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Mechanalysis-On-Line for Vibration Diagnostics and Protection of Hydro Power Generators

Author: Peter W. Hills, Dip. Man, MBA, FInstNDT, FInstDiag Engs
Managing Director & CEO

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1. Introduction

Hydro-electricity (Hydel) is a generic term for energy created by falling water. Dams hold back water creating a reservoir of potential power; a water gate lets it surge through a tunnel leading to the turbines which in turn spin electricity generators. Hydro-electricity has become more important today because it's a renewable energy resource that is far less harmful to the environment than traditional methods of generating electricity. The high capital investment is one that can provide returns for 50 to 100 years or more. Ensuring the plant is in an optimum mechanical and electrical condition calls for a condition based maintenance strategy. Maintaining on-condition is not only cost effective but also a management proactive tool. One prime condition monitoring measure is vibration, the ECG of industrial machinery health. Applying an on-line mechanical-analysis diagnostic system, associated with process data, provides management with essential information to optimise plant availability based on objective facts.

A condition based maintenance strategy enables Operations to better understand and predict the availability and operational life of Hydel machinery. The development of incipient faults, not obvious even to the experienced engineer's ear, are quickly identified and tracked. Shaft speed, the ratio of bearing housing mass to shaft diameter, the type of bearing, lubricating system, magnetic forces etc all influences a machine's time to failure. To ascertain the discrete condition of the rotating elements requires an array of sensors continuously measuring vibration & process events, to warn and alarm in real time as well as archive data for historical analysis.

Today's Hydel Managers are expected to have a clear understanding of their production process as well as the machinery to ensure optimum plant availability. Amongst the wide range of information tools is the proven Mechanalysis-On-Line Machinery Condition Monitoring Diagnostic system. Many of the condition management measurement techniques for Hydel machinery are not widely understood, often due to competing features marketed by vendors; this paper attempts to demystify the main issues.

2. Hydro Turbines Overview

There are a range of turbine types for different circumstances. The selection of the turbine depends upon the site characteristics, principally the head and flow available, plus the desired running speed of the generator and whether the turbine will be expected to operate in reduced flow conditions. Hydro Turbines can be crudely classified as high-head, medium-head, or low-head machines, as shown in the table below:

Turbine Type	**Head Classification**		
	High (>50m)	***Medium (10-50m)***	***Low (<10m)***
Impulse	Pelton Turgo Multi-jet Pelton	Crossflow Turgo Multi-jet Pelton	Crossflow
Reaction		Francis (spiral case)	Francis (open-flume) Propeller Kaplan

2.1. Impulse and Reaction Turbine Operations

Electricity generation usually requires a shaft speed as close as possible to 1500rpm to minimize the speed change between the turbine and the generator. Since the speed of any given type of turbine declines with head pressure, low-head sites need turbines that are inherently faster under a given operating condition. The faster a machine rotates its mechanical imperfections will become more evident such as vibration which is a function of the square of the speed. In the past Hydel plant would operate 24/7 but as countries develop a more integrated power strategy, turbines are often required for peak load and then are turned off at low demand situations. As a result many no longer run continuously; this constantly changing operating cycle creates new problems for machinery due to increased cyclic stresses that ultimately reduces the plant's useable life.

2.2. Control of Hydel Machinery

A typical control panel monitors the operation of the hydro scheme; the main functions are:

- Start up and shut down the turbine
- Synchronise the generator with the local network
- Monitor the upstream water level and ensure it is maintained above its minimum value
- Operate the flow-control valve to the turbine to match the availability of water
- Detect faults and activate warning or shut-down sequence such as **excess vibration**

On larger plants supplying three phase power, it is essential for the control panel to have the following displays:

- a voltmeter with a selector switch to read the voltage between phases and the line voltage
- an ammeter on each phase to measure current
- a frequency meter
- a kilowatt meter, for the instantaneous power
- a kilowatt-hour meter, for the energy generated over a period
- a power factor meter
- **a vibration protection monitor**

2.3. Typical Hydel Machinery Faults

Typical faults experienced in hydro machinery are: Shaft Alignment, Bearing Alignment, Mechanical Balance, Magnetic Balance, Magnetic Centre, Thermal Stability and Bearing Clearances, Stator Winding integrity etc. To identify such faults, detection systems may be functional or sophisticated depending on the duty and complexity of the machinery. Installing an array of sensors in new Hydel plant is often easier than existing installations, especially those associated with the stator windings. However, case mounted vibration sensors are non invasive and can be installed while the machine is operating. Eddy current proximity probes are also relatively straightforward to install but may have to be done during a major maintenance outage.

3. Condition Monitoring Strategies

Machinery condition monitoring in the 21st Century is shifting to more on-line diagnostics, intimately linked to plant processes and operations. Companies are realising that the practice of operating a small cell in an organisation doing 'break-down' vibration analysis can often be costly mainly due to expert staff turnover affecting programme continuity. The trend is now towards outsourcing such services or make use of an on-line consultant who has access to the raw data via the internet. Moving data and not people is much more cost effective if quality data is generated and accessible.

System Life Cycle is an essential business driver today, especially where consumer electronics like PCs etc are often considered obsolete in just three years! When managers select a Machinery Fault Analysis System, they will want one that is sustainable and provides long term user value. The facts of modern life are that all computerised diagnostic systems will have a limited life. However, this should not also apply to the prime machinery protection system measuring for warning and alarm/shutdown. Buyers must insist on spares and maintenance support from 15 to 20 years as a basic supply requirement.

Selecting an electronic protection system that is interdependent such as a slave and master is a limiting arrangement. Those systems where the master monitor sends processed data to the slave analyser ensues early obsolescence of the whole system. An architecture that separates the Plant Protection Monitor (warning & alarm) allowing the Diagnostics to complement the system has a greater longevity and will prove a better investment in the long term. It also means original raw data is available for meaningful analysis whereas the master/slave configuration is limited.

Applying **condition monitoring strategies** to capital intensive Hydel plant is a proven formula towards better and objective life cycle analysis. The Mechanalysis-On-Line system based on vibration and process parameters will contribute towards this prime objective. However, there are complementary detection methods that may or may not apply depending on the duty of the generator and its relationship to the electrical grid. The more remote Hydel systems are designed to provide for the local region and hence need to run constantly and so need only vibration monitoring. For machines constantly changing duty, measurement parameters such as air gap, flux and capacitive discharge etc may apply but these phenomena also result in higher vibration which in any case is detected by the main system. The additional measurements often require specialist diagnostics data capture system to identify the subtle changes over a long time. The various condition monitoring systems for Hydel are now outlined as follows.

3.1. Air Gap Monitoring:

The stator rotor air gap is this is where mechanical energy is converted into electrical current and is a useful parameter to help ascertain structural weakness and or strength. An unbalance air gap can cause split phase current, stress on rotor and stator, vibration and local overheating which decrease a unit's efficiency. It consists of an array of low profile sensors (from 4 to 16 according to machine configuration) fixed to the upper plane of the stator wall. Data can be visualized in rectangular, polar, and spectral fashion.

3.2. Magnetic Flux Monitoring:

The system detects magnetic field imbalances which also manifests as **vibration** and stator overheating. The magnetic flux emanating from each rotor pole is measured to help define whether the cause of variation is electrical or mechanical. A low profile sensor is fixed to the stator wall providing data for analysis. Mechanalysis (India) Ltd has installed around 30 stator end winding (SEW) monitoring systems in India. This is a long term machine life cycle investment but National Power of the UK are now using the SEW to indicate the success of 'tightening' the stator windings say every three years. The reduction in vibration gives assurance that the maintenance work on the stator has been successful.

3.3. Partial Discharge:

Often asked for but like magnetic flux monitoring it is primarily an indicator of the state of winding insulation. Capacitive sensors are likewise located in the windings. There are many claims as to its benefits that may become relevant for plants that operate on and off as load varies. However, the partial discharge system is still considered by many to be experimental.

3.4. Vibration Monitoring System (VMS):

The three basic facts of rotating machinery are:

1. All machines vibrate
2. An increase in vibration suggests a developing fault
3. Each rotating element generates its own unique vibration signal

It is a proven fact that vibration measurement is the most sensitive to machinery status and an increase is the earliest indicator of impending trouble. Most machinery is maintained by mechanical engineers who have to contend with many parameters such as material expansion while setting a machine. In spite of a range of high technology tools, precision measuring devices such as lasers etc, only when the machine is actually rotated can its' smooth running condition be fully determined. The effects of magnetic imbalance, incorrect air gap and mechanical inaccuracies will result in varying levels of vibration. As such, employing a VMS is the prime requirement for every Hydel installation.

Vibration is the cyclic or oscillation motion of a body or component from its position of rest or its neutral position. Whenever vibration occurs there are four forces involved that determine the characteristics of vibration. They are:

1. The exciting force such as unbalance, misalignment, magnetic imbalance
2. The mass of vibrating system
3. The stiffness
4. The damping characteristics

The characteristics that define vibration, and are needed to understand the behaviour of vibrating machinery. The three prime key parameters are:

1. **Amplitude** (how much?) i.e. Displacement (microns), Velocity (mm/sec), Acceleration (g)
2. **Frequency** (how often the signal moves back and forward) Hz or CPM (cycles per minute)
3. **Phase** (the time relationship between vibrating forces)

When the three prime parameters are coupled with a machine's speed, load and effects of the process, a more precise diagnosis becomes possible. When applied to case or shaft mounted sensors on rotating machinery the selected measurement unit is determined by the rotor speed or frequency of the machinery elements. A general guide is as follows:

Measurement Units	Definition	Units	Machine Speed Range in CPM
Displacement	The total distance a mass travels back and forth as it vibrates	microns peak-peak	<600
Velocity	A measure of how fast the mass is moving back and forth.	mm/sec Peak or RMS	600 - 120,000
Acceleration	The rate of change of velocity	g's	120,000

4. Vibration Protection Monitors and Sensors

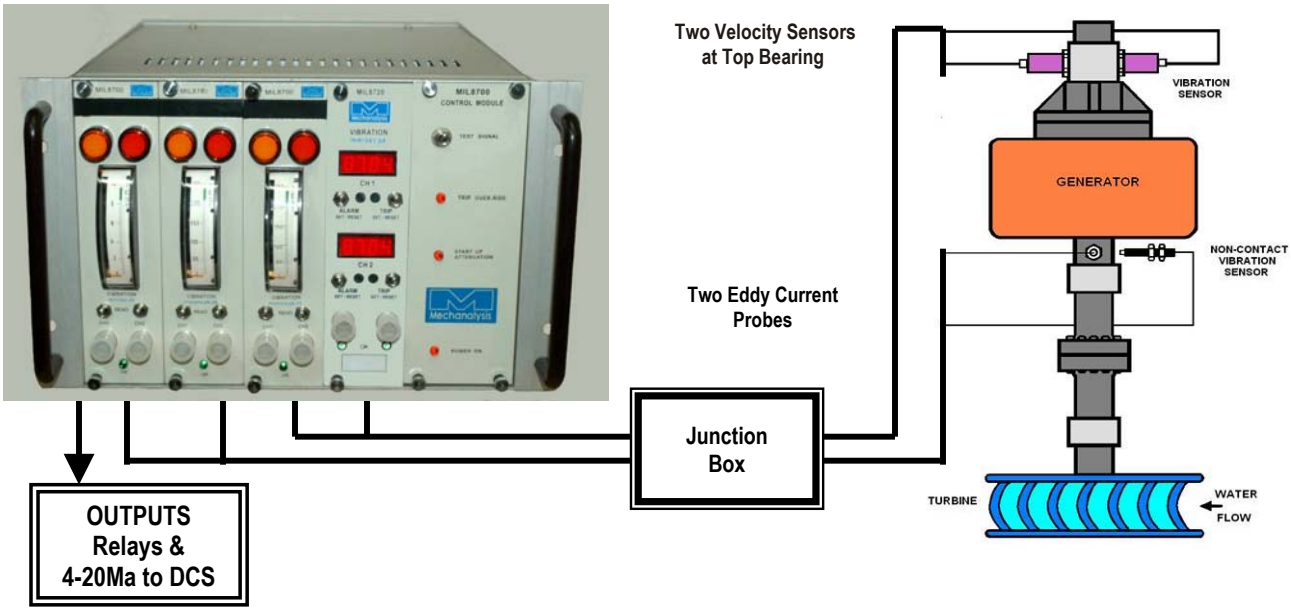
Due to the nature of Hydel machinery, vibration measurements are best taken with permanently mounted sensors. Like any prime measurement, the sensor's ability to transfer the optimum signal is fundamental to the success of the system; mounting vibration sensors requires particular attention. The more difficult non contact eddy current probes are usually installed by the suppliers. Case or surface mounted sensors (inductive velocity or accelerometers) can be fitted by C&I engineers or contractors. Unless the sensors are installed to specification, the system will not deliver the protection and diagnostics required. False alarms and misleading signals are common with poorly located sensors with users often blaming the measuring instrument quite unjustifiably.

Establishing the optimum signal from a bearing to the outer casing can often be a trial and error exercise depending on the bearing's housing construction. In all cases, on-line permanent stud mounted sensors in the horizontal, vertical axial positions related to the rotating shaft centre line will give the optimum performance. Sensors that are mounted in different planes are more sensitive to certain faults than others but there is a certain degree of signal cross over. Below is a guide to the primary and secondary indications.

Orientation / Plane	Primary Indication	Secondary Indication
Horizontal 90°	Unbalance	Alignment, Looseness, Gear Meshing
Vertical 0° to 180°	Looseness	Unbalance, Alignment
Axial	Alignment	Unbalance, Gear Meshing
Dual Sensors 45°	Unbalance, Shaft Position	Looseness, Alignment

4.1. The Basic Monitor System Architecture

A typical Frances Turbine would have the minimum number of sensors positioned as shown below:



Eddy Current Probe for Shaft Position

The illustrated eight channel monitor (4 dual channel modules) is specifically designed for Hydel Monitoring; it requires less panel space with its 254mm (10") rack. At turbine's the top bearing, case mounted velocity sensors indicates either Velocity or Displacement; detecting out of balance caused by mechanical or electrical effects. Shaft position measurement is achieved by the centrally positioned eddy current probes (ECP) set apart at 90° angle. If associated with diagnostic software, shaft centre line and orbits indications are possible. If there is access, the lower bearing can also be monitored with case or ECPs. Spare channels are available for additional vibration sensors speed, temp etc. A typical velocity sensor, sealed to IP65 and suitable for the speed range yet giving a linear output throughout its frequency range is illustrated as is an eddy current probe at the turbine shaft.

Inductive Velocity Sensor

An alternative to the panel mounted rack monitor is the Machinery Data Transmitter which also has warning and alarm relays and converts the vibration signal to 4-20mA. This is usually transmitted to a Distributed Control System (DCS). While the MDT is a low cost solution, (reduced cable costs etc) the MDT output signal does not allow remote analysis of the raw vibration signal as in the case of the Rack system with its buffered BNC outlets per channel.

An even lower cost solution is the loop powered Accelerometer system that, unfortunately, is often promoted by instrumentation engineers since they are comfortable with their traditional 4-20mA DC standard. However, since vibration is an AC signal it needs to be treated differently. Only those Machinery Signal Transmitters (MST) that offer both 4-20mA and buffered time waveform signal for on-line diagnosis can be considered suitable for strategic machinery.

4.2. How to Select a Vibration Measurement System

The following summarises the questions a manager needs to ask when proposing a condition management solution for an organisation new to the technology:

Objectives, Budgets, Skills, Needs	System Capabilities
What do we want to achieve?	On-Line Monitoring (warning, alarm & shut-down by operator decision)
Budget for equipment & Training?	On-Line Protection (strategic & high speed requiring automatic alarm & trip)
Core competency? Knowledge level?	On-Line Diagnostics (associated with Protection System)
Number & type of machines to be monitored?	Networking data (distributed to DCS and Operator Displays)
Integration with plant processes, computerised maintenance management systems (CMMS) ?	Vibration and performance monitoring software (for machine life cycle analysis)

The most important aspect when selecting a condition monitoring system is that it must be part of an overall company strategy to improve plant availability. It must also have the commitment of executive office, operations and maintenance managers as part of the company strategic plan. Whichever system is selected, it will not return the benefits or expectations of all parties as it will be seen as a gadget and viewed in isolation of the main business activities.

This paper now focuses on the predictive capabilities of a Mechanalysis-On-Line vibration based condition monitoring programme for Hydel plant.

5. Mechanalysis-On-Line Multi-channel Machinery Diagnostics

An effective multi-channel on-line diagnostic system is the integration of hardware and software to measure machinery performance 24/7 in real time. It will present easily recognisable information on machine status to enable Operators to take preventative decisions. Raw data is continuously captured and stored so that Machinery Diagnostic Engineers can study steady-state, machinery start-up and post trip conditions in order to pinpoint incipient machinery or process faults. Not all diagnostic systems are intended for 24/7 data capture and can be moved around the plant for investigative or research purposes. This portability offering flexibility is a cost effective solution for many budget conscious users.

The price/performance of on-line diagnostics systems has improved markedly over recent years. The price per measured point now makes the choice for an on-line diagnostic system a practical proposition. Systems offer high quality information and greater user value than ever. Both Operations at the Central Control Room (CCR) and Maintenance can have customised networked data available 24/7 to suit their specific requirements. Headquarters also has access to any or all data for strategic analysis purposes.

The power of the Mechanalysis-On-Line system give the capability to monitor almost limitless number of Hydel machines at one site and brings the data to the Operators desk as well as maintenance managers.

5.1. On-Line Vibration System Strengths and Weaknesses

The strengths and weaknesses of a Mechanalysis-On-Line Multi-channel System are not exhaustive but the main issues need to be appreciated as they will influence the purchase decision.

Strengths

1. High quality data available for machinery analysis
2. Data collection automatic and continuous
3. Consistent data collection
4. Instant alarms machine faults
5. Amp, Freq, Phase, load collected
6. Very powerful analysis capability
7. Links with other process data
8. Data a is distributed to DCS
9. Visible to Operations & remote services
10. Works with or without protection monitors
11. Ideal for plant life assessment

Weaknesses

1. Measurements limited to number of installed sensors
2. Needs installed sensors wired to CCR
3. Economic with critical machines
4. Analysis can be complex
5. Requires skilled diagnostician or a remote service
6. Cost per measurement point
7. Can be a relatively high initial investment

5.2. Criteria for Hardware & Software Selection

A guide to selecting both hardware and software is always difficult to establish but the following criteria covers the main elements.

Hardware

1. Proven reliability
2. Flexibility for addition of on-line inputs
3. Relative cost to machinery investment
4. Ease of use hardware with software
5. Frequency & Dynamic range
6. Measurement parameters
7. Operation & Display types
8. Transducer types & interface
9. Phase & Speed reference inputs
10. Data communications
11. Number of years spares available
12. Upgradeability
13. Local support services with core competence
14. Obsolescence policy and process

The Software

1. It must have standard functions & features for ease of use
2. Defines what type of data is collected
3. Defines how dynamic & process data is collected
4. Records process information
5. Will have intelligent alarming that automatically generates reports
6. Distributed data available for all to view of plant condition
7. Data export capability for analysis of process performance
8. Hard copy reports easy to generate
9. Links with CMMS
10. Exports data to other plant performance management reports
11. Number of years supported
12. Upgradeability
13. Local or web support ensures response and reduced risk
14. Obsolescence policy and process

5.3. System Description

As part of Mechanalysis (India) Ltd's (MIL) 'Systems Integration' business strategy, the company has partnered with Beran Instruments Ltd of the UK. Their synergy of products and complementary strategic business fit offers Indian industry an unrivalled opportunity. MIL provides a widely proven and economic Protection Monitor System with Alarm and Trip capability. Designed and manufactured in India, its appropriate technology offers outstanding reliability. Beran completes the picture with its highly proven and comprehensive Multi-channel Condition Monitoring Diagnostics system. These complementary condition management solutions can also be supplied individually as both products will integrate with most third party systems. They do not operate to the usual Slave and Master architecture but gives extra redundancy. Should one system fail, the second continues to provide protection by issuing warnings to operations. This parallel processing architecture means a much longer operating and support life for spares etc.

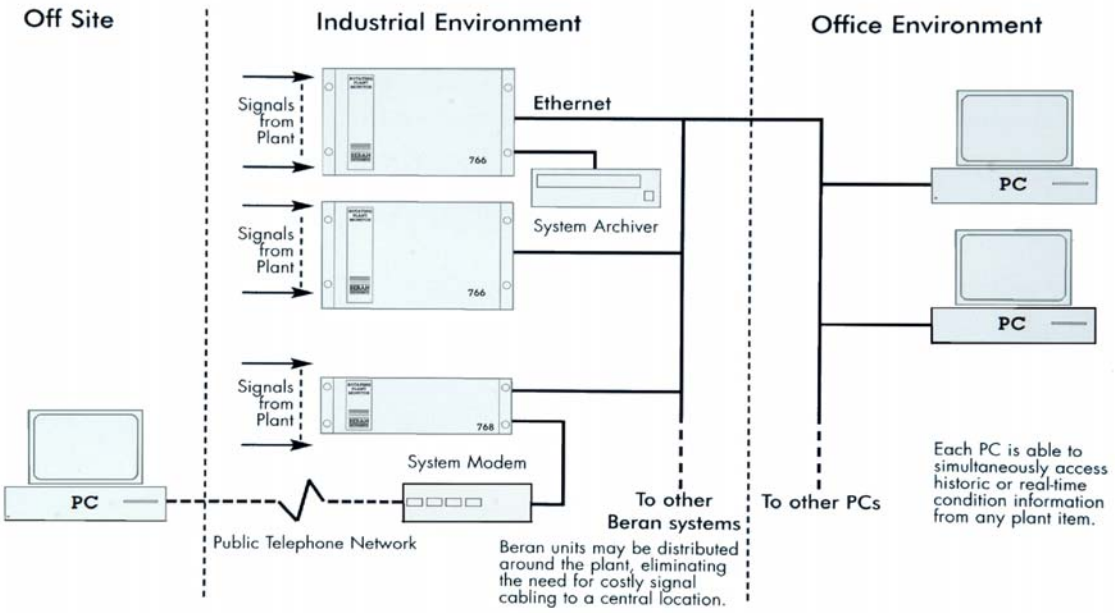
The key features are addresses the following:

User Man Machine Interface	**Data Handling**	**Effective Functionality**
Easy to use and configure Software	Fast data capture	Powerful alarm functions
MS Windows-based user front end	Comparison of real-time data with historic	Automatic plant-state detection
LAN, WAN or Dial-Up compatible	Remote access to real-time & historic data	Expandability through modular design

Unless these prime features are available the multi-channel on-line system will not deliver the desired outputs.

5.4. Open Communications

A key requirement of modern systems is open and net-workable communications as shown in the schematic below. It enables multiple machinery to be monitored in real time and able to capture data on all machines at the same time in the event of a complete plant trip as well as machine start up routines. The system speed is not compromised during this multi-tasking situation.



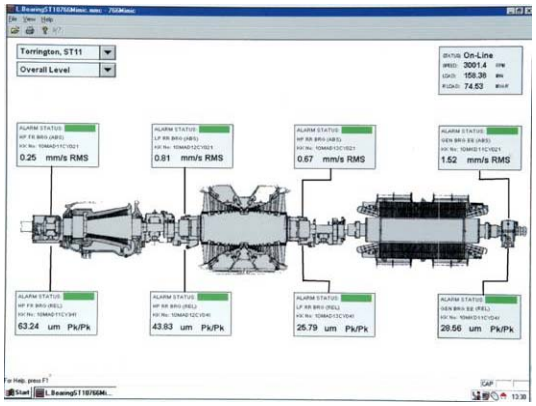
Network Architecture – LAN or WAN and Modem Access

Fully Net-workable, communications on LAN or WAN, the system is available on a building block arrangement. Additional units can be added as the need arises without compromising the system performance. Subsequent data acquisition devices do not require repeat software modules as that initially purchased can be extended as the site system expands. Static data can be transmitted by serial link to the Beran unit thus saving wiring costs and simplifying data exchange.

5.5. Diagnostic Information Outputs

Customised MIMICS are available with Operator access to real-time or alarm log views. Operations have access to machine status reports to suit their requirements. Maintenance and Diagnostic engineers or a remote Support Services can study issues in greater depth at any time, particularly when comparing current with historical data. An important requirement of any system is that it provides decision making information and not simply data.

1. MIMICS – Customised Man Machine Interface
2. Windows Familiarity – User Friendly.
3. Context Sensitive Set-Up, incorporates a Help Wizard
4. Bargraph/Histogram: current overall values for 16 channels
5. Single bearing order, magnitude & phase with plant load to time
6. Reconstructed Orbits across 4 bearings Waterfall
7. FFT waterfall with average historic & real-time
8. Run-up of single bearing in polar format with vector change etc.
9. Multi-plots – 3 bearings with respect to machine speed using 'Y' axis
10. FFT with zoom along 'Z' axis

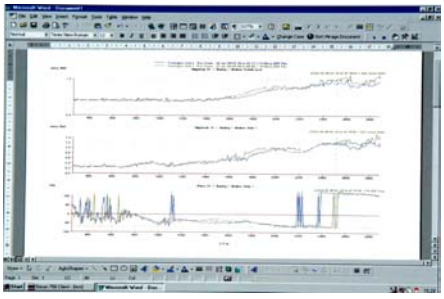


Plant Operator MIMICS

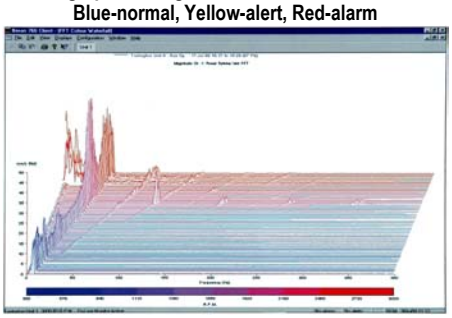
5.6. Selected User-Definable Graph Displays

It is often said a picture tells a 1000 words, the selected screens below could indeed justify a 1000 words but the purpose of this paper is to expose the Manager to the variety and power of the Mechanalysis-On-Line diagnostic system outputs. The following are a small example of the almost limitless number of selections possible.

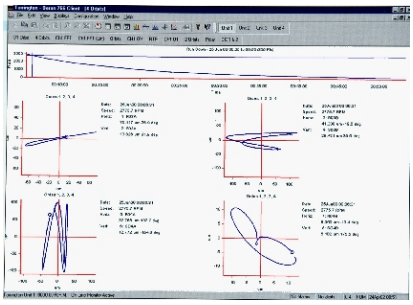
Bargraph / Histogram : current overall values
Blue-normal, Yellow-alert, Red-alarm



Bode plots, Load and Phase



Waterfall Display
Colour parameter changes with speed



Orbits
Can also be Reconstructed

6. The Benefits of Mechanalysis-On-Line Condition Monitoring Diagnostics

The benefits of multi-channel diagnostics are many, primarily, is the greater Operator confidence in strategic machinery health and consequent increased plant availability. Advanced warning of component failure and accumulating machinery behavioural trends for optimising production and system design are readily realised. Subsidiary features of the diagnostic system are summarised:

1. High quality data available for strategic machinery analysis
2. Historical data can be reconstructed e.g. Orbits
3. Automatic un-attended data acquisition
4. Links with other process data for overall efficiency life cycle optimisation and incident analysis
5. Consistent comparable data for analysis
6. Data is distributed to DCS
7. Alarms machine faults instant to Operator's displays
8. Amp, Freq, Phase, load collected - overcomes false alarms
9. Works with protection monitors or independently
10. Rebuild historical data to compare with current for detailed comparisons and change
11. Very powerful analysis capability – pre & trip fault review
12. Ideal for plant life assessment

7. Future Trends for Condition Monitoring of Hydel Machinery

Industry is fast recognising that multi-channel on-line diagnostics is more dependable and consistent than off line vibration analysers for strategic machinery. Plant life cycle analysis is now an accepted tool for long term business planning. As Operations and Maintenance organisations are converging; distributed data assists this process. Remote analysis by experts operating from central or back offices will evolve as confidence is gained, even though the technology and service exist today.

"With Mechanalysis-On-Line Condition Monitoring Diagnostics, the Plant Manager will be in control of events rather than the other way round."

References:

Hills P. W. (2001) - *Condition Management Review – Russia NDT World March 2001*

Dunn S. (2002) - *Condition Monitoring in the 21st Century – The Plant Maintenance Resource Centre, Australia*

Hewitt G. (2003) - *Smart Condition Monitoring at Power Technology Ltd UK – Beran Technical Report*

Hills P. W. (1996) - *Production Benefits from a Vibration Based Condition Monitoring Programme - Indo-US Symposium on Emerging Trends in Vibration and Noise Engineering Delhi, India*

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Mechanalysis (India) Ltd

30 Years in Power

A Partnership for Power Users

The Mechanalysis Approach

Getting you started

Keeping you going

Taking you further

Mechanalysis (India) Limited
Reg. Office: 47-48 Jolly Maker Chambers II, Nariman Point, Mumbai, 400 021, India
Tel.: +91(22)2202 7430 Fax: +91(22)2285 0480 www.mechanalysisindia.com