Proceedings of The Institute of Acoustics

CONDITION MONITORING BY VIBRATION ANALYSIS.

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Introduction

Monitoring plant condition and establishing deterioration trends succeeds if the monitoring sensor, data processing and information interpretation are correctly related to the anticipated dominant failure mode (reference 1) in more prosaic terms, a vibration monitor will only monitor vibration effects - it is not an appropriate technique if deterioration is arising from corrosion under static conditions.

There are plenty of vibration effects and they are most frequently of a critical nature.

Large displacements, usually associated with low frequencies, invariably produce failure through overstressing.

Large velocities, usually associated with medium-high frequencies, invariably apply a combination of high stresses and frequent reversals and thus relate to fatigue-type failure modes.

Large accelerations, usually associated with high frequencies, invariably implies the presence of high dynamic forces between interacting components, transmitted by contact, therefore an implied surface reaction and a failure through surface deterioration, surface deterioration may be the result of wear or of discrete surface destruction (pitting, galling, flaking).

Different components have failure potentialities and modes of different kinds. A journal in a plane bearing is likely to suffer from stresses imposed by eccentricity or unbalance. A roller element bearing is likely to fail through surface fatigue and the removal of discrete surface elements. A gear tooth, under the influence of rolling/sliding action with intensive contact pressures presents a complex failure situation with both 'traditional wear' and spalling as likely dominant factors - or tooth bending and cracking a further alternative.

Trends and Sensors.

The idea behind monitoring is to measure a parameter, compare it against a previous parameter and identify the change or trend. The parameter must obviously be that which is related to the failure mode and the sensor that device (transducer or pick-up) which has the most reliable sensitivity at such a parameter.

Measurements therefore use proximity probes to detect displacement; seismic-mass vibrometers to measure velocity; piezoelectric accelerometers to measure acceleration. There are simpler devices which give 'simple' information, such as frequency meters and stroboscopes; there are complex sensors such as impedance heads which may incorporate strain gauges with accelerometers. Under the correctly chosen circumstance each method has its appropriate application and each has advantages and disadvantages which can be considered during their selection (reference 2).

Data Processing.

Signals derived from sensors are generally alternating electrical voltages which are analogous to the displacement, velocity or acceleration being measured. They may be processed for diagnostic purposes as X-Y polar displays on cathode ray tubes, waveforms, frequency-based spectra of various kinds and a range of comparative graphs or just simple determinate numbers according to the measurement required. The author (reference 2) has dealt with the better-known techniques to some extent, although the commercial exigencies of publishing restricted the amount of coverage which could be applied. A few of these techniques are described separately.

Displacement - X-Y Plots.

Many power station turbines and ship's propulsion machinery use proximity probes. The orbit traced out by an X-Y plot from two probes arranged at 90° gives an indication of the cause of malfunction, thus

Malfunction	Orbit
initial pre-load of shaft	elliptical
high load on shaft	banana-shaped
extremely high load	figure 8 shape

Apart from such useful diagnostic information, the extremity of shaft movement must be such that the bearing clearance is not taken up so that the shaft and bearing rub.

Wave-form Plots.

Simple plots from either hand-held vibrographs or pen-recorders of low-frequency structural vibrations have some applications. In general, time-domain analysis as this implies can be used for such purposes as signal averaging and from this to kurtosis measurement.

Signal Averaging.

It is held that the many combinations of frequencies and phases in the vibration from a machine has characteristics similar to those of random vibrations. Consequently the opinion exists that the 'wave-forms' of such vibrations is beneficially assessed by a statistical averaging of their parameters. This involves the collection of 'ensembles' of impulses in the store of a computer or micro-processor and from this the evaluation of such quantities as standard deviation and the distribution.

Kurtosis.

For many modes the physical effect associated with deterioration is to produce a series of shocks. Shock pulse monitoring (reference 3) offers an excellent practical method for monitoring shock pulses due to deterioration in rolling-element bearings. In other situations, the random nature of signal-averaged vibrations shews up a growth of shock 'spikes' which spread out the distribution pattern. It is possible to measure this spread by statistical means using the kurtosis coefficient (reference 4) and from this to assess the extent of deterioration.

Frequency Analysis.

Vibration recordings may be divided into frequency domains by methods ranging from the use of filters to methods involving computers and Fast Fourier Transforms (reference 5). Such a print-out of vibration parameter against a frequency base is known colloquially as a 'signature' or 'thumb print'.

Such a record relates the vibration of each particular component according to its discrete frequency. Accordingly, signatures taken over a period of time which indicate a change in vibration at a particular discrete frequency automatically provide diagnostic information which can be related to a change in condition. The use of computers and microprocessors opens up the use of this method to using vibration parameters such as power spectral density which have a greater sensitivity to condition change (reference 6).

Transfer Analysis.

Structural vibrations are particularly important monitors of structural integrity for which purposes the measurement of vibration transmissibility through impedance measurements have been developed and applications include the difficult problems of off-shore structures (reference 7). In essence measurements of cause (force) and effect (vibration) are made by the use of an impedance head, if the ratio of force to vibration changes, the flexural weakness due to structural failure becomes evident.

Conclusion.

These notes have only touched briefly on some aspects of condition monitoring, other refined techniques deserve consideration as opportunity permits. Cross-correlation (reference 8) and cepstrum - used to identify and locate failing or failed turbine blades - (reference 9), are just two methods of processing data to arrive at meaningful information. Not only is this meaningfulness relevant to the data but without consistant signals from sensors with a long-life reliability the whole business can lead to wrong decisions. This leads finally to the matter of decisions reached from the trends obtained by vibration monitoring. Somewhere along the line someone must decree when deterioration has reached an unacceptable level. Some attempts have been made to develop a philosophy going right back to Rathbone in 1939 (reference 10) who undertook a study for the Fidelity Guarantee Insurance Corporation. Other specifications by VDI, BSI and other bodies, when examined by Downham (reference 11) give one reason to believe that more still remains to be explored in this interface between science and operational research.

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