TECHNICAL NOTE

Machine Health Monitoring (MHM)
VS1000 & SI1000.

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Application Description

Machine Health Monitoring provides tremendous leverage by reducing downtime and preserving assets. Vibration monitoring enables preventive maintenance on almost any type of machine. It could be done by recurrent control or real time analysis. Condition monitoring involves fixing sensors to mechanical or electrical parts of the machines in order to track failures and malfunctions.

Nowadays, accelerometers are the most common and flexible sensors for this task. Just about any machine or motor could be analyzed through this process. The table below shows a non-exhaustive list of applications:

Components Monitored	Possible Faults	Frequency Range
Support structure	Imbalance, external vibrations, oil whirl	DC 0 Hz – 100 Hz
Shaft, gear, slide-bearing	Imbalance, misalignment, hunting mesh, looseness	DC 0 Hz – 1’000 Hz
Gear, bearing	Mesh faults, gear pitting, shocks	100 – 10’000 Hz
Bearing, motor	Acoustic vibrations	10’000 – 100’000 Hz

Due to the large number of applications and contents of MHM, this document focuses exclusively on low frequency vibrations, from DC 0 Hz to 1’000 Hz. The following applications could be considered:

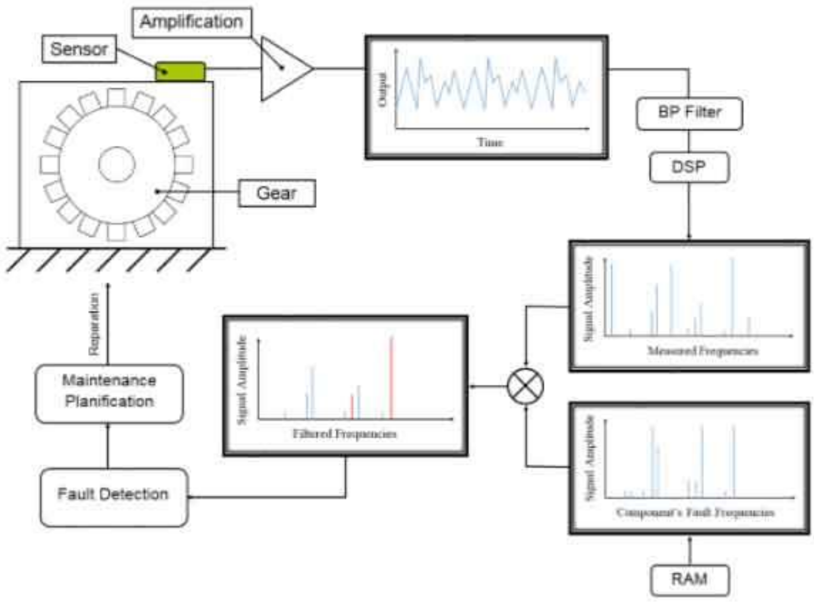
- Hunting tooth detection
- Fan monitoring in cooling towers
- Slow speed agitators in industries
- Geophysical measurement equipment

The market is mostly targeted by the industry. As an example, more than 30’000 plants in the US apply monitoring for critical, expensive components, each plant having 3 to 5 vibration transmitters.

Explanation of the System

MHM will be set up according to the type of faults needed to be analyzed, by measuring different frequency ranges. In general, spectrum analysis is used to identify the different vibration frequencies. An example of a configuration is shown in figure 1.

The signal output is transformed by a DSP unit, generating a frequency spectrum for each sampling cycle. The spectrum is then compared to the component’s reference spectrum, given by the supplier of the component. This operation allows determining whether the frequency of a vibration is caused by the component monitored or by an external fault. If the amplitude of a vibration exceeds a threshold, an alarm is triggered and impending repairs are scheduled.



Environment Analysis

The purpose of MHM is to prevent mechanical failure by detecting increasing vibrations. A fault within a system may trigger a devastating chain reaction: for example if a tooth on a pinion gear is broken, it will inevitably damage the contact gears. The broken gears could cause imbalance in their respective shafts, potentially harming the bearings as well.

MHM requires reliable sensors, resistant in much cases to high temperature and repetitive shocks. The system must be able to operate in a wet and corrosive environment (e.g. contact with steam in a cooling tower). Furthermore, the sensors must perform as long as the component being analysed.

There are various ways to set up a sensing system to the desired component. Handheld measurements are the simplest option, but they require frequent maintenance reviews. Sensors mounted on magnets measure rotating components; on the other hand, they influence the inertia and could cause vibrations. Proximity measurements are also a possibility, despite being difficult to install. Lastly, stud mounts satisfy the condition of permanent monitoring and bring little if any disturbance to the system.

MHM Conditions

Monitoring at low frequencies implies two major requirements. First of all, the noise produced by the sensor must be as low as possible: the lesser the amount of electronic noise generated, the earlier a fault is detected. As an example, some CNC machinery demands sensors with a noise level between 75 and 90 dB, operating at a low frequency (DC 0 Hz – 1'000 Hz). Secondly, maximizing voltage output is key to set a sufficient alarm threshold. A good range would be from ±2g to ±10g.

The frequency range of the sensor depends on both the operating frequency and the nature of the potential fault. Fans located in a cooling tower turn at a very low frequency, typically from 100 to 1000 RPM (~ 2 Hz – 20 Hz). Motors generally turn from 500 up to 3'000 RPM (~ 10 Hz – 50 Hz). The table below describes the frequency of the most common defects in terms of the system's rotation speed.

nature of fault	fault frequency	plane
imbalance	$1 \times$ RPM	radial
misalignment	$1,2 \times$ RPM, sometimes $3,4 \times$ RPM	radial, axial
oil-whip, oil-whirl	0.42 to 0.48 $\times$ RPM	mainly radial
mechanical looseness	$2 \times$ RPM and $0.5, 1.5, 2, 5$ etc. $\times$ RPM	radial
bearing faults	bearing fault frequencies, shock pulses between 20 - 60 kHz	radial, axial
gear faults	$f_{mesh} = \#teeth \times f_{gear}$ and harmonics	radial, axial

Source from http://rduin.nl/papers/thesis_01_ypma.pdf, table 1.2

Technical Solutions

A wide variety of sensors could be used for machine health monitoring. Although many physical properties could be measured to obtain a vibration analysis, the accelerometers remain best option. The table below focuses only on acceleration, velocity and displacement sensors.

Accelerometers offer the best solution in term of installation costs and measurement flexibility. Piezoceramic accelerometers include PE and PR sensors. Both sensors have a broad bandwidth, but cannot measure very low frequency vibrations. MEMS capacitive accelerometers are more accurate than the piezoceramic sensors due to a compensation for thermal drift.

Sensors Criteria	Eddy Current Probe	Electrodynamic Sensor	Piezoceramic Accelerometer	MEMS Capacitive Accelerometer
Frequency Range (Hz) @ ±3 dB (max.)	0 – 10'000	10 – 2'000	5 – 10'000	0 – 7'000
Acceleration Measurement	NO	NO	YES	YES
Velocity Measurement	NO	YES	YES	YES
Displacement Measurement	YES	YES	YES	YES
Installation Costs	High	Low	Low	Low
Electronic Noise	Low	High	High	Low
Durability	High	Low	Low	High

Colibrys: a Trustworthy Company

All sensors stated above are able to withstand harsh environments: during qualification phase, many tests are done on each sensor after assembly in order to respect the performance required. The sensor is sealed by a ceramic housing for excellent hermeticity. A self-test function is available on a pin to check if a problem within the sensor has appeared (e.g. electrostatic disturbance, saturation).

The vibration sensors are optimum for this application, and Safran Colibrys proposes 2 very high performance sensors family.

	VS1000	SI1000
Package	LCC20	LCC20
Range available	2g, 5g, 10g	3g and 5g
Noise level	7 µg/√Hz	0.7 µg/√Hz
Dynamic range	90dB	108dB
Non-linearity FS (typically)	0.1%	0.3%
Bandwidth (typically)	DC to >7000Hz (-3dB)	DC to >500Hz (-3dB)

VS1000 is a high end capacitive MEMS accelerometer, specially designed for vibration measurements from DC to medium frequencies. Thanks to its low noise, resistance to repetitive high shocks and insensitivity to temperature environments, VS1000 guarantees confident and accurate vibration measurements in rugged environments.

SI1000 is a high-end capacitive MEMS accelerometer specially designed for Strong Motion Class B seismic measurements. It provides extremely low noise, excellent linearity and temperature stability, wide frequency response in a small form-factor and hermetically sealed package. SI1000 guarantees very accurate and stable vibration measurements, requiring neither recalibration nor maintenance during the lifecycle of the system.