EXPERIMENTAL INVESTIGATION ON REDUCING ENERGY COST BY IMPROVING SHAFT MOTOR COUPLING ALIGNMENT

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This report is submitted
in fulfillment of the requirement for the degree of
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DECLARATION

I declare that this project report entitled "Experimental Investigation on Reducing Energy Cost by Improving Shaft Motor Coupling Alignment" is the result of my own work except as cited in the references

Signature	:	....
Name	:	NUR AIN AQILA BINTI RUSLAN
Date	:	....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (With Honours).

Signature :. ....

Name of Supervisor : DR REDUAN BIN MAT DAN

Date : ....

ABSTRACT

Misalignment of shaft is the most common fault happens on rotating machinery. Several studies have shown that misalignment of shaft motor coupling has introduced up to 15 percent extra energy consumption by motor to rotate the shaft. In addition, misaligned rotating machinery has increased the cost due to repair and replacement to a new machinery and also on the manpower involvement. In this study, an analysis of energy losses caused by misalignment of shaft motor coupling will be carried out, with the main objective of finding correlation between energy consumptions with different degrees of misalignment of shaft by experimental investigation. A Machine Fault Simulator, MFS was be utilized to carry out the experimental investigation under different degrees of misalignment. The additional tools, ammeter clamp, and multimeter will be included in this study and will be used to analyse the results. This study also includes on the remedial for the misalignment of shaft, either by using straightedge or dial indicator or laser indicator in order to achieve the objective of reducing cost initiative proposal due to early damages to the machinery causes by misalignment of shaft motor coupling the industry. To simplify, this study at the end, embarks the result of how degree of misalignment affects the energy consumed by motor to rotate the shaft. This shows how a preventive and predictive maintenance is beneficial with the objective of reducing energy consumption by initiatively proposing initiative in improving the misalignment of shaft motor coupling to reduce the cost in industry.

ABSTRAK

Penjajaran aci yang salah adalah kesalahan yang paling biasa berlaku pada mesin berputar. Beberapa kajian telah menunjukkan bahawa penjajaran aci yang salah telah memperkenalkan sehingga 15 peratus penggunaan tenaga tambahan oleh motor untuk memutarkan aci. Di samping itu, jentera berputar yang tidak jelas telah memberi kesan kepada kos untuk meningkat disebabkan pembaikan dan penggantian kepada jentera baru dan juga penglibatan tenaga manusia. Dalam kajian ini, analisis kehilangan tenaga yang disebabkan oleh penjajaran aci yang salah akan dijalankan, dengan objektif utama mencari hubungan antara penggunaan tenaga dengan darjah penyelarasan aci yang berbeza dengan siasatan eksperimen. Simulator Kerosakan Mesin, MFS akan digunakan untuk menjalankan penyelidikan eksperimen di bawah tahap penyelarasan yang berbeza. Alat tambahan, pengapit ammeter, dan multimeter akan digunakan juga dalam kajian ini dan akan digunakan untuk menganalisis hasilnya. Kajian ini juga merangkumi pemulihan bagi penjajaran aci yang salah, sama ada dengan menggunakan lurus atau penunjuk indikator atau penunjuk laser untuk mencapai matlamat mengurangkan cadangan inisiatif kos kerana kerosakan awal kepada punca-punca jentera yang disebabkan oleh pemisahan gandingan motor aci industry. Untuk mempermudah, kajian ini pada akhirnya, memulakan hasil sejauh mana ketidakseimbangan menjejaskan tenaga yang digunakan oleh motor untuk memutarkan aci yang kemudian menggambarkan kelebihan apabila metodologi pencegahan dan ramalan dilaksanakan dengan tujuan untuk mengurangkan penggunaan tenaga dengan mencadangkan inisiatif dalam meningkatkan penjajaran aci yang salah untuk mengurangkan kos dalam industri.

DEDICATION

To my beloved parents

ACKNOWLEDGEMENT

I would like to express my deepest appreciation to all those who provided me the possibility to finish this report. A special gratitude I give to our final year project supervisor, DR Reduan Bin Mat Dan, whose contribution in stimulating suggestions and encouragement, helped me to coordinate my project especially in writing this report.

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Last but not least, I have to appreciate the guidance given by other supervisor as well as the panels especially in our project presentation that has improved our presentation skills thanks to their comment and advices.

.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE	TITLE	PAGE

LIST OF APPENDICES

LIST OF SYMBOLS

P	-	Energy Consume
I	-	Current
V	-	Voltage
Hz	-	Frequency
Pa	-	Pascal
A	-	Ampere
º	-	Degree

LIST OF ABBREVIATIONS

MFS	Machine Fault Simulator
AC	Alternative Current
VFD	Variable Frequency Drive
DMM	Digital MultiMeter
VOM	Volt-Ohm Milliammeter
DVOM	Digital Volt-Ohm Milliammeter

CHAPTER 1

INTRODUCTION

1.1 Background

Misalignment of shaft is an abnormality location of the virtual shaft from location of driven shaft determined at energy transmission point, where the driver machine shaft is not on same centreline as the driven machine shaft. Misalignment causes vibration problems to more than 70% of rotating machinery (Behera, Behera and Naikan, 2014). Misalignment may happen to the machine internally or externally. Angular Misalignment and Parallel Misalignment are the two types of misalignment. Angular Misalignment is when the driven and the driver shafts intersect at an angle while Parallel Misalignment is when the centrelines of the driven and the driver shafts are parallel (Liu et al., 2017). In reality, the combination of both types mostly causing misalignment of shaft (Ferrando Chacon et al., 2014).

From a view of maintenance and reliability in industrial plant, alignment of rotating machinery is the most highlighted topic in determining answers in lowering costs and increasing reliability (Jesse et al., 2017).Other than that, as said in the study, two answers that highly support the energy consumption to be decreased are firstly decreasing of loads on mechanical parts, for example couplings, bearings, and seals with improved misalignment. Moreover, decreased loads result in lower operating temperature, lesser wear on mechanical systems, lower noise and vibration and also decrease stoppage due to breakage. Thus, the operating life span of equipment will longer and more reliable. Secondly, by improving misalignment, the energy efficiency will increase too.

The project study the impact on energy consumption in improving misalignment of shaft motor coupling. It will reduce cost and increase the operating life of the machine by reducing vibration and parasitic loads due to misalignment. When coupling and bearing of shaft operating in a misaligned condition, energy consumption will increase thus acting against mechanical systems which causing machinery damages thus requires high amount of money to either repair or replace. This defectively misaligned machine has introduced up to 15% extra energy (Dockyard and Watson, 2012). Therefore, by removing high energy vibration sources such as misalignment, can also lower the energy consumption of the machine up from 10 to 15 percent.

This study also proposes on the remedial of the misalignment of shaft that can be done manually or either way. As for manually, the method only requires to use straightedge, condition based maintenance program and dial indicators. Furthermore, the method requires to use laser guided tools. The remedial methods are comparable based on time consume, efficiency, accuracy and friendly usage.

1.2 Problem Statement

Misalignment is the incorrect arrangement or position of something in relation to something else. There are a lot of factors of misalignment of shafts occur, some are inaccurate assembly of parts, material of the parts expand due to surrounding temperature, excessive energy consumption and coupling failure. These factors have caused high energy consumption in rotating the shaft motor coupling. Thus, misalignment is crucial to be fixed because misaligned rotating machinery affects high cost to the industry. As misalignment causes early damages to the machinery, loss in production due to short operating life of the machine.

These problems will be long-term if it is not fixed or it will indirectly affect people, such as the workers need to work overtime, the owner of the industries as the cost will be high to support, the users or third parties will may be harmed due to unsafe machine or equipment to use. This study will prove the previous studies by an experimental investigation on reducing energy cost by improving shaft rotor coupling alignment.

1.3 Objective

This project embarks on the following objectives:

1. To study the impact on energy consumption due to the misalignment of shaft motor coupling.
2. To propose cost reduction initiative due to early damages to the machinery causes by misalignment of shaft motor coupling the industry.

1.4 Scope of Project

This study embark on experimental investigation to achieve its objectives in Condition Based Maintenance Lab of Fakulti Kejuruteraan Mekanikal, UTeM, using Machinery Fault Simulator and a few additional tools. This Machinery Fault Simulator and some additional electronic tools will give out measurements and data. The data is going to be used in plotting the chart of the energy consumption due to misalignment of shaft motor coupling against the degree of misalignment of shaft motor coupling.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter explains on previous researches which are related to this case study and few of basic theories which are to be used including machine fault simulator, misalignment of shaft motor coupling, types of misalignment, causes of misalignment, impaired of the misalignment, relation of misalignment with energy consumption of the motor and few additional tools.

2.2 Shaft Motor Coupling Misalignment

Misalignment is an abnormality location of the virtual shaft from location of the driven shaft determined at energy transmission point, where the driver machine shaft is not on same centreline as the driven machine shaft. Misalignment causes vibration problems to more than 70% of rotating machinery (Behera, Behera and Naikan, 2014). Figure 1 shows an image of shaft coupling. Shaft coupling is a device that connects two shafts together at their ends in order to conduct energy.

Figure 1 Shaft Coupling

2.3 Types of Misalignment of Shaft Motor Coupling

Misalignment of shaft motor coupling may happen to the machine externally or internally. Angular misalignment and parallel misalignment are the two types of misalignment as shown in Figure 2(a) and 2(b). Types of misalignment can also be determined by phase difference tolerances. Parallel and angular misalignment have different behaviour in vibration analysis, that both has different characteristics in differentiating which one is parallel and which one is angular (Califa, 2017).

Figure 2 (a) Parallel Misalignment (b) Angular Misalignment

2.3.1 Parallel Misalignment

Figure 3 shows a parallel misalignment. Parallel misalignment is when the centreline of the driver and driven shafts are misaligned, not intersect, parallel to each other (Ghani et al., 2016). Parallel misalignment produce comparative to the 1X order large vibration is within the radial direction (Behera, Behera and Naikan, 2014).

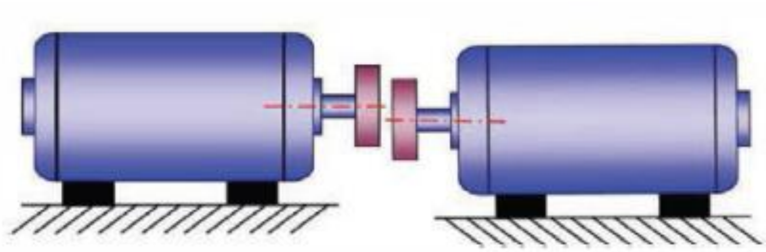


Figure 3 Parallel Misalignment between two shafts (Behera, Behera and Naikan, 2014)

It means that on radial direction, the vibration analysis is strong at 2X order and lower at 1X order, then it is vice versa in axial direction. While the phase difference for parallel misalignment in radial and axial direction that is 180º ± 30º.

2.3.2 Angular Misalignment

Figure 4 shows an angular misalignment. Angular misalignment is when the centrelines of the driven and driver shafts intersect at an angle (Estupinan, 2018). For angular misalignment, the vibration analysis is strong at 1X comparatively to 2X order in axial direction but in radial direction, orders of 1X and 2X is obviously almost similar. The phase differences tolerance for angular misalignment as in axial direction is 180º ± 30º while in radial direction it is 0º ± 30º.

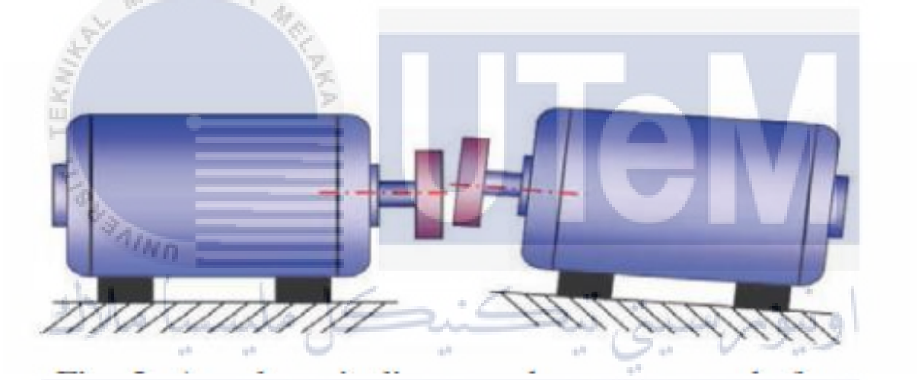


Figure 4 Angular Misalignment between two shafts (Behera, Behera and Naikan, 2014)

2.3.3 Detecting Misalignment Using Vibration Analysis

In the case of rotating machines, misalignment fault can be detected using vibration analysis (Estupinan, 2018). Both parallel and angular misalignment will come out with different pattern of spectrum and phase relation such as shown in Figure 5 and Figure 6.

Figure 5 shows the detail characteristics of parallel misalignment in vibration analysis in radial direction, which the order axis of the graph shown, 2X part is usually larger than the 1X. But, the size of 2X comparative to the size of 1X is usually determined by the arrangement and building of the coupling .

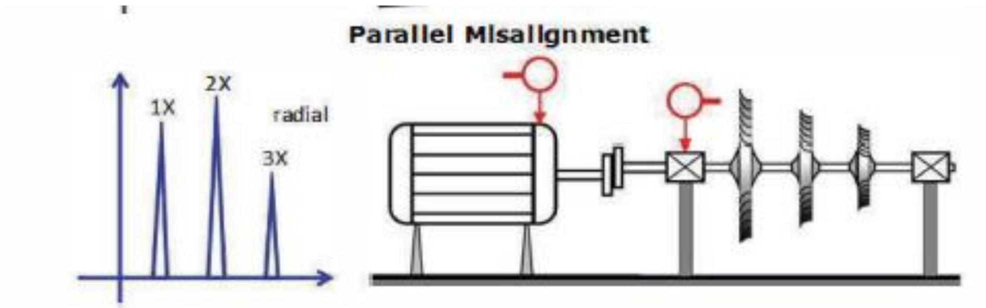


Figure 5 Typical Spectrum and Phase Relations of Parallel Misalignment (Behera, Behera and Naikan, 2014)

The typical spectrum and phase relations shown in Figure 6 explains the angular misalignment. If any 1X, 2X or 3X dominates symptoms occur, it will lead to issues with coupling where this wide misalignment case could trigger the series of rotational frequency harmonics.

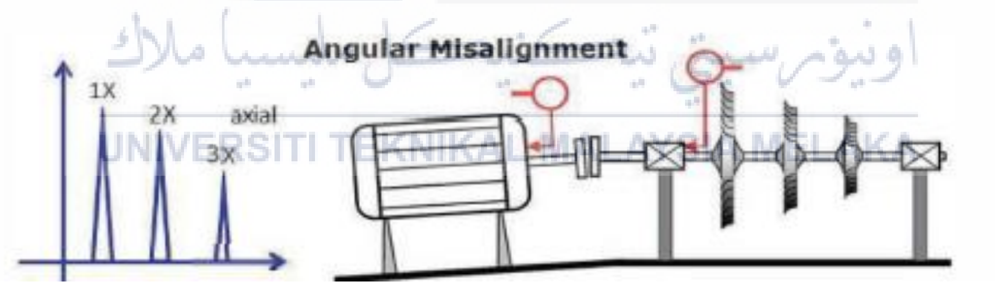


Figure 6 Typical Spectrum and Phase Relations of Angular Misalignment (Behera, Behera and Naikan, 2014)

There are three characteristic peak frequencies in diagnosing shaft fault. Firstly at 1X, the peak is at obvious being. Secondly, the peak is smaller at 2X. Thirdly, the last peak is proportionally to the natural frequency of the system (Ferrando Chacon *et al.*, 2014; Naveen Rathi, Amit Gupta, B. Manpreet, Rajesh Kumar, 2014).

Both parallel and angular misalignment has equal nonlinear effect. In Angular misalignment, ratio of 1X component and higher harmonic components greater than parallel misalignment. (Ferrando Chacon et al., 2014) . As in reality, the combination of both mostly causing misalignment of shaft as shown in Figure 7(c).

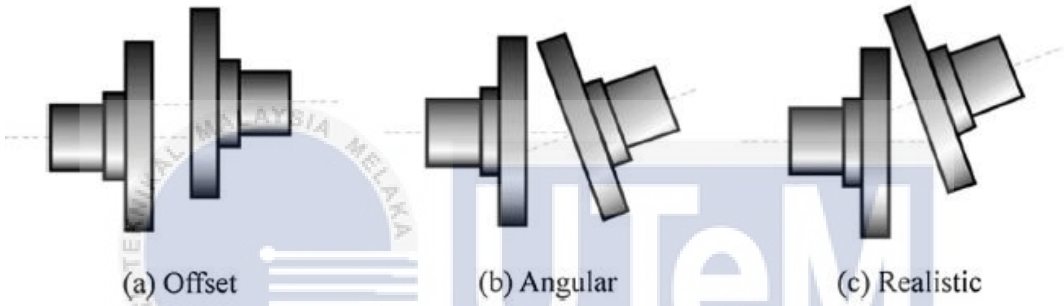


Figure 7 (a) Offset or Parallel Misalignment (b) Angular Misalignment (c) In Reality Misalignment Happened (Simm et al., 2016)

2.4 Causes of Misalignment

The root cause of a misalignment condition is not usually clear physically and may be varies. To be precisely, the major problems that have been causing misalignment of shaft motor coupling to happen are inaccurate of manufacturing, soft foot, thermal growth and additional loads. Most of these causes which lead to misalignment to occur, will cause the rotating machinery to require higher energy consumption to rotate the shaft motor coupling.

2.4.1 Inaccurate of Manufacturing

Misalignments introduced by inaccurate of manufacturing (Ioan Damian, Ion Oancea, 2008). This manufacturing defects mostly found on new equipment which is also from a mistake in an alignment procedure (Simm et al., 2016). Besides, misalignment of shaft motor coupling is also caused by error in assembly (Wang and Jiang, 2018) that this usually found in human error and mechanical error.

2.4.2 Soft Foot

Soft Foot, generally looseness of hold down bolts area (Behera, Behera and Naikan, 2014). Soft foot describes an improper contact between the baseplate that supports the machine casing and the machine casing. When there is present of soft foot, the equipment will tend to move during operation (Ahmad, 2015). Soft foot is like a wooden chair that is straight-backed which when one of the leg is shorter, that it does not touch the floor, it will cause a rocking move in the chair, while mechanically it will lead to misalignment of shaft in rotating machinery (Case, B., 2010).

Soft foot is a major issue causing misalignment in rotating equipment to happen. Soft foot will change and stress the casing of machine leading to a not consistent rotational centrelines of shafts problem (Dockyard and Watson, 2012). Because of this, problems with the rotor air gap, bearing or seal fit and coupling wear tend to happen. Figure 8 and 9 shows the soft foot explained. Soft foot should be repair before final operation and alignment (Ahmad, 2015).

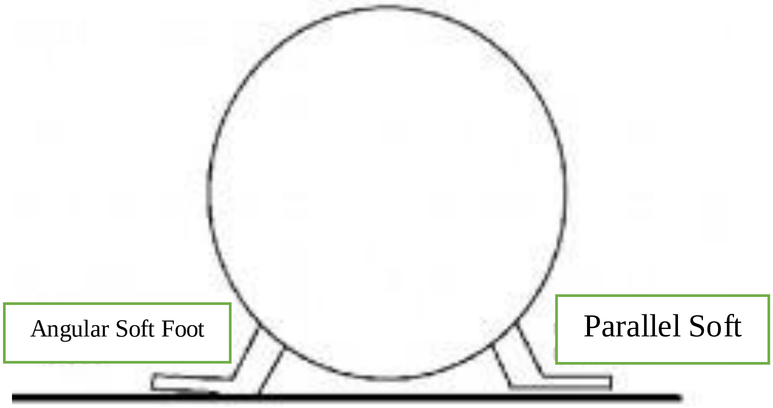


Figure 8 Types of Soft Foots (Case, B., 2010).

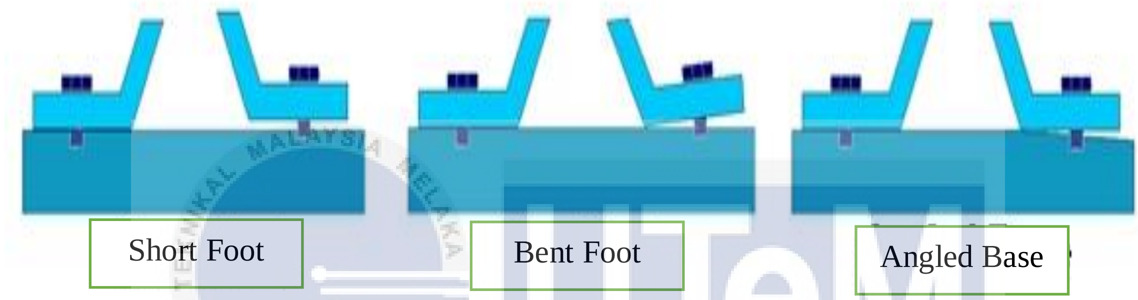


Figure 9 Three types of angular Soft Foot Conditions (Case, B., 2010).

2.4.3 Thermal Growth

Thermal growth as shown in Figure 10, is when equipment operates exceed the ambient temperature that will affect one unit of equipment to move proportionally to another that will lead to misalignment (Mishra, 2012). Thermal growth is not always a factor in aligning machinery, but if the machines is big, hot, fast operating and must be aligned in a close tolerance, thermal growth is the factor. In shaft alignment, depends on the surrounding temperature, machines that run hot usually have thermal target which means shafts may be misaligned at room temperature but when the shafts heat up to operating temperature, the shafts will be aligned. Different types of materials will expand or changing in size at different rates based on the coefficient of linear thermal expansion when heat is applied (Mishra, 2012).

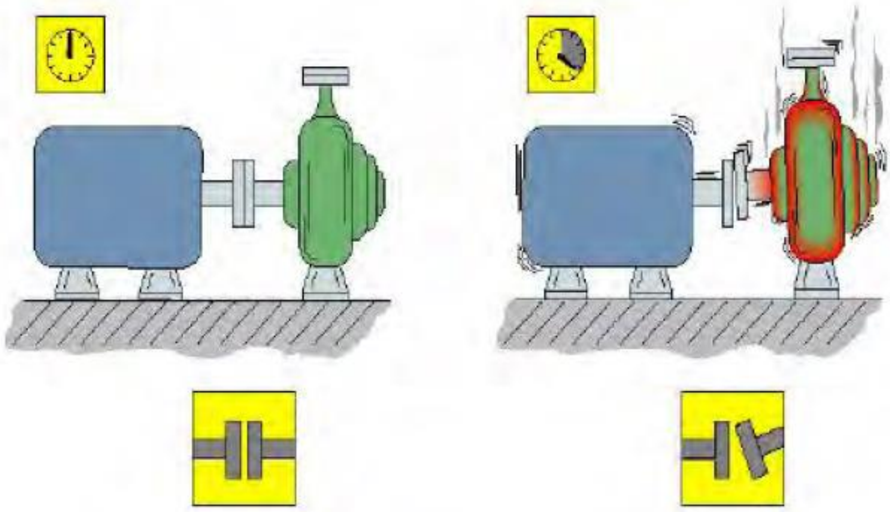


Figure 10 Thermal Growth of Rotating Machinery (Ludeca, 2002)

2.4.4 Additional Loads

The top most prevalent cause of misalignment to happen is, additional loads on mechanical parts such as couplings, seals, bearings and journals (Dockyard and Watson, 2012). According to that, when additional loads present, it will lead to cyclic fatigue, thus results in excessive energy consumption (Hines, 1997). Explaining it more, when there is overload occur, and the machine runs in a long time with these conditions, thus will significantly reduce the life of bearings, seals, coupling and shaft (Estupinan, 2018). Addition to that, this will also save money from repairing or replacing a machine when early precaution is being practiced.

2.5 Impaired of Misalignment

Misalignment of shaft motor coupling in rotating machinery can be detected in many ways either at early stages or after the equipment has failed. This rotating machinery fault will also lead to decreasing in bearing seal and coupling life, this will lead to increase in equipment downtime. Thus, the rotating machinery will degrades faster(Litwin, Olszewski and Wodtke, 2011; Estupinan, 2018). The cost of performing an additional move to improve an alignment must be weighed against the costs of not performing the move (Hines, Jesse and Edmondson).

This is because there will be increased in inventory parts. Besides, it will cause the repair orders to be higher than normal. Misaligned machinery is costly that it may be forcing plant to shut down and also devote the manpower to remedy the problem. It could also be that the plant itself is the surrounding catastrophic failure and a plant health risk (Hines, Jesse and Edmondson).

Example in crowned spur gear pair area, misalignment has caused errors in mounting or inaccuracy in manufacturing and elastic deflection under load which results in transmission error (Bhatkar et al., 2017). In addition, the transmission error has contributes to abnormal noise and vibration in gear set. Misaligned shaft condition will consume energy that costs money and profiTable of the company.

2.6 Energy Cost Due To Misalignment of Shaft Motor Coupling

Figure 11 shows two types of coupling in thermogram view which shows amount of heat energy generated due to misalignment (Ahmad, 2015). Similar findings shown about misalignment has highly cost the energy consumption in (Hines, Jesse and Edmondson, Safar, 1984; Dockyard and Watson, 2012; Behera, Behera and Naikan, 2014; Estupinan, 2018). High energy consumption is from increase loads on the mechanical parts that will also affect the noise and vibration to be high (Dockyard and Watson, 2012). Between both types of misalignment, energy consumption from angular misalignment is higher compared to parallel misalignment (Simm et al., 2016).

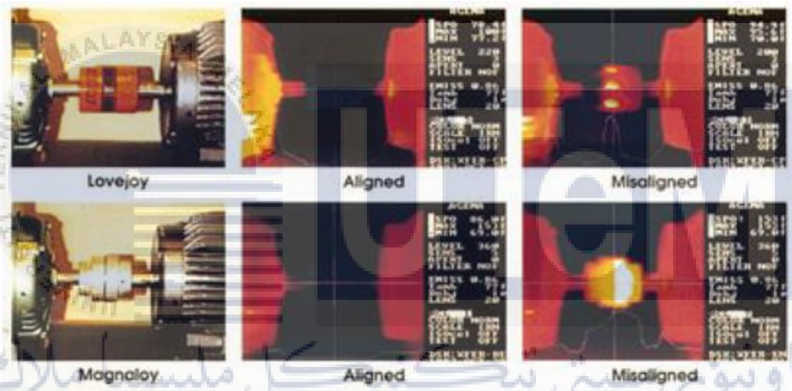


Figure 11 Thermogram of two different types of coupling (Ahmad, 2015)

In addition to that, additional loads that affect high energy consumption will also increase the operating temperature, wear on mechanical systems and breakage downtime (Jesse et al., 2017). To be worst, the catastrophic failure of surrounding machinery will happen, then potential of the health risk to the plant is high (Hines, Jesse and Edmondson). Otherwise in hydroenergy plants, oil leakage on the natural body of water happened due to misalignment of shaft (Litwin, Olszewski and Wodtke, 2011).

This happens because of the viscosity of oil is higher than water, showing the carrying load of oil is higher than water, and the current lubricated bearings of water have load-carrying ability that is weak to support (Litwin, Olszewski and Wodtke, 2011). Higher degree of misalignment will lead to higher vibrations, thus increase the energy consumption (Estupinan, 2018).

Based on previous studies, the misalignment degree changed the amplitude of the vibrations. Then, the current consumption changed with a similar chances as the vibration changed (Estupinan, 2018), which the current consumption indicates the energy consumption which is measured using current clamp connected directly to the data acquisition system. The proof to this situation is shown in Figure 12 and Figure 13.

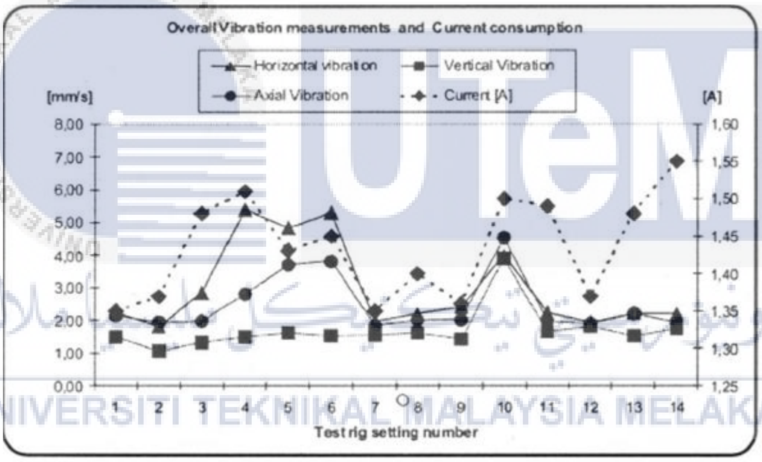


Figure 12 Vibration taken on The Inboard Motor Bearing and Current Consumptions (Estupinan, 2018)

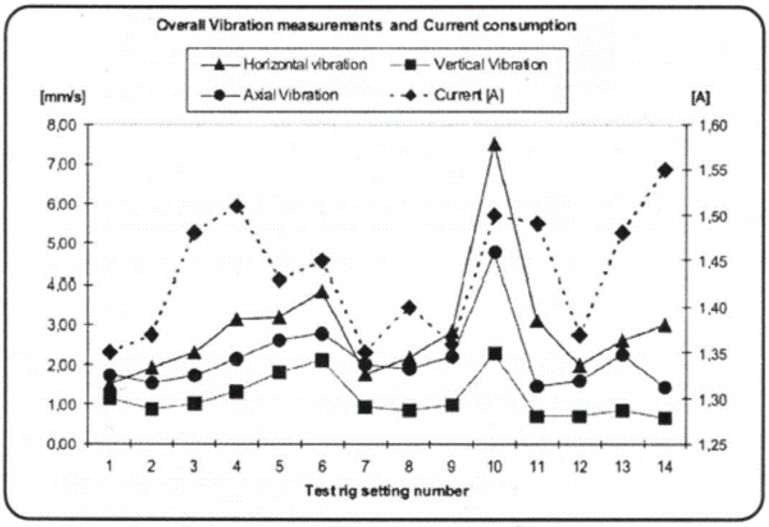


Figure 13 Vibrations taken on The Side Coupling Rotor Bearing and Current Consumptions(Estupinan, 2018)

2.7 Types of Shaft Motor Coupling Alignment Method

Shaft motor coupling alignment process is about positioning the centre lines of the driven and the driver machine to be parallel and intersect in creating collinear shafts. Shaft alignment is an essential technique in maintenance and installation of a rotating machine (Garg et al., 2017). There are two categories of method to align misaligned shaft motor coupling either by using straightedge and dial indicator as for manually or by laser as shown in Figure 14.

Two answers that highly support the energy to be used lesser with proper alignment are firstly decreasing of loads on mechanical parts, for example couplings, bearings, and seals with improved misalignment (Jesse et al., 2017). Decreased loads result in lower operating temperature, lesser wear on mechanical systems, lower noise and vibration and also decrease stoppage due to breakage (Hines, 1997). Thus, the operating life span of equipment will increase and more reliable. Secondly according to Jesse, by improving misalignment, the energy efficiency will increase. Energy consumption will be high when coupling and bearing operating in a misaligned condition. Extra energy will wastes money and acts against the mechanical systems.

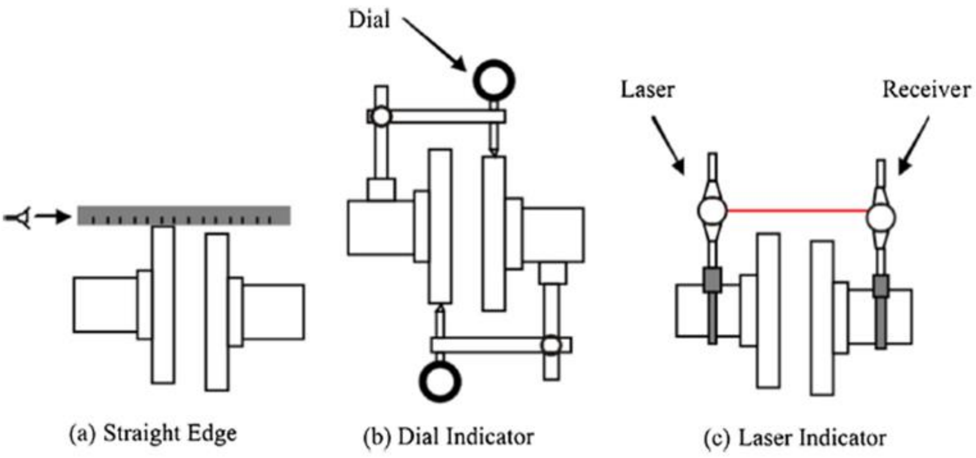


Figure 14 Types of Shaft Alignment Method (Simm et al., 2016)

2.7.1 Straightedge

Figure 15 shows a common manual tools used in alignment measuring. The straightedge method is used as a first step of alignment method which is called "rough align". The tape measure commonly used to measure distances between machinery foot and the points of shaft measurement (Piotrowski, 2006).

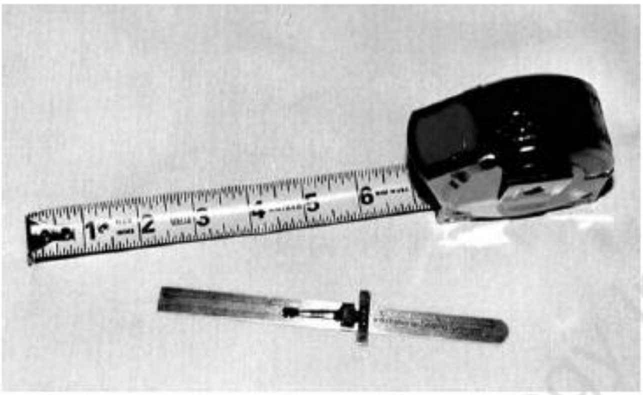
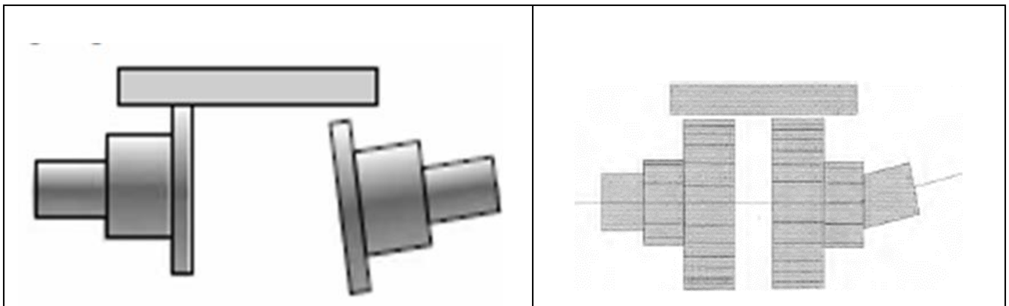


Figure 15 (Piotrowski, 2006)

Figure 16 shows how ruler as straightedge has been used as a straightedge in aligning the shaft. The equipment of this method is cheap and readily available. This method requires repeated times of corrections yet the completed alignment is not guaranteed to be accurate (Ludeca, 2002).



(a) Before (b) After

Figure 16 How Straightedge being used (Piotrowski, 2006) and (Ludeca, 2002)

2.7.2 Condition Based Monitoring Method

Condition based maintenance is a practice that should be implemented in industries. The health of the rotating machinery is predicted by the three important condition monitoring techniques, which are temperature, vibration and wear (M. SARATH KUMAR and B.S. PRABHU, 2017) (Sohre, 1972). This is to reduce their rate of deterioration and to ensure their proper functionality and properly maintenance program optimize the relationship between operating profits and equipment ownership by balancing cost of equipment failure and involved production loss with cost of maintenance (LCE, 2015). This process of maintenance ensure that machine and equipment work in targeted level of confidence. Then, repair tasks and maintenance that follow basic procedures, somehow reduce the chances of faults that are unexpected and unnecessary losses of money, time and production (Susin, 2001).

Condition based maintenance program are such as breakdown maintenance, which allow machine to run until failure, preventive maintenance which is scheduled activities of maintenance in planned time intervals by replace or repair damaged equipment before obvious failure happen. Then, the predictive maintenance which is maintenance activities held only when functional failure detected and also proactive maintenance which it trace all failures to their root cause, analysing each failures that happen (Cornelius Scheffer, 2004).

2.7.3 Dial Indicator

This dial indicator, as shown in Figure 17, is a method that is more accurate than the straightedge method (Piotrowski, 2006). The dial indicator mounted on one shaft and the other on other shaft. Then, it is reversed to other shaft and steps repeated.

Figure 17 Dial Indicator (Piotrowski, 2006)

Figure 18 shows how the dial indicator is being installed to the rotating machinery. Besides, it is easier for graphical plot compared to other methods yet, it is quite not easy to use, because it needs to rotate both shafts in order to get accurate alignment. Other than that is that the dial indicator is not accurate for shaft that is close-coupled (Ahmad, 2015).

Figure 18 Installation of Dial Indicator (Ludeca, 2002)

2.7.4 Laser Indicator

Figure 19 and Figure 20 show how the laser indicator been installed and applied The laser uses optical triangulation, where the red laser line is projected onto the shaft surface and a photodiode detector is used to measure fraction of the reflected light where to calculate the distance of measuring, uses the angle of incidence (Simm et al., 2016). Laser Indicator or Laser-Optical method of shafts alignment in rotating machinery is more accurate and simple than other mechanical methods. It requires lower energy consumption and increases mean time between failures (Garg et al., 2017).

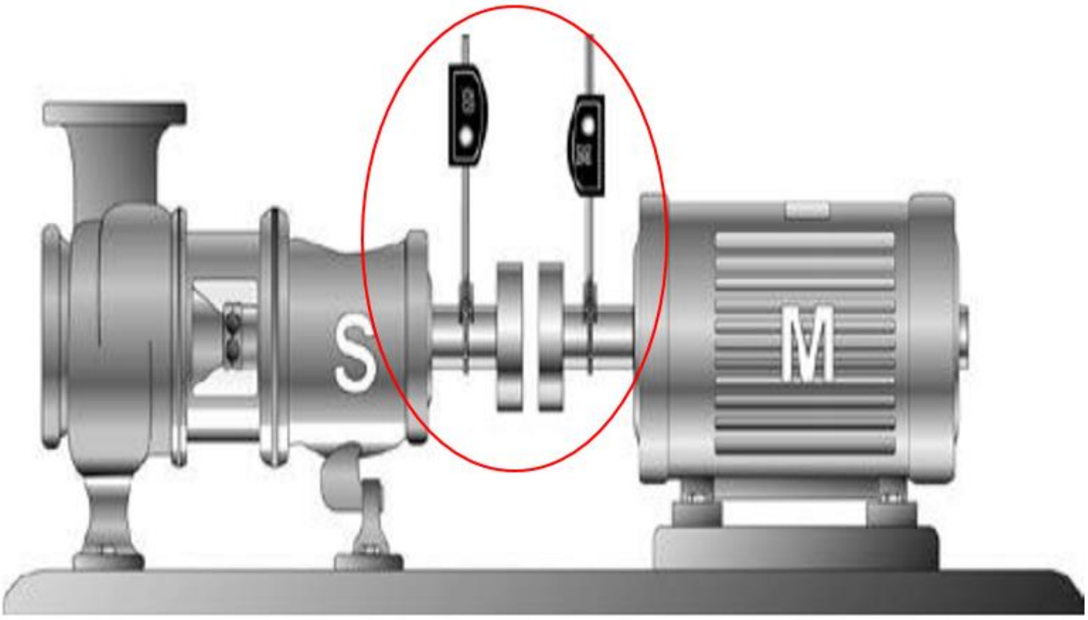


Figure 19 Installation of Laser Indicator (Garg et al., 2017)

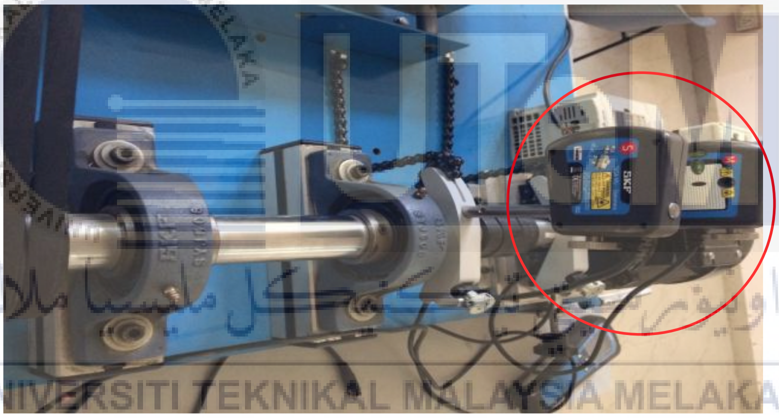


Figure 20 Application of Laser Indicator (Garg et al., 2017)

Laser alignment has a long-term benefit such as improving machine productivity and reliability, lowering repair cost of machine, lowering cost on workers, reducing energy consumption of machine, minimizing time of machine repairing and installation (Garg et al., 2017).The Laser Indicator is the most precise method in controlling measurement of the misalignment tolerances (Estupinan, 2018). It is a non-contact method which is designed to be applied easily to various types of rotating machinery. Figure 21 is an example of a laser indicator experimental test rig set up.

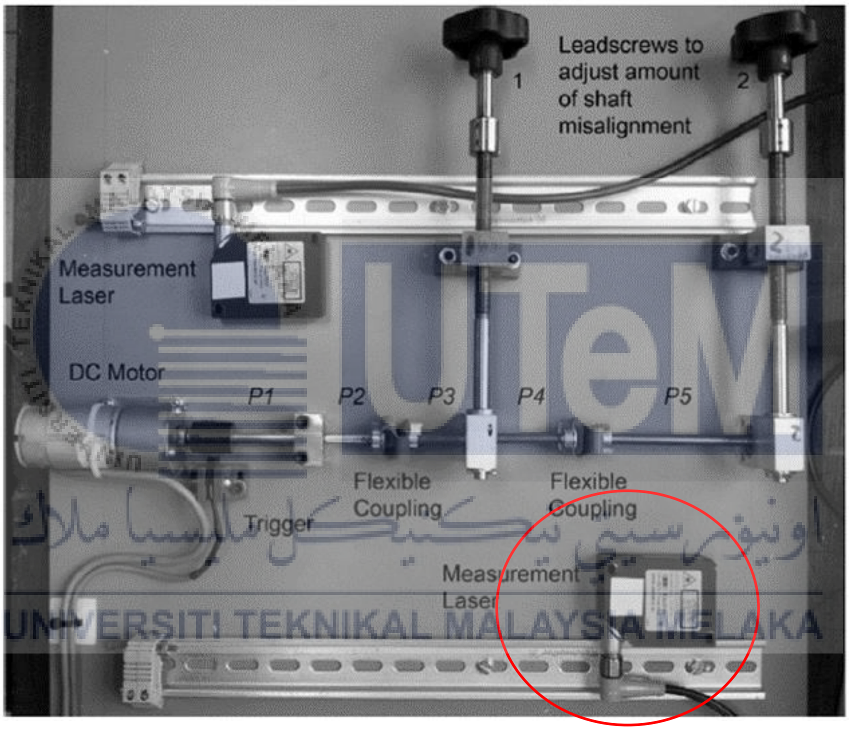


Figure 21 Example of Laser Indicator Experimental Test Rig Setup (Simm et al., 2016)

2.8 Experimental Investigation Tools and Machine

Some tools and a machine is to be used in order to do this experimental investigation. The tools are ammeter clamp, and multimeter, while the machine is the Machine Fault Simulator, MFS.

2.8.1 Machine Fault Simulator, MFS

Recent high demand on reliability of system in finding solution in diagnosing the fault in time and in guaranteeing the machine to run normally need to be solve imperatively. Especially to those machines that have misalignment faults, Machinery Fault Simulation (MFS) is introduced in generating data of system vibration with varies rotor faults along with varied loads (Cai *et al.*, 2013; Ghani *et al.*, 2016).

Machine Fault Simulator made up of one induction motor, one AC variable frequency drive (VFD), one shaft, two couplers, two bearings and one belt drive. Addition to that, to get the stator current, signals of vibration and torque respectively, three current clamps, one torque encoder and four accelerometers were used (Zhou, Wee and Zhong, 2010). Figure 22 and 23 explain the described characteristics of Machine Fault Simulator.

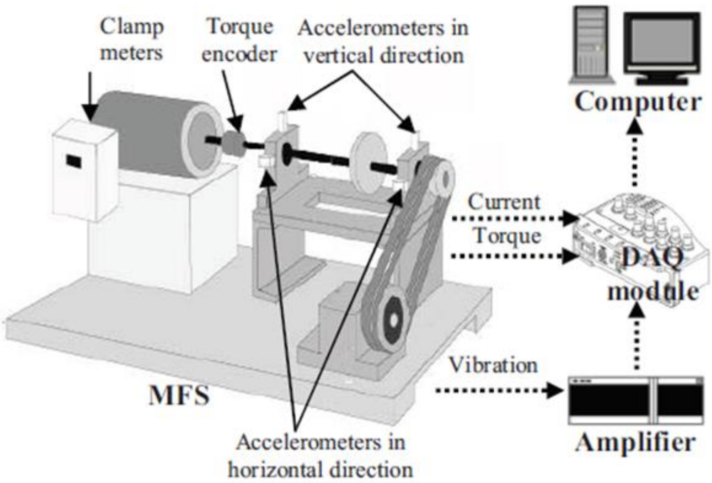


Figure 22 Faults Detection Experiment Setup (Zhou, Wee and Zhong, 2010)

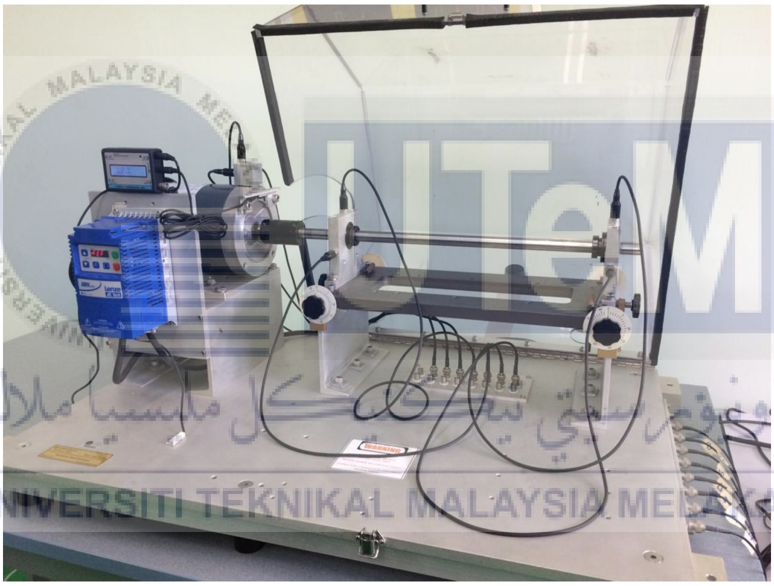


Figure 23 MFS in Condition Based Maintenance Lab in Faculty of Mechanical Engineering, University Teknikal Malaysia Melaka

2.8.2 Ammeter Clamp

Figure 24 is a Clamp Ammeter which is an electrical meter with AC. It measures the current flowing in all the conductors flowing through the probe depending on the phase relationship of currents such as load currents, ac voltage and continuity of switches. Fuses and contacts (Fluke Cooperation, n.d.). Usually, only one conductor pass through the probe.

Figure 24 Digital Ammeter Clamp (Fluke Cooperation, n.d.)

2.8.3 Multimeter

Multimeter or in other word, it is a Volt-Ohm-Miliammeter (VOM), is a measuring instrument electronically by combining few measurement functions in one unit. A common multimeter can measure voltage, current, and resistance. Figure 25 (a) and 25 (b) show that there are two types of multimeter which are analog multimeter which has pointer that will react in showing reading, and Digital Multimeter (DMM,DVOM) that has numeric display and graphical bar which show the measured value. To be compared the precision, digital multimeters are more precise and more valuable in cost (Duncan and Steiner, 1991). Aside from that, Analog Multimeter is still being use especially in cases when monitoring rapidly various value.

 (a) Analog Multimeter	 (b) Digital Multimeter

Figure 25 Analog and Digital Multimeters

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discuss on the methods used to carry out this experimental investigation project. In order to get a good requirement, this methodology starts with design of experiment. Then followed by tools setup and experiment conduction. Next, determining either the increasing in the degree of misalignment affecting the energy consumptions or not. Last, analysing the data with a brief discussion and the conclusion of the experiment as shown in Figure 26.

3.2 Project Flow Chart

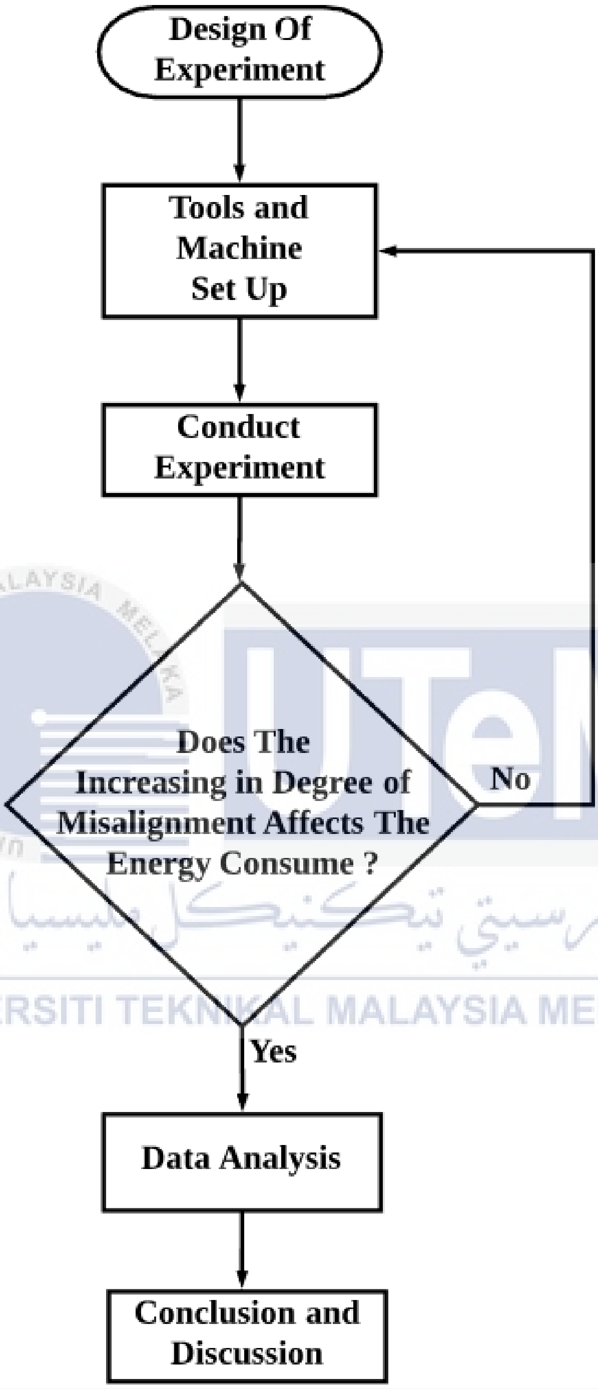


Figure 26 Project Flow Chart

3.3 Design of Experiment

Designing is the first step to any experiments or project. It is an experiment purposely at predicting the outcome by introducing a difference of the preconditions of input variables. It is also a method of thinking to picturize the flow of the experiments that need to be done in order to achieve a desired goal. Design of experiment is essential especially working in team because it makes people in charge aware in a lot of aspect. Thus, design of experiment must be clear and understandable to be referred in the future. Figure 27 shows how the design of the experiment going to be held and Table 2 shows the target variables for the experiment.

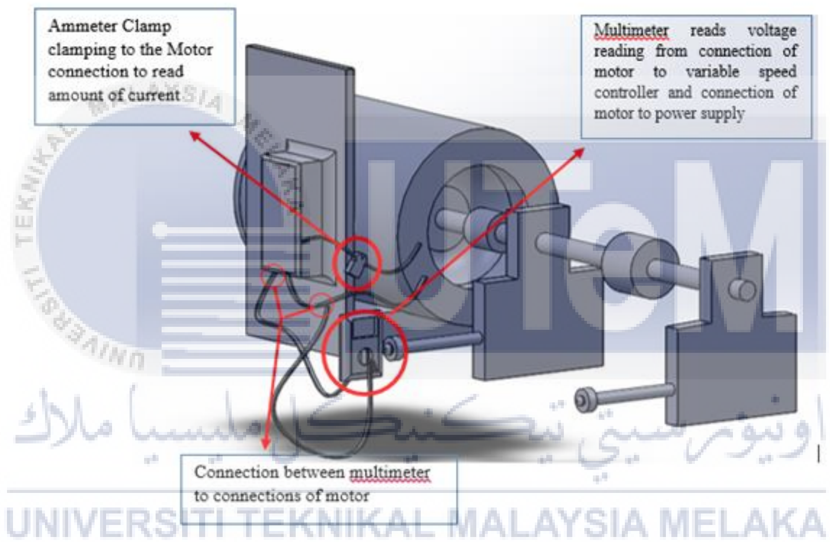


Figure 27 Sketching of the design of experiment using SolidWork 2013

Table 1 Design of Experiment in Table

Controlled Variable	Frequency of Rotational of Shaft
Manipulated Variable	Degree of Misalignment of shaft
Responding Variable	Voltage and Current reading which indicate the Energy Consumption

3.4 Tools and Machine Setup

Machine and tools used in this experiment are MFS, Ammeter Clamp and Multimeter. Setting up the MFS, shown in Figure 28 by following the Standard Operating Procedure, SOP of it that is attached in the appendix 1 and appendix 2.

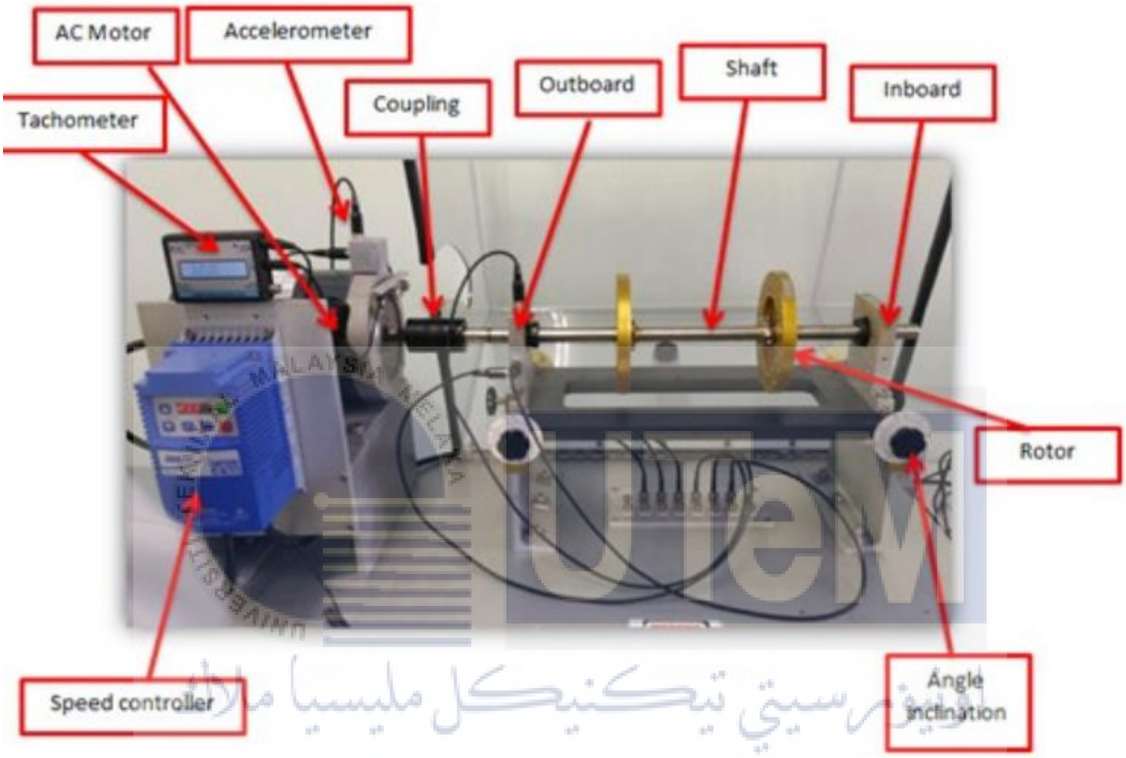


Figure 28 MFS Set Up (Ghani et al., 2016)

Figure 29 (a) and 29 (b) show multimeter and ammeter clamp respectively. These tools has been used to determine the current and voltage flows of the motor in rotating the misalignment shaft. The multimeter reads the voltage value when attached to points of voltage in and voltage out of the motor. Then, the ammeter clamp clamped on the connection from AC motor to read the current value. This experimental investigation starts with measuring the current and voltage of shaft with 0º of misalignment. Then, measuring the current and voltage of the shaft with increasing degree of misalignment.

(a)

(b)

Figure 29 Tools To Be Used

Figure 30 shows how the degree of misalignment condition plan set up in the experimental investigation. Figure 31(a) is the aligned setup, 31(b) is the parallel misalignment setup, 31(c) is the angular misalignment setup.

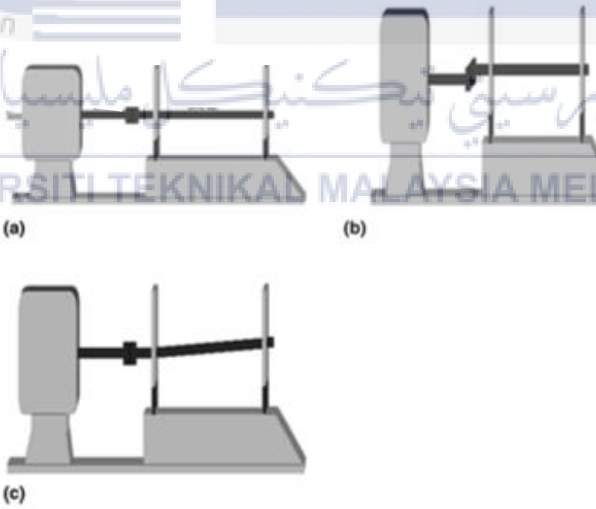


Figure 30 Set Up of Misalignment Condition (Verma, Sarangi and Kolekar, 2014)

3.5 Experiment

In this experimental investigation, the frequency of rotational shaft has been set as controlled variables, which is the fix data while the degree of misalignment of shaft motor coupling will be the manipulated variables, the changing data. For the energy consumption by AC motor of MFS, will be the responding variables. These variables by details shown in Table 3. This variables are set up due to investigate the energy consumption by the AC motor of the MFS to rotate shaft, either it will be affected or not as the degree of misalignment of shaft motor coupling increase, starting from 0º. The energy consumption by AC motor of the MFS will be determined from the current and voltage measurement with the formula in equation (3.1).

$$P=IV \tag{3,1}$$

where;

P is Energy Consumed

I is the amount of current used

V is the amount of voltage produced

3.6 Data Analysis

The data analysis shows the results of this experimental investigation which is the expected result or outcome is identifying either the degree misalignment of shaft will affects the energy consumption of the motor or not. For the case of it does not affecting, the process will go back to tools and machine setup which an error may occurred. If the result is affecting the energy consume, the data collected will be used to plot a graph of The Energy Consumption by Motor to Rotate Shaft against The Degree of Misalignment of Shaft Motor Coupling as shown in Figure 31 which then, will be analysed.

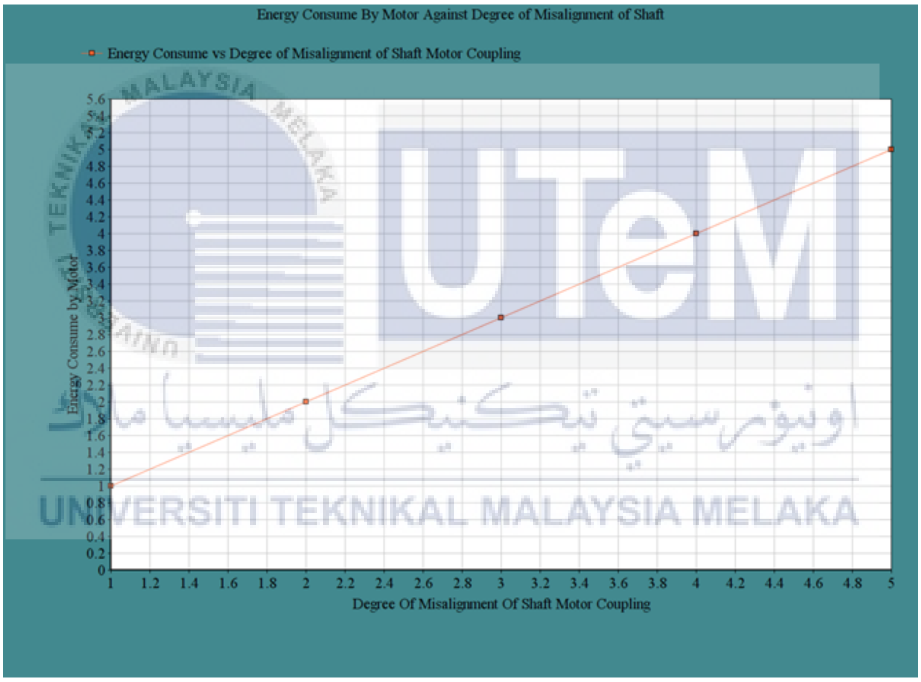


Figure 31 Example of Graphical Expected Result

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CHAPTER 4

RESULTS AND ANALYSIS

4.1 Experimental Description

This experimental investigation was conducted to prove an analysis from the studies, that when the degree of misalignment of shaft motor coupling increase, the energy consumed by the motor to rotate the shaft will be affected. Thus, this chapter will explains the result on experimental investigation of the energy consumption during misalignment of shaft happened on Machinery Fault Simulator (MFS). The gains of energy consumption by measuring the voltage and the current readings using equipment discussed in chapters before were shown and applied (Weiss, April 1991). The calculation and graph plotting of the readings were shown to strengthen the investigation in proving the analysis. Figure 32 shows how the equipment of the additional tools, the ammeter clamp and the multimmeter, have been set up with Machine Fault Simulator (MFS) which run with fix 30 Hz of speed frequency in every degree of misalignment in each types of misalignment to get the current reading and voltage reading in order to be used in calculating the energy consumed by the motor to rotate the shaft using the equation or formula of P=IV.

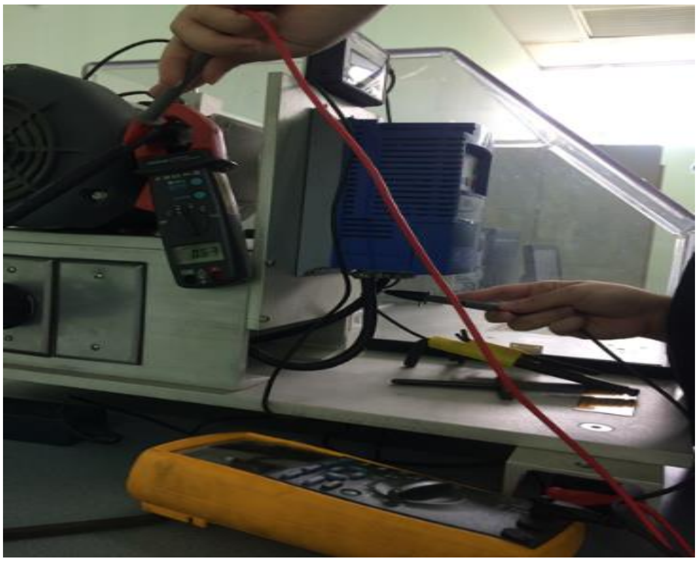

Figure 32 How the ammeter clamp and the multimeter is used on the MFS

4.2 Experimental Results

This part shows on the current and the voltage readings obtained from the experimental investigation from the parallel misalignment case and the angular misalignment case. Table 2 below shows current and voltage readings for perfectly aligned shaft, also the calculated energy consumed to rotate the perfectly aligned shaft. For each degree of misalignment, it was set up to run the MFS three times in getting an average readings of current and voltage to calculate the energy consumed by the motor to rotate the shaft.

Table 2 Readings of current and voltage and calculated energy consumed by motor when shaft in perfectly aligned

Degree Of Misalignment (◦)	Current Reading on Ammeter Clamp,I (Amp)	Average Current Reading, I (Amp)	Voltage Reading on Multimmeter, (V)	Average Voltage Reading,(V)	Energy Consumption (P=IV) Watt
0º	0.59	0.58	3.76	3.87	**2.24**
	0.58		3.85		
	0.57		4.00		

4.2.1 Current and Voltage Reading of Parallel Misalignment of Shaft Case.

As explained in the appendix 1 attached on how the parallel misalignment of shaft is set up on MFS, which said that by unscrewing the jack bolts the predetermined amount on the back side of the machine and for the front side of the machine, screw in the jack bolts the predetermined amount, both ends of the rotor base must be moved out of alignment the same amount in ensuring that the motor and rotor shafts remain parallel. Table 3 shows the readings stated and the energy consumed.

Table 3 Readings of current and voltage and calculated energy consumed by motor when shaft in parallel misalignment

Degree Of Misalignment (◦)	Current Reading on Ammeter Clamp,I (Amp)	Average Current Reading, I (Amp)	Voltage Reading on Multimmeter (V)	Average Voltage Reading,(V)	Energy Consumption (P=IV) Watt
5	0.58	0.57	4.13	3.97	**2.26**
	0.56		3.96		
	0.58		3.84		
10	0.58	0.58	4.12	4.12	**2.39**
	0.58		4.13		
	0.59		4.10		
15	0.62	0.61	4.29	4.21	**2.57**
	0.60		4.21		
	0.61		4.14		
20	0.64	0.65	4.44	4.34	**2.82**
	0.66		4.30		
	0.65		4.27		
25	0.66	0.66	4.43	4.41	**2.91**
	0.64		4.39		

	0.68		4.42		
30	0.69	0.70	4.46	4.55	**3.19**
	0.70		4.61		
	0.70		4.57		
35	0.74	0.73	4.72	4.81	**3.51**
	0.73		4.83		
	0.73		4.88		
40	0.76	0.77	5.20	5.20	**4.00**
	0.77		5.30		
	0.77		5.10		

4.2.2 Current and Voltage Reading of Angular Misalignment of Shaft Case.

As explained in the appendix 2 attached, on how the angular misalignment of shaft is set up on MFS, which said that by unscrewing the one of the two jack bolts the predetermined amount on the back side of the machine and for the front side of the machine, screw in the opposite jack bolts the predetermined amount, this condition will point the rotor shaft to one side, introducing angular misalignment. Table 4 shows the readings stated and the energy consumed.

Table 4 Readings of current and voltage and calculated energy consumed by motor when shaft in angular misalignment

Degree Of Misalignment (◦)	Current Reading on Ammeter Clamp,I (Amp)	Average Current Reading, I (Amp)	Voltage Reading on Multimmeter, (V)	Average Voltage Reading,(V)	Energy Consumption (P=IV) (Watt)
5	0.68	0.69	4.37	4.42	**3.05**
	0.68		4.47		
	0.70		4.43		
10	0.74	0.73	4.57	4.55	**3.32**
	0.72		4.56		
	0.73		4.53		
15	0.76	0.75	5.01	4.84	**3.63**
	0.75		4.86		
	0.75		4.64		
20	0.76	0.76	4.86	4.92	**3.74**
	0.76		5.00		
	0.76		4.90		
25	0.79	0.78	5.11	5.11	**3.99**
	0.78		5.15		
	0.78		5.08		
30	0.80	0.83	5.45	5.33	**4.42**
	0.83		5.30		
	0.79		5.25		
35	0.83	0.86	5.55	5.54	**4.76**
	0.86		5.48		
	0.88		5.60		
40	0.91	0.90	5.64	5.72	**5.15**
	0.90		5.80		
	0.88		5.73		

4.2.3 Analysis Current and Voltage Reading of Angular and Parallel Misalignment of Shaft Case.

Based on Table 3 and Table 4 before, there are three readings of current and voltage for each degree of misalignment for each types of misalignment. The readings are then counted into average readings. Table 3 shows readings for parallel misalignment which the lowest readings are 0.57 Amp of current and 3.97 V of voltage, increasing minimally from 0^{o} to 40^{o} until reached the highest readings of 0.77 Amp of current and 5.20 V of voltage. For angular misalignment case as shown in Table 4, the highest readings are 0.90 Amp for current and 5.72V for voltage which has been increase as the degree of the misalignment change from 0.69 Amp of current and 4.42V of voltage readings. Thus, this somehow explains the differences between parallel and angular misalignment that angular used current and voltage supplied more than parallel misalignment. Referring to previous studies, misalignment fault uses extra electrical power to rotate the shaft because, the motor has been applied additional loads due to the misalignment which make it operates in abnormal condition. Additional or parasitic loads which will cause cyclic fatigue and thus will results in equipment wear and plant shutdown.

4.3 Graph and Analysis

This part shows the corresponding of energy consumed by the motor to rotate the shaft as the degree of the misalignment of shaft increase in parallel misalignment and angular misalignment cases. The amount of energy consumed when the degree of misalignment is 0º, or in the other word when it is in perfectly aligned condition, was only 2.24 Watt. In this analysis part, there are also the linear lines or called as line best fit, to identify the linear equations shown on both parallel and angular misalignment graphs which relates the degree of misalignment of shaft and the energy consumed by motor to rotate the shaft. The equations embark a conclusion and a proof to the corresponding analysis obtained, which the x integer in the equation represents the degree of misalignment of shaft rotor coupling.

4.3.1 Graph for Energy Consumed by Motor in Parallel and Angular Misalignment Cases

Figure 33 shows the comparison of energy consumed by motor to rotate the shaft in angular case and in parallel case. It shows that angular misalignment consumed more energy to rotate the shaft compare to when the shaft in parallel misalignment condition. Angular misalignment is a type of misalignment where the centerlines of the driven and driver machine coincide but with angle. Due to the eccentric centerlines condition along with the angle in between, this has form forces and moment causing the variation in energy responses that will increase as the degree of misalignment increase (Chandra Sekhar Reddy and Sekhar, 2015). In Figure 33 above shows the linear equation of line best fit for each types of misalignment which is the proof to the analysis if the degree of misalignment is above 40º, the energy that will be consumed to rotate the shaft will also increase.

In Figure 33, it shows a corresponding of energy consumed by motor to rotate shaft in parallel misalignment as the degree of misalignment of shaft increase. Based on the data measured and calculated above, when there is increment in degree of misalignment of shaft, the increment in energy consumed by the motor to rotate the shaft also happened. First change of degree of misalignment is from 0º to 5º, the energy consumed increase from 2.24 Watt to 2.26 Watt. Even the energy increment, is only the slightest, which is 0.02 Watt, the analysis for the parallel alignment affecting the energy consumption of the motor to rotate the shaft is proven.

Parallel misalignment is when the centrelines between two shafts did not coincide each other, and being parallel to each other, this pictures a machine condition which is operating under exceeding or high operating condition (Hines, Jesse and Edmondson,; Dockyard and Watson, 2012; Estupinan, 2018). This has cause the motor to use high energy to rotate the shaft in order to operate the machine. Thus, due to this condition, it will affect the machine to undergo a fatigue cycle that may be resulting in catastrophic failure on plant. The linear equation for this graph is stated in equation (4,3,1) below.

$$y = 0.2349x + 1.8993 \qquad (4,3,1)$$

Figure 33 also shows a corresponding of energy consumed by motor to rotate shaft in angular misalignment as the degree of misalignment of shaft increase which explains, the increasing of energy consumed by the motor to rotate the shaft as the degree of misalignment was set to be increase from 5º to 40º. For angular misalignment data, the highest energy consumed to rotate the shaft is 5.15 Watt, and it starts with increment of 0.81 Watt from 2.24 Watt of shaft with 0º of misalignment. Angular misalignment has shown increment of energy consumed by motor to rotate the shaft at first change of degree of misalignment higher than parallel misalignment case has shown.

Angular misalignment usually happens because of soft foot, the base of the driver or driven equipment sometimes not stable or not in the same level that may cause the machine to move in rocking motion like a baby's cradle when operating. When soft foot happen, it tends to make the shaft of the driver machine and the driven machine to be misaligned with angle. The centerlines of the shafts still coincide with each other but with angle and it is not in linear position. Thus this make the motor to rotate the shaft with extra energy (Ferrando Chacon *et al.*, 2014; Verma, Sarangi and Kolekar, 2014; Estupinan, 2018) . The linear equation for this graph is stated in equation (4,3,2) below.

$$y = 0.2919x + 2.6939 \qquad (4,3,2)$$

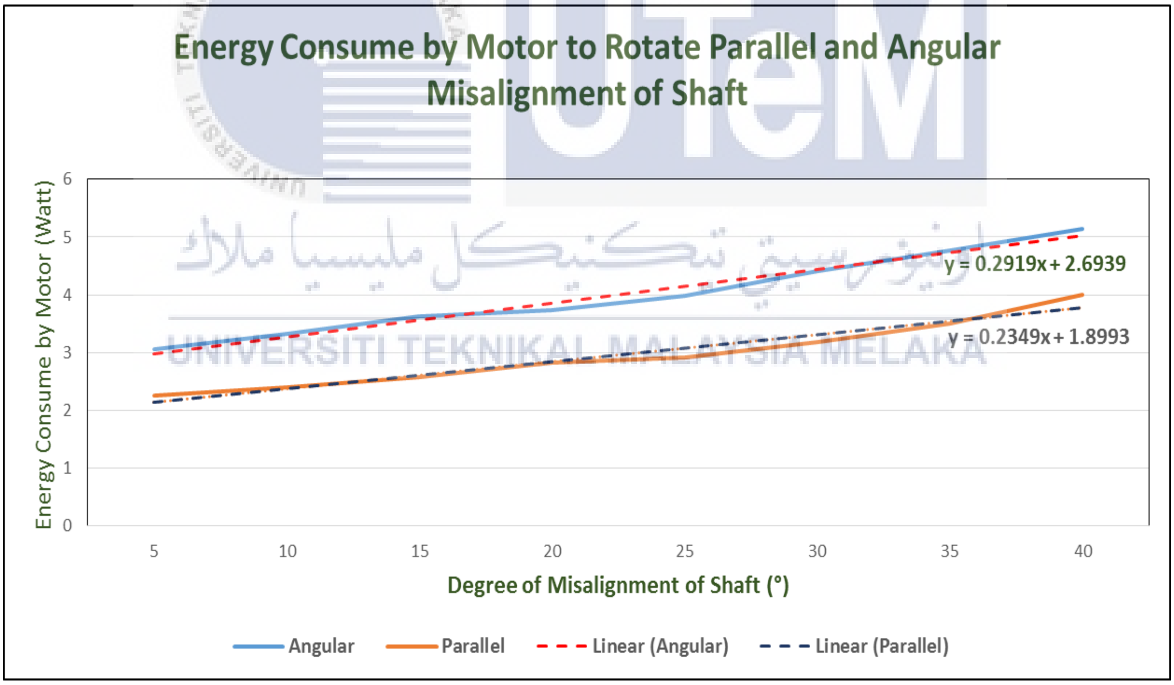

Figure 33 Corresponding of energy consumed by motor with increasing degree of misalignment in parallel and angular cases.

Generally, when the shaft in parallel or angular misalignment condition, the analysis for both were all showed the same pattern which is the energy consumed by the motor to rotate the shaft increase as the degree of misalignment of shaft increase. This is due to improper aligned shafts generates reactive forces in coupling that has cause machine vibration. It means that this experimental investigation has achieved or proven when the data and analysis obtained is similar to the previous study that is also shown in Figure 34.

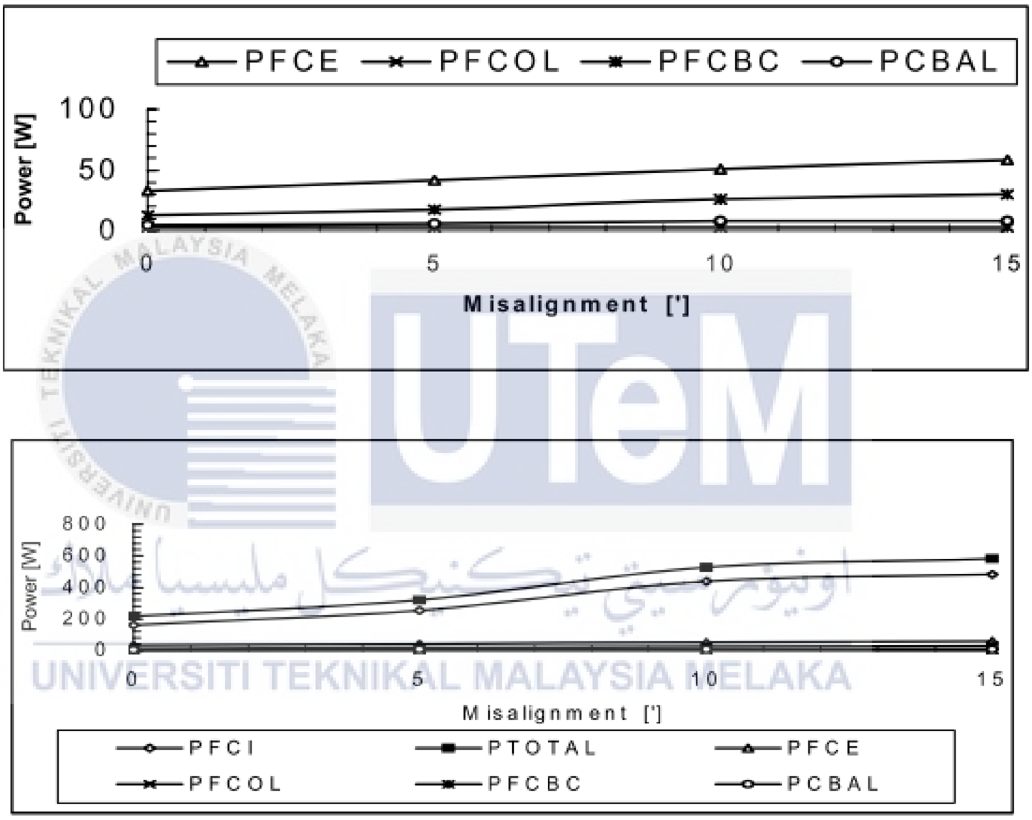

Figure 34 Degree of misalignment vs Power Loss

In reality, the real condition of what really happens is the combination of parallel and angular misalignment, if it said that a machine is having a misalignment fault or problem (Hili *et al.*, 2005; Nakhaeinejad and Ganeriwala, 2009; Litwin, Olszewski and Wodtke, 2011; Behera, Behera and Naikan, 2014; Ferrando Chacon *et al.*, 2014; Verma, Sarangi and Kolekar, 2014; Liu *et al.*, 2017; Wang and Jiang, 2018). Reactive forces developed due to rolling elements, bearing and coupling deformations by misalignment of shafts (Tirumalai, February, 1998) that because of this, will consumed extra energy to operate the rotating machinery.

To differentiate between angular and parallel is hard, because shaft misalignment frequently happened in large rotor bearing systems like steam turbine shafts, gas turbines shafts and aircraft rotating components (Hines, 1999), which what really matters when there is misalignment fault happen in large components is the remedy, which is just the same to every types of misalignment (Nower, May/June 1994). High level of misalignment may lead to fatigue cracks or rotor to stator rubbing, thus may lead to catastrophic failure to plant.

4.4 Cost Reduction Initiative

Misalignment happened due to many factors, such as soft foot, additional loads, thermal growth and inaccurate assembly which then will lead to extra energy consumption and extra after cost involve such as manpower cost needed to repair the misalignment, repair or replace cost of damage, cost for electrical power used in time of fixing the misalignment and others.

All those costs can be tamed if early precautions been practiced. Early precautions practices are such following the condition based maintenance program, that detect early stages of abnormalities for example in this misalignment cases is the motor will produce abnormal noise and vibration when there is fault happening to it to give a sign that it needed to be checked and fixed by predictive maintenance or proactive maintenance or preventive maintenance program.

Every industry should have a schedule on when to do maintenance on machines to frequently check the machine conditions in order to maintain the machines reliability to operate in a long time. Next is, when there is failure detected in machineries, the operators should not ignore or wait until the machines broke down, instead the operators should have been immediately checking on the machineries to fix it before it breaks. In order to solve on the causes of failure to know the remedial on how to fix it, the operators should always make a fault tree analysis, to analyse the root cause of a failure happen.

Thus, when misalignment happen, the only accurate method or equipment to be used to fixed the misalignment degree is by using laser indicator, which is quick and easy to be used (Garg *et al.*, 2017). It will save time, save cost, save energy consume so that it will not cost the industries in big amount of money.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

5.1.1 Objective One: To study the impact on energy consumption due to the misalignment of shaft motor coupling.

In conclusion, this experimental investigation has achieved the first objective of this study which is to identify the impact of misalignment on the energy cost to rotate shaft motor coupling. Even it is just tested for 0 to 40 degree of misalignment difference, the analysis has shown the increment of the energy consumed to rotate the shaft rotor coupling as the degree of misalignment increase 43.5 percent for parallel misalignment and 41 percent for angular misalignment. Besides, the analysis of the graph has also been calculated to outcome an equation which can be the answer for the degree of misalignment of shaft that is exceeding 40º. From previous studies it also obtained that the misalignment fault that happened on rotating machineries is the combination of both angular and parallel misalignment, because the reasons of the misalignment to happen is varies, that may sum up to cause the misalignment to be the combination of both parallel and angular misalignment.

Besides, an experimental investigation has also been conducted to evaluate experimentally the influence of the misalignment of shafts towards energy consumption by motor to rotate the shaft. From this experiment, the misalignment of shafts has strong influence on the energy consumption of motor to rotate the shaft and this proven the previous studies that the higher the degree of misalignment of shaft, the higher the energy will be consumed by the motor to rotate the shaft (Inc., 1994). Improper aligned shafts generates reactive forces in coupling that has cause machine vibration which lead to high energy consumption. High energy consumption generally, has cost high electrical bill and when the rotating machineries down, cost more repair orders and more manpower to include, thus cost high amount of money towards the industries to pay for the repair orders and the manpower.

Thus, high energy consumption due to misalignment of shaft that happened has varies impacts towards the rotating machineries in plants. A potentially high stresses in the bearings, shafts, couplings and seals due to misalignment has generates an abnormal vibration towards these components (Hili *et al.*, 2005; Kumar, Krishnan and Sarangi, 2015). Further, these parasitic loads will decrease the operating life of the machinery. When the operating life of the machineries slow down to decrease, it will increase the inventory part in making the repair order to be higher than usual, to keep on repairing in order to extend the life of the machines (Xu, October 1993). Misalignment of shaft in rotating machineries produced abnormal noise (Verma, Sarang i and Kolekar, 2014; Chandra Sekhar Reddy and Sekhar, 2015)

5.1.2 Objective Two: To propose cost reduction initiative due to early damages to the machinery causes by misalignment of shaft motor coupling the industry.

Apart from wasting moneys towards the repeating repair orders in inventory part, it is better to waste or spend on the remedial of this misalignment of shaft condition which is also the cost reduction initiative. The lowest cost is by applying the condition based maintenance, which is preventive, proactive maintenance and predictive maintenances practices and also by using the straightedge and the dial. Dial indicator is better in accuracy compared to the straightedge but it is not an easy type of equipment to use because it requires to rotate both side of shaft, the driven and the driver shaft, to make it align.

Condition based maintenance program is a practice that should be implemented in industries. All rotating machineries should be monitored, especially on the vibration which is an indication of misalignment. This is due to insufficient bolt tightening, coupling faults, or foundation settling. Furthermore, the new installed equipment for alignment changes should be rechecked after three to six months of operation, due to foundation settling. Besides, employing the right personnel is necessary, which is the detail-oriented person who will stick with the job until it is done right, that can make all the difference in an acceptable alignment.

Next is the predictive maintenance techniques, such as frequency spectrum analysis and vibration test, these tests can be used to distinguish between shaft misalignment, electrically caused vibration or bearing wear. Other than that is by using the laser indicator, a non-contact method, which is made to be the easiest to use in controlling the misalignment, it requires less energy and increase the mean time between failures(Cheng, Mustafa and Oelmann, 2012; Rexnord, 2014). This laser indicator has many long term benefits, which it will improve the machine reliability and productivity, reduce the repair cost of machine and also cost of workers. Furthermore, it will also reduce the energy consumption of the machine, thus reducing the time of machine repair and installation. Therefore, based on study on the previous studies, the second objective has been achieved. The cost reduction initiative due to early damages to the machinery causes by misalignment of shaft motor coupling the industry has been proposed.

5.2 Recommendation

For future research, it is recommended to do an experiment with varies speed and varies degree of misalignment, to investigate on the behaviour and pattern of the energy consumed when in different angle of misalignment with varies speed.

Besides, the result and analysis of misalignment of shaft experiment would be better and an eye-opener if there is an actual motor and driven equipment such as pump, just a simple model in the condition based maintenance lab to make known on how the rotating machineries faults happened in real plant.

Last but not least, alignment equipment such as laser indicator is recommended to be designed and innovated for calibrating and maintenance activities, in order to achieve and record accurate data reading.

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APPENDICES

Appendix 1 Standard Operating Procedure of MFS for Parallel Misalignment

A.1 Alignment

A.1.1 Procedures for introducing parallel misalignment

The MFS must be in alignment prior to starting this exercise. For increased vibration amplitude, install a rigid shaft coupling. Be sure to disconnect the electrical power to the motor.

1. Remove alignment T-handle pins
2. Screw the horizontal jack bolts inward until they contact the rotor base plate.
3. Rotate the outer rings of all four plastic dials until the index line matches the zero mark.
4. Determine how much horizontal misalignment is desired. For example, you ay wish to introduce 10 mils (0.0010 inches).
5. Loosen all four socket head cap screws that secure the rotor base plate to the support channels
6. On the back side (side away from you). Unscrew the jack bolts the predetermined amount.
7. On the front side of the machine (side just in front of you), advance or screw in the jack bolts the predetermined amount. For parallel misalignment, both ends of the rotor base must be moved out of alignment the same amount. Introducing this condition will assure the motor and rotor shafts remain parallel
8. Tighten the socket head cap screws that secure the rotor base plate to the support channels
9. Close the protective cover
10. Energize the motor and start the MFS. Collect vibration data as necessary.
11. The shafts can be approximately realigned by loosening the socket head cap screws that secure the rotor base plate and reversing the jacking movements to bring the dials back to zero.

Appendix 2 Standard Operating Procedure of MFS for Parallel Misalignment

A.1.2 Procedures for introducing angular misalignment

The MFS must be in alignment prior to starting this exercise. For increased vibration amplitude, install a rigid shaft coupling. Be sure to disconnect the electrical power to the motor.

1. Remove alignment T-handle pins
2. Screw the horizontal jack bolts inward until they contact the rotor base plate.
3. Rotate the outer rings of all four plastic dials until the index line matches the zero mark.
4. Determine how much angular misalignment is desired. For example, you may wish to introduce 10 mils (0.0010 inches).
5. Loosen the socket head cap screws that secure the rotor base plate to the support channels
6. On the back side (side away from you). Unscrew one of the two jack bolts the predetermined amount.
7. On the front side of the machine (side just in front of you), advance or screw in the opposite jack bolts the predetermined amount. This condition will point the rotor to one side introducing angular misalignment. To make it easier for the rotor base plate to pivot, it is suggested that the other two jack bolts be unscrewed slightly (1 mil or so).
8. Tighten the socket head cap screws that secure the rotor base plate to the support channels
9. Close the protective cover
10. Energize the motor and start the MFS. Collect vibration data as necessary.
11. The shafts can be approximately realigned by loosening the socket head cap screws that secure the rotor base plate and reversing the jacking movements to bring the dials back to zero.

Appendix 3 Gannt Chart for PSM 1

NO	TASK	WEEK														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Preparation Of Progress Report															
2	Articles and Journals Searching and Reading															
3	Progress on Literature Review and Submission Of Progress Report															
4	Progress on Methodology															
5	Progress on Full Report															
6	Preparation Of Slide Presentation															
7	Submission of PSM 1 Report															
8	Presentation PSM 1															

Appendix 4 Gannt Chart for PSM 2

NO	TASK	WEEK														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Preparation Of Tools and Machine															
2	Experiment Setup and Submission Of Progress Report															
3	Collecting Data															
4	Analyzing Data															
5	Progress on Full Report															
6	Preparation Of Slide Presentation															
7	Submission of PSM 2 Report															
8	Presentation PSM 2															