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Mechanalysis-On-Line Protection of Small Hydro Power Generators

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1. Introduction

As the World becomes more aware of global warming Hydro Electric Plants are becoming a more important contributor. Despite the negative aspects of taking up land, the positives outweigh these through flood control, irrigation when you need it and environmentally clean electric power generation.

The hydroelectric generator differs from thermal units in that it generally runs at slower speeds and has a considerably long life cycle. To ensure continuous and reliable performance one important measure is the level of vibration it develops.

It is a well know fact that all machines vibrate and each rotating element generates its own unique frequency. By detection, analysis and correction vibration techniques the hydroelectric machine's performance and maintenance periods are optimised.

This paper briefly describes the types of hydro turbines and then outlines typical faults related to the Smaller Hydro Electric Generator used in rural installations in India. It discusses the benefits of operating a vibration condition monitoring and protection system and its importance in prolonging the hydro turbine life cycle. A glossary of the main terms is appended to assist the reader.

Overview: Hydroelectricity is a generic term for energy created by falling water. For instance, hydroelectric dams hold back water, creating a reservoir of potential power. A water gate lets it surge through a tunnel leading to turbines. The water turns the turbines which in turn spin electricity generators. Hydro-electricity is very important because it's a renewable energy resource that is far less harmful to the environment than traditional methods of generating gas and electricity.

There is often confusion as to which type of turbine should be used in 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.

2. Hydro Turbines

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

Impulse and Reaction Turbines: 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, low-head sites need turbines that are inherently faster under a given operating condition

2.1. Types of Turbines

Turbines are also divided by their principle of operation and can be either **Impulse** or **Reaction** turbines.

The rotor of the Reaction turbine is fully immersed in water and is enclosed in a pressure casing. The runner blades are profiled so that pressure differences across them impose lift forces, just as on aircraft wings, which cause the runner to rotate. In contrast an Impulse turbine runner operates in air, driven by a jet (or jets) of water.

2.2 Impulse Turbines

There are 3 main types of Impulse turbine in use:

1. Pelton
2. Turgo
3. Crossflow (or Banki) turbines.

Pelton Turbines consists of a wheel with a series of split buckets set around its rim; a high velocity jet of water is directed tangentially at the wheel. The jet hits each bucket and is split in half, so that each half is turned and deflected back almost through 180°. Nearly all the energy of the water goes into propelling the bucket and the deflected water falls into a discharge channel below

Turgo Turbines are similar to the Pelton but the jet is designed to strike the plane of the runner at an angle (typically 20°) so that the water enters the runner on one side and exits on the other. Therefore the flow rate is not limited by the discharged fluid interfering with the incoming jet (as is the case with Pelton turbines). As a consequence, a Turgo turbine can have a smaller diameter runner than a Pelton for an equivalent power.

Crossflow Turbines have a drum-like rotor with a solid disk at each end and gutter-shaped “slats” joining the two disks. A jet of water enters the top of the rotor through the curved blades, emerging on the far side of the rotor by passing through the blades a 2nd time. The shape of the blades is such that on each passage through the periphery of the rotor the water transfers some of its momentum, before falling away with little residual energy.

2.3 Reaction Turbines

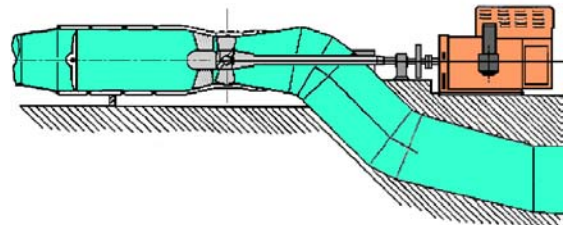
These turbines exploit the oncoming flow of water to generate hydrodynamic lift forces to propel the runner blades. They are distinguished from the impulse type by having a runner that always functions within a completely water-filled casing.

All reaction turbines have a diffuser known as a ‘draft tube’ below the runner through which the water discharges. The draft tube slows the discharged water and reduces the static pressure below the runner and thereby increases the effective head.

The two main types of Reaction Turbine are:

1. Propeller (with Kaplan variant)
2. Francis

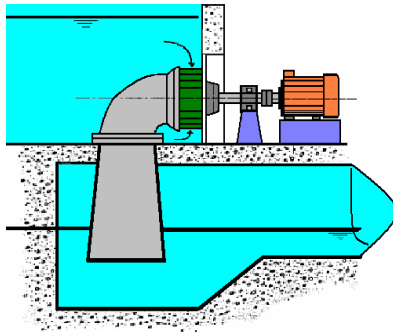
Propeller-type Turbines are similar in principle to the propeller of a ship, but operating in reversed mode. Various configurations of propeller turbine exist; a key feature is that for good efficiency the water needs to be given some swirl before entering the turbine runner. With good design, the swirl is absorbed by the runner and the water that emerges flows straight into the draft tube. Methods for adding inlet swirl include the use of a set of guide vanes mounted upstream of the runner with water spiralling into the runner through them. Another method is to form a “snail shell” housing for the runner in which the water enters tangentially and is forced to spiral in to the runner.



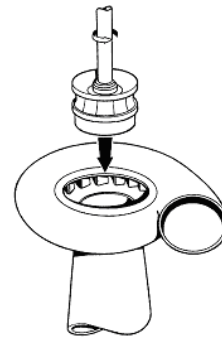
When guide vanes are used, these are often adjustable so as to vary the flow admitted to the runner. In some cases the blades of the runner can also be adjusted, in which case the turbine is called a *Kaplan*. The mechanics for adjusting turbine blades and guide vanes can be costly and tend to be more affordable for large systems, but can greatly improve efficiency over a wide range of flows.

Francis Turbines are essentially a modified form of propeller turbine in which water flows radially inwards into the runner and is turned to emerge axially. For medium-head schemes, the runner is most commonly mounted in a spiral casing with internal adjustable guide vanes. Since the cross-flow turbine is now a less costly (though less efficient) alternative to the spiral-case Francis, it is rare for these turbines to be used on sites of less than 100 kW output.

The Francis turbine was originally designed as a low-head machine, installed in an open chamber without a spiral casing. Thousands of such machines were installed in the UK and the rest of Europe from the 1920s to the 1960s. Although an efficient turbine, it was eventually superseded by the propeller turbine which is more compact and faster-running for the same head and flow conditions. However, many of these 'open-flume' Francis turbines are still in place, hence this technology is still relevant for refurbishment schemes.

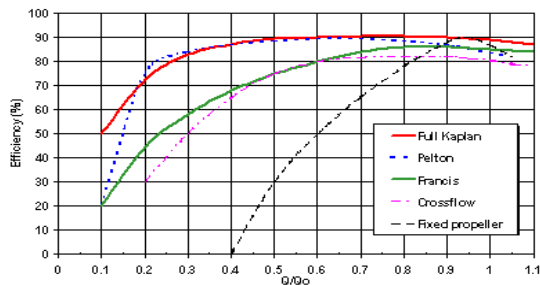


SPIRAL-CASE FRANCIS



OPEN-FLUME FRANCIS

A significant factor in the comparison of different turbine types is their relative efficiencies both at their design point and at reduced flows. Typical efficiency curves are shown below:



Part-flow efficiencies An important point to note is that the Pelton, Crossflow and Kaplan turbines retain very high efficiencies when running below design flow; in contrast the efficiency of the Francis turbine falls away sharply if run at below half its normal flow, and most fixed-pitch propeller turbines perform poorly except above 80% of full flow.

2.4 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**

2.5 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. However the small and micro hydro operator is unlikely to be able to justify the investment or indeed afford a relatively sophisticated vibration monitoring system. Whilst the trend is now towards outsourcing services by making use of a vibration analyst, such services are generally needed at the commissioning stage and when indications of machinery trouble need in depth understanding.

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.

Specifically for mini and micro hydro plant in rural India, appropriate technology has to be kept in the mind of the designer and plant vendor. Also such systems should be affordable and supportable in India at short notice.

3.1. 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. Pioneering Condition Based Maintenance (CBM) in India

In 1974 the company commenced trading in India as a joint venture but is now 100% Indian owned. For over 30 years Mechanalysis (India) Ltd (MIL) (formerly IRD) pioneered condition monitoring techniques towards the zero maintenance objective in India. MIL is largely credited with training the Nation for improved productivity by optimising machinery availability through a vibration analysis programme. MIL has now evolved to become a System Integrator by global sourcing and local manufacturing a range of portable vibration instruments, protection monitors and supplying on-line multi-channel diagnostic systems.

MIL provides consultancy and sales support from Delhi, Kolkata, Mumbai and Chennai. The recent remodelling of the National Service Centre, Manufacturing Works and Administration in Mumbai and new state of the art 'All India Sensor Calibration Service' reflects the commitment MIL has made to ensure customer value.

5. Vibration Protection Monitors and Sensors

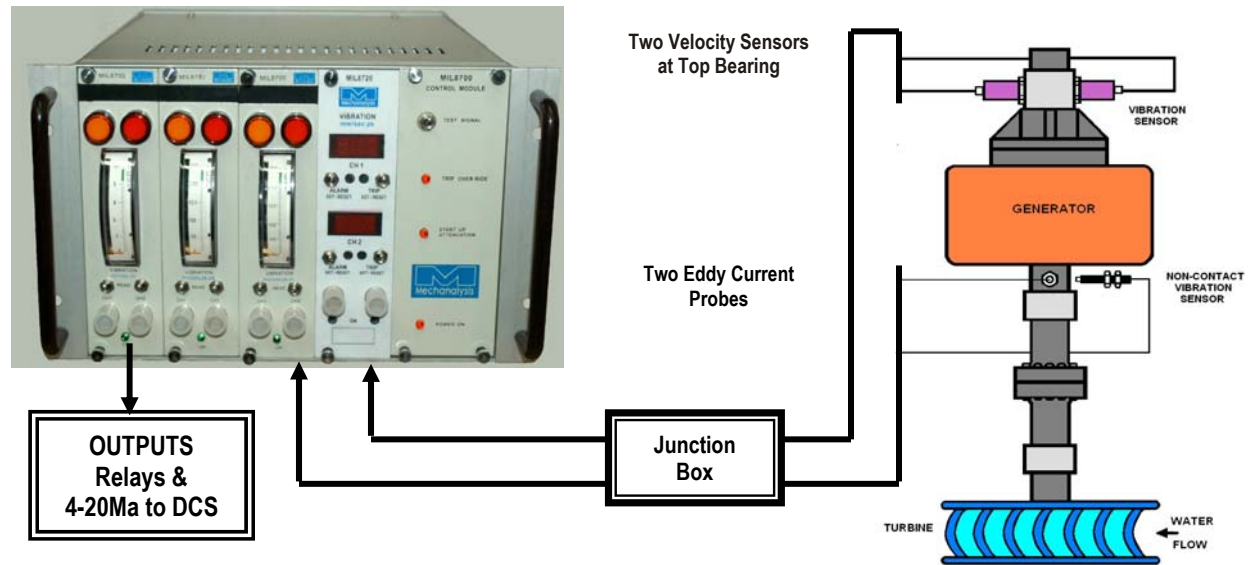
Due to the nature of Hydel machinery, vibration measurements are best taken with permanently mounted sensors. Like any prime measurement, the sensor's ability to transfer the optimum signal is fundamental to the success of the system; mounting vibration sensors requires particular attention. The more 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

5.1. The Traditional Hydro Monitor System Architecture

A typical Francis 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

5.2. Low Cost Mechanalysis-On-Line

The above arrangement is suitable for the larger turbine installations but for the lower budget mini and micro installation and those existing units that would benefit from more objective technology there are appropriate technology solutions.



Some installations that have no monitoring will benefit by just a single channel of measurement. Even measuring just one bearing point will indicate the out of balance state of the rotor and any influencing factor. The model MIL1224 or MIL1225 measures in displacement and velocity respectively. The unit is sold as an ‘Engineered Package’ complete with sensor, cable, mounting kit and the instrument for under 50,000 rupees. It has warning and trip relays as well as a 4-20mA output for a recorder. It consists of basic integrated circuitry without a microprocessor making it easily maintained by even a local radio technician. Further its robust circuitry will survive the harsh power fluctuations whereas the microprocessor needs more stabilised power supply. However, its performance over the past 30 years has shown the unit and sensor to be highly reliable requiring little if no maintenance. It would be advisable for it to have a calibration check made from time to time. The analogue display meter is time proven and easy to read. It also has the advantage of indicating any fluctuations that are not easily determined by the digital meter. The complete package is suitable humid environments up to 95% non-condensing.

5.2 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.

6. Installation & Commissioning

Although it is understood that skilled engineers will install and maintain mini and micro Hydel plant, getting the best from a vibration monitoring system may require assistance from the supplier. However, the basic single channel vibration monitor is supplied as a complete engineered system with all components and detailed installation instructions and schematics. The major challenge is the positioning and secure mounting of the sensor, the rest is straight forward. An electrician should easily be able to install the system.

Once installed, portable vibration analysis instruments should be used to produce a baseline machinery signature that will illustrate the status of the installation (whether good or bad) and provide a reference for the future. System vendors should be able to provide such a service.

For more complex installations a multi-channel simultaneous on-line diagnostic machinery analyser should be applied. This more advanced specialist tool requires expertise that is available in India and is advisable when seeking the relationship between vibration, speed, load and bearing temperatures etc.



Typical Vibration Analyser / Balancer

7. Summary

This paper has discussed some of the more proven hydro electric technologies that are in use all over the world. Selection depends on the head and volume of water and so with a vibration monitoring system selection of the system sophistication and options are available. The rural mini and micro hydro electric plant will however have two prime characteristics: low generation capacity and cost. Mechanalysis-On-Line is an appropriate solution with technology that matches the end users technical and commercial needs. However, Mechanalysis can take the user further with state of the art Multi-Channel On-Line Condition Monitoring Diagnostics. Whichever is the appropriate application to the machinery both enables the Plant Manager to be in control of events rather than the other way round.”

References:

Hills P. W. (2006) - Mechanalysis-On-Line for Vibration Diagnostics and Protection, of Hydro Power Generators, National Seminar-'Challenges in Hydro Power Generation' 16-18 March, 2006, at Chandigarh (iiPE)
 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
 D. E. Franklin (1982) - Hydro Electric Generating Unit Vibration Monitor for Bearing Protection and @Rough Load Zone@ Indication. R&D B. C. Hydro & Power Authority Canada Sept1982
 D. L. Bernhard (1987) - Vibration Monitoring Equipment and Systems for Predictive Maintenance of hydro Electric Plants, IRD Mechanalysis Inc. USA, Jan 1987

Glossary of Selected Terms for Hydro Power Generators

Capacity factor	The ratio of energy output per year to the maximum output if the system runs at full rated capacity all year round.
Flow Duration Curve	A graph showing the percentage of time that the flow at a particular gauging station equals or exceeds certain values.
Gross Head	The difference between the upstream and downstream water levels.
Headrace	The channel that forms the inlet to a turbine.
Installed Capacity	The total maximum output (kW) of the generating units in a hydropower plant.
Kilowatt (kW)	Unit of power, equal to 1000 watts
Kilowatt hour (kWh)	Unit of electrical energy, equal to the electricity supplied by 1 kW working for 1 hour. 1 kWh = 3600 Joules
Net Head	The pressure head available to the turbine after friction losses through the intake and trash rack.
Output	The amount of power (or energy depending on definition) delivered from a piece of equipment, station or system.
Penstock	A pipe (usually steel, concrete or plastic) that conveys water under pressure from intake to turbine.
Sensor Velocity	A vibration sensor that measures Velocity in mm/sec which is easily integrated to Displacement in microns.
Sensor - Non Contact	Uses eddy current to measure the relative varying air gap between shaft and bearing
Sluice Gates	A vertical shaft slide gate, which can be operated either manually or by electric motors (there are other types).
Spillway	A controlled discharge of excess flow back into the river.
Tailrace	The channel that takes flow away from the turbine outlet
Turbine	A machine converting the speed and/or pressure of flowing water into rotational energy.
Vibration Protection Monitor	A shaft/bearing vibration measuring device with warning and alarm/trip relays to protect the machine from self destruction
Vibration Measurements	Hydro plant rotor vibrations are usually measured in microns displacement peak to peak. This indicates the amount of mechanical movement
Weir	A low dam which is designed to provide sufficient upstream depth for a water intake while allowing flow to pass over its crest.

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