Machine Condition Monitoring System
Application Note: Refinery and Petrochemical Plants

Need for Machine Monitoring System in a Refinery Plant

Monitoring the running condition of plant machinery is, without a doubt, important. Most efforts to move away from Preventive Maintenance (time based maintenance) to Predictive Maintenance (also called condition-based maintenance) have come about in the last 15 years, particularly in large industrial plants. By monitoring plant machinery, one can plan outages and repairs and save a lot of money. Unplanned outages, resulting from machinery failure, are very costly. The outages are usually longer and the repair cost is often higher because damaged parts have to be replaced or repaired instead of replacing just worn out parts.

Objectives of Vibration Monitoring

Effective for many root causes i.e. imbalance, misalignment, abnormal roller bearing, abnormal sleeve bearing, abnormal speed reducer, looseness, etc.

Preventing unscheduled downtime
Extending machine usable time
Reducing energy costs
Reducing downtime when machine is down
Preventing failures
What Are the Major Products of a Refinery?

**Gasoline**: Currently the most important product of refineries, gasoline may contain additives to enhance performance and protect against rust.

**Kerosene**: The first major product of a refinery, kerosene is used in jet fuel and for cooking and space heating.

**Liquefied Petroleum Gas**: Known as “LPG,” this product is produced for use as fuel and as a material to manufacture other chemicals.

**Distillate Fuels**: These products consist primarily of diesel, used to power vehicles and generators, and domestic heating oils.

**Residual Fuels**: These “leftover” fuels are used in ships, power plants, and commercial and industrial facilities.

**Coke and Asphalt**: Coke is almost pure carbon and may be used in anything from electrodes to charcoal for home grilling. Asphalt is used in roads and roofing.

**Petrochemicals**: These products are primarily intended to produce plastics and synthetic fibers and rubbers.

**Lubricants**: These products are the result of special refining processes. They are used in motors and as industrial greases and cutting oils.

**Solvent**: The term encompasses a variety of products used for purposes such as cleaning and degreasing.
Sour waters are derived from various distillation tower reflux drums in the refinery.
The “other gases” entering the gas processing unit includes all the gas streams from the various process units.
Refinery Processes

**Alkylation**
Alkylation is a process for chemically combining isobutene with light olefinic hydrocarbons, typically C3 and C4 olefins, (e.g. propylene, butylene) in the presence of an acid catalyst, usually sulphuric acid or hydrofluoric acid. The product, alkylate (an isoparaffin) has a high octane value and is blended into motor and aviation gasoline to improve the anti-knock value of the fuel.

**Rotating Machines in the Alkylation Area**
- Refrigeration gas compressor and its turbine
- Feed pump

**Catalytic Cracking**
Catalytic cracking is a process which breaks down the larger, heavier and more complex hydrocarbon molecules into simpler and lighter molecules by the action of heat and aided by the presence of a catalyst, but without the addition of hydrogen. In this way, heavy oils (fuel oil components) can be converted into lighter and more valuable products (notably LPG, gasoline and middle distillate components). The catalytic cracking unit is known as the Fluidised Catalytic Cracking or FCC. The FCC feed is also known as Vacuum Gas Oil (VGO) because it is generally a product from the Vacuum Distillation Column.

**Fluidized Catalytic Cracking (FCC)**
FCC is a process whose objective is to convert low value gas oils to valuable products (naphtha and diesel) and slurry oil.

**Primary Process Technique**
Catalytic cracking increases H/C ratio by carbon rejection in a continuous process.

**Process Steps**
- Gas oil feed is dispersed into the bottom of the riser using steam
- Thermal cracking occurs on the surface of the catalyst
- Disengaging drum separates spent catalyst from product vapours
- Steam strips residue hydrocarbons from spent catalyst
- Air burns away the carbon film from the catalyst in either a “partial-burn” or “full-burn” mode of operation
- Regenerated catalyst enters bottom of riser-reactor

**Rotating Machine Details in the FCC Area**
- Air blower motor
- Heat pumps compressor (turbine driven), wet gas compressor and turbine
- Expander

**Hydrogen Plant**
The most commonly used method of hydrogen production is the steam reforming process. The main process consists of the reaction of steam with a hydrocarbon over a catalyst at around 750-800°C temperature, in order to form hydrogen and carbon oxides. The whole process starts with:

**Purification of the Raw Material**, in which toxins, like, sulphur and chloride are removed ensuring maximum life of the downstream steam reforming and other catalysts.

**Steam Reformation** is the next step which can also be stated as the essence of the working process of a hydrogen gas plant, involves the main hydrogen-producing reaction. [There are numerous process designs for the 'Steam Reforming Reaction'. The conventional design is 'High Pressure and High Temperature Process Design', which is basically used by refineries to generate Hydrogen. Another design is the 'Low Pressure Design, which is also rich in carbon-di-oxide and is primarily used for direct reduction plants].

...
High Temperature Shift and Low Temperature Shift, the third step and consists of the reaction of carbon monoxide with steam in two phases, namely high temperature and low temperature. This reaction results in carbon dioxide and additional hydrogen.

The Purification Process, this is the final step which produces 99.99% product hydrogen and an-off gas by using Pressure Swing Absorption unit (PSA).

Rotating Machine Details in the Hydrogen Plant Area
Feed gas and Make-up gas compressors

Vacuum Gas Oil (VGO)
Primary objective of VGO is to recover valuable gas oils from reduced crude via vacuum distillation.

Primary Process Technique
Reduce the hydrocarbon partial pressure via vacuum and stripping steam

Process Steps
- Heat the reduced crude to the desired temperature using fired heaters
- Flash the reduced crude in the vacuum distillation column
- Utilise pump around cooling loops to create internal liquid reflux
- Product draws are top, sides, and bottom

Rotating Machine Details in the VGO Area
ID Fan and FD fan
Recycle gas compressor (turbine driven)
Various critical pumps

Delayed Coking
Delayed coking is a high severity "bottom of the barrel processing" scheme by which heavy crude oil fractions can be thermally decomposed under certain conditions or elevated temperatures to produce a mixture of lighter oils and petroleum coke. The light oils can be processed further in other refinery units or blended into products. The coke can be used either as a fuel or in other metallurgical applications such as the manufacture of steel or aluminum.

Rotating Machine Details in the Delayed Coking Area
Heater charge and other critical pumps
Coke gas compressor

Distillation (Atmospheric and Vacuum)
This is the first stage in refining, for separating crude oil components at atmospheric pressure by heating and subsequent condensing, of the fractions (unfinished petroleum products) by cooling. Distillation under reduced pressure (less than atmospheric) i.e. vacuum distillation lowers the boiling temperature of the liquid being distilled, permitting the production of distillates at a lower temperature than would be necessary in atmospheric distillation, thus avoiding coke formation.

Rotating Machine Details in the Crude Distillation Area
Various types of pumps and rotary compressors
ID and FD fans
**Thermal Cracking**

In this process, heat and pressure are used to break down, rearrange, or combine hydrocarbon molecules. Thermal cracking includes vis-breaking, delayed coking, fluid coking, and other similar processes.

**Vis-breaking**

Vis-breaking is a relatively mild thermal cracking process in which heavy atmospheric or vacuum-distillation bottoms are cracked at moderate temperatures to make light products and produce a lower viscosity residue than the initial feed to the unit.

Vis-breaking process achieves about 30% of residue conversion to lighter products. Vis-breaking is one of the least costly upgrading processes, and is common where there is still a relatively large use of heavy fuel oil. But with the problems of surplus fuel oil compounding the world over, the importance of this process is expected to decline.

**Hydrotreating**

Hydrotreating is used for treating petroleum fractions in the presence of catalysts and substantial quantities of hydrogen. Hydrotreating results in desulphurisation (removal of sulphur) denitrification (removal of nitrogen compounds) and conversion of olefins to paraffins.

**Reforming (Aromatics)**

The Reforming process rearranges hydrocarbon molecules in the naphtha (or naphtha type) feed, thereby converting paraffins and naphthenic type hydrocarbons into aromatic type hydrocarbons, suitable for blending into finished gasoline. Since its product, reformate, is richer in aromatics than its feed, naphtha, this process is also used to produce aromatic petrochemicals (Benzene, Toulene and Xylene).

**Clean fuel**

**Rotating Machine Details in the Clean Fuels Area**

- Make-up gas compressor
- Feed pump / motor
- Air cooler
- Recycle gas compressor / motor / turbine
- ID and FD fan
- Feed charge pump / motor
- Dryer bottoms pumps / motor
- Hot oil pump / motor
Spent Acid Regeneration Area

Sulfuric acid is one of the largest chemicals produced by weight in the world. This acid is used in nearly every industry including agro-products, mining, paper and pulp, steel production, water treatment, surfactants (soaps), plastics and petrochemicals. Sulfuric acid regeneration processes service the petrochemical industry through recycling the sulfuric acid used as a catalyst in alkylation units. This is an important service within the refining process that supplies the alkylation unit with fresh active catalyst. Spent acid regeneration is a service based process that must provide the product as promised so that production on the refinery is not affected. In attempts to deliver acid as promised a preventive maintenance and performance prediction culture has evolved.

Rotating Machine Details in the Spent Acid Regeneration Area

Refrigeration gas compressor and turbine

Captive Power Plant

The residues identified in the foregoing sections can be used for power generation via any of the following routes:

- Conventional steam power plant
- Steam power plant with fluidised bed combustion system
- Integrated gasification and combined cycle power plant

Rotating Machine Details in the CPP Area

- Gas turbine
- Steam turbine
- Air compressor
- FD fans of auxiliary boilers
- FD fan turbine drives of auxiliary boiler
- Utilities i.e. air compressor and cooling water pump

Marine Terminal Farm

A refinery's marine terminal provides for the loading and unloading of tankers for oil storage.

Rotating Equipment in this Area

- Crude transport pump
- Gasoline jetty pump
- Diesel jetty loading pump
- Kerosene loading pump

Rail Terminal Farm

An oil depot (sometimes called a tank farm, installation or oil terminal) is an industrial facility for the storage of oil and/or petrochemical products and from which these products are usually transported to end users or further storage facilities. An oil depot typically has tankage, either above ground or underground, and gantries for the discharge of products into road tankers or other vehicles (such as barges) or pipelines.

Oil depots are usually situated close to oil refineries or in locations where marine tankers containing products can discharge their cargo. Some depots are attached to pipelines from which they draw their supplies and depots can also be fed by rail, by barge and by road tanker (sometimes known as "bridging").

Most oil depots have road tankers operating from their grounds and these vehicles transport products to petrol stations or other users.

Rotating Equipments in this Area

- Crude charge pumps
- Diesel MTF transfer pump
Refinery plants are divided according to the criticality into categories as shown in the triangle below. The most critical machines are turbines and compressors, which depends on the secondary critical machines like fans, motors, pumps, cooling towers fans, blowers, fin fans.

Looking at today's scenario, monitoring of these machines is imperative for increasing the efficiency and thereby reliability of the plant.

### Pyramid for Machinery in Refinery Plants

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Machine</th>
<th>Suitable Product</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1st Level Critical Machines</td>
<td>Compliant to API 670 Std.</td>
<td>EX / ATEX certified</td>
</tr>
<tr>
<td></td>
<td>Compressors (centrifugal and recipe type)</td>
<td>Transducer : FK Series, CA and CV Series monitor : VM-7B series and Infisys RV200 analysis and diagnostic software</td>
<td>Radial shaft, axial shift, rod drop, frame vibration, key phaser measurement</td>
</tr>
<tr>
<td></td>
<td>Turbine</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pump and motors – 1st critical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>2nd Level Critical Machines</td>
<td>Transducer : FK series, CA and CV series monitor AP2000 / VM-25 Monitoring system</td>
<td>Radial shaft, casing vibration, key phaser measurement</td>
</tr>
<tr>
<td></td>
<td>Pump and motors – 2nd critical</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Blower</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fin fans</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cooling tower fans</td>
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</table>

This machine monitoring solution is a cost effective maintenance tool which ensures the total availability of plant. Condition characteristics of the machine such as bearing damage, unbalance, alignment or cavitation enable a differentiated evaluation of mechanical stress which will keep us on track about when to have the shut down, and the process is ongoing without any manual interruption. Hence it is possible to protect the equipment from expensive consequential costs.

In order to take the machines for maintenance, we need to know the state of the health of the machine without dismantling it. This is possible only by online monitoring. Implementing predictive maintenance leads to a substantial increase in productivity of up to 35%.
The detailed machine monitoring system architecture in refineries indicates that vibration sensors are mounted on the turbine/compressor/motors shaft or bearing. Details of monitoring are as below:

- X & Y direction relative vibration of the main bearing shafts
- Accelerometers for gear box vibrations
- X & Y direction vibration sensors for foundation/casing
- Axial sensor for thrust bearing axial position
- Rod drop sensors for piston rod drop monitoring
- PT100 sensors for the main bearings temperatures

All sensor inputs are connected to a machine monitoring system which will be housed in the control panel. The machine monitoring system is primarily a safety solution with the basic condition monitoring capability for machines, where a number of faults can be detected early and remotely displayed on a Windows computer in a control room. A separate panel PC is installed in the control panel to view vibration data in the form of bar graph display or digital display.

All the critical equipment in the plant is equipped with Shinkawa machinery management software and hardware i.e. proximity probes VK/FK series for radial/axial displacement and rod drop measurement, CA series accelerometers, VM-7B series Machinery protection system as per API670 compliant and Infisys RV200 advanced machine monitoring analysis and diagnostic software which will be installed in the data gathering computer system.

Infisys RV200 software allows plant management to manage their machinery and minimize the possibility of an unplanned shutdown which leads to huge costs in production. Another advantage such as planned shutdown permits maintenance to prepare the required manpower and spare parts, which reduces down time, as maintenance can understand nature of the problem.
Typical Machine Monitoring System Requirements in Control Room

Control room in safe area

- Ethernet/FO cable
- Field cables
- Field Atex Zone
- Sensor housing, IP65 / ATEX
- Input from sensors (non contact type sensor, accelerometers) ATEX certified
- Display output near Machine in panel
- Centrifugal Compressor

Buffer output, BNC on front panel, and terminal at the back
- Analog output 4~20mA or 1~5VDC Isolated
- Relay outputs Each monitor module DAN, ALT, CH-ok Rack common SYS-OK, PWP-ok

MMS Panel

- Analysis server software installed with: Infisys RV200 analysis and diagnostic software
- Analysis output

Schematic shows a plant-wide machinery protection and management system for all the critical and essential plant machinery. A plant-wide system will have products including transducer systems, machinery protection systems and latest state of the art machinery management software, such as Infisys RV200 software.

All the critical and essential machines in the plant are instrumented with appropriate machine protection systems and are connected to RV200 data acquisition workstations. All these workstations are then linked together by an independent fiber-optic network that enables the plant managers to manage their machines from wherever they might be in the plant.
Transducer System

**FK Series Displacement Eddy Current Transducers**

The FK-202F transducer is the eddy current type non-contact displacement/vibration transducer, used for measuring shaft vibration, axial position, rotating speed and phase mark (phase reference) from small rotating machinery to large critical machinery such as turbines and compressors in plants. In addition, the FK-202F is designed to meet the API (American Petroleum Institute) standard 670 (5th Edition) requirements, often referred by the machinery protection systems for the petroleum refinery and the petrochemical plant in world wide.

Suitable for various applications: shaft vibration, axial position, rotating speed and phase mark of the critical rotating machinery.

Environmental friendly design: lead-free soldering, RoHS directive compliant and downsized.

Wide variety of driver mounting: DIN-rail adaptor, 4-screw cramp plate adaptor (to replace VK series and others)

API standard 670 (4th Edition) compliant

Intrinsically Safe: TIIS, CSA, ATEX, NEPSI, KTL

CE directive compliant

**CA/CV Series Velocity Sensor and Accelerometers**

Multi-purpose and intrinsically safe accelerometers. Available in both top and side connectors, or with top and side exit integral cables.

High temperature, low frequency and piezo velocity transducers

Available in both top and side connector versions

Machinery Protection / Monitoring System

**VM-7B Series – Simple, highly functioning and consistent performance - four channel API 670 Std. Monitoring System**

The VM-7B series monitor is designed according to ISO international standards and the API standards, and has the functions and features of the machine condition monitor, is used for machines in plant, and is used for the machine protection system defined in the API standard 670 in particular.

**Features**

- Redundant power supplies.
- True redundant communication to DCS / PLC
- Isolated 4-20 mA output
- Single monitor module (VM 701B) for 7 parameters
- Inbuilt analysis function in each module (optional)
- Inbuilt relay in each module
- Fully programmable relay in the rack for any configuration and logic

Raw signal output – front BNC and rear terminals

API 670 compliant

24 Bit microprocessor

Lead free soldering – caring environment

44 Input channel in each rack
Analysis Hardware for Software Integration (AP 2000)

This is a real time processor for steady state and transient measurements from monitor racks via raw signals for analysis and diagnostics purpose. Output from these units will be ether net and connected to software. Monitoring system (as per API 670 Std) has sensor signal output either on monitor front BNC or rear terminals. This signal will be connected with a multipair cable to the Shinkawa terminal box which will convert this into D connector output. This D Connector output will be then be connected to the Shinkawa analysing processor which will process this signal and give high speed analysis data output in form of ethernet TCP IP. This output will be then connected to a server where RV200 analysis software will be loaded and further processing and GUI plots will be made as an expert analysis and diagnosis system.
VM-25 monitoring system is designed with IoT in-mind, contains features and functions required for BOP (Balance of Plant) monitoring. VM-25 can be customized to suit end user needs, and its compact design means it fits almost anywhere.

**Features**

- Digital communication – Modbus / TCP communication with IoT system via single ethernet cable
- Right-sized – available in 4, 6 and 8 channel monitoring arrangements along with up to 4 recorder outputs and up to 8 relay outputs
- An optimized design – enables installation in small spaces along with multiple mounting arrangements. Dimensions, 120 x 160 x 100mm.

**Functions**

- Standard vibration measurement (velocity, acceleration transducers)
- Modbus / TCP communication
- A 7 digit LED front-facing display
- Recorder output (non-isolated)
- Optional recorder output (isolated)
- Relay output
- Dedicated configuration software enables operators to change monitor settings

### Example System Configuration

Machines e.g. pump, compressor, fan, blower, cooling tower fan, motor, generator, centrifugal separator, mid / small steam / gas turbines, etc.

VM-25 monitor housed in field junction box (ATEX)

Modbus communication to DCS/PLC

4-20mA/1-5VDC contact output

Relay output

Buffer output

Accelerometers, Atex certified
**Features**

Machine train diagram (24 machine train diagrams or less can be registered) current value summary

Trend graph: over all, GAP, 0.5X amp./phase, 1X amp./phase, 2X amp./phase, not 1X amp., and RPM

Bar graph: over all, 0.5X, 1X, 2X, Not 1X

Other graphs

Waveform, Spectrum, Lissajous, Vector plot, Orbit, S-V graph, X-Y graph, Transient trend, Transient Waveform/Spectrum, Transient Lissajous, Transient Lissajous and Waveform, Transient polar plot, Transient (bode diagram), Transient orbit, Trend during alarm, Waveform/Spectrum during alarm, system history, alarm history

With the latest analysis technology, online vibration analysis systems are capable of analysing and managing, all sorts of data essential for large rotating machinery, on personal computers. The software based on the WindowsNT™ platform allows easy operation and various analysis functions.

**InfiSYS RV200** has analysis view software that takes data out from the analysis module VM-742B and displays the same. It displays the set value, measurements, and the status of the analysis module and the analytical data.

**InfiSYS RV200** has diagnosis software that gives the health of the rotating machinery i.e. displays the reason for the internal faults. A malfunction cause is displayed in descending order of the factor as a result of diagnosis.

**Diagnosis possible malfunctions cause:** unbalance, permanent bow, lost rotor parts, misalignment, critical speed, rotor crack, nonsymmetrical rotor, gear inaccuracy, seal rub, oil whirl, oil whip, steam whirl/ seal whirl, cavitations, wing vibration, draft core, surging.
Remote Vibration Monitoring System (RVMS)

Need for 24X7 Vibration Monitoring for Machines
Currently, in many plants, the technical know-how of vibration monitoring is limited, which calls for specialised support and timely guidance to avoid emergency shutdown.

Forbes Marshall provides the solution for advanced remote vibration monitoring through an analysis software.

All the data related to vibration and process values of the machines are captured 24x7 at intervals as required by the user. So whenever we request for any data of any period, we will be able to get it. This will give the information of when the alarm had occurred and what was the fault i.e. abnormality in the machine.

Benefits
Remote monitoring through analysis software is effective for old and new power plants – starting from 1MW to 1000MW.

User can monitor and analyse the vibration of his rotating machinery very well, which will result in better maintenance of the machinery.

Dynamics of machinery like critical speeds, behavior of machinery in transient conditions like startup and shutdown will be better understood to pin point any abnormal condition.

Analysis and display functions i.e. machine trains, trend graph, spectrum, shaft center line position, bode/polar plot, orbit display, vector plot, alarm status, etc. The user can prevent any possible failure by taking corrective action.

This will eventually increase equipment availability and reliability and reduce costs.

Internet explorer via web connectivity can be used to see details anywhere globally on any PC or mobile.

It is used on any machine for any vibration analysis function requirement.

It gives advance information to customers on machine issues to avoid shut down. Experts use know how of multiple plants to guide plant O&M teams.

Vibration Consultancy Services Agreement (VCSA)

Proactive Care for Critical Rotating Machines
Imagine if you could monitor the health problems of critical rotating machines – even before the symptoms become evident.

A Forbes Marshall specialist will be promptly available at your doorstep to address the problem.

The Consultancy Services Agreement (CSA) is a suite of proactive asset care services tailored to your individual needs and designed to help you harness the full potential of the installed condition monitoring systems.
Our Expertise
Survey of rotating machines in your plants
Possible suggestions for vibration monitoring requirements
Vibration consultancy support for giving reports monthly / quarterly for critical machines and secondary critical machines
Right proposal to optimise the on line monitoring cost
Complete turnkey execution, engineering and documentation
Vibration analysis and diagnosis reporting for the right time to shut down to save cost. Customised condition monitoring and reporting plan for your plant.

Specialists Available On Call
When there is a problem, we can perform diagnostics and give you advice on the cause and how to fix it. We can provide this service, quarterly, monthly or on-demand.

Personalised Solutions for Individual Needs
With a complete knowhow of on-line vibration monitoring systems and machine details, we have developed the Vibration Consultancy (Vib Con), a unique service for customers in all types of industries. Through this service, we offer our clients remote vibration analysis and give reports for every critical rotating machine in the plant, by either remote monitoring of critical machines 24 X 7 and/or periodic measurements by visits to the plant for other critical machines such as large pumps, ID/FD/PA fans, centrifuges, large blowers, gear boxes, motors, crushers, compressors and other rotating machines.

Implementing predictive maintenance leads to a substantial increase in productivity (upto 35%), on the one hand preventing unpredicted shutdowns, while on the other, anticipating corrective operations so that they can be carried out under the best conditions.

Recommendations
We recommend the complete Machine Monitoring System as per system designed based on API 670. It should be globally proven and should have good service network and support.

We recommend accelerometers /Velometers for bearing vibration, Non contact type Eddy current sensors for Radial Shaft, Axial displacement, Rod drop, key phasor measurement and standalone Machine monitoring system equipment wise depending on criticality.

We recommend that all machine tripping must be taken from a reliable API 670 Design machine and MMS.

As far as possible there must be sensors upto JB in rotating machine OEMs scope and monitoring system with complete integration with owner or large EPC/PMC.

Supplier should have a proven track record in India for more than 2-3 years in refinery plant alongwith EIL (Engineers India Limited) approval.