Measurement Types in Online Machinery Monitoring

Online machinery monitoring for rotating equipment is typically divided into two categories: **Protection Monitoring** and **Prediction Monitoring**.

The measurement types for protection monitoring somewhat overlap with those used for prediction, but there are many differences. The division between whether protection monitoring or prediction monitoring is applied to a rotating asset depends on the criticality of the asset and the maintenance philosophy of the company that runs the asset. In general, rotating assets can be thought of in terms of their criticality to keep the process running and productive.

The asset pyramid shows the typical criticality distribution of rotating assets in any plant. Usually only the critical, essential, and more expensive important assets are considered for online monitoring. In addition to criticality, the type of component measured is another important factor in determining measurement type. For example, rotating assets have two general classes of bearings:

1. **Antifriction bearings**
2. **Fluid film sleeve bearings**

The most frequently used for online monitoring are measurement types one through seven and sometimes eight (surface temperature only). In some processes that have fluid flow, dynamic pressure pulsations analysis helps in understanding the process assets.
Measurement Types in Online Machinery Monitoring

Not all assets require or have all these measurement types. In the case of critical assets such as large steam turbines, guidelines such as the API 670 specification are considered the standard for fulfilling the correct protection for those assets.

Protection Measurement Types

- **Shaft Vibration** (relative)
- **Shaft Vibration** (absolute)
- **Bearing Vibration** (relates to prediction monitoring)
- **Position Measurement**
- **Eccentricity**
- **Phase** (reference pulse, relates to prediction monitoring)
- **Differential Expansion**
- **Valve Position**
- **Speed Measurement** (acceleration, direction, and more)
- **Axial Position Protection**
- **Process Variables**
Shaft Vibration (relative)

This measurement type is always done on a fluid film sleeve bearing and is supplied using eddy current sensor technology. For each monitored bearing there will be either one or two eddy current sensors mounted radially. If there is just one eddy current sensor per bearing, it will usually be located exact top center on the bearing (Figure 3 and Figure 4). If two eddy current sensors are used, they are usually mounted 90° apart at the 10:30 and 1:30 clock positions on the bearing (Figure 5, Figure 6, Figure 7). When using the two sensor dual-channel mode, the orbit of the shaft can be recorded (Figure 2).

Eddy current sensors require converters to power them and to convert their output to the correct scaled voltage data per displacement unit, typically mV/micron or mv/mil. An eddy current sensor with its cable and converter all together form a chain and should be calibrated together to ensure the highest accuracy displacement measurement. The eddy current sensor chain output is always measured in terms of displacement as shown in Figure 4 through Figure 7.
MEASUREMENT TYPE
Machine Health Monitoring Sensors

Shaft vibration (absolute)

This measurement type is always done on a fluid film sleeve bearing. With absolute shaft vibration, the relative shaft vibration is measured using an eddy current sensor as detailed in the prior section, and the absolute bearing housing vibration is measured using an accelerometer or velocity sensor along the same axis as the eddy current sensor. Subtracting the relative vibration from the correct phase of the absolute vibration results in the absolute shaft vibration of the shaft in space. The evaluation of the measurement is done as $S_0-p$ (displacement 0 to peak) or $S_p-p$ (displacement peak to peak), as shown in Figure 8 and Figure 9.
Bearing vibration readings are taken on both antifriction bearings and fluid film sleeve bearings. To measure the bearing or machine case overall absolute vibration, the following measurement technologies are usually employed:

1. Accelerometer (piezoelectric based)
2. Velocity sensor (piezoelectric based)
3. Velocity sensor (seismic, electrodynamic based)
4. Displacement (position)
5. Displacement (vibration)

These sensors are all surface mounted on the bearing or machine case and will report all the vibration (absolute) that they detect in their perpendicular axis to the mounting surface.
Eddy current sensors are used to measure position and expansion on shafts, bearing housings, and machine cases on rotating machines.

Because of the large range in shaft and case sizes and the large possible range of movement, a range of different eddy current sensor sizes must be available to optimize the measurement. Some position measurements are single channel and some are dual channel. Axial position measurements on shafts are typically taken to ensure the rotating assembly inside the machine case is not close to rubbing a casing seal. A seal rub can result in a catastrophic failure of the machine rotor.

- Single Channel
- Dual Channel
- Dual Channel Continued
- Single-Cone Measurement
- Double-Cone Measurement
- Measuring Range Calculation
Eccentricity

Shaft eccentricity is the dynamic movement of the outer shaft surface to the geometrical center of the shaft (also called residual gap). This measurement requires a tachometer phase reference to initiate the time series collection and the measurement consists of one complete shaft revolution measured with an eddy current sensor.

The signal is measured in a frequency range of 0.017 Hz (1.02 rpm) to 70 Hz (4200 rpm) using eddy current sensor data. $Sp$-$p$ (Shaft Displacement Peak to Peak, Figure 24) and $S_{min}$/$S_{max}$ (Shaft minimum/maximum, Figure 25) are typical expected analysis parameters.
Reference pulse

A tachometer, typically an eddy current sensor, is used to produce a pulse when a shaft keyway or some other target passes it once per shaft revolution. This tachometer timing pulse can be used to provide a phase reference point for all the vibration measurements on a machine. This allows phase comparisons of the multiple vibration measurements on a machine using two dimension visuals such as each bearings XY orbit data. Since the shaft has a reference mark that the phase is based upon, the angular position of the absolute vibration data can be calculated.

A trigger wheel cannot be used with a tachometer to generate a phase reference pulse because there is no unique tooth on the trigger wheel to reference.
Differential expansion (relative expansion) is a measure of the change in the clearances between machine parts caused by thermal expansion or contraction. (e.g., rotor disks to turbine housing). A variety of methods to measure this effect are used but the most common method is by using eddy current sensors.

Smaller thermal expansion displacements can be treated as single or tandem eddy current sensor measurements. Larger expansions have to be handled through Tandem or Double Cone dual eddy current sensor setups.

A pre-calculation of the expected maximum expansion must be done to determine the best differential expansion measurement type setup required.
Valve position

Valves have long travel displacements and the travel amount is used to determine whether a valve is open, partially open or closed. LVDT’s have the long displacement measurement capability to measure valve position.
Speed measurements are usually collected by an eddy current sensor reading a pulse wheel or a gearwheel. The current speed in hertz is calculated by dividing the amount of pulses per second by the number of gear teeth on the wheel. By having many pulses per revolution it’s possible to quickly determine if the asset speed is consistent, accelerating or decelerating.

The use of two speed sensors on the same trigger wheel allows the direction of rotation to be detected and monitored.
Axial position protection

A fluid film sleeve oil “thrust” bearing is designed to be the fixed bearing of a fixed/floating bearing pair. This bearing is expected to keep the shaft from wandering in the axial direction which will result in a catastrophic event when the clearances in a rotating machine such as a steam turbine disappear and high speed metal to metal contact of the rotor with the housing and seals occur.

So it is important to know that the thrust restraint fixing mechanism is intact. This measurement is sometimes setup as a 2 out of 3 (2oo3) measurement to ensure there is no doubt that the thrust restraint is intact and not moving axially.
MEASUREMENT TYPE
Machine Health Monitoring Sensors

Because of the growing application of sophisticated and networked modern analysis and diagnostic online prediction and protection systems, it becomes increasingly easy and essential to capture process parameters and trend them along with the online prediction and protection analysis parameters to allow the visualization of potential relationships between them.

For a steam turbine the important parameters to capture and trend are the effective power and the reactive power of the turbine. In addition, temperature and steam pressures should be tracked and trended.