Predictive Maintenance Practices

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Predictive Maintenance Practices

Prepared by
Functional Committee

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Preamble

Indian petroleum industry is the energy lifeline of the nation and its continuous performance is essential for sovereignty and prosperity of the country. As the industry essentially deals with inherently inflammable substances throughout its value chain – upstream, midstream and downstream – Safety is of paramount importance to this industry as only safe performance at all times can ensure optimum ROI of these national assets and resources including sustainability.

While statutory organizations were in place all along to oversee safety aspects of Indian petroleum industry, Oil Industry Safety Directorate (OISD) was set up in 1986 Ministry of Petroleum and Natural Gas, Government of India as a knowledge centre for formulation of constantly updated world-scale standards for design, layout and operation of various equipment, facility and activities involved in this industry. Moreover, OISD was also given responsibility of monitoring implementation status of these standards through safety audits.

In more than 25 years of its existence, OISD has developed a rigorous, multi-layer, iterative and participative process of development of standards – starting with research by in-house experts and iterating through seeking & validating inputs from all stake-holders – operators, designers, national level knowledge authorities and public at large – with a feedback loop of constant updation based on ground level experience obtained through audits, incident analysis and environment scanning.

The participative process followed in standard formulation has resulted in excellent level of compliance by the industry culminating in a safer environment in the industry. OISD – except in the Upstream Petroleum Sector – is still a regulatory (and not a statutory) body but that has not affected implementation of the OISD standards. It also goes to prove the old adage that self-regulation is the best regulation. The quality and relevance of OISD standards had been further endorsed by their adoption in various statutory rules of the land.

Petroleum industry in India is significantly globalized at present in terms of technology content requiring its operation to keep pace with the relevant world scale standards & practices. This matches the OISD philosophy of continuous improvement keeping pace with the global developments in its target environment. To this end, OISD keeps track of changes through participation as member in large number of International and national level Knowledge Organizations – both in the field of standard development and implementation & monitoring in addition to updation of internal knowledge base through continuous research and application surveillance, thereby ensuring that this OISD Standard, along with all other extant ones, remains relevant, updated and effective on a real time basis in the applicable areas.

Together we strive to achieve NIL incidents in the entire Hydrocarbon Value Chain. This, besides other issues, calls for total engagement from all levels of the stake holder organizations, which we, at OISD, fervently look forward to.

Jai Hind!!!

Executive Director

Oil Industry Safety Directorate
FOREWORD

The oil industry in India is 100 years old. As such, a variety of practices have been in vogue, because of collaboration/association with different foreign companies and governments. Standardisation in design philosophies and operation & maintenance practices at national level were hardly in existence. This, coupled with feed back from some serious accidents that occurred in the recent past in India and abroad, mandated the need of the industry to review the existing state of designing, operating and maintaining oil and gas installations.

With this in view, Ministry of Petroleum & Natural Gas in 1986 constituted Safety Council, assisted by Oil Industry Safety Directorate (OISD), staffed from within the industry, in formulating and implementing a series of self-regulatory measures aimed at removing obsolescence, standardizing and upgrading the existing standards to ensure safer operations. Accordingly, OISD constituted a number of Functional Committees of experts, nominated from the industry to draw up standards, recommended practices and guidelines on various subjects.

The present document on “Predictive Maintenance Practices” was prepared by Functional Committee constituted for total review of OISD standards on Rotary Equipment.

This document is based on the accumulated knowledge and experience of Industry members, equipment manuals, national and international codes of practices etc. This document is meant to be used as a supplement and not as a replacement for existing codes, standards and manufacturers' recommendations. It is hoped that provision of this document, if implemented objectively, may go a long way to improve safety and reduce accidents in the Oil and Gas Industry. Suggestions for amendments, if any, to this document should be addressed to:

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These documents are intended only to supplement and not to replace the prevailing statutory requirements.
# LIST OF FUNCTIONAL COMMITTEE MEMBERS

<table>
<thead>
<tr>
<th>S.N</th>
<th>Name</th>
<th>Organisation</th>
<th>Position in Committee</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Mr. D.K. Puri</td>
<td>Reliance Industries Limited</td>
<td>Leader</td>
</tr>
<tr>
<td>02</td>
<td>Mr. S.K. Chatterjee</td>
<td>Hindustan Petroleum Corporation Limited</td>
<td>Member</td>
</tr>
<tr>
<td>03</td>
<td>Mr. P. Veerabhadra Rao</td>
<td>Hindustan Petroleum Corporation Limited</td>
<td>Member</td>
</tr>
<tr>
<td>04</td>
<td>Mr. T.V. Venkateswaran</td>
<td>Reliance Industries Limited</td>
<td>Member</td>
</tr>
<tr>
<td>05</td>
<td>Mr. A.K. Dash</td>
<td>Indian Oil Corporation Limited</td>
<td>Member</td>
</tr>
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<td>06</td>
<td>Mr. Deepak Prabhakar</td>
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<td>07</td>
<td>Mr. R.C. Agarwal</td>
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<td>Member</td>
</tr>
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<td>08</td>
<td>Mr. K Ravi</td>
<td>Kochi Refineries Limited</td>
<td>Member</td>
</tr>
<tr>
<td>09</td>
<td>Mr. Shamsher Singh</td>
<td>Oil Industry Safety Directorate</td>
<td>Member Coordinator</td>
</tr>
</tbody>
</table>
## CONTENTS

<table>
<thead>
<tr>
<th>SL.NO.</th>
<th>DESCRIPTION</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>Introduction</td>
<td>01</td>
</tr>
<tr>
<td>2.0</td>
<td>Scope</td>
<td>01</td>
</tr>
<tr>
<td>3.0</td>
<td>Definitions</td>
<td>01</td>
</tr>
<tr>
<td>4.0</td>
<td>Predictive Maintenance Program</td>
<td>02</td>
</tr>
<tr>
<td>5.0</td>
<td>Protection Systems</td>
<td>07</td>
</tr>
<tr>
<td>6.0</td>
<td>Calibration of Monitoring Instruments</td>
<td>08</td>
</tr>
<tr>
<td>7.0</td>
<td>Documentation</td>
<td>08</td>
</tr>
<tr>
<td>8.0</td>
<td>References</td>
<td>09</td>
</tr>
<tr>
<td>9.0</td>
<td>Annexure-I (Equipment Criticality)</td>
<td>10</td>
</tr>
<tr>
<td>10.0</td>
<td>Annexure-II (Frequency of Monitoring)</td>
<td>11</td>
</tr>
</tbody>
</table>
Predictive Maintenance Practices

1.0 Introduction

Reliable operation of rotary machines in hydrocarbon industry has a direct linkage to on-stream days. To achieve reliability, condition based Predictive Maintenance has proven to be an important tool. This document cover the basic philosophy and approach towards condition based Predictive Maintenance Practices for rotary equipment installed in the hydrocarbon industry. The rotary equipment covered by this document are Pumps, Compressors, Blowers, Fans, Steam & Gas Turbines, Engines, Motors, Generators, Gearboxes and Agitators.

2.0 Scope

This document covers the methodology for management of a Predictive Maintenance Program for rotary equipment in hydrocarbon industry through monitoring and analysis of Vibrations, Lube Oil Condition and Process/ Operating Parameters.

3.0 Definitions

3.1 Shall

Indicates mandatory requirement.

3.2 Should

Indicates recommendation or that which is advised but not mandatory.

3.2 Accelerometer

A piezoelectric sensor containing integral amplification with an output proportional to acceleration

3.3 ‘g’ Value

A unit of acceleration equal to 9.81 meters per second squared.

3.4 Piston Rod Drop

A measure of the position of the piston rod relative to the proximity probe.
3.6 Moisture Content

Amount of water present in both free and dissolved form in lube oil. (ASTM Test Method: ASTM D 6304 or ASTM D 4377).

3.7 Total Acid Number (TAN)

Total Acid Number, indicates the acidity of the lube oil. Used as an indicator to test the degree of oxidation of lube oil. (ASTM Test Method: ASTM D664 or ASTM D 3339).

3.8 Total Base Number (TBN)

Total Base Number, indicates the alkalinity of oil. Used as an indicator to test the amount of burnt residue in lube oil. (ASTM Test Method: ASTM D 4379).

3.9 Transducers

Devices used for measurement or monitoring of Acceleration, Velocity, Displacement etc. are collective known as transducers.

3.10 Viscosity


3.11 Vibration Meter

Instrument used for measuring vibrations in terms of displacement, velocity or acceleration.

3.12 Vibration Severity

Criteria for predicting the hazard related to specific machine vibration level.

4.0 Predictive Maintenance Program

The Predictive Maintenance Program to be followed by an organization unit shall be backed by well-defined criteria, execution methodology and effectiveness measurement.

4.1 Criteria

Criteria for effective Predictive Maintenance Program should include classification of equipment and identification of parameters that are indicative of various aspects of
equipment condition and monitoring of which, helps to identify potential failures and unsafe conditions for timely corrective action

4.1.1 Equipment Classification

Equipment classification is essential in order to identify and prioritize monitoring effort on equipment that has major impact on the safety and environment. An objective methodology is to be established so as to ensure that all equipment meeting certain criteria are essentially classified in the same manner.

Equipment should be classified as Critical, Semi-Critical & Non-Critical or having equivalent terminology considering the following factors, as a minimum;

a) Impact on health & safety (fire, health hazard, injury hazard etc.)

b) Impact on Environment (release of toxic gases etc.)

c) Impact on plant assets (fire, explosion etc.)

d) Criticality to Process (loss of production/ quality of product/s)

A sample methodology for equipment classification is given in Annexure–I.

4.1.2 Parameters of Monitoring

The following parameters should be considered for monitoring the condition of machine;

a) Physical Parameters

b) Lube Oil Condition

c) Process Parameters

4.1.2.1 Physical Parameters

Machine condition should be monitored by measurement of physical parameters such as vibration, axial displacement, rod drop and bearing temperature.

a) Vibrations

Vibration is an important physical parameter for monitoring the health of rotary equipment. Vibrations as referred to in this standard shall include Shaft or Casing vibrations. Recording of vibrations is done using permanent mounted probes i.e. online system or physical vibration measurement at predetermined locations using portable probes i.e. offline system. The parameters to be monitored include acceleration (‘g’ Value, Peak Value, Envelopes etc), velocity, displacement etc.
On Line Monitoring Systems

Permanent mounted probes/ transducers, connected to an on line monitoring system should be installed on Critical Equipment like, Centrifugal Compressors, Steam and Gas Turbines, Multi Stage Pumps and other large machines. Shaft vibrations should be used to monitor high-speed machines with hydrodynamic bearings, like Turbines and Centrifugal Compressors.

For other critical low speed equipment like Reciprocating Compressors, casing vibrations should be used for monitoring.

Offline Monitoring Systems

All classified rotating equipment condition shall be monitored using offline monitoring systems/ measuring instruments. The complete equipment (which includes driver, gear box and driven equipment) should be covered under offline monitoring system.

b) Axial Displacement

Axial displacement is an important parameter to be monitored in equipment like centrifugal compressors, screw compressors, steam and gas turbines and high-speed centrifugal pumps.

The provision for online measurement of axial displacement should be provided on all critical machines with hydrodynamic thrust bearings. A list of equipment using this monitoring technique should be maintained.

Alarm and trip values should be pre-set so as to ensure early warning and safe shutdown in case of abnormality.

c) Rod Drop

Critical reciprocating compressors should be fitted with rod-drop indicators to detect rider ring wear, piston rod breakage etc.

The rod drop indicators should be wired up to DCS & alarms and trips values be set so that the machines are protected against catastrophic failure.

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d) Bearing Temperature

Bearing temperature of critical equipment like centrifugal compressors, screw compressors, steam and gas turbines and high-speed centrifugal pumps should be monitored continuously. Alarm and trip values should be pre-set so as to ensure early warning and safe shutdown in case of abnormality.

The equipment that does not have continuous/online bearing temperatures measurement system, the bearing housing temperature should be measured using offline portable instrument to monitor the condition of bearing.

4.1.2.2 Lube Oil Condition

Lubricating oil plays an important role in the safe operation of rotary equipment. Monitoring of the lube oil condition is essential to ensure proper lubrication quality in order to prevent failures. Lube oil condition can also give indications of impending equipment failure. A procedure shall be established in order to identify equipment for which lube oil condition is to be monitored. The parameters to be monitored are as follows:

**Appearance** – Color, Presence of metal debris, sludge or free water.

**Physical Properties** – Viscosity, Dissolved moisture, TAN, TBN, Flash Point.

Total Acid Number (TAN), Total Base Number (TBN) and Flash Point should be monitored wherever applicable. A procedure should be established to monitor the lube oil parameters. The frequency of monitoring of these parameters shall be established based upon relevant standard, OEM recommendation and past experience. Advanced tools like Ferrography, Metallography, Particle Count and Wear Debris Analysis should be considered for critical equipment.

4.1.2.3 Process Operating Parameters

A procedure should be established to ensure that process-operating parameters of equipment are monitored on a periodic basis depending on the criticality. The parameters to be monitored shall be different for different type of equipment. For example; it may include fuel and lube oil consumption for engines; ampere load and winding temperature for motors; suction and discharge pressures for compressors, etc. etc. The operating values for these parameters should be compared with normal values and the limits of safe operation. The protections or control measures should be activated when safe limits are
crossed. The procedure should also define the actions to be taken in case of abnormal observations of the parameters.

4.2 EXECUTION OF PROGRAM

4.2.1 Recording of Parameters

A comprehensive procedure should be established to define and measure various parameters (mentioned under 4.1) to be monitored along with frequency. The records of monitoring of parameters shall be maintained.

A list of equipment and their parameters being monitored should be maintained. The list should segregate the equipment being covered under on-line and off-line monitoring system. It should be ensured that equipment which are not covered under online monitoring, are covered under offline monitoring and at a defined frequency.

4.2.2 Monitoring Frequency

Based on the criticality of the equipment, monitoring frequency shall be fixed for each equipment.

This frequency shall be defined for each of the parameters mentioned in the section 4.1.

A table depicting a typical frequency of monitoring of different parameters for various types of rotary equipment is attached at Annexure-II.

4.2.3 Analysis & Diagnosis

The trends for the parameters shall be monitored and the cases, which have recorded higher values or have shown increasing trend, shall be analyzed for probable root causes and suitable corrective actions should be recommended and implemented.

All parameters being monitored using on-line systems shall have in-built alarm systems that provide early warning in case of any machine abnormality.

These alarms shall be set based on manufacturers’ recommendation, other relevant standards or user experience.

Where the alarms are set based on the user’s experience, rationale for arriving at these settings shall be duly approved and records maintained.

The alarm and danger values shall be pre-set for equipment that are being monitored using off-line systems. These values shall be decided based on international standards or

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user’s experience. The rationale for the setting of the alarm values shall be duly approved and documented.

System shall be established to ensure all equipment that has crossed the preset alarm limits or set values as defined in the procedures are analyzed for abnormality. Identified persons who have adequate knowledge and skill shall carry out this analysis and diagnosis.

A periodic review of the technology available, skills and knowledge requirement should be carried out and training should be imparted to ensure that diagnostic skills are up-to-date.

4.2.4 Corrective Actions

The corrective actions as recommended shall be implemented. The implementation of recommendations shall be prioritized based on the severity of the problem and criticality of the equipment. A system shall be in place to track down the implementation of corrective measures.

4.2.5 Closure

On completion of the recommended corrective action, the equipment parameter shall again be checked to ensure that the values have normalized. The new result shall be recorded and the work order/ request/ notification closed.

4.2 Program Effectiveness Measurement

Effectiveness of the condition-based predictive maintenance program should be checked periodically and records maintained. Some of the measures that may be selected to monitor effectiveness are

a) Number of breakdowns without warning

b) Number of incorrect warnings.

c) Recurrence of problems

d) Unplanned viz. a viz. planned maintenance ratio

The endeavor should be to continuously improve the effectiveness of condition based predictive maintenance system.

5.0 Protection Systems

All Critical equipment in continuous service shall have protection systems with adequate redundancy. Procedures should be in place to carry out periodic check on the health and accuracy of these systems. Records of such tests carried out shall be maintained.

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It should be ensured that on-line devices are connected to alarm & trip systems and the alarm & trip values are set to provide adequate warning for impending failure or deterioration of the equipment.

Procedures should ensure that any changes in the alarm or trip values should be affected after review and due approval.

6.0 Calibration of Monitoring Instruments
A system shall be in place to ensure that all monitoring instruments are calibrated periodically. A list of all the instruments, with their status of calibration and the calibration date should be maintained.

The calibration of equipment shall be done using standard calibration methods applicable following national or international standards.

7.0 Documentation
System should be established to maintain proper records as required by this document.

Organizations shall maintain proper records either in paper form or in electronic form duly authorized by responsible persons, with respect to the following:

a) Critical Equipment
b) Equipment being Monitored
c) Parameters being monitored
d) Alarms and trip settings against parameters
e) Correction notices given
f) Corrective action taken
g) Closure
h) Calibration
i) Monitoring of effectiveness
j) Protection systems
k) Training records of persons responsible for Condition Monitoring
8.0 References

a) API 670
b) API 614
c) ISO 2372
d) VDI/ ISO for balance quality
Annexure- I

Equipment Criticality

Equipment criticality shall be decided based on methods decided by the organization. The method shall include the requirements from the Process, Safety and Environment.

Weighting factor (WF) shall reflect the overall importance of the particular parameter for the equipment. For services that are hazardous, the weighting factor for the Safety Index needs to be the highest. For equipments handling products that have impact on environment, the weighting factor for environment index shall be the highest.

Aspects like legal requirements, protections available etc can be considered while allocating the rating.

The table below gives a sample worksheet for calculation of the criticality. The criticality will be decided by the generation of a composite index, which is the weighted sum of all the factors being considered.

<table>
<thead>
<tr>
<th>Equipment Tag</th>
<th>Process Index</th>
<th>Safety Index</th>
<th>Environment Index</th>
<th>Cost Index</th>
<th>Composite Index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rating (a)</td>
<td>Rating (c)</td>
<td>Rating (e)</td>
<td>Ratin (g)</td>
<td>axb+cxd+exf+gxh</td>
</tr>
<tr>
<td>Pump A</td>
<td>10</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Pump B</td>
<td>5</td>
<td>2</td>
<td>10</td>
<td>3</td>
<td>5.4</td>
</tr>
</tbody>
</table>

The cut off score for deciding on equipment as critical can be fixed and the critical equipment identified accordingly. A second cut-off score for identifying semi-critical equipment can also be fixed. Equipments that do not fall within this score can be deemed as non-critical.

Care should be taken to ensure that the rating is given so as to reflect the condition at site.

This annexure demonstrates one method of classification. However, other methods which are objective and which consider the essential factors mentioned in the section 4.1.1 may also be adopted.

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Annexure-II

A Typical Frequency of Monitoring

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>Parameter</th>
<th>Vibration</th>
<th>Temperature</th>
<th>Oil Condition</th>
<th>Remarks</th>
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<tr>
<td><strong>Pumps</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Critical Centrifugal Pumps</td>
<td>Weekly</td>
<td>Weekly</td>
<td>Monthly</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Others</td>
<td>Monthly</td>
<td>Monthly</td>
<td>Quarterly</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Reciprocating Pumps</td>
<td>Monthly</td>
<td>-</td>
<td>Quarterly</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Turbines</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Large</td>
<td>On-Line</td>
<td>On-Line</td>
<td>Monthly</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Small Drive</td>
<td>Fortnightly</td>
<td>Fortnightly</td>
<td>Quarterly</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Compressors</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Centrifugal</td>
<td>On-Line</td>
<td>On-Line</td>
<td>Monthly</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Reciprocating</td>
<td>Fortnightly</td>
<td>Fortnightly</td>
<td>Monthly</td>
<td>Online rod drop for critical service</td>
<td></td>
</tr>
<tr>
<td>- Screw</td>
<td>Weekly</td>
<td>Weekly</td>
<td>Monthly</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fans &amp; Blowers</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Air Fin Coolers</td>
<td>On line</td>
<td>N/A</td>
<td>N/A</td>
<td>For Critical Services</td>
<td></td>
</tr>
<tr>
<td>- Blowers</td>
<td>Monthly</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Fans</td>
<td>Fortnightly</td>
<td>N/A</td>
<td>Quarterly</td>
<td></td>
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