An Investigation of Acoustic Emission Responses of a Self Aligning Spherical Journal Bearing

P. Raharjo[a], Shukri A. Abdusslam[a], Tie Wang[b], F. Gu[a] and A. D. Ball[a]

[a]School of Computing and Engineering, University of Huddersfield,

Queensgate, Huddersfield, HD1 3DH, UK

[b]Gear Transmission Institute, Taiyuan University of Technology, Shanxi, P.R.China

Abstract

High power industrial machinery such as steam turbines and large pumps use journal bearings as rotor supports because this type of bearing is a high load carrying capacity. However, abnormal operating conditions in the journal bearings will degrade machine performance, shorten life time and increase the risk of operation. Bearing condition monitoring can detect faults at early stage and hence minimise the occurrence of catastrophic failures. Vibration measurement from an accelerometer is an effective method for monitoring journal bearing. However, due to frequency limitation, it cannot give accurate monitoring results when the bearing produces high frequency excitations such as asperity contacts. For overcoming the limits, acoustic emission (AE) is required for detecting early faults in self aligning journal bearings in high frequency ranges. AE source in journal bearings may originate from sliding friction. The friction in sliding bearings depends on lubricated regions which are influenced by load, speed, lubricant viscosity and bearing conditions. When bearing is operated in boundary lubricated region more asperity contact occurs and generates large AE responses. 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. Mixed lubrication occurs between boundary and hydrodynamic lubrication range and creates medium of AE value. The result of AE experiment for self-aligning spherical journal bearing indicates that AE can detect bearing fault in high frequency range till 15000 Hz. For addition there is a positive correlation between speed, load and AE RMS value. For lubricant, if the lubricant has higher viscosity, it generates smaller AE amplitude. The AE characteristic also shows that AE RMS value relates to the friction curve.

Keywords: *Self aligning spherical journal bearings, condition monitoring, vibration, acoustic-emission.*

1. INTRODUCTION

Journal bearings are used widely in load machinery such as steam turbines and large pumps. A self-aligning spherical journal bearing (SASJB) consists of a spherical plain bearing that has a spherical contact surface which permits the bearing to move freely in all directions, which gives it the capability to self-aligning to accommodate a degree of misalignment. Although bearings are relatively reliable, their faults will be likely cause catastrophic failure and serious disadvantages both in economic, engineering term and safety issues. Moreover, most engine or machinery problems are caused by bearing failures, with over 40% of motor failures in machines of 100HP (75kW) or more, due to bearing problems (Schoen *et al*, 1995).

Vibration analysis is one of the most commonly used condition monitoring techniques in industry. The great advantage of using vibration analysis is that it yields relevant data in a quantitative format and can be operated remotely in real-time. Based on the measured signal, pre-set alarm limits can be triggered automatically (Roylance, 2003).

Nevertheless vibration analysis can only detect signal in sonic frequency range and cannot detect signal in ultrasonic frequency range. The frequency range of the acoustics emission is an extension from audible or sonic to ultrasonic range. Therefore, this case must be measured in an ultrasonic range approximately about 100 kHz, where vibration monitoring can't detect problem in the ultrasonic range (Dickerhof *at al*, 2006).

Acoustic or sonic analysis is the measurement of sound pressure waves generated by component contact inside equipment and radiated from the surface of the machine. Its application in industry with respect to monitoring bearing faults is relatively new (Grible, 2006).

AE is an inspection technique which detects elastic waves generated by such sources as cracking, cleavage, fretting and so forth. To treat AE waves theoretically, elasticity dynamics is needed to model AE sources and solve the wave propagation equations (Ohtsu, 2000).

Thermography analysis is a predictive maintenance technique that can be used to monitor the condition of plant machinery, structure, and systems. The analysis uses instrumentation designed to monitor the emission of infrared energy to determine operating temperature. By detecting thermal condition such as areas being hotter than they should be, an experienced technician can locate and define incipient problems within the machine and/or plant (Moobley, 2002).

Many condition based maintenance and non destructive testing techniques can be applied to manufacturing, petroleum refining, chemical and associated industries. A survey on condition monitoring system in industry showed that the industry used vibration analysis in 17% of cases, oil analysis 13%, infra-red thermograph 12%, human senses 11%, motor current analysis 9%, dye penetrated examination 9%, ultrasonic testing 9%, magnetic particle inspection 7%, AE analysis 5%, and other methods 3% (Higgs *at al*,2004).

Previous researchers have studied lower frequency ($f \leq 20$ kHz) vibration characteristics of hydrodynamic journal bearings in addition to the high-frequency vibration characteristics in the frequency range $f \geq 100$ kHz for monitoring and detecting damages in ball and journal bearings. These studies give relatively little information regarding acoustical properties of the bearings (Rho *at al*, 2003).

This paper focuses on the AE response characteristic of the self aligning spherical journal bearing. AE characteristics of self aligning spherical journal bearing are investigated through time domain, frequency domain and trending analysis of radial load, speed and lubricant viscosity variation.

2. AE FROM JOURNAL BEARINGS

The majority of problems in rotating machines are caused by faulty bearings. The classical failure of mode of rolling element bearings is localized defect, mostly by fatigue cracking in the bearing under cycling contact stressing (Widner and Litmann, 1976).

AE is the phenomenon of transient elastic wave generation in material under stress. When the materials is subjected to stress in certain level, a rapid release of strain energy takes places in the form of elastic waves which can be detected by AE transducer close to it (Choudury and Tandon, 2000).

AE can also detect signal from a tribosystem (any system of tribological components such as bearings) in the ultrasonic frequency range between 20 kHz and 1 MHz (Kolubaev *at al*, 2010).

Tribology is the science of tribein or the study of rubbing or sliding process including friction, lubrication and wear (Cludema, 1996).

The source of AE signal in friction may come from mechanical loading and failure of materials by friction pair operation such as elastic interaction, plastic deformation, change in friction surface structure and appearance of wear debris and formation of fatigue pit.

Journal bearing may be made of many different materials including sintered bronze, which holds oil to reduce friction, and various metals that are cast in place to make a soft slippery surface for really heavy shafts in sliding contact. Hence, the AE analysis can be used to detect the journal bearing early failure.

2.1 AE Generation by Asperity Contact

Acoustic Emission may be defined as a transient elastic wave generated by the rapid release of energy within a material. Its generation mechanisms can be explored by considering the contact between two solid surfaces which are separated by the asperities of random height distribution. Figure 5 shows a smooth surface with another being rough.

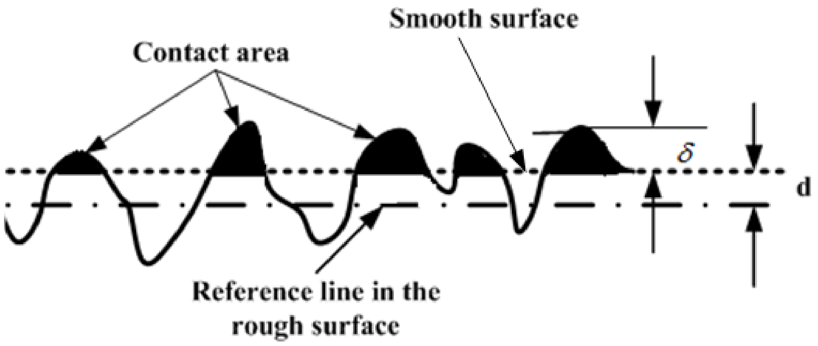

Figure 1- Contact of rough and smooth surfaces (Fan *at al*, 2009).

Based on this model the elastic energy release rate of the asperity can be obtained **(**Fan *at al*, 2009) as

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

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); Velocity (V in m/s); R′(m) is equivalent radius of the contact surface; W (N) is radial load.

Equation (1) means that higher energy rate will be produced when V and W are high. Accordingly, the strength of AE will be high. In addition, because the random distribution of the asperity, the energy release also that have a random behaviour with time. However, because of the asperities are close each other, it means that the frequency range will be high.

The intensity of AE activity depends on the properties of material. The effective factors tend to increase the relative amplitude of the AE response such as high strength, high strain rate, low temperature, thick section, brittle, crack and cast materials (Miller and McIntire, 1987).

Other particular effect of the AE process is called the Kaiser effect. The Kaiser effect is a special phenomenon that affects on the crack growth, when a defined stress applied on material and caused AE and the emission is not induced in material until the defined level of stress has been exceeded, even if the load is completely removed and reapplied again (Miller and McIntire, 1987).

This phenomenon also gives effect to the AE process caused by an abnormal or fault in a rolling bearing or a journal bearing when a rotating component is passing the fault and creates stress in the material.

2.2 AE signal generation by sliding friction

However, the two components of a bearing are usually separated to certain degree by a lubricant film. If the lubricant film is thick enough to separate the components' contacting surfaces, then the friction coefficient is reduced that results in longer bearings life.

The lubrication regimes can be distinguished by using the Stribeck curve. The curve plots the relationship between the friction force and velocity.

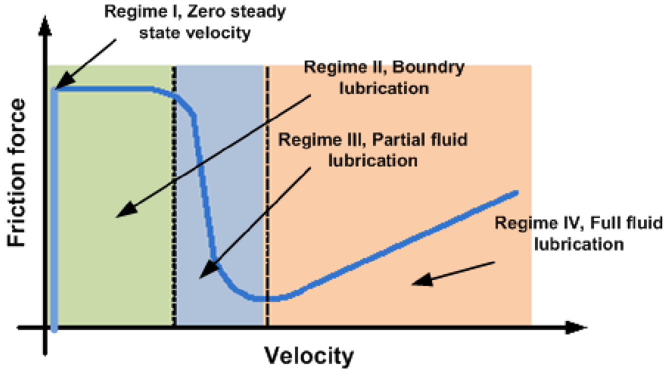

Figure 2-The Stribeck curve (Helouvry, 1991)

The friction coefficient of a bearing is very important because it determines the bearing life time. The coefficient of friction for a full lubricated journal bearing is a function of bearing modulus, diametric clearance ratio, and bearing length to diameter ratio. The bearing modulus depends on the absolute viscosity of lubricant as well as angular speed and bearing pressure (Khurmi and Gupta, 2005).

Boundary lubrication occurs when the lubricating film has the same thickness as the surface of roughness. The high points of asperities on the solid surface will contact each other. On the smoothest machined surfaces the high of asperities is 0.025 μm. Boundary lubrication also occur when the pressures of the lubricated contacts become too high, the running speed too low or the surface roughness too big. The surface films vary in thickness from 5.10^{-9} to 5.10^{-8} m, the minimum film thickness of mixed lubrication regime is h_{min}~10^{-9}m, (h<Ra) (Hamrock, 2006).

Mixed lubrication occurs between boundary and hydrodynamic lubrication range. The fluid film thickness is slightly greater than the surface roughness (h~Ra), so that there is very little asperity or high point contact, but the surfaces are still close enough together to affect each other. The minimum film thickness of mixed lubrication regime is h_{min} ~10^{-8}m and the minimum thickness of the end lubrication regime is h_{min} ~10^{-6}m. (Smith and Dennis, 1994).

Hydrodynamic lubrication means that the load-carrying surfaces of the bearing are completely separated by a relatively thick film of lubricant, so it can prevent metal-to-metal contact. Hydrodynamic lubrication does not depend upon lubricant under pressure introduction. The film pressure is created by the moving surface itself pulling the lubricant into a wedge-shaped zone at a velocity sufficiently high to separate the surfaces against the load on the bearing. Hydrodynamic lubrication is also called full-film or fluid lubrication (Nisbett, 2008).

When two solid bodies contact each other, the true contact areas between them only occur at a limited number of points. The pressures on those points are very high and create a decisive effect on wear and friction.

The friction of solid surface occurs within contacted spot because of the heterogeneity random shape of the asperity contact. Asperity contact is the main AE source in sliding friction (Bonnes and McBride, 1991).

AE analysis is appropriate measurement procedure to detect incipient failure at sliding bearing through the correlation between emitted acoustic signal and energy dissipated in the sliding metallic contact. Damage or failure can be recognized independently by contact geometry, sliding speed, shell material or real shell temperature lubricant temperature with significant increase of the amplitude in the frequency range around 100 kHz (Dickerhof *at al*, 2006).

3. TEST FACILITIES

3.1 Bering Test Rig

The experimental study was carried out on a 4kw bearing test rig. Two the self-aligning spherical journal bearing are installed in between the driving AC motor and a loading DC motor. As shown in Figure 3, a hydraulic cylinder is mounted in the middle of the bearing shaft so that radial bearing load can be applied. The specification of the tested journal bearing is shown in Table 1. The bearing can undertake 10kN radial load. For this test only 10% of the value is applied because different low quality lubricant was tested.

Table 1- Specification of the journal bearing and parameter values

Type of bearing	Self aligning journal bearing
Bearing code	SA35M/S 4170
Diameter of bearing (hole)	D=35 mm
Length of bearing	L=76 mm
Spherical radius of bearing	D_o=82 mm
Lubrication system	Ring lubrication system
Maximum load	10kN

The test rig is equipped with a load cell for measurement of the radial load on the bearing, two accelerometers to measure vibration on the bearing housing, a microphones and a AE sensor to measure the AE signal from the bearing. A 16-channel high speed data acquisition system was employed to record all the measurements simultaneously at a sampling rate of 96 kHz.

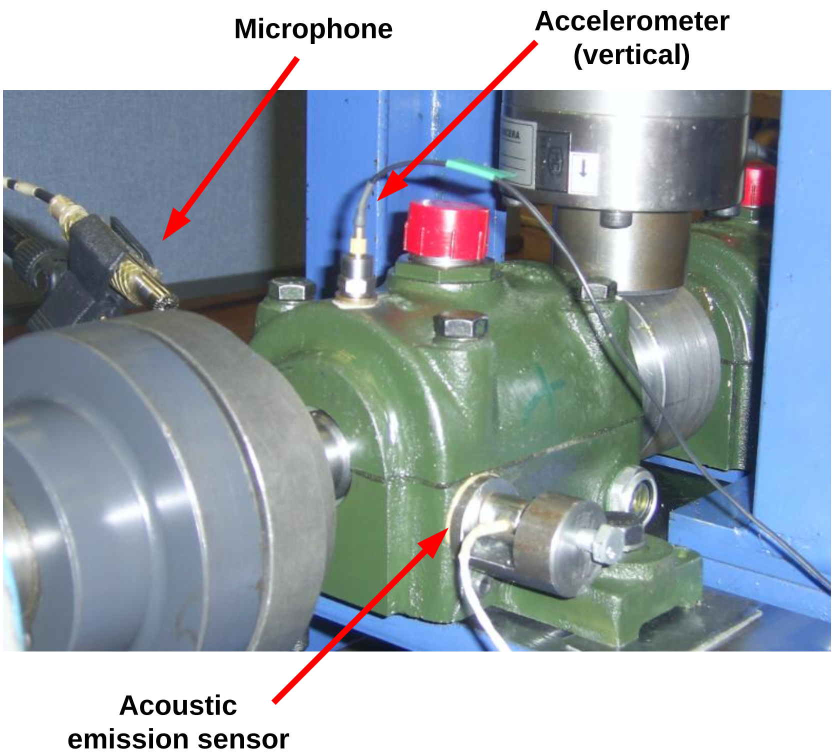

Figure 3- Installation of Vibro-acoustic and AE transducers

The AE sensor is a Transducer AE Dunegan/Endevco Model D9201 AD68, shown in figure 4. The output signal from AE sensor was pre-amplified 40dB for optimal digitalisation in the subsequent data acquisition system.

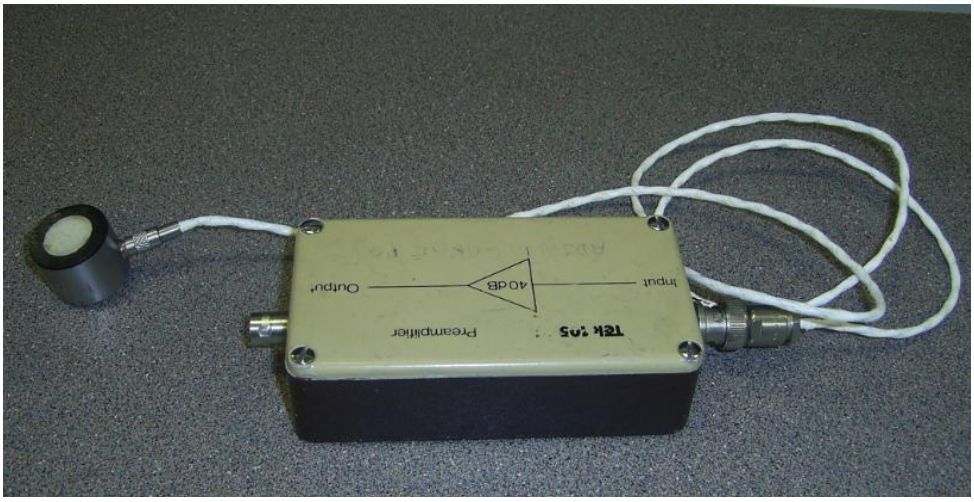

Figure 4- Acoustic Emission Transducer

3.2 Test Procedure

To study and evaluate AE characteristics of the bearing, a test was implemented to consist of three set of tests corresponding to variable load, variable speed and variable viscously respectively.

In the test of variable load, the test was conducted under constant torsion load of 40% and at 100% of speed or 1420 rpm but with radial loads: 45.3, 277.0, 445.8, 678.8, 843.2 and 904N which are 0.45%, 2.8 %, 4.5%, 6.8%, 8.4% and 9.0% of the maximum bearing load. The bearing was lubricated with specified lubricant ISO VG 68. The low load applied to prevent the bearing from early damage when it operates under low quality lubricants.

In variable speed test, the test was conducted under constant of 40% torsion load, radial load 223.4 N at speed variation 10.20, 40, 50, 60, 80 and 100% of speed. The test rig use lubricant ISO VG 68 as well.

In the test with different lubricants, the test was conducted under constant of 40% torsion load, radial load 45.3 N at 100% speed with variation of viscosity of ISO VG 22, 32, 46, 68 and ISO VG 100.

4. RESULTS AND DISCUSSION

4.1 Acoustic Emission Analysis

There are two types of recognised AE signal analysis: the time domain and frequency domain, they are the most common techniques used for monitoring in AE applications (Mechefske *et al*, 2002). Based on waveform shapes, AE signal can be burst, continuous and mixed types. The parameters that can be extracted from the signal depend on the type of the signal. For the burst type of signal the parameters are the duration of AE event, AE counts, AE count rate, AE energy, AE peak amplitude and also the signal rise time or decay time (Mechefske *et al*, 2002). However, for less burst AE signals, common waveform parameters such as RMS, kurtosis many based for characterising the signals. In the frequency domain, many different feature parameters such as spectral peak, mean of spectral amplitudes etc can be used. AE results from the self align bearing are presented in the time domain and the frequency firstly and then AE feature parameter such as root mean square (RMS) value is explored in associating with radial load, speed and different types of lubricants.

4.2 Load Characteristics

Figure 5 shows the AE responses in the time domain of the journal bearings operated on 100% of speed, 40% torsion load with the radial loads variation. The figure indicates that the type of AE responses is mixing between the burst type and continuous type but more it is pronounced with the latter. In addition, it also can be observed that the amplitude in the time domain increases with increasing in radial load. It means that more AE events are generated at higher load which is contestant with the mode studied in Section 2.

To present connection of the AE signals to load more accurately, the common wave parameters are calculated. Figure 6 describes the analysis of time domain vibration signal consists of the RMS value, Peak value, Peak factor and Kurtosis. From the four graphs show a consistent result is the RMS value and the Peak value. Based on the Kurtosis value indicates that the maximum value of 3.3 and 0.3 minimum, this means that data distribution are normal distribution and flat topped distribution.

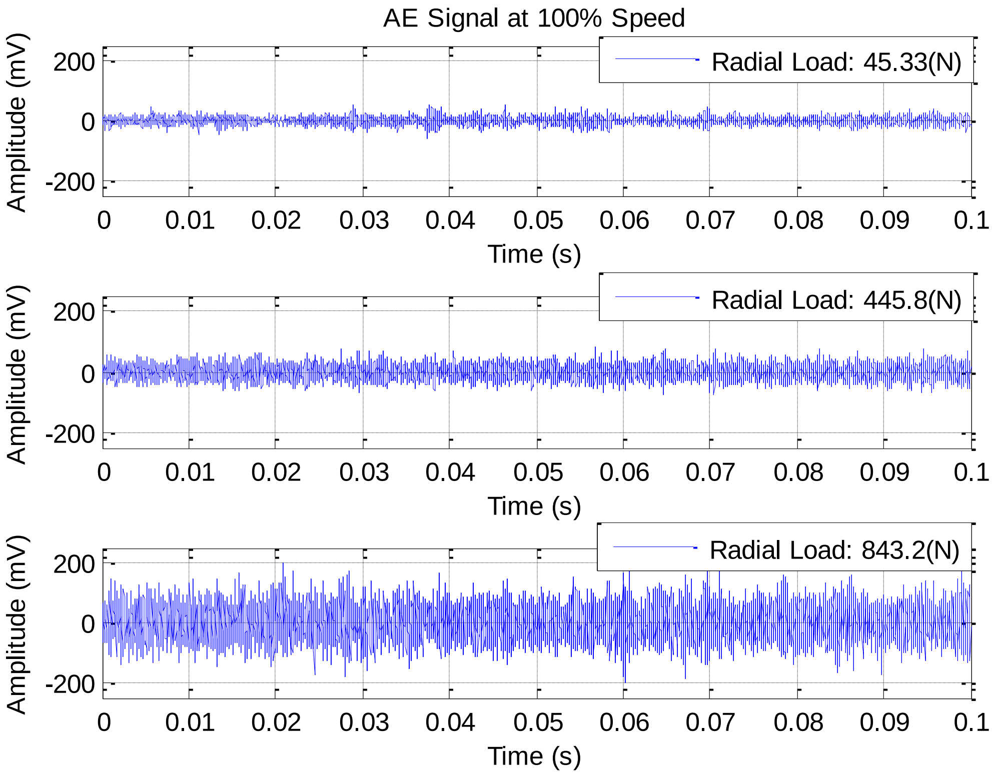

Figure 5- AE signal under 40% Torsion Loads at 100% Speed

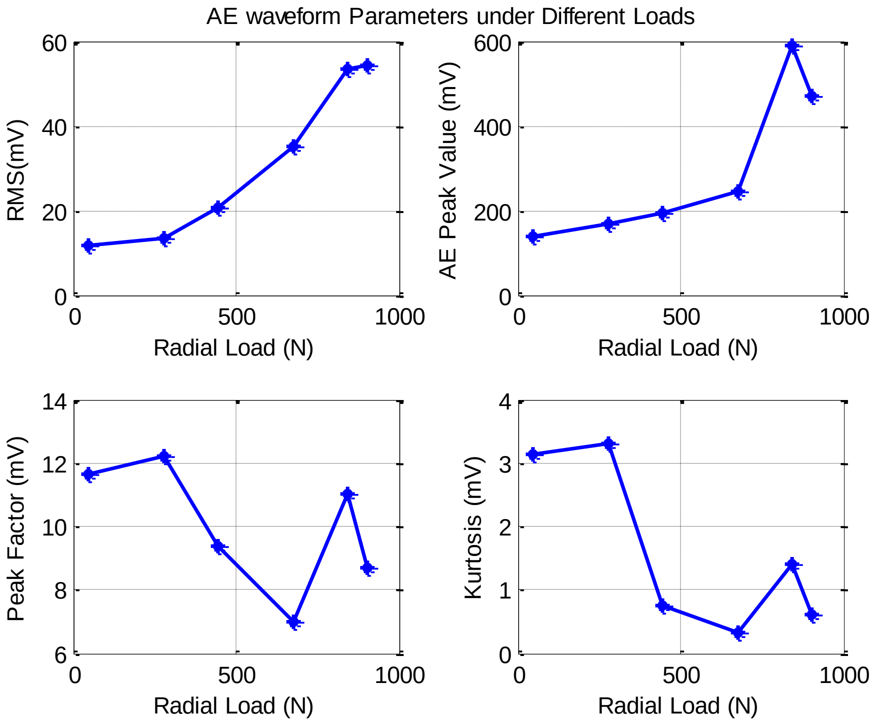

Figure 6- AE signal under Different Load at 100% Speed Torsion

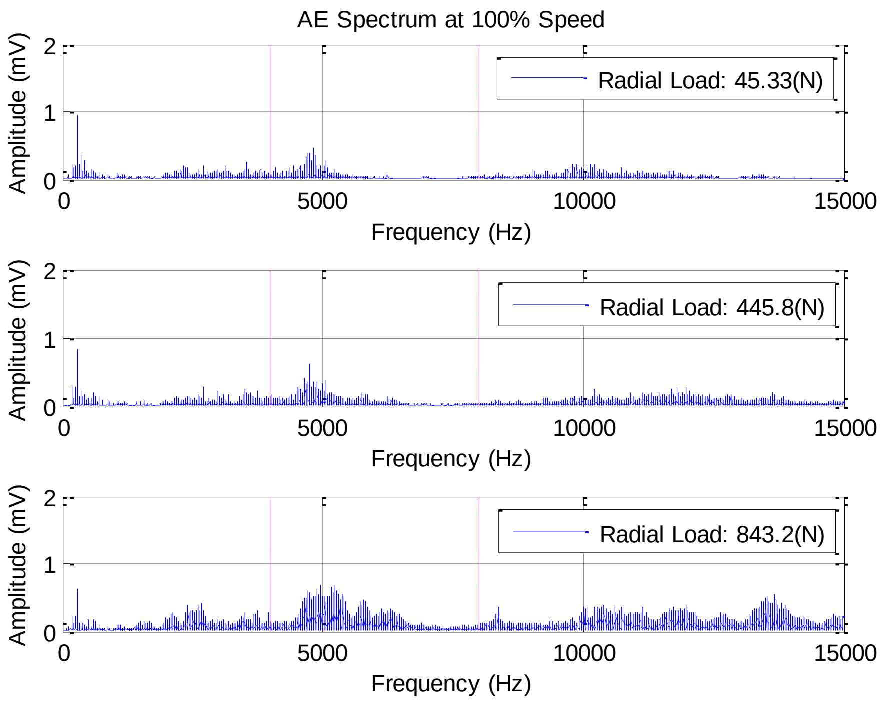

Figure 7- AE Spectrum under different loads at 100% Speed

In the frequency domain AE response of figure 7 shows that the high amplitude dominant around in 1000, 5,000 and 12,500Hz. With increasing in radial load, the peak value did not show changes significantly, but significant changes occur in the wider spectrum, that may indicate the average releasing energy.

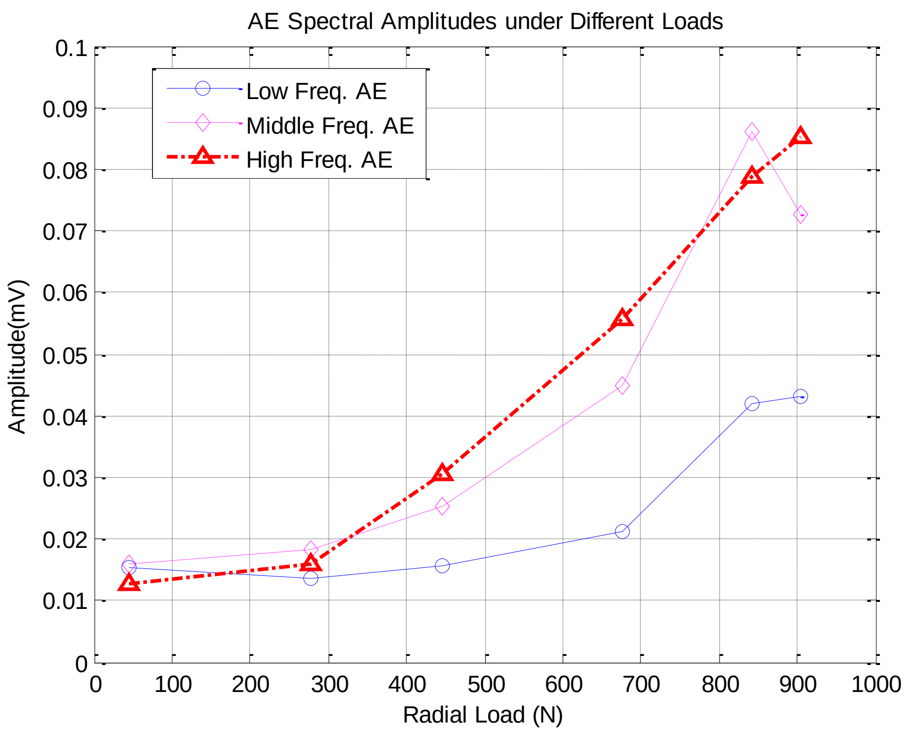

Figure 8- AE Spectral Characteristic under Different Loads at 100% Speed

Figure 8 shows the characteristics of the relationship between the radial load and the AE amplitude in low frequency range (<4,000Hz), middle frequency (4,000Hz <f≤8,000Hz) and high frequency (>8,000Hz). At low frequency, medium and high frequency indicates that by increasing the radial load followed by AE significantly increasing.

In the low, middle and high frequency there is a positive correlation between the radial load and AE RMS value. This image may also show the relationship between the radial load, AE RMS and the friction coefficient because that figures similar to the Stribeck Curve, when it operated in hydrodynamic conditions. In other words there is a relationship between AE signals and tribo-system phenomena particularly in the processes of friction and wear. (Hase at al, 2009).

Based on the AE signal generation by asperity contact theory, the elasticity energy released in unit time is influenced by the load, number of asperity in a unit area and speed. If the load is increased, the acoustic energy released is also increased. Likewise if the speed is increased, the AE energy also rose.

4.3 Speed Characteristics

Figure 9 shows the AE signals under a constant radial load but different speeds. It can be seen that there is a gradual increase in AE amplitudes with loads. It means that more AE events occur when more asperity contact resulting from higher load.

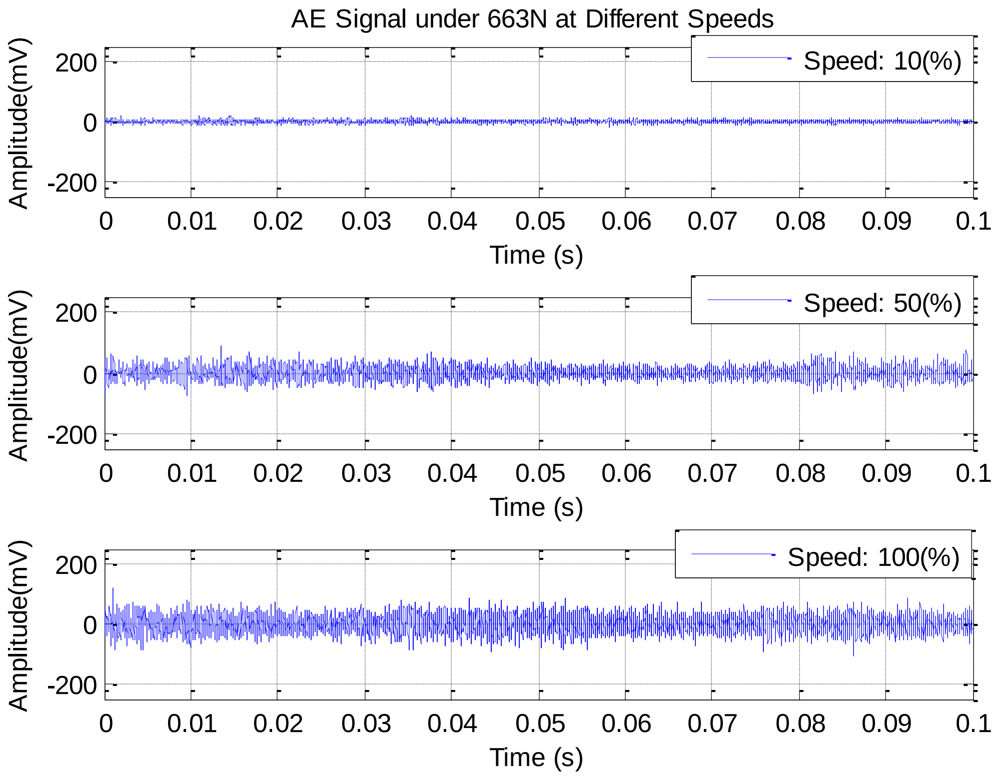

Figure 9- AE signal varying with Speed under 663N Loads

AE wave parameters in Figure 10 shows that the RMS value exhibits a monotonic increase with loads. This trend then can be a good representation of the AE events and hence bearing operation. However, Peak value, Peak factor and Kurtosis show less agreement with AE generation process, therefore they may be not effective indicators of bearing condition.

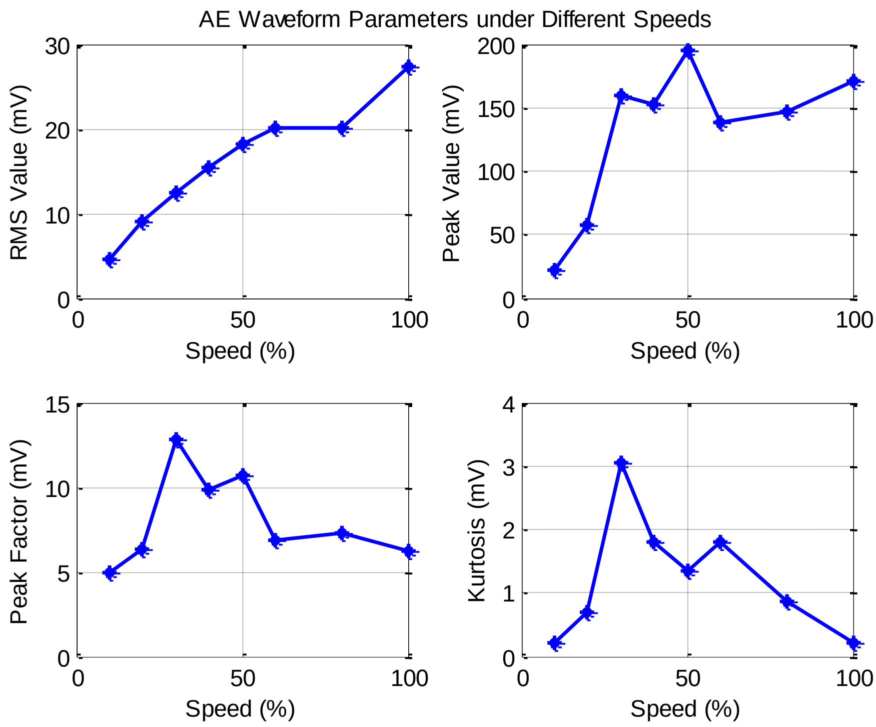

Figure 10- AE Waveform Parameters under 663N Loads for Different Speeds

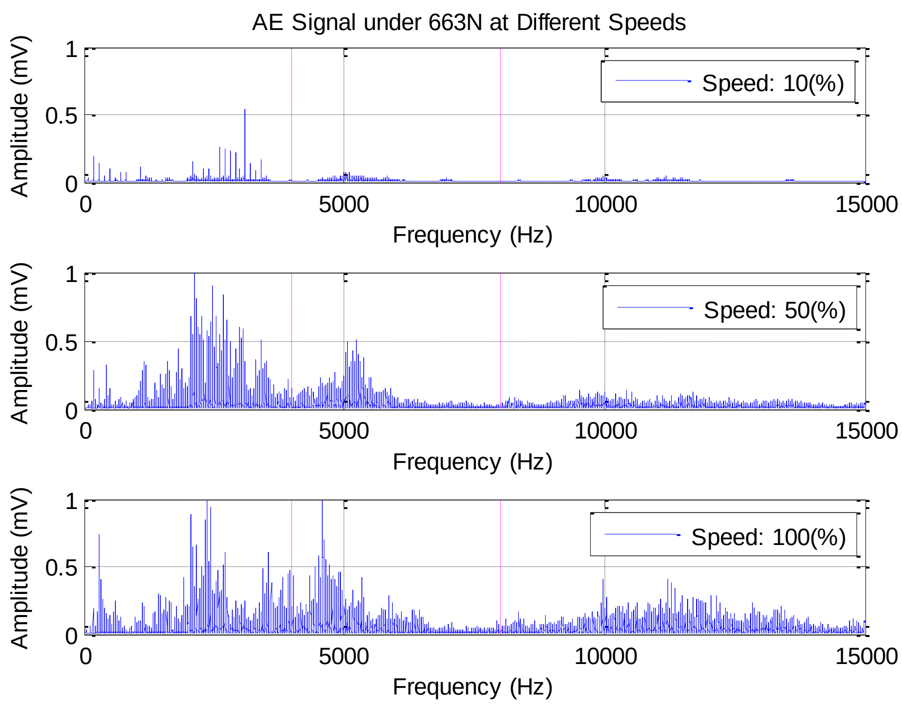

Figure 11- AE Spectrum for different speeds under 663N Loads

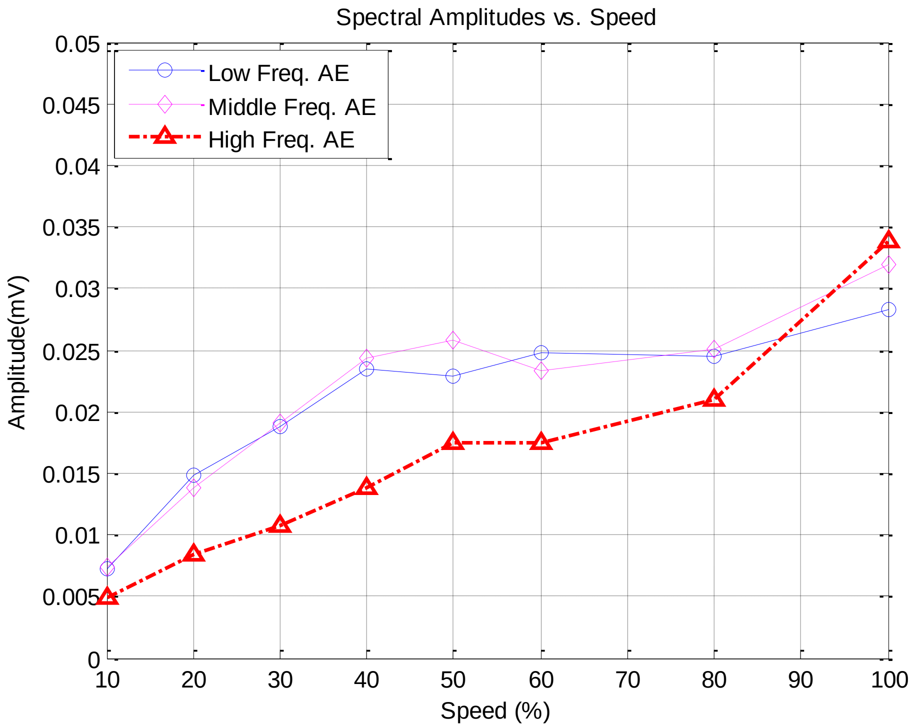

Figure 12- AE Spectral Amplitude versus speeds under 663N loads

Figure 11 shows the AE spectrum in the journal bearings under constant torsion and radial at speed variation. From the picture seen that the dominant amplitude occurs at high amplitude at frequency: 2,500Hz, 5,000Hz and 12,500Hz. If the speed increases, the amplitude of AE increases as well.

Figure 12 shows the relationship between the speeds of the shaft with the AE RMS value on the bearing operated at 40% torsion load and from the hydraulic radial loads 663N at low frequency (4,000Hz), middle frequency (4,000Hz<f≤8,000Hz) and high frequency (>8,000Hz). . Figure present also that there is a positive correlation between speed and AE RMS value and may relate to friction curve as well.

4.4 Lubrication Characteristics

Figure 13 shows the AE signal at the NDE bearing under load 40% torsion load at 100% speed with a light radial load and the variation of lubricant viscosity of ISO VG 22, 32, 46, 68 and ISO VG 100.

In figure 13 indicates that by using a higher viscosity of lubricant, the result of signal amplitude is getting smaller. This is supported also by data in Figure 14. The graph in figure 14 shows that the RMS value, Peak value, Peak factor and Kurtosis. In the RMS value and peak value is clearly seen that if the lubricant has higher viscosity, it generate smaller AE amplitude. The distribution data for a lubricant that less than 68cSt showed normal distribution but for lubricant that greater than 68cSt the data distribution indicates peaked distribution.

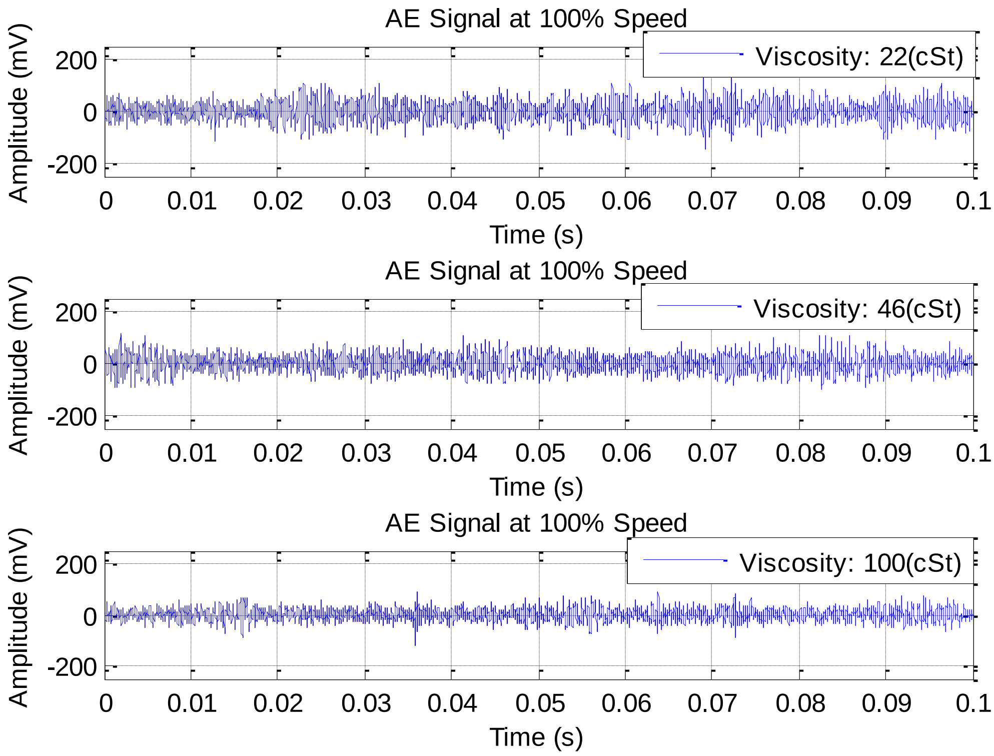

Figure 13- AE Signals for lubricants under 663N loads at 100% Speed

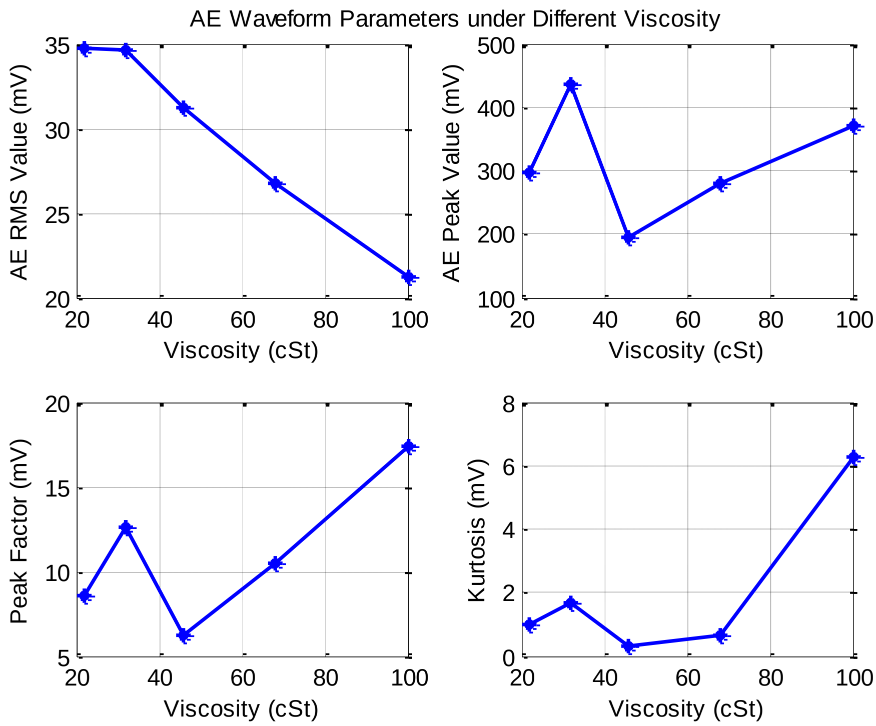

Figure 14- AE waveform parameters for lubricants under 663N loads and 100% speed

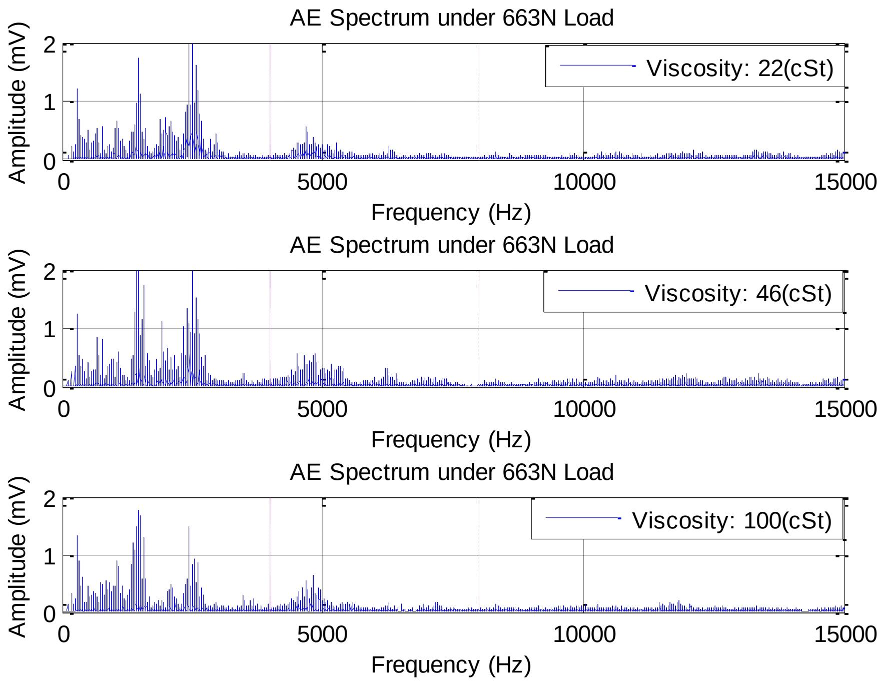

Figure 15- AE Spectrum for lubricants under 663N loads at 100% Speed

Figure 15 shows the AE spectrum in the self-aligning journal bearings with lubricant viscosity variation. From the pictures it appears that the higher the viscosity of lubricants used in the smaller maximum amplitude and distribution. High amplitude dominant occurs at 2,500Hz and 5,000Hz.

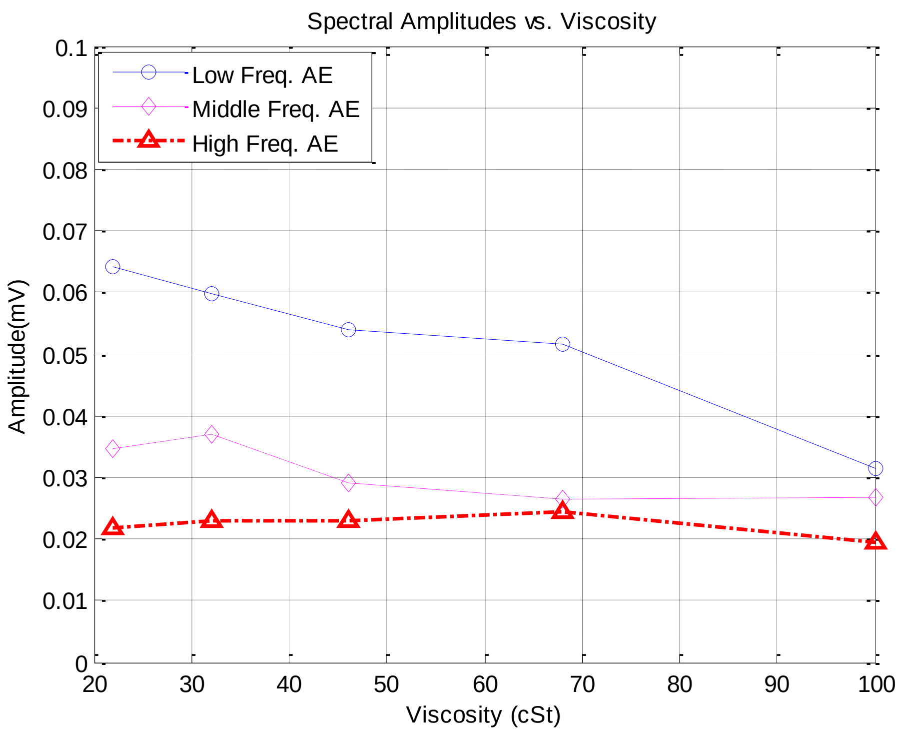

Figure 16- AE Spectral Characteristic under 663N loads at 100% Speed and Different Viscosity

Figure 16 shows correlation between viscosity variation and mean amplitude in different frequency bands. In the middle frequency and low frequency there is a negative correlation between viscosity of lubricant and AE amplitude. It means when the viscosity of lubricant increase, the AE events will decrease. If a lubricant with high viscosity is used the oil film will be thinker and hence the number of asperity in a unit area will decrease. This lead to that the elasticity of energy released decrease.

From above findings it is confirmed that changes of AE signals with load, speed and lubricant are consistent with that of the Srtibeck-curve. Therefore, AE can be an effective representation of the friction condition of journal bearings. In particular, AE amplitude in the low frequency may correlate with the mechanical structure problems such as vibrations from rotors whereas amplitude in the middle and high frequency relates with the friction and wear in the bearing.

5. CONCLUSSION AND FUTHER WORK

The study of AE characteristics of a journal bearing has found that the higher radial load and operating speed, the higher amplitude of AE responses due to higher rate of elastic energy release from asperity contact. The RMS values in the time domain and the spectral amplitude in the high frequency range are better feature parameters to represent the increasing behavior of AE with load and speed.

On the other head, the higher viscosity of lubricant enables bearing to operate under better lubrication films, which leads to the smaller amplitude of AE responses. The AE RMS value and spectral amplitudes in the low frequency range can be an effective indicator of changes in lubricants.

6. REFERENCES

Schoen, R. R, Habetler, T.G, Kamran, F and Bartheld, R.G, (1995), *Motor bearing damage detection using stator current monitoring*. IEEE Trans. On Industry Application, Vol. 31, No. 6, pp. 1274-9.

Roylance, B. J. (2003), *Machine failure and its avoidance-what is tribology's contribution to effective maintenance of critical machinery*? Proc. IMechE, Volume 217, Part J, Engineering Tribology, J05302.

Dickerhof, M. Albers, A. Burger, W. Sovino, R, (2006), *Monitoring Lubrication Regimes in Sliding Bearings – Using AE Analysis,* Practicing Oil Analysis, May 2006, Noria Publication.

Gribble,J. (2006) *Acoustic analysis for the rest of us*. Machinery Lubrication. Noria Publication. No. 839.

Ohtsu, Masayasu, (2000), *Moment tensor analysis of AE and sigma code. Acoustic Emission Beyond Millennium*, Elsevier, Tokyo, Japan

Mobley, K.R. (2002), *An introduction to predictive maintenance. Plant Engineering*, Second Edition, Elsevier Science, USA, Butterworth Heinemann.

Higgs, P.A, Parkin, R., Jackson, M., Al-Habaibeh, A., Zorriassatine, F. and Coy, J. (2004) *A survey of condition monitoring systems in industry*. Proc. ESDA, 7th Bienial ASME Conference Engineering System Design and Analysis, July 19-22, Manchester, UK.

Rho, B-H. Kim, D-G and Kim, K-W. (2003), *Noise analysis of oil-lubricated journal bearings*. Proc. IMechE. Vol. 217 Part C: J. Mechanical Engineering Science, C07502.

Widner, R.L and W.E. Litmann,W.E, (1976), *Bearing Damage*, National Bereu of Standard, Special Publication, No. 423.

Choudhury, A and N Tandon,N, (2000), *Application of acoustic technique for detection of defect in rolling element bearing*, Tribology International 33, pp. 39-45.

Kolubaev, E.A, Kolubaev, A.V, Sizova,O.V, (2010), *Analysis of Acoustic Emission during Sliding Friction of Manganese Steel*, Technical Physics Letters, No. 8, pp. 762-765, Pleiades Publishing Ltd. ISSN 1063-7850.

Cludema, K, (1996), *Friction, Wear, Lubrication*, A Textbook in Tribology, CRC Press, Florida, USA).

Fan, Y, Gu, F, Ball, A, (2009), Modelling acoustic emission generated by sliding friction, Wear, Elsevier, pp. 1-5.

Miller, R.K, McIntire, (1987), *Non Destructive Testing Hand Book*, Volume 5, *Acoustic Emission Testing*, American Society for Non destructive Testing, p. 603, ISBN 0-931403-0202) .

Helouvry, A, B, (1999), Control of Machines with Friction, Kluwer Academic Pubhliser, USA.

Khurmi, R. S. Gupta, J. K. (2005), *A text book of machine design.* Reprint Edition, S. Chand & Co Ltd, India.

Hamrock, Bernard J. (2006).*Mechanical Engineers' Handbook: Materials and Mechanical Design*, Volume 1, Third Edition. Edited by Myer Kutz, John Wiley & Sons, Inc. Columbus, Ohio)

Smith, S. Dennis, J. (1994) .*An Introductory Guide to Industrial Tribology*, Editor Roger C Baker, Mechanical Engineering Publication Limited, London.

Nisbett, B.(2008) Shigley's Mechanical Design, Eight Edition, McGraw Hill Primis Companies

Bonnes, R.J, McBride, S.L, (1991), Adhesive and abrasive wear studies using acoustic emission techniques, Wear, Volume 149, Issues 1-2, pp. 41-53.

Mechefske, C.K, Sun, G, Sheasby, J, (2002), *Using Acoustic emission to monitor sliding wear,* Insigh, Volume IV, No. 8.

Hase, A, Hiroshi Mishina, H and Wada, M, (2009), *Acoustic Emission in Elementary Processes of Friction and Wear*, *In-Situ Observation of Friction Surface and AE Signal*, Journal of Advanced Mechanical Design, System, and Manufacturing, Vol. 3, No. 4 , p. 333-344.