ACOUSTIC EMISSION ANALYSIS FOR BEARING CONDITION MONITORING

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Report submitted in partial fulfilment of the requirements for the award of
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BORANG PENGESAHAN STATUS TESIS♦

JUDUL: **ACOUSTIC EMISSION ANALYSIS FOR BEARING CONDITION MONITORING**

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Finally to individuals who has involved neither directly nor indirectly in succession of this thesis. Indeed I could never adequately express my indebtedness to all of them. Thank you.

ABSTRACT

Acoustic emission (AE) was originally developed for non-destructive testing of static structures, however, over the years its application has been extended to health monitoring of rotating machines and bearings. It offers the advantage of earlier defect detection in comparison to vibration analysis. Current methodologies of applying AE for bearing diagnosis are reviewed. The investigation reported in this paper was centered on the application of standard acoustic emissions (AE) characteristic parameters on a rotational speed. An experimental test-rig was designed to allow seeded defects on the inner race, corrode and contaminated defect. It is concluded that irrespective of the rotational speed and high levels of background noise, simple AE parameters such as amplitude and AE counts provided an indications of bearing defect. In addition to validating already established AE techniques, this investigation focuses on establishing an appropriate threshold level for AE counts.

ABSTRAK

Pelepasan akustik (AE) pada asalnya dibangunkan untuk ujian tidak memusnahkan struktur statik, bagaimanapun, sejak beberapa tahun permohonan telah dilanjutkan kepada pemantauan kesihatan mesin dan bearing berputar. Ia menawarkan kelebihan mengesan kecacatan awal berbanding dengan analisis getaran. Metodologi semasa memohon AE untuk menanggung diagnosis dikaji semula. Penyiasatan yang dilaporkan dalam kertas ini berpusat pada permohonan pelepasan akustik standard (AE) parameter ciri pada kelajuan putaran. Eksperimen ujian pelantar telah direka untuk membolehkan kecacatan pilihan pada perlumbaan dalam, mengakis dan tercemar kecacatan. Ia menyimpulkan bahawa tanpa mengira kelajuan putaran dan tahap bunyi latar belakang, parameter AE mudah seperti amplitud dan tuduhan AE memberi tanda-tanda kecacatan bearing. Selain mengesahkan teknik AE telah ditubuhkan, penyiasatan ini memberi tumpuan kepada mewujudkan tahap ambang yang sesuai bagi tuduhan AE.

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LIST OF ABBREVIATIONS

AE	Acoustic Emission
NDT	Non Destructive Testing
dB	Decibels
N	Counts
A	Amplitude
D	Duration
R	Rise Time
COTS	Custom off the shelf
MB	Megabytes
RPS	Revolution Per Second

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Acoustic emission (AE) can be described as a phenomenon of transient elastic wave generation in materials under stress. Acoustic emission is related to the internal changes of material structure caused by external physical action such as temperature and load. The transient waves will form of displacement vibration in the material which can be recorded by sensor such displacement gauges or accelerator gauges.

Function acoustic emission (AE) technique is detects stress waves that generated during transient elastic waves release of stored strain energy in material subjected to external mechanical load, fracture mechanisms and material state can be evaluated in a non-destructive manner. Application acoustic emissions has been applied in many fields such as structural manufacturing process (Choi et al. 1992), machine tool monitoring (Cherfaouie et. al 1998) and tribological and wear process monitoring, gear defects monitoring and bearing monitoring.

In mechanical, application of the high frequency acoustic Emission (AE) technique in condition monitoring of rotating machinery has been growing over recent years. In test rig this is particularly true for bearing defect diagnosis and seal rubbing. The main drawback of acoustic emission with the application of AE technique is the attenuation of the signal and as such the AE sensor has to be close to its source. In test rig, it is often practical to place sensor AE on the non-rotating member of the machine such as bearing. Therefore, the AE signal originating from the defective component will suffer severe attenuation before reaching the sensor. Usually typical frequencies associated with AE activity range 20 to 1MHz.

The acoustic emission (AE) method is a high frequency analysis technique which initially developed as a non destructive testing (NDT) tool to detect crack growth in material and structure. Now, AE method has been increasingly being used as condition monitoring tool of engineering assets such as structures and industrial machines.

In this study, envelop analysis bearing condition monitoring for detecting of bearing defect in signal process.

1.2 PROBLEM STATEMENT

Acoustic emission is non-destructive testing for detection in rotating machinery that can be conducted to investigate the acoustic emission response of defective bearings. In acoustic monitoring is can even detect the growth of subsurface cracks whereas vibration monitoring can normally detect a defect when it appears on the surface (Tandon,1990) and in this study we have attempted to provide corroborative evidence that bearing defect can be measured and analyzed using acoustic emission method.

In this research was develop fabricate and design bearing used test rig to investigate the changes acoustic emission signal of simulated defects on the defect on cylindrical roller bearing and the analysis of the result will do with this test.

1.3 OBJECTIVES

The main objective for this research is:

i. To detect bearing condition using acoustic emission method

1.4 SCOPE OF RESEARCH

For this research, the acoustic emission testing will be done to detect a signal from test rig. From test rig can used in non-destructive testing for the detection of defect bearing and failure detection in rotating machinery. The result from the test will be analyzed according to the acoustic emission technique.

With different defect of the bearing such as contaminant, corrode and inner race have different result for acoustic parameter. From this experiment also want to study the parameter of acoustic emission such as counts and energy counts and amplitude. Data from acoustic emission parameter will be analyzed to get the characteristic of acoustic.

1.5 HYPOTHESIS

In this research, some of the hypothesis has done such as:

i. Different defect bearing used in test rig, so the prediction of the result will get different result from acoustic parameter such as different ring-down counts, events and peak amplitude of the signals.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The purpose of this chapter is to provide a review of past research efforts related to acoustic emission testing, type of bearing, type of bearing defect and mechanical testing that test rig. A review of other relevant research studies also provides. The review is organized chronologically to offer insight to how past research efforts have laid the groundwork for subsequent studies, including the present research effort.

2.2 ACOUSTIC EMISSION

Acoustic emission is defined as generation of transient elastic waves produced by a sudden redistribution of stress in a material. Detection and analysis of acoustic emission signal can get valuable information of a discontinuity in material such as bearing defect (Mathews, 1983). Typical sources of acoustic emissions include plastic deformation, wear, micro fracture, bubble collapse, impact and friction. When these waves reach the surface of the material they can be detected and measured by acoustic emission sensors. Acoustic emission signals are generally only a few microvolts to milivolts in amplitude when measured at the sensing element and range from several kHz to a MHz. At these frequencies, signals are strongly attenuated in air so a suitable couplant is required between the sensor and material to ensure signal transmission.

2.2.1 Acoustic emission and bearing defect diagnosis

Yoshioka have shown on research state that acoustic parameters identified bearing defects before they appeared in the vibration acceleration range whilst Catlin reported acoustic emission activity from bearing defects were attributed to four main factors, including random noise generated. It was noted that signals detected in the acoustic emission frequency range represented bearing defects rather than other defects such as imbalance, misalignment, looseness and shaft bending.

Tandonet on research investigated acoustic emission counts and peak amplitudes for an outer race defect using a resonant type transducer. It was concluded that AE counts increased with increasing load and rotational speed. However, it was observed that AE counts could only be used for defect detection when the defect was less than 250μm in diameter; through AE peak amplitude provided an indication of defects identification on various sized bearings and rotational speed. It was observed that AE counts were low for undamaged bearings. In addition, it was observed that AE counts increased with increasing load and speed for damaged undamaged bearing.

A clear relationship between rms level, rotational speed and radial load has been reported. The use of AE counts is dependent on the particular investigation and the method of determining the threshold level is at the discretion of the investigator. For this reason, the investigation presented in this paper firstly validates the use of rms for diagnosis and secondly, ascertains the suitability of AE counts for bearing diagnosis. In addition, selection of the appropriate threshold level is investigated.

2.2.2 Features of Acoustic Emission (AE) Signal

The commonly measured acoustic emission parameters are counts, events and peak amplitude of the signal. Ringdown counts involve counting the number of times the amplitude exceeds a preset voltage (threshold level) in a given time and gives a simple number characteristic of the signal. An event consists of a group of ringdown counts and signifies a transient wave. Each of the AE signal feature shown in the image described below

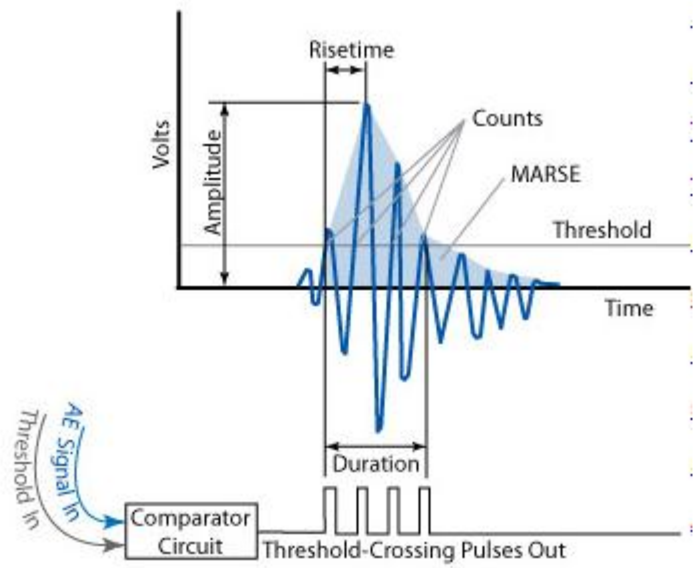

Figure 2.1: AE signal features

(Source:Yoshioka and Fujiwara, 1984)

Amplitude, A, is the greatest measured voltage in a waveform and is measured in decibels (dB). This is an important parameter in acoustic emission inspection because it determines the detectability of the signal.

Signals with amplitudes below the operator-defined, minimum threshold will not be recorded (Yoshioka and Fujiwara, 1984).

Rise time, R, is the time interval between the first threshold crossing and the signal peak. This parameter is related to the propagation of the wave between the source of the acoustic emission event and the sensor. Therefore, rise time is used for qualification of signals and as a criterion for noise filter (Yoshioka and Fujiwara, 1984).

Duration, D, is the time difference between the first and last threshold crossings. Duration can be used to identify different types of sources and to filter out noise. Like counts (N), this parameter relies upon the magnitude of the signal and the acoustics of the material (Yoshioka and Fujiwara, 1984).

MARSE, E, sometimes referred to as energy counts, is the measure of the area under the envelope of the rectified linear voltage time signal from the transducer. This can be thought of as the relative signal amplitude and is useful because the energy of the emission can be determined. MARSE is also sensitive to the duration and amplitude of the signal, but does not use counts or user defined thresholds and operating frequencies. MARSE is regularly used in the measurements of acoustic emissions (Yoshioka and Fujiwara, 1984).

Counts, N, refers to the number of pulses emitted by the measurement circuitry if the signal amplitude is greater than the threshold. Depending on the magnitude of the AE event and the characteristics of the material, one hit may produce one or many counts. While this is a relatively simple parameter to collect, it usually needs to be combined with amplitude and/or duration measurements to provide quality information about the shape of a signal (Yoshioka and Fujiwara, 1984).

2.2.3 Concept wave propagation

The main deficiency of this analysis is that the wave propagation through the structure exhibits several dispersive wave modes. Due to the characteristics of propagation of these wave modes, there are certain characteristic frequency ranges that propagate with sufficient magnitude to be sensed by the AE sensors. These frequency ranges vary as a function of structural properties and geometry even when the damage mechanism is identical (Tandon, 1990). Thus, it is not reasonable to directly associate certain AE signal frequency ranges with certain damage mechanisms in a way that is independent of the material and geometry of the structure. None of these AE signal analysis techniques used in laboratory studies has proven to be capable of consistently dealing with the difficulties encountered in large structure, namely, large amounts of data, the elimination of noise sources, material anisotropy, and the influence of wave propagating effects (attenuation and dispersion). These analyses often gave controversial results because they lack a physical justification (based on the theory of AE) for the signal features used to sort the experimental signals into different source mechanisms.

2.2.4 Acoustic Emission signal

AE signals is a characteristic of the process which produces it. Hence the AE signals contain information about the AE source, which includes location, magnitude, and damage mechanisms; the structure through which the wave propagates in the form of transient stress waves; and the monitoring system including the sensor (i.e., piezoelectric sensors) either mounted on or embedded in the structure and the associated signal processing electronics. With the ever increasing power of data acquisition systems and the increased sensitivity of new sensors, recording the entire waveform with high fidelity becomes feasible. This waveform approach characterizes AE signals by employing transient wave theory to predict the signals generated by different types of damage mechanisms. This, in turn, enables experimentally measured acoustic emission data to be interpreted in a physically meaningful manner.

2.2.5 Acoustic emission pre-processing

AE pre-processing involves amplification and filtering to refine the bandwidth and avoid aliasing. Signals are characterized as continuous, burst or mixed mode. Continuous emissions are burst that occur too closely together to differentiate between individual events, appearing as an increase in the background signal level. They typically have no distinguishing features other than their amplitude and frequency content. Burst emissions are typically discrete transients with relatively short decay times and even shorter rise times. Last is mixed mode AE contains a number of large individual burst above a background emissions. As most AE is broadband, processing is usually done in the time domain.

Hits and events are important concept to traditional AE signal analysis. A hit is defined as AE burst that exceeds a certain voltage threshold. Generally speaking, an event occurs when the peak voltage remains above the threshold for consecutive hits. Both hit and event date features are therefore a function of the type and value of the selected threshold (Bansal, 1990). Thresholds are referred to as fixed, in which case they are set to an absolute value for the duration of the rest or floating, where the threshold level is set as a defined amount (a fixed voltage or fixed number of standard deviation) above the background level. Fixed thresholds are typically used when monitoring static equipment, whilst rotating machinery requires floating thresholds to avoid swamping acquisition hardware when fluctuations in operating conditions cause the background signal level to rise. Unfortunately, the ability of COTS (custom off the shelf) AE hardware to manipulate thresholds is limited. Modern AE systems are theoretically capable of detecting and analyzing up to 20,000 hits per second.

Whilst hit features are extracted from a sensor's amplified filtered voltage output, continuous signal descriptors are generally extracted from the signal envelope or from filtered, digitalized waveforms. The number of simultaneous waveforms that can be collected depends on the amount of data, which is a function of acquisition rate and resolution, and the acquisition system's digital bandwidth: 4 channels of 16-bit waveform data, collected at 5MHz, will result in 40 megabytes (MB) of data per second. This data must pass across the computer's PCI bus to the hard disk for storage. Hard disk is typically restricted to writing data at approximately 40MB per second. As a result, undertaking multi-channel AE data acquisition consumes a large proportion of the computing power available in standard desktops and portable computers. It is therefore difficult to perform real-time advanced signal analysis of digitalized waveforms, such as discrete-wavelet or short-time-frequency transformation, on unoptimized consumer-grade- hardware

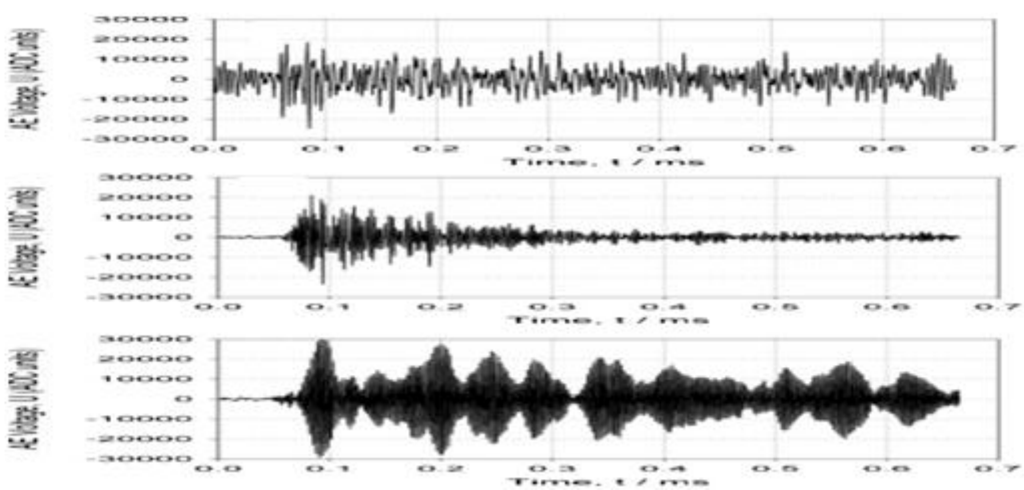

Figure 2.2: Type of acoustic emission signal

(Source: Yoshioka and Fujiwara, 1984)

2.3 TYPE OF BEARING

In experiment test rig, type of bearing use is cylindrical rolling bearings. Rolling bearings come in many shape and varieties, each with its own distinctive features. However, when compared with sliding bearings, rolling bearings all have the following advantages:

i. The starting friction coefficient is lower and there is little difference between this and the dynamic friction coefficient.
ii. They are internationally standardized, interchangeable and readily obtainable.
iii. They are easy to lubricate and consume less lubricant
iv. As a general rule, one bearing can carry both radial and axial loads at the same time
v. Maybe used either high or low temperature applications.
vi. Bearing rigidity can be improved by preloading.

Most rolling bearing consist of rings with raceway (inner ring and outer ring), roller and cage. The cage separates the rolling element at regular intervals, holds them in place within the inner and outer raceways and allows them to rotate freely. The surface on the rolling element roll is called the "raceway surface". The load placed on the bearing is supported by this contact surface. Generally the inner ring fits on the axle or shaft and the outer ring on the housing. Theoretically, rolling bearing are so constructed as to allow the rolling elements to rotate orbitally while also rotating on their own axes at the same time. The function of cages bearing is to maintain rolling elements at a uniform pitch so load is never applied directly to the cage and to prevent the rolling element from falling out when handling the bearing.

Rollers bearing on the other hand are classified according to the shape of the rollers; cylindrical, needle, tapered and spherical. Rolling bearings can be further classified according to the direction in which the load is applied; radial bearings carry radial loads and thrust bearings carry axial loads.

2.3.1 Cylindrical roller bearings

In our study, we used cylindrical roller type NU203. Cylindrical roller bearing uses rollers for rolling elements, and therefore has a high load capacity. The rollers are guided by the ribs of the inner or outer ring. The inner and outer rings can be separated to facilitate assembly and both can be fit with shaft or housing tightly. If there are no ribs, either the inner or the outer ring can move freely in the axial direction. Cylindrical roller bearings are therefore ideal to be used as so-called “free side bearings” that absorb shaft expansion. In the case where there is a rib, the bearing can bear a slight axial load between the end of the rollers and the ribs. Cylindrical roller bearings include the HT type which modifies the shape of roller end face and ribs for increasing axial load capacity. And the E type standardized for small-diameter sizes.

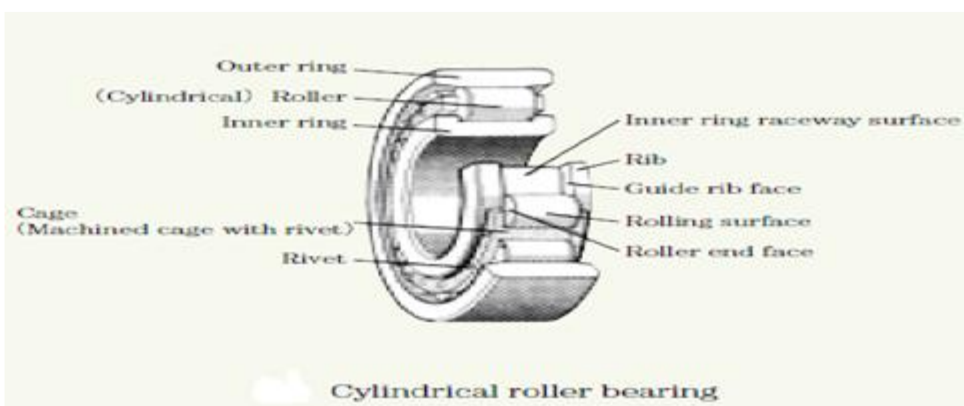

Figure 2.3: Cylindrical roller bearing schematic

(Source:Tandon. and Nakra, 1990)

Figure 2.4: Cylindrical roller bearing

(Source:Tandon. and Nakra, 1990)

2.4 TYPE OF BEARING DEFECT

Bearings are among the most important components in the vast majority of machines and exacting demands are made upon their carrying capacity and reliability. Therefore it is quite natural that rolling bearings should have come to play such prominent part and that over the years they have been the subject of extensive research. Indeed rolling bearing technology has developed into a particular branch of science.

Among the benefits resulting from this research has been the ability to know the defect of bearing from signal and frequency sensor. There may be many reasons bearing defect such as heavier loading than has been anticipated, inadequate or unsuitable lubrication, careless handling, ineffective sealing or fits that are too tight, with resultant insufficient internal bearing clearance. Each of these factors produces its own particular type of damage and leaves its own special imprint on the bearing. Type of defect bearing that we used in test rig is corrode, outer race defect and contaminant.

2.4.1 Corrode

Corrode is the phenomena of oxidation or dissolution occurring on the surface and is produced by chemical action (electric chemical action including combination or cell restructuring) with acid or alkali. Corrosion occurs when a sulphur or chlorine compound contained in lubricant additives decomposes under high temperature. Also, occurs when water gets inside bearings. The countermeasures corrode is by enhancement of sealing capability, periodic inspection of lubricant, provision for adequate rust prevention during storage of bearings

Figure 2.5: Corrode cylindrical roller bearings.

(Source: Tandon. and Nakra, 1990)

2.4.2 Inner race defect

In inner race the defect usually is flaking and pitting. Flaking is a phenomenon in which the bearing surface turns scaly and peels off due to contact load repeatedly received on the raceway and rolling surface during rotation. Occurrence of flaking indicates that the end of a bearing's life is near. Pitting is a phenomenon in which small holes 0.1mm in depth are generated on the raceway surface by rolling fatigue. Flaking and fitting occur early in a bearing/s service life under conditions that during operation, bearing internal clearance becomes narrower than specified, bearing ring is mounted at an inclination by mistake, flaw is created during mounting, or brinelling, nicks and rust occur on the raceway surface or rolling surface and inaccurate shape of shaft or housing (imperfect circle, depressions on surface.). the way to countermeasure the flaking is use a bearing with heavier rated load, check if abnormal load is being generated, improve lubrication method to ensure better formation of lubricant film, by increasing the viscosity and when a failure is discovered at an early stage, the countermeasures described above should be taken, after investigating the causes. Way to countermeasures pitting is by increase viscosity of lubricant to ensure better formation of lubricant.

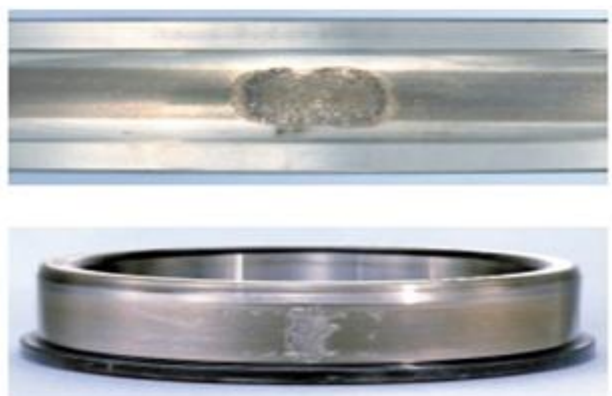

Figure 2.6: Inner race defect

(Source: Tandon. and Nakra, 1990)

2.4.3 Contaminant

In contaminant defect the phenomena is wear and fretting. Wear is caused mainly by sliding abrasion on parts including the roller end face and rib, cage pocket surface, cage and the guide surface of the bearing ring. Wear due to contamination by foreign matter and corrosion occurs not only to the sliding surface but also to the rolling surface. Fretting is a phenomena which occurs when slight sliding is repeatedly caused on the contact surface. On the fitting surface, fretting corrosion occurs, generating rust like powder. Usually wear causes by improper lubricant or shortage of lubricant and contamination by foreign matter. The cause fretting is vibration load and slight on fitting surface caused by load.

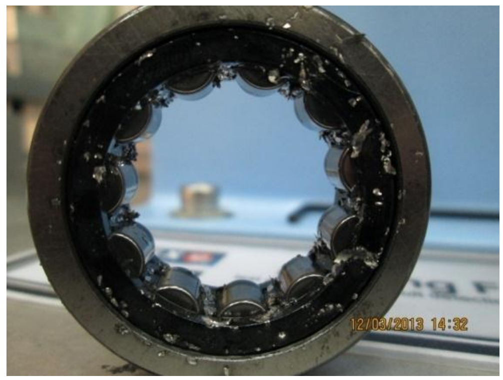

Figure 2.7: Contaminant defect (wear)

2.5 TEST RIG

In this part is to design and fabricate bearing condition monitoring test rig. Condition monitoring is a process to determine the operational state and health of a machine and if failure to monitor the condition of machine components will result in unnecessary maintenance costs. In test rig, bearing is critical components in machine and a defect such as corrode, outer race and contaminants may cause malfunction and may even lead to failure of the machinery. Therefore they have received great attention in the field of condition monitoring. Objective develop test rig for detect bearing defect is to design the bearing condition monitoring test rig and to fabricate bearing condition monitoring test rig.

In design test rig, the criterion that must be considered is interchangeable bearing and has durability to operate in longer life cycle. In interchangeable bearing, the top part of bearing can be opened so the different type of bearing defect can be to continue with other experiment. The design must be easy to user to opened and close the housing and not effect to bearing. In durability criteria is to operate in longer life cycle. The durability of bearing housing based on the stability of the housing base can against the vibration and can avoid from misalignment shaft.

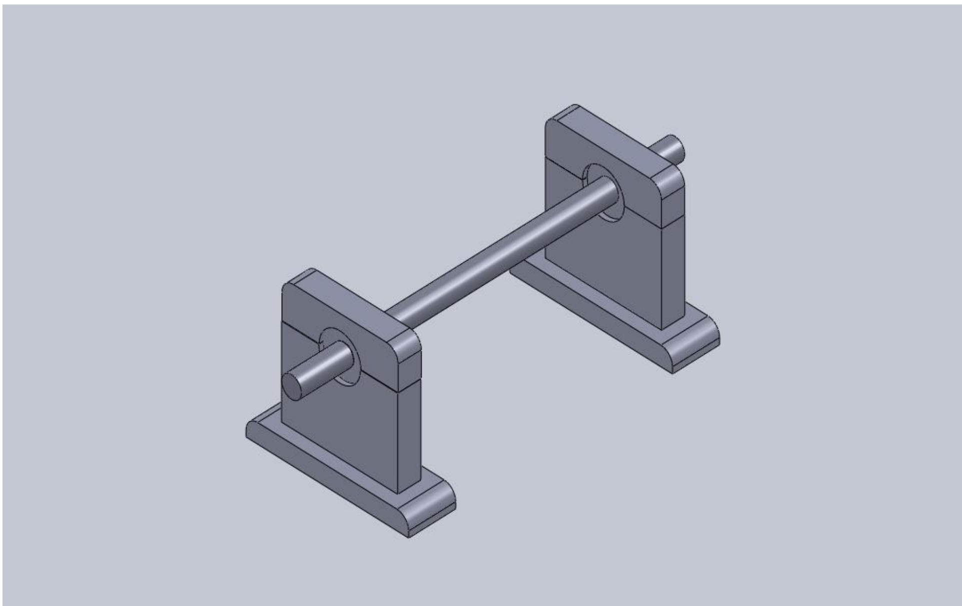

Figure 2.8: Schematic diagram housing and shaft design

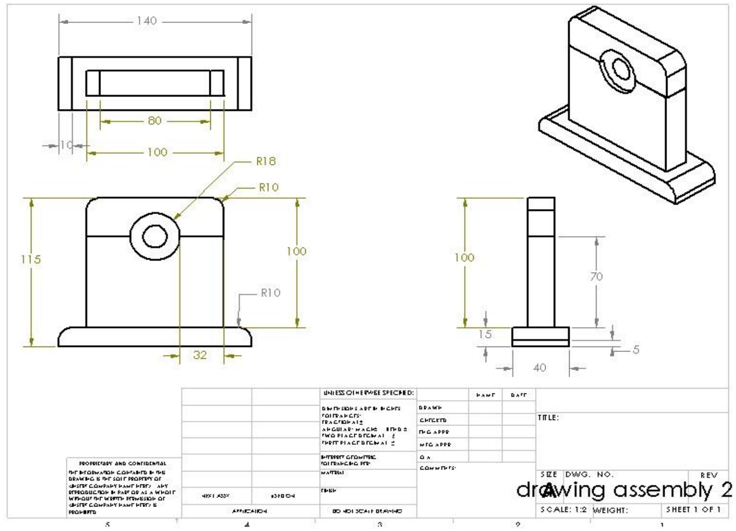

Figure 2.9: Diagrams housing design

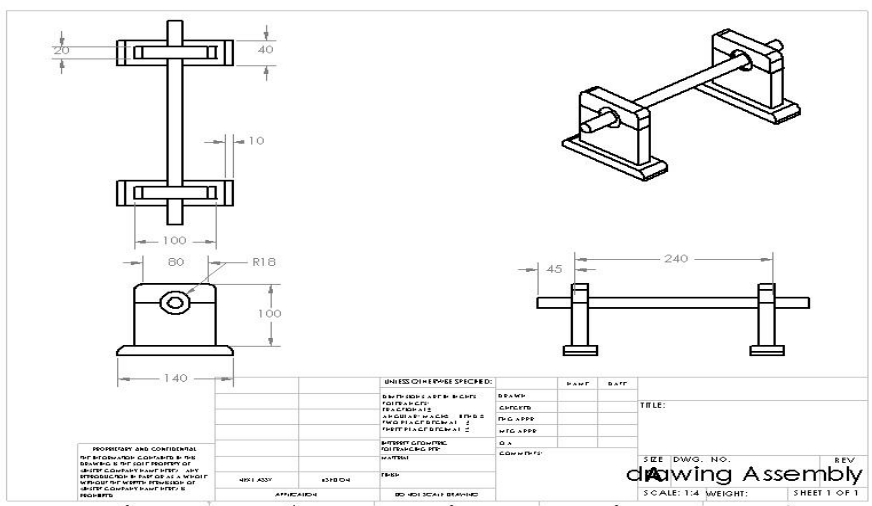

Figure 2.10: Diagrams shaft design

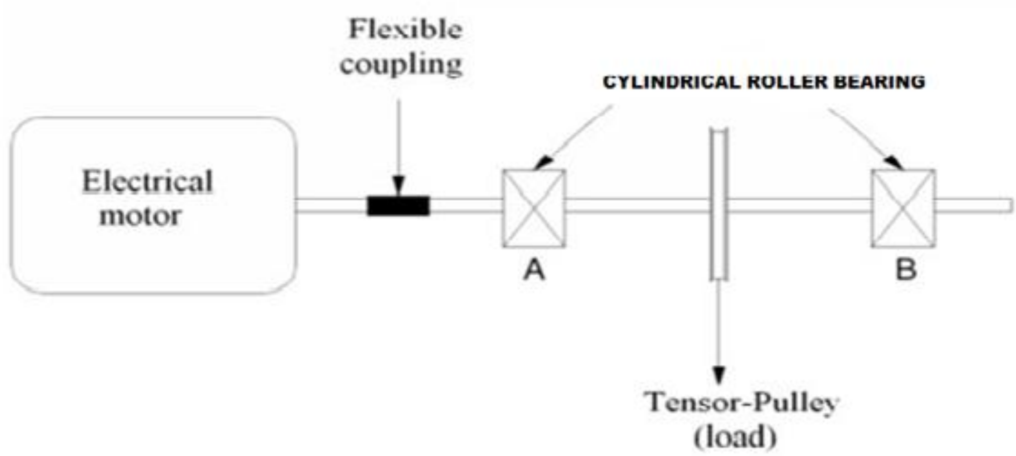

Figure 2.11: systematic diagram test rig

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter is to provide a methodology to get acoustic emission analysis for bearing condition monitoring. From develop test rig for detect bearing defect ,testing procedure, test setup, sensor calibration test and data flow analysis is provide to explains in this chapter methodology

3.2 PROJECT FLOW CHART

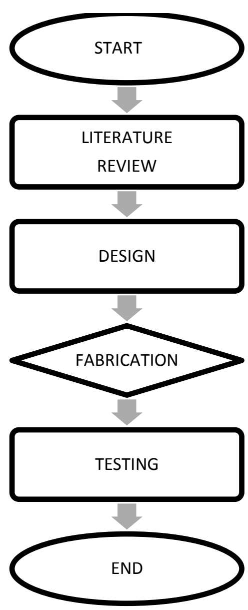

Figure 3.1: Flow chart fabricate bearing and design test rig

Flow chart shows the process of fabricate bearing and design test rig, the first step is literature review means do research about the problem statement of bearing. Problem statement is to study the bearing condition monitoring the test rig had to be designed, to do monitoring work of that bearing to understand the bearing failure mechanism and bearing condition in machines must be monitored during the production.

The next is step design, from the problem statement make design to solve that problem using software solid work. From design make prototype with actual measurement. After finish and have good design is fabrication the product using machine and lastly is testing the design whether can be used or not.

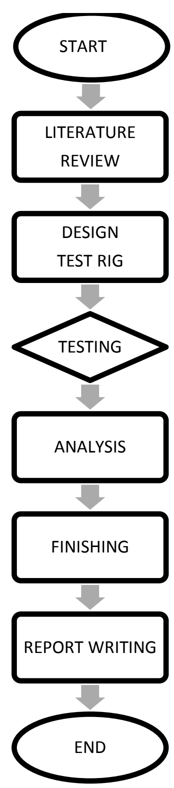

Figure 3.2: Flow chart methodology acoustic emission

Flow chart shows the methodology to do acoustic emission analysis for bearing condition monitoring. In literature review, doing research about acoustic emission, test rig, type of bearing and type of defect to more understand more before doing experiment acoustic emission. Next step is design test rig, fabrication housing and shaft is important part in design test rig. Design fabrication using autocad and solidwork is important before makes housing and shaft test rig used machine because have a dimension and avoid from mistake to place in test rig.

The bearing type NU203 was chosen because free side bearings that absorb shaft expansion compare to other type of bearing. Type of defect used is contaminant, outer race and corrode. Next process is run the experiment to detect bearing condition using software physical acoustic to analysis the result. Lastly is write report after analysis the result.

3.3 ACOUSTIC EMISSION TEST SETUP

3.3.1 Testing Procedure

Prior to seeding defects the test-rig was operated to provide an indication of background noise levels. Three types of defects were seeded on the inner and outer races. The seeded fault was a uniform surface line defect that was accomplished with an engraving machine. The test rig was operated at three different rotational speeds: 30%, 60% and 90% of speed motor test rig. At each rotational speed three load cases were considered constant. For background noise measurements the rig was operated at up 100% of speed motor with no radial load. To simulate realistic diagnostic conditions, the timing of data acquisition for every one of the one hundred data files during test conditions was selected randomly within 5 minute test period. It was felt this approach was representative of the method to be employed during diagnosis of operational units. Moreover, it provided a good test on the suitability and robustness of AE for bearing diagnosis. Prior to extracting AE characteristics parameters, all one hundred data files were linked, creating a chain equivalent to 0.8 seconds. As such, AE count vales calculated for each test conditions were in effect an accumulation of counts over one hundred data files and the rms values were equivalent to the average over one hundred data files.

3.3.2 Test Setup

A test rig was designed to simulate early stage of bearing defects (Figure 3.3). The rig consisted of a motor/gear box unit providing a rotational speed range of 0% to 100% rotational speed. Two aligning support bearings, a rubber coupling and a larger support were employed. The test bearing investigated was a cylindrical roller bearing, type N203. This type of bearing was chosen because of linear contact, rotational torque is higher for bearings than for ball bearings but rigidity is also higher and load capacity is higher for rolling bearings. Cylindrical roller bearings equipped with a lip can bear slight radial loads. A radial load was applied to the top of bearing via hydraulic cylinder ram supported by an “H” frame. All attempts were undertaken to ensure the amount of grease within the bearing remained the same. It must be noted that all tests and simulations, the receiving transducer was cemented with superglue onto the bearing housing. To ensure even distribution of the couplant across the face of the sensor, a small amount of glue was place in the centre of the intended position of the sensor. The sensor was then carefully presses onto the surface, spreading the couplant uniformly.

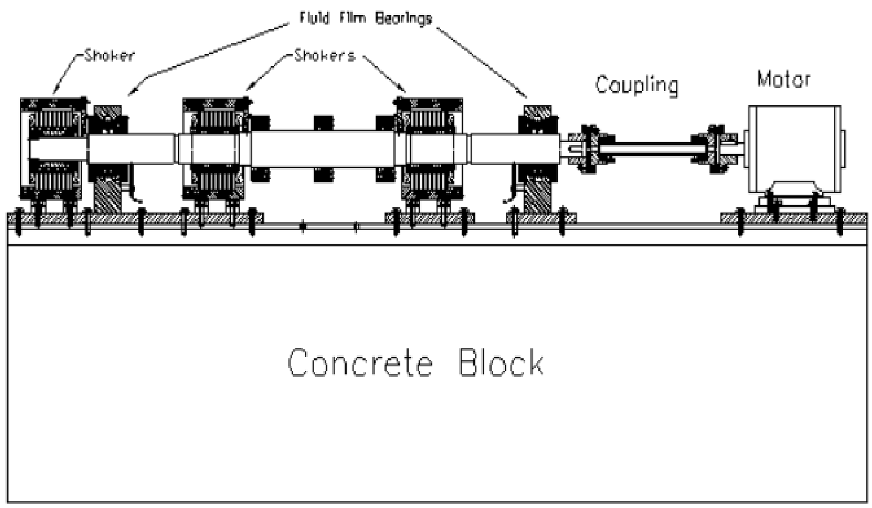

Figure 3.3: Test rig setup

(Source: Tandon. and Nakra, 1990)

3.4 DATA FLOW ANALYSIS

The most commonly measured AE parameters are amplitude, rms, energy, counts and events. Counts involve counting the number of times the amplitude exceeds a preset voltage (threshold level) in a given time and gives a simple number characteristic of the signal. The AE parameters measured for diagnosis in this particular investigation were amplitude and AE counts, energy count. In determining the threshold level for AE counts, five values as a percentage of the lowest amplitude background noise observed were employed. The percentage values selected were 10%, 30%, 50%, 70% and 90%. The reason for selecting these specific values was it offered a wide range of values, particularly useful as the investigators hoped to ascertain and determine the influence of threshold value on AE count results. Usually determining the threshold levels have been at the discretion of the investigator and in most cases, the value are probably selected depending on intuition and experience on the particular test rig .

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

The purpose of this chapter is to provide a result from experiment test rig related to acoustic emission. Four type of bearing defect that contaminated defect, inner defect, corrode defect and healthy is used to get result about bearing condition using acoustic emission method. The result was used three parameter is amplitude, count and energy count to compare result.

4.2 REVOLUTION PER SECOND (RPS) OF TEST RIG

Acoustic Emission response of bearing brand FAG model NU203 with no defect and various defects (roller defect, contaminated defect, inner defect, corrode defect) has been measured with same radial loads and speeds. Radial loads was constant 0.5 kg and radial load from 30 %, 60% and 90% revolution per second (RPS) has been used for measurements. The load has been constant at 30% RPS. The responses for other test bearings have been measured at same load and RPS. The statistical distributions have also been obtained for 30 % RPS.

Figure show the data of type of defect bearing with percent revolution per second of motor test rig with tachometer reading.

Table 4.1: Data speed tachometer reading

Type defect bearing	% RPS	Tachometer reading (RPS)
contaminated	30 60 90	14.75 29.68 44.59
Inner	30 60 90	14.83 29.70 44.70
corrode	30 60 90	14.66 29.51 44.52
healthy	30 60 90	14.86 29.74 44.75

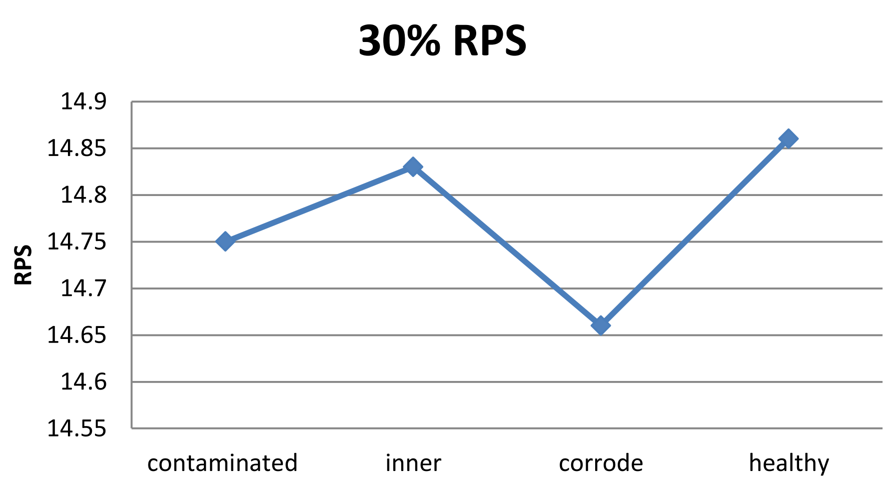

Figure 4.2: Graph 30% revolution per second (RPS)

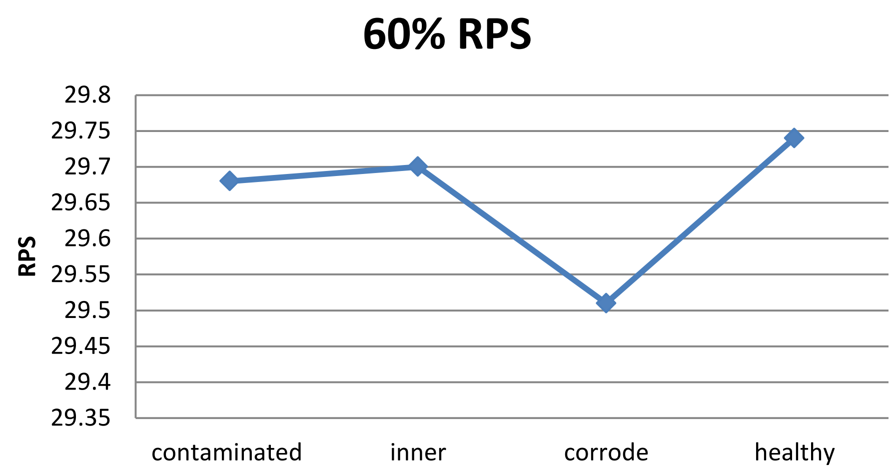

Figure 4.3: Graph 60% revolution per second (RPS)

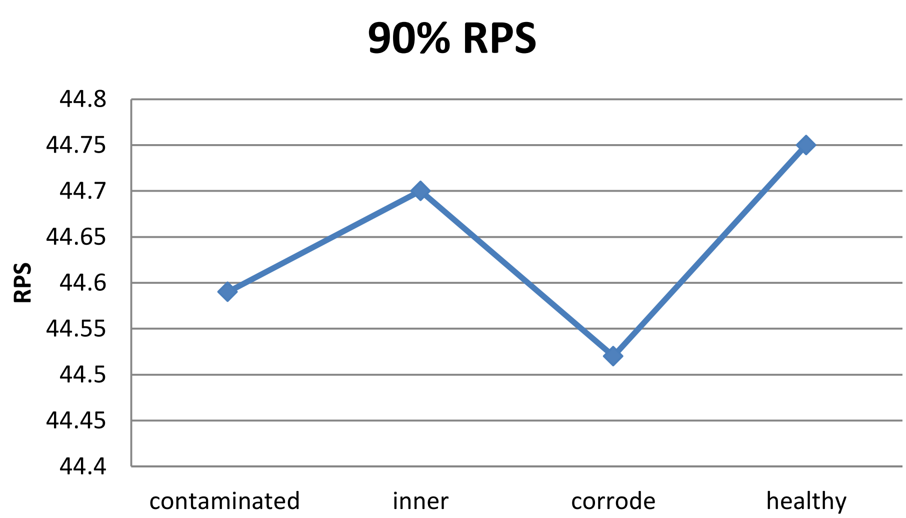

Figure 4.4: Graph 90 % revolution per second (RPS)

From graph above can see that different type of bearing with same percent revolution per second (RPS) have different reading using tachometer. It is because with defect affect the revolution per second and slow the acceleration of motor. Corrode defect bearing with 30 %, 60 % and 90 % is the lower reading revolution per second using tachometer 30 % with 14.66 rps, 60 % with 29.51 rps, 90 % with 44.52 rps compare to other defect.

The next tachometer slow is contaminated defect with reading 14.75 rps, 29.68 rps and 44.59 in 30 %, 60 % and 90 % of speed test rig. Next lower reading is inner defect. Healthy bearing that no have any defect is higher speed using tachometer reading (RPS) 30 % with 14.86 rps, 60 % with 29.74 rps and 90 % with 44.75 rps.

It seems like hypothesis that different defect bearing used in test rig will get different result from speed. Higher reading tachometer mean defect is small or no defect compare to lower reading tachometer has a defect will make speed decrease.

4.3 AMPLITUDE OF DEFECT BEARING

Amplitude is one of the parameter that used in research acoustic emission to detect bearing condition. Amplitude is important parameter in acoustic emission inspection because determines detectability of the signal. The signal below threshold will not be recorded. Amplitude measured voltage in a waveform and it measure in Decibels (dB).

1) Healthy graph :

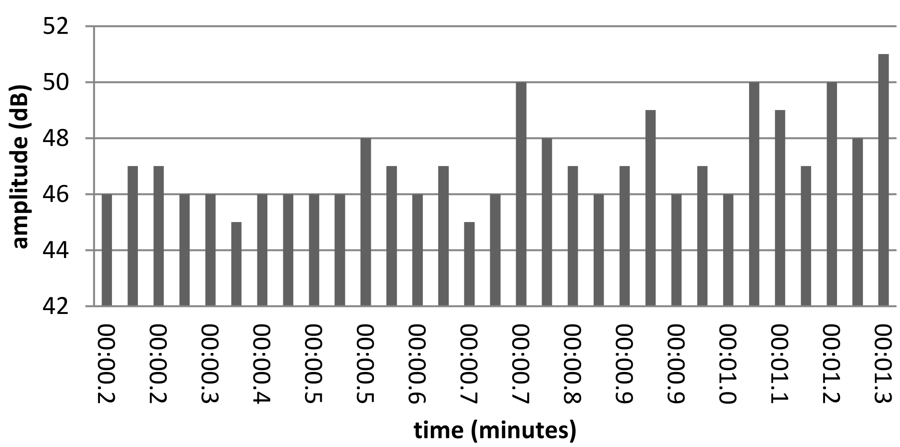

Figure 4.5: Graph healthy bearing at speed 30 % RPS amplitude

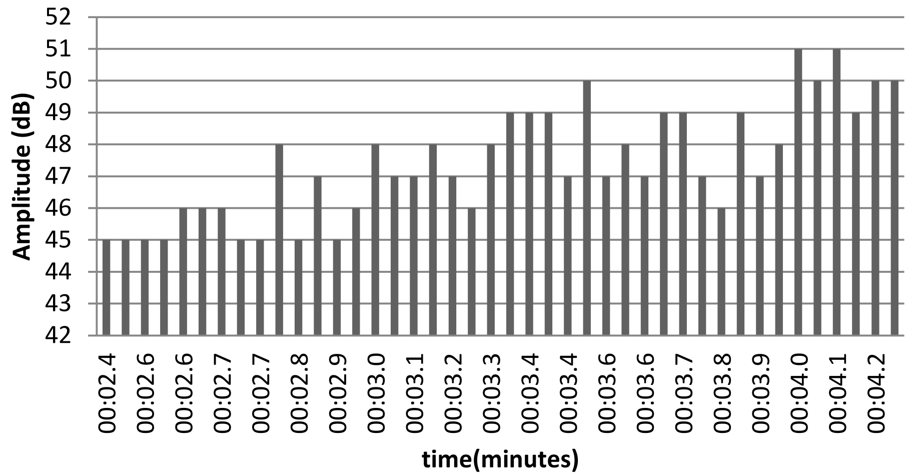

Figure 4.6: Graph healthy bearing at speed 60 % RPS amplitude

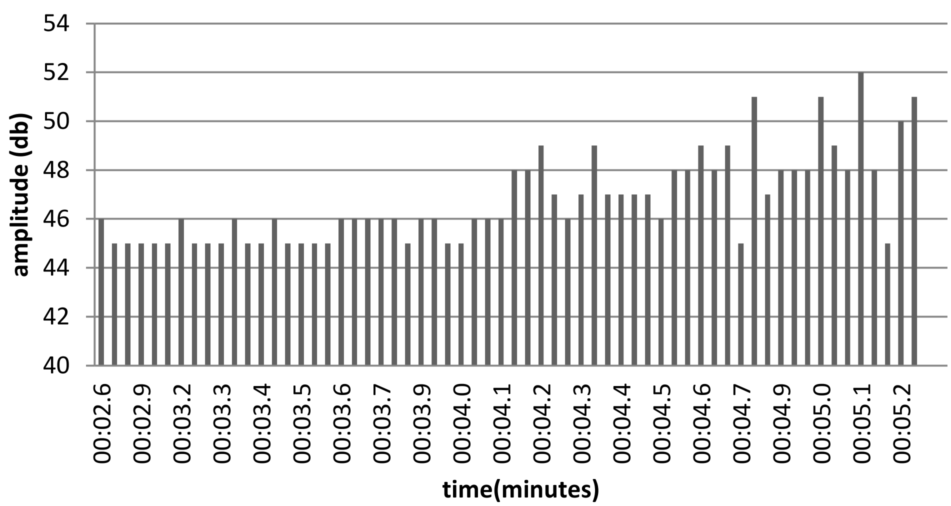

Figure 4.7: Graph healthy bearing at speed 90 % RPS amplitude

In graph healthy Figure 4.5, Figure 4.6 and Figure 4.7 show the amplitude healthy bearing. In healthy experiment, it was no defect was having in bearing so the result gets almost same with different speed of motor test rig. In Figure 4.5, maximum amplitude is 50 decibels in amplitude vs. time graph. The higher amplitude in healthy in 60 % is 51 dB and 90 % speed in motor of test rig that 52 decibel. Healthy graph show that increasing speed of motor test rig will have little different amplitude with 30 % and 60 % speed in motor test rig because healthy is just experiment control and not have any defect on bearing.

2) contaminated defect graph:

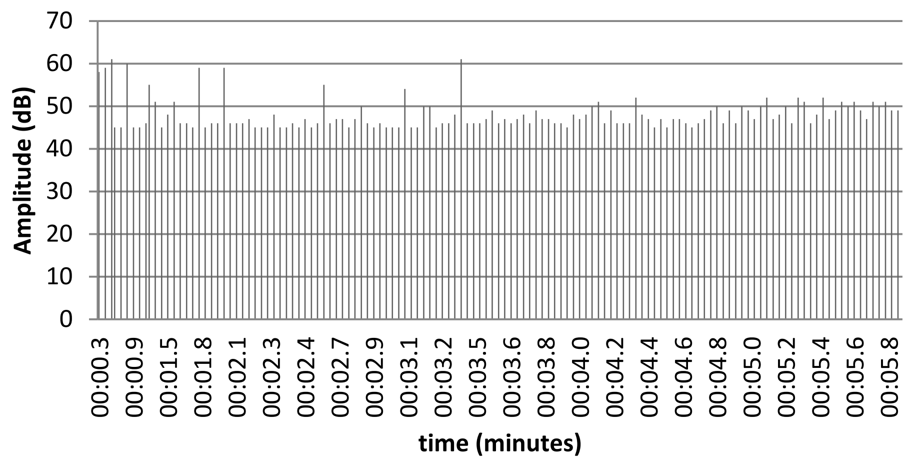

Figure 4.8: Graph contaminated defect 30 % RPS amplitude

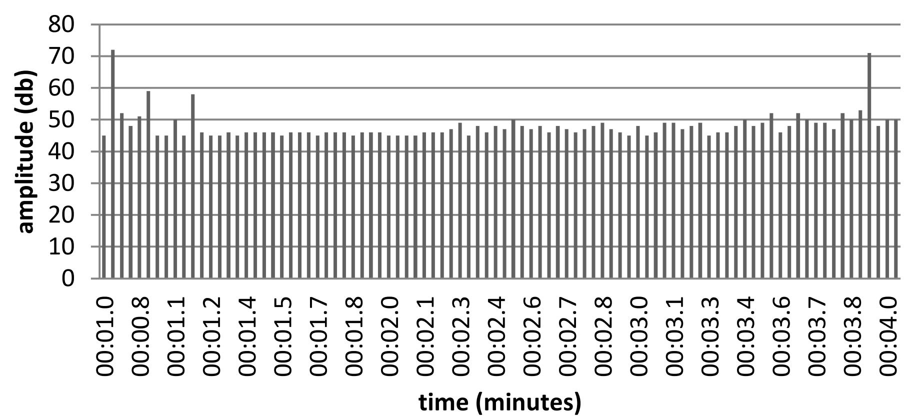

Figure 4.9: Graph contaminated defect 60 % RPS amplitude

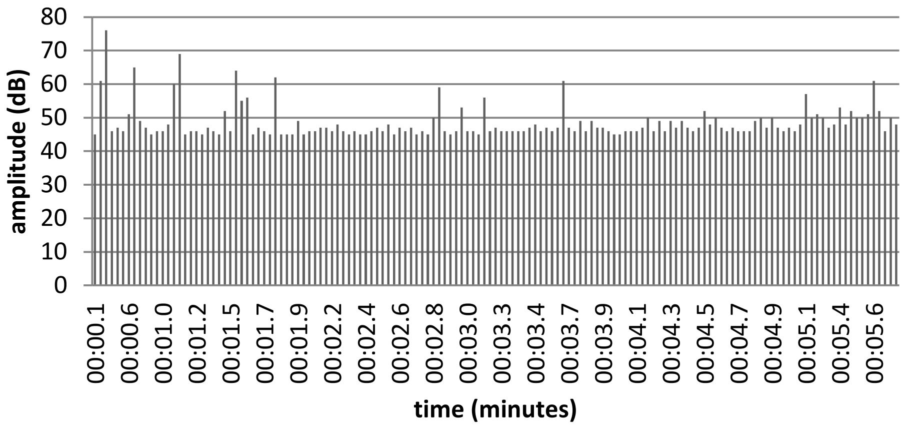

Figure 4.10: Graph contaminated defect 90 % RPS amplitude

Graph Figure 4.8, Figure 4.9 and Figure 4.10 show amplitude contaminated defect bearing. Increasing speed of motor test rig will increase amplitude of the experiment. Higher amplitude was recorded in contaminated defect is 76 decibel (dB) in Figure 4.10. In Figure 4.9, the higher amplitude is 72 decibels and the lower amplitude record is 61 decibels in Figure 4.8. Pattern graph up and down because when contaminated defect hit the sensor will make amplitude higher compare sensor was no hit the sensor.

3) Corrode defect graph :

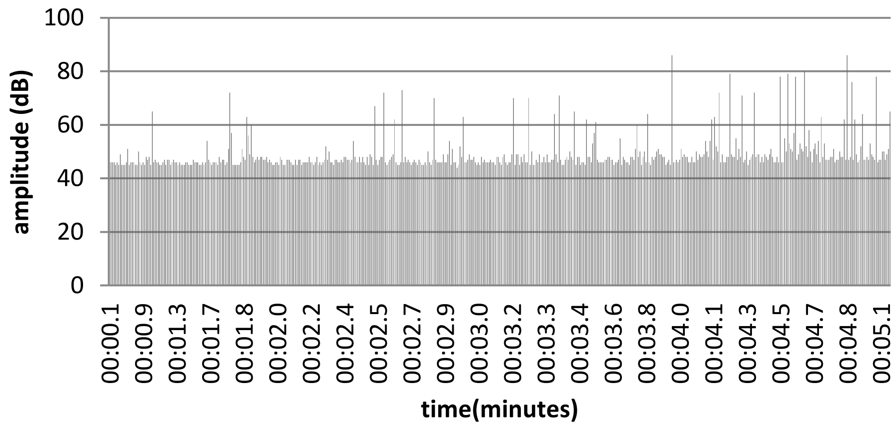

Figure 4.11: Graph corrode defect 30 % RPS amplitude

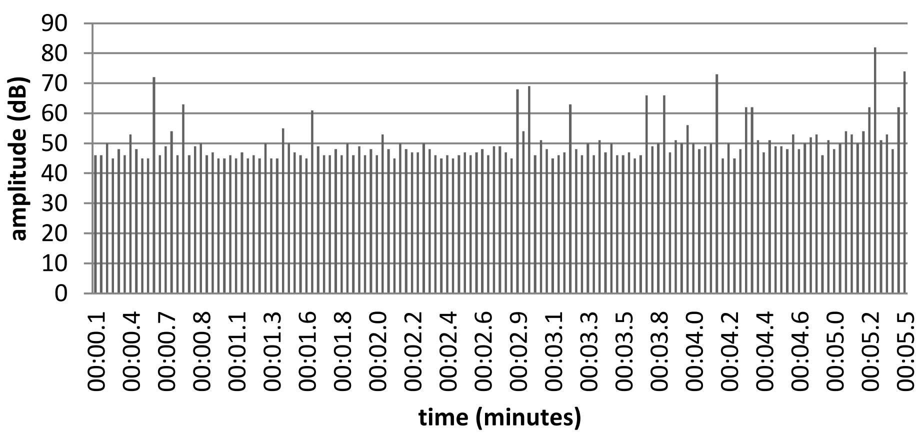

Figure 4.12: Graph corrode defect 60 % RPS amplitude

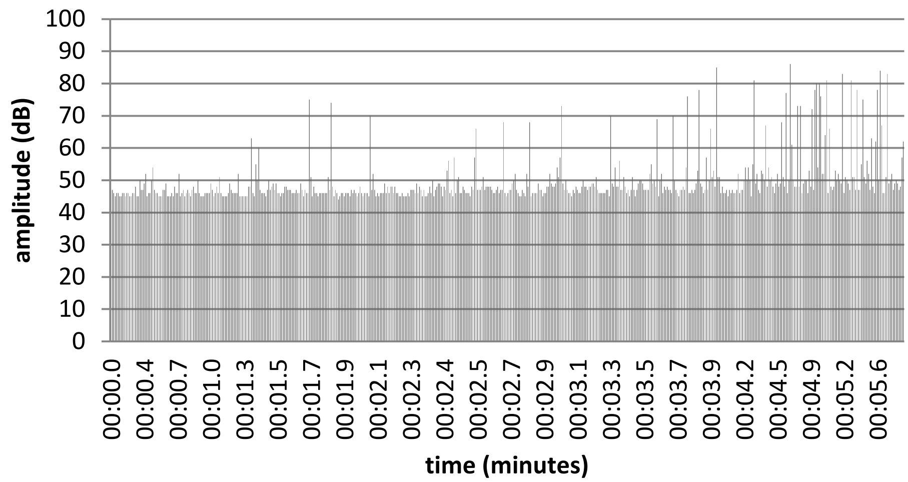

Figure 4.13: Graph corrode defect 90 % RPS amplitude

Graph corrode defect in Figure 4.11, Figure 4.12 and Figure 4.13 show the amplitude corrode defect. In graph Figure 4.11, the higher amplitude is 80 decibel and in graph Figure 4.12 and 4.13, the higher amplitude was record is 82 decibel and 86 decibel. In corrode defect can be concluded that higher speed of motor test rig will higher amplitude.

4) Inner defect graph :

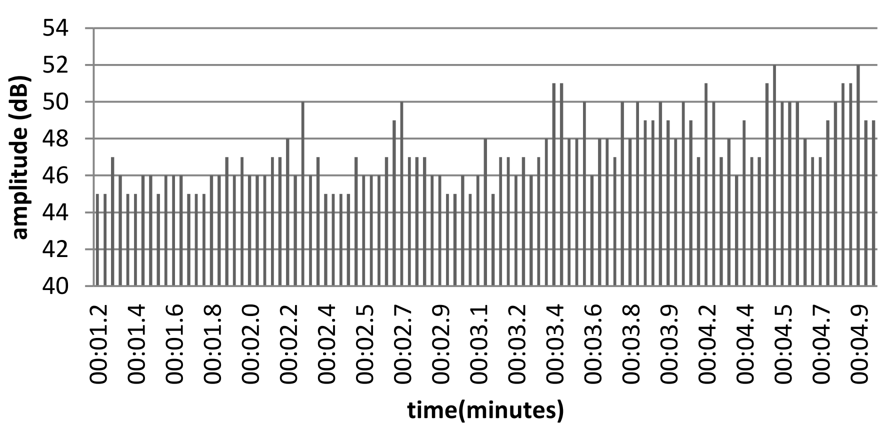

Figure 4.14: Graph inner defect 30 % RPS amplitude

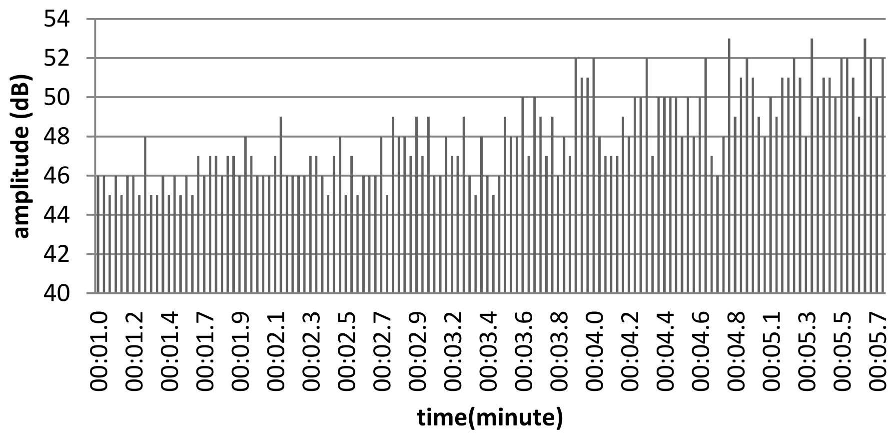

Figure 4.15: Graph inner defect 60 % RPS amplitude

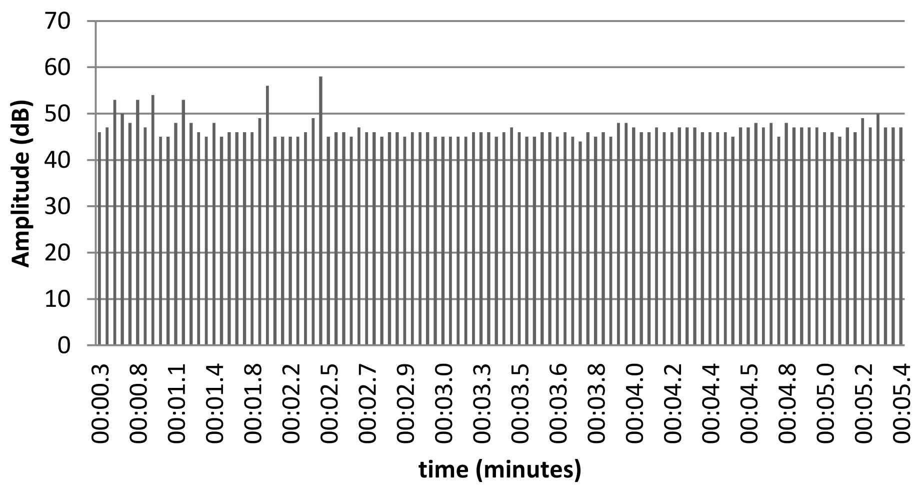

Figure 4.16: Graph inner defect 90 % RPS amplitude

In graph inner defect Figure 4.14, Figure 4.15, and Figure 4.16 show the amplitude inner defect. Amplitude high in every inner defect because transient waves will form of displacement vibration in the material which can be recorded by sensor such displacement gauges or accelerator gauges. Graph inner defect Figure 4.14 show the maximum amplitude was record is 52 decibel and 52 decibels maximum amplitude in graph inner defect Figure

4.15. In inner defect 90 % also the higher amplitude is 58 dB. It can be concluded increasing speed of motor test ring into 90 % will higher amplitude of inner defect compared to 30 %.

From four defect (contaminated defect, corrode defect, inner defect and healthy) can see that every defect have value in amplitude. The higher amplitude is corroding defect that 86 decibel in 90 % speed of motor test rig. The second higher is contaminated defect in 90 % speed of motor test rig with 76 decibel. Next higher is inner defect bearing with 58 decibels and lower amplitude is healthy bearing with 52 decibel. Using higher speed of motor test rig will make maximum amplitude in defect experiment. Corrode defect higher compared to other defect because corrode defect has higher stress waves that generated during transient elastic waves release of stored strain energy in material subjected to mechanical load. Amplitude is important parameter in acoustic emission inspection because it determines the detectability of the signal. Summarize of the amplitude can be shown in Table 4.17.

Table 4.17: Summarize of the amplitude

Speed (RPS)	Healthy bearing (dB)	Contaminated defect (dB)	Corrode defect (dB)	Inner defect (dB)
30	50	61	80	52
60	51	72	82	53
90	52	76	86	58

4.4 COUNTS

Count is the second parameter used in to detect bearing condition using acoustic emission method because number of pulses emitted by measurement circuitry if the signal amplitude greater than threshold. Counts are depending on magnitude acoustic emission event and characteristic, one shot may produce one or many count. It is important to provide quality information about shape signal.

1) Count healthy graph :

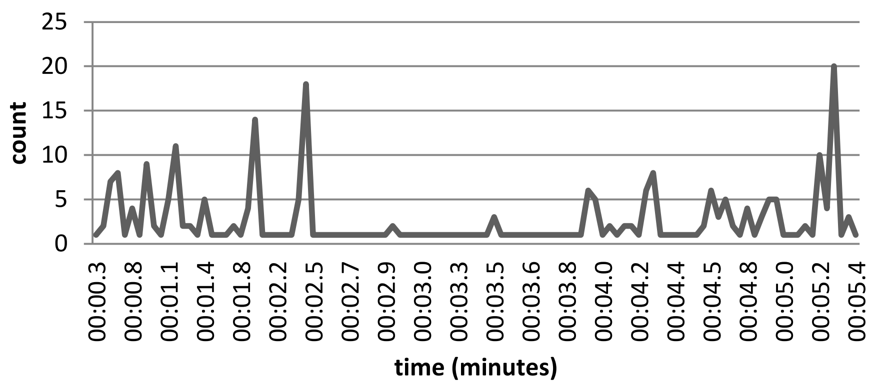

Figure 4.18: Graph healthy bearing at speed 30 % RPS count

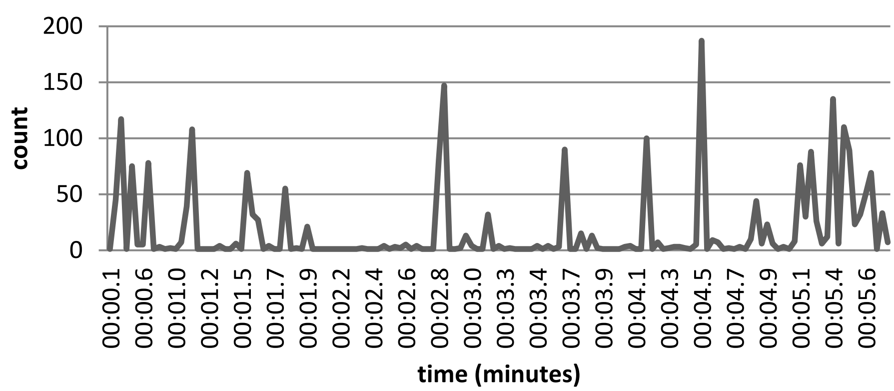

Figure 4.19: Graph healthy bearing at speed 60% RPS count

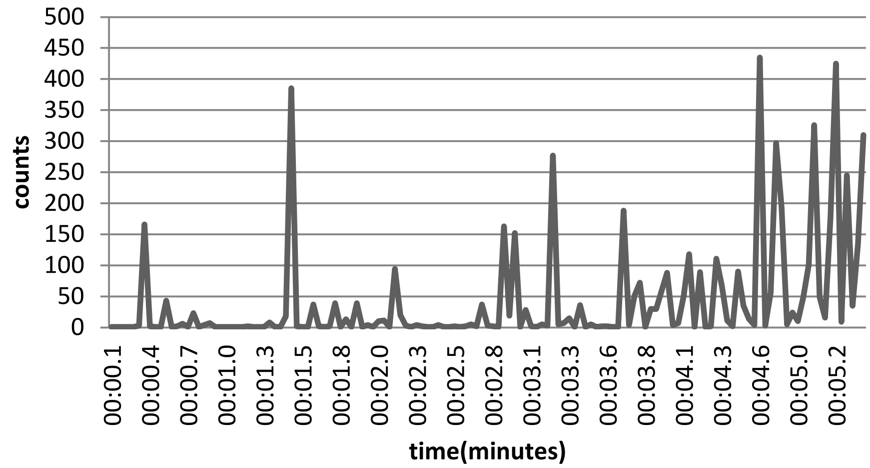

Figure 4.20: Graph healthy bearing at speed 90% RPS count

Graph Figure 4.18, Figure 4.19 and Figure 4.19 show count healthy bearing. Healthy bearing is type of bearing that have no defect .Figure 4.18 the maximum count is 20, in Figure 4.19 is 187 counts. But is Figure 4.20 the maximum count has is 425 counts. Graph healthy can be concluded that increasing speed will have many counts in point not have maximum count.

2) Counts contaminated graph :

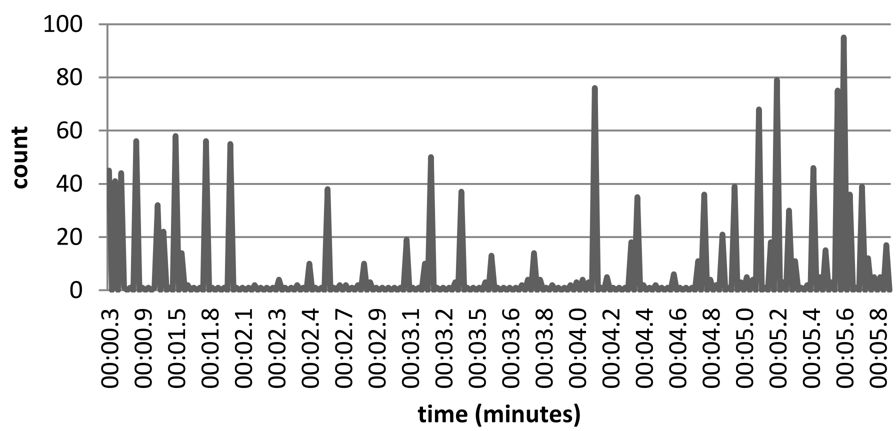

Figure 4.21: Graph contaminated defect 30 % RPS count

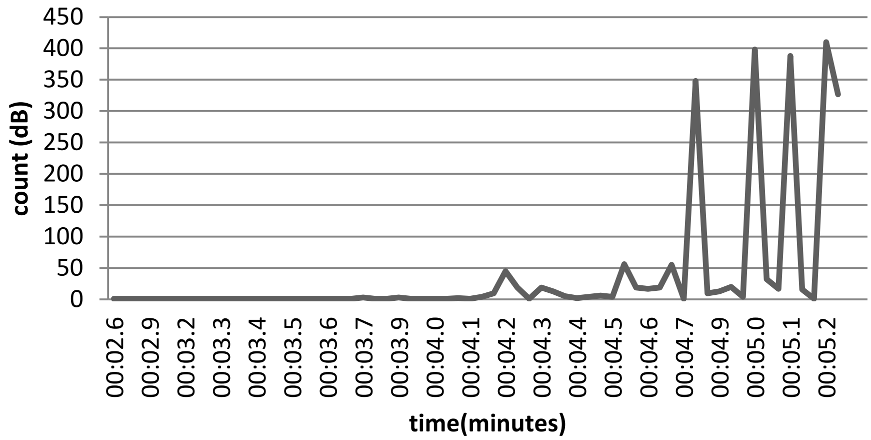

Figure 4.22: Graph contaminated defect 60 % RPS count

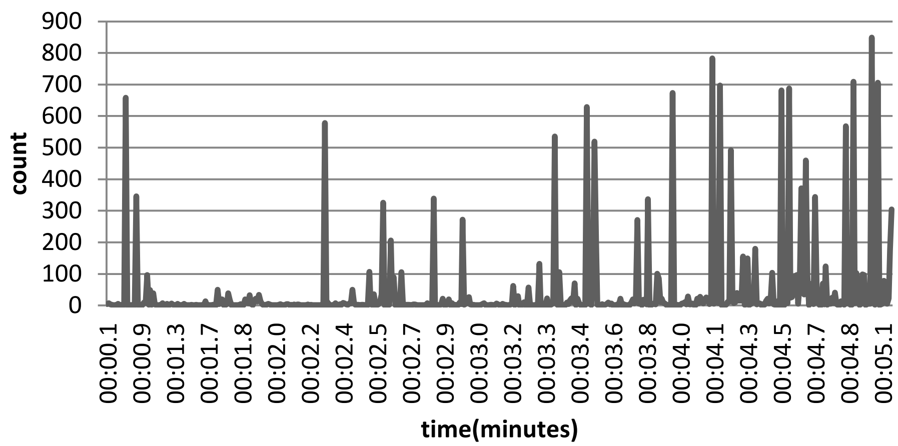

Figure 4.23: Graph contaminated defect 90 % RPS count

In count graph Figure 4.21, Figure 4.22 and Figure 4.23 show count contaminated defect. Figure 4.21 show the maximum count is 95 but maximum count in Figure 4.22 is 410. Higher amplitude in contaminated defect is 849 counts in Figure 4.23. It can be concluded that increasing speed of test rig will increase count in contaminated defect in every speed of the experiment.

3) Count corrode graph :

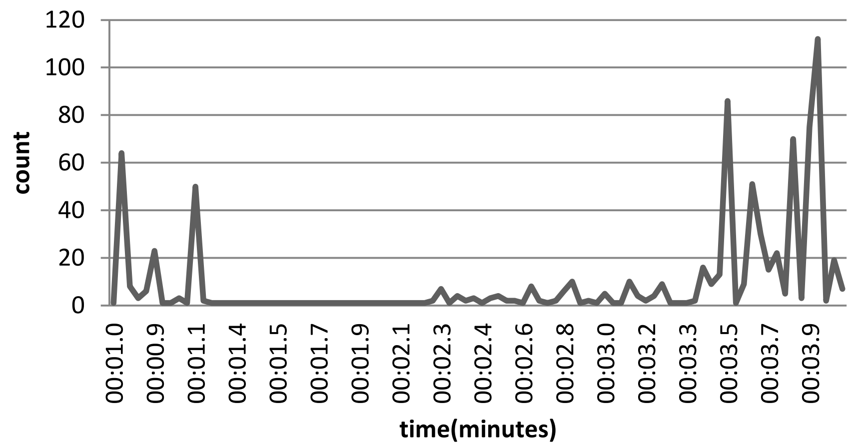

Figure 4.24: Graph corrode defect 30 % RPS count

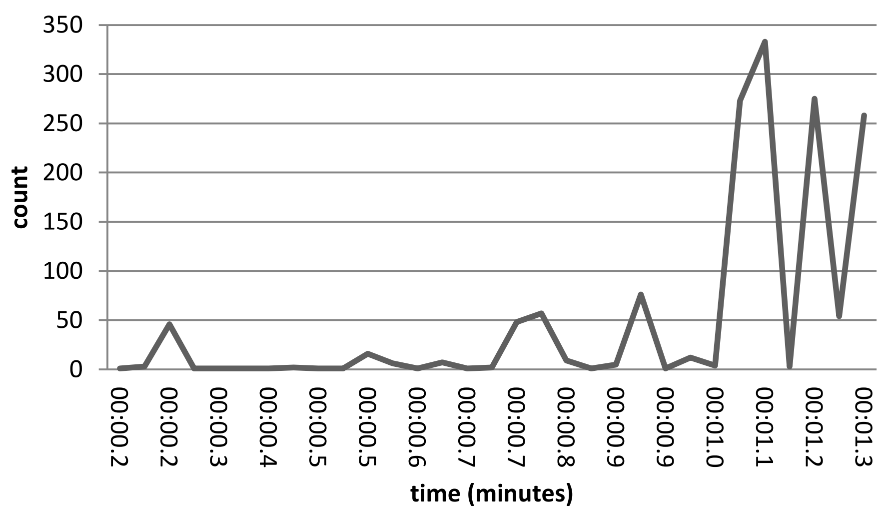

Figure 4.25: Graph corrode defect 60 % RPS count

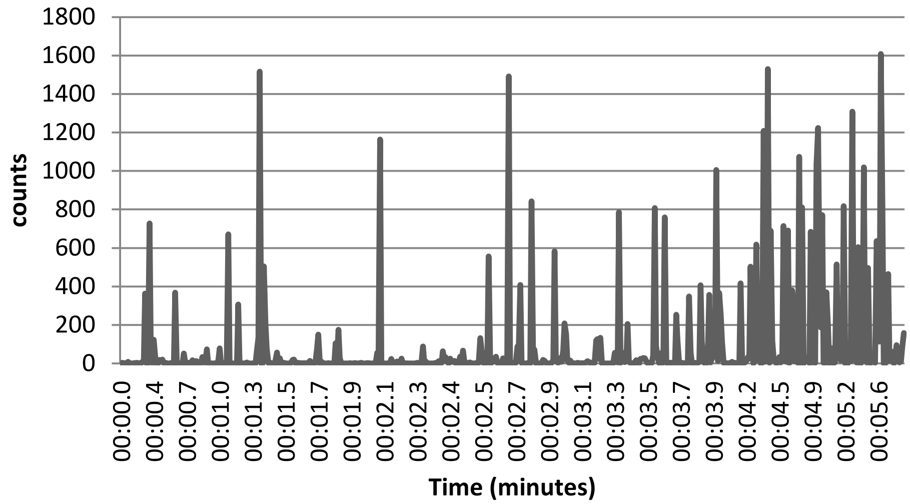

Figure 4.26: Graph corrode defect 90 % RPS count

In corrode defect graph show that count corrode defect. The maximum defect in 30 %, 60 % and 90 % is 112 counts, 333 counts and 1607 counts. It clear that count is maximum in higher speed that 90% of the motor test rig compared to 30% and 60% of the motor test rig.

4) Count inner defect graph :

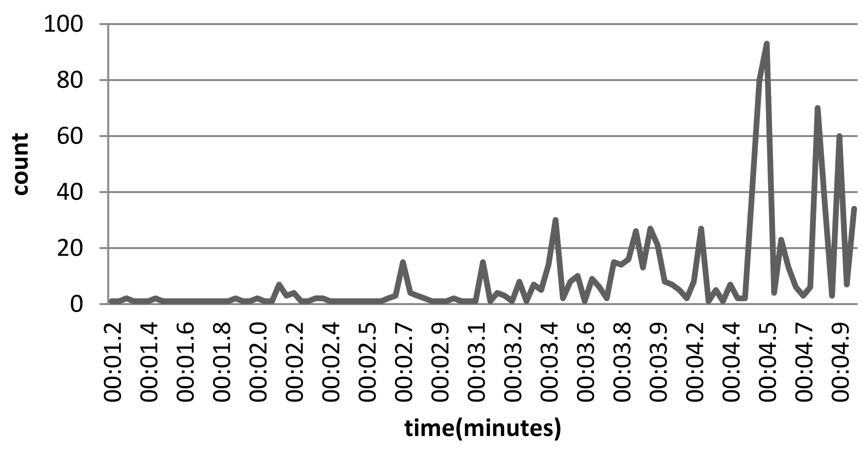

Figure 4.27: Graph inner defect 30 % RPS count

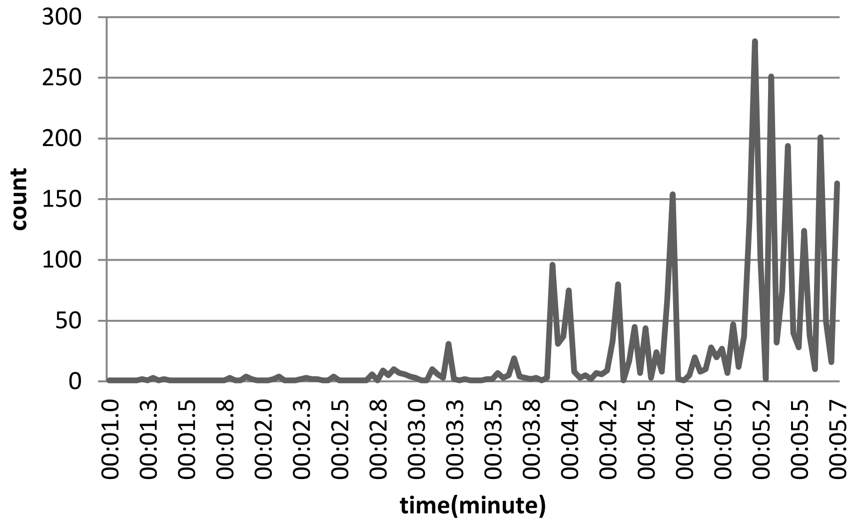

Figure 4.28: Graph inner defect 60 % RPS count

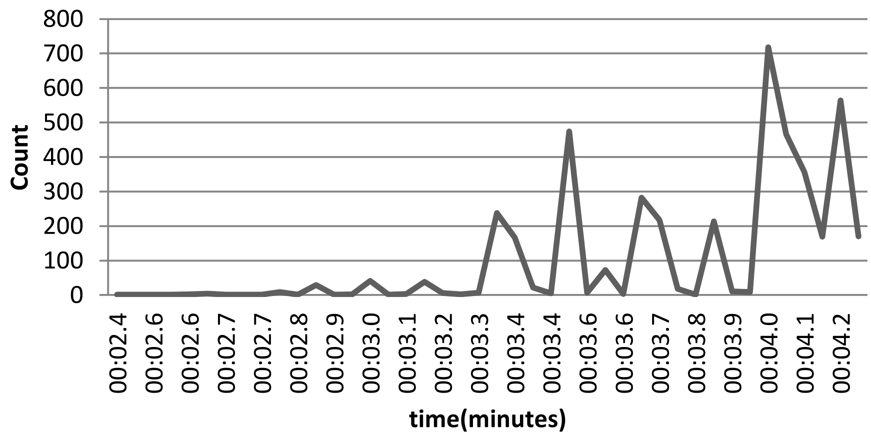

Figure 4.29: Graph inner defect 90 % RPS count

Graph inner defect show the count inner defect in 30 %, 60 % and 90 % speed of motor test rig. Maximum counts in Figure 4.27 are 93, 280 counts in Figure 4.28 and 718 count in Figure 4.29. In inner defect can be make conclusion that higher speed of motor test rig will make higher count in inner defect.

From four experiment in count can concluded that is corrode defect has 1607 count, inner defect has 718 counts, contaminated defect has 849 counts and healthy has 425 counts in experiment test rig. Corrode defect higher compared to contaminated defect, inner defect and healthy. Corrode defect higher because has larger number of pulses emitted by the measurement circuitry. One hit can produce many count in inner defect because has greater magnitude of the acoustic emission event and the characteristics of the material. Next higher count is contaminated defect followed by inner defect. Healthy is lower count because healthy bearing is no any defect and as a controlled experiment only. Also, magnitude of the acoustic emission event and the characteristics of the material are lower. Summarize of the count can be shown in Table 4.29.

Table 4.30: Summarize of the count

Speed (RPS)	Healthy bearing	Contaminated defect	Corrode defect	Inner defect
30	20	95	112	93
60	187	410	333	280
90	425	849	1607	718

4.5 ENERGY COUNTS

Energy count is to measure of the area under the envelope of the rectifier linear voltage time signal from the transducer. The relative signal amplitude and useful energy because energy of the emission can be determined. Energy count parameter is sensitive to the duration and amplitude of the signal but does not use counts or user defined thresholds.

1) Energy counts healthy graph :

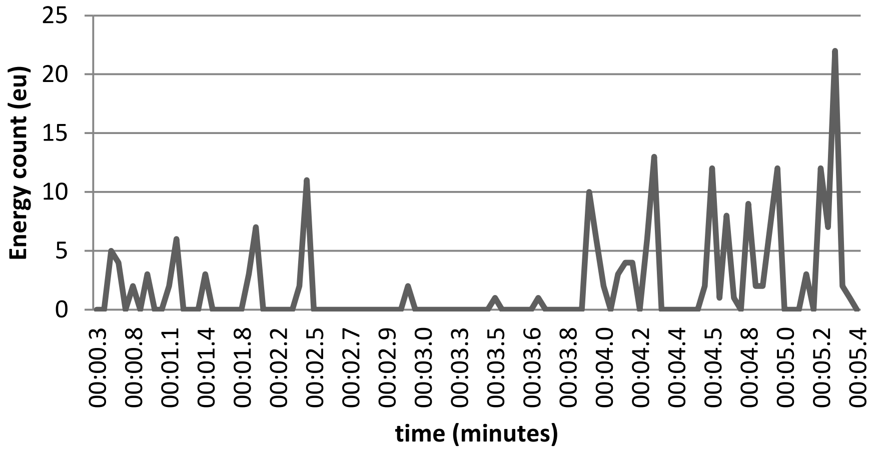

Figure 4.31: Graph healthy bearing at speed 30 % RPS energy count

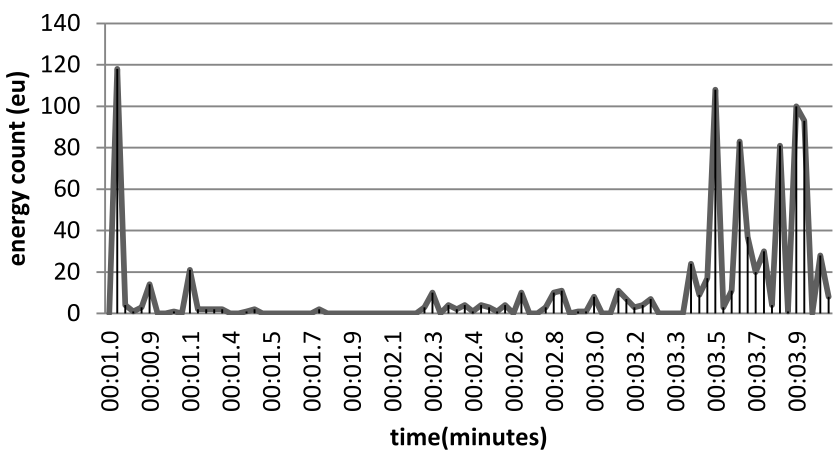

Figure 4.32: Graph healthy bearing at speed 60 % RPS energy count

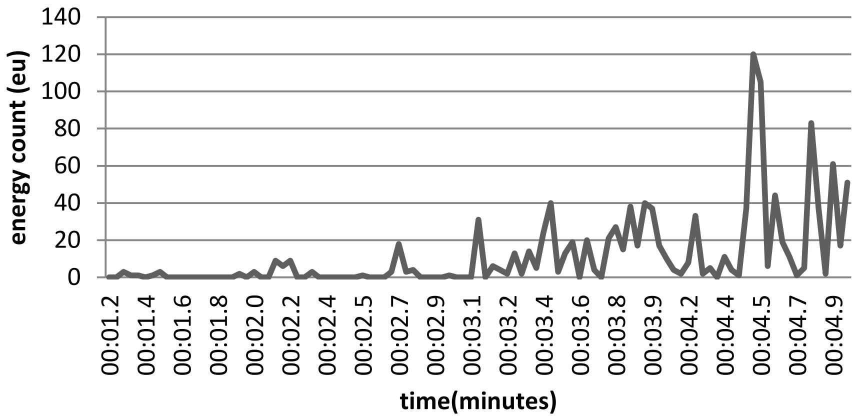

Figure 4.33: Graph healthy bearing at speed 90 % RPS energy count

In healthy energy count vs. time show that a little different with Figure 4.31, Figure 4.32 and Figure 4.33 because healthy bearing is no have any defect on bearing. The different is used different speed of motor test rig. In Figure 4.31 the higher energy count is 22 eu, 118 eu in Figure 4.32 and 120 eu was record in Figure 4.33. It can be concluded that different speed will get different energy count in experiment.

2) Energy counts contaminated defect graph :

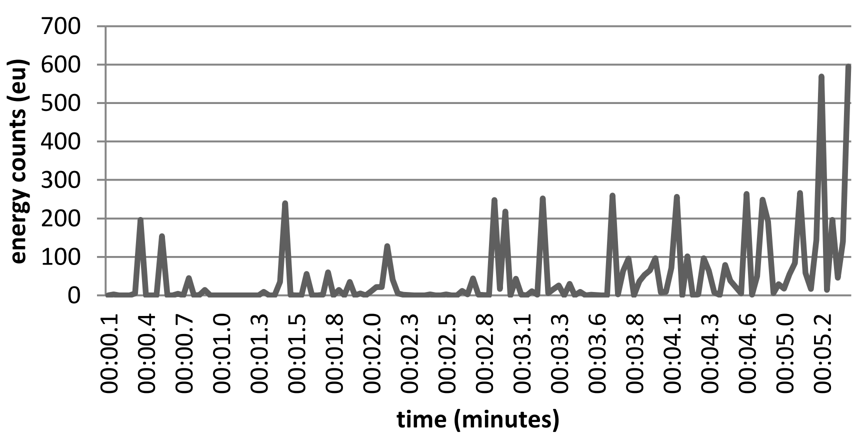

Figure 4.34: Graph contaminated defect 30 % RPS energy count

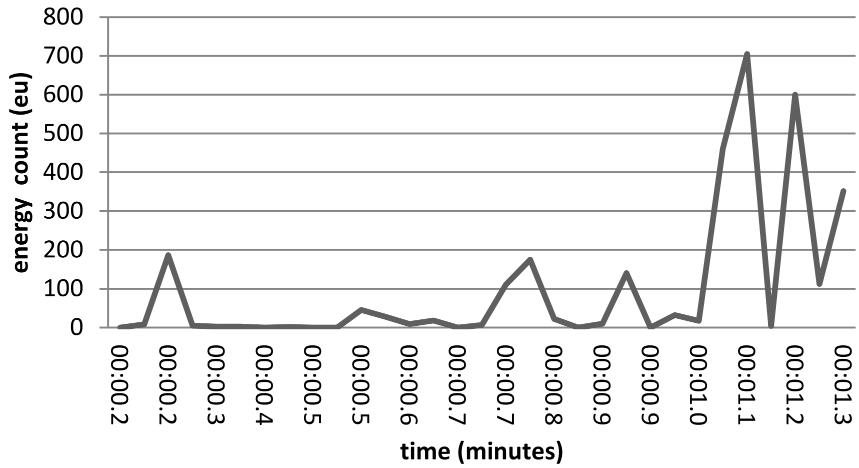

Figure 4.35: Graph contaminated defect 60 % RPS energy count

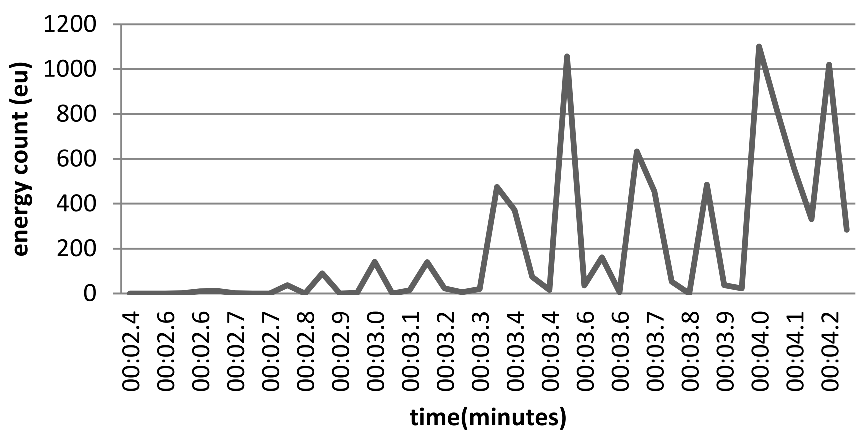

Figure 4.36: Graph contaminated defect 90 % RPS energy count

In graph contaminated energy count show the energy count contaminated defect. It can be seen in Figure 4.34 that energy counts was recorded are 595 eu. Different with contaminated 60 % of speed motor test rig in Figure 4.35 that higher energy counts is 705 eu. The maximum energy count in contaminated defect in Figure 4.36 is 1101 eu. Energy count will maximum when higher speed of motor test rig used in acoustic emission experiment.

3) Energy counts corrode defect graph :

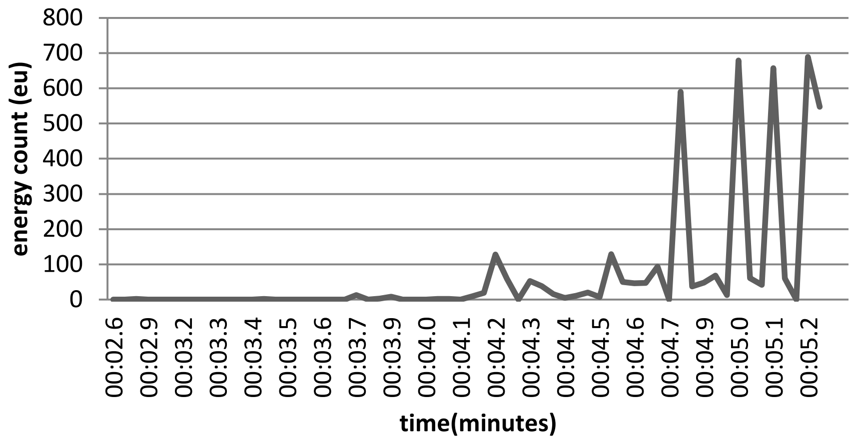

Figure 4.37: Graph corrode defect 30 % RPS energy count

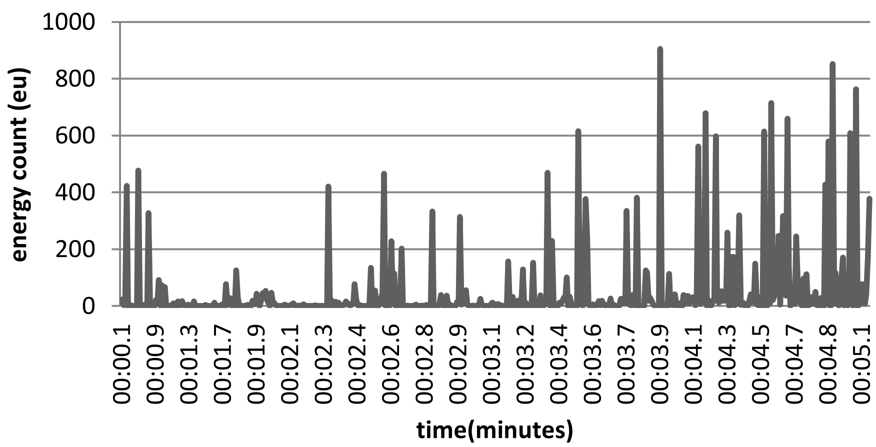

Figure 4.38: Graph corrode defect 60 % RPS energy count

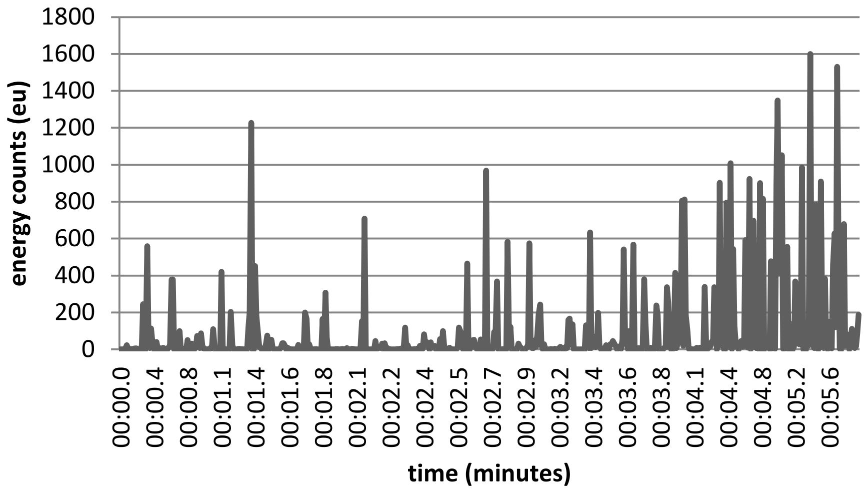

Figure 4.39: Graph corrode defect 90% RPS energy count

In graph corrode defect energy count show the energy count corrode defect. It can be seen in Figure 4.37 that energy counts higher was 689 eu. Corrode defect 60 % of speed motor test rig in Figure 4.38 recorded the energy count was 905 eu. The maximum energy count contaminated defect in Figure 4.39 that is 1600 eu. Energy count will maximum when higher speed of motor test rig used in acoustic emission experiment.

4) Energy counts inner defect graph :

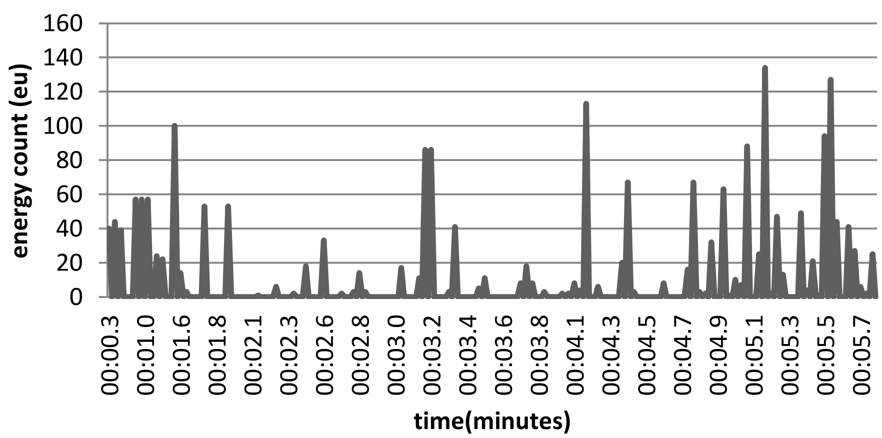

Figure 4.40: Graph inner defect 30 % RPS energy count

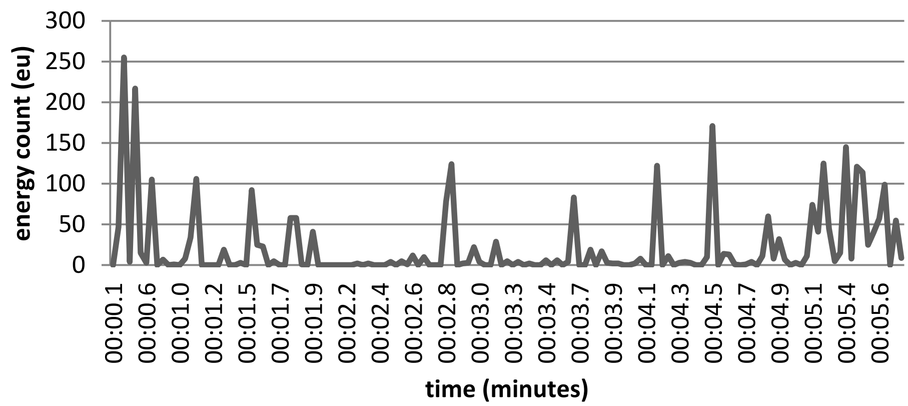

Figure 4.41: Graph inner defect 60 % RPS energy count

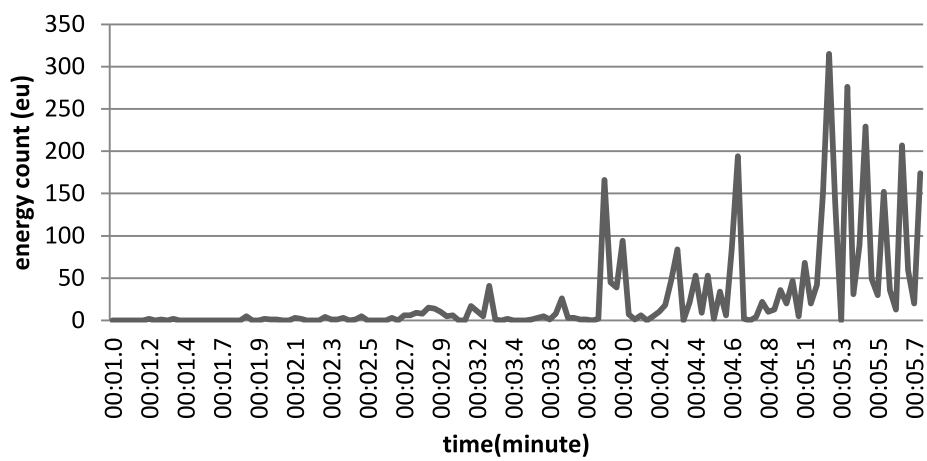

Figure 4.42: Graph inner defect 90 % RPS energy count

In graph inner defect energy count show the energy count inner defect. At Figure 4.40 higher energy count recorded are 127 eu. Different with inner defect 60 % of speed motor test rig in Figure 4.41 was recorded energy count are 255 eu. The maximum energy count was record inner defect in Figure 4.42 that is 315 eu. Energy count will maximum when higher speed of motor test rig used in acoustic emission experiment.

From four experiment in energy count can be concluded that corrode defect has higher energy count that is 1600 eu compared to contaminated defect with 1101 eu, inner defect with 315 eu and healthy with 120 eu. Corrode defect has higher area under the envelope of the rectified linear voltage time signal from the transducer and energy of the emission can be determined. Energy count is sensitive to the duration and amplitude of the signal. Summarize of the energy count in table 4.41.

Table 4.41: Summarize of the energy count

Speed (RPS)	Healthy (eu)	Contaminated defect (eu)	Corrode defect (eu)	Inner defect (eu)
30	22	595	689	127
60	118	705	905	255
90	120	1101	1600	315

4.6 DISCUSSION

The speed plots show that there is a substantial increase in acoustic emission counts with increase in speed. This increase is observed in the case of both undamaged and damaged bearings. From separate studies, similar findings have been reported by other researchers. Change in speed, even in under the same loading condition, causes significant change in dynamic stresses. This change in stress value is probably responsible for the change in acoustic emission counts with speed. In the present study, emission has not been detected for some cases of good bearings running at low speed of 5% and 10 % speed of motor test rig.

Distribution of ringdown counts show that an undamaged bearing that healthy is the lower range of ringdown counts. Maximum count are emitted in healthy bearings is 425. With a defect on a bearing element, there is a tendency for the counts to be emitted with higher ringdown counts. With the smallest defect on the inner race, contaminated and corrode defect are emitted over the smallest count. This trend continues as the defect progresses. However, with the larger defect sizes, the emission of events with higher ringdown count increases.

Distribution of events by peak amplitude shows that for good bearings low event emission occurs over a narrow range of amplitude. With a defect on a bearing, not only a rise in event emission rate is observed but the events are emitted over a wider range of peak amplitude. Maximum emission of events, however takes place with lower values of peak amplitude. As the defect progresses there is not much change in the range of peak amplitude over which the events are emitted. In experiment for a larger defect size more events are emitted with higher values of peak amplitude.

In setting threshold or background noise measurements the test rig was operated at 80% speed of motor test rig with no radial load. Background noise is voltage level which has to be exceeded before an acoustic emission signal is detected and processed and to measure acoustic emission bursts by means of a new signal conditioner. In test rig, threshold setting is 45 db.

Background results clearly indicated a rise r.ms value in increasing rotational speed. Results from four defects indicated than an increase in speed resulted in an increase of amplitude, counts and energy counts. In addition, at fixed rotational speed there was evidence to suggest that increasing the load also resulted in an increase parameter. This was particularly the case for all defect such as contaminated defect, inner defect, corrode defect and healthy. For the inner race defect simulation, the experiment was repeated 3 times for 5 minute each experiments, the same trend was observed in result. Summarize of all parameter in table 4.42.

Table 4.42: Summarize of all parameter

Type of defect	Amplitude (dB)	Count	Energy count (eu)
Healthy	52	425	120
Contaminated	76	849	1101
Corrode	86	1607	1600
Inner	58	718	315

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

The usefulness of the acoustic emission method for defect detection in bearing defect has been investigated. The use of acoustic emission parameter such as counts, counts and amplitude has been validated as a robust technique for detecting bearing damage. The method of ringdown counts has been found to be a very good parameter for the detection of defect in inner race, contaminated defect and corrode defect. For the sharp rise in the value of counts for the smallest defect size tested indicates that this may serve as a good parameter for incipient fault detection in bearings. The present study also shows that as the speed increases, more events are emitted with higher values of peak amplitudes and ringdown counts. In addition, it has been shown that the relationship between bearing mechanical integrity and acoustic emission counts, energy count and amplitude is independent of the speed of test rig. Whilst numerous exotic diagnostic techniques such as higher order statistics, neural networks and wavelets could be employed to aid diagnosis, all attempts must be made to keep the method of diagnosis simple and robust as this is the only way to encourage the adoption of this invaluable technique.

5.2 RECOMMENDATION

In experiment test rig, two objectives must be achieving that to develop test rig for detect bearing defect and detect bearing condition using acoustic emission method. In first objective the problem is design shaft and housing test rig. Design shaft using aluminium is easy but must be accurate measured. In design shaft, I must be fabricating 3 or more shaft to make sure fix with housing and bearing. Also, in fabricating housing the important thing is fixing with shaft and bearing. The next recommendation is bearing must be used the same brand. Although used same type but not same brand the result was not accurate. Firstly in doing this experiment, I used two brands of bearing but after see the result, it was too different and not same like other brand result then using the same brand of the bearing to standardize the experiment. Type of defect was used also the problem, it was difficult to make defect that have same size. So solution used defect without allow the size of the defect and effect a little of the result.

In second objective, the recommendation is the lecturer must be provided some lesson about software acoustic emission. It is because in doing experiment, I was taken two week to install the software and about one month to explore and understand the software acoustic emission. Second recommendation is doing early the experiment because many final year students were doing test rig experiment. When many student used test rig many problem can cause such as must be change the shaft and housing before running experiment and must be deal the other student the date to do experiment.

In analysis result acoustic emission, the recommendation is after doing experiment selects the parameter or important thing want to analysis such as amplitude, count and energy count.

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