

The Use of Acoustic Emission for Estimation of Bearing Defect Size

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Abstract Vibration monitoring of rolling element bearings is possibly the most established diagnostic technique for rotating machinery. The application of Acoustic Emission (AE) for bearing diagnosis is gaining ground as a complementary diagnostic tool, however, limitations in the successful application of the AE technique have been partly due to the difficulty in processing, interpreting and classifying the acquired data. Furthermore, the extent of bearing damage has eluded the AE diagnostician. The investigation reported in this paper was centered on the application of the Acoustic Emission technique for identifying the size of a defect on a radially loaded bearing. An experimental test-rig was designed such that defects of varying sizes could be seeded onto the outer race of a test bearing. It was concluded that AE can provide an indication of the defect size, thus allowing the user to monitor the rate of degradation on the bearing.

Keywords Acoustic emission · Bearing defect · Condition monitoring · Defect size · Vibration analysis

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Introduction

Acoustic emissions (AE) are defined as transient elastic waves generated from a rapid release of strain energy caused by a deformation or damage within or on the surface of a material [1]. In this particular investigation, AE's are defined as the transient elastic waves generated by the interaction of two surfaces in relative motion. The interaction of surface asperities and impingement of the bearing rollers over the seeded defect on the outer race will generate AE. Due to the high frequency content of the AE signatures typical mechanical noise (less than 20 kHz) is eliminated. There have been numerous investigations reported on applying AE to bearing defect diagnosis [2–11]. This paper investigates the relationship between the defect size and AE activity.

Experimental Test Rig and Test Bearing

The bearing test rig employed for this study had an operational speed range of 10–4,000 rpm with a maximum load capability of 16 kN via a hydraulic ram. The test bearing employed was a Cooper split type roller bearing (01B40MEX). The split type bearing was selected as it allowed defects to be seeded onto the races, furthermore, assembly and disassembly of the bearing was accomplished with minimum disruption to the test sequence, see Fig. 1.

Data Acquisition System and Signal Processing

The transducer employed for AE data acquisition was placed directly on the housing of the bearing, as shown in

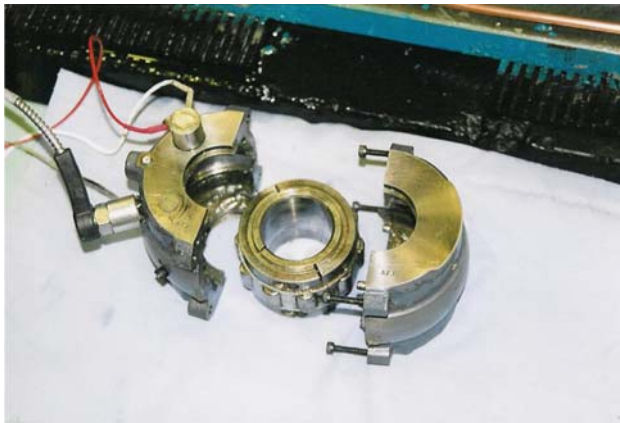


Fig. 1 Bearing test rig

Fig. 1. A piezoelectric type AE sensor (Physical Acoustic Corporation type WD) with an operating frequency range of 100–1,000 kHz was employed. This acquisition card provided a sampling rate of up to 10 MHz with 16-bit precision giving a dynamic range of more than 85 dB. In addition, anti-aliasing filters (100 KHz to 1.2 MHz) were built into the data acquisition card. A total of 256,000 data points were recorded per acquisition (data file) at sampling rates of between 8 and 10 MHz, dependent on simulation. Twenty (20) data files were recorded for each simulated case; as listed within the experimental procedure. The defects were seeded with an engraving machine.

Experimental Procedure

The aim of this program is to establish a correlation between AE activity with increasing defect size. This was accomplished by controlled incremental defect sizes at a fixed speed. For this particular test program, two experiments (E1 and E2) were carried out to authenticate observations relating AE to varying defect sizes. Each experiment included seven defects of different lengths and widths, as shown in Table 1. A sample defect is shown in Figs. 2 and 3. In experiment-1 (E1), a point defect (D1) was increased in length in three steps (D2–D4) and then increased in width in three more steps (D5–D7). However, in experiment-2 (E2), a point defect was increased in width and then in length interchangeably from D1 to D7. Both experiments were run at 2,000 rpm and at a load of 4.4 kN. The AE sampling rates for the first and second experiments are 8 MHz and 10 MHz, respectively. The seeded defects resulted in material protrusions above the mean surface roughness, (Fig. 2). It should be noted that condition D0 is the defect-free condition.

Table 1 Notation for test program-2 with seeded defect dimensions

| Experiment 1 | | Experiment 2 | |
|-----------------------------------|--------------|---------------------------------|-------------|
| Defect size (width × length) mm | | Defect size (width × length) mm | |
| <i>Defects of different sizes</i> | | | |
| E1-D0 | No defect | E2-D0 | No defect |
| E1-D1 | 0.85 × 0.85 | E2-D1 | 0.85 × 1.35 |
| E1-D2 | 1 × 2.95 | E2-D2 | 2 × 1.35 |
| E1-D3 | 1 × 7.12 | E2-D3 | 2 × 4 |
| E1-D4 | 1 × 15.83 | E2-D4 | 4 × 4 |
| E1-D5 | 3.98 × 15.83 | E2-D5 | 8 × 4 |
| E1-D6 | 8.66 × 15.83 | E2-D6 | 13 × 4 |
| E1-D7 | 13.6 × 15.83 | E2-D7 | 13 × 10 |

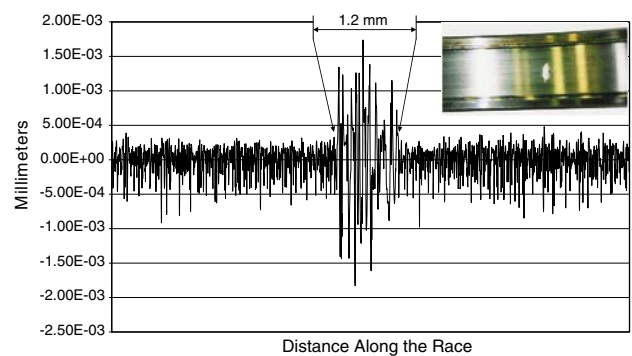


Fig. 2 Surface profile of a line defect condition

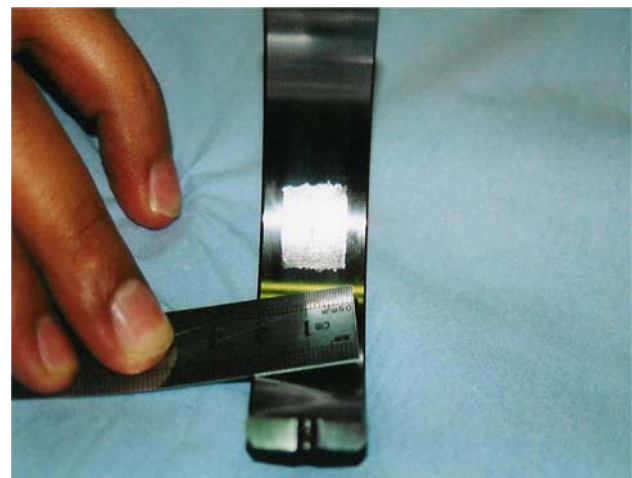


Fig. 3 The largest seeded defect, E1-D7, 13.6 × 15.83 mm

Observations of Experiment-1 (E1)

This experiment included seven defect conditions; D1–D4 had a fixed width with increasing length while defects

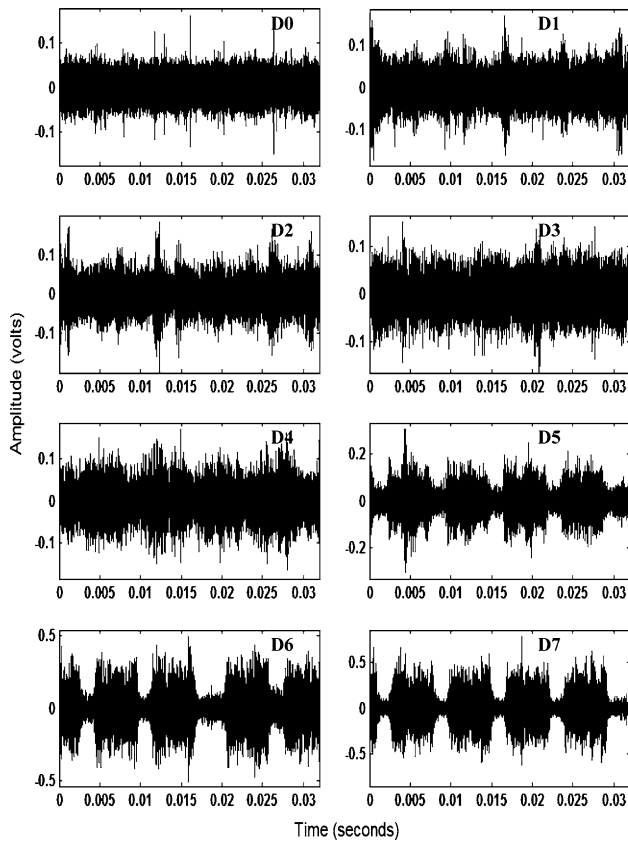


Fig. 4 Sample AE time wave forms for defects D0–D7 (Experiment-1)

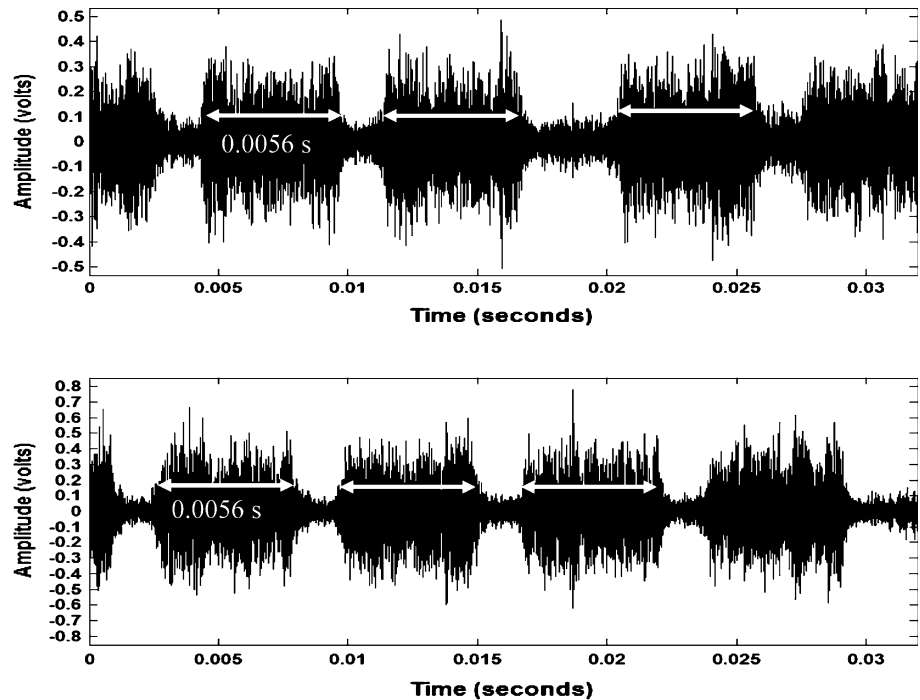
D4–D7 had a fixed length with increasing width (Table 1). From observations of the AE time waveforms, AE bursts were clearly evident from defects D4–D7, as shown in Fig. 4. The x-axis in these figures corresponds to one shaft revolution at 2,000 rpm. For defects D4–D7 the width of associated defect AE burst was measured in an attempt to relate the AE burst duration to the defect size. Interestingly, the bursts with equal defect length D4 to D7 had near identical burst durations, as shown in Fig. 5. For the other defects (D1–D3), the burst duration could not be separated from underlying background noise, most probably due to the size of the seeded defect. Also it was observed that the ratio of amplitude of the AE burst to underlying operational background noise increased incrementally from D4 through to D7, as the defect increased in width (Table 2).

Two conclusions can be drawn, firstly, increasing the defect width increased the ratio of burst amplitude to

Table 2 Burst to noise ratio’s for defects of fixed defect length (15.8 mm)

| Defect | Burst duration (s) | Burst amplitude (V) | Noise amplitude (V) | Burst to noise ratio |
|--------|--------------------|---------------------|---------------------|----------------------|
| D4 | 0.0061 | 0.13 | 0.09 | 1.4:1 |
| D5 | 0.0056 | 0.18 | 0.09 | 2.0:1 |
| D6 | 0.0056 | 0.33 | 0.11 | 3.0:1 |
| D7 | 0.0056 | 0.46 | 0.10 | 4.6:1 |

Fig. 5 Burst duration for defect D6 & D7 (Experiment-1)



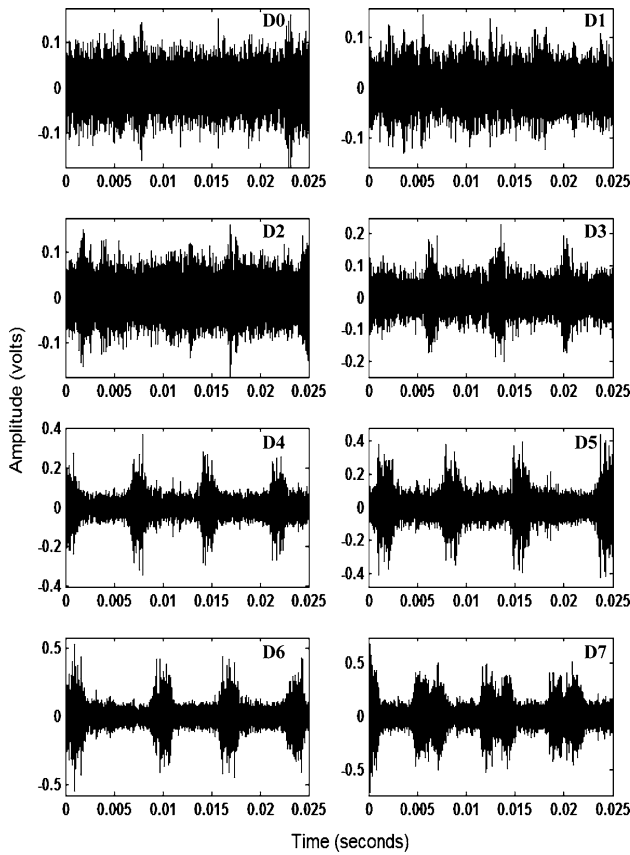
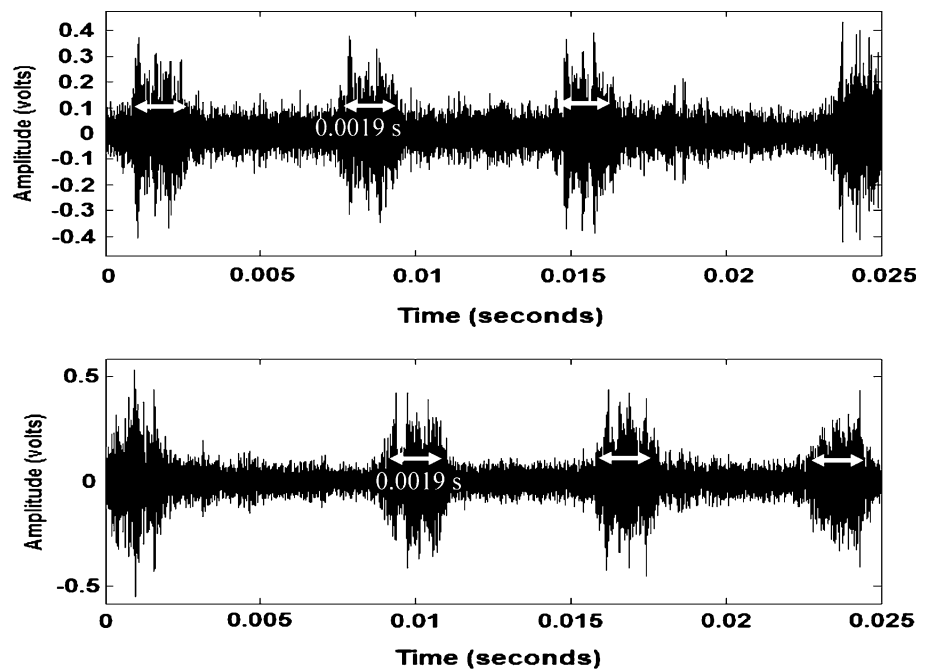


Fig. 6 Sample AE time wave-forms for defects D0–D7 (Experiment-2)

Fig. 7 AE waveform bursts for defects D5–D6 (Experiment-2)



operational noise (i.e., the burst signal was increasingly more evident above the operational noise levels, as shown in Fig. 4). Secondly, it was deduced that increasing the defect length increased the burst duration. To confirm this, a second experiment was performed utilizing the same running conditions but with different defect size combinations. Furthermore, the second test was undertaken to ensure repeatability, and a new bearing of identical type to that used in Experiment-1 was employed.

Observations of Experiment 2 (E2)

The difference between this experiment and that reported in the previous section is 2-fold. Firstly, the defect size and arrangement of the seeded defect progression was different from Experiment-1 and secondly, the AE data captured was sampled at 10 MHz. Observations of the bursts durations for defects D1–D7 (Fig. 2), identified that for defects D3 to D7, the burst duration was discernable; these defects had widths of at least 2 mm. It was also observed that the AE bursts for defects D3–D6 (Fig. 6) were similar; these defects had the same length of 4 mm. Clearly when the defect was increased in length from 4 to 10 mm (D6–D7) the burst duration increased dramatically (Figs. 6, 7, and 8). Table 3 details information on burst duration, amplitude, etc.

A summary of AE burst duration for Experiments-1 and -2 are detailed in Table 4. From Table 4 a linear

Fig. 8 AE waveform burst for defect D7 (Experiment-2)

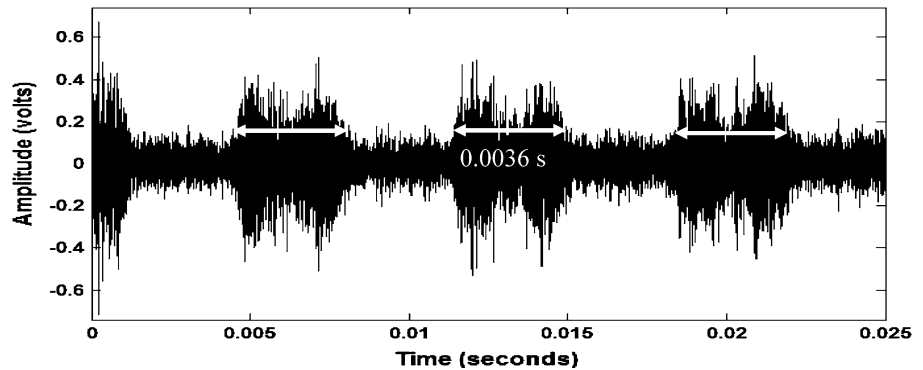


Table 3 Burst to noise ratio's for defects with a fixed length (4 mm) and a defect (D7) with an increased length (10 mm)

| Defect | Burst duration (s) | Burst amplitude (V) | Noise amplitude (V) | Signal to noise ratio |
|--------|--------------------|---------------------|---------------------|-----------------------|
| D3 | 0.0018 | 0.17 | 0.10 | 1.7:1 |
| D4 | 0.0018 | 0.24 | 0.09 | 2.7:1 |
| D5 | 0.0019 | 0.32 | 0.10 | 3.2:1 |
| D6 | 0.0019 | 0.43 | 0.11 | 3.9:1 |
| D7 | 0.0036 | 0.42 | 0.11 | 3.8:1 |

Table 4 Defect length and width versus burst duration from Experiments 1 and 2

| Exp. | Defect | Length (mm) | Width (mm) | Burst duration (s) |
|------|--------|-------------|-------------|--------------------|
| 2 | D3–D6 | 4 | 4, 8 and 13 | 0.00185 |
| 2 | D7 | 10 | 13 | 0.00360 |
| 1 | D5–D7 | 15.83 | 4, 9 and 14 | 0.00564 |

relation between the burst duration and the defect length is noted.

Discussions and Conclusions

The source of AE for seeded defects is attributed to material protrusions above the surface roughness of the outer race. AE transients associated with the defect frequency were observed. The relationship between defect size and AE burst duration is a significant finding. In the longer term, and with further research, this offers opportunities for prognosis. AE burst duration was directly correlated to the seeded defect length (along the race in the direction of the rolling action) whilst the ratio of burst amplitude to the underlying operational noise

levels was directly proportional to the seeded defect width.

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