Vibration Analysis of Centrifugal Pump

by

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Dissertation submitted in partial fulfillment of

The requirement for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

SEPTEMBER 2013

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

Mechanical Engineering Programme

Universti Teknologi PETRONAS

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Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

December 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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NURULHUSNA BINTI MOHD MOHTAR

ABSTRACT

In this project, the main objective is to develop vibration analysis of centrifugal pumps by using MATLAB by Mathworks software to convert the raw data into the FFT spectrums and detect the defects of the pumps. The defects are identified by using LUDECA's machinery fault diagnosis as well as the ISO 10816 standards as the guidelines.

The centrifugal pumps parameters such as the load and frequency are taken from the literature that varies depending on the experiment done in the study. From the MATLAB software, the spectrums are generated and analyzed.

In conclusion, the frequency of the spectrums determines the defects' nature and on the other hand, the amplitude of determines the defects' severity.

ACKNOWLEDGEMENT

I would like to express my gratitude to my passionate supervisor, AP Dr. Tadimalla V. V. L. N Rao who has been very supportive for his assistance throughout this project period. In addition, I am very thankful to have my close friends and colleagues from Mechanical Engineering class whom very supportive and helpful. Last but not least, I would like to thank my beloved family for their continuous support and encouragement in my studies and this project, especially.

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ABBREVIATION AND NOMENCLATURES

DFT	–	Discrete Fourier Transform
FFT	–	Fast Fourier Transform
Hz	–	Hertz
ISO	–	International Organization for Standardization
MATLAB	–	Matrix Laboratory software (Mathworks, Inc.)
mm/s	–	Millimeters per second
RPM	–	Revolution per minute

CHAPTER ONE

1. INTRODUCTION

1.1. Background Study

A centrifugal pump, or known as a centrifuge pump, is one of the common and often critical operating equipments in the power generation, oil and gas, and also petrochemical industry. This pump type is widely used because it possessed numerous benefits despite its uncomplicated design. The advantages and disadvantages of the centrifugal pump can be seen as follows.

Table 1.1: The advantages and the disadvantages of a centrifugal pump

Advantages	Disadvantages
High discharging capacity.	Loud noise and high vibration.
Higher operating speeds.	Not able to generate high pressure.
Lift highly viscous liquids. (e.g: Oil, muddy and sewage water, chemicals)	-

Even though centrifugal pumps are applicable to most industries and easy to operate, most companies take them for granted by not monitoring or maintaining them. This will reduce its life span and performance. There are several causes that can affect the centrifugal pumps service, mostly associated with vibration, and they are either mechanical cause, hydraulic cause or peripheral cause.

Vibration problems are usually associated with centrifugal pump as high vibration can be a threat to the pump and to the surrounding. Therefore, vibration analysis has been used as a predictive maintenance procedure as well as a support for machinery maintenance decisions. Due to the vibration level that is increasing over time, the machines can have some form of warning before breakdown completely.

By measuring and analyzing the machine's vibration, the nature and severity of the defects can be determined. Additionally, the machine's failure can also be predicted by using the same set of data.

1.2. Problem Statement

Centrifugal pump needs to be maintained so that their lifespan is longer and the product quality is at optimum. Due to the loads, some vibration and noise is inevitable at certain point therefore, it must be kept in a certain limit not only for the sake of that particular machine, but to the safety of the surroundings such as worker and other components need to be taken care as well.

Other than that, the cost of replacing an overhauled machine is larger than to prevent the crisis beforehand. Hence, the developing faults have to be detected at early stage so that maintenance team can be able to overcome the obstacle without putting the machine into halt. This process may look redundant but it is very important in long term.

1.3. Objectives

There are some significant objectives that are expected to be achieved at the end of the project.

1) To understand the principle of vibration that is used in the analysis of centrifugal pump.
2) To be able to identify the faults' nature and severity of the centrifugal pumps.
3) To be able to perform vibration analysis with the aid of MATLAB software.

1.4. Scope of Study

In this project, these are the scope of study that being involved, generally:

- The application of centrifugal pumps.
- Vibration analysis used in determining the centrifugal pumps failure.
- Use simple model of a centrifugal pump for simulation and analysis.
- Use MATLAB software is used as the tool to do the computation of the simulation and analysis.
- A single speed pump motor is used.

1.5. Relevancy of the Project

This project is relevance as the vibration analysis is acknowledged as a very useful tool in preventive maintenance. Other than that, centrifugal pumps are the common machine used in the industries. The understanding to the vibration analysis of centrifugal pump is very relevant in the current application as well as applying mechanical theory and knowledge by using software to do the analysis.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Working Principle of Centrifugal Pump

A regular centrifugal pump is one of the simplest pieces of equipment in any process plant. The prime purpose of the centrifugal pump is to convert the energy of a prime mover which comes from motor or turbine, into kinetic energy and then into pressure energy of a fluid that is being pumped. Commonly, the pump consists of an impeller and the volute or diffuser, where the impeller is the rotating part that converts driver energy into kinetic energy and the volute or diffuser is the stationary part that converts the kinetic into pressure energy.

Oppositely, according to Podugu et al (2011), there are two main components of the centrifugal pump which are stationary pump casing and an impeller. The pump casing guides the liquid that is entering from the suction nozzle to the centre of the impeller. On the other hand, the impeller imparts a radial and rotary motion to the liquid to increase the pressure and kinetic energy. However, the volute also comes into the picture with the purpose of collecting the discharged liquid from the periphery of the impeller at high velocity. By increasing the flow area, the volute gradually causes a reduction in fluid velocity.

Khin et al (2008) also adds that in a centrifugal pump, the liquid is forced by atmospheric or some other pressure into a set of rotating vanes. Similarly, by using the pump casing or housing, a set of rotation vanes are enclosed and used to impart energy to a fluid through centrifugal force.

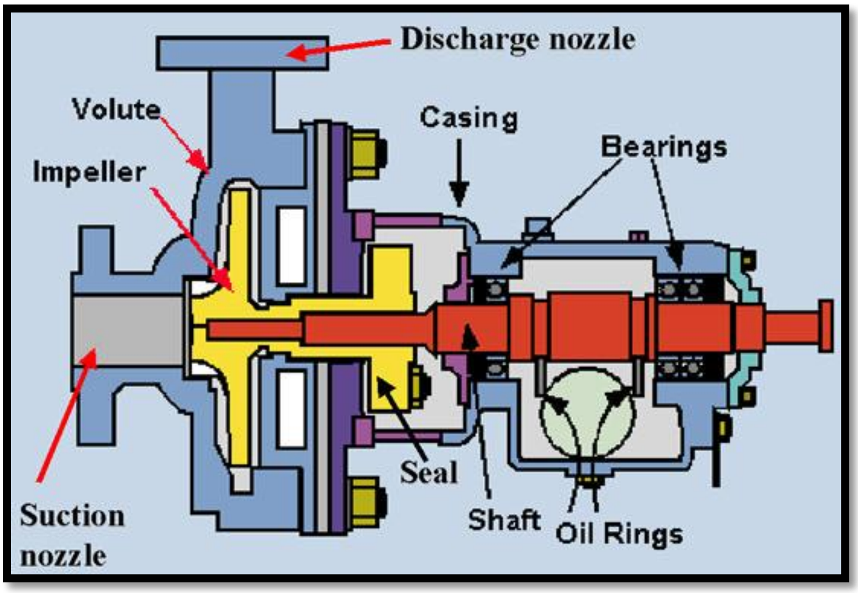

Figure 2.1.1: General components of a centrifugal pump. (Sandev)

Explained by Sahdev (2003), the process liquid enters the impeller of the centrifugal pump by passing through the suction nozzle. The liquid in the cavities between the vanes outward is spun hence the centrifugal acceleration is provided. The movement of the liquid out from the impeller causes more liquid to enter due to the low-pressure area.

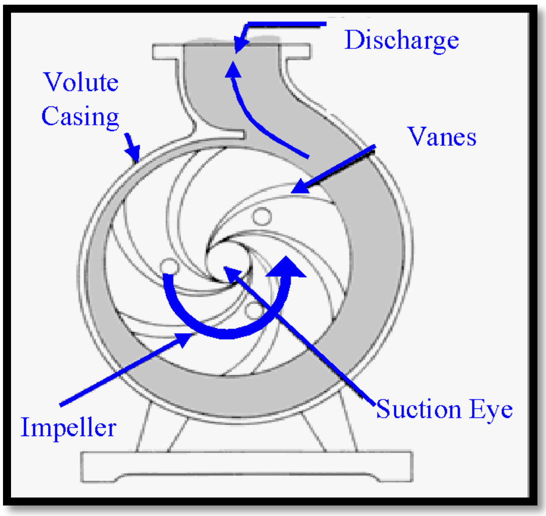

Figure 2.1.2: Liquid flow path inside an impeller. (Sandev)

Sandev (2003) adds that the end product produced by the centrifugal force is kinetic energy. The velocity at the edge or vane tip of the impeller is proportional to the energy given to the liquid. Therefore, as the size of the impeller is bigger or the quicker the impeller revolves, the velocity of the liquid at the vane will be higher and greater energy is imparted to the liquid.

By creating a resistance to the flow, the kinetic energy of the liquid coming out from the impeller is utilized. This is where the pump volute or casing functions as the first resistance to the flow. The liquid further decelerates as it passes through the discharge nozzle and according to the Bernoulli's principle, the velocity is converted to pressure.

Hence, the head developed can be expressed by the following formula,

$$H = \frac{v^2}{2g} \tag{2.1}$$

Where *H* is the total head *developed (m); v* is the velocity at periphery of impeller (m/s); *g* is gravity acceleration, 9.81 m/s^2.

Meanwhile, the formula for peripheral velocity is as follows,

$$v = \frac{N \times D}{229} \tag{2.2}$$

Where *v* is the velocity at periphery of impeller (m/s); *N* is the speed of impeller in RPM; *D* is the impeller diameter (m).

According to Choi (2007), the number of centrifugal pumps used in the industry is plenty, the run to down time maintenance method is commonly implemented. This means during the pump is down, there is no maintenance or attention shall be given. Conservatively, the companies always assume the replacement of the pump with the new one is always affordable.

However, there are ways of doing things that can reduce the cost of purchasing another unit of pump at the same time, maintaining the performance of the pump at its optimum. For pumps that are operating at critical position, some measurements such as vibration, temperature and noise might be undertaken and analyzed. This process is called preventive maintenance and it can prevent any catastrophic failure of the respective pump or any relating machineries. Nowadays, the industrial companies have a wide awareness on predictive maintenance and started to apply them in the pump operation despite the faults can always occur in the centrifugal pump due to low efficiency operation of the pump itself.

2.2. Vibration

Shreve (2004) states that vibration can be simply define as the cyclic or rotating motion of a machine or its components from the static position hence the force generated within the particular machine will cause vibration. A simple machine vibration system can be represented as the following forced spring mass damper system.

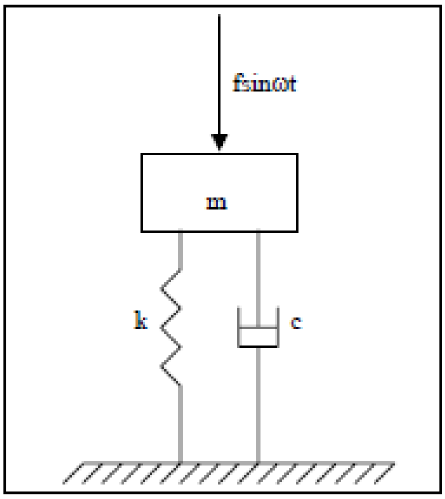

Figure 2.2.1: Spring Mass Damper System – Forced Response

The response of a forced system given by the equation,

$$m\ddot{x} + c\dot{x} + kx = F_o \sin \omega t \tag{2.3}$$

Where F_o is the amplitude of the applied force (m); ω is the driving frequency (rad/s); t is time (s); m is the load (kg); c is the damping coefficient; k is the spring constant.

According to Commtest Inst. (2006), machine vibration is the back-and forth movement of machines or the components. However, Sinha (2003) focuses more on vibration in machines, particularly a rotating machine. He adds that a rotating machine mainly consists of three major components which are rotor, bearing and foundation. Most of the time, the vibration based signal is used to identified the faults that occur in the bearing or rotor or both.

According to Ravindra Birajdar et al (2009), the vibration in centrifugal pump, in this case, has a significant effect on the machine's performance. This is due to the possibility of the machine to undergo a premature failure as the vibration level is increasing over time and loads, mainly because of the equipment has started to destroy itself. He adds there are several sources of vibration in centrifugal pumps and they can be classified in to three categories; Mechanical causes, Hydraulic causes as was as the Peripheral causes. Some of the examples of the source according to their categories can be concluded as the table follows.

Table 1.2.1: Vibration causes in centrifugal pump. (Ravindra Birajdar et al. 2009)

Types of Causes	**Source**
Mechanical	Unbalanced rotating components
	Damaged impellers and non concentric shaft sleeves
	Bent or warped shaft
	Worn or loose bearings/parts
Hydraulic	Operating pump beyond Best Efficiency Point (BEP)
	Vaporization of the product
	Internal recirculation
	Water hammer
Peripheral	Harmonic vibration from equipments/driver
	Pump operates at critical speed
	Temporary seizing of seal faces

Likewise, A. Albraik et al (2012) have the same opinion on the source of vibration in a centrifugal pump. According to the latter, as the worn impeller causes loss in discharge pressure, it contributes to the loss of pump efficiency. As a result, power consumed by the particular pump will either stay the same, or increase as wear occurs.

In the industry, many of the pumps do not have a proper pressure indicator or flow instrumentation that can detect abnormal hydraulic operating conditions after a period of time of operations. Hence, vibration measurement is a robust method even though conventional for the detection of vibration faults of the pumps such as cavitations. It also represents the most viable tool to the plant personnel.

2.3 Vibration Time Waveform

To determine the sources of high vibration is one of the main objectives of the analysis. In order to take the vibration measurement, some tools are used commonly, an accelerometer as a sensor. However, not only accelerometer but velocity sensor and displacement probes can be used as well. The sensor detects the vibration and delivers the vibration data to an analyzer to be stored. Most of the time, a portable vibration analyzer is preferred to be used with the sensor. The analyzer provides the amplification of the sensor signal and converts the analogue to digital, filtering, and conditioning of the signal.

Dunton (1999) says that the vibration analysis time waveform data was viewed on oscilloscopes and frequency components in the early days. The following is the relationship between frequency and time.

$$f = \frac{1}{p} \tag{2.4}$$

Where f is the frequency (Hz) and p is the period of time (s).

Meanwhile, the total sample period desired can be calculated by this formula,

$$Total\ sample\ period\ (s) = \frac{60 \times Number\ \ of\ revolutions}{Speed\ \ (RPM)} \qquad (2.5)$$

The time waveform is effective to be used in the applications of gears, sleeve bearing machine, looseness, rubs and beats.

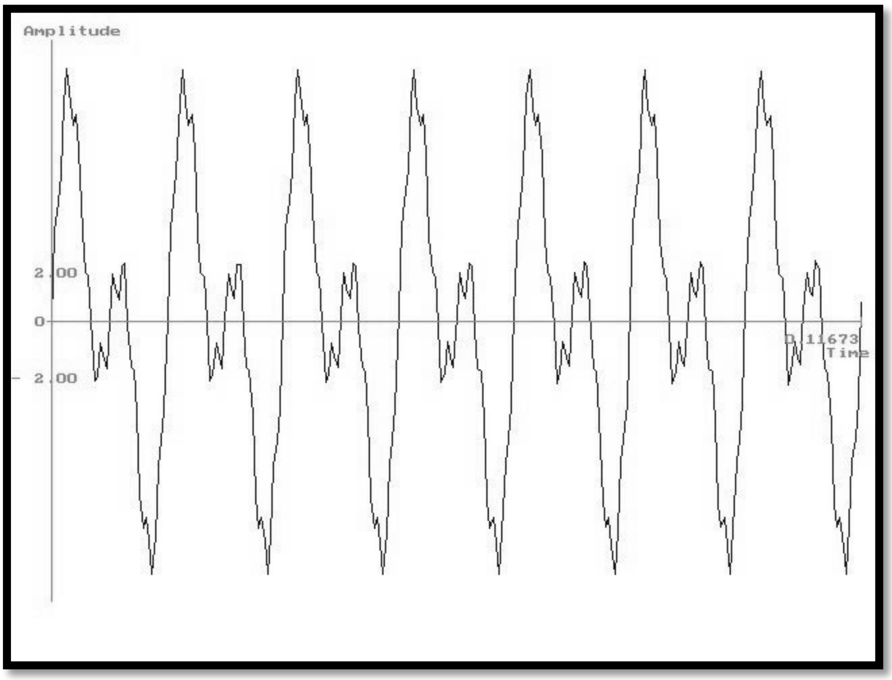

Figure 2.3.1: Example of a time waveform. (Dunton, 1999)

From the patterns of the waveform, the faults of machine can be determined. Each cause can be diagnosed by detecting the trends such as unbalance, eccentricity, bent shaft and misalignment. The amplitude severity also gives an information on how severe the condition of the machine.

Time waveform is the basic method to display the raw vibration data but the spectra can be presented in various ways but the most popular ones are Fast Fourier Transform (FFT) and Power Spectral Density (PSD) for vibration analysis purposes.

2.4 Fast Fourier Transform Spectrum

According to Sek (2009), the Fourier series is a periodic function that can be represented as a sum of infinite number of (co-)sinusoidal components at equally spaced frequencies with the interval of 1/T, where T is the period of the function. The number of FFT elements is equal to the size of the time sample. The second half of these complex numbers corresponds to negative frequencies and contains complex conjugates of the first half for the positive frequencies, and does not carry any new information.

Huang (2011) says theoretically, Fourier Transform is a tool to switch between the time domain and the frequency domain. In order to convert the signal in the time domain to frequency domain, a Fourier transform is used. On the other hand, to convert back the frequency domain components back to the original time domain signal, an inverse Fourier transform is used. Both transforms are represented by these following formulas,

- Continuous-Time Fourier Transform;

  $$F(j\omega) = \int_{-\infty}^{+\infty} f(t)e^{-j\omega t}\,dt \qquad (2.6)$$

  $$f(t) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} F(j\omega)e^{j\omega t}\,d\omega \qquad (2.7)$$

- Discrete-Time Fourier Transform;

  $$X\left(e^{j\omega}\right) = \sum_{n=-\infty}^{+\infty} x[n]e^{-j\omega n} \qquad (2.8)$$

  $$x[n] = \frac{1}{2\pi}\int_{2\pi}^{X}(e^{j\omega})e^{j\omega n}\,d\omega \qquad (2.9)$$

Meanwhile, The Fast Fourier Transform (FFT) is just a very efficient algorithm for computing the Discrete Fourier Transform (DFT),

In vibration analysis, the FFT is used to see the spectrum which is the graphical display of the frequencies of the machine components that is vibrating together with the amplitude of the components at these frequencies, referring to Commtest Inc. (2006). In addition, the cause of vibration and the condition of the machine can be inferred by studying the individual frequency at which the component vibrates, as well as the amplitudes corresponding to those frequencies.

CHAPTER THREE

3 METHODOLOGY

3.1 Research Methodology

Firstly, in order to have a better understanding of the project, the author has been searching for the previous studies on Vibration Analysis of Centrifugal Pump. With this, the author may have a clearer view on vibration analysis as well as some other opinions regarding the topic. From books to journals and conference paper, they are the main sources for the author to start doing the project.

Since the author has some experience in the field of vibration maintenance during her industrial training, she can grasp the procedure to take the measurements on the site. In order to conduct the simulation, some parameters need to be set beforehand by taking the reference from the real experiment done in the industry by previous researchers. The recorded data is then proceeded to be analyzed by MATLAB software, which the author has to program accordingly.

The simulation is done for a few sets of parameters, to see the differences of the pump vibration. The raw vibration data is then converted to an FFT spectrum in order to have the desired format to be compared to the machinery guideline to see the presence of the defect and its severity.

All the results are recorded and labeled accordingly. Next, the results are analyzed and discussion is being drawn. Finally, list of the pump faults can be determined from the analyzed data. Also, the severity of the faults can be determined as well. Conclusion is made.

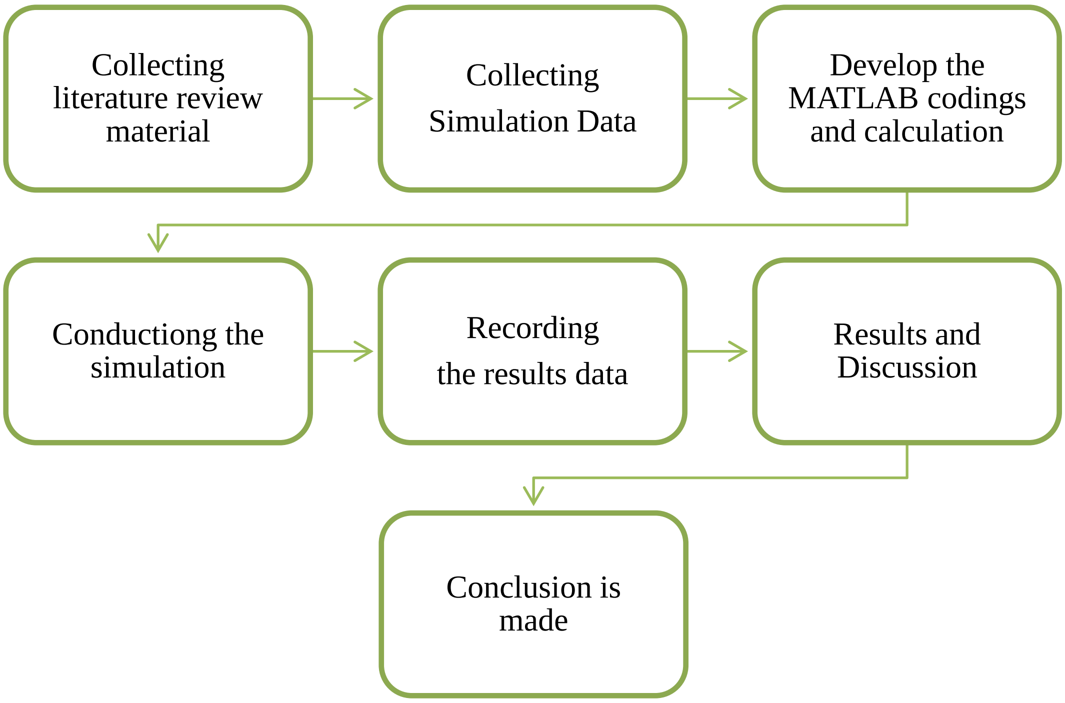

Figure 3.1.1: Schematic diagram depicting the general approach of the project

3.2 Key Milestone and Gantt Chart

On the other hand, there are few key milestones that need to be achieved in order to meet the objective of this project.

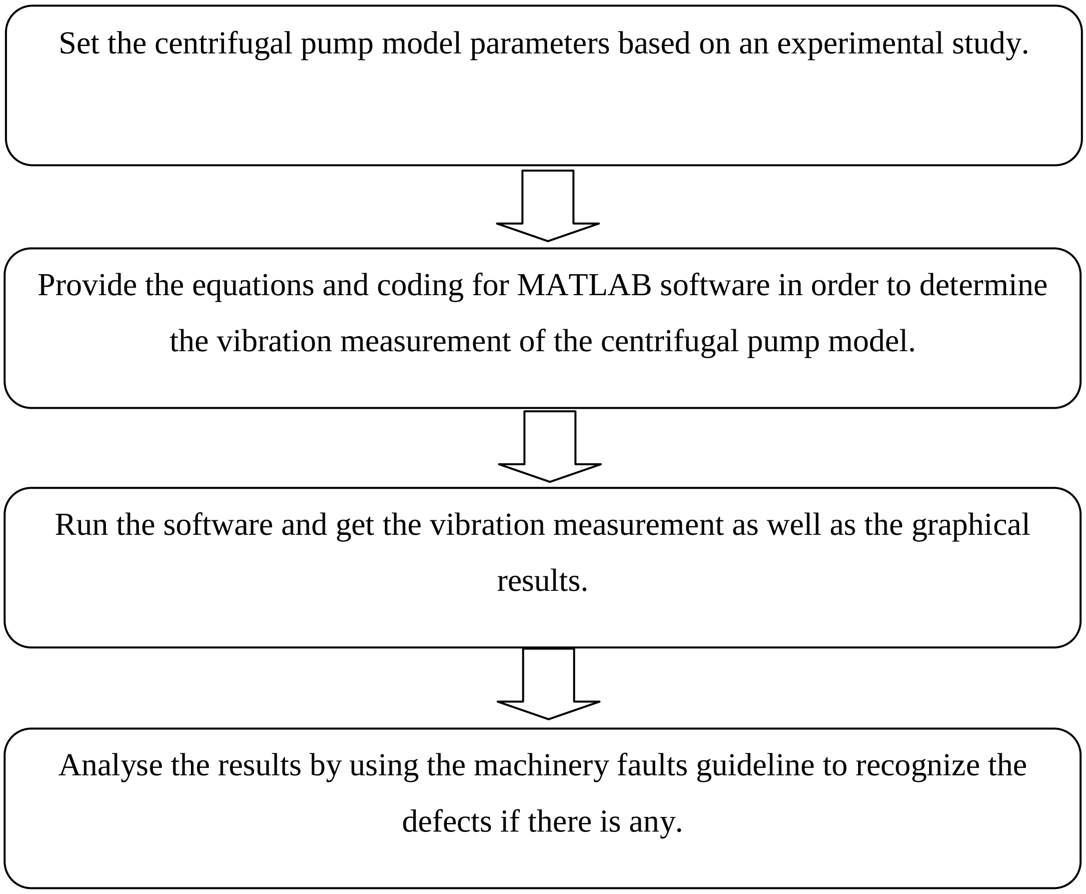

Figure 3.1.2: Schematic diagram depicting the key milestone of the project

This project is mainly to develop a simulation of a centrifugal pump and to get the vibration data to be analyzed. The simulation of the above is done by using MATLAB.

The parameters of the centrifugal pumps are following the experimental study done by Ali et al (2009). The pump is running at a single speed of 3000 rpm with the assumption is made that the measurement takes place on the pump bearing, in radial.

Then, the vibration sampling equation is run, for each of the parameter to obtain the waveform data of the centrifugal pump as well as the FFT spectrum for further analysis. The step-by-step procedure in the software can be seen in the Appendix.

The next milestone is after the graphical data is recorded, the analysis begins by observing the vibration level of each of the result. The defects are identified by using LUDECA's Machinery Faults guideline as well as the ISO 10816 Standard. These two guidelines can also be referred in the Appendix.

Last but not least, the defects possible causes are studied and recommendations are proposed in the next chapter. To see the timeframe of the project, a Gantt chart is drawn as follows.

No	Work Description	Weeks															
		Final Year Project I															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	**Project title selection:** Vibration Analysis of Centrifugal Pump																
2	**Preliminary Research Work:** 1) Research on the centrifugal pump assembly 2) Vibration analysis 3) Method to simulate data (MATLAB)																
3	**Extended Proposal:** 1) Prepare an extended proposal (draft) 2) Submit the extended proposal																
4	**Proposal Defense Presentation:** 1) Prepare the material to present (Background Study, Problem Statement, Objectives, Scope of Study, Literature Review, Methodology) 2) Presentation examined by two examiners																
5	**Continuation of Project Work:** 1) Exercises on MATLAB tutorial on Vibration Problems. 2) Research on Centrifugal Pumps parameter based on case study.																
6	**Interim Report:** 1) An interim report needs to be drawn (draft) 2) Submit the interim report.																
		END OF FINAL PROJECT I															

Figure 3.1.3: Gantt chart showing the project timeframe for FYP I

No	Work Description	Weeks															
		Final Year Project II															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	**Generate coding in MATLAB:** 1) Produce waveform. 2) Produce spectrum.	■	■	■	■												
2	**Obtain the results generated:** 1) Waveform & Spectrum data – Without Load 2) Waveform & Spectrum data – With Load					■	■	■									
3	**Submission of Progress Report:** 1) An extension of a report based on the Interim Report with some results obtained. (draft) 2) Submit the progress report.								■								
4	**Continue Project Work:** 1) Process the results. 2) Analyze the plots to find defects in the centrifugal pump.									■	■						
5	**Pre-SEDEX Presentation:** Poster presentation to an external examiner.											■					
6	**Continue Project Work:** 1) Finalize the analysis of centrifugal pump based on diagnosis guideline. 2) Conclusion and recommendation for future work is drawn.												■	■			
7	**Dissertation & Technical Paper:** 1) A full dissertation is prepared together with a technical report. 2) Submission of complete dissertation and technical report.													■	■		
8	**Oral presentation:** 1) Final presentation of the project. 2) Presentation is examined by three examiners.															■	
9	**Submission of hardbound dissertations.**																■
		END OF FINAL YEAR PROJECT															

Figure 3.1.4: Gantt chart showing the project timeframe for FYP II

CHAPTER FOUR

4 RESULT AND DISCUSSION

4.1 Measurement of Vibration Data without Load

The measurement is taken at the pump bearing, horizontally. The speed of the centrifugal pump is constant which is at 3000 rpm. One complete oscillation is about 0.02 seconds hence the four oscillations take about 0.08 seconds to complete.

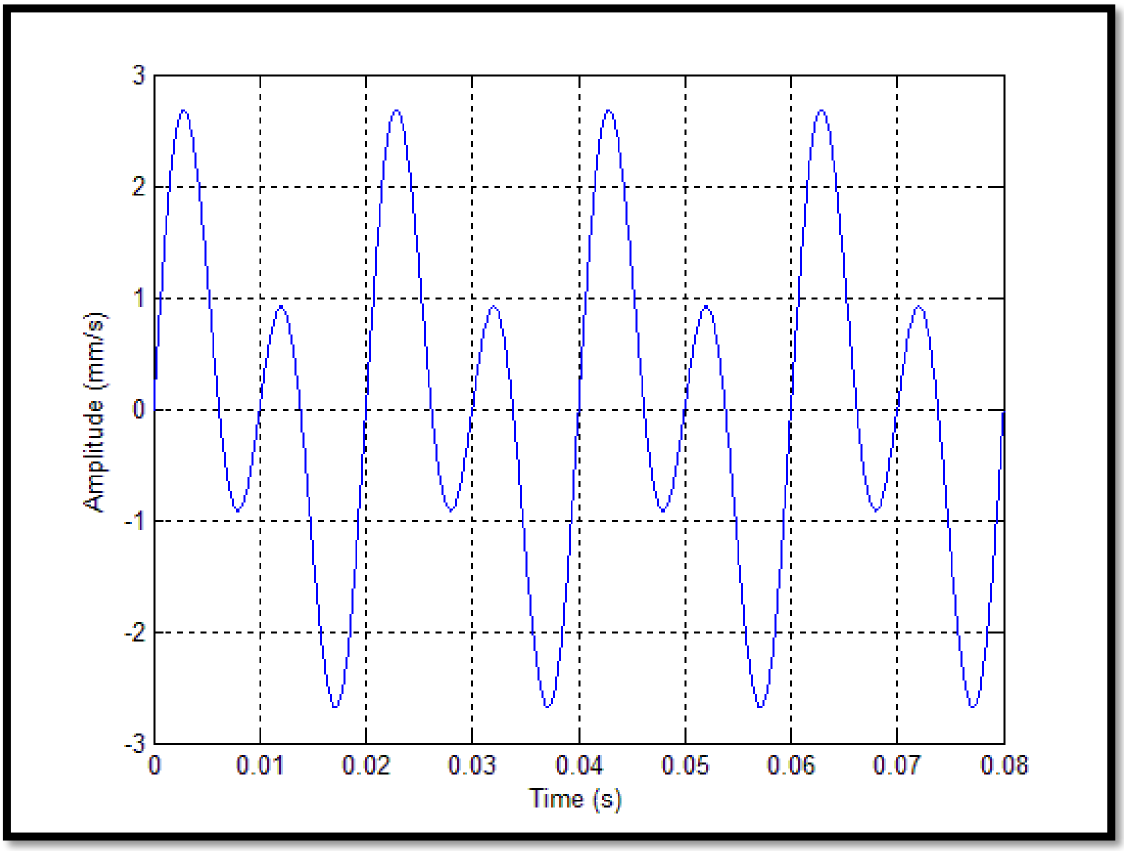

Figure 4.1.1: Horizontal waveform at 3000rpm and no load

In the above figure, the waveform shows the vibrating machine fluctuates in between 3 mm/s to minus 3mm/s. Also, for each oscillation, there are two peaks that can be observed.

On the other hand, below is the relative FFT Spectrum. The full spectrum is observed at 500 Hz but in order to see the significant line, it is magnified to 150 Hz of frequency.

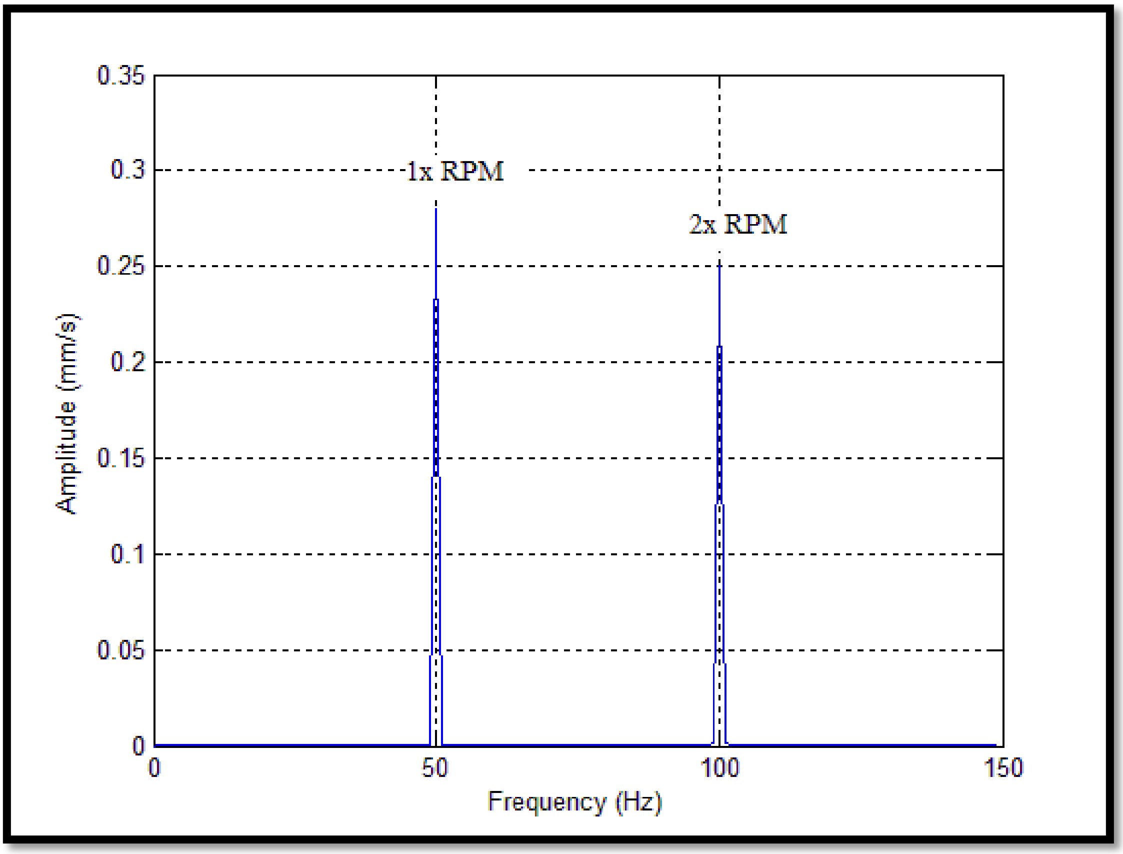

Figure 4.1.2: Horizontal spectrum at 3000 rpm and no load

As seen in the above figure, there are two significant amplitude of vibration in the 1x RPM and 2x RPM, both amplitude at 0.3 mm/s and 0.25 mm/s respectively.

The measurement is taken at the pump bearing, vertically. The speed of the centrifugal pump is constant at 3000 rpm. One complete oscillation is about 0.02 seconds hence the four oscillations take about 0.08 seconds to complete.

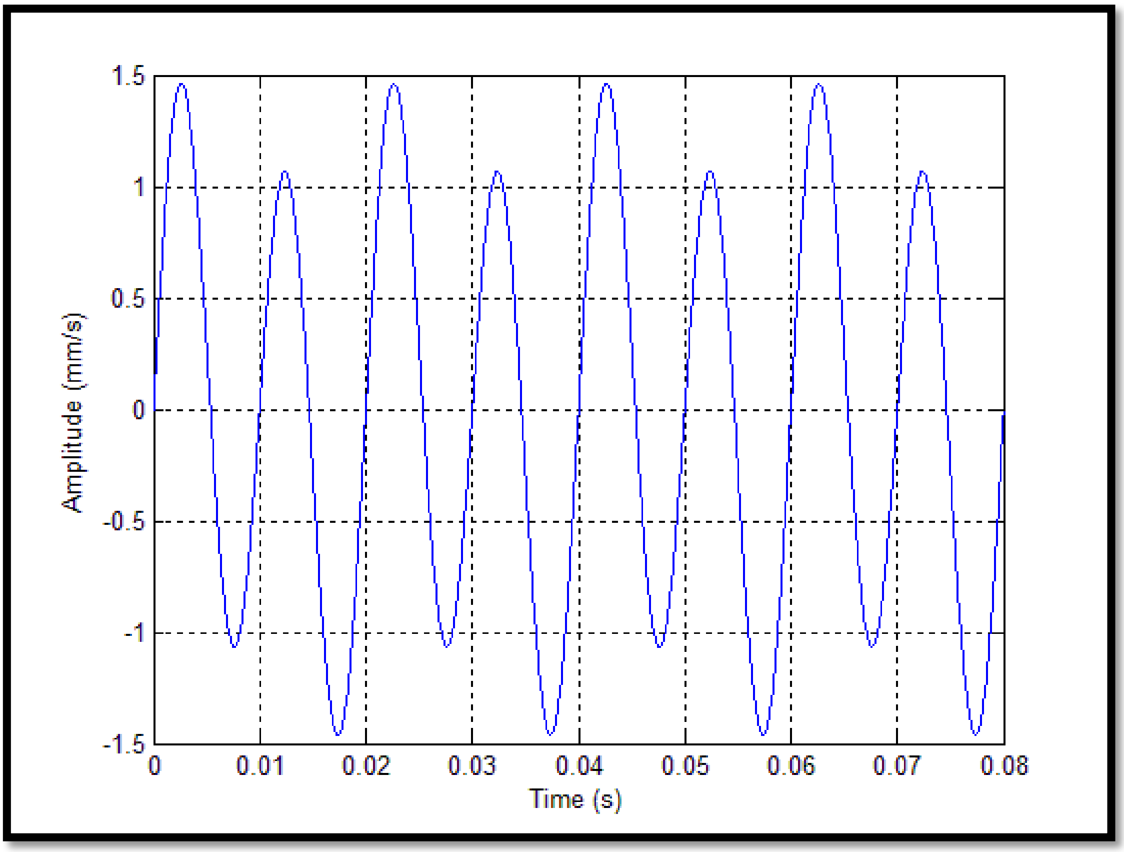

Figure 4.1.3: Vertical waveform at 3000 rpm and no load.

In the above figure, the waveform shows the vibrating machine fluctuates in between 1.5 mm/s to minus 1.5 mm/s. Also, for each oscillation, there are two significant peaks that can be observed. An FFT is used in the following to see more detail about the vibration reading.

The following plot shows the spectrum for the previous waveform. The spectrum is magnified to 150 Hz of frequency in order to focus on the significant lines as seen below.

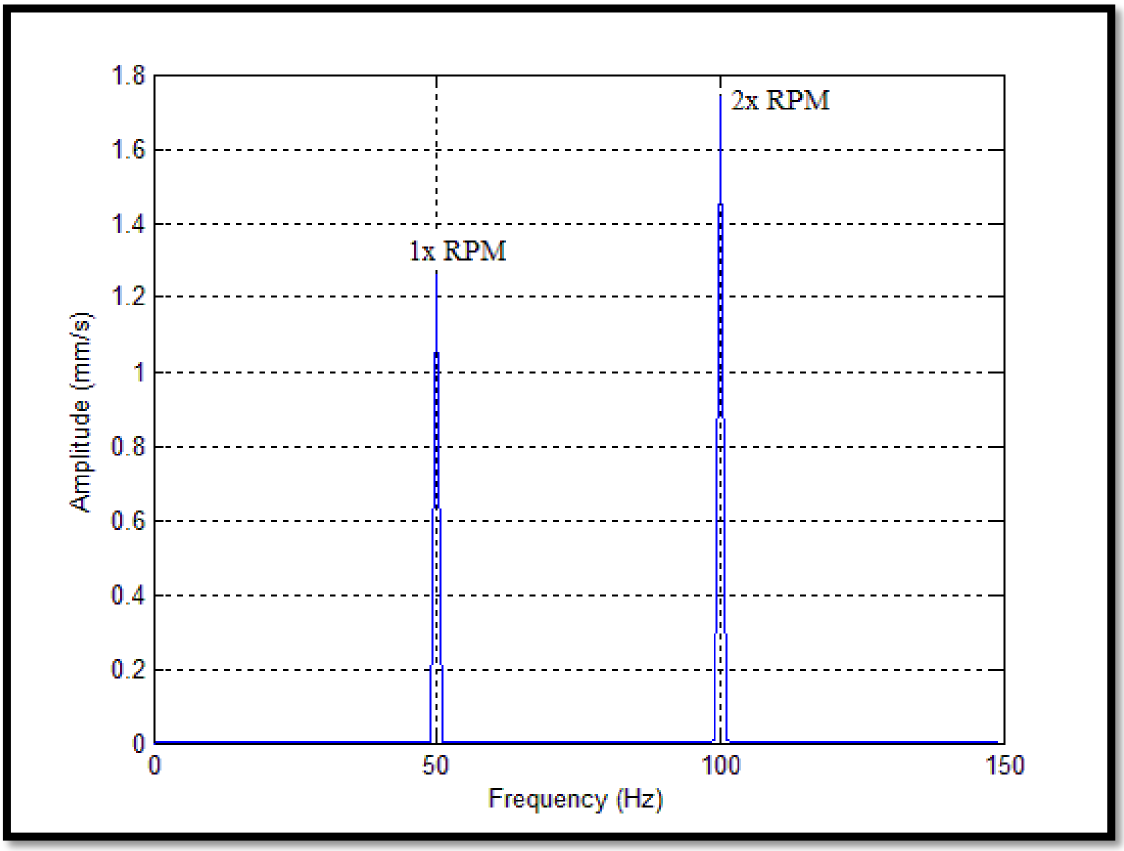

Figure 4.1.4: Vertical spectrum at 3000 rpm with no load

In the vertical measurement, there is a high reading of amplitude compared to the horizontal measurement. The readings are at 50 Hz and 100 Hz, valued 1.25 mm/s and 1.75 mm/s each.

4.2 Measurement of Vibration Data with 0.5 Nm Torque Load.

Similarly, the measurement is taken at the pump bearing, horizontally. The speed of the centrifugal pump is constant which is at 3000 rpm. One complete oscillation is about 0.02 seconds hence the four oscillations take about 0.08 seconds to complete.

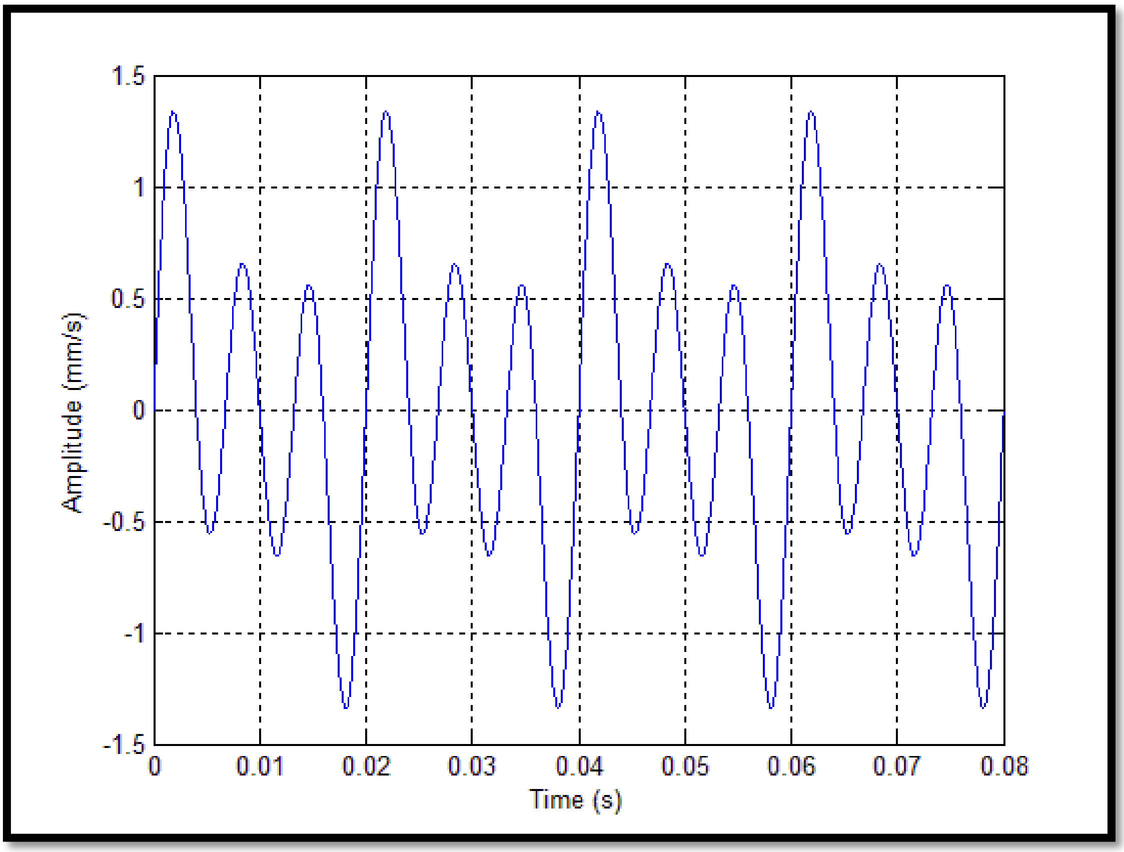

Figure 4.2.1: Horizontal waveform at 3000 rpm and 0.5 Nm load

In the above figure, the waveform shows the vibrating machine fluctuates in between 1.5 mm/s to minus 1.5 mm/s. Also, for each oscillation, there are three significant peaks that can be observed. An FFT is used in the following to see more detail about the vibration reading.

In relation to the previous plot, the following plot shows the FFT spectrum of the horizontal vibration measurement. The spectrum is magnified to 200 Hz of frequency to closely observe the significant lines.

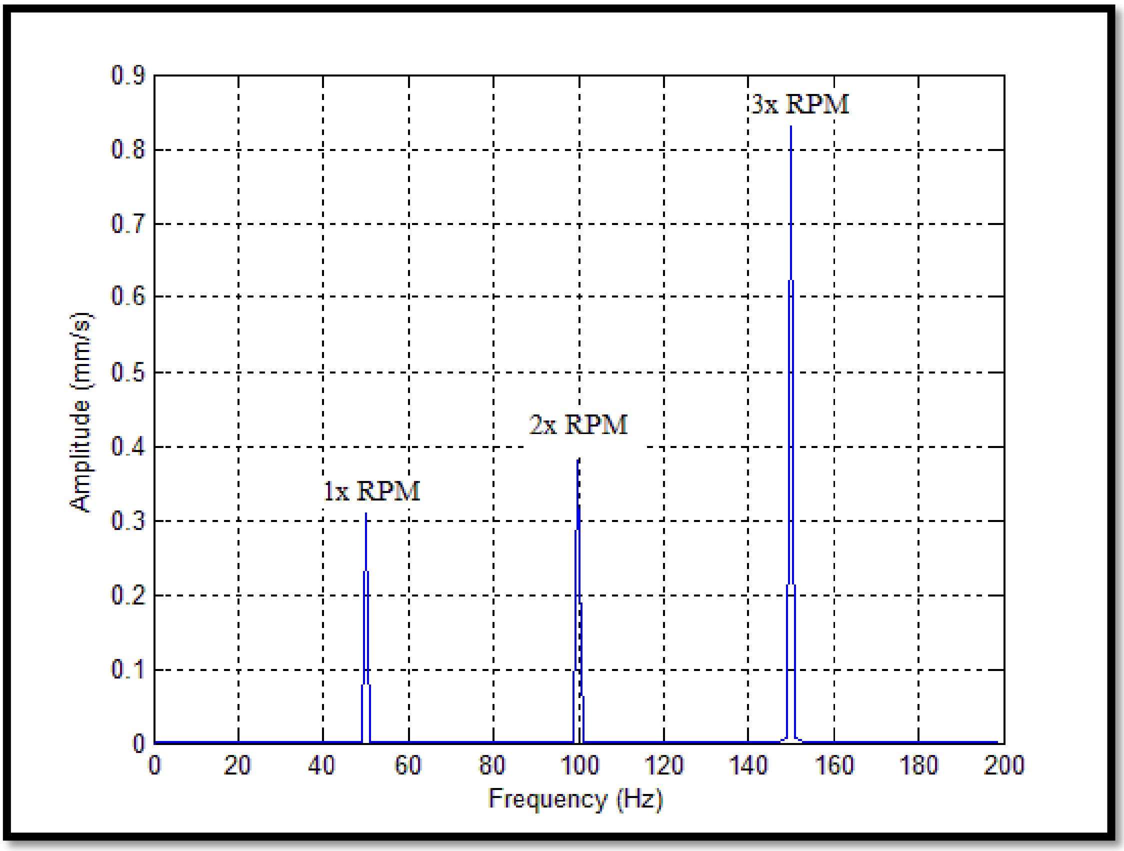

Figure 4.2.2: Horizontal spectrum at 3000 rpm and 0.5 Nm load

Different from the measurement taken during no load condition, there are three significant readings that can be observed from the above plot. They are measured at 0.31 mm/s, 0.38 mm/s and also 0.83 mm/s in the harmonics of 50 Hz.

The measurement is taken at the pump bearing, vertically. The speed of the centrifugal pump is constant at 3000 rpm. One complete oscillation is about 0.02 seconds hence the four oscillations take about 0.08 seconds to complete.

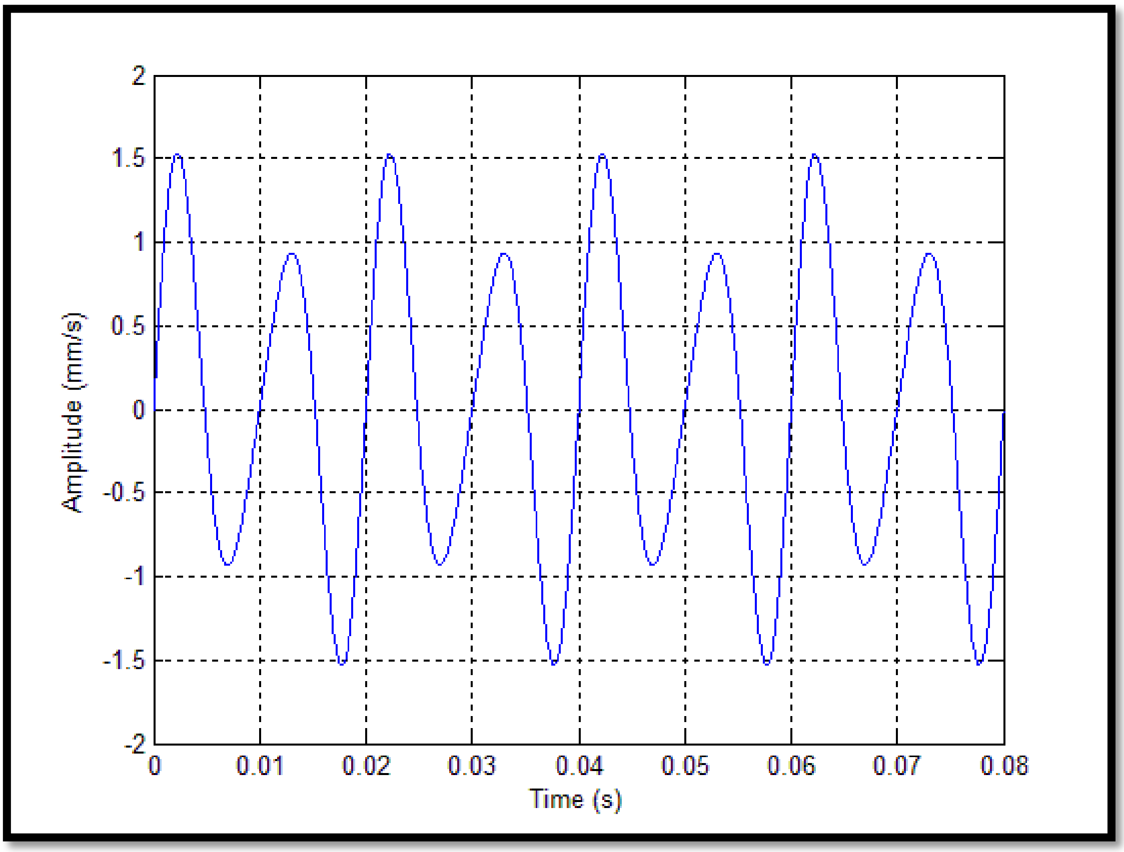

Figure 4.2.3: Vertical waveform at 3000 rpm and 0.5 Nm load

In the above figure, the waveform shows the vibrating machine fluctuates in between the amplitude of 2 mm/s to minus 2 mm/s. Also, for each oscillation, there are three peaks that can be observed.

On the other hand, below is the FFT Spectrum relative to the previous waveform. The full spectrum is observed at 500 Hz but in order to see the significant line, it is magnified to 200 Hz of frequency.

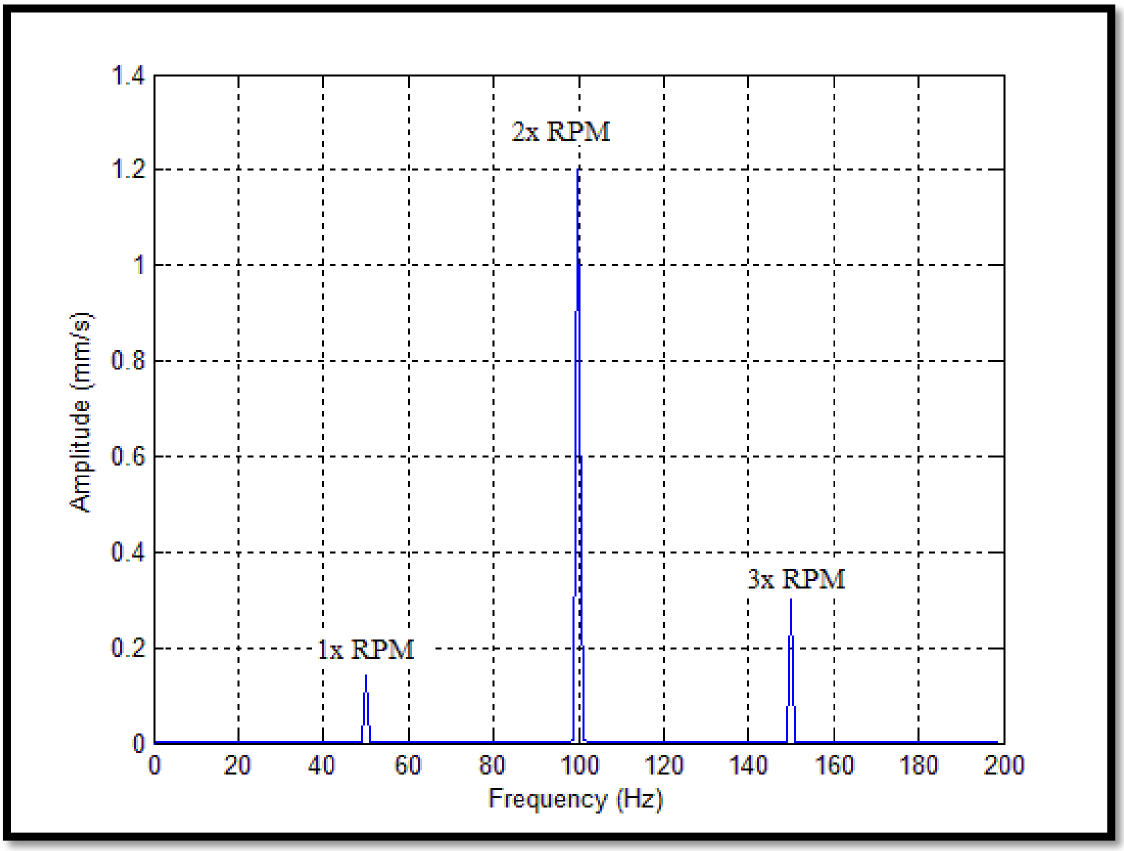

Figure 4.2.4: Vertical spectrum at 3000 rpm and 0.5 Nm load

In the vertical measurement, there is a high reading of amplitude compared to the horizontal measurement. The readings are at 50 Hz, 100 Hz and 150 Hz, valued 0.15 mm/s, 1.20 mm/s and 0.3 mm/s each.

From the results achieved, it can be concluded that there are only two significant lines show in the no load condition. Meanwhile, during the 0.5 Nm loading, there are three significant lines showing at the spectrum. They are all at the harmonics of 50 Hz. The measurement of the amplitudes for each spectrum plot can be seen in the table below.

Table 4.1: Vibration amplitude with no load

Position	Horizontal		Vertical	
3000 RPM (Harmonics of 50Hz)	1x	2x	1x	2x
Amplitude (mm/s)	0.28	0.25	1.26	1.74

Table 4.2: Vibration amplitude with 0.5 Nm load

Position	Horizontal			Vertical		
3000 RPM (Harmonics of 50Hz)	1x	2x	3x	1x	2x	3x
Amplitude (mm/s)	0.31	0.38	0.83	0.14	1.20	0.3

In accordance to the ISO 10816 for the Class III Rigid Foundation, the above centrifugal pump is in a good condition due to its amplitude which is below 1.8 mm/s. Generally, the pump is still operating well under a low vibration level. However, there are developing faults that can be detected at early stage.

According to the LUDECA's Machinery Faults Diagnosis guide, there are two developing faults that can be seen from the spectrums of the centrifugal pump vibration. They are unbalance and also misalignment problem.

During unbalance fault, there is a signal at the rotation speed in both horizontal and vertical direction. In relation to the previous result, there are significant signal at 50 Hz frequency (1x rpm) for both horizontal and axial direction. Furthermore, from Table 4.1 the vibration amplitude at vertical direction is higher which indicates that the unbalance is more severe vertically.

As per the vibration measurement after a load being added in Table 4.2, the horizontal direction amplitude is slightly increased but in the vertical direction the amplitude decreases. This shows the loading is balancing the vertical direction at the same time increase the unbalance at the horizontal direction.

On the other hand, the misalignment fault can be seen when there is a repeating signal in harmonics of 50 Hz. In both conditions of the pump, there are two and three significant signals presents that compliment the misalignment problem.

Thus far, unbalance and misalignment are the developing faults that can be detected in this centrifugal pump. However, there are many more defects that can occur due to the excessive vibration. Hence, regular maintenance is recommended for the pumps as the vibration defects are amplifying over time.

CHAPTER FIVE

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Vibration analysis is critical for monitoring the centrifugal pumps performance and conditions due to the simple assembly of the pump. By using vibration analysis, not only it can detect the current fault, but with further study it can be applied as a predictive measure upon the upcoming faults that the pumps may faced.

From the above results, it is proven that a simple waveform drawn by a rotating machine such as centrifugal pump can be further processed by using the signal processing function in the MATLAB. Therefore, from the spectrum generated, the common faults detected in a centrifugal pump are imbalance and misalignment of the rotating shaft despite there are many other defects that can be experienced by the pump.

Therefore, it can be concluded that the frequency of the spectrum can determine the faults of the pumps and the amplitude of the spectrum can determine the magnitude or severity of the pump.

Hence, the vibration analysis is ideal to be implemented to the centrifugal pumps monitoring as a preventive maintenance tool.

5.2 Recommendation

There are few recommendations that can be made for future work:

- Perform a real experimental vibration of a centrifugal pump model.
- Instead of a single speed pump, the scope of study can be widened to variable speed pump.
- Use different software such as ANSYS to perform the vibration modal analysis and hence, simulate the vibration waveform.

CHAPTER SIX

6 REFERENCES

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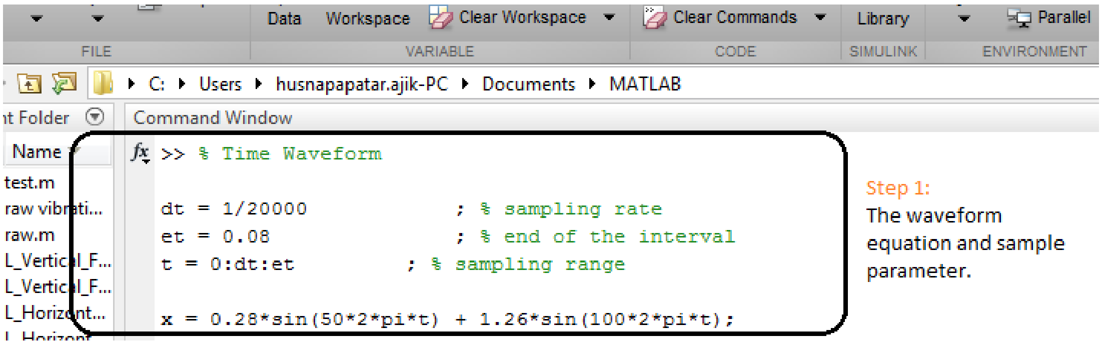
CHAPTER SEVEN

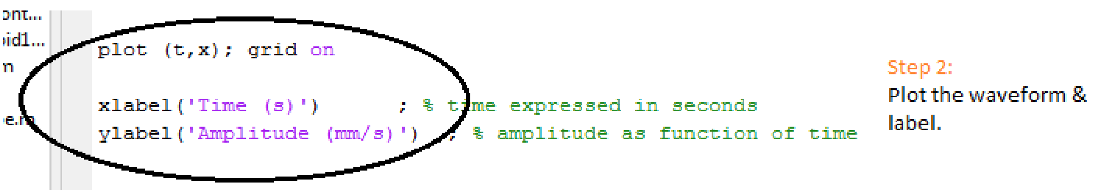
7 APPENDICES

APPENDIX I: Step-by-step procedure in MATLAB software.

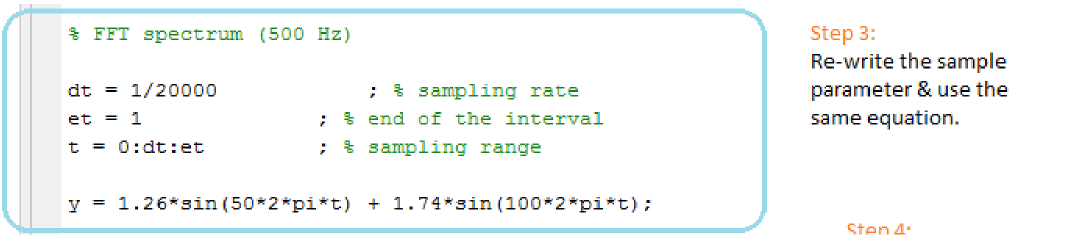
a) Step 1



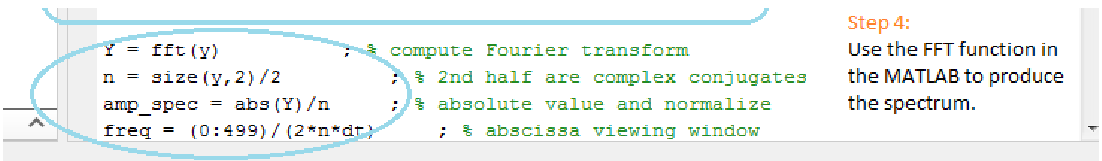
b) Step 2



c) Step 3



d) Step 4

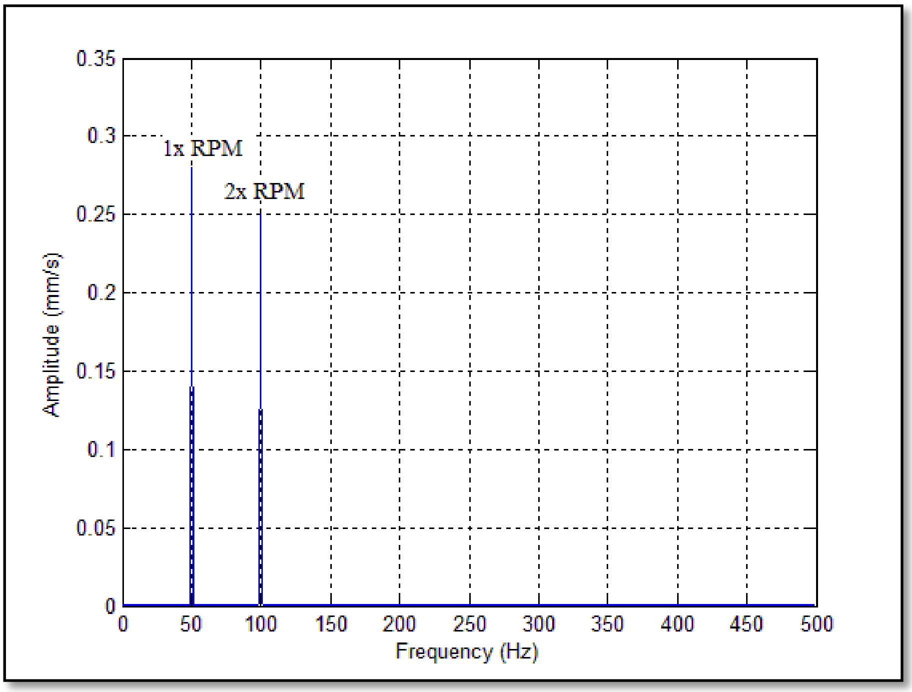


Appendix II: Coding for plot generation in MATLAB software.

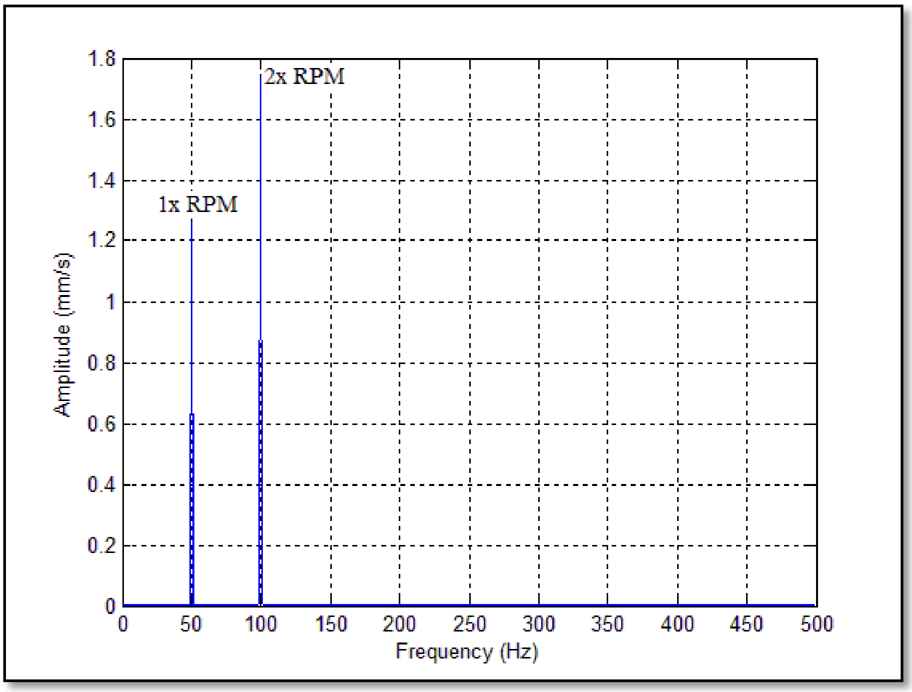
```
% Time Waveform

dt = 1/20000                  ; % sampling rate
et = 0.08                     ; % end of the interval
t = 0:dt:et                   ; % sampling range

x = 0.28*sin(50*2*pi*t) + 1.26*sin(100*2*pi*t);

plot (t,x); grid on                  % plot amplitude waveform

xlabel('Time (s)')            ; % time expressed in seconds
ylabel('Amplitude (mm/s)')    ; % amplitude as function of time


% FFT spectrum (500 Hz)

dt = 1/20000                  ; % sampling rate
et = 1                        ; % end of the interval
t = 0:dt:et                   ; % sampling range

y = 1.26*sin(50*2*pi*t) + 1.74*sin(100*2*pi*t);

Y = fft(y)                    ; % compute Fourier transform
n = size(y,2)/2               ; % 2nd half are complex conjugates
amp_spec = abs(Y)/n           ; % absolute value and normalize
freq = (0:499)/(2*n*dt)       ; % abscissa viewing window

plot(freq,amp_spec(1:500)); grid on       % plot amplitude spectrum

xlabel('Frequency (Hz)')      ; % 1 Herz = number of cycles/second
ylabel('Amplitude (mm/s)')    ; % amplitude as function of frequency


% FFT spectrum [150 Hz (Magnified)]

freq = (0:149)/(2*n*dt)       ; % abscissa viewing window

plot(freq,amp_spec(1:150)); grid on       % plot amplitude spectrum

xlabel('Frequency (Hz)')      ; % 1 Herz = number of cycles/second
ylabel('Amplitude (mm/s)')    ; % amplitude as function of frequency
```

Appendix III: Full spectrum of 500 Hz frequency.

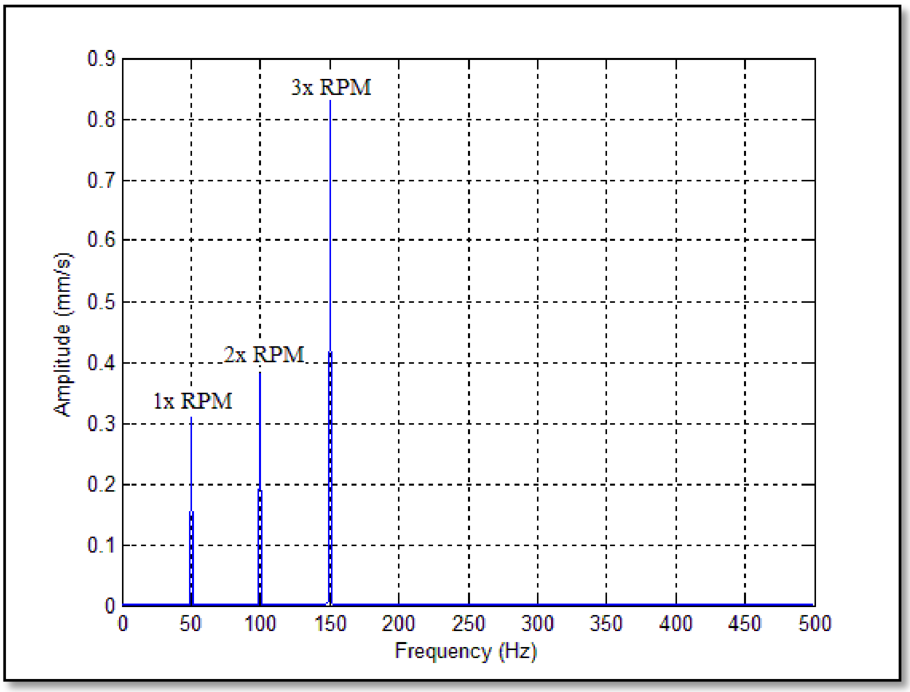
a) Horizontal direction, no load.



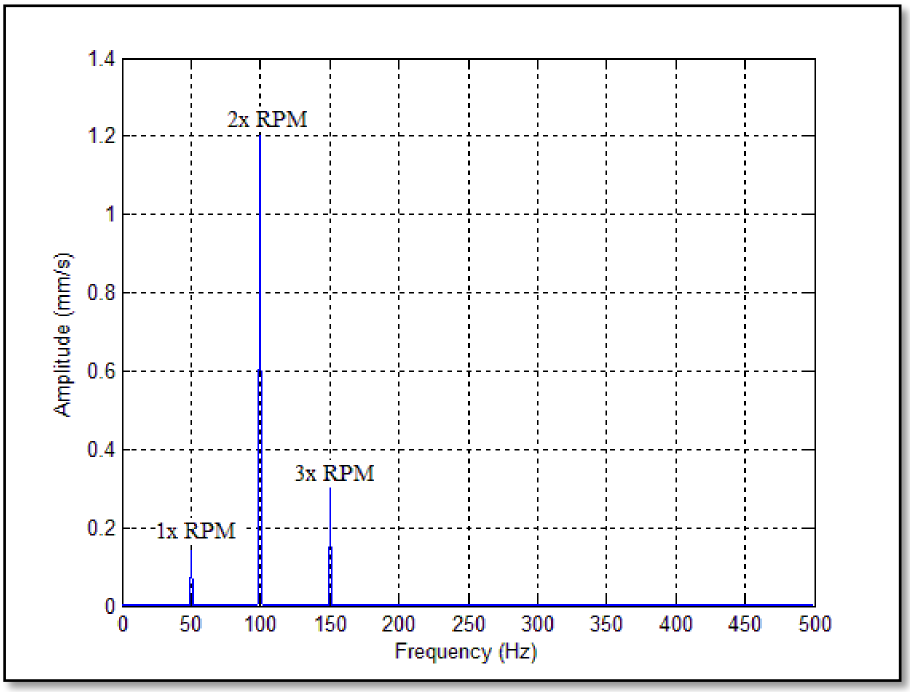
b) Vertical direction, no load.



c) Horizontal direction, 0.5 Nm load.



d) Vertical direction, 0.5 Nm load.



APPENDIX IV: Vibration severity standards by ISO 10816.

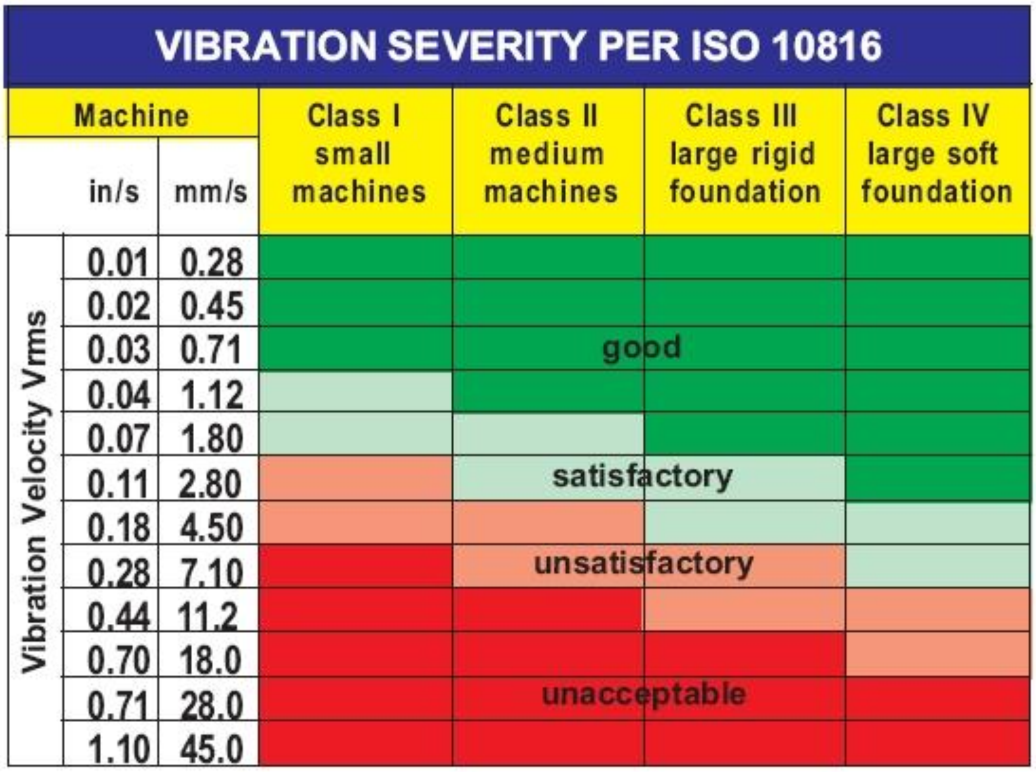
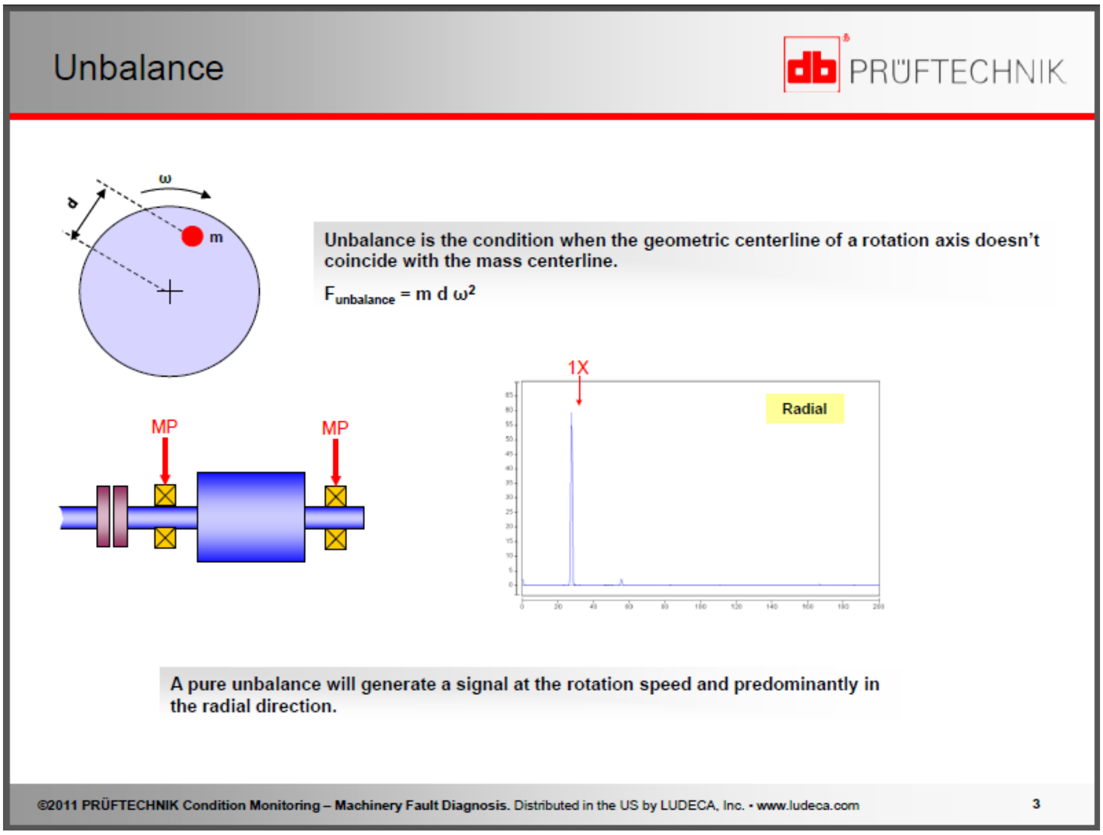


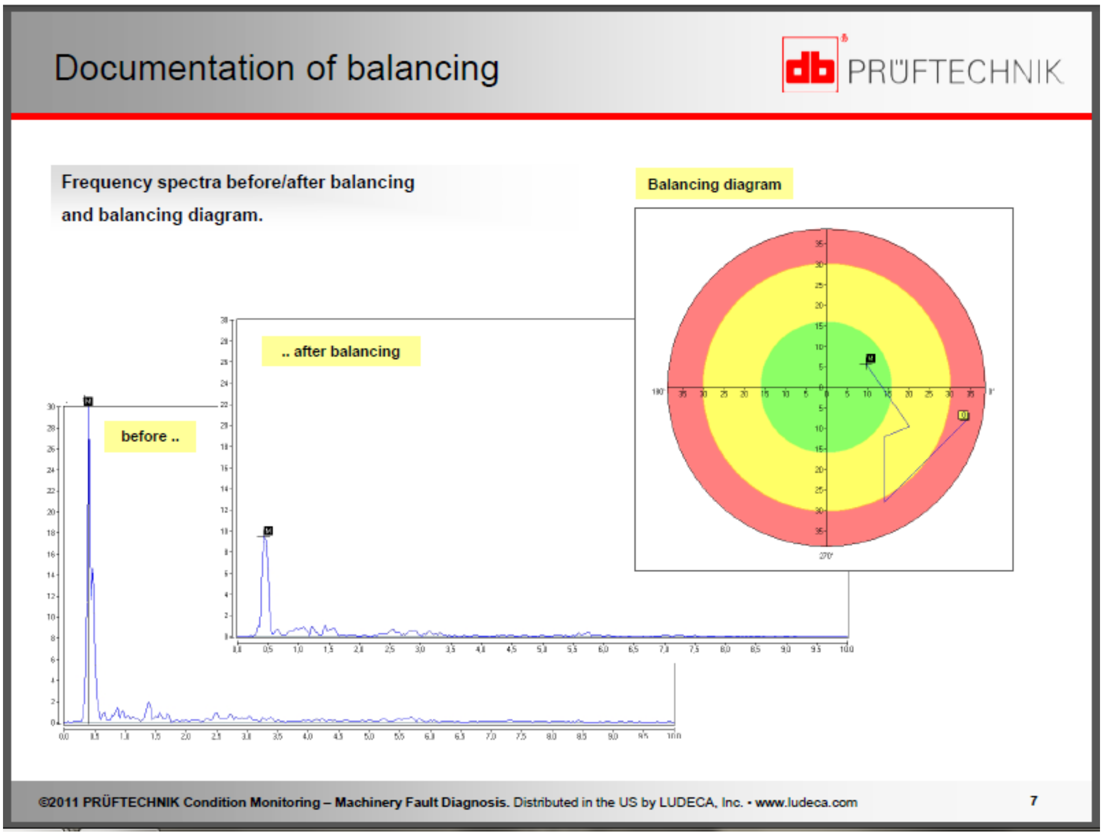
Image retrieved from http://www.reliabilitydirectstore.com/articles.asp?id=122

APPENDIX V: Unbalance Defect – LUDECA Machinery Fault Diagnosis

a)

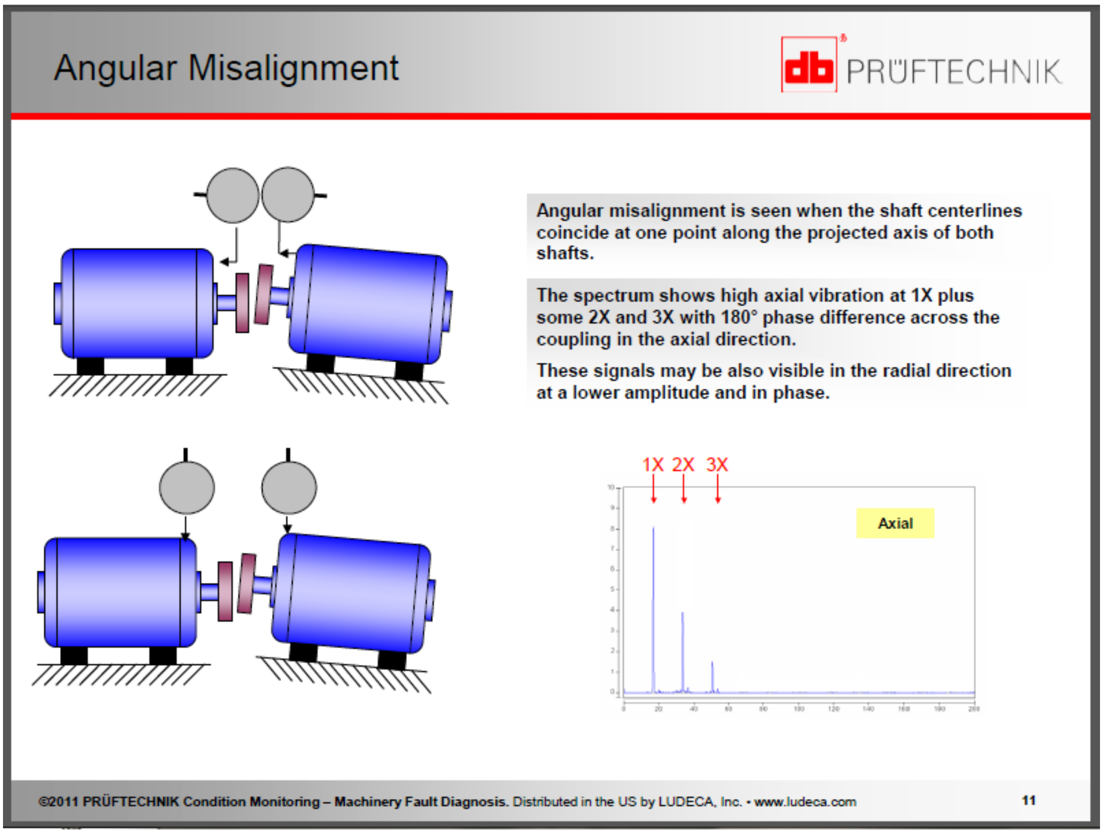


b)



APPENDIX VI: Misalignment Defect: LUDECA Machinery Fault Diagnosis

a)



b)