Journal of Quality in Maintenance Engineering, Volume 15, Issue 2, 2009, Pages 193 - 201

OBSERVATIONS OF ACOUSTIC EMISSION IN A HYDRODYNAMIC BEARING

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Abstract

Numerous studies have been conducted in the field of Acoustic Emission technology applied to rotating machine fault diagnosis. Principally most of the work to date has been focused on correlating Acoustic Emission (AE) activity to the defect condition on rolling element bearings with limited investigations on hydrodynamic bearings. In developing the AE technology for monitoring hydrodynamic bearings operated under variable speed and load conditions it is essential that a relationship between the operational variables and the generation of AE is established. This paper presents experimental tests aimed at understanding the influence of speed and load on generation of Acoustic Emission in a hydrodynamic bearing. It is concluded that the power losses associated which such bearings has a direct influence on the generation of AE.

Keywords: Acoustic Emission, Condition monitoring, Hydrodynamic bearing.

1. Introduction

Acoustic Emission (AE) is defined as the range of phenomena that results in the generation of structure-borne and fluid-borne propagating waves due to the rapid release of energy from localised sources within and/or, on the surface of a material [1]. The typical frequency content of AE is within the range of 100 kHz to 1 MHz.

The AE technology is continually developing into a complimentary technology to other condition monitoring technologies such as vibration analysis [2, 12-29].

In the application of AE to hydrodynamic bearings (journal bearings) Sato [3] was the first investigator that directly addressed monitoring the integrity of such bearings with AE. Typical problems that are associated with journal bearings include wear and metal wipe which is a direct consequence of the shaft making contact with the journal. Such frictional contact is a prime source of AE. Others [4 to 8] have applied the AE technology to shaft-seal rubbing in large power generation turbines. Leahy et al [9] undertook the most realistic controlled verification of applicability of AE to shaft seal rubbing and Al-Shaikh Mubarak et al [10] attempted to apply the technology for monitoring blade rubbing. Whilst in all the cases highlighted above the measurement of AE was predominately made at the journal bearing housing, no attempt was made to understand the factors that govern the generation of AE within the bearing as a function of the operational variables such as load, film thickness and speed. The aim of this investigation is to ascertain the relationship between rotational speed, applied load, theoretical film thickness and AE r.m.s for hydrodynamic bearing, which hitherto has not .been explored.

2. EXPERIMENTAL PROGRAMME

The hydrodynamic bearing test rig employed for this study had an operational speed range of between 500 to 4000 rpm . The test bearing had a radius of 40 mm, length of 80mm and a recommended radial clearance of 0.04 mm. The bearing was lubricated with Castrol Magna BD 68 (ISO 32) with a base oil kinematic viscosity at 40°C and 100°C of 68cSt and 8.8cSt respectively. For these tests a maximum load of 800N was applied. One of the fundamental reasons for testing under very lightly loaded conditions was to ensure that a minimum film thickness of the test bearings was much larger than the surface roughness of the bearing (3μm Ra).

Two Physical Acoustics Pico type sensors (200 KHz to 750 KHz frequency bandwidth) were placed directly onto the test bearing at each end, see figure 2. The sensor output was amplified at 40 dB. The 'PICO' type sensor was employed due to its size (5 mm in diameter and 5 mm in height) making it suitable for placement in confined areas.

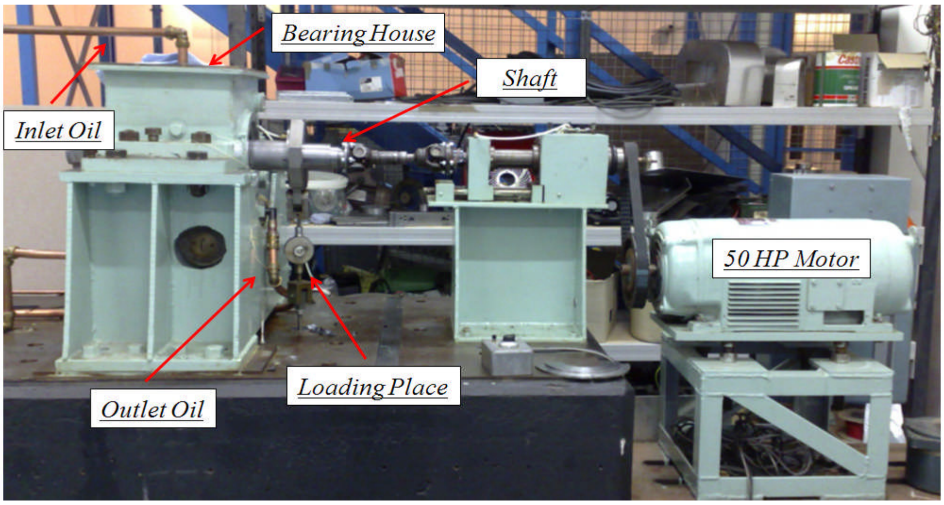

Figure 1 Test rig layout

In addition, two thermocouples used for measuring the journal temperature during the tests were welded onto the bearing race adjacent to the AE sensors. The test conditions investigated included five rotational speeds 500, 1000, 2000, 3000 and 4000 rpm and six load conditions, 300N, 400N, 500N, 600N, 700N and 800N. Loading was accomplished by placing weights onto a load plate linked to the rotating shaft either side of the test bearing, see figure 1. As such for a test condition of 800N, 400N force was applied to each loading plate. Acoustic Emission r.m.s values were calculated in real time by the analogue-to-digital converter over a time constant of 10milli-seconds and at a sampling rate of 100 Hz. AE waveforms were sampled at 2MHz.

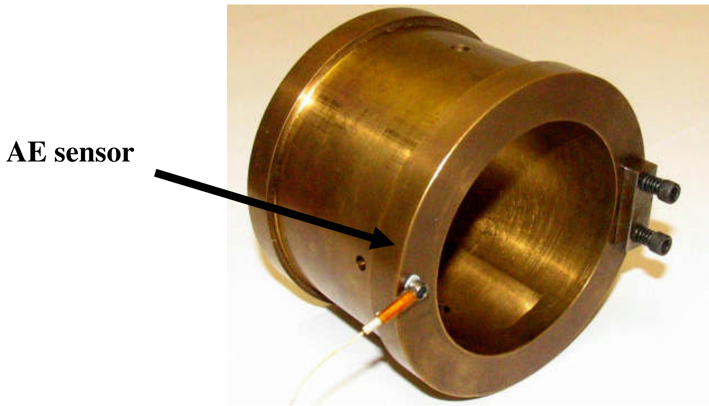

Figure 2 Location of AE and thermocouple sensors on test bearing

For this investigation tests involved varying the applied bearing load for fixed rotational speed whilst recording the AE r.m.s activity; each load condition was investigated under near constant temperatures. This was done in an attempt to eliminate the influence of temperature during the tests. Prior to performing the tests, the temperature of the test bearing was raised to approximately 40°C; this was achieved by running the test-rig in excess of 1000 rpm at 100N. As soon as the desired temperature was reached, the test sequence began. The test involved running the bearing at five rotational speeds and increasing the radial load, starting at 150N, and increasing the load in 50N increments every 5-minutes to a maximum of 400N. The five speed conditions investigated were, 500, 1000, 2000, 3000, and 4000 rpm. The test simulations under each load and speed condition was maintained at 5-minutes as longer operation would have significantly comprised the authors attempts to maintain near isothermal conditions. Over 4 experimental tests programmes were undertaken where the experimental procedure described was repeated.

3. RESULTS AND DISCUSSIONS

The results of this test are presented in figures 3, 4 and 5. Figure 3 highlights observations of theoretical minimum film thickness (h_0) and AE r.m.s measured on the bearing for a fixed speed condition. It is evident is that an increase in load resulted in a decrease in theoretical minimum film thicknesses and a corresponding increase in measured AE r.m.s values. This highlighted the sensitivity of the AE technology is discriminating such small differences in film thickness. Also It must be noted that during these test conditions, the temperature varied by a maximum of approximately ±3°C. All calculations of minimum film thickness and power losses were based on well established procedures [11].

From figure 4, it was noted that the change in load had a negligible influence on the level of AE activity for that particular speed condition, however, the change in rotational speed increased AE levels significantly even though the actual predicted change in minimum film thickness with increased speed was of the order of less than 1% for the tests conditions (see table A1 in Appendix). The corresponding increase in AE levels from changes in speed were in the order of over 150% on average, see table A2 in the Appendix. The authors attribute this significant change to the shearing effect of the lubricant which is a function of the rotational speed. As with hydrodynamic bearings there is no asperity contact and the corresponding increase in AE levels is attributed to the friction associated with the shearing of the lubricant. The values of AE r.m.s and minimum film thickness presented in figures 3 and 4 were obtained by averaging all AE r.m.s and h_o values measured and calculated over the specific load condition.

Observations showed AE levels increased with power losses, see figure 5, and averaged data is given in the appendix, table A3. All calculations of power loss at every test condition are presented in figure 5. It is worth stating that due to the minimal influence of load on film thickness under these test conditions, the power losses associated with varying loads, at the same speed condition, was very similar, see figure 5. The increase in AE with power loss was not surprising given that increase in speed results in more power loss due to the increased friction in the shearing of the lubricant. A reduced minimum film thickness causes increased power losses and such energy losses are noted by an increase in AE r.m.s levels. A relationship between the power losses and AE r.m.s levels was determined:

$$\text{AE (r.m.s in volts)} = A.W^3 - B.W^2 + C.W - D \qquad (1)$$

where W = power loss (KW), A = .006, B = 0.005. C = 0.01 and D = 0.01

This equation holds based on the assumption that the load has minimal influence on the film thickness which is the case for this investigation.

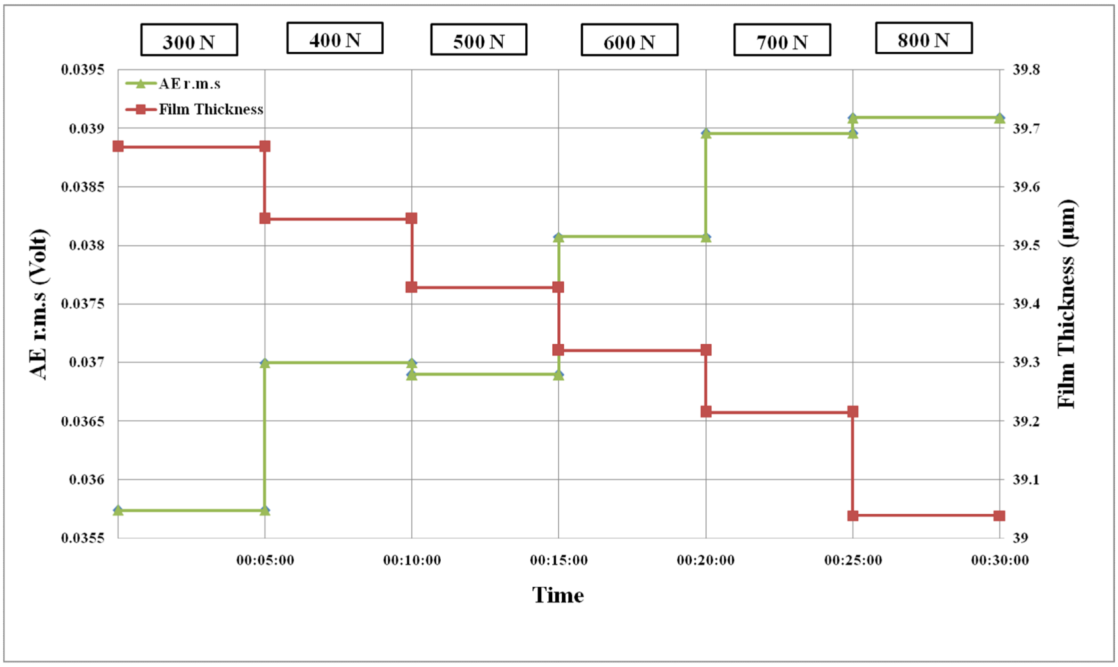

Figure 3 AE r.m.s levels for Load conditions (4000 rpm)

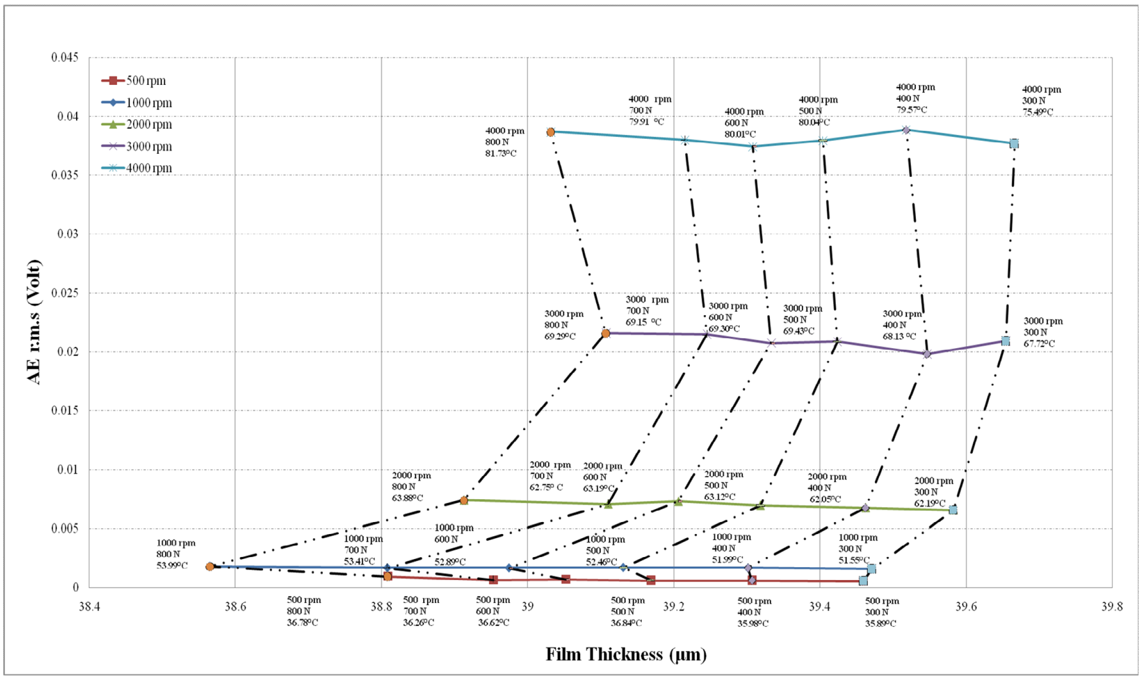

Figure 4 AE r.m.s levels for varying speed and load conditions (40dB amplification)

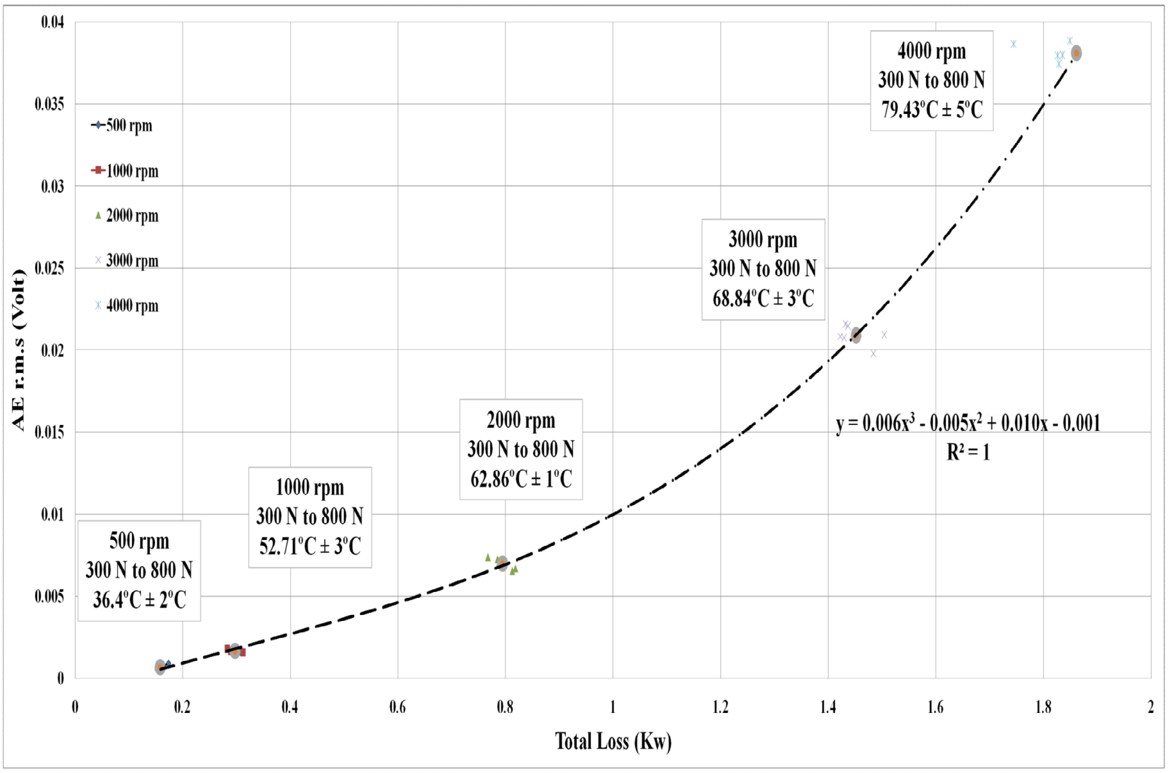

Figure 5 **AE r.m.s and total power loss for varying speed and load conditions**

3.2 Rubbing Test

A presumption made for most of the results presented is that under hydrodynamic conditions there is no asperity contact between the rotating shaft the bearing. It was thought prudent to assess the sensitivity of the AE measurements to the onset of contact between the shaft and the journal. In the rubbing tests the shaft was forced to rub against the journal. This was achieved by slowly increasing the load on the bearing at the drive end only; the loading of the bearing was changed rapidly at incremental values of 50N force to a maximum load of 400N. Initially the test was run at 1000 rpm (16.67 Hz) with a 50N load for 5 minutes, after which 50N increments were made within a two minute time frame to the maximum load of 400N at the drive end only. Interestingly, at 350N a significant increase in AE levels was noted, see figure 6. In addition, AE waveforms were acquired at each force increment as depicted in figure 6. It was noted that associated with the rise in AE levels the AE waveform was modulated at the rotational shaft speed, see figure 6 and 7. Figure 7 highlights a few AE waveforms showing varying degrees of amplitude of the modulated waveform, which is postulated to be a function of the intensity of the rub. Such observations validate the results of others [3, 4] as indicative of a rubbing contact within the journal.

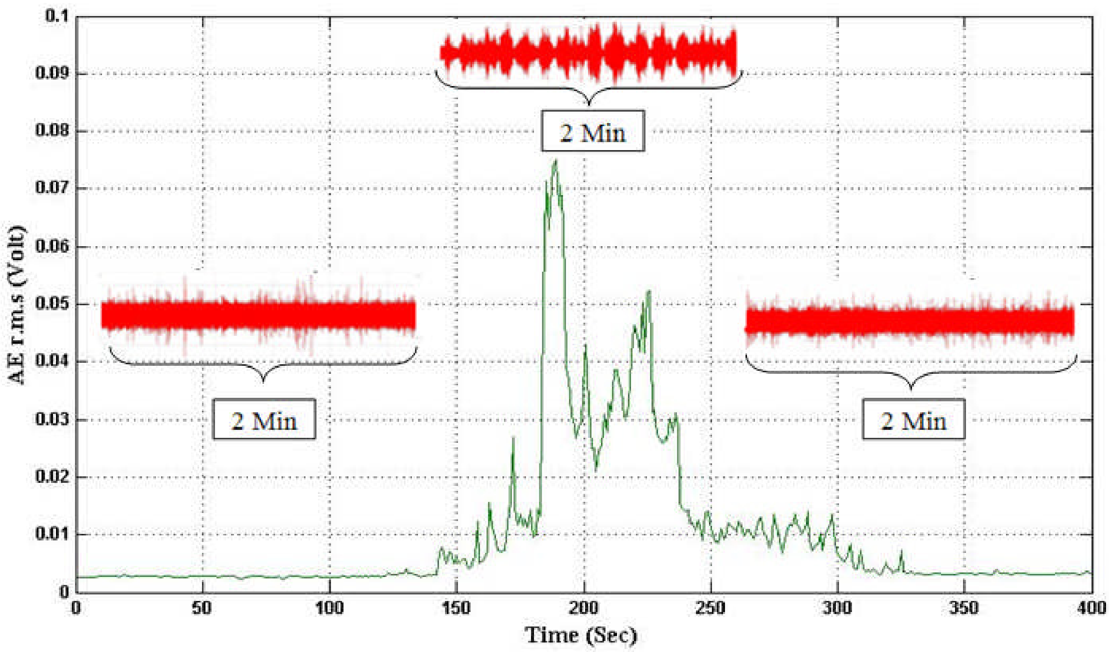

Figure 6 **AE r.m.s levels and associated sample waveform during rub tests**

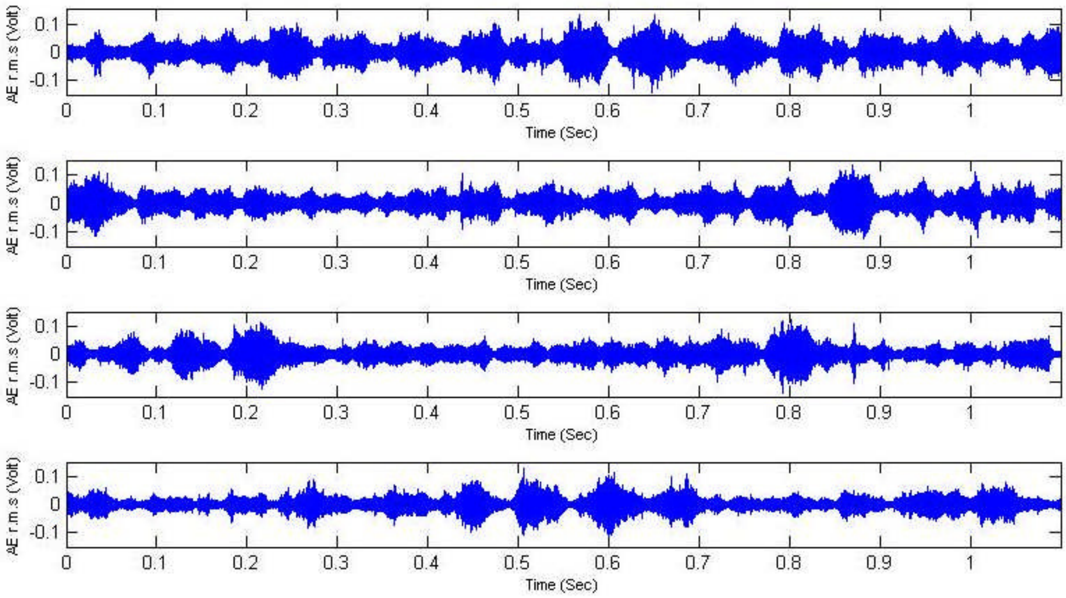

Figure 7 **Modulated AE waveforms due to rubbing between 170 seconds and 220 seconds of figure 6**

4. CONCLUSIONS

The observations presented have confirmed that in a properly maintained hydrodynamic lubrication regime a principal source of AE is the friction in the shearing of the lubricant. It has been shown that an increase in running speed generates higher AE activity in comparison to an increase in bearing load. This is attributed to the powers losses as a direct result of shearing of the lubricant film. Lastly, the application of AE to detection of bearing wipe has been demonstrated and further research is needed to fully understand the influence of operational variables on AE over a much broader operating range, including oil viscosity and bearing material effects.

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APPENDIX A

Table A1 AE r.m.s and minimum film thickness values

Film Thicknesss µm	800 N	%	700 N	%	600 N	%	500 N	%	400 N	%	300 N	%
4000 rpm	38.81	-0.63	38.95	-0.37	39.05	-0.20	39.17	-0.10	39.31	-0.01	39.46	0.03
3000 rpm	38.57	0.90	38.81	0.78	38.97	0.59	39.13	0.48	39.30	0.41	39.47	0.28
2000 rpm	38.91	0.50	39.11	0.35	39.21	0.32	39.32	0.27	39.46	0.21	39.58	0.18
1000 rpm	39.11	-0.19	39.25	-0.08	39.33	-0.06	39.42	-0.05	39.55	-0.07	39.65	0.03
500 rpm	39.03	-	39.22	-	39.31	-	39.40	-	39.52	-	39.67	-

Table A2 Changes in AE r.m.s levels for varying speed and load conditions

AE r.m.s	800 N	%	700 N	%	600 N	%	500 N	%	400 N	%	300 N	%
4000 rpm	0.0009	92.89	0.0006	165.32	0.0007	147.48	0.0006	178.42	0.0006	176.73	0.0005	192.01
3000 rpm	0.0018	315.48	0.0017	324.53	0.0016	341.08	0.0017	311.93	0.0016	308.24	0.0016	318.60
2000 rpm	0.0074	192.32	0.0070	204.87	0.0073	185.06	0.0069	200.75	0.0067	194.85	0.0065	219.97
1000 rpm	0.0216	79.20	0.0215	76.94	0.0207	80.49	0.0209	81.97	0.0198	96.09	0.0209	80.20
500 rpm	0.0387	-	0.0380	-	0.0374	-	0.0379	-	0.0389	-	0.0377	-

Table A3 Relative percentage changes in AE r.m.s and total power loss

%	Total KW	Total KW %	AE r.ms	AE r.ms %
500 rpm	0.159	-	0.001	-
1000 rpm	0.298	87	0.002	152
2000 rpm	0.795	166	0.007	319
3000 rpm	1.451	82	0.021	199
4000 rpm	1.861	28	0.038	82

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2009-05-29T00:00:00Z

S. Ali Mirhadizadeh, D. Mba, Observations of acoustic emission in a hydrodynamic bearing, Journal of Quality in Maintenance Engineering, Volume 15, Issue 2, 2009, Pages 193 - 201.

http://doi.org/10.1108/13552510910961138