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Characterization of Acoustic Emissions from Journal Bearings for Fault Detection

Hossein Towsyfyan, Parno Raharjo, Fengshou Gu and Andrew Ball
School of Computing and Engineering, University of Huddersfield,
Queens gate, Huddersfield, HD1 3DH, UK
Telephone: 00447454547412
E-mail: Hossein.Towsyfyan@hud.ac.uk

Abstract

Acoustic emission (AE) technology is one of the most established diagnostic techniques for rolling bearing monitoring in rotating machinery. The application of high-frequency AE for bearing diagnosis is gaining acceptance as a useful complimentary tool. This paper demonstrates the use of AE measurements to investigate the AE characteristics of self-aligning journal bearings under different rotational speed, radial load and lubrication condition. To undertake this task, a purpose-built test rig was employed for collecting AE signals from the journal bearings. Then, the collected data was processed using time domain and frequency domain analysis methods which are of the most common techniques used for monitoring in AE applications. The results shown that the data analysis method applied in this work is effective for characterising complicated AE signals. Based on obtained results, it is concluded that the AE energy levels in high frequency range higher for the higher radial load and speed condition. For different lubricant cases AE energy becomes high when the viscosity is lower, which means that AE can be used to detect lubrication degradation in journal bearings.

1. Introduction

Journal bearings are used widely in high power industrial machinery such as steam turbines and large pumps. These can be grouped into bushing, split journal bearing, spherical or self-aligning plain/journal bearing, tilting pad bearing and thrust bearing. A self- aligning spherical journal bearing, as shown in figure 1, consists of a spherical plain bearing that has a spherical contact surface permits the bearing to move freely in all directions, which gives it the capability to self-aligning to accommodate a few degree of misalignment.

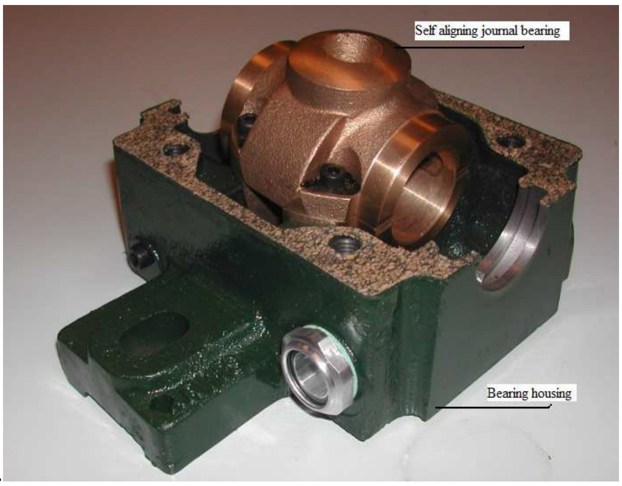

Figure 1. Self-aligning spherical journal bearing

Journal bearings are reliable and considered superior to rolling element bearings in high load capacity, vibration absorption, shock resistance, quietness, and long life. All these characteristics come from the journal bearing principle of supporting a shaft by a thin oil film [1]. However, asperity contact is inevitable in the processes of machine start and stop, or under severe working conditions, such as insufficient lubricant supply, high operating temperature, and heavy loading. Figure 2 gives the interaction between two relative moving surfaces in journal bearings. As the first component contacts second component under a load condition, the approaching surface between them becomes a closely interrelated system influencing the way one component slides over another. As sliding starts, any fluid lubricant will shear and the viscous response to surface discontinuities will produce pressure in the fluid. If the pressure is sufficient to balance the applied load, sliding will occur with no solid contact between the surfaces. Increase in the load causes a decrease in the thickness of fluid film [2].

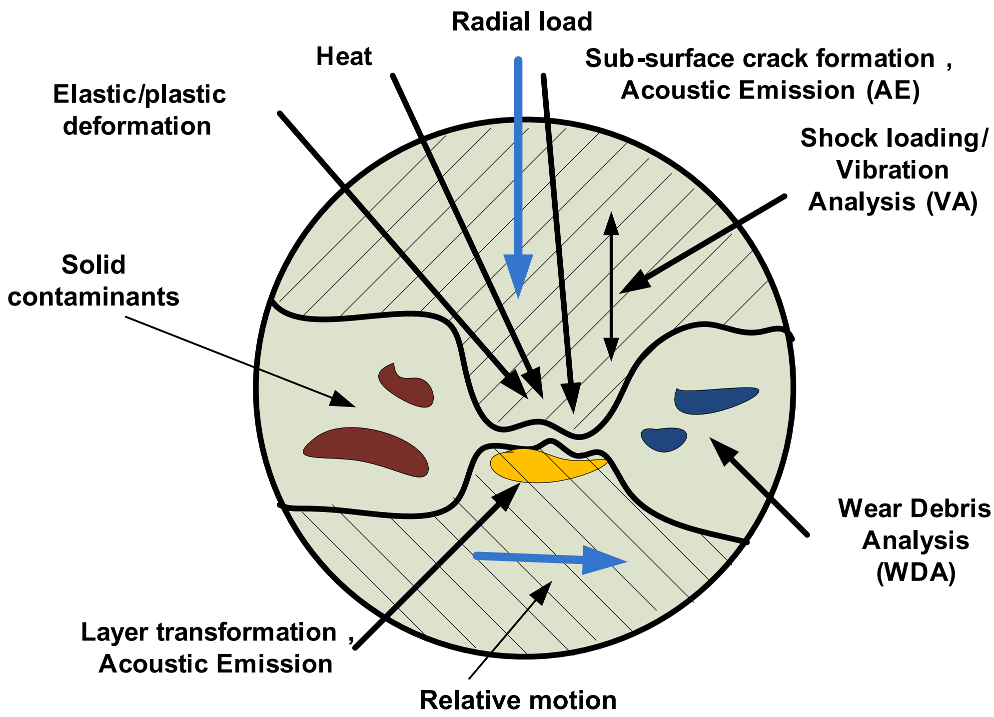

Figure 2. Interaction between two surfaces in relative motion [3].

AE is an inspection technique which detects elastic waves generated by such sources as friction, crack initiation and propagation and product leaks. Since asperity contact produces high frequency excitations, AE is required for detecting early faults in self -aligning journal bearings due to frequency limitation of other methods such as vibration measurement. A tremendous amount of work has been reported over the last 30 years on applying AE to bearing condition monitoring (CM) [4-7], however Its application in industry with respect to monitoring bearing faults is relatively new [8].To date most published work, Raharjo et al. studied the AE response characteristic of the self -aligning spherical journal bearing, they reported that AE can detect bearing fault in high frequency range and proved a positive correlation between speed, load and AE RMS value [7]. Dickerhof et al. investigated lubrication regimes in sliding bearing using acoustic emission. They showed that acoustic emission analysis is an appropriate measurement procedure to detect incipient failure at sliding bearing with correlation between the emitted acoustic signal and the energy dissipated in the sliding metallic contact [9]. In Al-Ghamd and

Mba's investigation [10], defects of varying severity in rolling element bearings were detected by AE RMS amplitude and burst duration. By comparing the vibration and shock pulse with acoustic emissions, Tandon et al [11] proved that the measurement of AE peak amplitude was the best condition monitoring technique for the detection of grease contaminants in motor bearings.
Off line processing of AE signal waveforms recorded during condition monitoring is another challenging problem in AE area. During condition monitoring on bearings, today's Acoustic emission systems are able to process thousands of AE events per second and record them to data storage. A number of studies have investigated the use of the time domain and frequency domain techniques in processing the AE signals from bearings and showed that using these techniques, it is possible to process AE signals using sophisticated computing methods [10-13].
In this paper, the AE characteristic of self-aligning journal bearings is investigated using time domain and frequency domain analysis. In this regard, AE results from the self- aligning bearing are presented in the time domain and the frequency firstly and then AE feature parameter such as AE mean value is explored in associating with radial load, speed and different types of lubricants.

2. AE FROM JOURNAL BEARINGS

Bearings are in a central position in the monitoring of the condition of rotating machinery and their condition monitoring can detect faults at early stage and hence minimize the occurrence of catastrophic failures. AE source in journal bearings may originate from sliding friction [7].The friction in sliding bearings depends on lubricated regions which are influenced by load, speed, lubricant viscosity and bearing conditions. Hydrodynamic lubrication means that the bearing surfaces are completely separated by oil film, almost there is not severity contact and hence creates very small AE signal. In practical oil lubricated bearing applications the hydrodynamic situation may appear only in certain running conditions, like in the starting situation if the bearing is full of oil. When bearing is operated in boundary lubricated region, more asperity contact occurs and generates large AE responses. Mixed lubrication occurs between boundary and hydrodynamic lubrication range and creates medium of AE value.
Generation of AE signals can be explored by considering the contact between two solid surfaces which are separated by the asperities of random height distribution. Figure 3 shows a smooth surface with another being rough. In this particular study, AE's are defined as the transient elastic waves generated by the interaction of two solid surfaces which are separated by the asperities of random height distribution.

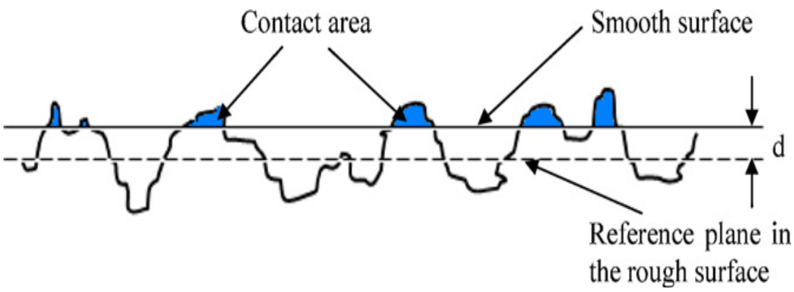

Figure 3. Contact of rough and smooth surfaces [14]

With assumption that the separation of the smooth plane and the reference plane in the rough surface is d, it can be concluded from figure 3 all the asperities with a height in excess of d would contact with the smooth surface and generate AE signals. So the probability of making contact at any selected asperity can be expressed as:

$$p(z > d) = \int_d^\infty f(z)dz$$

The value f(z) for any height z is proportional to the probability of finding a point with the height of z and could be estimated by surface roughness measurement techniques. If the number of asperities per unit area is DSUM (which can be estimated using the empirical relationship), the expected number of contacts in any unit area is:

$$n_a = \mathrm{D}_{\mathrm{SUM}} \int_d^\infty f(z)dz$$

Based on the model developed by Fan et al [14], the elastic energy release rate of the asperity can be obtained as:

$$\dot{E} = \frac{2A.\mathrm{n_a}.V.W^{4/3}}{5(3E'.R'^2)^{1/3}} \tag{1}$$

Where A is the effective contact area of the two surfaces; n_a is the number of asperity in a unit area; E' is equivalent elastics modulus for two different material solid contacts (E' in N/m^2); V is Velocity (V in m/s); R' (m) is equivalent radius of the contact surface; W (N) is radial load. Based on equation (1), higher energy rate will be produced when sliding speed and radial load are high. On the other hand, if the lubricant film is thick enough to separate the components' contacting surfaces, then the lower energy rate will be produced. Equation for the minimum lubricant film thickness (h_{min}) for the hydrodynamic lubrication regime can be found in the work of Cracaoanu (15) as follow:

$$h_{\min} = c.f(\alpha, G).(\frac{\eta.V}{P})^n \tag{2}$$

In which c is a constant, $f(\alpha, G)$ is a function which depends on contact geometry (G) and pressure-viscosity coefficient (α), n is a power coefficient (~ 0.7), η is dynamic viscosity, v is velocity, and p is the mean contact pressure. Considering Eq.(2), it can be concluded that if lubricating oil has low viscosity, it would not stay in the contact area under load, and would immediately flow away, then result in decreasing the minimum thickness of lubricant. Actually it is the viscosity property of oil which keeps it in a film, allowing it to lubricate and separate asperities that may otherwise contact each other and generate AE. Cann and Lubrecht (16) explain that the greater film thickness is due a higher effective viscosity. Considering Eq.(2), inconsistence effect of velocity (V) for equation (1) is concluded, according to Eq.(1) increasing the velocity will result in lower $h_{\min}$ and AE generates higher amplitude. This case is caused by mixed lubrication regime in between shaft and bearing.

3. Experimental Test Rig and Test Bearing

The test rig is displayed in figure 4. The driving power is a 9.0 kW, 3-phase, 4 pole AC electric inductions motor. Its speed and load are controlled by a Siemens Micro Master Controller so the drive shaft can be run at different speeds up to a maximum of 1450 rpm. Two pairs of HRC flexible couplings couple the motor to the DC generator trough cylindrical steel shafts. Two journal bearings SA35M supporting the shafts are tested. The bearing nearer the motor is called as DE or drive end bearing and the other bearing is NDE or non-drive end bearing. A radial load is applied to the central shaft using a hand pump with a pressure gate to pressurize a hydraulic cylinder ram, which is connected to a load cell and pressure transmitter.

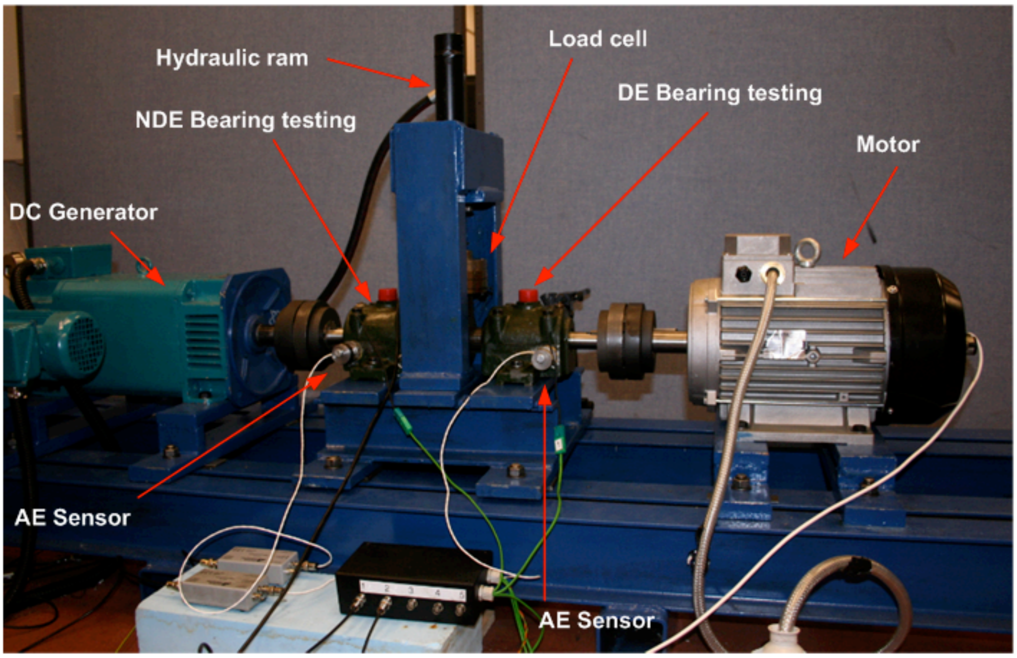

Figure 4. Lay out of the test rig

The specification of the tested journal bearing is shown in Table 1.

Table 1. Self-aligning Journal Bearing Specification

Types of bearing	Self-aligning journal bearing
Bearing code	SA35 M/S4170
Diameter of bearing (hole)	35 mm
Length of bearing	76 mm
Spherical radius of bearing	82 mm
Lubrication system	Oil ring
Maximum load	10 kN

4. Data Acquisition System and Signal Processing

The transducer employed for AE data acquisition was placed directly on the housing of the two journal bearings. A WD S/N FQ36 AE sensor with an operating frequency band from 100k to 300k was employed to obtain the AE signals, allowing high frequency events due to asperity contacts to be monitored. The signal from AE sensor is amplified and acquired by a 2MHz high speed data acquisition system with 16 bit resolution.

5. Experimental Procedure

The aim of this program is to establish a correlation between AE activity with rotational speed, radial load and lubricant viscosity variation. This was accomplished by controlled incremental radial load at constant speed and viscosity. The bearings were lubricated with specified lubricant ISO VG 32, ISO VG 46 and ISO VG 68 .Table 2 represents the values of input variables of experimental tests.

Table 2. Input test

Speed	Radial Load	Lubricant
25 %	0, 10 and 20 bar	ISO VG 32,46 and 68
50 %	0, 10 and 20 bar	ISO VG 32,46 and 68
75 %	0, 10 and 20 bar	ISO VG 32,46 and 68
100 %	0, 10 and 20 bar	ISO VG 32,46 and 68

6. Results and Discussion

6.1 .Signal Characteristics

Observations of AE energy monitored for different radial load are presented in this part. A sample of AE signals for NDE journal bearing is shown in figure 6. The figure indicates that the type of AE responses is mixing between the burst type and continuous type. It can be seen that the amplitude in the time domain increases with increasing in radial load. It means that more AE events are generated at higher load.

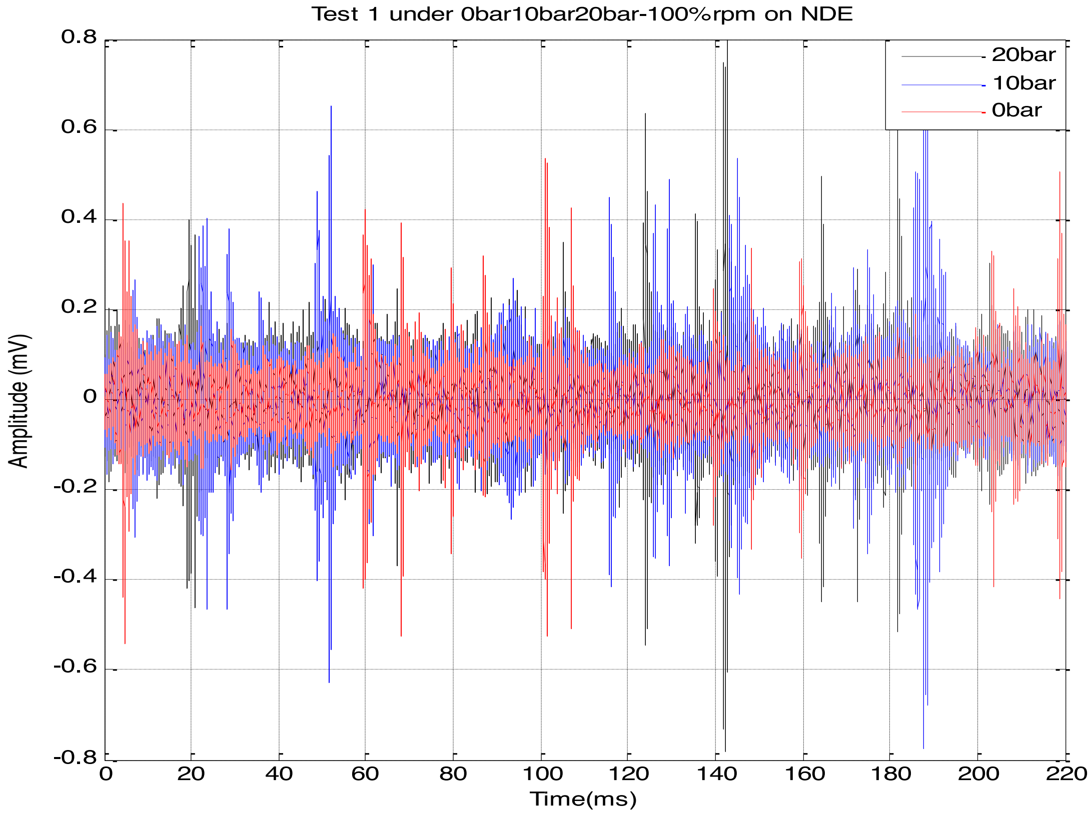

Figure 6. AE signal for NDE journal bearing

A sample of AE spectrum for NDE journal bearings is shown in figure 7. It can be seen that in the low frequency events, a significant rise in AE energy levels was observed. Also, it was noted that AE energy levels were higher for the higher load conditions due to higher rate of elastic energy release from asperity contact.

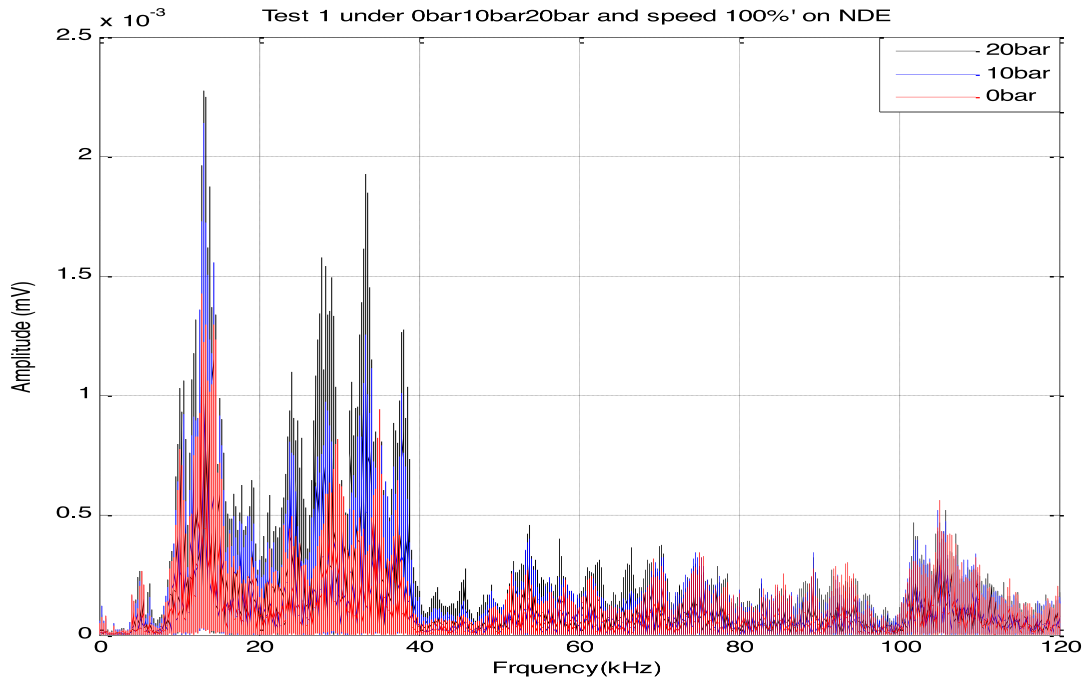

Figure 7. AE spectrum for NDE journal bearing

6.2. Speed and Load Characteristics

The correlation between rotational speed and AE Mean spectrum values for NDE journal bearing is presented in figure 8. It can be seen that for all tests, AE Mean spectrum value was higher for the higher load conditions. Furthermore, it was noted that the AE Mean spectrum value increased slightly with the rotational speed.

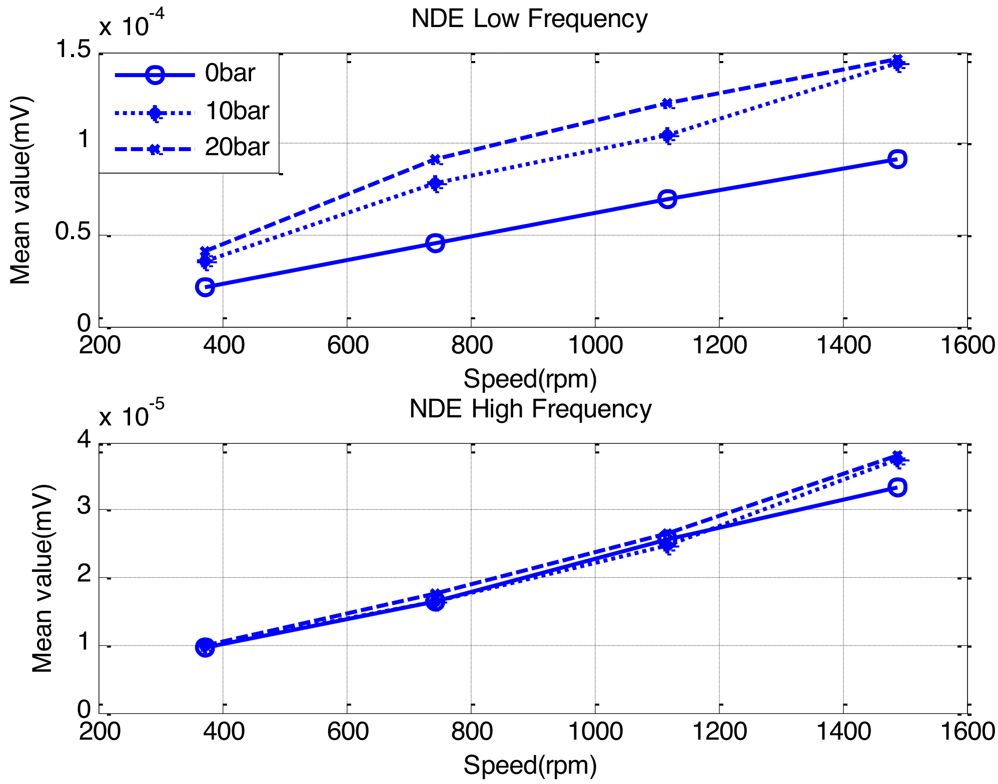

Figure 8. AE Mean spectrum value and rotational speed for NDE journal bearing

6.3. Lubrication Characteristics

Figure 9 shows the AE signals at NDE bearing under 20 bar radial load at 100% speed and the variation of lubricant viscosity of ISO VG 32, 48 and 68. The figure shows the burst type of acoustic emission which can be explained by influence of the vibration of the bearing on the lubrication regime. Vibration can cause more asperity contacts, which means increase the acoustic emission level of the bearing. Based on figure, it can be concluded the higher viscosity of lubricant enables bearing to operate under better lubrication films, which leads to the smaller amplitude of AE responses.

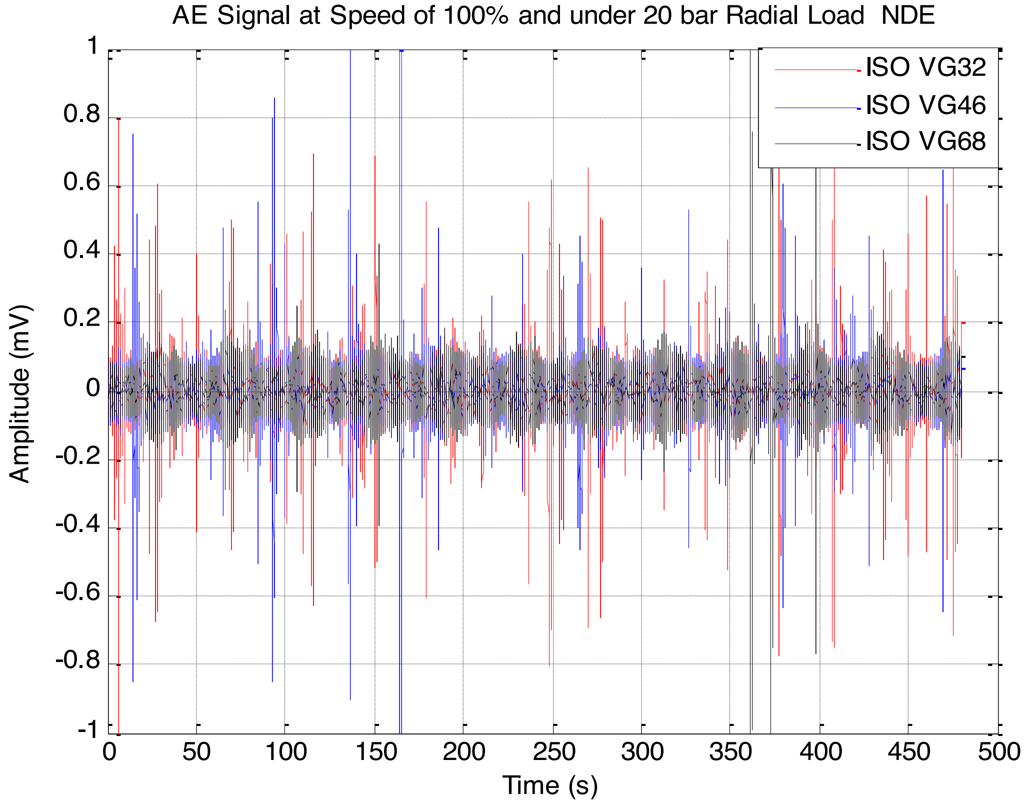

Figure 9. AE signal for NDE journal bearing

A sample of AE spectrum for NDE journal bearing is shown in figure 10. It can be clearly seen that if the lubricant has higher viscosity, it generates smaller AE amplitude.

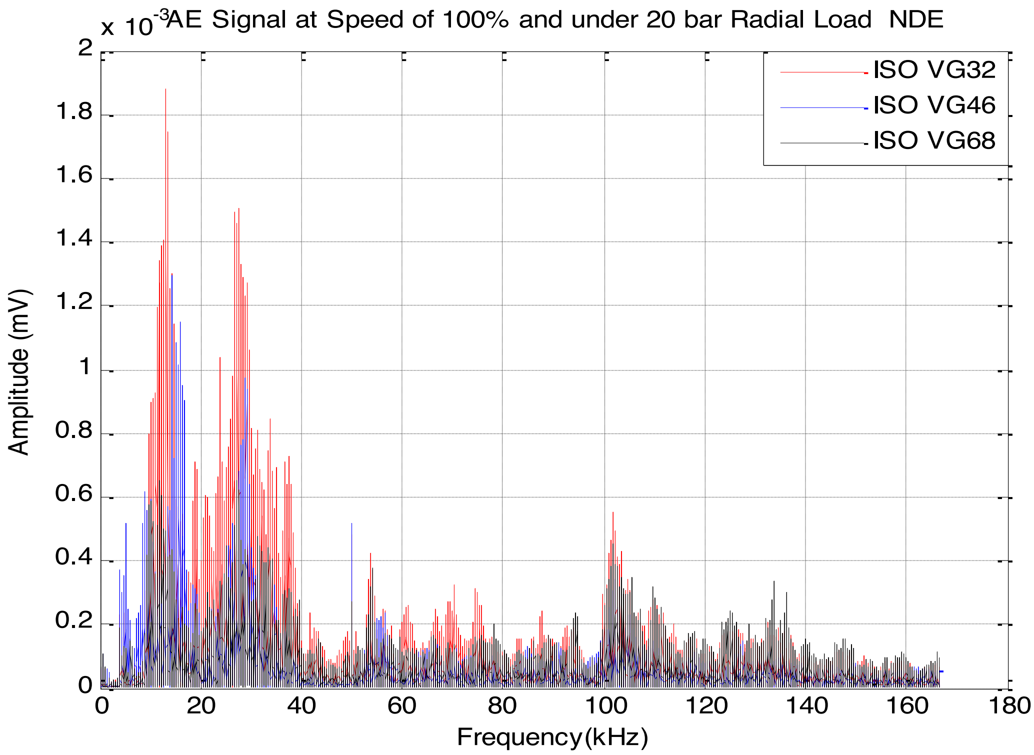

Figure 10. AE spectrum for NDE journal bearing

The correlation between rotational speed and AE Mean spectrum values for different working condition is presented in figure 11. It can be concluded that AE Mean spectrum value is higher for the lower viscosity conditions.

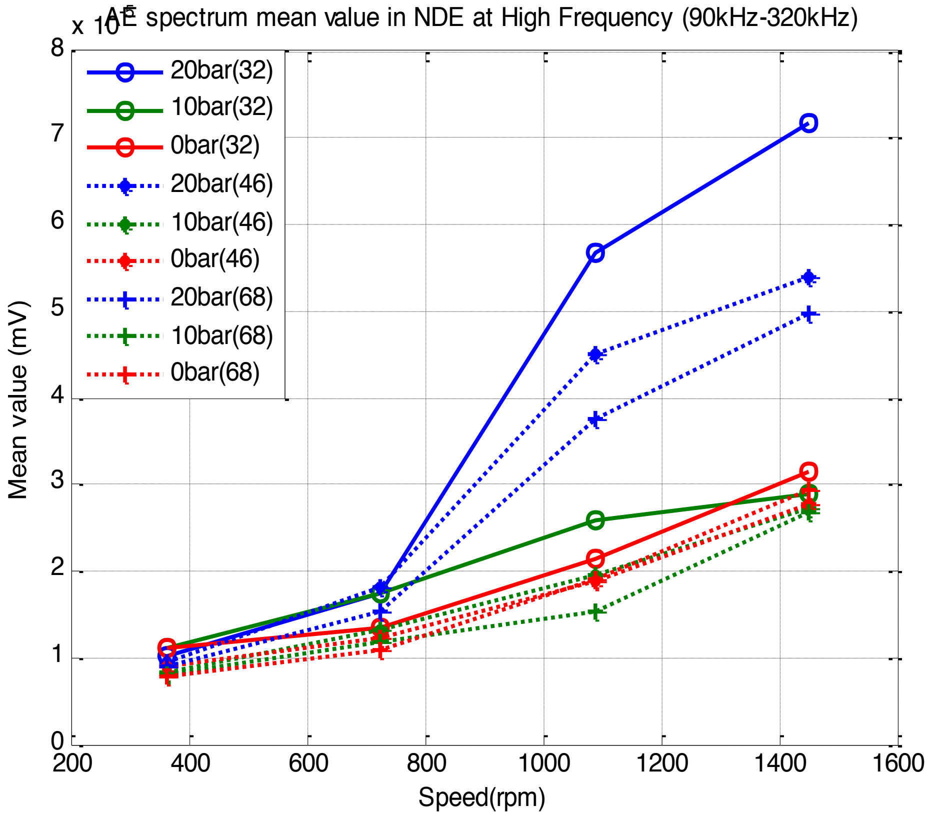

Figure 11. AE Mean spectrum value at speed, load and viscosity variation for NDE journal bearing.

7. Conclusion

This paper was combined with two established signal processing methods: time domain and frequency domain analysis in an effort to produce a powerful combination that in common can distinguish AE features in self-aligning journal bearing components under the working condition. Based on obtained results AE characteristics were directly correlated to the radial load, rotational speed and lubricant variation. The AE signal achieved in this research was mixing type, It successfully demonstrated the AE energy level were higher for the higher load and speed conditions due to higher rate of elastic energy release from asperity contact, on the other head, the higher viscosity of lubricant enables bearing to operate under better lubrication conditions, because increasing the viscosity will reduce the asperity contact, which leads to the smaller amplitude of AE responses.

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