Experimental Study on Gas Turbine Engine Dynamics

by

Tengku Norhanisah Bt Tengku Kamaruddin

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
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Approved by,

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(Ir Idris B Ibrahim)

UNIVERSITI TEKNOLOGI PETRONAS
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September 2011

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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TENGKU NORHANISAH BT TENGKU KAMARUDDIN

ABSTRACT

Rotordynamic analysis has been widely used in turbomachinery design. The analysis includes analytical analysis, computational or simulation analysis and also throughout an experimental study. The process of study gas turbine's behavior has become one of the major aspects in its design and health condition monitoring. The analysis could help manufacturer to have further understanding on gas turbine rotordynamic in order to improve its efficiency and performance for a long run. The design of the rotor assembly is a proprietary item and therefore is not accessible to public. Using the industrial gas turbine and performing an experimental study on the gas turbine, the understanding and analysis of rotordynamic can be improved. This study focuses only rotordynamic analysis through an experiment. The objectives of this study is to study the concept of rotor dynamic and develop the rotor dynamic experimental studies based on previous journals. The experiment is conducted on a real size axial gas turbine using accelerometer and spectrum analyzer. The result is analyzed to find the critical speed of the gas turbine and the effect of speed to the gas turbine behavior. Using peak to peak analysis, the gas turbine is observed and concluded that as the speed increases, the amplitude of the gas turbine is also increases up to certain point.

ACKNOWLEDGEMENT

In the name of Allah S.W.T, The Most Gracious, The Most Merciful, all praises to Him for His gratitude, blessings and opportunity. The author would like to acknowledge the following parties for their help and support during the completion of the final year project:

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TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1
INTRODUCTION

1.1 Background study

Gas turbine is a power plant, which produces a great amount of energy for its size and weight. Gas turbine achieved a rapid advancement in today modern world, both among utilities and merchant plants as well as the petrochemical industry and utilities around the world. Thus, it is important to improve and optimize it usage for further advancement for future technology. One of the main aspects in gas turbine development is the rotor dynamic analysis. Many manufacturers in the past focused only on the capacity of the gas turbine while neglecting the effect of rotordynamic on the gas turbine efficiency.

Rotordynamic is a study of turbomachinery behavior and diagnosis of rotating structures. In this analysis, the vibration trending is observed and critical speed of the gas turbine in determined. Critical speed is important characteristic in determining the point or speed the gas turbine will experience excitation which caused vibration. Without having an understanding in the rotordynamic analysis, there would not be an improvement in turbomachinery design process. Thus, the performance of turbomachinery will not be optimized.

In this research paper, author will analyze the characteristic of gas turbine rotordynamic through the experiment. The experiment is conducted on a real-size radial gas turbine. Thus, through this studies and experiments, the author hope to have better understanding on gas turbine behavior and also to improve in future rotordynamic analysis.

1.2.Problem Statement

Rotordynamic analysis of turbomachinery specifically gas turbine had been major discussion over the years. Thus, understanding the rotordynamic of the gas turbine is very critical in developing the gas turbine engine predictive maintenance capability tool. The design of the rotor assembly is a proprietary item and therefore is not accessible to public. Using the industrial gas turbine and performing an experimental study on the gas turbine, the understanding and analysis of rotordynamic can be improved.

1.3. Objective

- Study the concept of rotordynamic.

  In order to carry out with the experiment, the most important aspect is to study is the concept of rotordynamic. By reading journals of previous works, the author could have a deeper understanding on the concept and also adapted with the previous analysis that have been done. This could also be cross reference to the author in outlining the methodologies to be used in this research paper.

- Develop the rotordynamic experimental studies.

  Once the author finally has an understanding on gas turbine rotordynamic concept, the next process is to outline the procedure to be used for the experiment. The procedure must be reliable and justify so that the result is accurate and acceptable to be analyzed. Then, the experiment will be carried out using the propose procedure.

- Provide parametric analysis.

  After the experiment is conducted, the author will provide the parametric analysis. The result from the experiment will then be used to be analyzed. The rotordynamic characteristic will be concluded through the result of analysis.

1.4. Feasibility of the project

The scope of this project is to understand the concept of gas turbine rotordynamic, to develop the rotordynamic experimental studies and to provide parametric analysis. The time frame given is approximately about 3 months to complete the project. The author believed that the project will be completed in the given time frame. The equipment and tools needed to conduct the experiment are all available and provided, thus there will not be much issues to be completed the project if the author follow the dateline in the Gantt chart accordingly.

CHAPTER 2
LITERATURE REVIEW

2.1 Critical analysis of literature

2.1.1 Gas Turbine

The advancement of turbomachinery in today modern world is moving rapidly. The most impressive example is NASA's space shuttle main engine turbopumps which produce 70, 000 hp in two turbine stages about the size of frisbee (Vance, 1988). The contribution of turbomachinery to the world is undoubted. From everyday usage of electricity to conquering the universe, turbomachinery is partly contributing. It is important to study the rotordynamic of these turbomachinery to improve the current technologies of turbomachinery and also optimize its efficiency.

Gas Turbine is one of Turbomachinery. Gas turbine being a turbomachinery is energy conversion devices that convert mechanical energy to thermal/pressure energy or vice versa.

Turbomachinery can be classified based on three categories (Peng, 2008):

a) Direction of energy transfer, either from mechanical to thermal/pressure or vice versa;
b) Type of fluid medium handled, either compressible or incompressible; and
c) Direction of flow through the rotating impeller, it can be axial, radial or mixed with respect to the rotational axis.

2.1.2 Rotordynamic

The discipline of rotordynamic is concerned with the free and forced response of structural system that contains high-speed rotating assemblies (Earl Logan, 2003). Earl emphasizes the dynamic characteristics of systems with rotor assemblies that spin normally about their longitudinal axes. Study on rotordynamic concerns on turbomachinery equipment namely gas turbine, pump, compressor, generator and etc. Rao stated that rotating machines can develop excessive stresses in torsion because of low torsional natural frequencies of the system involving flexible couplings (Rao, 1996). Thus the increasing demand for power and high speed transportation, the rotors of these machines are made extremely flexible. Another common source in rotordynamic is related to inertia of moving parts in the machine. The forces are usually periodic and therefore produce periodic displacement observed as vibration (John M Vance, 2010). Vance stressed that the property of turbomachinery which allows these high energy densities and flow rates to be accomplished is high shaft speeds. Along with high speeds come high inertial load and potential problems with shaft whirl, vibration and rotordynamic instability (Vance, 1988).

Rotor dynamic analysis is one of the important processes for turbomachinery design and construction. Data gather from this analysis can assist in selecting design parameters to avoid unstable regions of operation or large amplitude response within the operating range of the system. Study of rotor dynamic of gas turbine for example can be used in the preliminary design of a new system, in the redesign of an existing design or in determining the cause of undesirable response characteristic of an existing system (Earl Logan, 2003). Besides that, the analysis gives valuable information to assess the performance of a machine and continuously monitor its health. The use of vibration and noise measurement and their analysis is rapidly becoming a standard form of maintenance of rotating machinery (Rao, 1996). Vance in his book listed out five main objective of rotordynamic analysis which are to predict critical speed, to determine design modification, to predict natural frequencies of torsional vibration, to calculate balance correction masses and location from measured vibration data and to predict amplitudes of synchronous vibration caused by rotor imbalance (Vance, 1988).

Most of the analyses were done using analytical solution which are finite element or transfer matrix approach. However, in this particular research, the rotor dynamic analysis will be conducted through an experiment.

2.1.3 Experimental studies

Masayuki Kita proposed analysis method for rotor vibrations of a compressor train with gearbox from a perspective of coupled lateral and torsional vibration and his method is applied to evaluate an actual rotor vibration (Masayuki Kita, 2007). In his experiment, he used an actual size gas turbine with gearbox for analysis whereby the author will use an axial gas turbine with single stage compressor with no gearbox. Even though the type of turbine used is different but he is among a few that used a real size gas turbine in his study compared to others that use laboratory rig (Lees, 2004) (Changqing Bai, 2010).

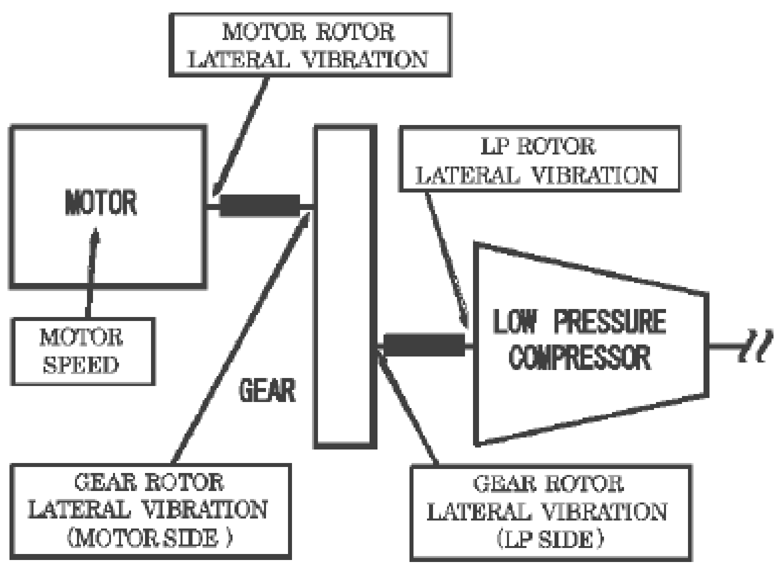


Figure 2.1: Measurement points in Gas Turbine with gearbox. **(Masayuki Kita, 2007)**

Unlike rig, conducting the analysis on the gas turbine could provide better analysis in order to understand the rotordynamic behavior. The rig did not provide with compressor and turbine blades, thus the result may not be as accurate as it should be. The gas turbine will be running on varies load as dynamic force can only be observed when the gas turbine experience different load. If the load is constant, the force will not be dynamic but static force. The variable for this experiment is the speed of the rotor (Changqing Bai, 2010). Maximum speed for this turbine is 1500 rpm and the speed will be increased from 500 rpm, 1000 rpm until 1500 rpm.

In critical speed analysis, gas turbine will be run from rest until maximum speed in order to identify at which point the amplitude is high and could be the possible the possible point for critical speed. The most widely used method for measuring critical speed is done during a startup or shutdown (John M. Vance, 1984). The vibration signal dor any suitable pickup can be fed through a synchronous tracking filter allowing a plot of synchronous vibration as a function of running speed. The critical speed is then identified by the peaks on this plot (John M. Vance, 1984).

The gas turbine will also be attached with magnetic accelerometer. At each point, two accelerometers will be placed to analyze the axial and lateral force (V. Hariharan, 2010). Besides Hariharm, Gareth L. Forbes in his study also used accelerometer to capture vibration. Randall proposed the used of accelerometer in gas turbine monitoring as it allows the measurement of signals with a frequency range of more than three decades with very good dynamic range. Such a range can be necessary to detect the full range of possible faults (Randal, 2004). This accelerometer will be connected to data acquisition system whereby the data is store.

In conclusion, rotordynamic study is an important aspect in turbomachinery design. Thus, this paper will further study the characteristic of gas turbine rotordynamic.

2.1 Number of references

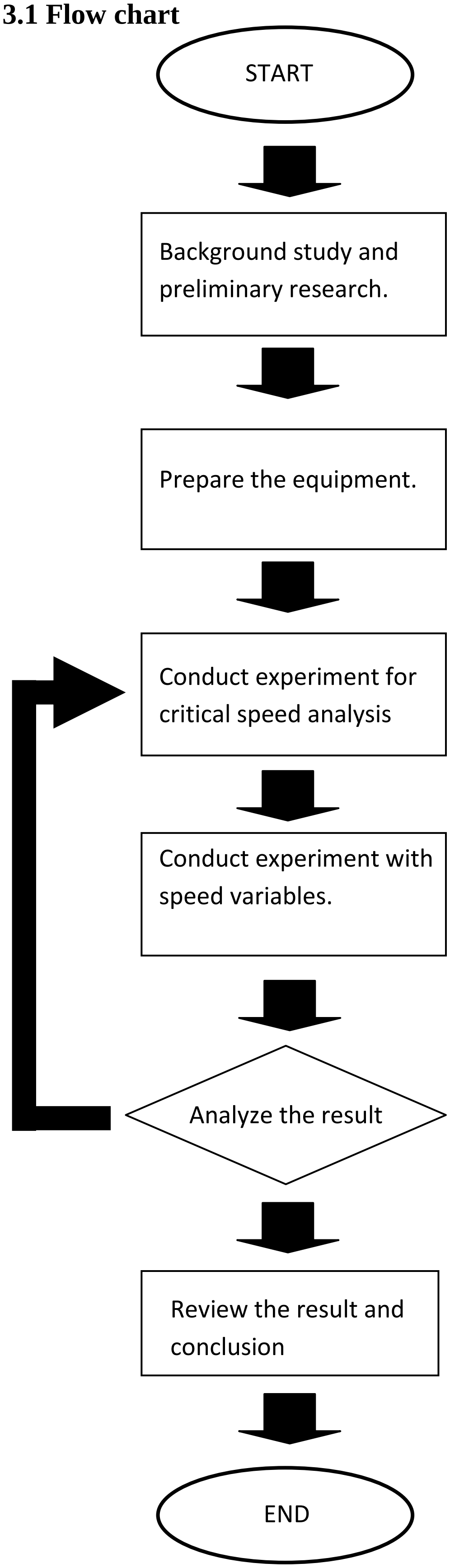
Table 2.1: Number of references

No	Author	Title	Objective	Method	Result
1	Masayuki Kita, Takeshi Hataya, Yasunori Takimasa	Study of Rotordynamic analysis method that considers torsional and lateral coupled vibration in compressor trains with gearbox. (2007)	To introduce rotor dynamic analysis method that is based on couple torsional and lateral vibration system	A spectral analysis is performed obtaining vibration measurement data on each part of the train during load operation. The vibration component of the rotating speed and its harmonic were observed at each spectrum.	The response ration of torsional and lateral vibration almost corresponds with the analytical result in actual measurement data which include various measured errors. Therefore, it is possible to estimate the torsional vibration level with data from the shaft vibration probe.
2	Changqing Bai, Hongyang Zhang, Qingyu Xu	Experimental and Numerical studies on nonlinear dynamic behavior of rotor system supported by ball bearings. (2010)	To investigate the nonlinear dynamic performance of rotor system using experiment and numerical approach	Four eddy current probes are attached closed to disk and bearings rig. The inputs from the probes are analyzed through data acquisition with 8 channels simultaneously. The sampling rate is 500 kHz maximum and sample size is 12 bits.	Numerical and experimental results show the subharmonic resonance not only cause severe vibration and strong noise but also induce the rotor to lose stability and damage
3	A W Lees, E D Price, M I Friswell	Identification of rotor dynamic machinery – a laboratory trial. (2004)	To validate the methods developed for the estimation of foundation parameters, shaft and bearing condition, alignment and unbalance distribution.	A rig with a single rotor on two bearings was used in the experiment. Three accelerometers and two proximity probes are attached on the rigs. The data analysis software developed using LABVIEW and calculation using MATLAB.	The main key of this analysis is the bearing forces of the turbo machinery. It is shown that there are substantial differences in the behavior of two nominally identical bearings.

4	V. Hariharan, P.S.S. Srinivasan	Vibrational Analysis of Flexible Coupling by Considering Unbalance. (2010)	To predict the vibration spectrum for rotor unbalance.	A self-designed simplified 3 pin type flexible coupling was used in the experiments. The rotor shaft accelerations were measured at four different speed using accelerometer and dual channel vibration analyzer (ADASH) under the balance (baseline) and unbalance conditions.	The experimental predictions are in good agreement with the ANSYS results. Both the experimental and numerical (ANSYS) spectra show that unbalance can be characterized primarily by one times (1X) shaft running speed.
5	Gareth L. Forbes, Robert B. Randall	Gas Turbine Casing Response to Blade Vibrations: Analytical and Experimental results. (2009)	To verify various aspect of analytical modeling procedure using experimental on commercial gas turbine.	The test rig consists of a 19 flat blade rotor arrangement driven by an electric motor. A microphone and accelerometer are located in the vertical plane above the blade on the casing. Measurements were taken with a shaft rotational speed of 2000 rpm, and analyzer sampling rate of 65.536 kHz of which the useful frequency range is 25.6 kHz.	Results for the simulated pressure signal shown here and in previous work have been shown to contain the same signal features as those which have been measured, namely; discrete peaks at multiples of shaft speed and narrow band peaks at multiples of shaft speed and blade natural frequency.

CHAPTER 3
METHODOLOGY

3.1 Flow chart



Deeper understanding is needed before continuing with the project. The important part is to understand rotordynamic analysis

The methodology for the project is outlined in order to identify which equipments to be used in the experiment.

Once the methodology is finalized, the experiment can be conducted using the proposed experimental set up.

The experiment is conducted for 2 analyses which are critical speed analysis and speed variables analysis.

The result taken from the experiment will be analyzed. If the result shows any fault or invalid, the experiment will be conducted again.

When the result is finalized, there will be discussion regarding the result and the result will be validated.

3.1.Project activities

Methodologies in this experiment is developed to comply with objectives that been stated in previous chapter.

1) **To study the concept of rotordynamic.**

In order to achieve the first objective, the author needs to do some background study on the concept of rotordynamic. Background study helps the author to have better understanding on the subject thus the author can plan the whole process of the project through a gantt chart. During preliminary research, it is found out that most study was done using analytical solution. This is whereby the gas turbine was model in software simulation and the result was predicted using the simulation.

The first step is to study the general concept of rotordynamic. Here, the author mainly refers to textbook by Earl Logan entitled Handbook of Turbomachinery, J.S. Rao entitled Rotor Dynamics and John M Vance book's entitled Rotordynamic prediction in engineering. All these books help the author to have basic understanding on rotordynamic and its analysis.

Following that, the author also read and study the journals of previous works related to gas turbine rotordynamic study. During this phase, the author outlined the methodologies used by other researchers and tries to find the best method. However, not much analysis was done using experimental on the real-size gas turbine. Most of the analysis were simulated or done on a test rig. Using all these references, the author developed the methodologies for this experimental study.

2) **Develop the rotordynamic experimental studies.**

There are two main analyses in this study:

1. Rotordynamic analysis of gas turbine's critical speed.
2. Rotordynamic analysis of gas turbine with variables speed.

The analyses are conducted separately because of different variables and conditions observed for each however the experimental set-up is the same.

Experimental Set-up (refer figure 2):

1. Prepare the equipment to be used. Refer table 2 for list of equipment.
2. Assemble accelerometer with the wire and connect to data acquisition system.
3. Attach accelerometer to the gas turbine. Since there are only 8 channel in the DAQ, only 4 point are taken on the gas turbine. One point requires two accelerometers for axial and radial axis.
4. Switch on the gas turbine and observe the graph of acceleration. Identify the critical speed of gas turbine before reaching its operating speed.
5. Repeat the experiment with fix speed while varying the load. Approximately, there will 4 different loads taken.
6. Repeat again the experiment with fix load while varying the speed. The maximum speed of the gas turbine is 3000 rpm, thus approximately there will be 3 to 4 data.
7. Turn off the gas turbine every 20 minutes to avoid over-heating.

Figure 3.1: Diagram of radial gas turbine with single stage compressor

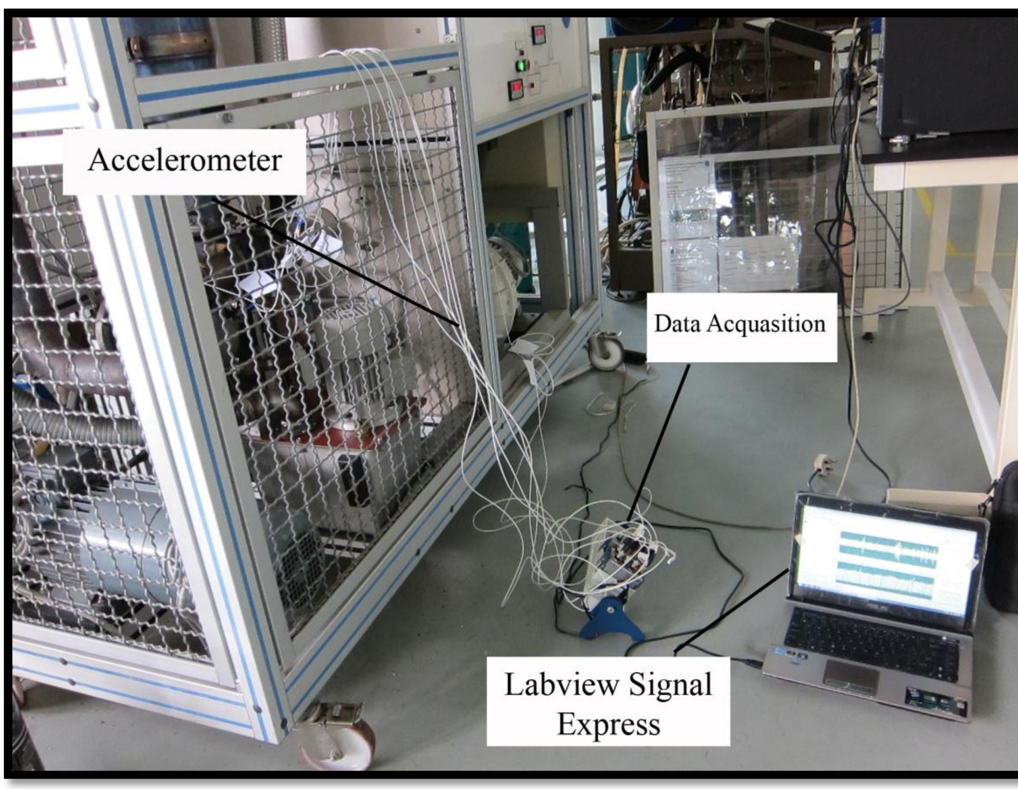


Figure 3.2: Experiment set up

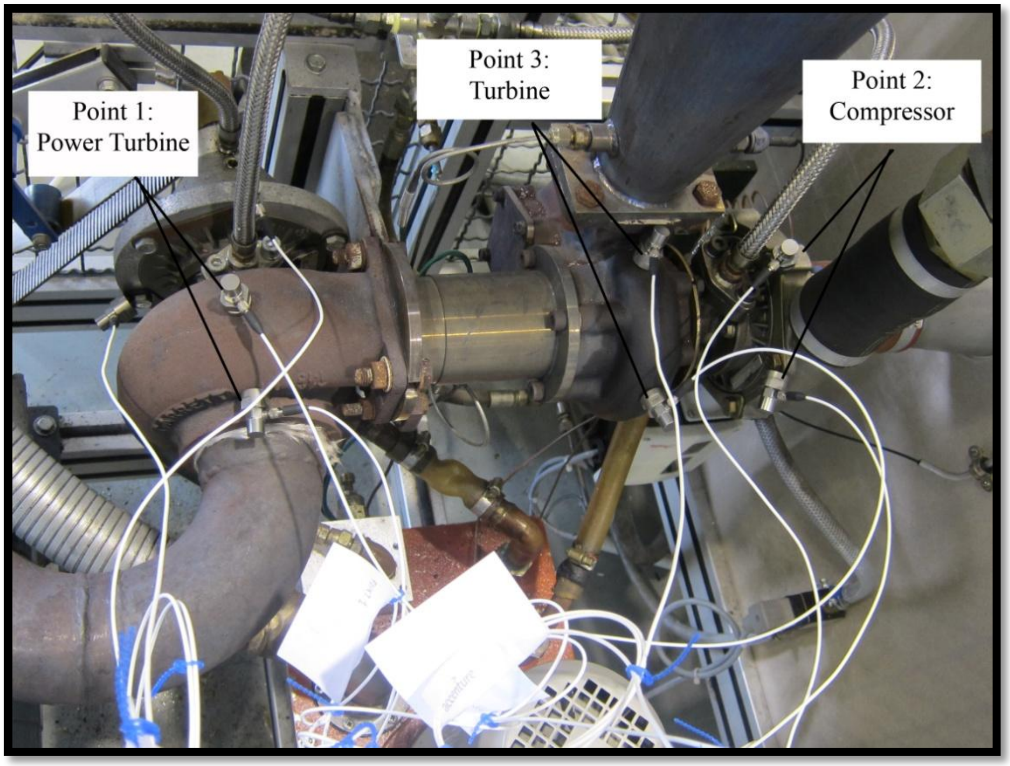


Figure 3.3: Three measurement points in this experiment

3) Provide parametric analysis.

In Labview Signal Express, the data are view in acceleration versus time which is basically in time domain. However, the data can be sent to be analyzed into power spectrum or filtering. Using graphic, the data can be better analyzed and understood. The purpose of this project is to have more understanding on gas turbine rotor dynamic. The graphic will help the author to observe the trending of the gas turbine.

In critical speed analysis, the parameter is still speed. The speed will be increased from steady state until it reaches an idling speed. The estimation idle speed is 1500 rpm. During the experiment, the trend is observed to estimate the point of critical speed.

3.2.Tools and equipments

There are tools and equipments need to be used during the entire experiment. All these tools and equipments are available at Universiti Teknologi PETRONAS. Below is the list of the tools and equipments use:

Table 3.1: List of Equipment

No	Item	Description
1	Gas Turbine	Gas Turbine is a type of internal combustion engine. The gas turbine that is going to be used in this project is radial gas turbine with single stage compressor.
2	Accelerometer	An accelerometer is an instrument for measuring acceleration, detecting and measuring vibrations. This accelerometer will be placed on the gas turbine to measure vibrations.
3	Labview Signal Express	Measure the frequency response, noise and distortion characteristics. This oftware is used to observe the frequency of the gas turbine.
4	Data Acquisition system	Data acquisition is the process of sampling signals input from the sensors. This system helps to record various data upon certain period of time.

CHAPTER 4
RESULT & DISCUSSION

4.1 RESULT OF EXPERIMENT

4.1.1 Critical Speed Analysis

The critical speed of a rotor is an operating range where turning speed equals one of its natural frequencies. This amplitude is commonly excited by unbalance of the rotating structure. If a rotor is operated at or near a critical speed, it will exhibit higher vibration levels, and is likely to be damaged. It is important to determine the critical speed of rotating equipment as it is where the amplitude is high. However, the data and parameter needed to calculate critical speed is not available, thus it is assumed through the experiment.

In order to identify the critical speed that caused high amplitude, the gas turbine was run from rest (steady state) until it reaches maximum speed. For the gas turbine that is used in this experiment, the maximum speed 1600 rpm. The graph established in spectrum analyzer will be reproduced as the scale is too big. The same data is transferred to Microsoft excel and new graph is produced using the same data. The data are available up to 25 hertz because the gas turbine is only run until 1600 rpm.

Figure 4.1 shows spectrum result of power turbine. Two accelerometers were attached to the shaft bearing located near to power turbine. In vertical and horizontal axis, the amplitude is high because it was in the start-up mode. As can be seen, the amplitude excite at the frequency of 5 hertz (300 rpm) at both axis.

The second point (Figure 4.2) that was taken on the gas turbine is at the shaft bearing of compressor. The data for vertical and horizontal axis show huge margin. However, it still can be seen that there is excitation at the frequency of 5 hertz. This shows a pattern in this spectrum analysis.

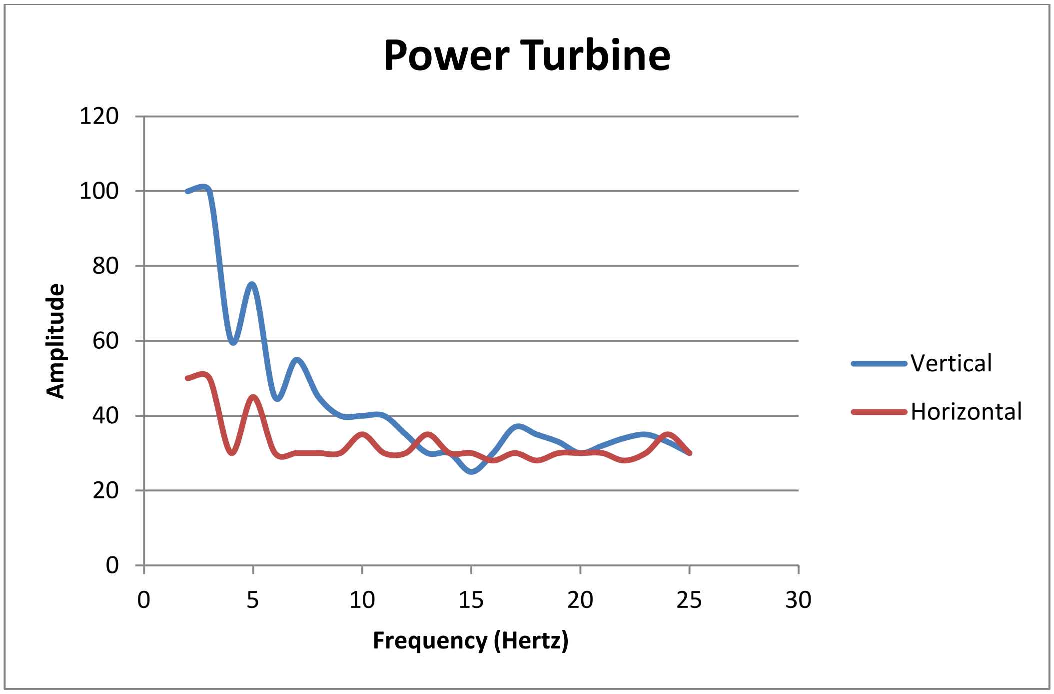


Figure 4.1: Spectrum Analysis for Power Turbine

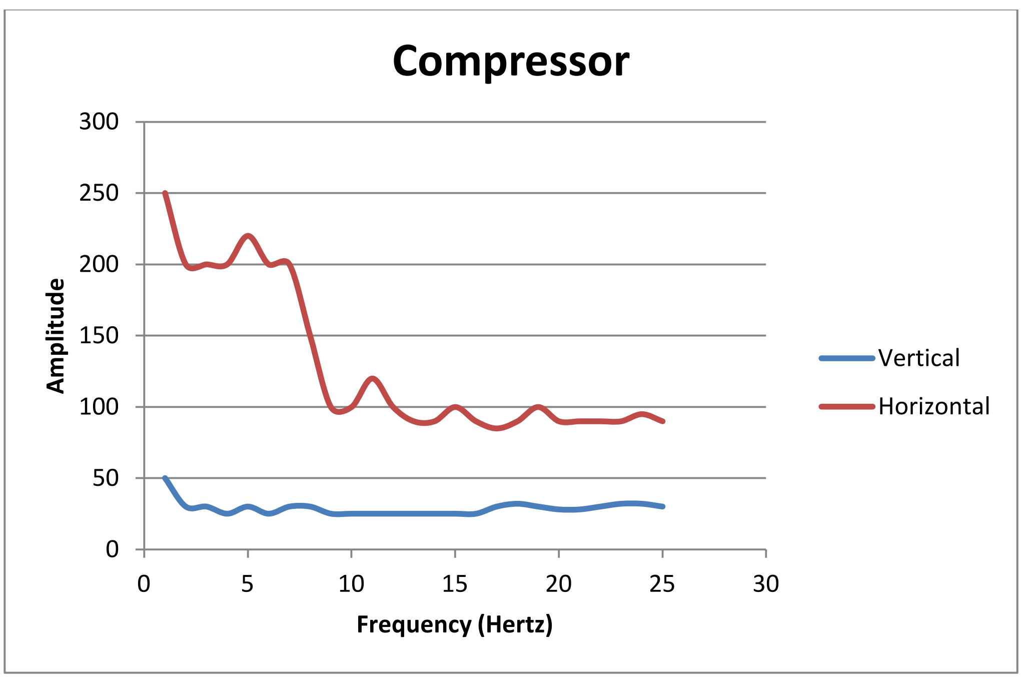


Figure 4.2: Spectrum Analysis for Compressor

The third point (Figure 4.3) is located at the shaft bearing near to the turbine. Amplitude value at 3 hertz shows the higher value. This could mean that the critical speed for that point is at 3 hertz (180rpm). Critical speed for the gas turbine could be more than one and this could be the first point for the gas turbine critical speed.

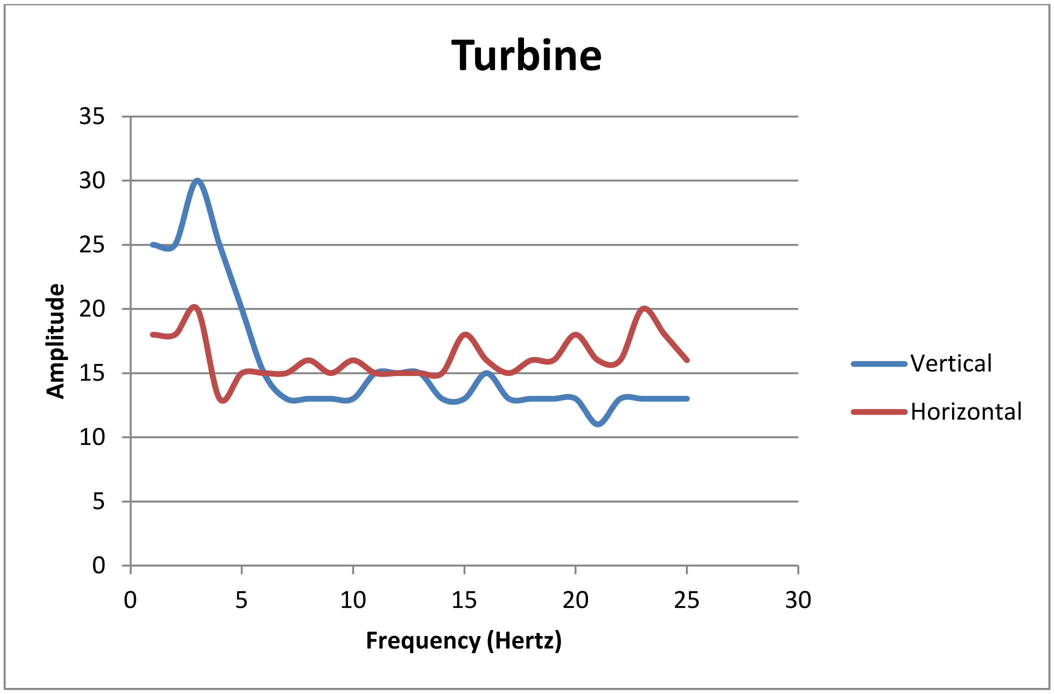


Figure 4.3: Spectrum Analysis for Turbine

Next, the author would like to include comparison between the three points at horizontal and vertical axis. The comparison between the three points at the same axis might help the author to identify if there is any significant pattern. The comparison at each axis can be observed in Figure 4.4 and Figure 4.3.

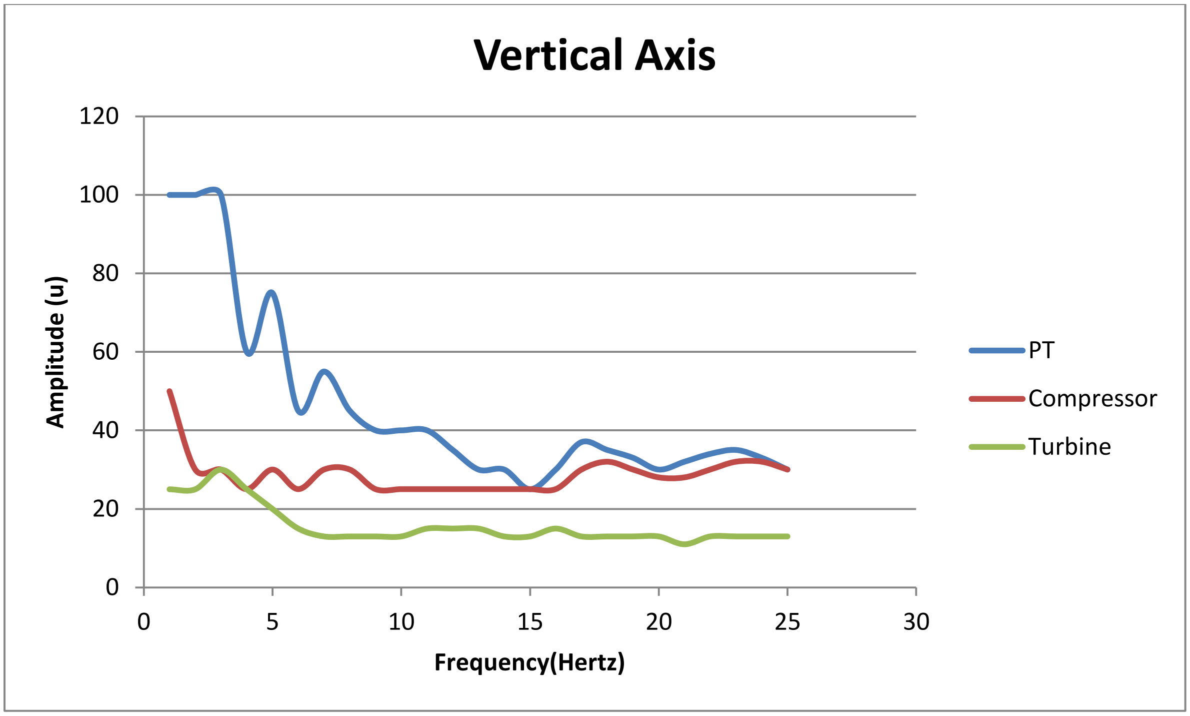


Figure 4.4: Spectrum Analysis for Vertical Axis

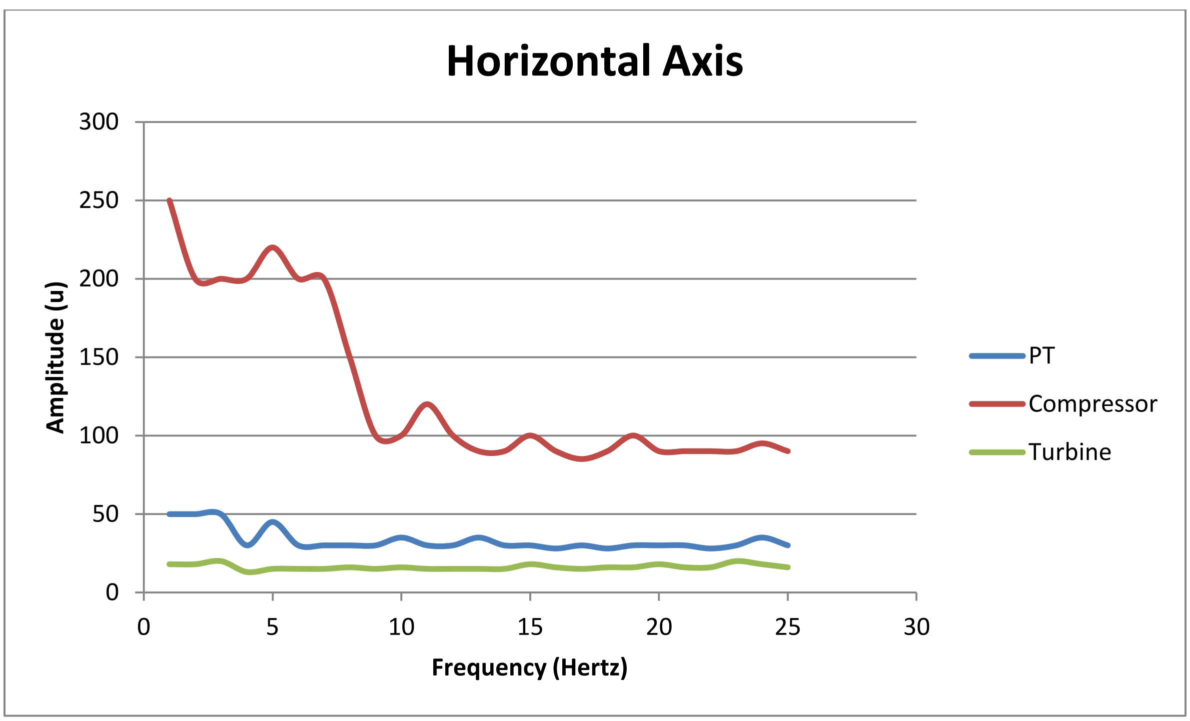


Figure 4.5: Spectrum Analysis for Horizontal Axis

4.1.2 Speed variables analysis

Speed variables analysis is the second analysis done in this project. The purpose of this analysis is to see the effect of different speed to the amplitude. The data were taken at three different speeds which are 500 rpm, 1000 rpm and 1500 rpm. The data is calculated using Peak to Peak in order to be better analyzed. Peak to Peak analysis is calculated by finding the maximum peak and divided with the minimum peak.

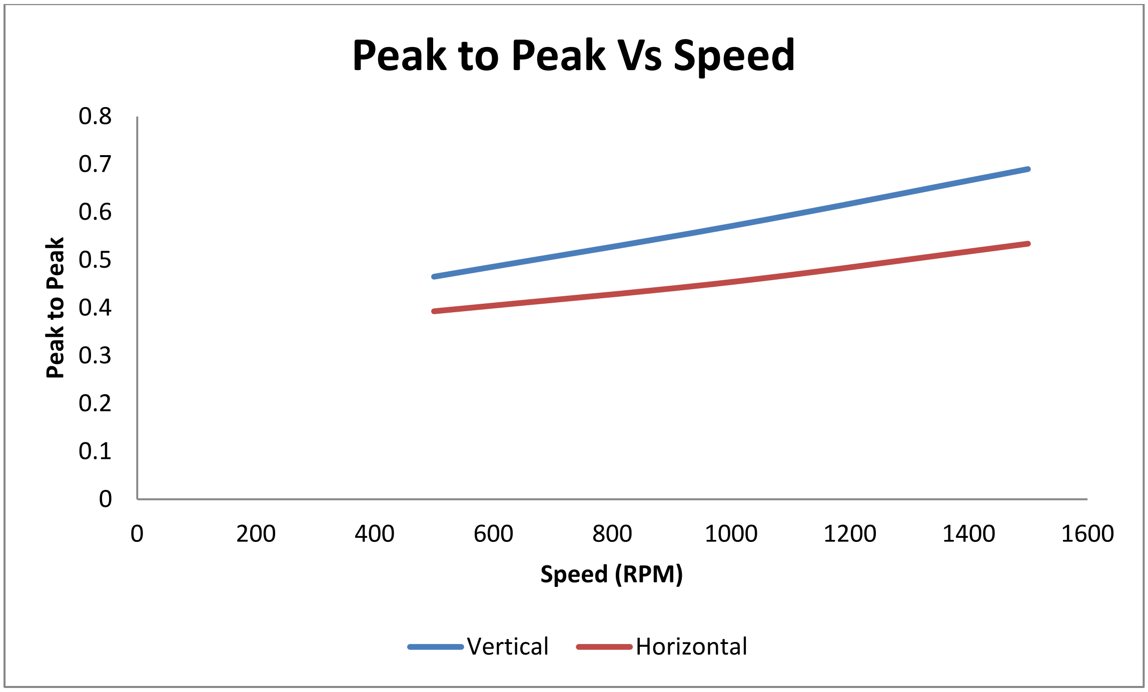


Figure 4.6: Peak to Peak Vs Speed for Power Turbine

As can be seen, the amount of amplitude is proportional to the incensement of the speed. However, the horizontal axis shows lower value than the vertical axis. This might due to the fact that the shaft is moving vertically than horizontally.

At compressor (refer Figure 4.7), the graph is a little bit different where the value in horizontal axis much higher than vertical axis. Even though the margin between the two is not high, it could still be a good assumption that the shaft is moving more in horizontal position rather than vertical position.

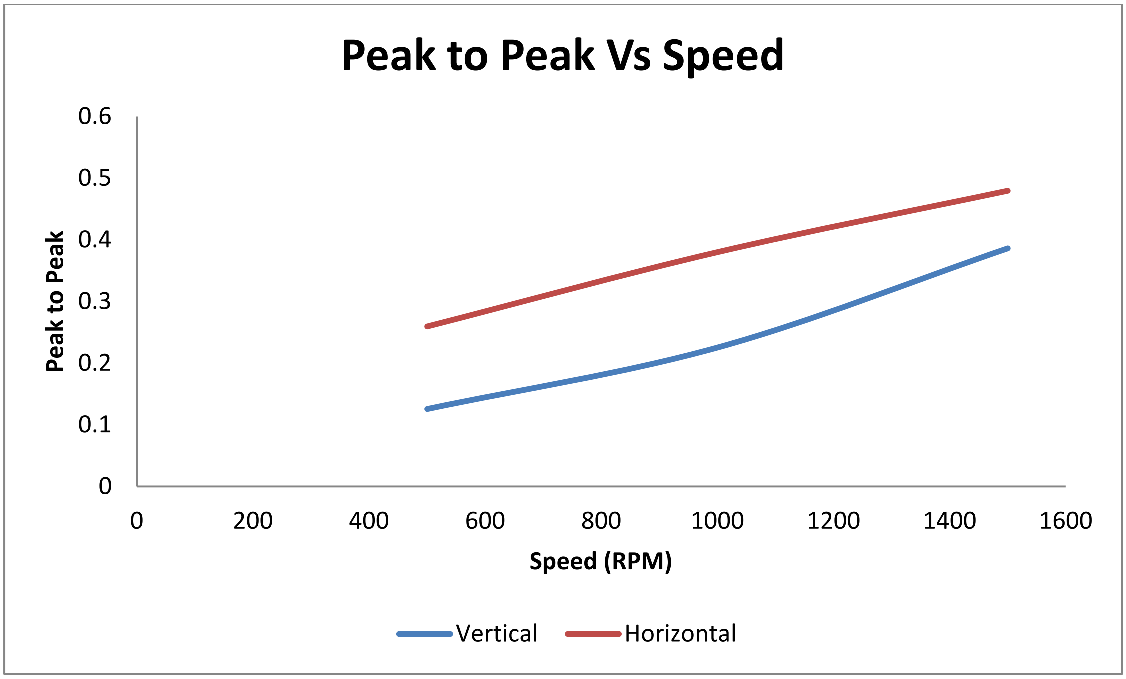


Figure 4.7: Peak to Peak Vs Speed for Compressor

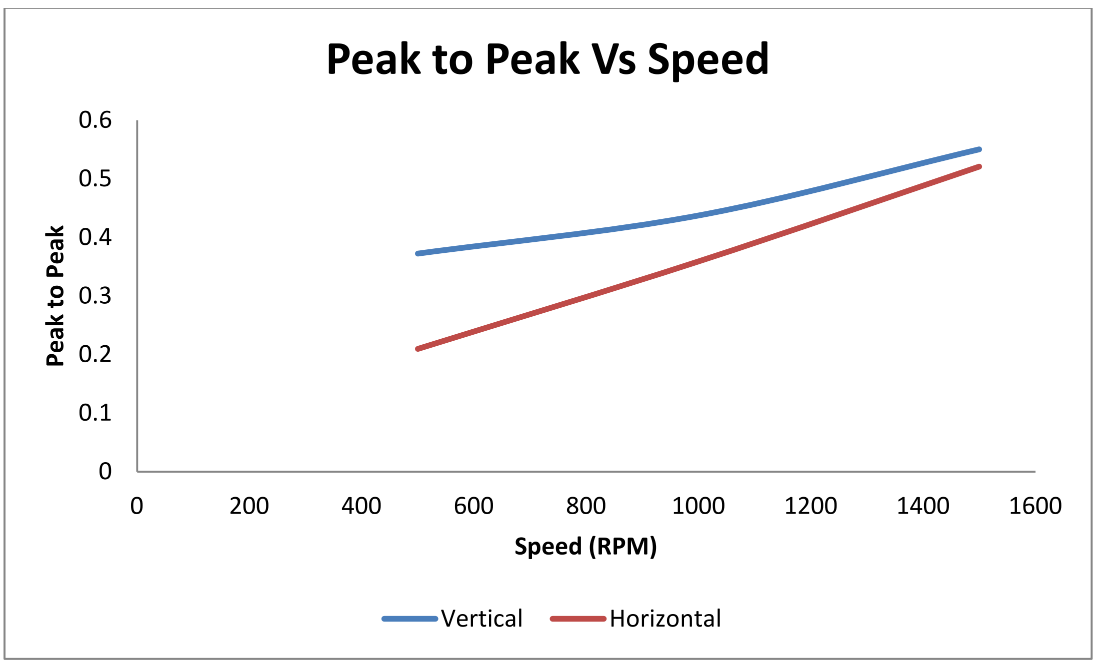


Figure 4.8: Peak to Peak Vs Speed for Turbine

Based on above figure, the value of amplitude is proportional to the speed. The margin between vertical and horizontal axis are closed, probably because the shaft rotate at the center compared to the previous one.

The author would also like to include comparison between the three points at horizontal and vertical axis. The comparison between the three points at the same axis might help the author to identify if there is any significant pattern. The comparison can be seen on Figure 4.9 and Figure 4.10.

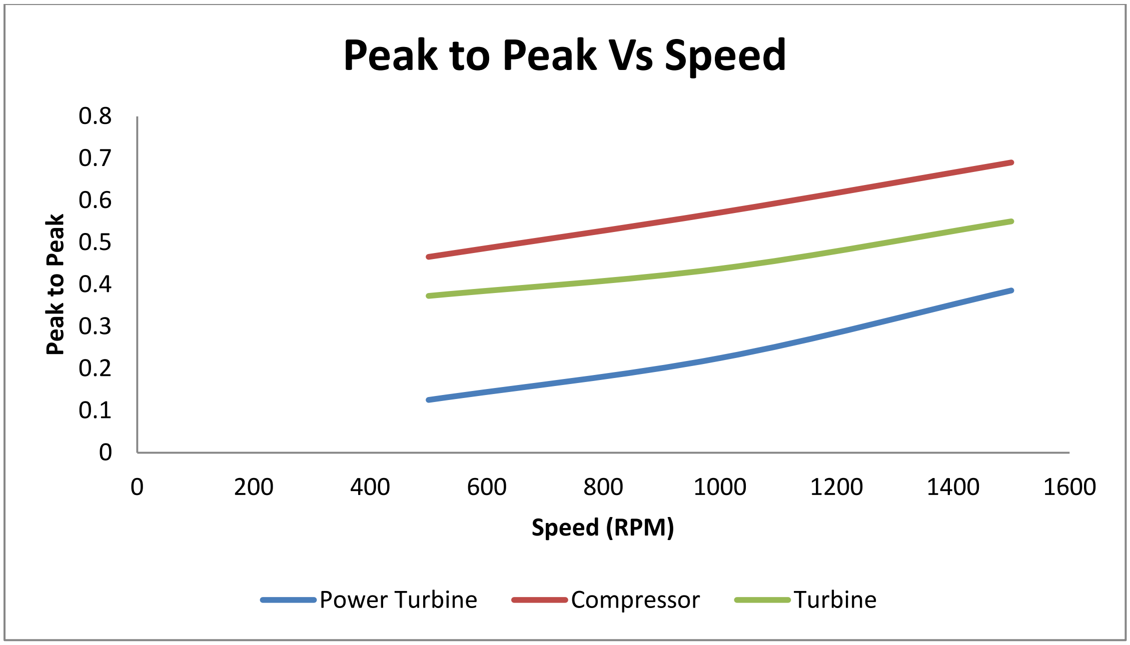


Figure 4.9: Peak to Peak Vs Speed for Vertical Axis

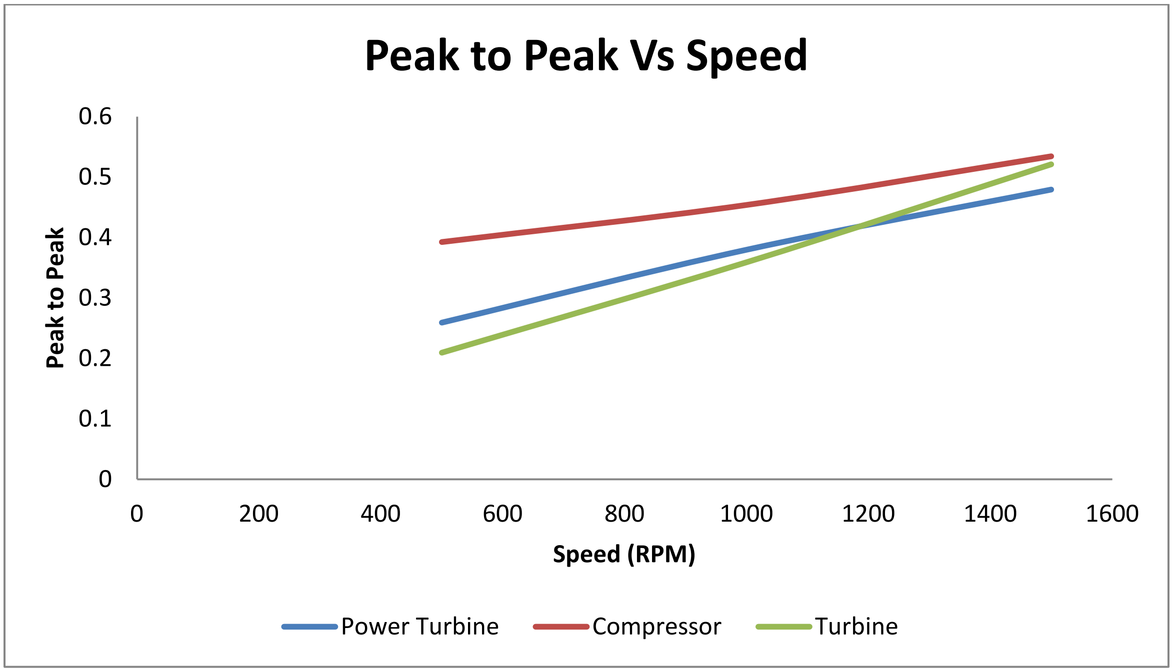


Figure 4.10: Peak to Peak Vs Speed for Horizontal Axis

4.2 DISCUSSION

Single stage gas turbine used in this project has a basic configuration as in Figure 4.11. A shaft is connected between the Compressor and Turbine. In order to hold the shaft, there will bearings at the compressor and shaft. However, due to load, the shaft is due to deflection. Through the experiment and analysis, the author tried to make assumption on the shaft deflection.

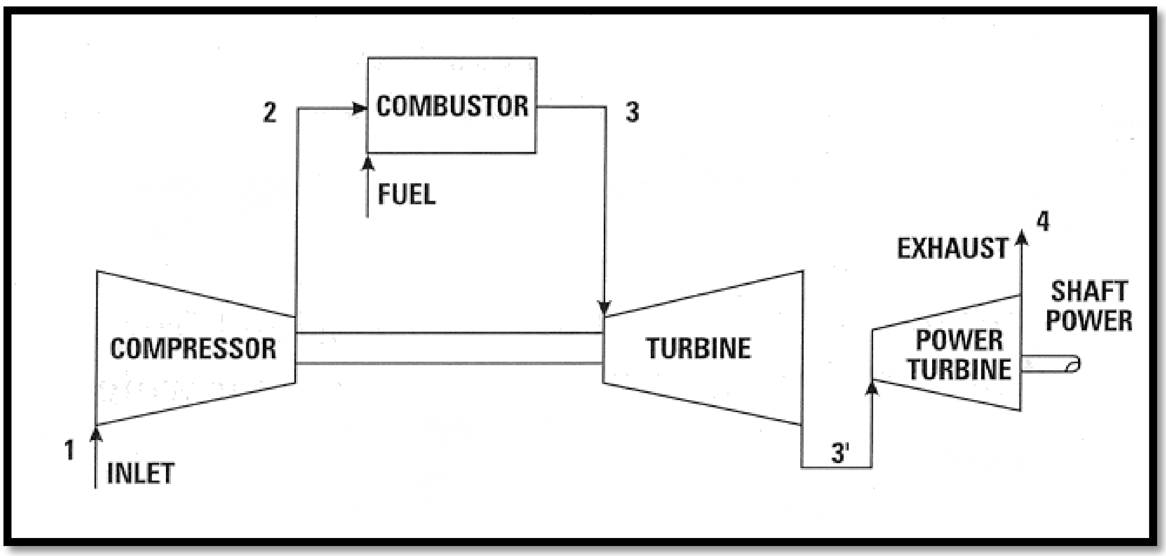


Figure 4.11: Shaft configuration in typical gas turbine

In critical speed analysis, the critical speed that been identified are as follow:

Table 4.1: Critical speed for each component

	Power Turbine	Compressor	Turbine
Frequency (Hertz)	5	5	3
Speed (RPM)	300	300	180

During these speed, the amplitude is observed to be the highest. Since the maximum speed for this gas turbine is only 1500 rpm, the critical speed taken is acceptable. There is other frequency where the amplitude shows some peak but it does not consistent at every point, thus it does not included as critical speed in this project.

It is observed in the critical speed analysis that there are certain points are having high amplitude while the others are having low points which lead to a high margin between the two. This could possibly happen because of the shaft deflection. In the graph between Power Turbine, Compressor and Turbine, the horizontal and vertical axis for compressor shows huge difference amplitude.

The data for Horizontal axis is in range of 100 to 200 while the data for Vertical axis is only between 0 and 50. This could indicate that at this point, the shaft moves horizontally and not in the centre compared to Power turbine and Turbine.

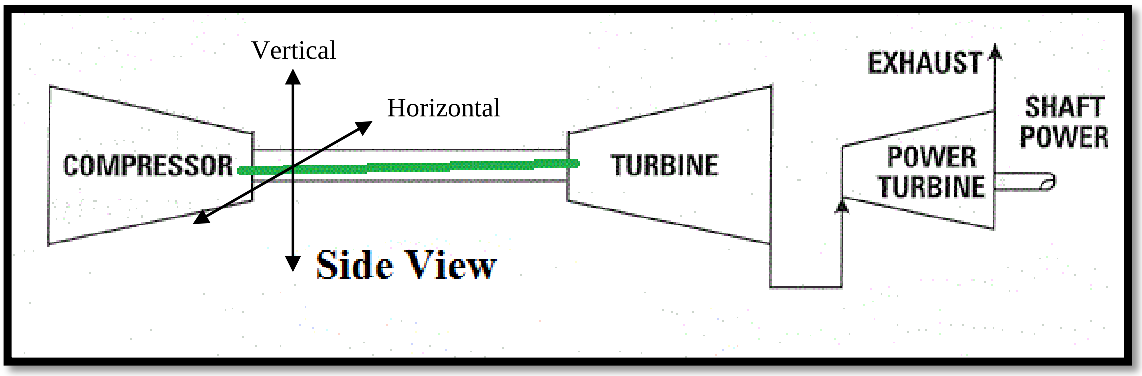


Figure 4.12: Shaft deflection in gas turbine

The assumption for the position of the shaft is not centered as at the point of compressor, the shaft probably at much lower position than the center itself. Since the amplitude range for horizontal axis is quite high, is can also assumed that the shaft is position more towards the right where the accelerometer is attached. The shaft at Turbine is assumed to be at the center as the amplitude for both axes are almost in the same range. The same assumption can be made at power turbine as the amplitude value at these points did not show much different.

In speed variables analysis, natural frequency for each speed is calculated, however there is no significant peak (amplitude) shows in the spectrum analysis. This could be due to the scale used in the spectrum is too big when the frequency that is used in this experiment is small. However, the author takes the data for peak to peak analysis. In this analysis, the different between maximum and minimum peak is calculated and it is plotted against the different speed where the data is taken.

As can be seen in the result section, the amplitude is increasing proportional to the speed. When the speed is increased, the amount of load is also increasing because it is dynamic load. If the load is fixed, it would be considered as static load while the project is for dynamic load. As the speed increase, the amount of noise will also increase. This could be one of the causes for high amplitude. Besides that, if there is miss-alignment in the shaft, it could also cause high vibration at higher speed.

CHAPTER 5
CONCLUSIONS & RECOMMENDATION

4.1 CONCLUSION

In conclusion, the study of gas turbine rotordynamic using experimental study is one of possible solution to understand behavior of gas turbine. In this study, the design data of gas turbine are not available. However, the analysis is done using experimental study. Based on the result, the shaft is found out to not to be at the center. The shaft is positioned more to the left at the point of compressor. Besides that, based on peak to peak analysis, the amplitude of the gas turbine is proportional to the speed of the gas turbine. The final result from this project is acceptable with few recommendations for future analysis. It is proven that the three objectives from this project are achieved.

4.2 RECOMMENDATION

There are few recommendations that can be proposed for this project for future expansion and continuation. Most of the studies were done by making comparison of analytical and experimental result. By comparing these two methods, it could improve the accuracy of the study. However, analytical method is not used in this study because the design of the rotor assembly is a proprietary item and therefore is not accessible to public. In the future, if the data of the rotor is available, the study could be elongated with both methods. Hence, the experimental method can be proven to be accurate.

Besides that, for better accuracy the proposed equipment to be used proximity probes where it can gain the displacement between the shaft and the bearing. Accelerometer that been used in this project is acceptable but the result could be improved by using proximity probe that has been used in other journals.

REFERENCES

Changqing Bai, H. Z. (2010). Experimental and numerical studies on nonlinear dynamic behaviour of rotor system supported by ball bearings. *Journal of engineering for gas turbine and power* , 1-5.

Earl Logan, R. R. (2003). *Handbook of Turbomachinery.* CRC Press.

Fabrega, F. M., Rossi, J. S., & d'Angelo, J. V. (2010). Exergetic analysis of the refrigeration system in ethylene and propylene production process. *Energy , 35* (10), 1224-1231.

Gareth L. Forbes, R. B. (2009). Gas Turbine casing response to blade vibrations: Analytical and experimental results. *Australian International Aerospace Congress 13th* .

John M Vance, F. Y. (2010). *Rotordynamic prediction in engineering.* John Wiley and Sons.

Lees, A. W. (2004). Identification of rotor dynamic machinery - a laboratory trial. *Vibrations in rotating machinery* , 373-382.

Logan, J. E., Kadambi, V., & Roy, R. (2003). Introduction. In J. E. Logan, & R. Roy, *Handbook of Turbomachinery* (2nd ed., pp. 1-35). Marcel Dekker, Inc.

Marconcini, M., Rubechini, F., & Ibaraki, S. (2008). Numerical Investigation of a Transonic Centrifugal Compressor. *Journal of Turbomachinery , 130*, 1-9.

Masayuki Kita, T. H. (2007). Study of Rotordynamic analysis method that considers torsional and lateral coupled vibration in compressor trains with gearbox. *Proceedings of the 36th of turbomachinery symposium* , 31.

Missirlis, D., Yakinthos, K., Storm, P., & Goulas, A. (2007). Modeling pressure drop of inclined flow through a heat exchanger for aero-engine applications. *International Journal of Heat and Fluid Flow , 28*, 512-515.

Moran, M. J., & Shapiro, H. N. (2006). *Fundamentals of Engineering Thermodynamics* (5th ed.). John Wiley and Sons, Inc.

Peng, W. W. (2008). *Fundamentals of Turbomachinery.* John Wiley & Sons, Inc.

R. Dufour, J. D. (1995). Transients and steady state dynamic behaviour of single stage compressor: prediction and experiments. *Journal of sound and vibration* , 23-41.

Randal, R. B. (2004). State of the art in monitoring rotating machinery. *Sound and Vibration* , 14-24.

Rao, J. S. (1996). *Rotor Dynamics.* New Age International.

Vance, J. M. (1988). *Rotordynamics of turbomachinery.* Wiley.

Meherwan P. Boyce (2002). *Gas Turbine Engineering Handbook*. Gulf Professional Publishing

Rama S. R. Gorla, Aijaz A. Khan (2003*). Turbomachinery: Design and Theory*. CRC Press

http://ezinearticles.com/?How-does-an-Accelerometer-Work?&id=285604

http://www.iitr.ac.in/outreach/web/CIRCIS/UG/DMM/Practical%20sessions.pdf

http://www.mate.tue.nl/mate/pdfs/7768.pdf

http://www.york.cuny.edu/~washton/student/Org-Behavior/lit_rev_eg.pdf

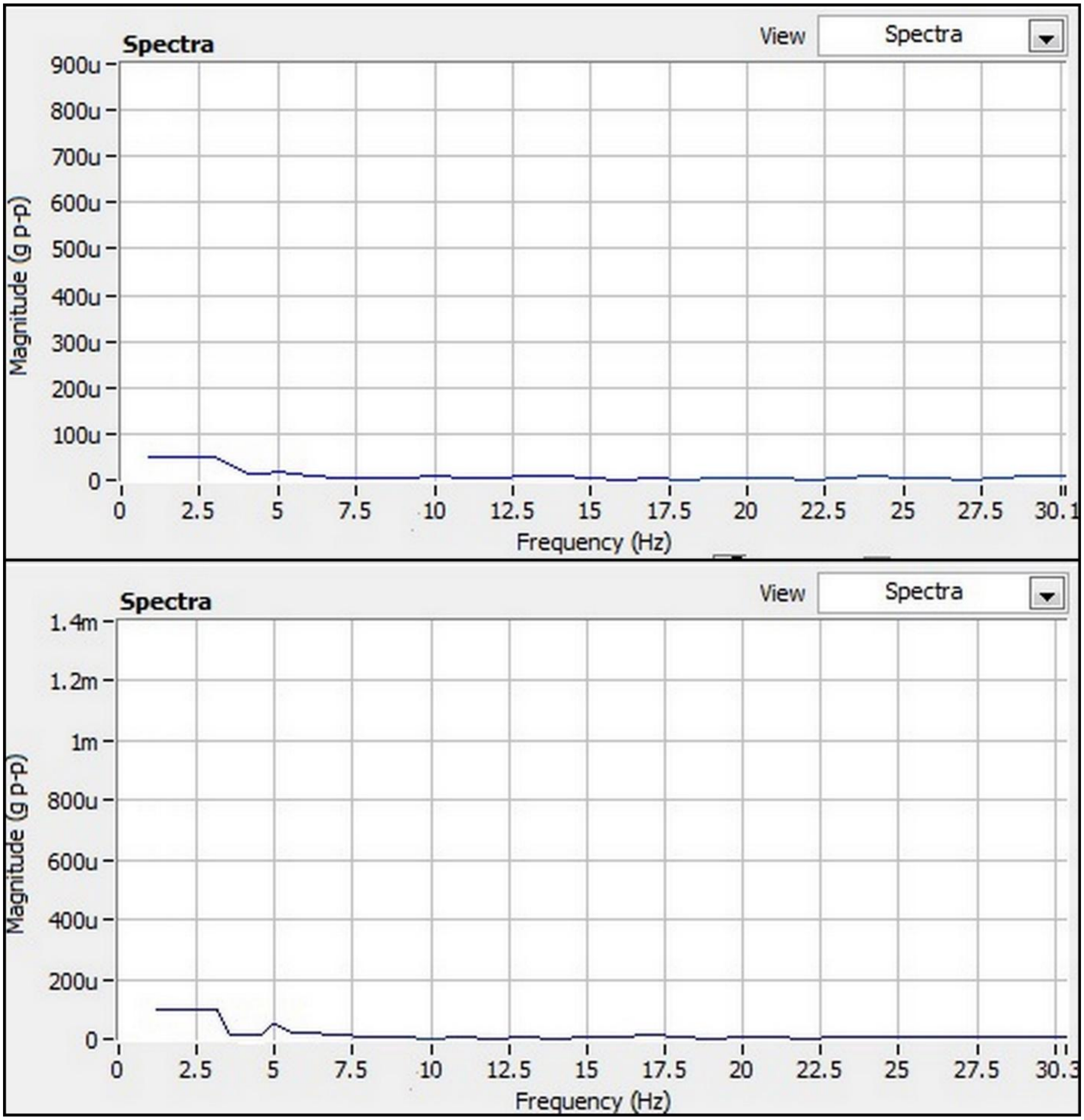
Appendix I

Gantt Chart

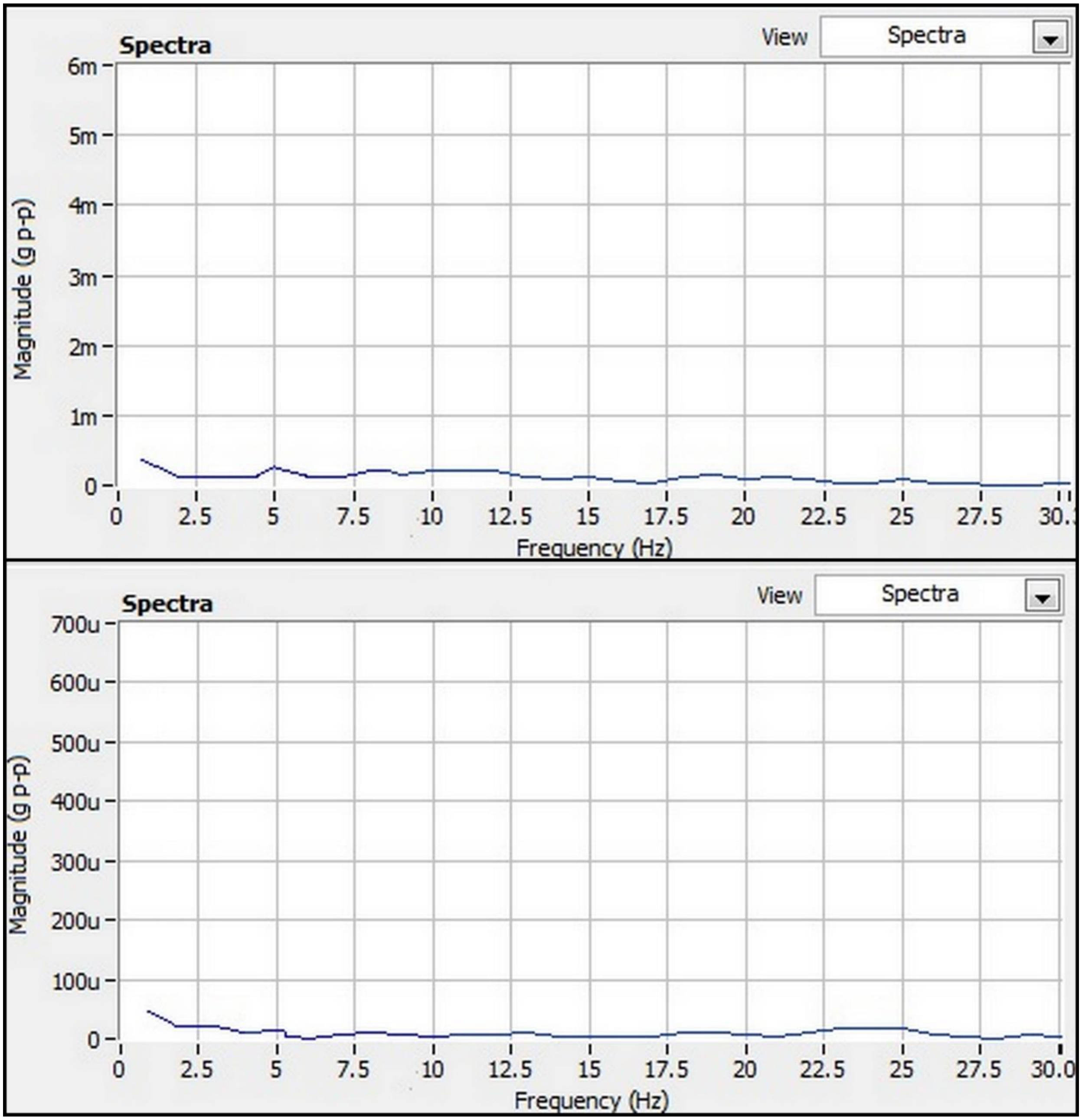
■ Process
● Key Milestone

	FYP 1														FYP 2														
Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Topic selection	■	■																											
Overview of topic		■																											
study on the topic		■	■	■	■																								
Collecting reference		■	■	■	■	■																							
preparation for proposal defense				■	■	■																							
Submission of proposal defense						●																							
Prepare methodology			■	■	■	■	■	■																					
Finalize the methodology								●																					
Prepare the equipment to be used						■	■	■																					
Preliminary results								■	■	■	■																		
Preparation for interim report									■	■	■	■	■																
Submission of FYP 1 report														●															
Start the experiment															■	■	■	■											
Analyze the result																	■	■	■	■									
Verify the result with other journal																			■	■	■								
Prepare for progress report																		■	■	■	■ ●	■							
Submission of progress report																								●					
Pre-EDX																													
Preparation on Final Report																						■	■	■	■				
Preparation on Technical Paper																						■	■	■	■ ●				
Submission of Draft Report																										●			
Submission of Soft Bound																										●			
Submission of Technical Paper																													
Preparation on Oral Presentation																									■	■	■ ●		
Oral Presentation																												●	
Submission of Hard Bound																													

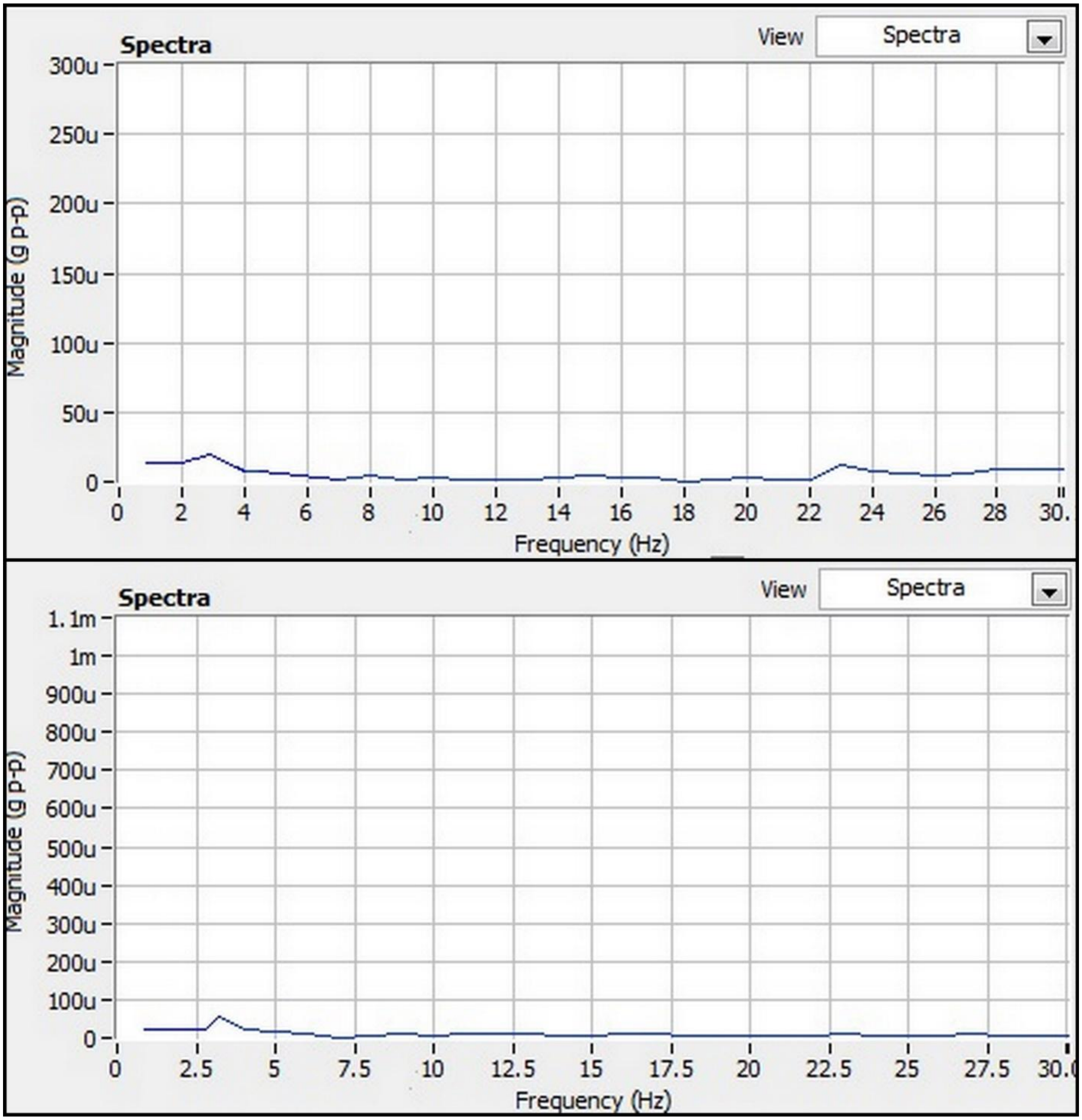
Appendix II



Spectrum Analysis for critical speed at Power Turbine (a) Horizontal (b) Vertical



Spectrum Analysis for critical speed at Compressor (a) Horizontal (b) Vertical



Spectrum Analysis for critical speed at Compressor (a) Horizontal (b) Vertical