

DEP SPECIFICATION

CONDITION MONITORING OF ROTATING EQUIPMENT

DEP 31.29.00.11-Gen.

December 2009

(DEP Circular 67/12 has been incorporated)

DESIGN AND ENGINEERING PRACTICE



This document is restricted. Neither the whole nor any part of this document may be disclosed to any third party without the prior written consent of Shell Global Solutions International B.V., The Netherlands. The copyright of this document is vested in this company. All rights reserved. Neither the whole nor any part of this document may be reproduced, stored in any retrieval system or transmitted in any form or by any means (electronic, mechanical, reprographic, recording or otherwise) without the prior written consent of the copyright owner.

PREFACE

DEPs (Design and Engineering Practice) publications reflect the views, at the time of publication, of:

Shell Global Solutions International B.V. (Shell GSI)

and/or

Shell International Exploration and Production B.V. (SIEP)

and/or

other Shell Service Companies.

They are based on the experience acquired during their involvement with the design, construction, operation and maintenance of processing units and facilities, and they are supplemented with the experience of Shell Operating Units. Where appropriate they are based on, or reference is made to, international, regional, national and industry standards.

The objective is to set the recommended standard for good design and engineering practice applied by Shell companies operating an oil refinery, gas handling installation, chemical plant, oil and gas production facility, or any other such facility, and thereby to achieve maximum technical and economic benefit from standardization.

The information set forth in these publications is provided to Shell companies for their consideration and decision to implement. This is of particular importance where DEPs may not cover every requirement or diversity of condition at each locality. The system of DEPs is expected to be sufficiently flexible to allow individual Operating Units to adapt the information set forth in DEPs to their own environment and requirements.

When Contractors or Manufacturers/Suppliers use DEPs they shall be solely responsible for the quality of work and the attainment of the required design and engineering standards. In particular, for those requirements not specifically covered, the Principal will expect them to follow those design and engineering practices which will achieve the same level of integrity as reflected in the DEPs. If in doubt, the Contractor or Manufacturer/Supplier shall, without detracting from his own responsibility, consult the Principal or its technical advisor.

The right to use DEPs is granted by Shell GSI, in most cases under Service Agreements primarily with Shell companies and other companies receiving technical advice and services from Shell GSI or another Shell Service Company. Consequently, three categories of users of DEPs can be distinguished:

- 1) Operating Units having a Service Agreement with Shell GSI or other Shell Service Company. The use of DEPs by these Operating Units is subject in all respects to the terms and conditions of the relevant Service Agreement.
- 2) Other parties who are authorized to use DEPs subject to appropriate contractual arrangements (whether as part of a Service Agreement or otherwise).
- 3) Contractors/subcontractors and Manufacturers/Suppliers under a contract with users referred to under 1) or 2) which requires that tenders for projects, materials supplied or - generally - work performed on behalf of the said users comply with the relevant standards.

Subject to any particular terms and conditions as may be set forth in specific agreements with users, Shell GSI disclaims any liability of whatsoever nature for any damage (including injury or death) suffered by any company or person whomsoever as a result of or in connection with the use, application or implementation of any DEP, combination of DEPs or any part thereof, even if it is wholly or partly caused by negligence on the part of Shell GSI or other Shell Service Company. The benefit of this disclaimer shall inure in all respects to Shell GSI and/or any Shell Service Company, or companies affiliated to these companies, that may issue DEPs or require the use of DEPs.

Without prejudice to any specific terms in respect of confidentiality under relevant contractual arrangements, DEPs shall not, without the prior written consent of Shell GSI, be disclosed by users to any company or person whomsoever and the DEPs shall be used exclusively for the purpose for which they have been provided to the user. They shall be returned after use, including any copies which shall only be made by users with the express prior written consent of Shell GSI. The copyright of DEPs vests in Shell GSI. Users shall arrange for DEPs to be held in safe custody and Shell GSI may at any time require information satisfactory to them in order to ascertain how users implement this requirement.

All administrative queries should be directed to the DEP Administrator in Shell GSI.

TABLE OF CONTENTS

1.	INTRODUCTION	4
1.1	SCOPE.....	4
1.2	DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS	4
1.3	DEFINITIONS	5
1.4	CROSS-REFERENCES	8
1.5	COMMENTS ON THIS DEP	8
2.	CONDITION MONITORING STRATEGY	9
2.1	GENERAL.....	9
2.2	CONDITION MONITORING	10
2.3	ON-LINE MONITORING	11
2.4	OFF-LINE MONITORING	14
2.5	TRIBOLOGY-BASED CONDITON MONITORING.....	17
2.6	CONDITION MONITORING PARAMETERS	17
3.	COMPETENCE AND QUALIFICATIONS OF ANALYSIS STAFF.....	25
4.	REFERENCES	26

APPENDICES

APPENDIX A	DEFINITIONS AND EXAMPLES OF VITAL, ESSENTIAL AND NON-ESSENTIAL SERVICES	29
APPENDIX B	GUIDELINES FOR CONDITION MONITORING ACCEPTANCE CRITERIA FOR TURBO OILS.....	30
APPENDIX C	CONDITION MONITORING PARAMETERS BY MACHINE TYPE	48
APPENDIX D	SHELL SMARTCONNECT IMPLEMENTATION REQUIREMENTS	69

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 shall be applied to new construction projects and should be applied to the review of existing rotating equipment condition monitoring. This DEP shall be used together with DEP 32.29.20.10-Gen.

This DEP may be used as part of an integrated asset management plan, which will include 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.

These 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.

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.

This DEP is intended for use in refineries, chemical plants, gas plants, exploration and production facilities, power generation plants and supply/distribution installations.

When DEPs are applied, a Management of Change (MOC) process should 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 may 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 his 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 this DEP in order to comply with the Manufacturer's requirements.

The Principal may then negotiate with the Manufacturer(s) concerned with the objective 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)/Manufacturer/Supplier/Vendor** 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 is financially responsible for its design and construction. The Principal will generally specify the technical requirements. 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 and abbreviations

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

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.

condition monitoring	measurement and analysis of a number of machine parameters, which are used to determine the current health of the equipment and thus the correct timing/extent of equipment maintenance. 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.
critical speed	characteristic shaft rotational speed at which resonances of a system are excited.
DACA (Data Acquisition and Control Architecture)	IT requirements for separation of data flow between the office domain and the process control domain. DEP 32.01.20.10-Gen. is the umbrella DEP for a series of DACA DEPs.
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>).
FAR (Field Auxiliary Room)	room located next to or in the subject plant/unit.
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.
FTM (Federal Test Method)	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. Keyphasor is a trademark of Bently Nevada Corporation.
machinery train	driver(s) and all of its associated driven pieces of equipment.
monitor 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.
OPC (Open Process Control)	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.
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. See also displacement pick-up.
radial shaft vibration	vibratory motion of the machine shaft in a direction perpendicular to the shaft longitudinal axis.
RBVOT	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	high-speed 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. See also transducer .
shutdown (danger/trip) setpoint	preset 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.
TOST (turbine oil stability test)	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. 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 which 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.
1 x	shaft running speed frequency
2 x	shaft twice running speed frequency
N x	shaft N times running speed frequency
Not 1 x	All frequencies except shaft running speed frequency

1.4 CROSS-REFERENCES

Where cross-references are made, the number of the part, section or subsection referred to is shown in brackets.

1.5 COMMENTS ON THIS DEP

Comments on this DEP may be sent to the DEP Administrator at standards@shell.com. Shell staff may also post comments on this DEP on the Surface Global Network (SGN) under the Standards folder.

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 outlined in ISO 17359. Guidelines for establishing procedures for failure mode analysis are given in ISO 13379 and should be followed to ensure an effective implementation.

Condition monitoring is defined as the measurement and analysis of a number of machine parameters, which 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:

- plant safety improvement
- reduction in environmental exposure
- rotating equipment protection
- predicting maintenance interventions
- rotating equipment performance optimisation
- operating cost optimisation
- availability improvement
- mechanical integrity improvement
- 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 which has the highest impact on the operation of the plant with consequential commercial 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 which 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.

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 which identifies the equipment to be monitored and defines the appropriate type of monitoring,

2.2 CONDITION MONITORING

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

a) Criticality.

As a first step in a condition monitoring program, the importance of the various 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, i.e. vital, essential spared and non-spared, and non-essential equipment.

b) Equipment complexity.

c) Types of failures (faults) expected to be detected for that equipment.

d) Type of maintenance scheme adopted for the subject 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, which 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 (Section 2.3);
- Off-line monitoring (Section 2.4).

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

- Vibrations, either shaft displacement and/or velocity/acceleration measurement of bearing housings, equipment casings and crank cases including phase angle
- Radial and axial shaft positions including phase angle
- Speed

- Bearing metal temperatures and/or bearing housing temperatures
- Bearing sump temperatures
- Lube and seal oil supply pressures and temperatures
- Seal oil consumption and lube oil leakages
- Lubricating oil condition by means of a number of parameters
- Lubricating oil exit temperatures at bearings (throw off temperature)
- Dry gas seal buffer gas and seal gas consumption and seal leakages
- Valve or valve cover temperatures of reciprocating compressors
- Pressure/volume diagrams of reciprocating compressors
- Rod position (rod drop) monitors for reciprocating compressors
- Piston rod packing leakage (flow, temperature, pressure or a combination of these)
- Hydraulic performance data of pumps and liquid expanders, including balance pressure
- Steam turbine steam data; including 1st stage steam pressure and steam valve position
- Compressor gas pressures, including reference gas and balance gas
- Gas turbine wheelspace and turbine exhaust temperatures
- 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)
- Inlet air filtration quality of gas turbines and large process air compressors
- 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.

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 MONITORING

In an on-line monitoring system 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 on a comparison basis a trend line of the machine condition can be established. This trend line will provide information to help determine whether the subject equipment will need to be taken out of operation for maintenance and/or overhaul.

On-line condition monitoring systems can either be a single system or a combination of distributed multiple systems. The main requirement for a combination of multiple distributed 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 architecture 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.

An on-line system shall automatically sample, process and store the various parameters, as described above, with a resolution that can be adjusted to the specific needs of the measured parameter. 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.

When a high end monitoring system is specified, it shall as a minimum meet the following requirements and shall provide instant information on:

1. The dynamic behaviour of each monitored machinery train component, including the various analysis techniques, both with current and with historical data. This includes 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, which 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.
2. 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.
3. The system shall have two-way communication with the plant DCS system in which the connected machinery is located via OPC or an equivalent open system. It 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. Furthermore, it shall be able to calculate the performance of electric generators and motors shall be possible. The system shall have all these performance calculating facilities included in its programming and shall store these data for trending purposes.
4. As in point 3, in facilities where a Data Historian is used the system shall have two-way communication with the plant Data Historian.

5. 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.
6. The system shall capture raw dynamic data when triggered by an event for subsequent analysis. The period of pre-event data shall be user definable and be at least 10 minutes. The 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. The dynamic data capture system should be integrated within the condition monitoring system.
7. The system shall compare all new data against reference baseline data (including spectra) and against all configured Alert/Danger limits and automatically preset excursions.
8. The system shall be capable of storing the following static vibration data:
 - o Overall amplitude (direct)
 - o Gap Voltage
 - o 1x amplitude and phase angle
 - o 2x amplitude and phase angle
 - o 4 additional user-defined Nx amplitude and phase angle measurements
 - o 4 user defined frequency band measurements (including subsynchronous)
 - o Not 1x amplitude
 - o S_{max}
9. The system shall be capable of displaying at least the following plots:
 - o Spectrum (synchronous and asynchronous, full and half spectrum)
 - o Waterfall
 - o Cascade
 - o Campbell
 - o Bodé
 - o Nyquist
 - o Polar
 - o Timebase
 - o Orbit/timebase
 - o Shaft centreline
 - o Acceptance region

- o X v. Y
- o Tabular lists
- o PV diagrams
- o Pressure v. crank angle
- o Vibration v. crank angle

10. Display of all measurements in SI or US Customary units.

The above requirements refer to applications where a high resolution on-line condition monitoring system (including spectral and timewaveform related data) is required. For applications 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. All supplied systems shall comply with DEP 32.01.20.10-Gen. for communications infrastructure, API 670 for machinery protection systems, and DEP 32.31.00.32-Gen. and DEP 32.31.09.31-Gen. for instrumentation.

For new installations, the responsibility for this system and the integration of this 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 this 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 MONITORING

Off-line monitoring differs from on-line 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.

Off-line 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 32.01.20.10-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:

1. They shall be programmable and flexible in their configuration of data points to be measured and the complexity of data to be taken.

2. 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.
3. 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.
4. They shall be resistant to ingress of dirt, rain and dust expected in the specified environment and ambient conditions (minimum IP 54).
5. The data collectors 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.
6. The data collectors 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.
7. The data collectors 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.
8. The central data processing and storage system for off-line condition monitoring shall have the same fundamental analysis features as the on-line system. This can be the same system as used for the on-line condition monitoring system although this is not mandatory.
9. For measurement repeatability, all machines identified for off-line condition monitoring shall have measurement locations clearly identified and appropriately prepared for the measurement type.

The off-line system's data collector shall also comply with the following specific requirements:

- a) Live display of current overall measurement values prior to acceptance for storage.
- b) Display of previous reading for comparison with currently collected value.
- c) Display of all valid Alarm values for a currently collected measurement.
- d) Battery life for continuous use for a nominal shift (8 hours minimum).
- e) Collection of vibration signals natively from accelerometers, velocity probes and displacement probes.
- f) Display of vibration readings in units of acceleration, velocity and displacement with values of r.m.s., peak and peak-peak.
- g) Display of all measurements in user selectable metric or imperial (US customary) units.
- h) 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).
- i) Collection of data from on-line condition monitoring racks (via buffered outputs in accordance with API 670).
- j) Capability to connect auxiliary probes such as infra red temperature devices, oil monitoring probes, etc.

- k) Separate phase trigger input.
- l) Amplitude autoscale.
- m) Spectrum display (minimum 400 lines, maximum at least 6400 lines).
- n) Selectable frequency ranges up to at least 20 kHz.
- o) Selectable resolution.
- p) True zoom (10 x zoom around any cursor frequency selected).
- q) Waterfall plots.
- r) Phase angle.
- s) Time waveform display.
- t) Windowing functions.
- u) Averaging.
- v) Enveloping measurements.
- w) Band alarms.
- x) Point naming minimum 20 characters (capable of accepting standard tag numbering).
- y) Multiple route upload and download capability.
- z) All data to be time stamped, synchronised with the plant master clock.

In addition to the above, the off-line system's software shall also comply with the following specific requirements:

- Compatible with Microsoft Windows Operating System
- Capable of and compatible with data export to the Shell Group's standard DCS systems (Honeywell, Yokagawa, Emerson), data historians (OSI's PI, Honeywell's PHD) and SAP.
- Capable of and compatible with data import from the Shell Group's standard DCS systems (Honeywell, Yokagawa, Emerson) and data historians (OSIs PI, Honeywell's PHD).
- Capable of and compatible with data imports from 3rd party data sources e.g. Oil analysis lab data, Excel spreadsheets etc. (via suitable drivers if required).
- Trend plots including multiple parameters (at least 10) and trend extrapolation.
- Baselines.
- Comparison of data from different machines.
- Scalar and spectral data storage for minimum 10 years for all measurement points.
- Capable of structured hierarchical plant configuration to enable logical data retrieval.

- Data collection routes.
- Data collection route scheduling.
- Remote data collector upload and download via modem or similar.
- Automatic comparison of all new data against reference baseline data (including spectra) and against all configured Alert/Danger limits and automatic presentation of excursions.
- Auto report generation capabilities.
- 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 two methodologies which are:

- 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 14830-1 and ISO 17359.

2.5.2 Particulate-based condition monitoring

Should be conducted in accordance with ISO 14830-1 and ISO 17359.

2.5.3 Lubricant/working fluid condition monitoring

As a minimum for acceptable lubricant quality, the oil samples should be analysed for water content, flash point, wear metals (lead, copper, tin, iron etc.), colour / visual appearance, rust, foaming, viscosity at 40 °C and 100 °C, TAN, (TBN for diesel engines), RBVOT 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

Amended per
Circular 67/12

According to the criticality ranking of specific equipment, on-line condition monitoring is required for equipment in essential non-spared service and other equipment deemed to require it. (DEP 31.29.40.10-Gen. specifies on-line condition monitoring for compressors in all essential services.) The objective of this 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 monitored includes all axial and centrifugal compressors and their drivers (incl. 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.

The **mechanical** and selected **process parameters** of the equipment shall be monitored in order to assess performance and mechanical integrity, and enable optimum equipment operation. Process parameters are shown in italics.

Unless otherwise specified, the minimum mechanical and process parameters to be monitored by the condition monitoring system are listed below for the main types of rotating equipment in accordance with the indicated standards:

Axial and Centrifugal Compressors: (DEP 31.29.40.10-Gen.)

Radial shaft vibrations

Axial thrust position (Axial displacement)

Phase angle (Keyphasor)

Journal bearing temperatures

Thrust bearing temperatures

Compressor speed (for variable speed drives)

Seal performance parameters

Lube oil pressure and level

Oil filter differential pressure

Tribology-based parameters

Compressor section inlet, interstage and outlet pressures, temperatures and flows

Recycle data such as surge parameters

Molecular weight of the process gas.

Liquid level in inlet separator(s)

Additional parameters for monitoring

Casing vibration

Torque (for mechanically driven compressors)

Power or current (for electrically driven compressors)

(If installed) Suction strainer differential pressure

Reference gas and balance gas pressure

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 will reduce throughput, as will excess leakage across labyrinth seals. Monitoring of leakage rates across interstage labyrinths on back-to-back compressors is especially important, as excessive leakages 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.

Reciprocating Compressors: (DEP 31.29.40.31-Gen.)

Main Bearing Temperatures

Crosshead Acceleration/Crankcase acceleration/Frame vibration

Rod position (rod drop) monitoring devices (for machines < 200mm stroke only if appropriate)

Provisions for P-V diagram analysis

Piston rod packing leakage

Suction and discharge valve temperature measurement (online)

Lube oil pressure and level

Oil filter differential pressure

Jacket water system failure

Tribology-based parameters

Cylinder pressure

Suction and discharge pressure and temperature per stage

Compressor flow per stage

Recycle flow rate

Liquid level in suction separator

Additional parameters for monitoring

Phase angle (Keyphasor)

Cylinder/packing lube oil flow

Gas turbines: (DEP 31.29.70.31-Gen. and DEP 31.29.70.11-Gen.)

Engine casing vibration

Radial shaft vibrations (where appropriate)

Axial thrust position/Axial displacement (where appropriate)

Journal bearing temperatures (where appropriate)

Thrust bearing temperatures (where appropriate)

Inlet air filter pressure drop (differential pressure)

Exhaust temperatures and exhaust temperature spread

Lube oil and hydraulic oil pressure

Tribology-based parameters

Power turbine 1st stage inlet nozzle temperature

Exhaust plenum pressure

Speed (GP and PT)

Power (via torque meter)

Compressor inlet and outlet pressure and temperature

Fuel gas flow and Wobbe index

Wheel space temperatures

Fuel control valve position

Fuel gas scrubber level

Lube oil tank level

Additional parameters for monitoring

Phase angle (Keyphasor)

Variable guide vane position (where applicable)

Hours run, number of starts and fired starts

Centrifugal pumps: (DEP 31.29.02.30-Gen.)

Radial shaft vibrations (plain bearing machines)

Axial thrust position (plain bearing machines)

Phase angle (Keyphasor)

Journal bearing temperatures (plain bearing machines)

Thrust bearing temperatures (plain bearing machines)

Tribology-based parameters

Suction and discharge pressure

Pump flow

By-pass flow

Additional parameters for monitoring

Pump speed

(If installed) Suction strainer differential pressure

Balance pressure (support thrust balance line flows for multistage high pressure pumps)

Lube oil pressure

Liquid expanders:

Vibration

Tribology-based parameters

Speed

Inlet and outlet flow

Power generated

Inlet Guide Vane position (if applicable)

For both centrifugal pumps and liquid expanders, the purpose of monitoring the above parameters is to obtain information allowing the operator to assess performance, including efficiency losses, and thus provide input to the maintenance schedule.

Steam turbines: (DEP 31.29.60.30-Gen. and DEP 31.29.60.31-Gen.)

Radial shaft vibrations

Axial thrust position (Axial displacement)

Journal bearing temperatures

Thrust bearing temperatures

Tribology-based parameters

Steam inlet, extraction and outlet (exhaust) pressures and temperatures

Speed

Wheel chamber pressure

Steam flow

Bearing temperature and labyrinth seal leakage.

Additional parameters for monitoring

Phase angle (Keyphasor)

Casing vibration

Inlet valve position

Lube oil pressure

Monitoring of the 1st stage wheel chamber pressure is important, as this provides information for assessing and planning overhaul intervals (e.g. loss of labyrinth clearances) and also provides details on the degree of fouling inside the steam turbine.

In a condensing steam turbine, monitoring of the steam condition at the outlet section is important, as erosion/corrosion damage may lead to premature blade failures. Determining the actual outlet conditions, particularly the steam wetness, of the steam turbine is difficult. Trending of the inlet and exhaust conditions and comparing these to data taken under new and clean conditions at different operating points of the turbine is therefore the best method of monitoring any deterioration in performance.

Generators/Alternators/Motors: (DEP 33.66.05.31-Gen., DEP 33.65.11.32-Gen., NEMA MG 1, IEC 60034-1, IEC 60034-14)

Radial shaft vibrations

Axial thrust position (Axial displacement)

Journal bearing temperatures

Thrust bearing temperatures

Winding temperatures

Current

Voltage

Tribology-based parameters

Speed

Frequency

Additional parameters for monitoring

Phase angle (Keyphasor)

Winding high frequency discharge for motors/generators > 6.6kV (e.g. by Rogowski coils in switchgear)

RIC Diesel Engines: (DEP 31.29.80.30-Gen.)

Lube oil temperature and pressure