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**VIBRATION-BASED CONDITION MONITORING:
INDUSTRIAL, AEROSPACE AND AUTOMOTIVE
APPLICATIONS**

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Vibration-Based Condition Monitoring: Industrial, Aerospace and Automotive Applications

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Abstract – *Vibration analysis is by far the most prevalent method for machine condition monitoring because it has a number of advantages compared with the other methods. It reacts immediately to change and can therefore be used for permanent as well as intermittent monitoring. With oil analysis for example, several days often elapse between the collection of samples and their analysis, although some online systems do exist. Also in comparison with oil analysis, vibration analysis is more likely to point to the actual faulty component, as many bearings, for example, will contain metals with the same chemical composition, whereas only the faulty one will exhibit increased vibration. Most importantly, many powerful signal processing techniques can be applied to vibration signals to extract even very weak fault indications from noise and other masking signals. Most of this concerned with these issues.*

Keywords: *Vibration-Based Condition, Monitoring, Industrial, Aerospace Automotive, Applications, Machine, Advantages, Method, Comparison, Importantly, Powerful, Processing, Techniques, etc.*

INTRODUCTION

Machine condition monitoring is an important part of condition-based maintenance (CBM), which is becoming recognized as the most efficient strategy for carrying out maintenance in a wide variety of industries. Machines were originally 'run to break', which ensured maximum operating time between shutdowns, but meant that breakdowns were occasionally catastrophic, with serious consequences for safety, production loss and repair cost. The first response was 'preventive maintenance', where maintenance is carried out at intervals such that there is a very small likelihood of failure between repairs. However, these results in much greater use of spare parts, as well as more maintenance work than necessary (Al-Najjar and Alsyouf 2004. Al-Najjar, 2009. Vlok, *et. al.* 2002). There is now a considerable body of evidence that CBM gives economic advantages in most industries. An excellent survey of the development of maintenance strategies is given by Rao in a keynote study at a recent Comadem (Condition Monitoring and Diagnostic Engineering Management) conference (Rao, 2009).

REVIEW OF LITERATURE:

The case presented in (Sundin, *et. al.*, 2007), from the Canadian pulp and study industry, is discussed further in connection with the authors' approach to prognostics. To base maintenance on the perceived condition of operating machines (many of which are required to run continuously for 12 months or more) requires that methods are available to determine their internal condition while they are in operation. The two main ways of getting information from the inside to the outside of operating machines are vibration analysis and lubricant analysis, although a few other techniques are also useful (McMillan and Ault 2008). This paper includes a description of the background for and methods used in condition monitoring, while most of the rest of the study is devoted solely to the methods based on vibration analysis, which are the most important. This paper describes the various types of vibration measurement used in condition monitoring, and the transducers used to provide the corresponding vibration signals. It also describes the basic problem in interpretation of vibration signals, in that they are always a compound of forcing function effects (the source) and transfer function effects (the

structural transmission path), and how the two effects may be separated.

Absolute vs Relative Vibration Measurement:

Proximity probes measure the relative motion between a shaft and casing or bearing housing (as illustrated in Figure 1). It is important to realize that this gives very different information from the absolute motion of the bearing housing, as measured by a so-called 'seismic transducer' as exemplified by an accelerometer. These two parameters are probably as different as the temperature and pressure of steam, even though sometimes related. The relative motion, in particular for fluid film bearings, is most closely related to oil film thickness, and thus to oil film pressure distribution, as calculated using Reynolds' equation (Raad, *et. al.*, 2003). It is thus also very important in rotor dynamics calculations, as these are greatly influenced by the bearing properties.

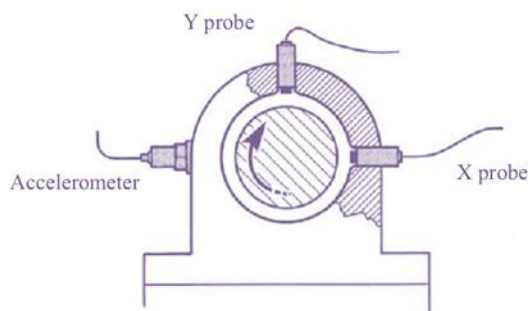


Figure 1 Illustration of absolute against relative vibration.

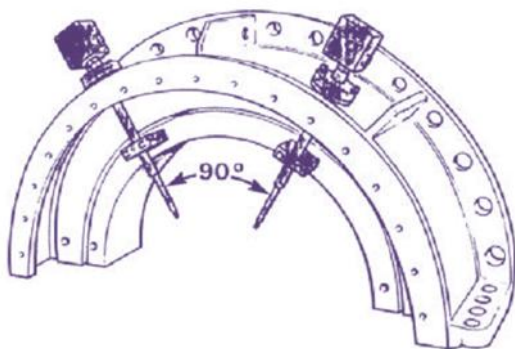


Figure 2 Proximity probes installed in a turbine bearing cap.

However, a fluid film bearing is a very nonlinear spring, and therefore the amplitude of relative vibration does not give a direct measure of the forces between the shaft and its bearing. An increase in static load, for example, causes the oil film to become thinner, and the bearing stiffer, with reduced vibration amplitude, even though the higher load might be more likely to cause failure. The absolute motion of the bearing housing, on the other hand, responds directly to the force applied by the shaft on the bearing (these being the same since the inertia of the oil film is negligible),

and since the machine structure tends to have linear elastic properties, the vibration amplitude will be directly proportional to the force variation, independent of the static load (Rao, 2005). In other words, the journal bearing stiffness and damping properties, and thus the dynamic bearing forces, are most directly related to the relative position and motion of the shaft in the bearing, but the response to these forces is most directly indicated by the absolute motion of the housing. An advantage of proximity probes is that they can measure both the absolute position of the shaft in the bearing and the vibrations around the mean position (Polytec, 2010). Direct current (DC) accelerometers do exist, but are rarely used in machine monitoring, since it is still not possible to integrate the signals directly to total velocity and displacement because of the lack of constants of integration. Accelerometers are thus used to measure fluctuations in acceleration around a mean value of zero. This can be integrated to absolute velocity and displacement (fluctuations), but excluding zero frequency. Other comparisons between the different types of transducers depend on the technical specifications for dynamic range, frequency range, and so on, so each type will be discussed in turn.

Velocity Transducers:

Transducers do exist which give a signal proportional to absolute velocity. They are effectively a loudspeaker coil in reverse and typically have a seismically suspended coil in the magnetic field of a permanent magnet attached to the housing of the transducer (as in Figure 3) or the inverse, where the coil is rigidly attached to the housing and the magnet seismically suspended. A body is said to be seismically suspended when it is attached to another by a spring such that when the second body is vibrated, the first will move with it at low frequencies, but when the excitation frequency exceeds the natural frequency of the suspended mass on its spring, it will remain fixed in space, and the second body will move around it. When the housing of the transducer (or pickup) is attached to a vibrating object, the relative motion between it and the seismically mounted component (for frequencies above the suspension resonance) is equal to the absolute motion of the object in space. To avoid problems with excessive response to excitation in the vicinity of the resonance frequency, the damping of the suspension is usually quite high, typically of the order of 70% of critical damping, and this also means that the amplitude response of the transducer is reasonably uniform almost down to the resonance frequency. Figure 4 shows the frequency response of a generalized vibration transducer of the type described, for different values of damping, against frequency ratio with respect to the natural frequency of the suspension (Antoni and Braun, 2005). It is seen that for critical damping ratio $f\ddot{A} = 0.7$, the frequency range for amplitude ratio close to one (i.e. output equals input) is as wide as possible. As will be seen from the Fourier analysis theory of reproduce

repetitive impulses, for example, all harmonics must be in phase at the time of occurrence, and this would not be the case if they were measured with such a transducer if the low harmonics were in the range of phase distortion.

accelerometers, velocity pickups are much heavier and bulkier. It will be accelerometer plus integrator is a much better velocity transducer.

CONCLUSION:

This study it was shown that the relation of the performance of various damage features to environmental variability and operational conditions is complex. Many of the damage features indicated good performance for the different damage types under different condition but suffered from suggestion swapping, where for one system state, damage caused an increase in the mean of the feature value, but in others the damage caused a decrease. The change in damage feature distributions makes it hard to establish specified thresholds to detect if damage is present. Classification of damage types become increasingly also become difficult. Out of the damage features covered, the newly proposed FMH feature continuously showed superior performance in detecting worn tooth damage compared to traditional gearbox damage features. This superior performance occurred for a number of different signal lengths, sampling frequencies and sensor locations. In addition to its superior performance in worn tooth damage detection, the FMH feature also was less sensitive to bearing damage than the traditional damage features.

FUTURE WORK:

This study has provided valuable information on the effect of varying environmental and operational parameters of various damage features under a number of damage conditions that occur in rotating machines. The majority of the damage features performed well under certain conditions while others did not. As such they can be used for group classification of various damage types as well as location in multidimensional data driven analysis.

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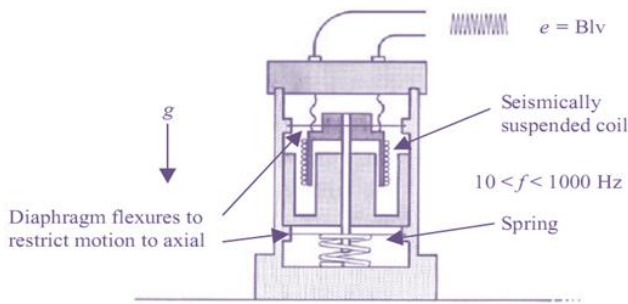


Figure 3 Schematic diagram of one realization of a velocity pickup.

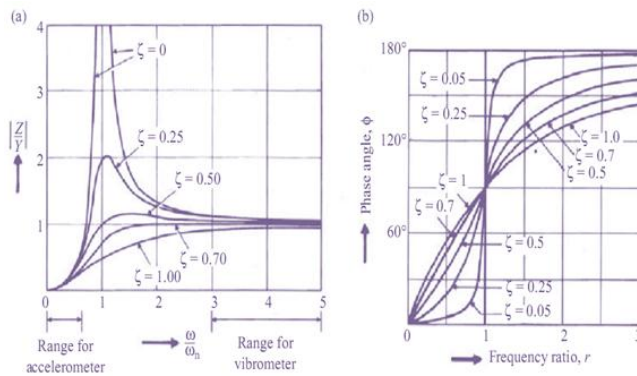


Figure 4 Frequency response of a seismically suspended vibrometer [17]: (a) amplitude characteristic;

(b) Phase characteristic. ζ = critical damping ratio

Necessarily follow the original. As will be seen from the Fourier analysis theory of reproduce repetitive impulses, for example, all harmonics must be in phase at the time of occurrence, and this would not be the case if they were measured with such a transducer if the low harmonics were in the range of phase distortion. In the case of a velocity pickup, the relative motion of the magnet in the coil gives a voltage signal proportional to velocity (and thus the absolute velocity of the housing). The dynamic range (ratio of largest to smallest measurable signal) of such a transducer is about 60 dB. The lower frequency limit is typically set (by adjustment of the suspension resonance frequency) to 10 Hz, while the highest measurable frequency is limited by the resonances of internal Components to about 1–2 kHz Much of the data for the VDI 2056 and ISO 2372 standards was gained with velocity transducers of this kind and that is the main reason why the frequency limits in those and later standards are 10 Hz to 1 kHz. Relative to

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