

DEP SPECIFICATION

CONDITION MONITORING OF ROTATING EQUIPMENT

DEP 31.29.00.11-Gen.

February 2014

DESIGN AND ENGINEERING PRACTICE



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1. INTRODUCTION

1.1 SCOPE

This DEP specifies requirements and gives recommendations for the condition monitoring of rotating equipment such as compressors, gas turbines, steam turbines, gas or liquid expanders, gearboxes, pumps, fans, electric motors and electrical generators. To maximise the benefits of current technology, it also covers the accessing of condition monitoring services such as Shell SmartConnect through remote connectivity.

This DEP applies to new construction projects and applies when reviewing existing rotating equipment condition monitoring.

This DEP should be used together with DEP 32.29.20.10-Gen.

This DEP may be used as part of an integrated asset management plan, which includes tools for:

- Equipment engineering/design documentation and development of procedures.
- Saving and retrieving equipment history (including performance and repair history).
- Condition monitoring, including tools to provide guidance for predictive maintenance or operational decision making (the subject of this DEP).
- Abnormal Situation Management (ASM) designed to diagnose incipient failures or deteriorating condition of the rotating equipment and to provide operational advice to prevent the condition from escalating.
- Aiding decision making with respect to: future operation, scheduling maintenance, replacement of rotating equipment and turnaround planning, all with account being taken of system constraints, trends and diagnosed faults.

The above tools are primarily intended to provide information (from manned and unmanned locations) to operations, maintenance and engineering (both on-site and in remote locations). Therefore, they should be capable of being integrated into existing or future condition monitoring systems and other process equipment (e.g., heat exchangers, fired heaters, reactors) to provide an integrated tool to maximise asset performance.

Development of condition monitoring tools is ongoing. This DEP mentions new developments in order to drive the technology and to ensure information technology (IT) system design can accommodate advances in condition monitoring whenever systems are upgraded.

This is a revision of the DEP of the same number dated February 2013; see (1.5) regarding the changes.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by Shell GSI, the distribution of this DEP is confined to Shell companies and, where necessary, to Contractors and Manufacturers/Suppliers nominated by them. Any authorized access to DEPs does not for that reason constitute an authorization to any documents, data or information to which the DEPs may refer.

This DEP is intended for use in facilities related to oil and gas production, refineries, chemical plants, gas plants, exploration and production facilities, power generation plants and supply/distribution installations. This DEP may also be applied in other similar facilities.

When DEPs are applied, a Management of Change (MOC) process shall be implemented; this is of particular importance when existing facilities are to be modified.

If national and/or local regulations exist in which some of the requirements could be more stringent than in this DEP, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable with regards to the safety, environmental, economic and legal aspects. In all

cases the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned, the objective being to obtain agreement to follow this DEP as closely as possible.

If the rotating equipment Manufacturer's requirements for the condition monitoring of its equipment are more stringent than the requirements in this DEP, the Contractor shall inform the Principal of this and shall provide a detailed proposal for the Principal's approval. This proposal shall include all deviations from the requirements in this DEP needed to comply with the Manufacturer's requirements. The Principal may then negotiate with the Manufacturer(s) concerned, the objectives being to reach an agreement to follow this DEP as closely as possible and to maintain the Manufacturer's warranty on the equipment.

1.3 DEFINITIONS

1.3.1 General definitions

The **Contractor** is the party that carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **original equipment Manufacturer (OEM)/Supplier** is the party that manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party that initiates the project and ultimately pays for it. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.3.2 Specific definitions

Definitions of terms used in this DEP but not mentioned below shall be in accordance with ISO 2041, ISO 13372 and API Std 670.

Term	Definition
Accelerometer	Pick-up (transducer) that converts an input acceleration to an output (usually electrical) proportional to the input acceleration
Alarm (Alert/Warning) Setpoint	Pre-set value of a parameter at which an alarm is activated to warn of a condition that requires immediate evaluation or corrective action
Availability	Measure of probability that a machine will, when used under specific conditions, operate satisfactorily and effectively when required to do so
Condition-Based Maintenance	Maintenance governed by condition monitoring programmes. See also "condition monitoring"
Condition Monitoring	Measurement and analysis of a number of machine parameters, that are used to determine the current health of the equipment and thus the correct timing/extent of equipment maintenance NOTE: Continuous monitoring provides simultaneous, automatic and uninterrupted collection of all status conditions and measured and calculated variables. It is normally available in real time mode.
CMS (Condition Monitoring System)	System for providing equipment health and performance monitoring capabilities See also "monitoring system"

Term	Definition
Critical Speed	Characteristic shaft rotational speed at which resonances of a system are excited.
Data Acquisition And Control Architecture (DACA)	IT requirements for separation of data flow between the office domain and the process control domain. DEP 32.01.20.12-Gen. is the umbrella DEP for a series of DACA DEPs
Δ Amplitude	Change in amplitude measurement (fixed magnitude or percentage change), typically used to trigger collection or storage of data
Δ Rpm	Change in rotational speed measurement (fixed magnitude or percentage change), typically used to trigger collection or storage of data, e.g., collection of spectra for a waterfall every 100 rpm during a rundown
Δ Time	Change in time sample measurement (fixed magnitude change), typically used to trigger collection or storage of data e.g., collection of spectra for a waterfall every 100 ms during a rundown
Displacement	Vector quantity that specifies the change of position of a body, or particle, with respect to a reference frame
Displacement Pick-Up	Pick-up (transducer) that converts an input displacement to an output (usually electrical) that is proportional to the input displacement (see also <i>proximity probe</i>)
Field Auxiliary Room (FAR)	Room located next to or in the subject plant/unit – designated for instruments and located in non-hazardous environment
Failure	Termination of the ability of an item to perform its required function
Flash Point (Of A Liquid)	Lowest temperature at which its vapour ignites when exposed to a flame. A minimum flash point is normally specified for safety reasons.
Federal Test Method (FTM)	Test method for oxidation and corrosion stability
Hazop	Hazard and operability study
IPF	Instrumented Protective Function
Keyphasor	Signal used in rotating machinery measurements, generated by a transducer observing a once-per-revolution event, e.g., the passage of a keyway. The sensing device may be a magnetic, capacitive, eddy current, or photoelectric probe. The Keyphasor signal is used for speed measurement and for reference/phase measurements when analysing and balancing. NOTE: Keyphasor is a trademark of Bently Nevada Corporation.
Machinery Train	Driver(s) and all of its associated driven pieces of equipment
Monitoring System	System comprising signal processing, alarm/shutdown/integrity logic processing, power supply, display/indication, inputs/outputs, and protective relays
Off-Line System	System that allows data capture on a periodic but not automatic basis. It is normally accomplished by manual data collection with time intervals that are typically daily, weekly, or monthly.
On-Line System	System that automatically scans information at specific time intervals. The system performs signal processing, alarming, data storage, reporting, etc. This can be continuous or periodic.

Term	Definition
Open Process Control (OPC)	Set of seven open standards for connectivity and interoperability of industrial automation and enterprise systems
Parameter	Measurable variable
Peak-To-Peak (Value of a Vibration)	Algebraic difference between the extreme values of the vibration in the units of measurement (in time domain)
Performance	Machine efficiency and capacity
Periodic Collection	Collection of all status conditions and measured variables at discrete time intervals
Pre-Event	Time period prior to occurrence of an event, typically a set time interval of data collection before a machine trip e.g., 10 minutes of retained historical data leading up to the machine trip
Proximity Probe	Non-contacting sensor that consists of a tip, a probe body, an integral coaxial cable and a connector; used to translate distance (gap) to voltage NOTE: See also displacement pick-up.
Radial Shaft Vibration	Vibratory motion of the machine shaft in a direction perpendicular to the shaft longitudinal axis
RPVOT	Rotating pressure vessel oxidation test
Reliability	Measure of the probability that a machine will perform its required functions without failure for a specified period when used under specific conditions
RTD (Resistance Temperature Detector)	Temperature sensor that changes its resistance to electrical current as its temperature changes.
RIC	Reciprocating internal combustion
Rotating Equipment	Equipment used to provide plant compression (includes reciprocating compressors at all speeds), electrical power generation, process pumping and safety duties.
Sensor	Device (such as a proximity probe, thermocouple, accelerometer, etc.,) that detects the value of a physical quantity and converts the measurement into a useful input for another device. NOTE: See also Transducer .
Shutdown (Danger/Trip) Setpoint	Pre-set value of a parameter at which automatic or manual shutdown of the machine is required.
Smartconnect	Shell's integrated condition monitoring services delivery system utilising remote connectivity to sites
S_{max}	Maximum value of shaft displacement from time integrated position 0 (zero)
TAN	Total acid number.
TBN	Total base number.
Temperature Sensor	Thermocouple (TC) or resistance temperature detector (RTD) and its integral sensor lead.
Thermocouple	Temperature sensor consisting of two dissimilar metals so joined to produce different voltages when their junction is at different temperatures.

Term	Definition
Turbine Oil Stability Test (TOST)	Standard test to oxidise an oil resulting in the formation of acids.
Transducer	Device designed to receive energy from one system and supply energy, of either the same or of a different kind, to another in such a manner that the desired characteristics of the input energy appear at the output NOTE: Also known as a sensor , a probe and a pick-up .
Tribology	Science and technology of interacting surfaces in relative motion, and of related subjects and practices. In the context of triboscience or tribotechnology it includes the study of lubrication, friction and wear.
Trip	Automatic or manual shutdown of a machine when a value of a monitored parameter exceeds a preset limit.
Velocity Pick-Up	Pick-up (transducer) that converts an input velocity to an output (usually electrical) that is proportional to the input velocity (also referred to as a velocimeter).
Vibration	Variation with time of the magnitude of a quantity that is descriptive of the motion or position of a mechanical system, when the magnitude is alternately greater and smaller than some average value or reference.
1x	Shaft running speed frequency
2x	Twice shaft running speed frequency
Nx	N times shaft running speed frequency
Not 1x	All frequencies except shaft running speed frequency

1.4 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section or clause number is shown in brackets (). Other documents referenced by this DEP are listed in (4).

1.5 SUMMARY OF MAIN CHANGES

This DEP is a minor revision of the DEP of the same number dated February 2013. The following are the main, non-editorial changes.

Section/Clause	Change
2.1	Made ISO 13379 into ISO 13379-1.
2.3	Added last sentence in 1 st paragraph regarding firewater pumps.
2.5.1 Note	Added sentence: "Further guidelines can be found in Oil Analysis Basics, Noria Corporation".
2.5.2	Added same sentence as above: "Further guidelines can be found in Oil Analysis Basics, Noria Corporation".
4	Deleted ISO 14830-1 and ISO 18436.8 in Reference section.
4	Added: "Oil Analysis Basics..."
Appendix B, Table B.1, B.2, B.3, B.4, B.5	Added Units in the Foaming (air separation) row.
Table B.6, B.7	Added Condemning limits in Spectrometry row.

1.6 COMMENTS ON THIS DEP

Comments on this DEP may be submitted to the Administrator using one of the following options:

Shell DEPs Online (Users with access to Shell DEPs Online)	Enter the Shell DEPs Online system at https://www.shelldeps.com Select a DEP and then go to the details screen for that DEP. Click on the "Give feedback" link, fill in the online form and submit.
DEP Feedback System (Users with access to Shell Wide Web)	Enter comments directly in the DEP Feedback System which is accessible from the Technical Standards Portal http://www.shell.com/standards . Select "Submit DEP Feedback", fill in the online form and submit.
DEP Standard Form (Other users)	Use DEP Standard Form 00.00.05.80-Gen. to record feedback and email the form to the Administrator at standards@shell.com .

Feedback that has been registered in the DEP Feedback System by using one of the above options will be reviewed by the DEP Custodian for potential improvements to the DEP.

1.7 DUAL UNITS

This DEP contains both the International System (SI) units, as well as the corresponding US Customary (USC) units, which are given following the SI units in brackets. When agreed by the Principal, the indicated USC values/units may be used.

1.8 NON NORMATIVE TEXT (COMMENTARY)

Text shown in italic style in this DEP indicates text that is non-normative and is provided as explanation or background information only.

Non-normative text is normally indented slightly to the right of the relevant DEP clause.

2. CONDITION MONITORING STRATEGY

2.1 GENERAL

This Section provides guidelines and functional requirements for the justification, selection and configuration of condition monitoring systems for rotating equipment. These systems can be applied to new and existing machinery installations but in all cases should be directed towards identifying and avoiding root cause failure modes as specified in ISO 17359. Guidelines for establishing procedures for failure mode analysis are given in ISO 13379-1 and should be followed to ensure an effective implementation.

Condition monitoring is defined as the measurement and analysis of a number of machine parameters that are used to determine the correct timing and extent of equipment maintenance, including the current health of the equipment.

The objectives of equipment condition monitoring are to achieve one or more of the following:

- a. Plant safety improvement
- b. Reduction in environmental exposure
- c. Rotating equipment protection
- d. Predicting maintenance interventions
- e. Rotating equipment performance optimisation
- f. Operating cost optimisation
- g. Availability improvement
- h. Mechanical integrity improvement
- i. Maintenance cost optimisation

Although plant safety improvement and environmental protection are of the highest importance, condition monitoring plays only an indirect role in them. In the petrochemical industry, it is the availability of critical rotating equipment that has the highest impact on the operation of a plant with consequential business impact.

What determines equipment availability is largely dependent on the type of equipment, its failure modes and its application, although many common characteristics exist. The availability of reciprocating compressors, for example, is typically poorer than that of centrifugal compressors, but keeping their lubricating oil cool, clean and dry applies to both equally. Parameters required for condition monitoring (based on known functional failure modes of each equipment type) are given in ISO 17359 and ISO 13373-1 and summarised in (2.6).

When applied systematically and consistently, condition monitoring of equipment provides additional synergistic benefits for a plant that result from closer cooperation between operations, maintenance and engineering departments. Condition monitoring tools, when available to appropriate staff, provide additional eyes and ears on the equipment, allowing earlier detection of developing faults and limiting their severity.

Condition monitoring requires capital investment, management support and a commitment to operate and maintain a monitoring system throughout the lifecycle of the operating plant. A cost-benefit analysis shall be part of the process of deciding whether condition monitoring is justified for an item of equipment and the level of monitoring to be undertaken (this may also be a requirement of insurance cover). Clear economic benefits shall be demonstrated before proceeding with condition monitoring.

2.2 CONDITION MONITORING

The condition monitoring to be applied in a plant shall be developed as part of the overall maintenance philosophy of the plant. A plant-specific condition monitoring strategy shall be developed that identifies the equipment to be monitored and defines the appropriate monitoring techniques.

The extent and specifics of condition monitoring of rotating equipment should be defined for each installed machine and depends on the following characteristics:

- a. Equipment criticality.
As a first step in developing the condition monitoring strategy, the criticality of the equipment items and their impact on plant operation/availability shall be defined. For this purpose, equipment items shall be individually classified. Experience has demonstrated that a "three category" classification provides adequate differentiation between the criticality of the relevant items. (Appendix A) provides a definition of the three categories, (1) vital, (2) essential spared and non-spared, and (3) non-essential equipment.
- b. Equipment complexity.
- c. Types of failures (faults) expected to be detected for the equipment.
- d. Type of maintenance scheme adopted for the equipment.
- e. Availability, expertise and effectiveness of site personnel combined with staffing policy, namely in-house or outsourcing.

This DEP does not address the controls and measurements used for machinery control, specifically speed and anti-surge control, but this information may be integrated into a common control and monitoring system.

As stated above, condition monitoring is defined as the measurement and analysis of a number of machine parameters that are used to determine the correct timing and extent of equipment maintenance, including the current health of the equipment.

Condition monitoring consists of two types of monitoring:

- On-line monitoring (2.3);
- Off-line monitoring (2.4).

A condition monitoring system shall typically include, but not be limited to, measurement of the following parameters:

- a. Vibrations, either shaft displacement and/or velocity/acceleration measurement of bearing housings, equipment casings and crank cases including phase angle
- b. Radial and axial shaft positions including phase angle
- c. Speed
- d. Bearing metal temperatures and/or bearing housing temperatures
- e. Bearing sump temperatures
- f. Lube and seal oil supply pressures and temperatures
- g. Seal oil consumption and lube oil leakages
- h. Lubricating oil condition by means of a number of parameters
- i. Lubricating oil exit temperatures at bearings (throw off temperature)
- j. Dry gas seal buffer gas and seal gas consumption and seal leakages
- k. Valve or valve cover temperatures of reciprocating compressors
- l. Pressure/volume diagrams of reciprocating compressors

- m. Rod position (rod drop) monitors for reciprocating compressors including rod runout indication
- n. Piston rod packing leakage (flow, temperature, pressure or a combination of these)
- o. Hydraulic performance data of pumps and liquid expanders, including balance pressure
- p. Steam turbine steam data, including first stage steam pressure and steam valve position
- q. Compressor gas pressures, including reference gas and balance gas
- r. Gas turbine wheelspace and turbine exhaust temperatures
- s. Thermodynamic performance data of compressors (head, flow, efficiency, power), steam turbines (steam flow, enthalpy drop, speed), gas turbines (compressor efficiency, speed, enthalpy), centrifugal pumps (head, flow, power, discharge pressure)
- t. Inlet air filtration quality of gas turbines and large process air compressors
- u. Electrical performance of electric motors and generators

Depending on the characteristics of the specific equipment, one or more of the above parameters will need to be monitored, either on-line or off-line. Recommended condition monitoring parameters by machine type are given in ISO 17359 and ISO 13373-1.

The type of monitoring to be applied depends largely on the type of equipment. The main objective is to prevent operating the equipment outside its integrity design envelope. For a typical plant, a condition monitoring system for rotating equipment shall consist of an on-line system and an off-line system.

2.3 ON-LINE CONDITION MONITORING

On-line condition monitoring shall be required for equipment in essential non-spared service as well as other equipment deemed to require it in accordance with the criticality ranking of specific equipment. However, equipment such as firewater pumps that are required to be spared and that do not run continuously need not have an online condition monitoring system.

On-line condition monitoring shall be required for compressors in all essential services as specified in DEP 31.29.40.10-Gen.

The objective of on-line condition monitoring is to obtain a detailed performance and mechanical behaviour database of the respective machinery to optimise planned maintenance and to maximise availability and reliability. Appropriate data shall be collected and stored for subsequent analysis and troubleshooting.

Typical equipment to be monitored includes all axial and centrifugal compressors and their drivers (including gearboxes), gas turbines and steam turbines in mechanical drive applications as well as generator drive applications, reciprocating compressors, screw compressors, non-spared high pressure pumps (e.g., hydrocracking unit, hydro de-sulphurisation unit process pumps, high-pressure boiler feedwater pumps, export pumps, water injection pumps) and electrical motors.

In on-line condition monitoring systems, a number of equipment parameters are automatically measured, sampled, analysed and stored in a database (either continuously or periodically).

- The sampling can be conducted on a time basis, an alarm basis, when a pre-determined change in a measured value is detected, and during transient conditions.
- The parameters shall be analysed and stored in a database so that a trend line of the machine condition can be established by comparing the parameter measurements. This trend line provides information to help determine whether the

subject equipment needs to be taken out of operation for maintenance and/or overhaul.

On-line condition monitoring systems may be a single system or a combination of distributed multiple systems.

- The main requirement for a combination of distributed multiple systems is that all information can be collected and analysed in one centralised database in order to facilitate the trending of relevant data over a minimum period of 10 years (two overhaul cycles minimum).
- For centralised server systems, data acquisition shall not be impaired by network communication disruption and hence, shall provide temporary local storage (24 hours minimum).
- Either single or multiple systems shall enable the display and review of data in the FAR (or equivalent) to enable machine start up data to be captured and reviewed during commissioning, before and after turnarounds and in the event of network disruption.

On-line condition monitoring systems shall automatically sample, process and store the parameter measurements, with a resolution that can be adjusted to the specific needs of individual parameters. Resolution may vary from milliseconds to hours or, in case of very slow changing parameters, to days. The final storage of data in the system shall be time based and event based. Both time and event based storage criteria shall be adjustable by the system user.

It is expected that in the event of a machine failure, the system will gather and store the data in such a manner that the failure investigation team can retrieve it at sufficient resolution to analyse the failure and support a root cause failure analysis. In addition, machine trips shall be captured at sufficient data resolution such that the rotating equipment and operational personnel can assess whether or not it is safe to restart the tripped machine.

When a high end on-line condition monitoring system is specified, it shall, as a minimum, meet the following requirements:

- a. The system shall provide instant information on dynamic behaviour of each monitored machinery train component, including the various analysis techniques, with both current and historical data.
 - Current and historical data shall include all radial bearing vibration measurements, casing vibration measurements and rotor axial displacement measurements of all monitored rotors.
 - Alarm and report facilities shall be provided in a programmable form that can be adapted to the specific machinery needs.
 - The system shall include, but not be limited to, the possibilities to trend sampled and calculated data and provide long term reporting on these.
 - Transient waveform data captured during machine start-ups and coastdowns shall be used to provide high resolution analysis displays such as Bodé plots and Nyquist diagrams as well as frequency analyses of vibration. Waveform data shall be captured in real time and for all monitored channels simultaneously; multiplexing of transient data is not acceptable.
 - Both real time and sampled data shall be included in the processing and reporting facilities.
 - Data storage shall extend to a minimum time span of 10 years (two overhaul cycles), either in total or compressed format, in order to serve as a database for assessments of maintenance requirements.
 - Provision for automated data backup and data management shall be available.

- b. The system shall collect all associated bearing temperatures of the machinery components and process and store them so that they can be related to the respective vibration and axial displacement data. If these data are measured in another system, such as plant DCS systems, they shall be imported from this system and correctly time stamped synchronously with the rotor-dynamic data collecting system. If they are also stored in the other system, they shall be available for analysis and reporting synchronously with the data of the condition monitoring system.
- c. The system shall have communication with the plant DCS system in which the connected machinery is located via OPC or an equivalent open system.
 - System shall be able to import all necessary data and measured parameters from the plant DCS system to compute the performance of the connected machines. This includes, but is not limited to, all data necessary to automatically calculate the correct thermo-dynamic performance of compressors, gas turbines, steam turbines, and hot gas and cold gas expanders, and the hydraulic performance of centrifugal pumps and liquid expanders.
 - System shall be able to calculate the performance of electric generators and motors.
 - System shall have all the above performance calculating facilities included in its programming and shall store the above data for trending purposes.
- d. In facilities where a Data Historian is used, the system shall have two-way communication with the plant Data Historian.
- e. All data shall be time stamped, synchronised with the plant master clock. This is required to enable correlation of equipment events with other plant events.
- f. The system shall capture raw dynamic data when triggered by an event for subsequent analysis. Event data shall be managed such that it is not overwritten or compressed in order to maintain maximum resolution on the event for post event analysis.
 - The period of pre-event data shall be user definable and be at least 10 minutes.
 - System storage capacity shall be sufficient to capture all monitored data, at programmable intervals, at least until the equipment comes to rest following a trip. Storage shall allow the capture and retention of alarm and transient data if network communication is disrupted. All channels shall be sampled simultaneously.
 - Dynamic data capture system should be integrated within the condition monitoring system.
- g. The system shall be capable of raw dynamic data sampling and storage when triggered by a change in rotational speed (Δ rpm), incremental change of time (Δ time) and change in amplitude (Δ amplitude).
- h. The system shall compare all new data against reference baseline data (including spectra) and against all configured Alert/Danger limits and automatically preset excursions.
- i. The system shall be capable of storing data at originally set resolution. Compression of data is permitted if the option exists for archiving original resolution data or if playback can restore its original resolution.
- j. The system shall be capable of storing the following scalar vibration data:
 - Overall amplitude (direct)
 - Gap Voltage
 - 1x amplitude and phase angle
 - 2x amplitude and phase angle

- 4 additional user-defined Nx amplitude and phase angle measurements
 - (minimum) 4 user defined frequency band measurements (including subsynchronous)
 - Not 1x amplitude
 - $S_{\max}$
- k. System shall be capable of displaying at least the following plots:
- Spectrum (synchronous and asynchronous, full and half spectrum) (with overall amplitude and amplitude at cursor frequency displayed)
 - Waterfall (with amplitudes, frequency and speed displayed on each curve)
 - Cascade (with amplitudes, frequency and speed displayed on each curve)
 - Campbell (with amplitudes and speed displayed)
 - Bodé (with overall amplitude, speed, Nx amplitudes and phase angles displayed and available as one plot, from slow roll to full speed)
 - Nyquist (with overall amplitude, speed, Nx amplitudes and phase angles displayed)
 - Polar (with Nx amplitudes and phase angles displayed)
 - Timebase (with overall amplitude and cursor amplitude displayed)
 - Orbit/timebase (filtered and unfiltered, with overall amplitude, cursor amplitude and phase angle displayed)
 - Shaft centreline (with rotor position coordinates within bearing clearance displayed). Reference voltage shall be user configurable to align the plot with the machine clearances.
 - Acceptance region (with limiting amplitudes and angles displayed)
 - X v. Y (with amplitudes displayed for each)
 - Tabular lists (all parameters selectable)
 - PV diagrams (with cursor readings displayed)
 - Pressure v. crank angle (with amplitude displayed at minimum 1° resolution)
 - Vibration v. crank angle (with amplitude displayed at minimum 1° resolution)
 - For proximity probe signals provision shall be made for runout (glitch) compensation.
- l. The system shall display all measurements in SI or US Customary units.
- m. The system configuration shall be independent of protection system configuration, i.e., changes to condition monitoring configurations shall have no effect on protection system functionality.

The above requirements apply to applications on machines requiring high resolution, on-line condition monitoring systems (including spectral and timewaveform related data). For applications on machines where this is not the case, all requirements not related to spectral and timewaveform linked data shall still apply.

Vibration measurement probes and signal processors/pre-amplifiers, which are normally mounted on the machinery skids or base plates, shall be supplied by the rotating equipment Manufacturer for new machinery installations and shall be as indicated on the rotating equipment data/requisition sheets.

On-line condition monitoring systems shall comply with DEP 32.01.20.12-Gen. for communications infrastructure, API 670 and DEP 32.29.20.10-Gen. for machinery

protection systems, and DEP 32.31.00.32-Gen. and DEP 32.31.09.31-Gen. for instrumentation.

For new facilities, the responsibility for the on-line condition monitoring system and the integration of the system in the plant instrumentation shall be included in the scope of the main instrumentation Contractor/Vendor. As a result of this, ownership of and maintenance responsibility for the system shall be vested with the instrumentation maintenance/engineering discipline in the plant.

Because the plant Rotating Equipment Engineering Department (or equivalent RE Support Team) has first priority in the use of the on-line condition monitoring system, the PC-based central data collecting and/or processing unit shall be connected to the Department's location for data access. System data for day-to-day operational personnel use shall be routed to the operations supervising panels in the Central Control Room (Plant Control Room). As access to instrumentation FARs (or equivalent) is frequently restricted, any FAR-installed parameter monitors shall be of the "blind type" and relay all data to the central processing and database of the system.

2.4 OFF-LINE CONDITION MONITORING

Off-line condition monitoring differs from on-line condition monitoring in that the parameters are measured on an intermittent time basis and not collected automatically. The main reason for this intermittent measurement is that it is either not necessary for the parameters to be measured continuously or it is not economically viable to monitor the subject machines on a continuous basis. As an example, oil sampling on a given machine might be conducted on a monthly basis even though the vibration measurements are taken continuously on-line.

For measurement repeatability, all machines identified for off-line condition monitoring shall have measurement locations clearly identified and appropriately prepared for the measurement type.

Off-line condition monitoring systems shall consist of a portable data collecting system and a central data processing and storage system. The supplied systems shall comply with the requirements of DEP 32.01.20.12-Gen. for communications infrastructure and data security and DEP 32.31.00.32-Gen. for instrumentation. The data collecting system shall consist of one or more portable vibration measurement and data collectors, which shall comply with the following general requirements:

- a. They shall be programmable and flexible in their configuration of data points to be measured and the complexity of data to be taken.
- b. They shall be suitable for all specified ambient conditions in which they are used and comply with all applicable electrical area classification requirements. The data collectors shall be intrinsically safe.
- c. They shall be suitable for use by personnel equipped with appropriate PPE, e.g., goggles, gloves, etc. Their size should not restrict mobility of personnel.
- d. They shall be resistant to ingress of dirt, rain and dust expected in the specified environment and ambient conditions (minimum IP 54).
- e. They shall have provisions to collect data from process related parameters and to store such data for further processing. Manual inputting (keypad entry) of such data into the data collector shall also be possible.
- f. They shall have provisions to allow on the spot analysis of the measured data without the need to connect to the central data processing and storage system.
- g. They shall have facilities to download their collected data into a central processing and storage system directly and updated and re-loaded with additional programming automatically.

The central data processing and storage system for off-line condition monitoring shall have the same fundamental analysis features as the processing/storage system for on-line

condition monitoring. One processing/storage system can be used for both on-line and off-line condition monitoring, although this is not mandatory.

Off-line condition monitoring system data collectors shall also comply with the following specific requirements:

- h. Live display of current overall measurement values prior to acceptance for storage
- i. Display of previous reading for comparison with currently collected value
- j. Display of all valid Alarm values for a currently collected measurement
- k. Battery life for continuous use for a nominal shift (eight hours minimum)
- l. No loss of data in cases where battery runs low or needs replacing
- m. Collection of vibration signals natively from accelerometers, velocity probes and displacement probes
- n. Display of vibration readings in units of acceleration, velocity and displacement with values of r.m.s., peak and peak-peak
- o. Display of all measurements in user selectable metric or imperial (US customary) units
- p. Collection of process parameter signals from sensors with common voltage, current and charge outputs (e.g., 0 to 5 V, 4 to 20 mA, 0 to 24 V, -15 to 0 V, etc.)
- q. Collection of data from on-line condition monitoring racks (via buffered outputs in accordance with API 670)
- r. Capability to connect auxiliary probes such as infra-red temperature devices, oil monitoring probes, speed probes, etc.
- s. Separate phase trigger input (from proximity probe, magnetic, laser or infrared sensors)
- t. Amplitude autoscale
- u. Spectrum display (minimum 400 lines, maximum at least 6400 lines)
- v. Selectable frequency ranges up to at least 20 kHz
- w. Selectable resolution (highest resolution at least equivalent to 6400 lines)
- x. True zoom (10 x zoom around any cursor frequency selected)
- y. Waterfall plots
- z. Phase angle
- aa. Time waveform display
- bb. Windowing functions (Hanning, Hamming, rectangular, flat top, exponential as minimum)
- cc. Averaging (selectable type; linear, exponential, and number; 2, 4, 8, etc.)
- dd. Enveloping measurements
- ee. Band alarms (minimum 2 per band)
- ff. Point naming minimum 20 characters (capable of accepting standard tag numbering)
- gg. Multiple route upload and download capability
- hh. Keyboard entry of non-measurement observations (plain language notes)
- ii. All data to be time stamped, synchronised with the plant master clock

In addition to the above, the off-line condition monitoring system software shall comply with the following specific requirements:

- a. Compatible with Operating System approved by the Principal.

- b. Capable of, and compatible with, data export to the standard DCS systems and data historians approved by the Principal.
- c. Capable of, and compatible with, data import from standard DCS systems and data historians approved by the Principal.
- d. Capable of, and compatible with, data imports from 3rd party data sources, e.g., Oil analysis lab data, electronic spreadsheets, etc. (via suitable drivers if required)
- e. Trend plots including multiple parameters (at least 10) and trend extrapolation
- f. Baselines
- g. Comparison of data from different machines
- h. Scalar and spectral data storage for minimum 10 years for all measurement points
- i. Capable of structured hierarchical plant configuration to enable logical data retrieval
- j. Data collection routes
- k. Data collection route scheduling
- l. Remote data collector upload and download via modem or similar
- m. Automatic comparison of all new data against reference baseline data (including spectra) and against all configured Alert/Danger limits and automatic presentation of excursions
- n. Auto report generation capabilities
- o. All data to be time stamped, synchronised with the plant master clock

2.5 TRIBOLOGY-BASED CONDITION MONITORING

2.5.1 General

A tribology-based condition monitoring program can provide important information about the mechanical health of rotating equipment. Such a monitoring program enables the detection of potential problems and forewarns the user to act prior to excessive mechanical damage or failure. Monitoring is performed by taking oil samples on a periodic basis, with analysis by competent in-house staff or an approved laboratory.

Tribology-based condition monitoring and diagnostics can be broadly categorised as consisting of the following two methodologies:

- Particulate-based condition monitoring (also referred to as equipment condition monitoring based on oil debris analysis); and
- Lubricant/working fluid condition monitoring (typically known as oil condition monitoring).

NOTE: Condition monitoring by analysis of oil samples (tests, sampling methods, sampling frequencies, cleanliness levels, etc.) should be conducted in accordance with ISO 17359. Further guidelines can be found in Oil Analysis Basics, Noria Corporation.

2.5.2 Particulate-based condition monitoring

Particulate-based condition monitoring should be conducted in accordance with ISO 17359. Further guidelines can be found in Oil Analysis Basics, Noria Corporation.

2.5.3 Lubricant/working fluid condition monitoring

For lubricant/working fluid condition monitoring, oil samples should be analysed, as a minimum, for water content, flash point, wear metals (lead, copper, tin, iron, etc.), colour/visual appearance, rust, foaming, viscosity at 40 °C (104 °F) and 100 °C (212 °F), TAN, (TBN for diesel engines), RPVOT and degradation index. In the absence of suitable acceptance criteria in appropriate ISO standards, OEM guidelines shall be sought. Typical values for Turbo GT 32 and other Turbo oils are given in (Appendix E).

2.6 CONDITION MONITORING PARAMETERS

2.6.1 General

Mechanical and selected process parameters of the equipment shall be monitored in order to assess performance and mechanical integrity, and enable optimum equipment operation.

The parameters to be monitored are listed by rotating equipment type. Process parameters are shown in italics. Monitored parameters are based on indicated standards for each machine type.

2.6.2 Axial and centrifugal compressors

NOTE: Process parameters are shown in italics.

Mechanical and process parameters to be monitored (From DEP 31.29.40.30-Gen. and DEP 31.29.40.10-Gen.)	
a.	Radial shaft vibrations (see Note 1)
b.	Axial thrust position (Axial displacement) (see Note 2)
c.	Phase angle (Keyphasor)
d.	Journal bearing temperatures
e.	Thrust bearing temperatures
f.	<i>Compressor speed (for variable speed drives)</i>
g.	<i>Seal performance parameters</i>
h.	<i>Lube oil pressure and level</i>
i.	<i>Oil filter differential pressure</i>
j.	<i>Tribology-based parameters</i>
k.	<i>Compressor section inlet, interstage and outlet pressures, temperatures and flows</i>
l.	<i>Recycle data such as surge parameters, e.g., control valve data, etc.</i>
m.	<i>Molecular weight of the process gas</i>
n.	<i>Liquid level in inlet separator(s)</i>

Additional parameters for monitoring	
o.	Casing vibration if plain bearing proximity probes not fitted (see Note 3)
p.	Torque (for mechanically driven compressors)
q.	Power or current (for electrically driven compressors)
r.	(If installed) Suction strainer differential pressure
s.	Reference gas and balance gas pressure
t.	Lube oil temperature

Periodic performance assessments should be carried out to help determine the overall compressor condition, and thus, the possible need for a scheduled overhaul and/or washing.

Fouling of impellers and discharge volutes, as well as excess leakage across labyrinth seals, reduce throughput.

Monitoring of leakage rates across interstage labyrinths on back-to-back compressors is especially important, as excessive leakage can lead to significant performance losses. The best way to monitor this is to compare the current performance of the machine against the

performance data of the machine in new condition and/or to rely on the Manufacturer's compressor test data.

The primary indicators of oil film seal degradation are an increasing/decreasing oil flow and reducing seal oil flash point value. Flow and flash point values can be trended and give a good indication of the condition of seal performance, alerting the operator before the contaminated seal handling facilities become overloaded.

- NOTES:
1. For all radial shaft vibration measurements, as a minimum, the following parameters are required to be monitored for each transducer:
 - a. Overall vibration
 - b. 1x vibration and phase angle
 - c. 2x vibration and phase angle
 - d. Subsynchronous vibration
 - e. DC gap voltage
 2. For all axial thrust measurements, as a minimum, the following parameters are required to be monitored for each transducer:
 - a. Axial displacement
 - b. Overall vibration
 - c. DC gap voltage
 3. For casing vibration measurements, as a minimum, the following parameters are required to be monitored for each transducer:
 - a. Overall vibration
 - b. 1x vibration and phase angle
 - c. 2x vibration and phase angle
 - d. Subsynchronous vibration
 - e. High frequency (band) vibration

2.6.3 Reciprocating compressors

NOTE: Process parameters are shown in italics.

Mechanical and process parameters to be monitored (From DEP 31.29.40.31-Gen.)
a. Main bearing temperatures
b. Crosshead acceleration/crankcase acceleration/Frame vibration (see Note 1)
c. Rod position (rod drop) monitoring (for machines < 200 mm stroke only if appropriate) (see Note 2)
d. Provisions for P-V diagram analysis
e. Piston rod packing leakage
f. Suction and discharge valve temperature measurement (online) (see Note 3)
g. Lube oil pressure and level
h. Oil filter differential pressure
i. Jacket water system failure
j. Tribology-based parameters
k. <i>Cylinder pressure</i>
l. <i>Suction and discharge pressure and temperature per stage</i>
m. <i>Compressor flow per stage</i>

<i>n. Recycle flow rate</i>
<i>o. Liquid level in suction separator</i>

Additional parameters for monitoring
<i>p. Phase angle (Keyphasor)</i>
<i>q. Cylinder/packing lube oil flow</i>

- NOTES:
1. For all crosshead, crankcase and frame vibration, as a minimum, the following parameters are required to be monitored for each transducer:
 - a. Overall vibration
 - b. Vibration v. crank angle
 2. For rod drop measurements, as a minimum, the following parameters are required to be monitored for each cylinder:
 - a. Overall vibration
 - b. Vibration v crank angle
 - c. DC gap voltage
 3. Temperature measurements to be per valve

2.6.4 Gas turbines

NOTE: Process parameters are shown in italics.

Mechanical and process parameters to be monitored (From DEP 31.29.70.31-Gen. and DEP 31.29.70.11-Gen.)
<i>a. Engine casing vibration (see Note 1)</i>
<i>b. Radial shaft vibrations (where appropriate) (see Note 2)</i>
<i>c. Axial thrust position/Axial displacement (where appropriate) (see Note 3)</i>
<i>d. Journal bearing temperatures (where appropriate)</i>
<i>e. Thrust bearing temperatures (where appropriate)</i>
<i>f. Inlet air filter pressure drop (differential pressure)</i>
<i>g. Exhaust temperatures and exhaust temperature spread</i>
<i>h. Lube oil and hydraulic oil pressure</i>
<i>i. Tribology-based parameters</i>
<i>j. Power turbine 1st stage inlet nozzle temperature</i>
<i>k. Exhaust plenum pressure</i>
<i>l. Speed (GP and PT)</i>
<i>m. Power (via torque meter)</i>
<i>n. Compressor inlet and outlet pressure and temperature</i>
<i>o. Fuel gas flow and Wobbe index</i>
<i>p. Wheel space temperatures</i>
<i>q. Fuel control valve position</i>
<i>r. Fuel gas scrubber level</i>
<i>s. Lube oil tank level</i>