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DEVELOPMENT OF BEARING FAULT DETECTION SYSTEM BASED ON VIBRATION SIGNAL (PEMBANGUNAN SISTEM PENETAPAN FAEDAH KESALAHAN BERDASARKAN ISYARAT GETARAN)

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ABSTRACT

Bearing is a type of rolling element in which are vastly used in industry or even for home appliances. The functions may be differ with each other, but most importantly it allow the movement of any shaft to rotate smoothly. The position and movement of this rolling element are varied for the required functions. The movement of this rolling element could sometimes disturbed by the bearing problems which account at about 40% of machines failure. Therefore, this research are conducted to emphasize bearing fault detection. Bearing conditions are monitored for 8 hours in order to receive a smooth vibration signal for the defected bearing. In that time duration, the vibration signal received may not be clear as this is due to outside noise vibration in which interrupts the vibration signal collection. But with skills developed in handling error, we can minimize the unwanted vibration signal. 5 sets of bearing are used for this research which includes 3 defected bearings in which we tested those bearings for analysis by using Fast Fourier Transform (FFT). The initial vibration signal received in which was conducted for the healthy bearing, is used as a benchmark to compare with the defected bearing’s vibration signal. The initial data collection was conducted using Dasylab. The collected data saved for analysis in Matlab. The initiations towards comparing the vibration signal can be determined from the bearing’ s feature frequency itself, outer race, inner race, the ball spin and also the bearing cage frequency. Nevertheless, FFT proved to be an effective method on monitoring bearing defect. For future research, a method of detecting the type of defect should be emphasize as this may reduce time consumption before the whole machine could damage.

ABSTRAK

Bearing adalah sejenis elemen rolling yang banyak digunakan dalam industri atau bahkan untuk peralatan rumah. Fungsi-fungsi mungkin berbeza antara satu sama lain, tetapi yang paling penting ia membolehkan pergerakan mana-mana batang untuk berputar dengan lancar. Kedudukan dan pergerakan unsur rolling ini berbeza-beza untuk fungsi yang diperlukan. Pergerakan elemen rolling ini kadang-kadang boleh diganggu oleh masalah galas yang kira-kira 40% kegagalan mesin. Oleh itu, kajian ini dijalankan untuk menegaskan pengesanan kesalahan galas. Kondisi galas dipantau selama 8 jam untuk menerima isyarat getaran halus untuk galas yang telah dibatalkan. Dalam tempoh masa itu, isyarat getaran yang diterima mungkin tidak jelas kerana ini disebabkan oleh getaran bunyi di luar yang mengganggu pengambilan isyarat getaran. Tetapi dengan kemahiran yang dibangunkan dalam menangani ralat, kita dapat meminimumkan isyarat getaran yang tidak diingini. 5 set galas digunakan untuk penyelidikan ini yang merangkumi 3 galas yang dibatalkan di mana kami menguji galas tersebut untuk analisis dengan menggunakan Fast Fourier Transform (FFT). Isyarat getaran awal yang diterima di mana yang dijalankan untuk galas yang sihat, digunakan sebagai penanda aras untuk membandingkan dengan isyarat getaran yang ditiupkan. Pengumpulan data awal dijalankan menggunakan Dasylab. Data yang dikumpul disimpan untuk analisis di Matlab. Inisiasi untuk membandingkan isyarat getaran boleh ditentukan dari kekerapan ciri galas itu sendiri, bangsa luar, bangsa dalaman, bola putaran dan juga frekuensi sangkar galas. Walau bagaimanapun, FFT terbukti merupakan kaedah yang berkesan untuk memantau kecacatan. Untuk penyelidikan masa depan, kaedah untuk mengesan jenis kecacatan haruslah ditekankan kerana ini dapat mengurangkan penggunaan masa sebelum seluruh mesin dapat merosakkan.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

In industry, machines are widely used in order to reduce manpower and even increase productivity. Rotating machinery are a common machine used in industry, since the rotating machinery has to rotate to do useful work. The work output are a major influence in order to produce a quality product. In a daily basis, a rotating machinery equivalent to the single-mass-damper system is a lumped mass on a massless, elastic shaft. With every work done, there are few defects to rotating machinery.

Some of the defect may came from misalignment which causing other faults and machine failure. This kind of defect has caused about 70% of rotating machinery problems. Rotor machinery which have misaligned rotor, will generate bearing forces and excessive vibrations making diagnostic process more difficult which may also lead to damage for other component as for this type of case is the flexible coupling. Other causes to this problem is the load which are applied to the machine either it is radial or thrust loading. For the radial loading case, imagine that weights are put on the bearing of a pulley which eventually causes bearing to roll. The example of condition for thrust loading condition is when a bearing is used to support a steel chair. So, in order to accommodate the continuous load applied to the rotating machine, bearing are used. For a clear view, as for example, if a car doesn't have any tyres, they might have to ski all the way to their destination. From here, the friction generated are much higher and the car are difficult to push down the road. It is the same concept as bearing. The rolling element as for this case metal balls bear an amount of load which are intended to reduce friction, but with the help or assistance of the outer and inner surface (race), allowing the device to rotate or move smoothly.

1.2 PROBLEM STATEMENT

With the constant load applied to the rotating machine, the bearing are used to coup the excess load in order to prevent any damage to the machine. But, there are limitations on the bearing itself, either during the assembling of the bearing or progressively. These limitations on the bearing can cause huge impact if it meant to be used continuously. It is either causing damage to the machine and whole operation in the industry thus, lead to high losses in the industry.

There are ways to control or curb this situation. The main step is to go through with maintenance planning before proceeding the next step. But, there are limitations for maintenance planning which needed the whole operation in the factory had to be stopped. The only solution is to replace the current method, which is maintenance planning to a new method which can avoid operation to froze, namely method monitoring. This new kind of approach are analysed through vibration signal. This method may not need the operation to be stopped, and can run normally.

This time-frequency analysis is the newly improved replacing the amplitude frequency analysis because the time-frequency analysis are improved in determining the defect location if there are a number of bearing located in the machine itself. As for the amplitude frequency analysis, the amplitude that are detected shows only the availability of defects inside the machine. There are still some limitations to this method but can be set aside. It may cause high cost or capital cost, because large amount of sensor needed namely accelerometer.

1.3 RESEARCH OBJECTIVE

The objectives of the project is to:-

i. To detect defect inside bearing using vibration signal.
ii. To analyse vibration signal by using specific software which is Dasylab and Matlab.

1.4 SCOPE OF THE RESEARCH

With the problem from the machine operated which are originated from the bearing itself, numerous ways to curb it from causing huge lost from machine failure. As load being applied either radially or from thrust loading, rotating machinery will accommodate the force from the load applied. So, does the bearing from the rotating machinery. There are limitation, whenever there are a number of load applied, can cause defect to the bearing. This defects may cause noise to the rotating machinery and produced vibration. From the vibration signal received, the time-frequency analysis can detect the type of defect inside a bearing. But with huge rotating machinery needed an amount of bearing. So, there will be different faulty inside either point defect, inner or outer race defect.

1.5 EXPECTED OUTCOME

The expected outcome for this research is that we hope a new researcher could come out with a new ideas or any addition to the current analysis that could detect the position of the bearing that were defected inside the rotating machinery and could reduce the consumption of a number of sensor and replaced it to a single sensor.

1.6 SIGNIFICANCE OF THE RESEARCH

The bearing may hold an amount of force from the loading being applied to the rotating machinery. But with the early detection of defects inside the bearing could save time consumption and avoid excess cost to the factory. With the operation run smoothly while the bearings are being monitored, there will be no clash on the production process and the maintenance by monitoring.

CHAPTER 2

LITERATURE REVIEW

2.1 REVIEW STUDY OF CURRENT VIBRATION ANALYSIS METHODS

In 2013, Wahyu Caesarendra wrote a journal on the circular domain feature based condition monitoring for low speed slewing bearing. From the paper, it presents the application of circular domain featuring calculation based condition monitoring method for slewing bearing with low rotational speed. Whenever the fault occurs, data reduction process will be employed by implementing piecewise approximation (PAA) in which detect any frequency alteration in the bearing signal. The circular domain features such as circular mean, circular variance, circular skewness and circular kurtosis from the processed data are then calculated and monitored. It is proved that for circular domain analysis, slight changes of bearing condition during operation can be identified more clearly if compared to other method such as time domain analysis and other signal processing method (wavelet decomposition and empirical mode decomposition (EMD) which eventually allow the engineer to better schedule the maintenance work. Four circular domain features were shown to consistently and clearly identify the onset (initiation) of fault from the peak feature value which is not clearly observable in time domain features. The application of the method is demonstrated with simulated data, laboratory slewing bearing data and industrial bearing data from Coal Bridge Reclaimer used in a local steel mill.

Slewing bearing is categorized in rolling element bearing that are commonly used in industrial machineries such as turntable, steel mill cranes, offshore cranes, rotatable trolley, escavators, reclaimers, stackers, swing shovels and ladle cars. It is made to support high axial and high radial load. This type of bearing are an important production part. Whenever the bearing breaks down, it can be very expensive due to the loss of production.

Some published literature or resources do mentioned that the rotating speed below than 600 rpm is classified as low rotating machinery, as for rpm greater than 600 are considered as high speed machinery, thus for this paper the rolling bearing run at speed greater than 600 rpm is categorized as typical rolling bearing. In the case of where fault is initiated in typical rolling bearing, the bearing can deteriorate rapidly within few hundreds or even thousands revolutions and result in changes in vibration within very short time from the onset of the fault. Hence, in this scope of study the use of features extraction methods such as time domain and frequency domain features calculation is adequate to distinguish the bearing condition. However, these methods are not suitable the identify the abnormal condition for low rotational speed bearing especially in extremely low rotational speed (≈ 1rpm) slewing bearing, due to low impact energy emission from the rotating elements in contact with a defect spot unable to show change in vibration signature thus become hardly detectable with conventional vibration analysis.

In 2014, a journal on rolling bearing diagnosing method based on Empirical Mode Decomposition (EMD) of machine vibration signal written by Radoslaw Zimroz tells on the using of EMD-based rolling element diagnosing method which shows potential for bearing damage detection at much earlier stage of damage development. By using EMD, a raw vibration signal collected is decomposed into a number of Intrinsic Mode Functions (IMFs). Then, a new method of IMF’s aggregation into three Combined Mode Functions (CMF’s) is applied and final the vibration signal is divided into three parts of signal, namely noise-only part, signal-only part and trend-only part. To continue on the bearing fault-related feature extraction from resultant signals, the spectral analysis of the empirically determine local amplitude is used.

Usually, bearing vibration signal is collected with sensor, mainly accelerometer installed on the bearing housing where the vibration sensor is often collecting active vibration sources from other mechanical components of the machine. At the early stage of defect development, the vibration signal that comes from bearing may be masked by the machine noise, thus the fault are harder to detect by vibration analysis technique. So, method of diagnostic signal extraction is needed to provide useful information regarding the bearing condition.

Such method that are highlighted in this paper is by using the Empirical Mode Decomposition (EMD) which were recently caught eye due to its functionality to self-adaptive decomposition of non-stationary signals. The EMD-based approach for rolling bearing diagnostics is investigated in this paper. Using EMP a raw vibration signal is decomposed into a number of Intrinsic Mode Functions (IMFs). After that, a new method of IMFs aggregation into three Combined Mode Functions (CMFs) is applied and finally the vibration signal is divided into 3 parts of signal, namely as noise-only part, signal-only part and trend-only part.

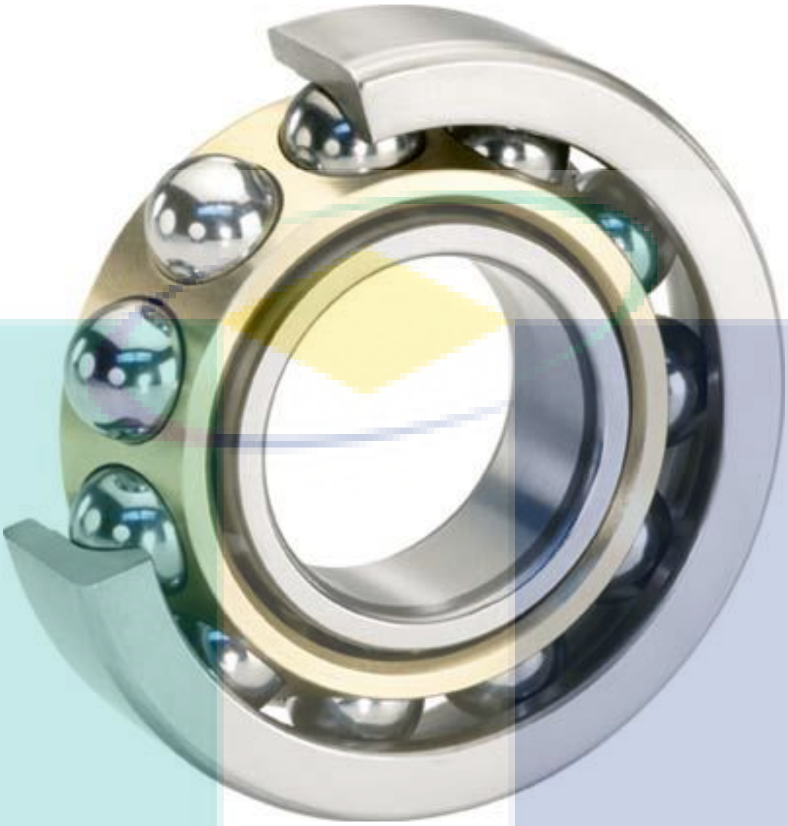
2.2 BEARING

Bearing is a useful component in for most of the technology created or used nowadays. For example, it is used for household appliances, industrial machines and car engine parts such as alternator and fans. The important of bearing does affect the performance of the products as it has their own uniqueness that could comply to any condition. Bearing may came in any shapes and types. The difference is inside the bearing, which is the rolling element. The rolling element is covered with raceways, inner and outer. The raceways covered the rolling elements from being contaminated and to increase the efficiency of movement for the rolling element. Grease which are applied on the space between rolling elements serves to facilitate the movement of the steel balls. After every maintenance of bearing, grease need to be applied to the steel balls as to prevent deficiency of grease that could potentially damage the bearing as a result of the friction of the steel balls and the raceways.

In industry, some amount of bearing are used instead of using only one. These bearing operate with within the movement of machine inside the industry. It may operate in few hours in a day or maybe continuously used. For industrial type of bearing, the different is with the size, but the feature is still the same as the small one. The size depends on the shaft the industry are using.

2.3 TYPES OF BEARING

a)



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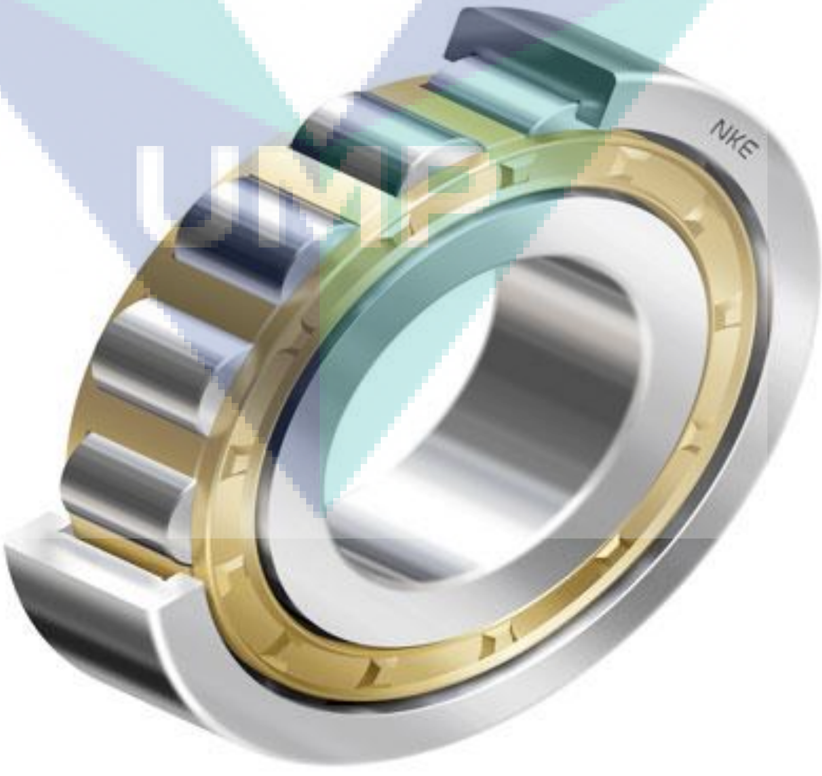

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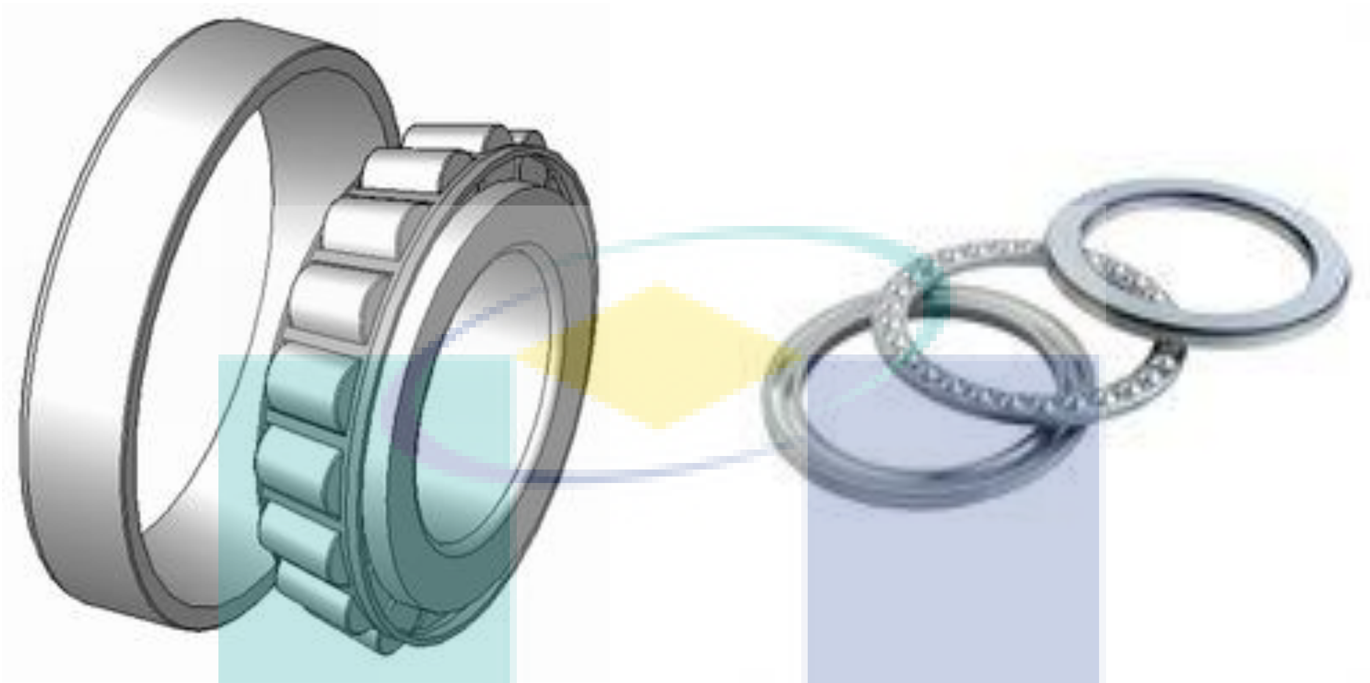


SOURCE: SKF Bearing Company

e)

SOURCE: The Timken Company

FIGURE 2.1: *Various type of bearing, a) Ball Bearing, b) Roller Bearing, c) Tapered Roller Bearing, d) Ball Thrust Bearing, and e) Roller Thrust Bearing*

There are many types of bearing, such types are Ball Bearings, Roller Bearings, Ball Thrust Bearings, Roller Thrust Bearings and Tapered Roller Bearings. Ball Bearings are a common bearing used but it can only handle small amount of weight. If an excessive weight applied to it, the bearings are prone to deform or damage will occur. The rolling element used is the steel balls. Example of the usage for Ball Bearings, such as for hard drives in computer and even for stand fan. The next bearing that are generally used, is the Roller Bearings. The advantage of using Roller Bearing is that it can withstand heavy loads. The primary rolling element is cylinder roller. But for this type of bearing can only handle radial loads but not thrust loads.

As for the Ball Trust Bearings and Roller Thrust Bearings, are designed only to handle almost only thrust loads. The difference are only situated on the amount of weight the bearing can handle. For the Roller Thrust Bearings, it can support larger amounts of thrust loads if it being compared to Ball Thrust Bearings, and are therefore located in car transmission to support helical gears. As for Ball Thrust Bearings, it is used for bar stools to support the seat.

The last type of bearing is the Tapered Roller Bearings. It is a type of bearing which are flexible, that can handle both large radial and thrust loads. This type of bearings are located in car hubs to cope both of the loads (radial, thrust).

2.4 BALL BEARING

The bearing that are used is the Ball Bearing type. Having the product number of YAR 203/12-2F, with the inner diameter of 12mm and the outermost diameter of 40mm. There are 2 number of grub screw of diameter 6mm to tighten up the bearing to the shaft. There are 8 steel balls inside the bearing between the inner and outer raceways. And the limiting speed for the bearing can accommodate is about 9500rpm.

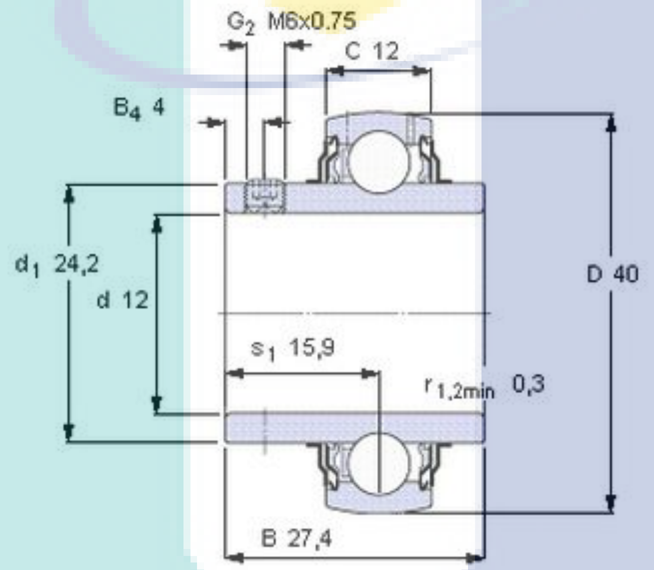


FIGURE 2.2: *Ball Bearing With Deep Groove Specification*

SOURCE: SKF Bearing Company

2.5 BEARING FAULTS

There are a few defects or damage to the bearing such as point defect, inner race defect and outer race defect. These faulty are the only that we have experimented. There are still few faulty to the bearing that not included.

2.5.1 POINT DEFECTS

This type of defect can be clearly seen outside of the bearing. From the appearance of it, it is actually a point or dented surface between the inner and the outer surface of the raceways. When the bearing rotates, it will eventually produce a noise or vibration signal that later will be collected. The cause for this type of defect is maybe because of outer distraction or outer disturbance to the bearing. Besides that, it may cause by ineffective seals to the bearing cage for the protection of the bearing.

2.5.2 INNER RACE DEFECTS

This type of defect is called the inner race defect. This defect is likely to happen inside the bearing which is hard for it to be detected. This raceway is the junction whereby the steel balls or the rolling elements rotate. With the condition inside the bearing are packed with many features including the rolling elements and also grease, it is hard for it occur and also detected. The causes for this type of defect is maybe because of inadequate or improper lubrication. It may also can be caused by maximum radial load applied to the bearing causing it to create defect inside the bearing.

2.5.3 OUTER RACE DEFECTS

This type of defect is called the outer race defect. The figure above shows damage to the outer raceway. This type of defect is similar to the inner raceway defect. It maybe because of heavy axial loading from the shaft or even imbalance. Imbalance is caused by the insufficient weight to the flywheel which are located between the first and the second bearing cage which are connected to the shaft.

2.6 VIBRATION MONITORING

Vibration analysis can be easily be related with ISO 10816. ISO 10816 is the standards in which providing full references or guidance for evaluating vibration severity in machines operating in a range of 10 to 200Hz frequency range or 600 to 12 000RPM of rotating speed. Examples of these types of machines are small, direct-coupled, electric motor and pumps, production motors, medium motors, generators, steam and gas turbines, turbo-compressors, turbo-pumps and fans.

Some of these machines can be coupled rigidly or flexibly, or connected through gears in order for it to be interconnected. The axis of the rotating shaft may be horizontal, vertical or inclined at any angle. The chart below can be combined with additional factors as described in this manual to classify the overall vibration severity of the equipment used.

VIBRATION SEVERITY PER ISO 10816					
Machine		Class I small machines	Class II medium machines	Class III large rigid foundation	Class IV large soft foundation
in/s	mm/s				
0.01	0.28	good	good	good	good
0.02	0.45	good	good	good	good
0.03	0.71	good	good	good	good
0.04	1.12	satisfactory	good	good	good
0.07	1.80	satisfactory	satisfactory	good	good
0.11	2.80	unsatisfactory	satisfactory	satisfactory	good
0.18	4.50	unsatisfactory	unsatisfactory	satisfactory	satisfactory
0.28	7.10	unacceptable	unsatisfactory	unsatisfactory	satisfactory
0.44	11.2	unacceptable	unacceptable	unsatisfactory	unsatisfactory
0.70	18.0	unacceptable	unacceptable	unacceptable	unsatisfactory
0.71	28.0	unacceptable	unacceptable	unacceptable	unacceptable
1.10	45.0	unacceptable	unacceptable	unacceptable	unacceptable

Vibration Velocity Vrms

TABLE 1: *Vibration Severity Per ISO 10816*

2.7 SENSORS

There are 2 types of sensors that are used for this project. Namely accelerometer and also tachometer. The following are the explanation regarding the sensors including the type and also the specifications.

2.7.1 ACCELEROMETER

The type of accelerometer that are used in this experiment is the Bruel & Kjaer 4507B – Piezoelectric CCLD Accelerometer, having sensitivity of 100mV/g. The function of accelerometer is to detect and receive vibration signal as for this case, the signal from the bearing. This miniature Accelerometer 4507 and 4508 are specifically designed to withstand the rough environment of the automotive industry. A combination of high sensitivity, low mass and small dimensions make them ideal for modal measurements, such as automotive body and power-train measurements, as well as for modal analysis on aircraft, trains and satellites.

FIGURE 2.3: *Bruel & Kjaer 4507B-Piezoelectric CCLD Accelerometer*

2.7.2 Tachometer

The tachometer that are used is the Pocket Laser Tach 200. Tachometer used to detect the rotating speed of a moving item as for this case, the rotating flywheel in order to detect and control the rotation of shaft. The PLT200 is a digital, battery-powered portable optical tachometer, which operates up to 25 feet from the reflective target using a laser light source.

FIGURE 2.4: *PLT200 Tachometer*

2.8 SOFTWARE

The software for this project to be conducted is using the Dasylab software and also the Matlab software.

2.8.1 DASYLAB

From research and analysis to large-scale production and quality control, use DASYLab to quickly create flexible and powerful monitoring and control applications without programming. With DASYLab, you can focus on your particular area of expertise, while tapping into the power of the display, analysis, and control features needed to fully process measurement data. DASYLab includes an interactive tutorial and more than 150 examples to help you quickly set up and develop your application.

Use DASYLab to interactively develop PC-based data acquisition applications by simply connecting functional icons. DASYLab offers real-time analysis, control, and the ability to create custom graphical user interfaces. You can configure many applications in a few minutes, rather than days or weeks.

2.8.2 MATLAB

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include:

- Math and computation
- Algorithm development
- Modeling simulation, and prototyping
- Data analysis, exploration, and visualization
- Scientific and engineering graphics
- Application development, including Graphical User Interface building

MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar noninteractive language such as C or Fortran.

2.9 VIBRATION METHOD DETECTION

For this bearing condition monitoring, there are few method that can be applied or used. As for to only monitor the availability of faulty for the bearing, the method that managed to use is the Fast Fourier Transform (FFT).

2.9.1 FAST FOURIER TRANSFORM

Fourier analysis of a periodic function refers to the extraction of the series of sines and cosines which when superimposed will reproduce the function. This analysis can be expressed as a Fourier series. The fast Fourier transform is a mathematical method for transforming a function of time into a function of frequency. Sometimes it is described as transforming a function of time into a function of frequency domain. It is very useful for analysis of time-dependent phenomena.

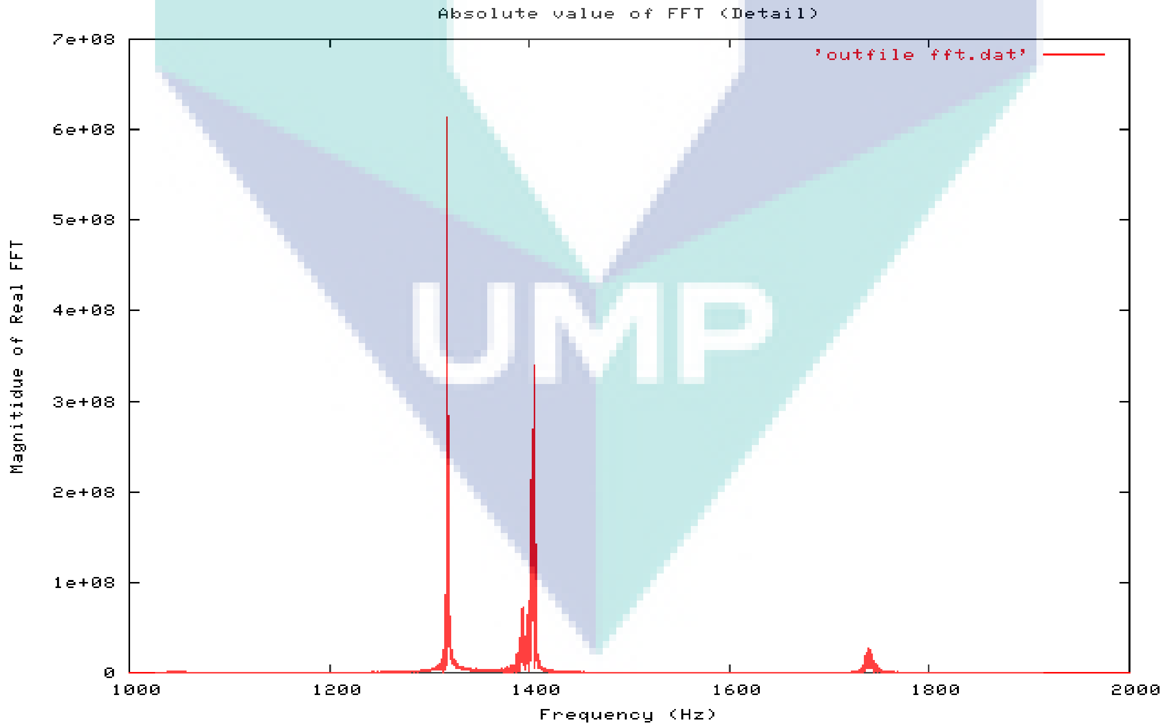


FIGURE 2.5: *Example of FFT*

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The first step on starting this project by planning using Gantt chart as shown in Figure 3.1. The flow chart acts as a reference to successfully carry out this case study step by step while the Gantt chart helps to make sure that the project is within its timeframe. It is then furthered with countless literature review throughout the whole project. Followed by designing experiment procedure and continued with experimental setup.

The data acquisition system (DAQ) which is interconnected with the accelerometer is the main system used for this project, therefore practicing calibration before data acquisition is imperative in order to achieve the expected result. Next, the vibration signal was further processed by using DASYLAB software and then MATLAB to develop a vibratory reading.

Finally, the analysis of the whole project will be tabulated, further discussed, and concluded in the following chapter after all the data collected have been verified.

3.2 DESIGN AND EXPERIMENTATION

The test rig for this project was design according to the desired design and compatibility which include the stability of the test rig. This project is conducted to investigate failure and vibration characteristic of ball bearings. It was designed specifically to imitate the application of ball bearings in the industry. The shaft was driven by a variable-speed 0.37kW, 50Hz electric motor with a frequency converter in order to control the speed of the motor. The motor and shaft were connected by using flexible coupling where it could minimize shaft alignment error. It has a tolerance in which the rotation of both of the shaft (motor and the shaft) can be at a free rotation. The front side of the shaft is fitted with a healthy bearing acting as a dummy, and the other shaft fitted with a tested bearing. A set of good bearings and another 3 bearings with different types of defect were used for testing. A flywheel is installed at the middle of the spindle in order to apply load to the shaft and at the same time minimizing the speed oscillations of the shaft (Nizwan et al, 2010).

The rotation speed is been set to 287RPM, 1466RPM and 2664RPM in which it is 10%, 50% and 90% of the maximum motor rotation. The vibration signals were acquired by using the Bruel & Kjaer 4507B accelerometer. Sensors are placed on horizontal directions to collect the data because horizontal bearing types were tested. Accelerations signals are acquired by using data acquisition system (DAQ) in which it is connected to the personal computer (PC). The Matlab's coding from its Toolbox were used to process the data while the Dasylab software were used to read the raw data or the initial vibration signal.

3.3 EXPERIMENTAL SETUP

The tools that are needed for this test rig to be setup:-

a) Flexible Coupling
b) Tested Bearing
c) Flywheel
d) Healthy Bearing
e) 4507B-Bruel & Kjaer Accelerometer (Location)
f) National Instrument Data Acquisition System (NiDAQ)
g) PC with Dasylab and Matlab Software

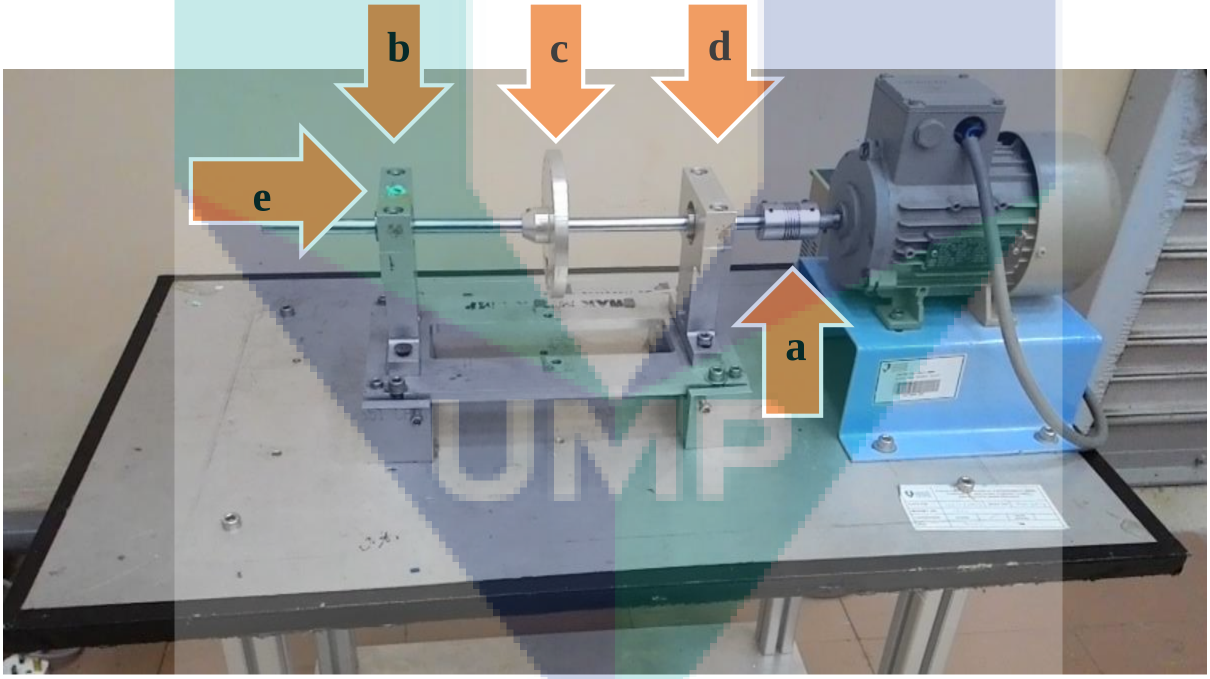


FIGURE 3.1: *Test Rig*

3.3.1 SENSOR CALIBRATION

Sensor calibration is a must for any analysis to ensure the instrument is performing as it is designed to. Correct and meaningful vibration transducer calibration ensures traceability to an absolute physical standard, which provides a defined degree of confidence in all of the vibration instruments. To calibrate a vibration accelerometer is to accurately determine its sensitivity in mV/g whereby the sensitivity of the accelerometer that are used throughout the analysis is 100mV/g.

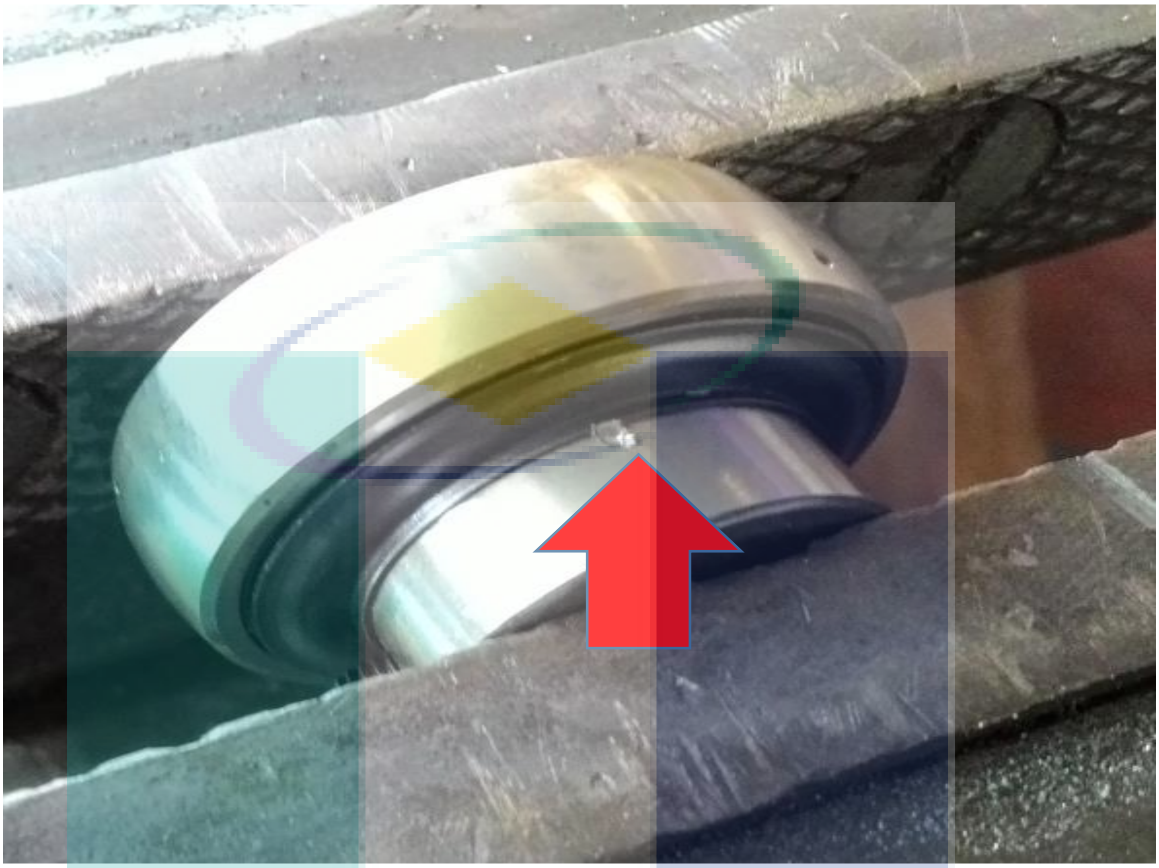
3.3.2 TESTED BEARINGS

There are about 3 defect on the bearing that are experimented for this project in which another 2 bearing as a healthy bearing. At the initial start of the experiment, both of the healthy bearing are used to get or collect the healthy vibration signal, to compare with the defected bearing. Following are the explanation of bearing fault location:-

Types of Defect	Location of Defect
Point Defect	Point or dented surface between the inner and outer raceway.
Inner Race Defect	A single scratch mark on the inner raceway
Outer Race Defect	A single scratch mark on the outer raceway

TABLE 3.1: *Types of Defect and the location of defect*

a)



b)

c)

FIGURE 3.2*: Shows various bearing defects, a) Point Defect, b) Inner Race Defect c) Outer Race Defect*

3.4 DATA ANALYSIS

DASYLab software is a software used for various acoustic emission and vibration analysis. This software act as a initial data receiver or collector for raw data reading or analysis. This raw data is then saved in order for it to be applied or analyse then using Matlab software. Following is the data layout for this experimentation:-

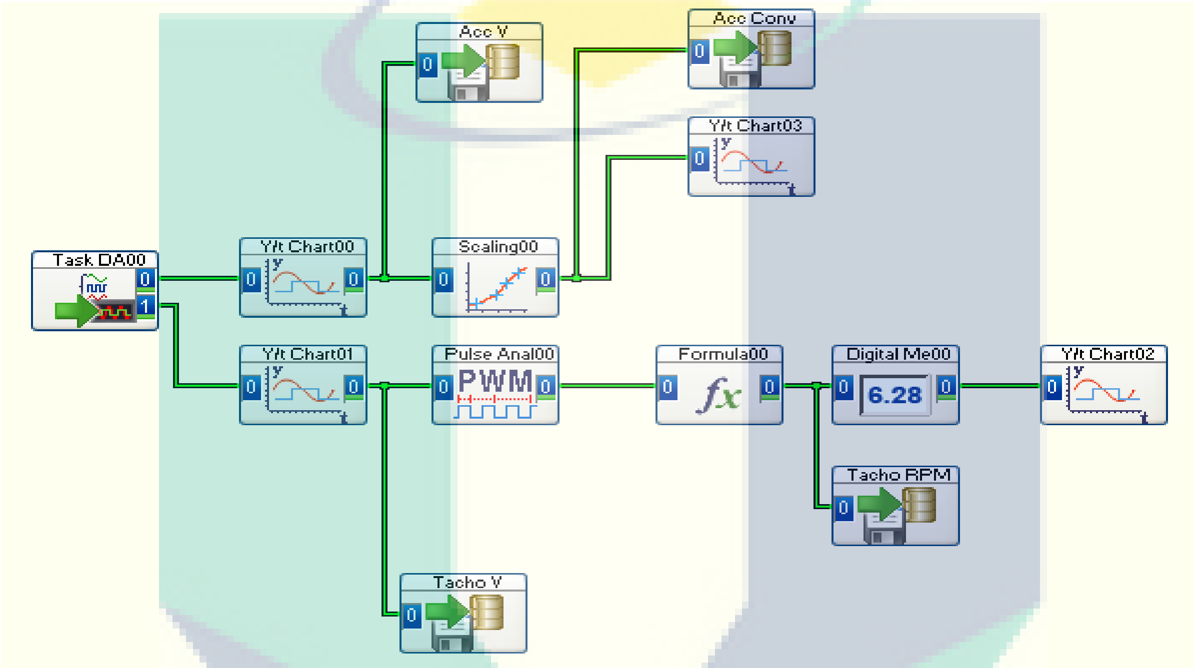


***FIGURE 3.3**: DASYLab's layout*

From the above figure, it shows the layout for DASYLab that were used during collecting the initial data. At first, the signal were received by 'Task DA00'. There are 2 channel inside it, namely for acceleration and also tachometer for channel 0 and channel 1 respectively. The channel 0 will passed through 'Scalling00' for unit conversion. And at last, the 'Y/t Chart03' will plot the graph for acceleration. As for 'Acc Conv', the data will be saved into hard disk drive (HDD). Same as for channel 1, it will first passed 'Pulse Anal00' and also 'Formula00' containing formula to get the result in RPM unit. The data will be saved into HDD as it passed the 'Tacho RPM'.

3.5 MATLAB'S ALGORITHM ANALYSIS

For this project, the MATLab's software will be used to analyse the data including the healthy and also the defected bearing. The Algorithm will only be analysed in frequency domain in order for any user to deeply understand the signal produced by a normal bearing and also the defected bearing.

3.5.1 FAST FOURIER TRANSFORM ANALYSIS

Fast Fourier Transform analysis is a type of frequency domain that are used in this project. The reason to use this method is to monitor clearly on the availability of defect inside the bearing by comparing with the healthy bearing. As show in figure below, it shows that still are a few other methods that can be conducted for this project:-

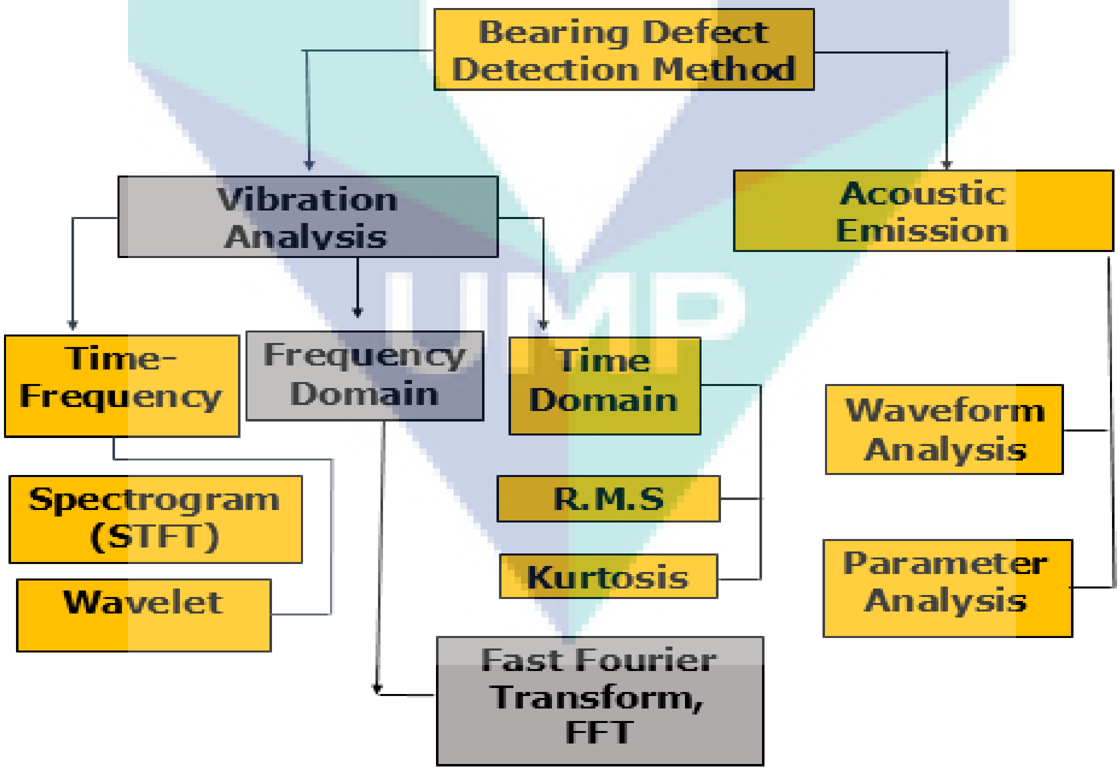


FIGURE 3.4: *Vibration analysis method*

To perform this type of analysis, the first step on starting the Matlab software is to open a new script editor as figure. The script editor are then filled by the coding that have been generated:-

```
function [Amp,freq]=freqdom(signal,sr)
%   signal - AE waveform
%   N      - number of sample
%   sr     - sampling rate in unit Hz
[M,N]=size(signal);
Amp=[];
T=1/sr;
k=[0:N-1];
t=k*T;
iter=0;
for i=1:1:M;
    iter=iter+1;
    f_k(iter,:)=signal(iter,:);
    F_K(iter,:)=fft(f_k(iter,:))/N;%complexs values
    F_K(iter,:)=2*abs(F_K(iter,:));%compute magnitude
    %Amp(iter,:)=20*log(F_K(iter,1:N/2)./1e-6);
    Amp(iter,:)=F_K(iter,1:N./2);
end
w=k*(1/(N*T)); %discrete Frequency Domain
freq=w(1:N./2);%Data from 50kHz to 400kHz

%Frequency domain plots [0,Nyquist freq]
%plotting from 0 to  freq
%plot(freq,Amp)
%xlabel 'frequency (Hz)'
%ylabel 'Amplitude (mV)'
%title 'frequency domain'
```

FIGURE 3.5: *FFT coding for MATLab*

The file that have been saved during using DASYLab are first opened. The file with the name ‘Healthy_00.ASC’ are first being ordered into columns of 30. The following 29 data will be repeated until each column are filled. Then the following imported data are saved in ‘.mat’ file format, ‘Healthy.mat’. Using the same data, ‘Healthy.mat’ file, the coding are applied to the following file. As a result, the software will produce a new set of graph of frequency domain, the FFT.

a) **b)**

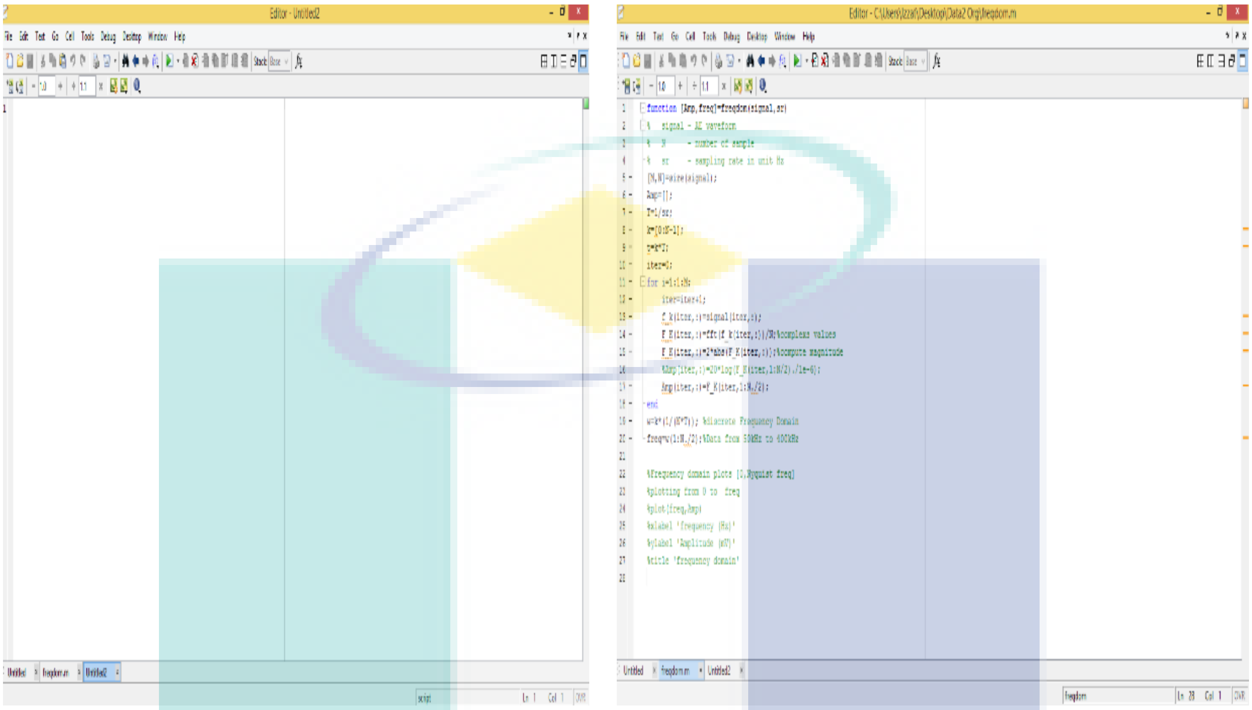


FIGURE 3.6: *Script editor for MATLab, a) new sheet, b) sheet filled with FFT coding*

For this type of method, it can clearly shows that each peak produced can be classify as inner race frequency, outer race frequency, ball spin frequency, and fundamental train frequency which is the bearing cage frequency. The following are the formula for each of the frequency:-

$$FTF = RPS\frac{1}{2} \times \left(1 - \frac{d}{D} \cdot \cos\phi\right)$$

$$BS = \frac{D}{(2d)} \times RPS \times \left[1 - \left(\frac{d}{D}\right)^2 \cos^2\phi\right]$$

$$OR = N \times FTF$$

$$IR = N \times (RPS - FTF)$$

FTF = Fundamental Train Frequency

BS = Ball Spin Frequency

OR = Outer Race

IR = Inner Race

d(Ball diameter) = 6mm

D(Pitch Diameter) = 28mm

$\Phi = 0$

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter represents the results of the experiment and further discusses the outcome of the analysis. For the purpose of vibration signals collection, about 4 sets of vibration signals are collected. It consists of the healthy part, point defect, inner race defect and outer race defect part. It may also including the variations of motor speed of 287RM which is the lowest speed, 1466RPM as the medium speed and 2664RPM as the highest speed. This speed represents about 10%, 50%, and 90% of the maximum motor speed.

4.2 FFT ANALYSIS RESULTS

4.2.1 HEALTHY BEARING

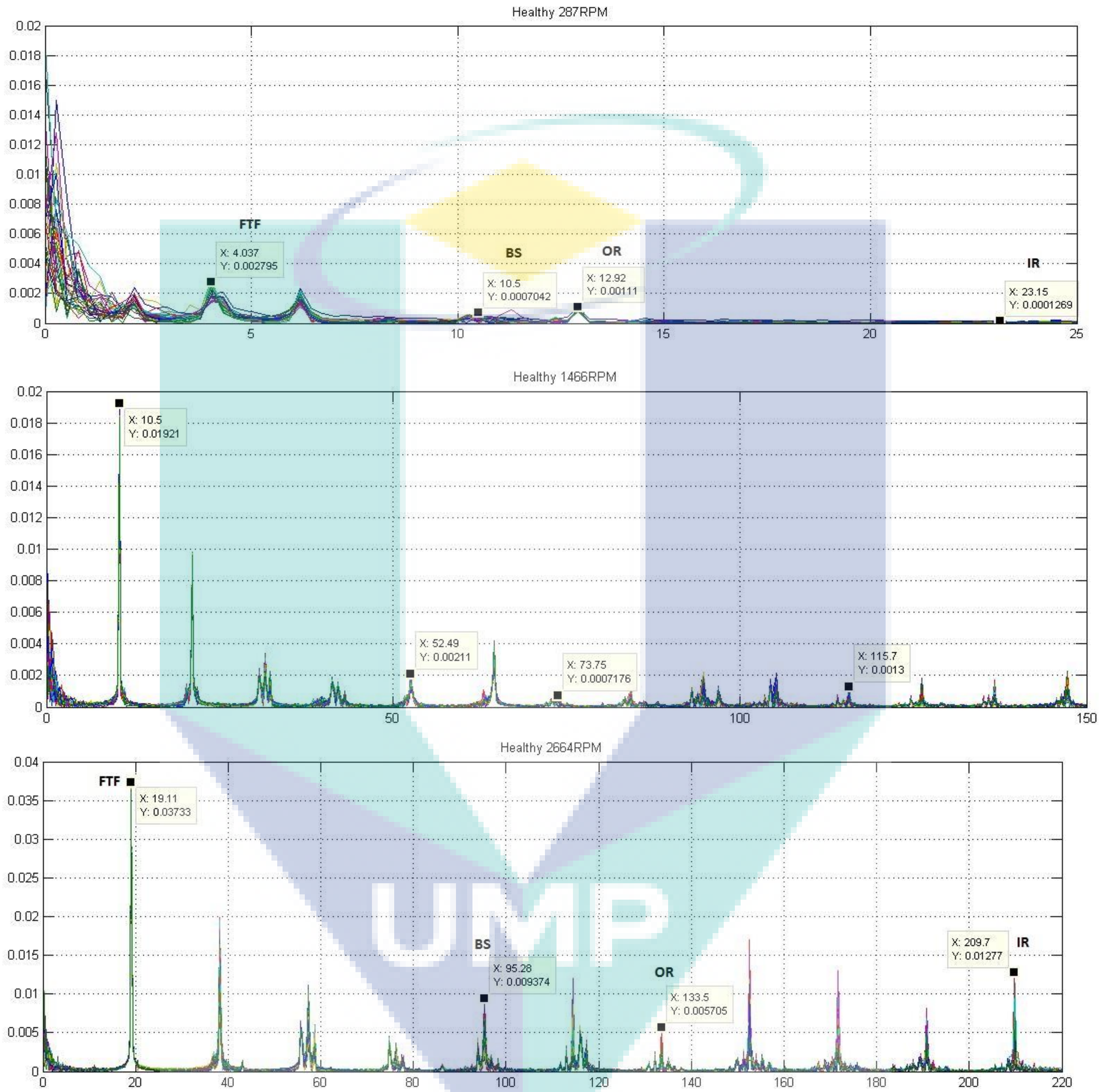


FIGURE 4.1: *FFT analysis for Healthy Bearing at 287RPM, 1466RPM and 2664RPM*

From the above figure, it shows that the initial graph or value for each frequency using the provided formula. An increment for each frequency is the natural effect considering the speed is increasing about 50% to 90% of the maximum motor speed.

4.2.2 POINT DEFECT BEARING

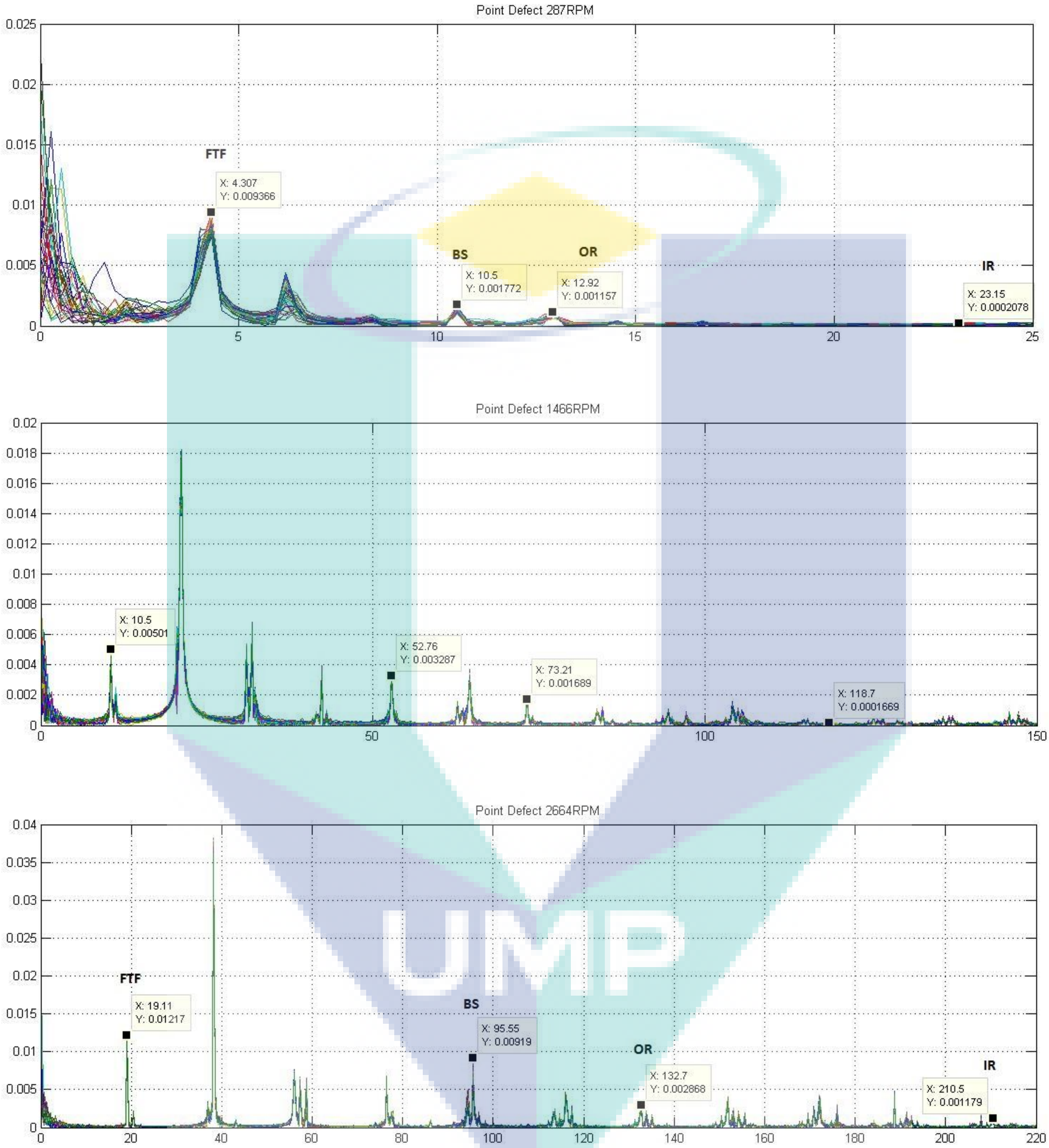


FIGURE 4.2: *FFT for Point Defect at 287RPM, 1466RPM, and 2664RPM*

The figure above shows that the Ball Spin, inner race and outer race frequency for 1466RPM speed as comparing with the healthy analysis. But there are slightly error on the Fundamental Train Frequency. It is maybe because of the signal inside the defect attenuates with signals with surrounding noise, in which could affect the peak of the concentrated frequency. But as for the speed of 2664RPM, the frequency for each of the concentrated peak are quite low compared to the healthy signal.

4.2.3 INNER RACE DEFECT

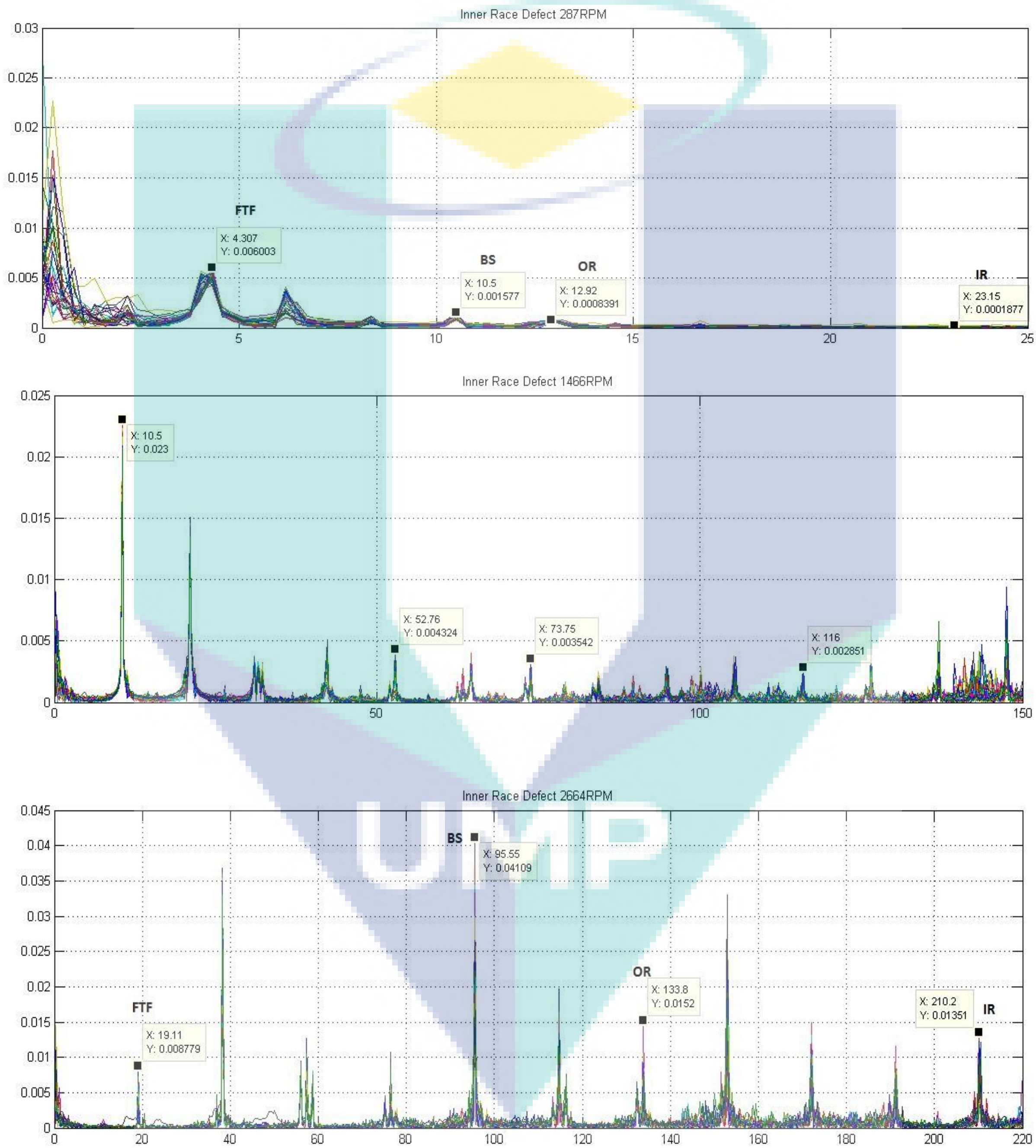


FIGURE 4.3: *FFT for Inner Race Defect at 287RPM, 1466RPM, and 2664RPM*

The figure above shows a decrement of signal amplitude for each of the concentrated frequency. It is mainly because of the vibration signal for inner race defect, collides with the signals that are generated by the ball spin, fundamental train and also the outer race. The amplitude decrement also can be detected for speed 2664RPM for each of the concentrated frequency.

4.2.4 OUTER RACE DEFECT

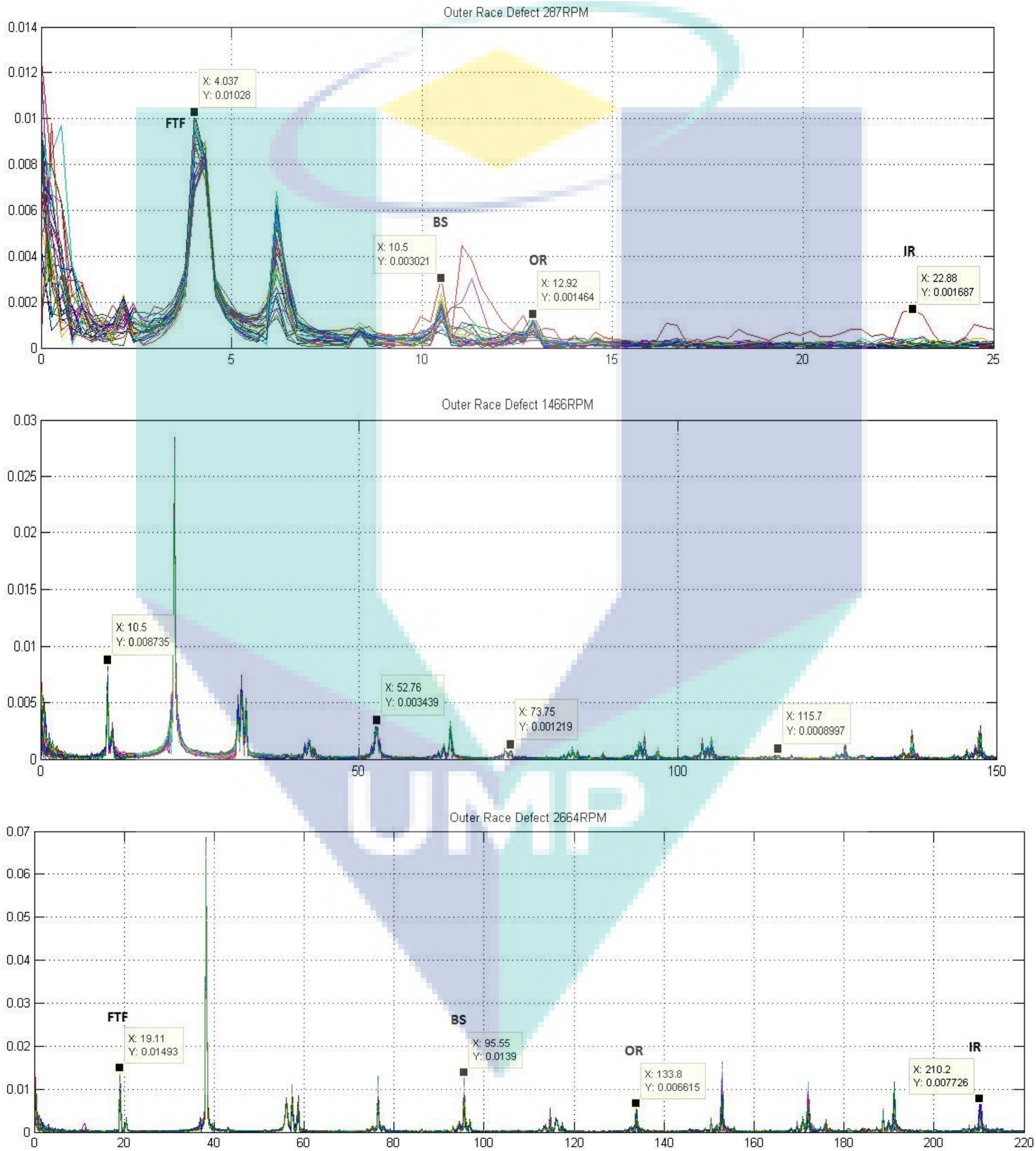


FIGURE 4.4: *FFT for Outer Race Defect at 287RPM, 1466RPM and 2664RPM*

For the case of outer race defect, the figure above shows an increment for the concentrated frequency at the speed of 287RPM, but as for the speed at 1466RPM and 2664RPM shows a significant drop on the amplitude length. This is due to some significant reason that can be made from the bearing itself.

For the speed at 2664RPM, which is the highest speed that are tested in the experiment for any defect detection, decrement of signal amplitude can be clearly seen as to be compared with the low speed of 287RPM. This is mainly due to gyroscopic effects. As stated on journal written by O.Ozsahin, during high rotational speeds, centrifugal forces and gyroscopic moments act on the balls of the bearings pressing the balls toward the outer race. This effect causes changes in the contact angles and kinematics of the balls as well as redistributing the contact loads in the bearing which leads to decreased stiffness.

CHAPTER 5

CONCLUSION AND RECCOMENDATION

5.1 CONCLUSION

The designed test rig for this type of experiment are proven to be at its best. This is due to its stability and concrete structure avoiding any other signals or noise to be exerted through the test rig and to the bearing.

The important thing for this experiment is to stabilize the outer feature such as the bearing cage and also the shaft alignment. Alignment of the shaft with the motor that are interconnected with flexible coupling are an important item as it helps the shaft to move linearly with the motor speed. As for the flywheel, it needs to be well balanced at its weight through try and error testing, by inserting small weight to it.

Bearing initial condition must be at its best. This is because as for specific defect such as the inner race defect, only defect on the inner race are acceptable. If there are any defect on the same specimen, it is considered rejected as it may interrupt the vibration signal that the accelerometer will received.

From the analysis, it shows that the signal produced by each of the bearing are quite consistent. This consistency can be seen during the speed of the motor at 1446RPM as to compare with 287RPM, it shows smaller difference in the signal amplitude, in which are difficult to examine or analyse. As for the motor speed at 2664RPM, it has been earlier concluded that there might be a gyroscopic effect affected on the bearing. Besides that, an additional conclusion to this problem is might be because of thermal expansion by the shaft and also bearing causing vibration signal disturbance, thus producing lower amplitude signal.

For the FFT type analysis, it is quite eligible method on monitoring bearing condition. So, this monitoring method may help in industry to reduce the time on defect detection on bearing.

5.2 RECCOMENDATIONS

First of all, to conduct this experiment, the highest speed should be less than 2664RPM in order to avoid uneven signal again. To improve the monitoring method, instead of using FFT method, use Empirical Mode Decomposition (EMD). The speciality of this method is that it is much more significant to the bearing case. It is useful on detecting the type of defect instead of detecting only the availability of defect. So, improvement to the type of method are one of the steps on improving this experiment.

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3) http://www.reliabilitydirectstore.com/ProductDetails.asp?ProductCode=RDI%20VI-1
4) http://www.directindustry.com/industrial-manufacturer/tachometer-66666-_3.html
5) http://www.acronymchile.com/sigproc.html
6) http://www.skf.com/group/products/bearings-units-housings/ball-bearings/y-bearings/y-bearings-with-grub-screws/index.html?prodid=103002201&imperial=false
7) http://www.sabearings.com/en/products/roller-bearings/cylindrical-roller-bearings/
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