performance monitoring of a typical crack gas compressor train (control signals not shown)

Symbol	Signal
p_{LS}	Live steam pressure
t_{LS}	Live steam temperature
Δp_{LSV}	Live steam orifice flow pressure drop
Θ_{LS}	Live steam valve position
p_{HP1}	HP turbine inlet pressure
Θ_{EX}	Extraction valve position
p_{LP1}	LP turbine inlet pressure
p_{EX}	Steam extraction pressure
p_{EX}	Steam extraction temperature
Δp_{EX}	Extraction steam orifice flow pressure drop
N	Speed
p_{LPD}	LP turbine discharge pressure
t_{LPD}	LP turbine discharge temperature
t_{CW1}	Condenser cooling water inlet temperature
t_{CW2}	Condenser cooling water discharge temperature
t_{C}	Condenser steam discharge temperature
p_{C}	Condenser steam discharge pressure
Δp_{C}	Condenser steam orifice flow pressure drop
P_{Sh}	Power

Symbol	Signal
Δp_{Filt}	Inlet filter pressure drop
t_{n}	Compressor inlet and discharge gas temp.
p_{n}	Compressor inlet and discharge gas pressure
Δp_{n-m}	Inter-stage pressure drop
m	Compressor mass flow
P_{Sh}	Compressor power
N	Compressor speed
Control Signals	Various control signals for power, fuel, bleed, guide vanes, stator vanes, etc.

Table 1 Standard monitoring inputs for condensing steam turbine (left) and compressor (right)

Steam Turbine Performance Calculations
Isentropic stage efficiency per part and total
Swallowing capacity
Specific steam consumption
Heat transfer coefficient of condenser
Condenser vacuum
Condenser gradient
Cooling water flow

Compressor Performance Calculations
Power consumption (actual conditions)
Pressure ratio (actual conditions)
Polytropic head (actual conditions)
Polytropic efficiency (actual conditions)
Corrected rotor speed
Corrected volumetric flow
Corrected polytropic head
Corrected power consumption
Corrected pressure ratio
Pressure ratio deviation
Polytropic head deviation
Polytropic efficiency deviation

Table 2 Standard monitoring techniques for condensing steam turbine (left) and compressor (right)

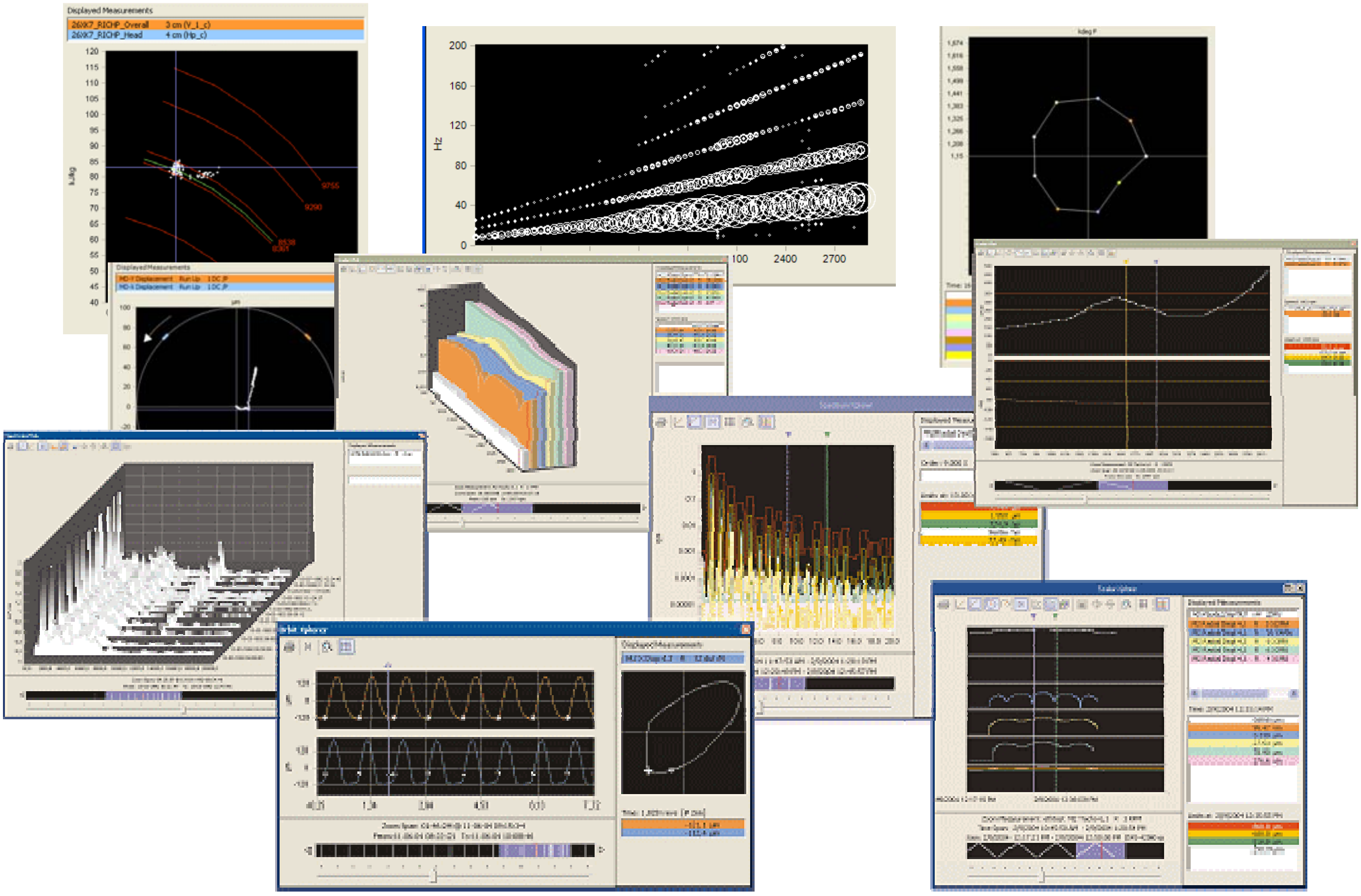
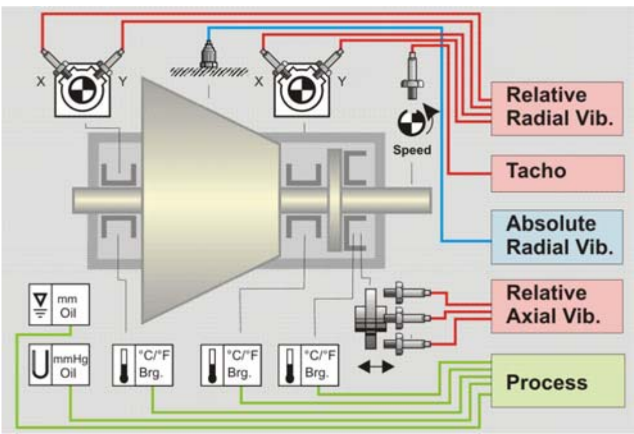


Figure 5 Plots used for condition and performance monitoring of a compressor train.

Vibration Monitoring
Both safety and condition monitoring can be done from the configuration shown in Fig. 4. Typical vibration and process parameters used for condition monitoring are shown in Table 3.



- **8x Relative vibration sensors** – Radial, axial and tacho (red)
- **1x Absolute vibration sensors** – Casing (blue)
- **5x Process sensors** – Imported or measured (green)

Figure 4 Vibration monitoring strategy for a typical crack gas compressor (only one stage shown)

Sensor (meas. point)	Measurements			Plots	Faults that can be detected and diagnosed
	Safety Monitoring (VC 6000)	Condition Monitoring			
		Trending SW	Diagnosis SW		
Relative radial vibr. (shaft)	o **Overall** (ISO:1Hz/10Hz - 1kHz) o $\mathbf{S_{max}}$	o **DC** (bearing position)	o **Autospectrum** (FFT) o **DC vs. RPM** o **1x, 2x, 3x**	Trend vs. time/speed, Spectrum, Waterfall, Orbit, Shaft position polar, Transient (Bodé)	Bearing damage, lack of lubrication, overload, wear, misalignment, unbalance
Tacho		o **Speed, phase**		Trend vs. time	Phase and triggering used in other measurements
Relative axial displ. (thrust brg)	o **DC** (displ.)			Scalar vs. time/speed	Bearing damage, lack of lubrication, overload, wear
Absolute radial vibr. (casing)	o **Overall** (ISO:1Hz/10Hz - 1kHz)	o **CPB6%**	o **Autospectrum** (FFT)	Trend vs. time/speed, Spectrum, Waterfall	General faults, flow problems, blade passage
Process (bearing, lube oil)		o **DC** (bearing temp. oil level, oil pressure)		Trend vs. time/speed	Bearing damage, lack of lubrication, overload, wear

Table 3 Standard vibration techniques for a compressor (single stage shown).

Benefits

Combined condition and performance monitoring strategy is very important for the critical compressor trains in an ethylene plant. By monitoring the condition of the machines, the run lengths between overhauls can be increased, maintenance downtime reduced, and unplanned downtime and spurious trips minimized.

Performance monitoring helps to detect leaking seals and fouling that reduce throughput. A 0.7 bar increase in the inter-stage or final discharge pressure of a crack gas compressor results in an estimated production increase of 1%. For an ethylene plant with 800 000 tons/year capacity, that gives an increase of €5,056,000/year in production revenues (at €632/ton), or €1,517,000 in operating profits (assuming 30% operating margin). A 0.7 bar reduction in suction pressure results in a 0.75% increase in production.

Performance monitoring is also used for optimizing the wash oil and wash water cleaning, and anti-fouling injection into the casings and intercoolers.

All of this results in expanding the operating envelope of the compressors while at the same time increasing safety, reliability and production.

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