Brüel & Kjær Vibro

Application Note

Monitoring Centrifugal Compressors

Turbo machinery employing centrifugal effects for increasing fluid or gas pressure have been in use for more than a century. The earliest machines using this principle were, undoubtedly, hydraulic pumps followed later by ventilating fans, blowers and compressors. The centrifugal compressor has become the reasoned choice for refrigerating plants, petrochemical and oil & gas industry.

*The **centrifugal compressor** is used widely in more or less all-modern processing applications. Where extreme high pressure is required the reciprocating compressor is the preferred type. When looking at gas turbines and especially jet engines, axial compressors are typically used.*

Horizontal split compressor

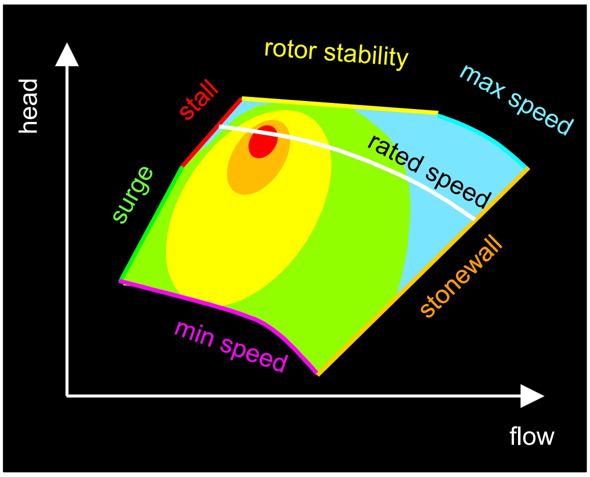
Recognising the need for different types of compression technology, the three above-mentioned compressor types are covering more or less all applications. B&K Vibro offers both standard and customised monitoring solutions that consider the application rather than the general monitoring approaches, based on in-depth knowledge about specific machinery elements influencing the machinery behaviour.

The **centrifugal compressor** has been the reasoned choice for refining plants and the oil & gas industry for more than 50 years. These compressors have capabilities ranging from below 1 MW up to around 50 MW and are preferred because of their high efficiency, good economy, low maintenance and high degree of reliability.

Centrifugal compressors are as standard equipped with proximity probes measuring either an overall shaft vibration level or the S_{max} level, at the bearing locations, depending on vender monitoring recommendations for judging the vibration state.

The centrifugal compressor is required to meet wider and wider performance conditions (wide operational speed range combined with large flow variations resulting in large variation in head or delivered pressure). In time with superior demands for high performing flexible compressors it is often seen that designs are stretched to their limit.

In the resent years one of the main problems when considering high performing centrifugal compressor applications, has been control of the design, especially when considering ***aerodynamic stability*** (e.g. surge prediction, flow instabilities, like rotating stall both in the stationary and rotational flow path).



Centrifugal Compressor performance map showing some typical design limitations

Rotordynamic stability, which was the main issue from the mid-fifties up to early-nineties, is today one of many areas of concern, when designing high performance applications. Consequently, when choosing **monitoring solutions** for centrifugal compressors it is important to consider not only shaft vibrations originating form the rotational speed, but also any special characteristics of various machine elements and aerodynamic impact.

Potential Failures have different distribution depending upon the application (mechanical design, operation range, environment etc.). Investigations show that around 50% of all failures can be assigned to product faults, i.e.

- Material faults (e.g. due to fatigue or off-design)
- Faults in planning
- Manufacturing faults
- Assembly and repair

Around 35% of all failures can be assigned to operational faults, i.e.

- Maintenance
- Mishandling

Most of these faults may be detected before they become critical by a system that combines vibration and performance monitoring. In order to minimize the machine installation costs, such monitoring systems are rarely recommended by the machine manufacturer. It is up to the end user of the compressor to balance the investment cost, and the cost of running a predictive maintenance system up against:

- Higher production output
- Less unexpected repairs
- Optimized maintenance scheduling
- Optimized machine performance.

Predictive Monitoring should include monitoring of both process and vibration parameters. The process parameters are used in making performance and efficiency calculations and the vibration parameters are necessary when judging the condition of the rotating parts.

It is important that the monitoring system is able of generating alarms on both measures and calculated input and each of the parameters are able to generate a relay output (alarms) for *safety reasons*.

The alarms, which are functions of one or more calculated or analog parameters (process and/or vibration), are with regard to process parameters typically based on:

- Compressor isentropic efficiency
- Compressor isentropic head
- Compressor volume flow
- Data corrections against atmospheric pressure.

With regard to vibration parameters:

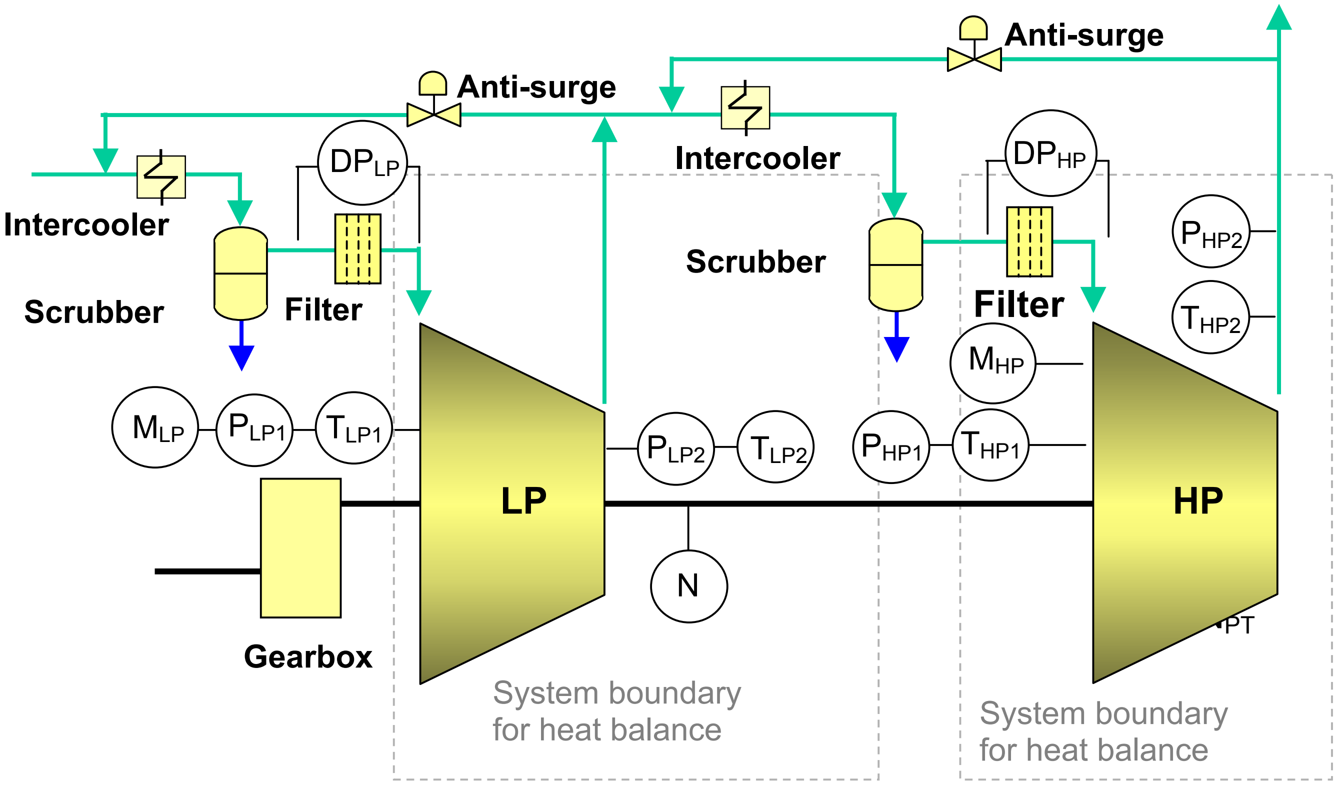
- Overall vibration level (according to API standards)
- Rotor synchronous amplitude and phase measurements (Minimum 1X & 2X)
- Casing and blade passing frequencies
- Journal Bearings – Gap, Orbit
- Rolling element Bearings – Bearing frequencies and high frequency noise

- Vibration parameter measurement tools:
- DC
- Band Pass / Smax measurements
- Dual Time function with limiting filters
- Vector measurements – Selective Magnitude and Phase
- FFT - Auto spectra with zoom capability
- Selective Envelope Spectra
- CPB Spectra

The ***Monitoring Set-up*** depends on the installed monitoring equipment and the monitoring strategy relevant for the specific application. As the manufacturer typically installs sensors in accordance to monitoring requirement (installation & design manual), complying with the prescriptive guarantee obligations, Brüel & Kjær Vibro monitoring strategies starts with basic considerations in respect to vendor specifications, respecting any guarantee requirements.

In dialog with the customer (end user or contractor) the overall monitoring strategy is scheduled and implemented accordingly.

The Brüel & Kjær Vibro conditioning monitoring system imports values from the DCS system, as scalar values (normally no additional process sensors needs to be installed).



Typical compressor process measuring positions (these signals are easily imported to COMPASS™ and used for judging the performance condition of the centrifugal compressor).

The Brüel & Kjær Vibro conditioning **monitoring** system **requirements** are considered as equal parts of warning of imminent failure and adequate protection (safety) of personnel and facilities from undesirable accidents. Furthermore, the goal is to provide “actionable” information to the operations and maintenance personnel, where actionable information is accurate and timely information that can be used to make intelligent machinery management decisions, i.e.:

- Continue or not?
- If it fails, what are the consequences?
- Can the machine be re-started?
- What should be inspected?
- Is the machine operating efficiently?
- Will it last until next scheduled overhaul/service?

The conditioning monitoring system **COMPASS™** is a fully automatic integrated monitoring system. Through its modular concept, COMPASS™ can be adapted to a large range of different machines so that all of the requirements of a modern condition based maintenance strategy are fulfilled by one, plant-wide system

All in one – COMPASS™ safety & predictive condition monitoring

COMPASS™ is a rack based (19 inches) modular safety and conditioning monitoring system, which can be tailored to meet any compressor application.

The compressor signals are conditioned, filtered and (if necessary) rectified, by the processor modules. Narrow-band filtering (order tracking) with regard to shaft speed, band pass measurements and any special analysis requirements, like S_{max}, orbit measurements, CPB, time function measurements etc., is done by the processor modules.

The processed signals is stored in the COMPASS™ database and displayed on the central computer, X-terminal or remotely accessed through the modem connection or Internet (using standard PC).

The **sensor selection** is based on measuring vibration, process and other relevant parameters. If any additional sensors are required you should consult your Brüel & Kjær Vibro representative.

Compressors require vibration sensors measuring vibration severity (or overall vibration levels), the direction vibration (reference sensor) and the motion of the shafts (position relative to bearings and seals) giving:

- Amplitude
- Phase
- Frequency

When monitoring of shaft vibration the best choice is the ***displacement sensor***. A reference sensor, typically a displacement sensor, measures the vibration phase.

Bearing cap or case mounted seismic sensors (e.g. accelerometers) are useful for evaluating casing vibrations and to provide absolute vibrations measurements. The sensor should be selected based on its response curve, frequency range, sensitivity and noise susceptibility.

The ***seismic sensor*** is often the preferred choice when obliging harsh environment, i.e. where the temperature is far too high for traditional displacement and velocity sensors. Therefore, when using seismic sensors, to measure shaft vibration considerations of where to mount the sensors are decisive for the result. The sensor should be mounted at a location where the vibration is transmitted directly to the sensor, without much loss.

The ***thrust position*** is extremely critical since thrust bearing failures and axial rubs can be catastrophic for centrifugal compressors. The thrust position is best measured with the displacement sensor(s) monitoring the thrust disc movement.

The **bearing** type of centrifugal compressors is usually fluid film bearings and rarely rolling elements bearing. The bearing type depends on manufacturer traditions and years of experience with particular designs; however, the tilting pad bearing is the preferred bearing design today.

The ***tilting pad bearing*** has the advantage of providing no destabilizing forces to the rotor system, but on the expense of low bearing damping. This is why centrifugal compressor manufacturer decide to install machinery elements like squeeze film dampers supporting the bearing(s), shunt holes in the division wall, use honeycomb or hole pattern seals instead of traditional labyrinth seals, inserts gas swirl- or thrust-brakes in the flow path etc. to improve the stability of the rotor-bearing system, by introducing damping and/or removing destabilizing gas forces.

All these machinery elements or components have their own characteristic and impact the rotor dynamic or aerodynamic stability differently. When defining the overall monitoring strategy for a centrifugal compressor the specific design of the application should be taken into account. Furthermore, different measurement and diagnosis techniques must be applied depending on the type of centrifugal compressor application.

Summary
Brüel & Kjær Vibro Conditioning monitoring system COMPASS™ used together with a well-considered monitoring strategy for the individual application yields the optimum proactive protection of centrifugal compressors.

The benefits of optimizing monitoring strategies to consider the criticality of the specific design and potential failure modes clearly distinguish in improved performance and reliability turning directly into revenue improvements or cost reductions.

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