Brüel & Kjær Vibro

Application Note

Monitoring Gas Turbines

Aero derivative gas turbines are effectively used within the Oil & Gas industry as a high power driver for gas compression and power generation. Focusing on maximum production output at minimum production cost has made the performance and maintenance requirements more important than ever before.

The machine monitoring strategy for a gas turbine should take the potential failure mode of the machine design into account. The machinery design and the recommendations of the manufacturer are equally important with respect to location and type of process and vibration sensors.

Gas turbine manufacturer base the acceptance of the machines on common standard and guidelines, like API, ISO, VDI etc. or in-house developed acceptance criteria. Usually gas turbines are pre-equipped with sensors based on the vendor specifications. Using this equipment and prescribed monitoring set-up should be regarded as an important part of the overall monitoring strategy, especially when considering the importance of maintaining guarantee. However by analyzing the potential failure modes of a gas turbine, **additional requirements to the monitoring strategy** and hence the monitoring system becomes evident.

Potential Failures have different distribution depending upon the application (mechanical design, operation range, environment etc.). Investigations show that around 70% 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

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 systems are rarely recommended by the machine manufacturer.

It is up to the end user of the turbine 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

Gas Turbine **Predictive Monitoring** can be divided into monitoring of:

- Process parameters
- Vibration parameters

The process parameters are used for making performance and efficiency calculations. The vibration parameters are necessary when judging the condition of the rotating parts. By combining vibration and performance data, better diagnostics can be made. A monitoring system shall be able to generate alarms not only on the input parameters, but also on the calculated values. By setting alarm levels on the calculated values, and other parameters the cost of running the system becomes considerably lower, since the system tells what is wrong when it is wrong. Instead of having to use hours every day to check the measurements on the machine, you can concentrate on the measurements where alarms have been generated. For a gas turbine following performance parameters are recommended to be calculated.

- Turbine isentropic efficiency
- Compressor isentropic efficiency
- Compressor isentropic head
- Compressor volume flow
- Data corrections against atmospheric pressure, ambient temperature, relative humidity speed and differential pressure of inlet filter.
- Heat rate (the actual heat input)
- Corrected heat rate
- Isentropic head
- Fuel gas consumption
- Air flow
- Gas turbine inlet temperature
- Firing temperature

Recommended vibration parameters:

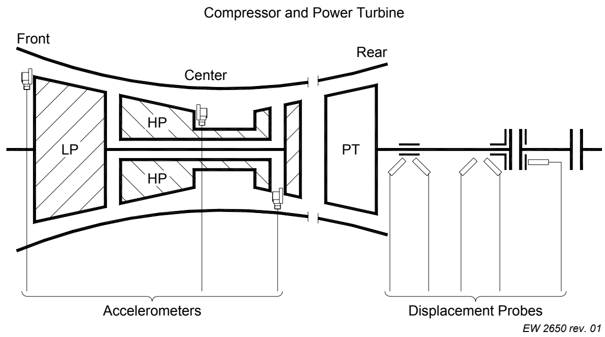
- Overall vibration level (according to API standards)
- Rotor synchronous amplitude and phase measurements (Minimum 1X & 2X)
- Casing and blade passing frequencies
- Journal Bearings – Gap, Orbit
- Rolling element Bearings – Bearing frequencies and high frequency noise

- Vibration parameter measurement tools:

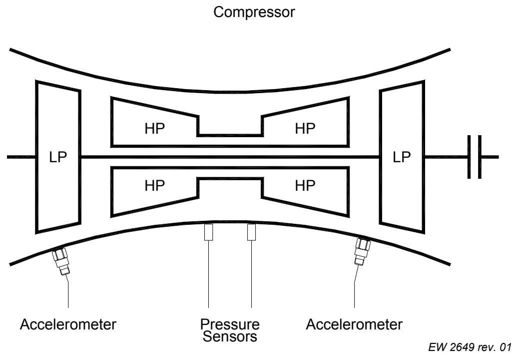
- DC
- Band Pass / Smax measurements
- Dual Time function with limiting filters
- Vector measurements – Selective Magnitude and Phase
- FFT - Auto spectra with zoom capability
- Selective Envelope Spectra
- CPB Spectra

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.

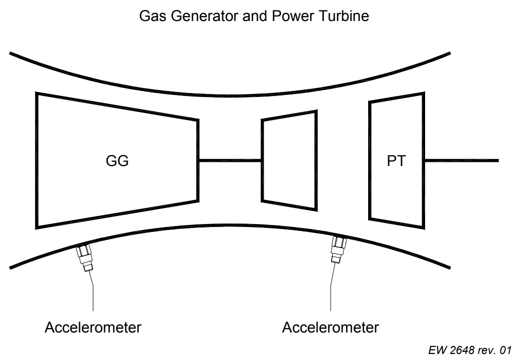
In dialog with the customer (end user or contractor) the overall monitoring strategy is scheduled and implemented accordingly.



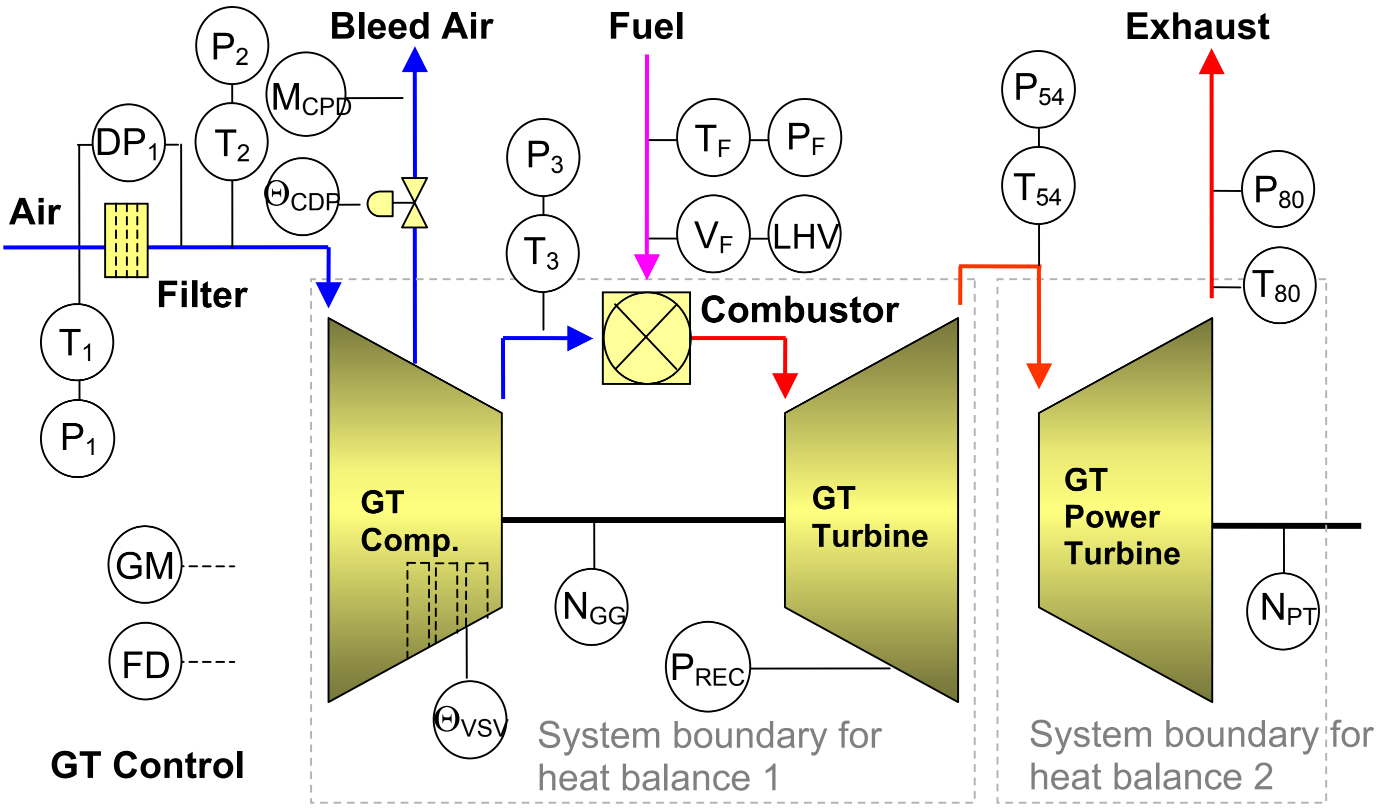
*Vibration sensor instrumentation for a **Rolls-Royce RB211** gas turbine, comprising of a 2 shafts gas generator and a power turbine.*



*Vibration sensor instrumentation for a General Electric **LM 6000** gas turbine (2 shafts based on the twin spool principle).*



*Vibration sensor instrumentation for a General Electric **LM 2500** gas turbine (2 shafts: gas generator and power turbine).*



LM 2500 process measuring positions (these signals are easily imported to COMPASS™ and used for judging the performance condition of the gas turbine).

The gas turbine control system (normally delivered by the manufacturer) requires a number of process sensors. Figure 5 shows the sensor installation for a typical gas turbine (LM 2500). The Brüel & Kjær Vibro conditioning monitoring system imports these values from the DCS system, as scalar values (normally no additional process sensors needs to be installed).

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 the right information to the operations and maintenance personnel, where the 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

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

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

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.

Gas turbines require vibration sensors measuring vibration severity, the direction vibration (reference sensor) and the motion of the shafts (position relative to bearings and seals) giving:

- Amplitude
- Phase
- Frequency

When monitoring shaft vibration on gas turbines ***displacement sensors*** are recommended. The vibration phase is measured by a ***reference sensor***; either an infrared or displacement sensor.

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. EEx approval for gas turbine sensors is normally required

The ***seismic sensor*** is often the preferred choice when obliging harsh environment, i.e. areas around the gas producer and power turbine, where the temperature is far too high for traditional displacement and velocity sensors. Therefore, when using seismic sensors, to measure shaft vibration, on a gas turbine, 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 very strong omni-directional vibrations found in some gas turbines may overload the sensor. Transducers with built in filters or mechanical filtering at the transducer location are required for some transducer locations.

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

The **Bearings** design of industrial gas turbines is quite different from aero-derivative applications. Industrial applications usually use fluid film bearings, while the aero-derivatives use rolling bearing elements. However, the bearing type depends on manufacturer traditions and if the industrial gas turbine design originates from aero-derivative applications.

Therefore, depending on the type of bearing {rolling element, fluid film and/or squeeze film bearings} different measurement and diagnosis techniques should be applied.

- ***Fluid film bearings*** (including squeeze film) are monitored from 0 to 10 times the rotational speed, with focus on the first few harmonics of the rotational speed and the shaft lateral resonant (natural) frequencies.
- ***Rolling element bearings*** are not only monitored with regard to outer, inner and ball pass fault frequencies, but special techniques like CPB, Envelope and Cepstrum analysis are successfully applied in order to predict approaching bearing faults.

It is not unusable to meet gas turbine designs containing both fluid film and rolling element bearings, dependent on the design of the shaft support and its arrangement.

Summary

Brüel & Kjær Vibro Conditioning monitoring system COMPASS^{TM} used together with a well-considered monitoring strategy for the individual gas turbine application yields the optimum proactive protection of gas turbines.

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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