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A comparison of some vibration parameters for the condition monitoring of rolling element bearings

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Abstract

In the present study some of the vibration parameters used for the detection of defects in rolling element bearings have been compared. Overall RMS, peak, crest factor, power and cepstrum of the vibration acceleration signal of the bearings with defects of different sizes have been measured and compared with those of good bearings. SPM measurements were also performed. The results of the measurements indicate that except for crest factor and SPM, all other parameters have detected defects in the bearings. The defect detectability of overall power is the best followed by peak and RMS measurements.

Key words: Condition monitoring; Rolling element bearings; Vibration

1. Introduction

Condition monitoring of rolling element bearings is of considerable importance to industry since an early detection of faults in them can prevent catastrophic failures in the machines. Vibration measurements are widely used for the detection of defects in bearings. These measurements are also used in the quality control departments of bearing manufacturers. A number of vibration parameters can be measured to detect the condition of rolling element bearings. Perhaps the most commonly measured parameter is the overall RMS acceleration level. Some vibration parameters have been monitored and compared during the life test of rolling element bearings [1,2]. In the present study the vibration parameters are compared for known and varying defect sizes introduced in the bearings. The parameters measured are overall RMS, peak, crest factor, power and the defect quefrency (reciprocal of frequency) level in the cepstrum of the vibration acceleration signal. Shock pulse measurements (SPM) were also performed. Crest factor is the ratio of the peak value of the signal to its RMS value. Cepstrum is defined as the spectrum of the logarithmic power spectrum and has been shown to detect defects in a four-ball life testing machine [3].

2. Measurements

The vibration measurements were performed on a test rig (Fig. 1(a)) in which the test bearings can be mounted at the end of the shaft. The support bearings in the rig are 25 mm bore deep groove ball bearings, prelubricated and sealed at both ends. The support bearings are low vibration generating. They were selected from a lot of similar bearings after measuring their vibrations in three broad frequency bands on a vibration test machine. The vibration measurements on the test bearings were performed at a speed of 1500 rpm. A radial load of 50 kg was applied to the test bearings by a lever-type arrangement (Fig. 1(b)).

The test bearings used in this study are SKF 6002 deep groove ball bearings with 15 mm bore. One circular defect was introduced in either the inner or outer race of these bearings by spark erosion. Bearings with defect diameters of 50, 100, 150, 250, 350 and 500 µm were prepared. The defect depth was kept constant as 100 µm (±10 µm). Six bearings without any defect were also tested to establish the vibration levels of good bearings. These test bearings were prepared and supplied for this study by the Engineering Research Centre of SKF. The dimensions of the minor axis of the Hertzian contact ellipse for the test bearings at 50 kg radial load was calculated as 183 µm and 118 µm for the outer and inner race respectively. The defect diameters introduced in the bearings are both smaller and bigger than the minor axis dimensions. In both cases the vibration levels are expected to increase because of the presence of defect. In the case of defect diameters bigger than the minor axis, the impacts of balls with defect produce higher levels of vibrations. When the defect diameter is smaller than the minor axis, a sudden increase in the contact stresses is expected on the passing of the balls over the defect because the contact area is suddenly reduced due to the presence of a defect. This sudden increase in the contact stresses is expected to result in higher vibration levels.

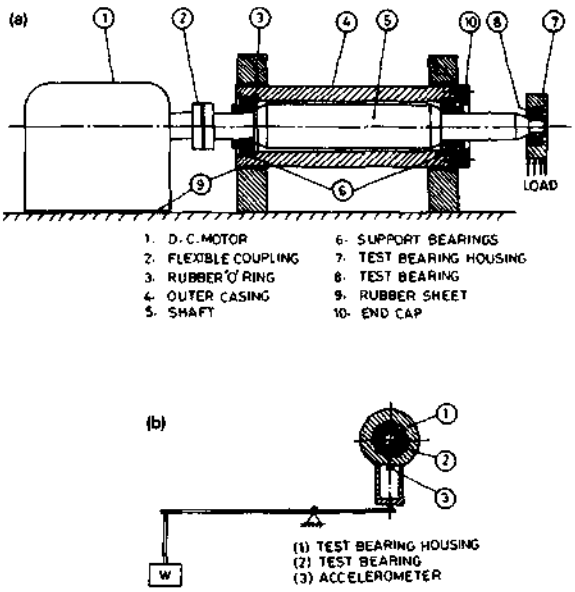


Fig. 1. (a) Bearing test rig; (b) loading arrangement.

Before measurements equal amounts of grease were applied to the test bearings. The bearings with outer race defect were mounted on the test rig with the defect located in the zone of maximum load. The high-resonant-frequency accelerometer was mounted on the test bearing housing to measure the vibrations in this zone. Vibration signals of bearings were recorded on a digital instrumentation cassette recorder through a charge amplifier. The frequency range for measurement of vibration RMS, peak and power was from 2 Hz to 20 kHz and for cepstrum measurements it was from 2 Hz to 6.4 kHz. The overall RMS and power levels presented are an average of 500 samples obtained on a real-time analyser. Vibration peak was measured on an electronic voltmeter in slow mode.

3. Results and discussion

The results of overall RMS, peak, crest factor and power of the vibration acceleration of the test bearings are shown in Figs. 2 to 5. The dashed lines in these figures represent the maximum and minimum levels obtained for the six good bearings tested. The dotted line is the average level produced by good bearings. There is only a small difference between the maximum and minimum values of RMS and power of good bearings. Except crest factor, all other parameters show higher levels for

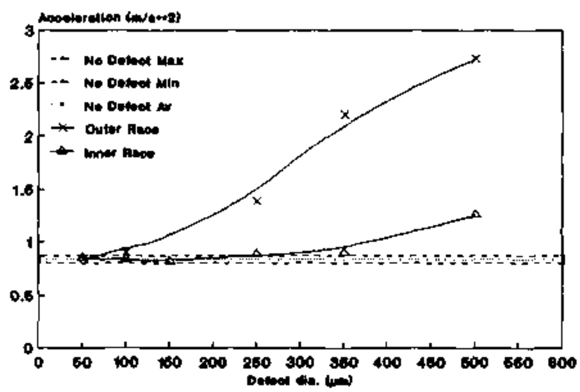


Fig. 2. Overall RMS vibration levels of bearings.

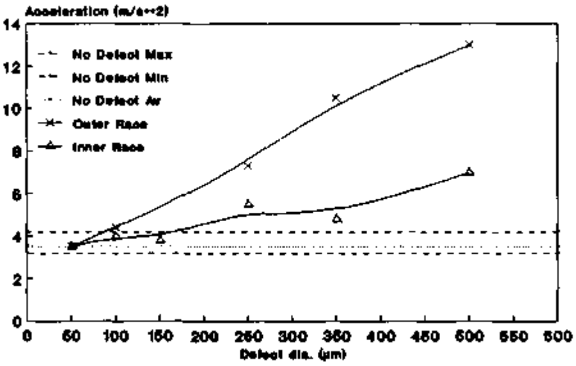


Fig. 3. Overall peak vibration levels of bearings.

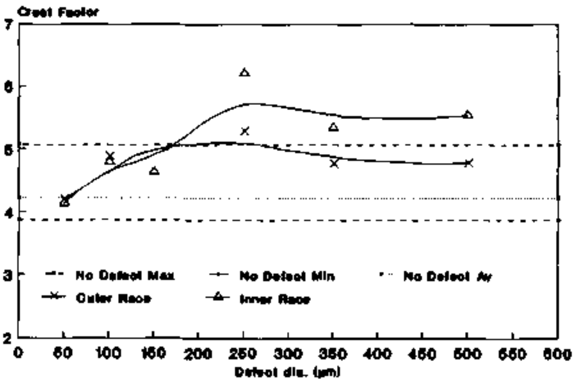


Fig. 4. Crest factor of bearings.

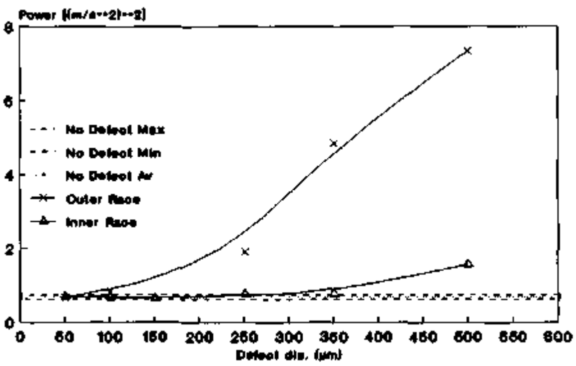
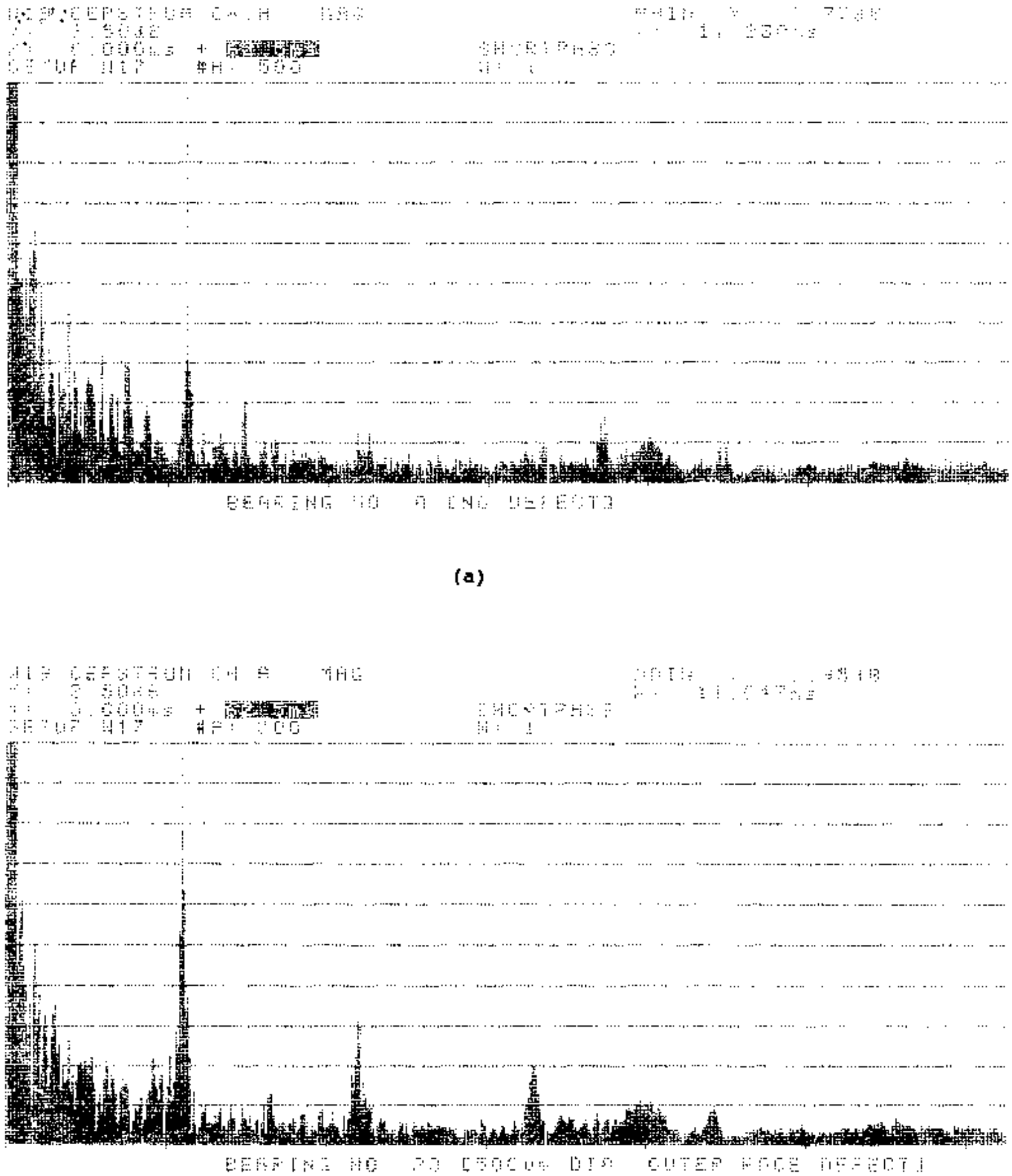


Fig. 5. Overall power of vibration acceleration of bearings.

outer race defected bearings as compared to those with defect in the inner race. Figure 4 indicates that the defect detection by crest factor is poor. Mathew and Alfredson [1] have also reported crest factor to be a poor indicator of the detection of incipient failure in rolling element bearings. The outer race defect diameters larger than about 75 µm are detected by RMS and power measurements (Figs. 2 and 5) whereas defect diameters larger than about 100 µm are detected by peak measurements (Fig. 3). Inner race defect diameters larger than about 300, 200 and 325 µm have been detected by RMS, peak and power measurements respectively (Figs. 2, 3 and 5).

Figure 6 shows the cepstrum obtained for one of the good and outer race defected bearings. The outer race defect frequency calculated for the test bearings at 1500 rpm is 89.7 Hz. The quefrency (reciprocal of frequency) corresponding to the outer race defect is 11.15 ms. Figures 6(a) and (b) show peaks very close to the calculated quefrency and its level for the outer race defected bearing is higher than that for the good bearing, indicating that the defect can be detected using these measurements. Figures 7 and 8 show the results of cepstrum measurements for different defect diameters for outer and inner race respectively. Figure 7 indicates that outer race defect diameters larger than about 75 µm have been detected. Surprisingly the inner race defect could not be detected by cepstrum measurements (Fig. 8). Distinct peaks were obtained at the inner race defect quefrency (7.4 ms) but their levels were not higher than those obtained for good bearings. This could be because the vibration increase in the case of inner race defected bearings was mainly in the high-frequency range of the spectrum (due to excitation of bearing elements/structural frequencies by the impacts of balls with defect) and not at inner race defect frequency.

SPM measurements were also performed on the test bearings using a hand-held probe. These measurements failed to detect the size of defects used in this study. Also, there was no trend of the normalized maximum shock pulse values (dB_M) measured. These values for the good bearings varied from 1 to 14 dB_M and the maximum value obtained for outer race defected bearings was 11 dB_M. Similarly for inner race defected bearings the value for a 500 µm diameter defect was 8 dB_M whereas for a 50 µm diameter defect it was 14 dB_M. A Bearing Analyser which indicates the condition of rolling element bearings in "code numbers" was also used. In this analyser the defect is indicated if the second



(a)

(b)

Fig. 6. Cepstrum of bearings: (a) with no defect; (b) with 500 μm diameter defect in the outer race.

digit of the code number displayed is 8 or 9. The measurements using this instrument also failed to detect defects as the second digit was either 0 or 1 for all the test bearings indicating a good condition. Discouraging SPM results have been reported by some other investigators [1,2] also.

3.1. Comparison of parameters

The vibration parameters have been compared in the form of defect detectability, which has been defined as the ratio of the level of the defective bearing to the maximum level of the good bearings.

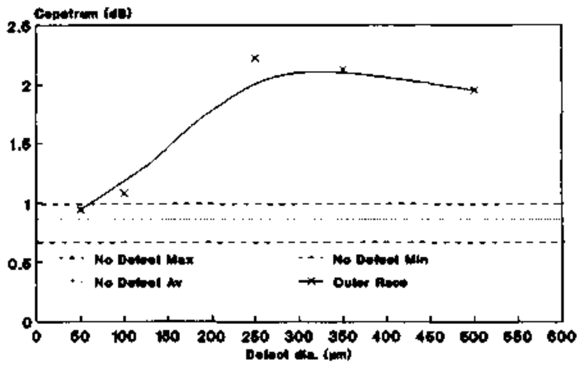


Fig. 7. Defect quefrency level in cepstrum of outer race defected bearings.

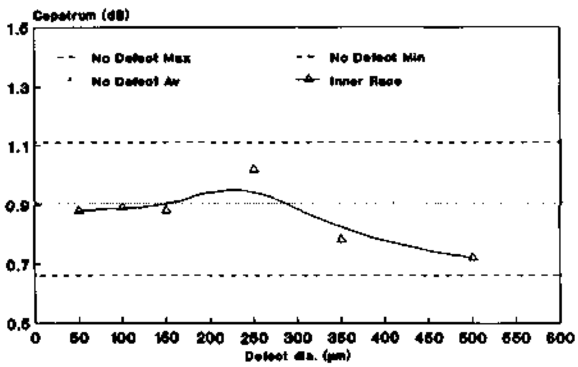


Fig. 8. Defect quefrency level in cepstrum of inner race defected bearings.

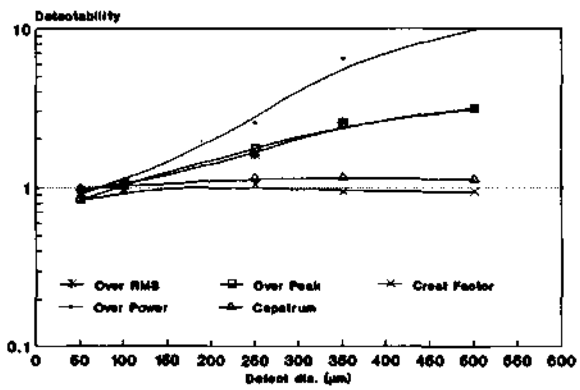


Fig. 9. Outer race defect detectability of bearings.

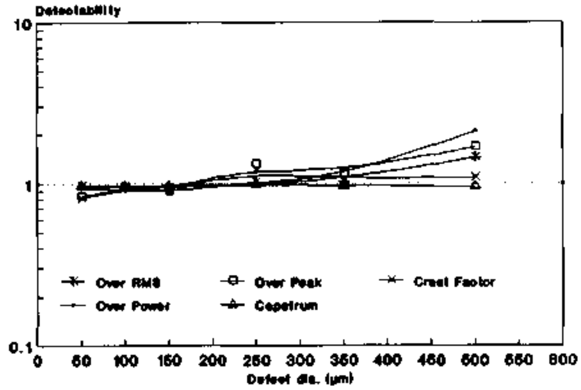


Fig. 10. Inner race defect detectability of bearings.

The detectability plots for the outer race and the inner race defects are shown in Figs. 9 and 10 respectively. They indicate that the defect detectability of overall power is the best, followed by peak and RMS measurements. The outer race defect is not detected by crest factor whereas the inner race defect is not detected by cepstrum.

4. Conclusions

Except for the SPM and crest factor all other vibration parameters detected defects in the bearings. However cepstrum measurements could detect only outer race defects. The smallest defect diameter detected in the outer race was 75 μm by measuring overall RMS or power of the vibration acceleration signal. In the case of inner race defects the smallest defect diameter detected was 200 μm by peak measurements. The defect detectability of overall power was the best followed by peak and RMS measurements.

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