Cairo University
Faculty of Engineering
Mech. Power Department

دبلوم تطبيقات التحكم الأوتوماتيكى فى نظم القوى الميكانيكية

MEP 599 Diploma Project-Spring 2021-2022

Gas Turbine Vibration Control

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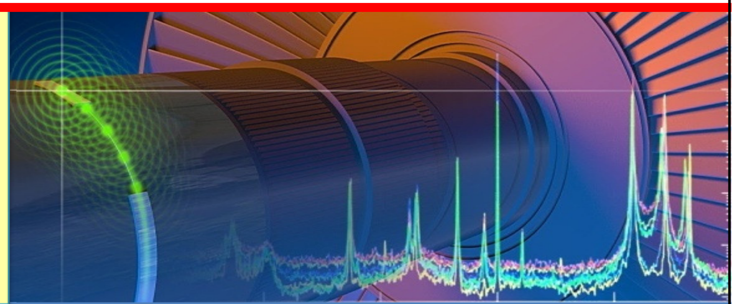
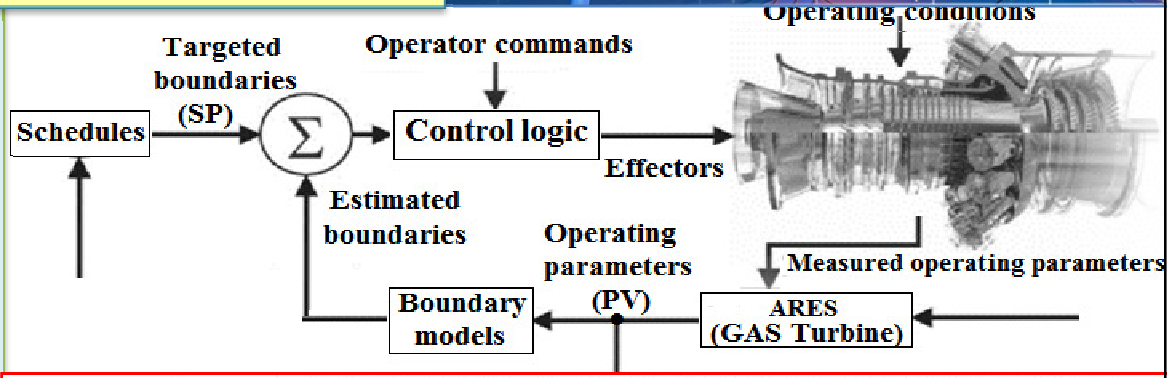
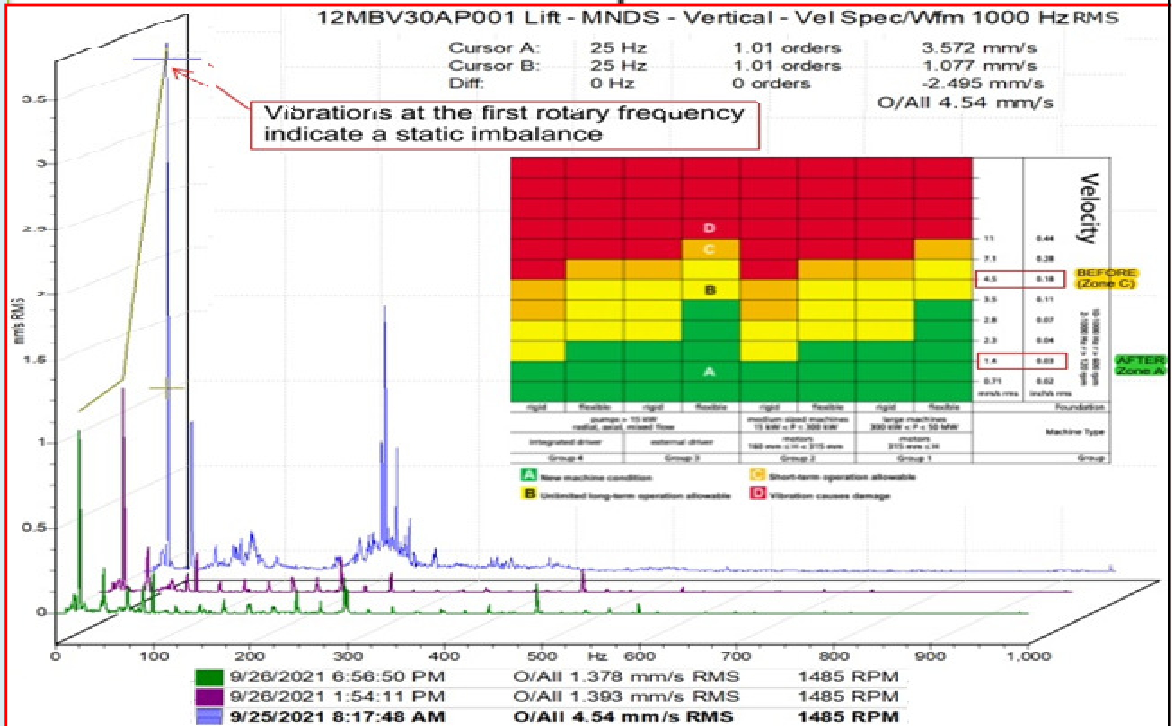
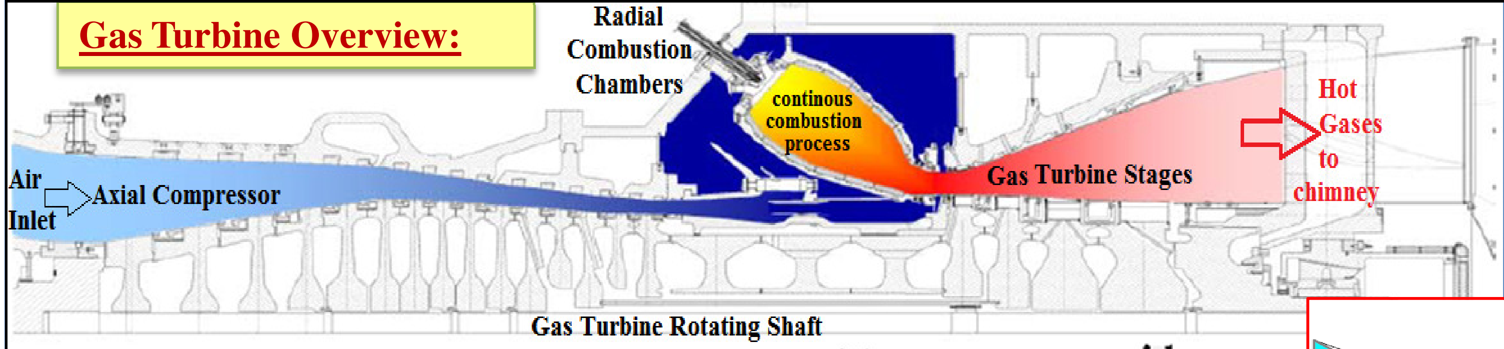


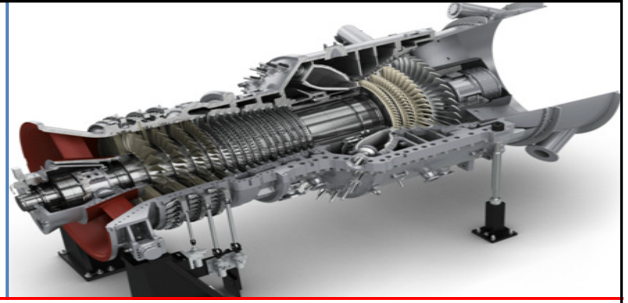
Abstract: This project presents a detailed analysis and experimental investigation of Gas Turbine Vibration Control System which is an essential part for safe operation & effective maintenance of any GT. We discus types of predictive maintenance that can be done on the GT and how to monitor and perform a comprehensive analysis of the "Vibration Spectrograph" of the GT in order to predict possible future failure of essential parts so that maintenance can be planned for the next downtime. Advantages of this method are that downtime & operation problems are minimized, spare parts will be ready for installation & reduction of maintenance cost. This report presents an overview of GT system & new trends used to improve its efficiency & performance including the GT Vibration measurement and Control System. We discus the ISO 20816 recommendations of restricted and unrestricted operation vibration limits in addition to sensor placement and the proper sensor type for different positions on the outer GT casing. The onsite experimental measurements are made on Siemens (model SGT-V64.3) GT used for power generation after it has been overhauled. Experimental results are done by The Bentley Nevada - Commtest VB7 "Vibration Analyzer". Detailed analysis of the "Vibration Spectrograph" was done in order to determine suitable solutions for GT current situation. In addition to these results, we used same technique on a faulty oil pump used for GT lubrication system and determined some effective maintenance and repair recommendations to be done.

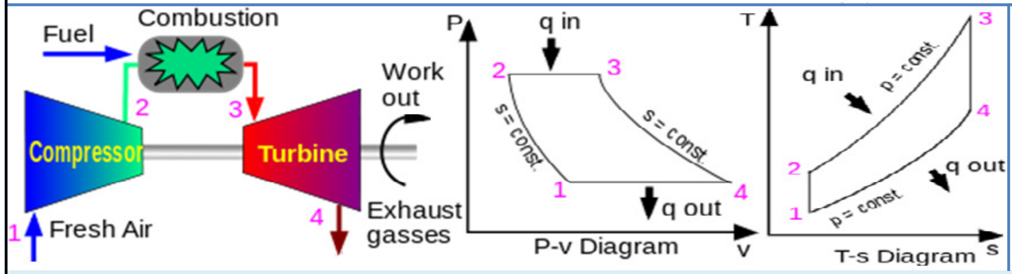


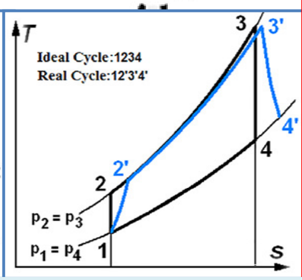


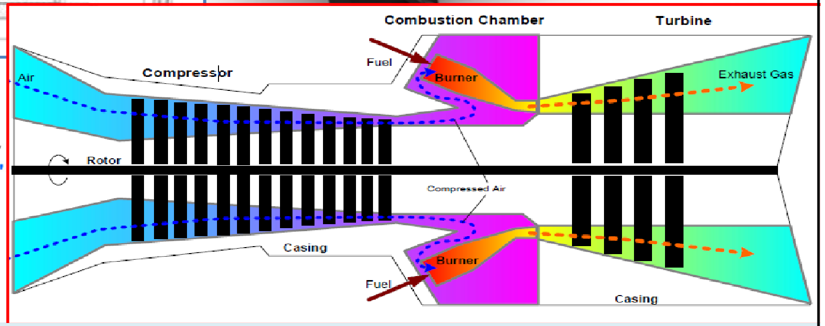
Gas Turbine Overview:











Gas turbines operate on the Bryton cycle. Gas turbine can be divided into 3 main segments: compressor, combustion chamber and turbine. Gas turbines are like the internal combustion engines where the air intake and compression stroke take place in the compressor. Combustion process is done in many radial combustion chambers. The expansion or power outlet stroke is done in the turbine as seen on above figures

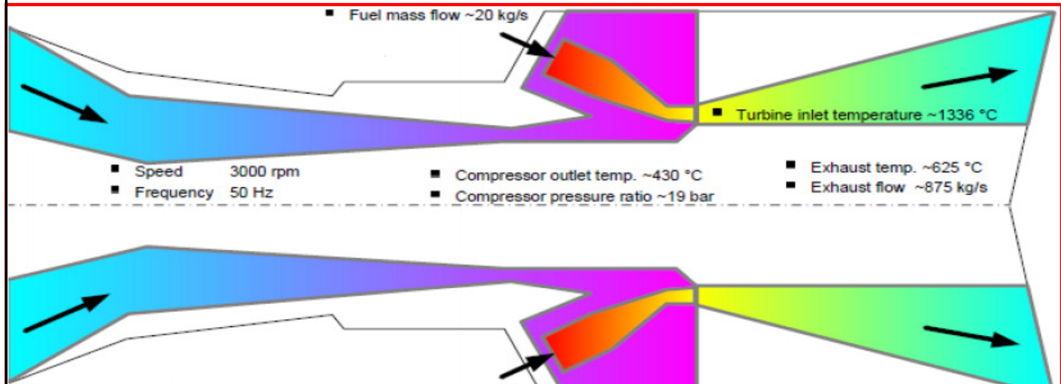


Figure 5: Gas turbine section working temp

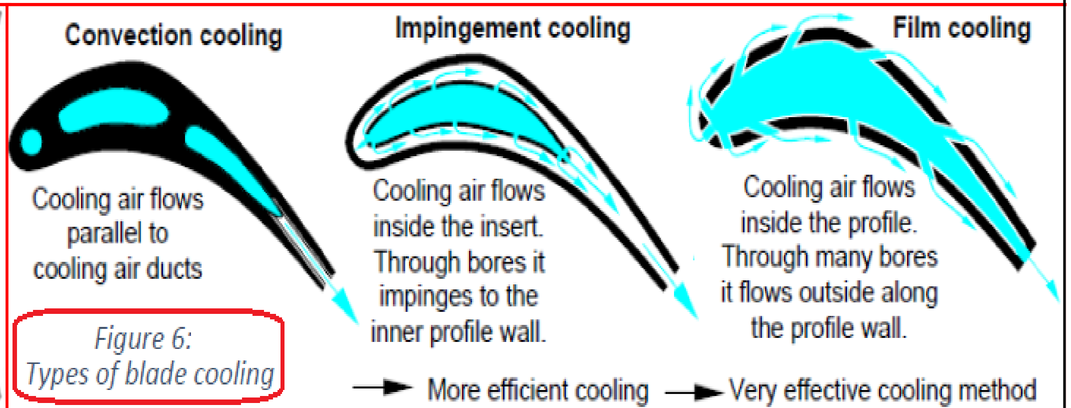
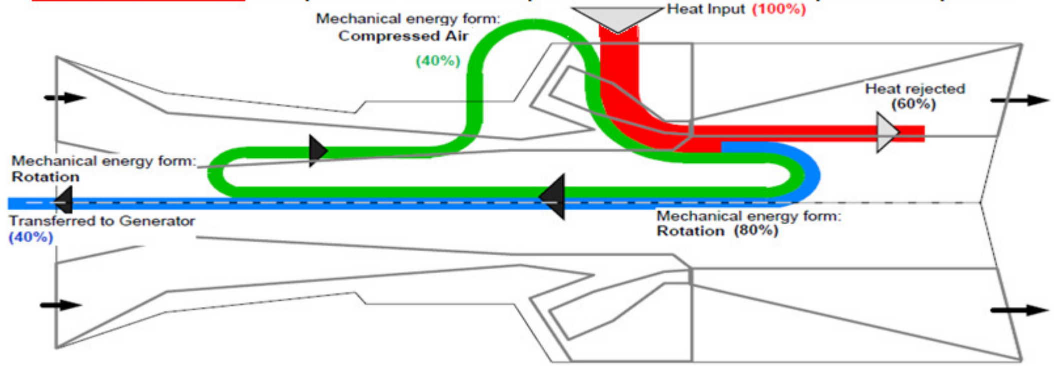


Figure 6: Types of blade cooling

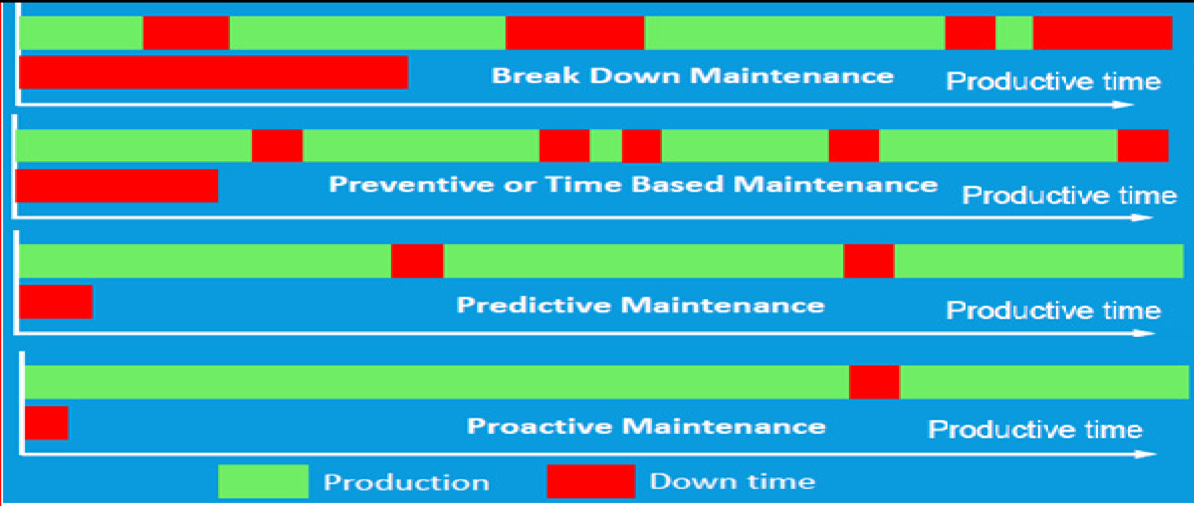
Flow of energy: Compressor can use up to 60% of the turbine produced power

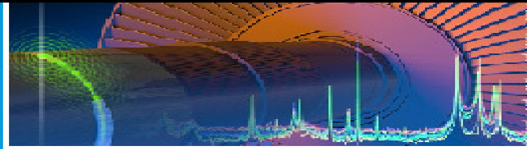


Turbine section suffer extremely high pressures and temperature specially the firsts stages. The blades must be cooled down to withstand high creep stress. Figure 5 shows 400MW gas turbine with turbine inlet temperature of 1336 ˚C.

Relatively cool air is extracted from the last compressor stages to cool down the blade called bleed air in addition to a ceramic coating to the blades to increase its service life. Gas turbine manufactures have devolved many techniques to cool down the turbine blade as shown in fig.6. The research showed that the best type and the most effective is film cooling.

The vibration signals in practice consist of many frequencies occurring simultaneously so that we cannot immediately see just by looking at the amplitude-time pattern, how many components there are, and at what frequencies they occur. These components can be revealed by plotting vibration amplitude against frequency.





Maintenance strategy

- **Reactive Maintenance**
- **Planned Maintenance**
- **Predictive Maintenance**
- **Proactive Maintenance**

Predictive Maintenance:

Advantage :

- Increased component operational life/availability.
- Decrease in costs for parts and labor.
- Better product quality.

Disadvantages :

- Increased investment in diagnostic equipment.
- Increased investment in staff training.

Breaking down of vibration signals into individual frequency components is called frequency analysis, a technique which may be considered the cornerstone of diagnostic vibration measurements. The graph showing vibration level as a function of frequency is called frequency spectrogram. When frequency analyzing machine vibrations, we normally find a number of prominent periodic frequency components which are directly related to fundamental movements of various parts of the machine. With frequency analysis we are able to track down source of undesirable vibration.

Gas Turbine Vibration Control System

- Gas turbine vibration measurement
- Machine health indication
- Development of failure
- Planned maintenance and action
- Down time and cost

- Casing Vibration
- Turbine bearing
- Compressor bearing
- Monitoring of any abnormal vibration

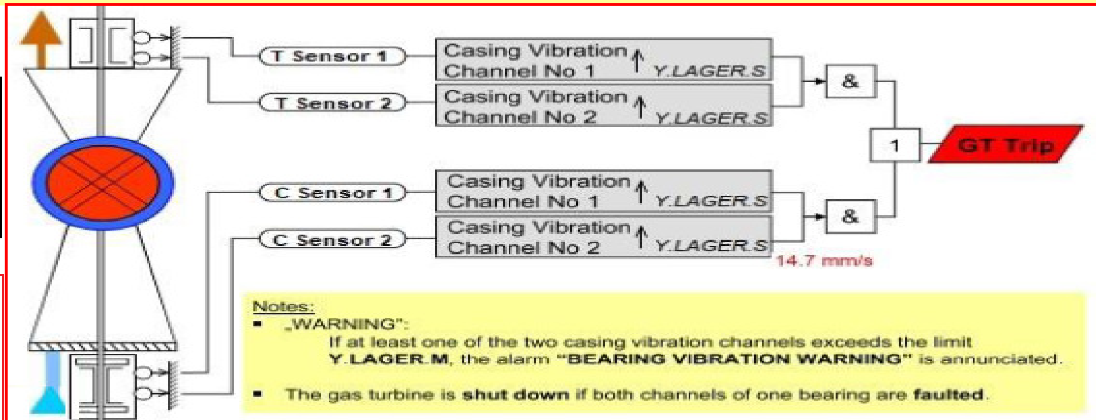


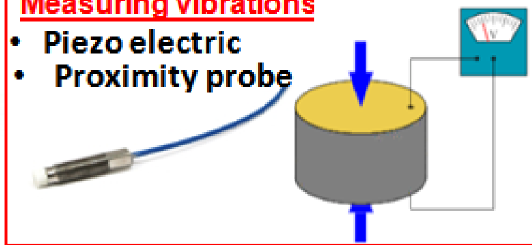
Figure 11: Simplified GT Vibration Control and Protection System

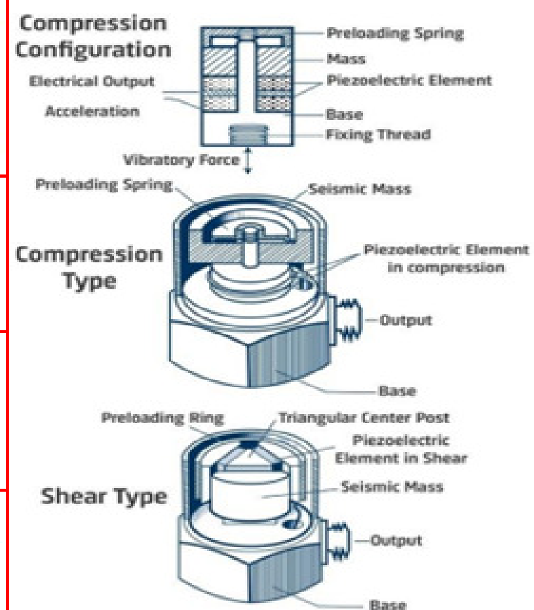
Casing vibrations are measured near the turbine bearing and near the compressor bearing using vibration pickups Turbine sensor 1 and Turbine sensor 2 (turbine bearing) and Compressor sensor 1 and Compressor sensor 2 (compressor bearing). Each transmitter signal is used by a processor module to calculate the effective vibration velocity, which is then output as a current signal that undergoes further processing in the I&C system. Because two equivalent channels are used to measure casing vibration, these channels are designated Channel 1 and Channel 2 for additional logic links. If at least one of the two channels exceeds the limit, a warning is annunciated as shown in fig. 11.

The gas turbine trips and is shutdown if one channel is faulted and the other channel exceeds the higher limit. If neither channel is faulted, the gas turbine trips and is shut down when readings of both channels exceed limit Y. An alarm is annunciated if trip is triggered.

Measuring vibrations

- **Piezo electric**
- **Proximity probe**





Vibration control logic: The vibration protection circuits monitor the absolute vibration velocity of the generator, compressor and turbine bearing housings against alarm and trip limits. Inadmissible vibrations can be caused by unbalance or blade breakage, for example. The vibration velocity is a measure for the smooth running of the turbine

If the vibration velocity increases above the alarm or trip limits

- an alarm (HIGH) is issued
- a trip alarm (TOO HIGH) is issued and a gas turbine trip actuated.

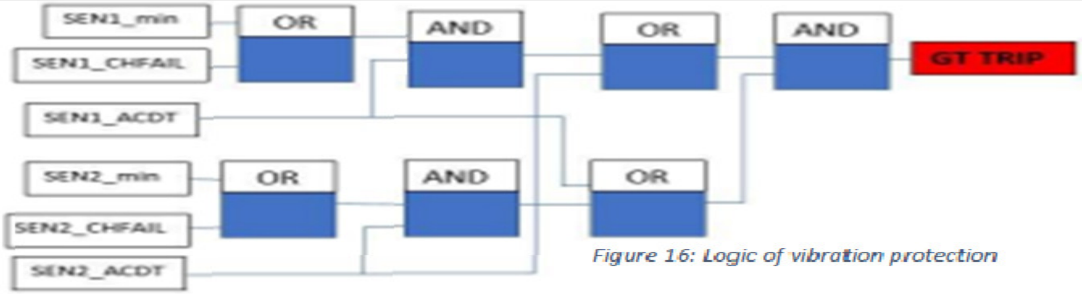
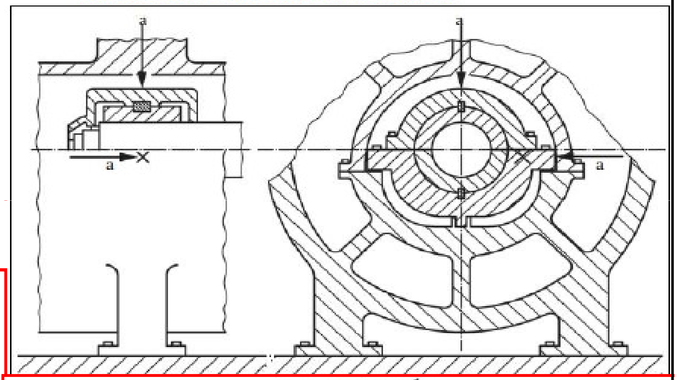


Figure 16: Logic of vibration protection

Measurements of vibration of non-rotating parts

For monitoring purposes, the measurement system shall be capable of measuring broadband vibration over a frequency range from 10 Hz to at least 500 Hz. If, however, the instrumentation is also used for diagnostic purposes, a wider frequency range and/or spectral analysis can be necessary. For example, in cases where the frequency corresponding to the first resonance speed (critical speed) of the coupled rotors is below 10 Hz, the lower limit of the linear range of the measurement system shall be reduced accordingly.

Direction of measurement



Measurements of vibration of rotating shafts

For monitoring purposes, the measurement system shall be capable of measuring broadband vibration over a frequency range from 1 Hz to at least three times the maximum normal operating frequency or 125 Hz, whichever is greater. If, however, the instrumentation is also used for diagnostic purposes, a wider frequency range (e.g., up to six times the maximum normal operating frequency) and/or spectral analysis can be necessary.

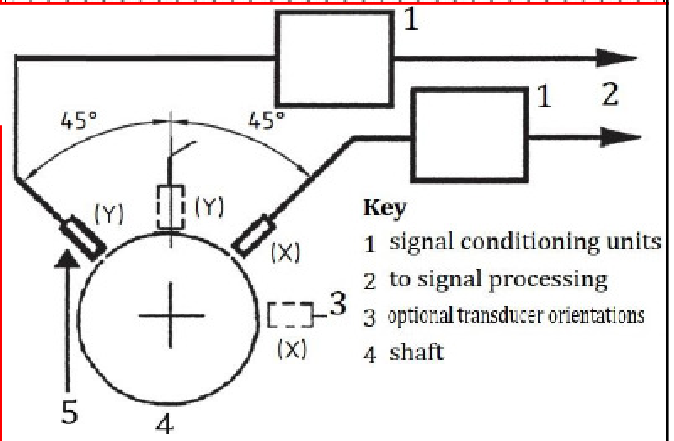
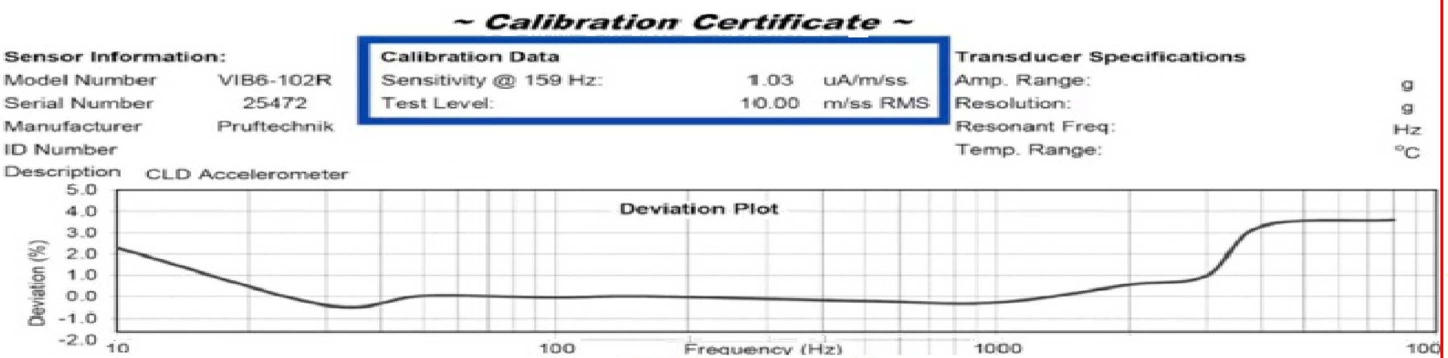


Figure 17: ISO recommendation for sensor placement

Sensor calibration

Annual calibration has to be done to make sure that the sensor is at top-notch condition. Sensitivity and output may change due to contentious vibration, heat and environmental condition although heavy-duty sensor is used. Usually calibration is done by a third party organization that provide a certificate that the sensor is suitable for operation or not. The sensor is placed which exert a range of known force and measure the output amplitude and sensitivity. The force range must match the sensor range so the sensor manufacturer and model must be selected on the calibration machine so every parameter is set correctly. After the test the machine, export a report as shown in fig.18.



~ Calibration Certificate ~

Sensor Information:	
Model Number	VIB6-102R
Serial Number	25472
Manufacturer	Pruftechnik
ID Number	
Description	CLD Accelerometer

Calibration Data		
Sensitivity @ 159 Hz:	1.03	uA/m/ss
Test Level:	10.00	m/ss RMS

Transducer Specifications	
Amp. Range:	g
Resolution:	g
Resonant Freq:	Hz
Temp. Range:	°C

Figure 18: Calibration Certificate

The most important part in the certificate is the calibration data section, which shows the sensor sensitivity and deviation curve, which shows the error in output reading, and that curve should be compared with the manufacture curve. Anyway, this check must be done annually to make sure that sensor is accurate enough as this sensor may cause gas turbine trip.

Gas turbine vibration protection alarm

The Gas turbine vibration levels and evaluation criteria in acc. to ISO 20816. The maximum vibration magnitude observed at each measurement location is assessed against four evaluation zones established from international experience as shown in the below figure.

ISO Evaluation Criteria

Zone A	The vibration of newly commissioned machines would normally fall within this zone
Zone B	Machines with vibrations within this zone are normally considered acceptable for unrestricted long-term operation
Zone C	Machines with vibrations within this zone are normally considered unsatisfactory for long-term continuous operation. Generally, the machine may be operated for a limited period in this condition until a suitable opportunity arises for remedial action.
Zone D	Machines with vibrations within this zone are considered as not acceptable for operation. Correction requiered.

Figure 15: Gas turbine vibration protection alarm zones

The zone boundary values are given in **DIN ISO 20816-2:2018-01 Annexes A** shown in fig, 15 for radial vibration of non-rotating parts at all bearings and axial vibration of thrust bearing housings as shown in table A.1.

The zone boundary values are given in **DIN ISO 20816-2:2018-01 Annexes B** for shaft relative vibration and shaft absolute vibration as per table B.1.

Table A.1 — Values for bearing housing or pedestal r.m.s. vibration velocity at zone boundaries

	Shaft rotational speed r/min	Bearing housing or pedestal r.m.s. vibration velocity at zone boundaries mm/s — Zone boundary A/B	B/C	C/D
Steam turbine and generator	1 500 or 1 800	2,8	5,3	8,5
	3 000 or 3 600	3,8	7,5	11,8
Gas turbine	3 000 or 3 600	4,5	9,3	14,7

NOTE Since it is not common practice to run gas turbines at 1 500 r/min or 1 800 r/min, no values are given.

Table B.1 — Values for shaft relative vibration peak-to-peak displacement at zone boundaries

	Shaft rotational speed r/min	Shaft *relative* vibration peak-to-peak displacement at zone boundaries µm — Zone boundary A/B	B/C	C/D
Steam turbine and generator	1 500	100	200	320
	1 800	95	185	290
	3 000	90	165	240
	3 600	80	150	220
Gas turbine	3 000	90	165	240
	3 600	80	150	220

NOTE Since it is not common practice to run gas turbines at 1 500 r/min or 1 800 r/min, no values are given.

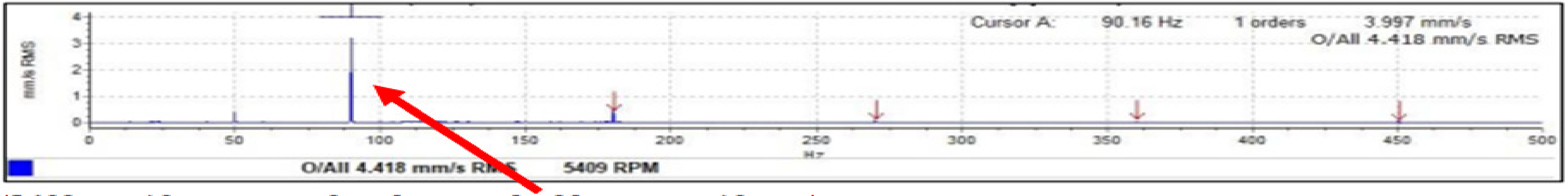
Gas turbine start up vibration condition

Gas turbine or any rotating machine start up is showing a sudden increase of the vibration at certain frequency and certain speed which indicating the natural frequency and critical speed of the machine. All rotating shafts, even in the absence of external load, will deflect during rotation. The unbalanced mass of the rotating object causes deflection that will create resonant vibration at certain speeds, known as the critical speeds. The magnitude of deflection depends upon the following:

- Stiffness of the shaft and its support
- Total mass of shaft and attached parts
- Unbalance of the mass with respect to the axis of rotation
- The amount of damping in the system

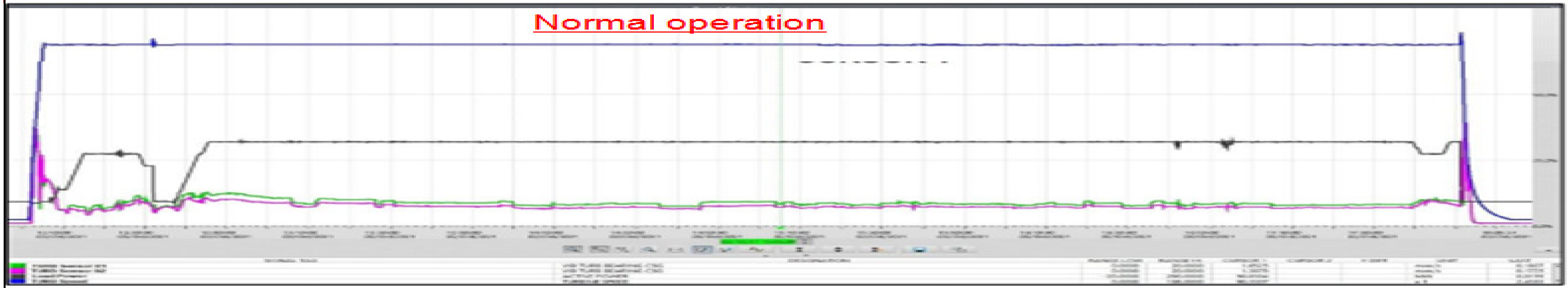
Figure 19: Gas turbine vibration trend during start up and shutdown

Diagnostics: Vibrations amplitude at the first rotary frequency indicates rotor static imbalance



Vibration analysis and diagnostics

Vibration is transmitted from installed sensor to the control central room as a protection overall velocity limit. But to identify the exact cause of vibration, the vibration must be analyzed via online analysis monitoring system or offline analyzer such as Bently Nevada – Commtest VB7 instrument where to diagnose the vibration excitation frequency which will indicate the cause. Figure 21 The vibration analysis was done and confirmed that the vibration increase shows high amplitude in one time the running speed. The vibration increase in the first rotary frequency indicates static imbalance.



Example of Vibration analysis of turbine lift oil pump