DETECTION OF BEARING FAILURE IN MACHINES

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Introduction

One of the potential problems common to all types of bearings is that at failure, the resultant machine repair can be costly, both financially and in production loss.

The vibrational energy emitted from rolling contact bearings can be monitored in a number of ways:

1. Overall amplitude of vibration level, based on time domain data.
2. Frequency spectrum of the time signal, usually up to 25 kHz.
3. Examination of the shock waves generated through the bearing housing when the rolling elements move over a damaged area.
4. Statistical parameter measurements applied to the time signal.

It is the latter approach that will be highlighted in this presentation.

Machined or ground surfaces are not perfectly smooth but consists of a pattern of asperities. In fact, only about 0.1% of the nominal contact area actually touches under normal loading conditions. When these surfaces are moving, as is the case of rolling element bearings, the asperity tips are alternatively welding and breaking off. Even so, most bearing surfaces exhibit randomness in asperity distribution in the direction of the machine process.

It has been well established in the metrology literature that the distribution of asperity weights for an undamaged surface to be normal, that is Gaussian in nature. It is this feature that allows the statistical parameter approach to work.

Background to the Statistical Parameter Method

The asperity distribution can be detected with an accelerometer, attached as near as possible to the bearing housing. This will, of course, also collect data relating to ball passing frequencies and other structural resonances. It is necessary therefore to separate the random data from deterministic data, by filtering. Fortunately, this usually works out quite well, and removing signal content below 2.5 kHz is usually satisfactory. The remaining data, from most bearings at normal running speed, should be mainly random. As the surface deteriorates due to damage, the "bell" shaped probability density function starts to lose its classic characteristics. Statistical moments can then be used to sense these changes.

In general, odd moments are related to information about the position of the peak of the PDF in relation to the mean value, while even moments indicate the characteristics of the spread of the distribution. It can be shown theoretically that the fourth moment, normalized by dividing with the square of the second moment, results in a coefficient called 'Kurtosis.' This has a value of 3.0, if the data exhibits a normal PDF. Values greater than 3.0 indicate damage developing, and less than 3.0 usually indicate deterministic signal contamination.

$$M_2 = \frac{1}{N}\sum_{i=1}^{N}\left[x_i^2 - \overline{x^2}\right] \tag{1}$$

$$M_4 = \frac{1}{N}\sum_{i=1}^{N} x_i^4 - \frac{4}{N}\,\bar{x}\sum_{i=1}^{N} x_i^3 + \frac{6}{N}\,\overline{x^2}\sum_{i=1}^{N} x_i^2 - 3\overline{x^4} \tag{2}$$

and

$$Kurtosis = \frac{M_4}{\left(M_2\right)^2} \tag{3}$$

One significant advantage that statistical methods have over the spectral approach is that the results from the former are essentially insensitive to load and speed changes, Fig. 1. Table 1 shows the moments as calculated from theory for different signal types. Notice the difference between random and Gaussian random.

Typical Results

Raw data can be collected in a number of ways. Under laboratory conditions, accelerometers positioned on the casing surrounding bearings under investigation can input analog signals directly into an A/D board in a microcomputer. Conditioning, filtering, and analysis can then be carried out using a variety of software packages. In-house software can be written in 'C' or Pascal for example, or such general commercial packages such as MATLAB, can be used very effectively. How the data processing is handled depends on the funds available, and the flexibility required for the mathematical processing.

In field work, for example on top of a 54 storey building in an elevator shaft, recording data from the accelerometers directly into a good quality tape recorder is often a much easier route to take. The processing can then be carried out in the relative comfort of the computer at home base.

Table 1

	Moment		**Normalized Moment using $(M_2)^n$**				
Data type	M_1	M_2	N_3	N_4	N_5	N_6	N_7
Sine	0.00	0.50	0.00	1.48	0.00	2.44	0.00
Square	0.00	1.00	0.00	0.98	0.00	0.98	0.00
Triangle	0.00	0.34	0.00	1.75	0.00	3.71	0.00
Random	0.48	0.07	0.13	1.94	82.90	4.74	2.81
Random Gauss	0.01	0.94	0.20	3.01	2.44	14.30	20.70

Fig. 2, shows the time domain results for similar bearings under different damage conditions, as summarized in Table 2.

Table 2

Bearing Number	Condition	Kurtosis Value
1	good	2.9
2	Hair line mark outer raceway	3.8
3	Severe scratches outer raceway	4.4

Plotting Kurtosis values against acceleration magnitudes is often termed a damage map, so for example in Fig. 3, a good bearing is first run lubricated, and then cleaned out and run dry. The numbers indicate Kurtosis measurements taken in the following frequency bands,

1. 2.5 to 5.0 kHz
2. 5.0 to 10.0 kHz
3. 10.0 to 20.0 kHz
4. 20.0 to 40.0 kHz
5. 40.0 to 80.0 kHz

Laboratory tests have shown that the damage map can be used to identify the type of damage process in progress. This summary is shown in Fig. 4.

Conclusions

The wide range of methods of detecting bearing damage that are available, have their individual strengths and weaknesses and are therefore dependant on the application. An understanding of the methodology involved in digital data processing is important in order to ensure valid interpretation of the results.

Statistical methods of various types are now being investigated, Kurtosis being the most tested approach so far and seems to offer a lot of potential for the future. Currently investigations are being carried out using other distributions such as the Beta and Weibull functions, applied to gearing as well as bearings. However, confidence still has to be built up with extensive field testing of these techniques.

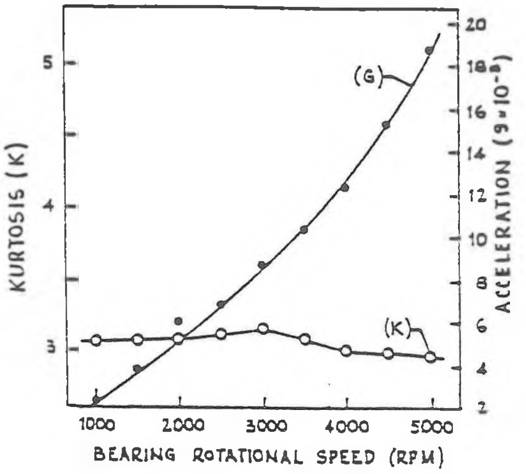

Fig 1 . Kurtosis and "g" level as Functions of Bearing Rotational Speed.

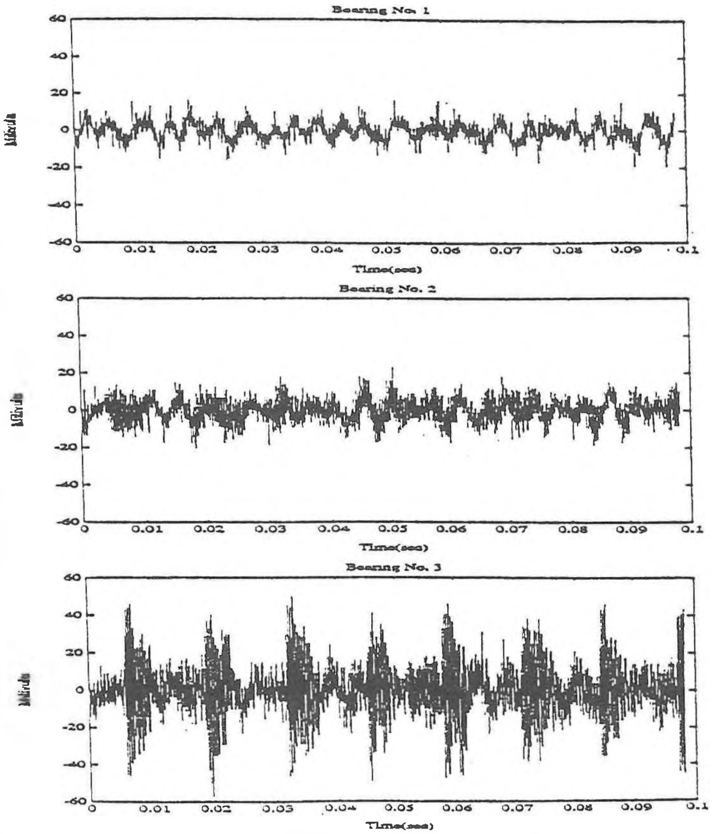

Fig 2. Vibrational Data for Different Stages of Damage.

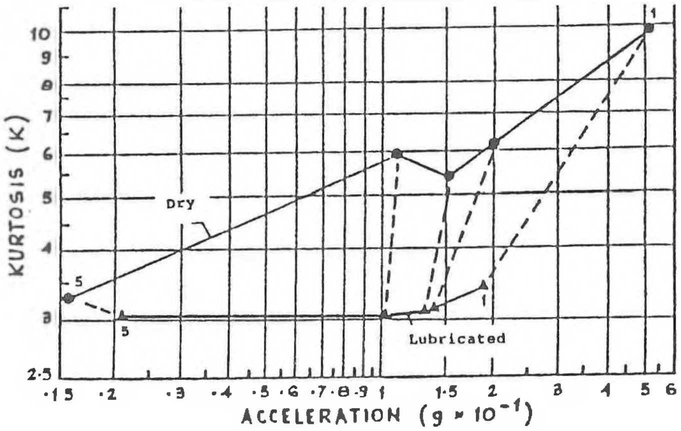

Fig 3. Difference between a Dry and Lubricated Bearing.

Fig 4. Tentative Centres of Diverse Damage Activities.