APPLICATION NOTE

Machine Health Monitoring (MHM) using VS1000 Vibration Sensor

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 industry. As an example, more than 30’000 plants in the US apply monitoring for critical, expensive components, each plant owning from 3 to 5 vibration transmitters.

Explanation of the System

MHM will be set up according to the type of faults to analyze, 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.

Safran Timing Technologies SA
Av. des Sciences 13
1400 Yverdon-les-Bains - Switzerland

T +41 58 100 5000
F +41 58 100 5001
ww.safran-navigation-timing.com

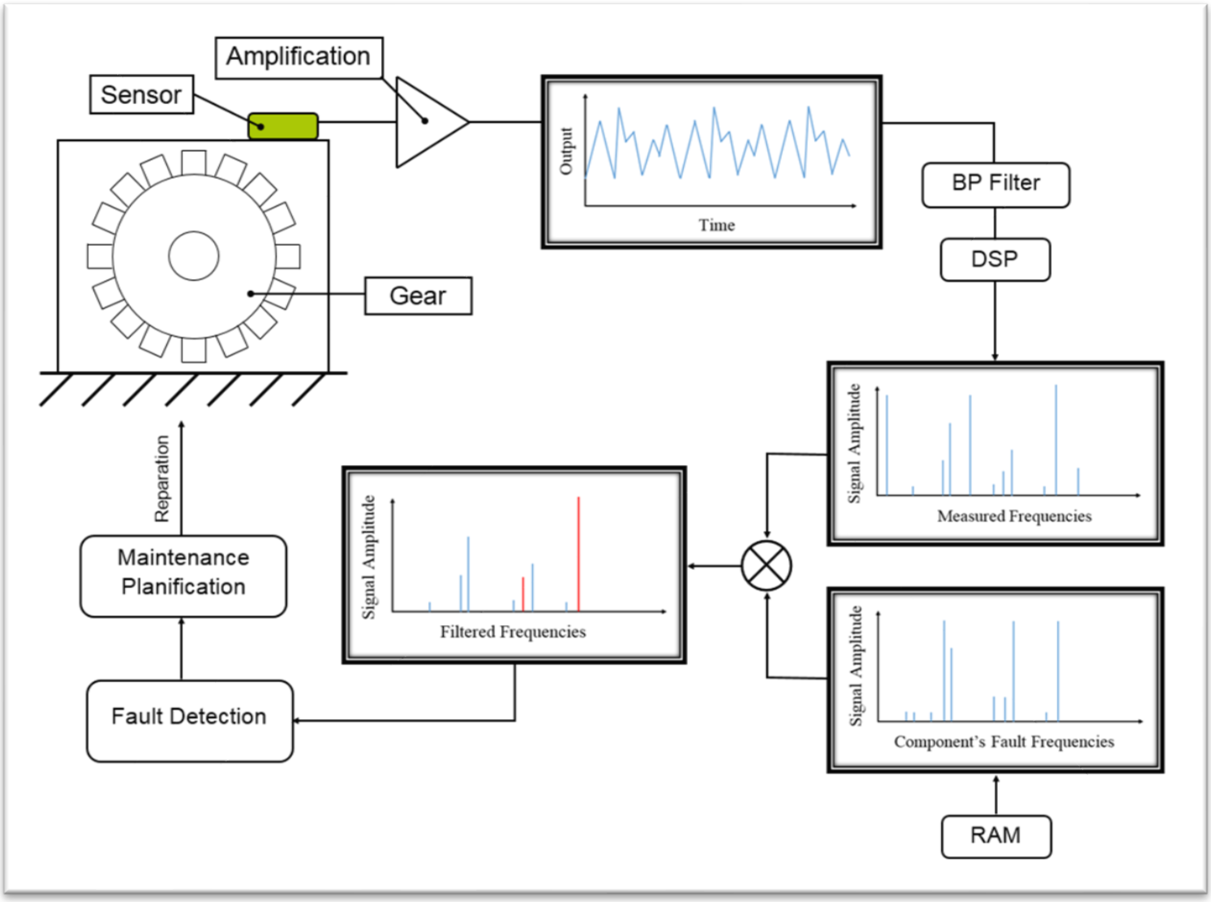

Figure 1: A possible monitoring architecture

Environment Analysis

The purpose of MHM is to prevent mechanical failure by detecting growing vibrations. A fault within a system may trigger a devastating chain reaction: for sample, 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 to possibly 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 last as long as the component being analyzed.

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 stipulation of permanent monitoring and bring little if any disturbance to the system.

MHM Conditions

Monitoring at low frequencies imposes two major requirements. First, the sensor noise floor must be as low as possible: the lower the electronic noise generated by the sensor, the earlier a fault can be detected. For example, certain CNC machines require sensors with a noise performance in the range of 75 to 90 dB while operating over a low-frequency bandwidth (DC to 1,000 Hz). Second, maximizing the sensor's voltage output is essential for establishing a sufficiently high alarm threshold while maintaining good sensitivity. An acceleration range of approximately ±2 g to ±10 g is typically well suited for this purpose.

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 monitoring machinery. Although many physical properties could be measured to obtain a vibration analysis, the accelerometers remain in the top position. The table below focuses only on acceleration, velocity and displacement sensors.

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	✗	✗	✓	✓
Velocity Measurement	✗	✓	✓	✓
Displacement Measurement	✓	✓	✓	✓
Installation Costs	High	Low	Low	Low
Electronic Noise	Low	High	High	Low
Durability	High	Low	Low	High

Accelerometers offer the best solution in terms 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 thanks to compensation for thermal drift.

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All of the sensors described above are designed to operate reliably in harsh environments. To ensure compliance with certification requirements, each sensor undergoes a series of qualification tests after assembly to verify that the specified performance levels are met.

The sensing element is enclosed in a ceramic package, providing excellent hermetic sealing and long-term reliability. In addition, a dedicated self-test pin is available to verify the sensor's integrity and detect potential malfunctions, such as electrostatic discharge (ESD) damage, internal faults, or saturation events.

The vibration sensors are for this application, particularly the VS1000 series. A recommended range of measurements would be between ±2g and ±10g. A noise level of 7 µg/√Hz - equivalent to class C at 90 dB - makes the VS1002 sensor suitable for very accurate measurements. The VS1000 sensors also have a non-linearity of 0.1% FS (typically), a linear frequency response from DC 0 Hz to 2500 Hz at ±5% (typically), and up to 7000 Hz at ±3 dB (typically).

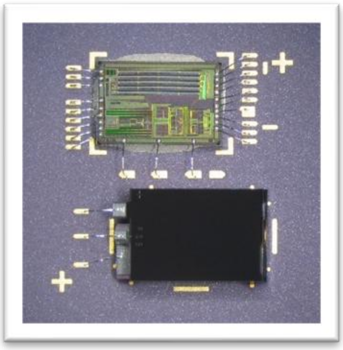

Figure 3: The VS1000 layout

Glossary:

- CNC: Computer Numerical Control
- dB: Decibel
- DC: Direct current
- DSP: Digital signal processing
- FS: Full scale
- Hz: Hertz
- MEMS: Microelectromechanical systems
- MHM: Machine health monitoring
- PE: Piezoelectric
- PR: Piezoresistive
- RPM: Rotation per minute

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1400 Yverdon-les-Bains - Switzerland

T +41 58 100 5000
F +41 58 100 5001
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