AUTOMATIC SELF-ALIGNMENT FOOTING SYSTEM FOR ROTATING SHAFT

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2022

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This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronic Engineering with Honours

Faculty of Electronic and Computer Engineering
Universiti Teknikal Malaysia Melaka

2022

DECLARATION

I declare that this report entitled "Automatic Self-Alignment Footing System for Rotating Shaft" is the result of my own work except for quotes as cited in the references.

Signature	:	………………………………………..
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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Bachelor of Electronic Engineering with Honours.

Signature	:	………………………………………..
Supervisor’s Name	:	IR. DR. ANAS BIN ABDUL LATIFF
Date	:	17 December 2021

DEDICATION

To my parents.

The reason of what I become today.

Thanks for your great support and continuous care.

To my supervisor.

Whose encouragement, guidance, and support from the start until the final level.

Lastly, I offer my regard and blessing to all of those who supported me in any aspect during the completion of the project.

ABSTRACT

Shaft misalignment can be classified into two types which are angular misalignment and offset misalignment. According to research, misalignment is responsible for about half of all machine failures. Bent rotors or crankshafts, bearing defects, coupling wear or loss, and bearing housing damage are all caused by misalignment. Excessive vibration and sound emission are the key causes of misalignment in rotating machinery. The research problem statement as well as the project's objective have been established. The scope of the study has been discussed. The details related to the project and study have been explained in depth in the literature review section. An automatic self-alignment system that consists of an accelerometer sensor, motor driver, and stepper motor integrates into a single microcontroller (NodeMCU ESP32) has been developed in order to reduce the vibration that occurs by correcting the misalignment. The design and development of the automatic self-alignment system are discussed in the methodology section. The product has then been tested by vibration testing to test the functionality and performance of product. The product is able to do the fine-tuned and can reduce the vibration that occurs during the rotating shaft.

ABSTRAK

Ketidakseimbangan poros dapat diklasifikasikan sebagai dua jenis iaitu ketidaksejajaran sudut dan ketidakseimbangan mengimbangi. Menurut penyelidikan, penyelarasan yang salah bertanggungjawab untuk kira-kira separuh daripada semua kerosakan mesin. Rotor bengkok atau poros engkol, kecacatan galas, kehausan gandingan atau kehilangan, dan kerosakan perumahan galas semuanya disebabkan oleh ketidaksejajaran. Getaran dan pancaran suara yang berlebihan adalah penyebab utama ketidaksejajaran dalam mesin berputar. Pernyataan masalah penyelidikan, serta objektif projek, telah dibuat. Skop kajian telah dibincangkan. Perincian yang berkaitan dengan projek dan kajian telah dijelaskan secara mendalam di bahagian tinjauan literatur. Sistem penyelarasan diri automatik yang terdiri dari sensor akselerometer, pemacu motor, dan motor stepper yang disatukan ke dalam mikrokontroler tunggal (NodeMCU ESP32) telah dibangunkan untuk mengurangkan getaran yang terjadi dengan memperbaiki ketidaksejajaran. Reka bentuk dan pembangunan sistem penyelarasan diri automatik dibincangkan dalam bahagian metodologi. Produk kemudian diuji dengan pengujian getaran untuk menguji kefungsian dan prestasi produk. Produk ini mampu melakukan penalaan halus dan dapat mengurangkan getaran yang berlaku semasa poros berputar.

ACKNOWLEDGEMENTS

First and foremost, praises and thanks to the God, the Almighty, for His showers of blessings throughout my Final Year Project work to complete it successfully. Without the guidance of our Almighty, this project would not be completed on time.

I would like to express heartfelt gratitude to my supervisor Dr Anas bin Abd Latiff for his patience guidance, enthusiastic encouragement and for giving me the opportunity to study with him about exciting case study for my Final Year Project. His support and constructive suggestions were the most important assets that lead this project complete. Last but not least, my thanks also extended to parents and all friends for their valuable support and constant encouragement throughout this project.

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LIST OF SYMBOLS AND ABBREVIATIONS

HRA	:	Human Reliability Analysis
RPM	:	Revolutions Per Minute
PCB	:	Printed Circuit Board
HMI	:	Human Machine Interface
LCD	:	Liquid Crystal Display
LED	:	Light Emitted Diode
ISO	:	International Organization for Standardization
IDE	:	Integrated Development Environment

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

This chapter describes shaft alignment in rotary machinery. This chapter covers the background of the study, objectives of study, problem statement, scope of the project and chapter overviews.

1.1 Background of Study

Nowadays, rotating machinery such as rotating shaft are widely used in the industry. The rotating part of the shaft is the most essential cause of vibration [1]. Misalignment of rotating shaft generate exaggerated vibrations, noise, coupling, and bearing temperature increases, and premature bearing, coupling, or shaft failure. The couplings were used to directly coupling the larger motors with their loads. The flexible coupling used to deflate vibration send from one equipment to another.

Misalignment happens when the centerlines of the motor and the driven device shafts are out of line with each other.

Misalignment of the shaft were exceptionally unacceptable since it can cause the rotating system to work sub-optimally, however, may likewise cause a mechanical heating impact that causes a quick wear of the machine bearings. Perfectly alignment shaft is not easy to be achieved and the couplings fastened to the shaft may occur parallel misalignment that also determined as lateral and axially misalignment [2]. Thus, proper shaft alignment affecting the smooth, effectiveness transportation of generating power to the driven equipment via the motor. It is important to attaining a correct shaft alignment when installing rotating mechanical systems.

Most of the industry is using a dial indicator to align the shaft. Dial indicator is used to check the parallelism between two surfaces of shaft whether the axis of dial indicator is in the same direction. But the dial indicators are not easy to read it and require the specialist person to read it. The person must know how to model the position of the shaft by calculating the machine moves. The installing dial indicator also consumes a lot of time, and it will delay the production of the company. Thus, a new system of alignment shaft must be developed for aligning the shaft while reducing the vibration.

1.2 Problem Statement

The two parallel shafts are not in same line cause the parallel misalignment. The angular misalignment is the difference of slope of one shaft compared to other shaft that occurs when the driven equipment shafts were to be extended. The shaft were cross one another than superimposed or running along centerline [3].

The accurately fine-tuned of the shaft alignment are difficult to achieve and impossible to be done on vertically and horizontally between the driven motor and a pump although the latest tool is used to maintaining the alignment conditions [4].

A human reliability analysis (HRA), which predicts the error probabilities of the operators, has been conducted for several decades in order to visualize the contributions of human errors to the reliability of systems [5].

1) Misaligning shafts can turn out a large number of machinery breakdowns and increase much of the unplanned downtime that results in a loss of production.
2) Failure to align the shafts properly will increase the amount of stress on the machinery that will cause vibration.
3) A manual alignment by engineer could affect an inaccuracy position of the shaft as a factor of human error.

1.3 Research Objective

The objectives are as follows:

i. To design an improve automatic self-alignment system that can sense vibration. **[RO1]**

ii. To integrates an accelerometer sensor, motor driver and stepper motor into a single microcontroller (NodeMCU ESP32). **[RO2]**

iii. To analyze the vibration reading during the shaft alignment process at different speed. **[RO3]**

1.4 Scope of Work

This project will look into the creation of an automatic self-alignment footing system for rotating shaft. This paper walks you through the steps of designing and developing an automatic self-alignment footing system for rotating shaft. To increase understanding of the shaft alignment process, the theoretical of the shaft alignment process will be used. To automate the system, this project integrates with an accelerometer sensor, motor driver and stepper motor into a single microcontroller (NodeMCU ESP32).

Accelerometer sensors are ICs that measure acceleration, which is the change in speed (velocity) per unit time. Measuring acceleration makes it possible to obtain information such as object inclination and vibration [6]. Then, motor drivers act as an interface between the motors and the control circuits. Motor requires high amount of current whereas the controller circuit works on low current signals. The function of motor drivers is to take a low-current control signal and then turn it into a higher-current signal that can drive a motor [7].

Next, a stepper motor is an electric motor whose main feature is that its shaft rotates by performing steps, that is, by moving by a fixed number of degrees. This feature is obtained thanks to the internal structure of the motor and allows to know the exact angular position of the shaft by simply counting how may steps have been performed [8].

Finally, the coding is then compile to the system and the performance during rotating shaft machinery is validate.

1.5 Significant of the Project

The project's findings will assist the industrial sector, potentially resulting in a longer life span for the machinery. It can also save the industry's budget by lowering the cost of maintenance. Furthermore, the outcome of this project will reduce noise pollution caused by vibration therefore all of this significant can lead to an impact on society and environment. This initiative is in keeping with the 9th Sustainable Development Goal, which is Industry, Innovation, and Infrastructure, and will be implemented in the industrial sector.

1.6 Report Structure

The Final Year Project consists of five chapters which are the introduction, literature review, methodology, results, and discussion and lastly conclusion. Chapter 1 is about the introduction of the project, problem statement, objectives, scope as well as the significance of the study.

Chapter 2 is about literature review that covers the gathered findings of numerous information from various sources such as journals, articles, books, and websites. This chapter will discuss about the latest findings, method use and the result of the related topic that found in the journal paper, books, or articles.

Chapter 3 is about research methodology. The methodology will be discussing about the experimental apparatus, methods, and procedures for data analysis.

Chapter 4 is about the result that will analyze and discuss the results obtained that related to the objectives. Lastly, the chapter of conclusion will summarize the report and suggestions for future work are also included in this chapter.

CHAPTER 2

LITERATURE REVIEW

This chapter will explain about the literature review from the research regarding of shaft misalignment, type of misalignment, causes and effects of misalignment, methods of alignment, and methods of misalignment, and the components involved in shaft alignment.

2.1 Shaft Alignment

A shaft is a rotating member that is used to transmit power. When members link together, shafts place members such as pulleys or gears in particular positions to transmit torque along the members. The shaft was created to carry out a specific function in a machine. Shaft alignment is the method of moving power from one shaft to another when two or more machines, such as motors and pumps, are positioned at the same location and the rotation axes of two shafts are matched when the engine is operating normally [9].

Shaft alignment is the alignment of the shafts of a coupled machine that consists of a driver and a driven machine. The powered machine receives rotating mechanical power from the driver machine, such as electric motors, turbines, or reciprocating machines, through a coupling. A powered machine that generates electricity, such as a generator, a fan, or a pump [10].

The driver transmitted power to the driven motor through a coupling that linked both shafts. When they are coupled together and rotate at their normal operating conditions, the centerlines of both shafts must remain in a single straight line. The primary goal of shaft alignment is to extend the life of a dynamic rotating system. To achieve this goal, the machinery components that have most likely failed must function properly within the constraints of their design [11].

The ideal shaft alignment would reduce unnecessary axial and radial forces on the bearings, resulting in longer bearing life and stability of the rotor under normal operating conditions, as well as minimizing shaft bending caused by power transfer from one coupling to another. Due to cyclic fatigue, it will also reduce the probability of shaft loss and wear rate in the coupling components. The exact alignment would maintain correct internal rotor clearances [3].

2.2 Shaft Misalignment

The difference in shaft direction from its collinear axis of revolution measured to transfer power while gear is working is known as shaft misalignment. The failure to align the shaft is responsible for 50% of machine downtime and the costs associated with machinery damage. Proper shaft alignment will prevent a lot of machinery damage and reduce downtime, which costs money and hurts productivity.

When the shaft or belt on rotating parts does not comply, causing harm to seals and couplings, company, and machine downtime costs skyrocket [4]. When the shafts of two rotatory machines are straightly coupled by a flexible coupling, any misalignment between the centerlines of rotation of the shaft can cause vibration and additional loads that can cause premature wear, catastrophic failure of bearings, seals, the coupling itself, and other machine components [12].

The shaft misalignment would increase the stress rate on the components, resulting in a slew of possible issues that will have a negative impact on a company's bottom line. Misalignment can lead to a variety of issues, including:

i. Increased friction causes unnecessary wear, high energy consumption, and the risk of equipment failure prematurely.
ii. Bearing and seal wear that leads to premature failure.
iii. Premature shaft and coupling failure.
iv. Excessive lubricant leakage in the seals.
v. Coupling and base bolt failure.
vi. Vibrations and noise levels have increased.

2.3 Type of Misalignment

Misalignment of rotating machinery, such as the shaft or belts, may damage seals and couplings, resulting in unplanned machine downtime. Misalignment of shafts was responsible for 50 percent of all equipment failure costs [4]. Parallel or angular misalignment, or a combination of both, may cause misalignment. Thus, parallel misalignment and angular misalignment are the two forms of misalignment.

2.3.1 Parallel Misalignment

Parallel misalignment occurs in the distance between two shaft centerlines, according to Wowk (2002). The horizontal plane had offsets that were displaced to the right or left, and the vertical plane had offsets that were located at various heights. In both the horizontal and vertical directions, parallel misalignment may occur. Misalignment of the shaft in the horizontal direction is known as horizontal misalignment.

Both shafts (motor and pump) are in the same horizontal plane, but the motor shaft has been pushed away from the pump shaft horizontally. Vertical shaft misalignment, on the other hand, happens on a vertical axis. Both shafts operate in the same vertical plane, but the motor shaft has been moved away from the pump shaft vertically. Figure 2.1 depicts a parallel misalignment that can damage both the driver and the devices being powered [13].

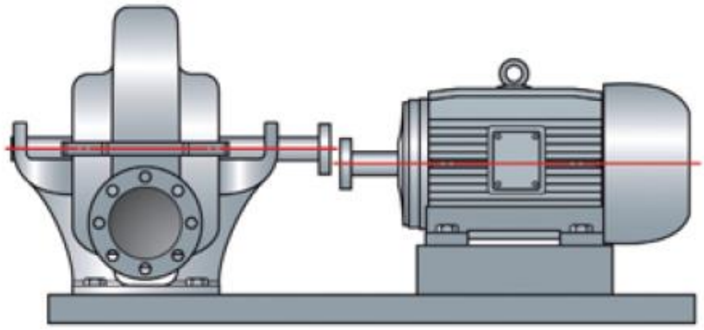


Figure 2.1 Parallel misalignment [13].

2.3.2 Angular Misalignment

When the motor is mounted at an angle to the driven engine, angular misalignment occurs when the shafts are not parallel but in the same plane with no offset. If the centerlines of the driver and driven machine shafts were to be extended, they would overlap. This misalignment has the potential to cause significant damage to the powered machinery. Horizontal, vertical, or both misalignments may result from the motor shaft's different slope from the stationary.

On one side or right, or below the beneath, an angle or misplacement may occur. Instead of superimposing or continuing down the centerlines, the shafts will overlap. Figure 2.2 depicts the angular misalignment that can damage the driver and the devices being powered [13].

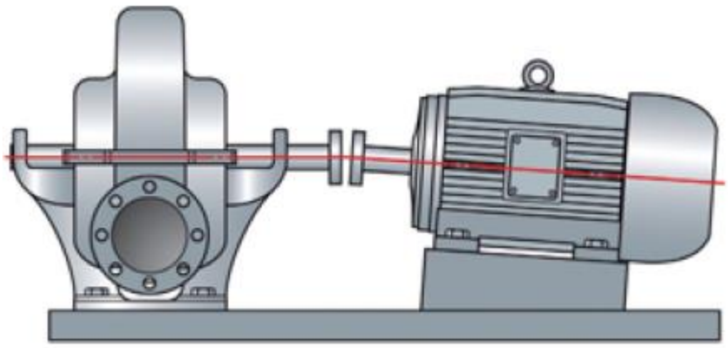


Figure 2.2 Angular Misalignment **[13]**.

2.4 Cause of Misalignment

Shaft misalignment can be caused by a variety of factors. The alignment procedure is one of them. When an alignment procedure is incomplete or incorrect, it may result in misalignment due to human error. Foundations, often referred to as baseplates, may settle into a lower position. This may result in misalignment of the settling. Even if the machinery is realigned, if the baseplates of the machines are not fixed, misalignment will occur again [14]. During machine startup, the initial torque is high, forcing the shafts out of line and causing torsional misalignment.

Aside from that, distorted couplings were the product of a coupling defect that originated in the manufacturing process. This misalignment occurs most often on new equipment or when the coupling fails. Furthermore, the machinery shifts proportionately to one another, resulting in a thermal growth misalignment due to relative movement misalignment. Different materials expand at different rates as they are heated. Thermal growth must be considered when the equipment is operated above ambient temperature [14].

Machines are often misaligned due to thermal growth when they are modified in the cold pre-working state. The offset value in the thermal condition was brought out by component manufacturers so that specialists could easily correct misalignment in the thermal growth condition. As the shaft is misaligned, the higher extreme temperatures increase and decrease the film thickness.

When working conditions are not met, the researcher discovered that the bearing's efficiency can be improved by a bulk deformity in the bearing geometry [15]. Due to inadequate establishment and intemperate shaft misalignment, equipment seal life was drastically reduced [9].

2.5 Effect of Misalignment

Misalignment in dynamic rotating machinery can be observed in a variety of ways, including excessive friction, extreme bearing temperatures, wear patterns, and noise. A system's preventive maintenance program includes a number of techniques. Inspections are usually carried out when damage occurs [14].

Misalignment causes vibration in machinery. Also, with self-aligning bearings and flexible couplings, aligning two shafts and their bearings to avoid forces that cause vibration is difficult. Vibration caused by misalignment occurs in both the radial and axial directions [14].

The vibration is affected by machine speed and coupling stiffness. Unbalance, misalignment, mechanical detachment, shaft break, and other malfunctions are common causes of vibration in spinning machinery. It is heavily influenced by the machine's velocity and the stiffness of the coupling [16].

Only the experienced operator will notice the odd sounds during operating. Misalignment of shafts will shorten the life of the equipment. The equipment's reduced service life necessitates unscheduled maintenance. As a result, the amount of time available for production is reduced [14].

2.6 Method of Correcting Misalignment

Alignment is needed when the powered machine is new or when it is being operated incorrectly. The primary goal of shaft alignment is to align the centerline of the driver and the driven machine in a single straight line. Thus, alignment is needed to avoid the effect of misalignment while increasing the shaft's operation rate [17]. There are various methods for fixing misalignment.

2.6.1 Traditional method

There are many methods for correcting shaft misalignment. Some industries continue to use the traditional method of alignment. The traditional method of fixing misalignment is usually quicker and simpler, but it is inefficient. Straightedge ruler, dial indicator, and laser alignment are all used to correct shaft alignment.

2.6.1.1 Straightedge / feeler gauge

The most popular technique for alignment is to use a visual line up and a straightedge. Figure 2.3 depicts a technique that allows technicians to inspect the working conditions and installation viability early in the installation process [18]. During straightedge ruler placement on two coupling halves, the maintenance inspector visually inspects the part to determine if it is properly aligned or not. Despite the fact that this technique is the most inaccurate that is needed by most precision machinery, the rough alignment technique is easy and quick to use [4].

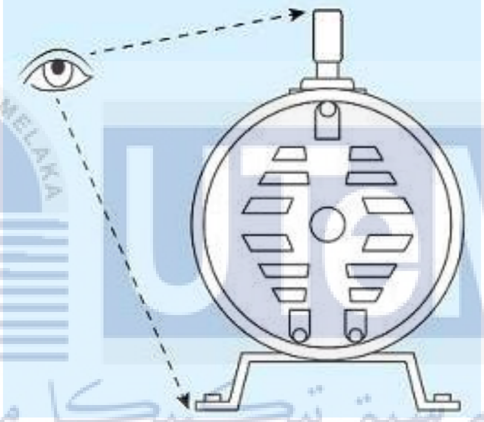


Figure 2.3 Visual line-up **[18]**

Straightedges serve the purpose of using the offset between the coupling halves depicted in Figure 2.4. Alignment may be corrected under the machine's feet (four feet). A feeler gauge is used to measure the space between coupling halves at the beneath and top of the coupling. The angularity of correction is measured and projected to the surface of the machine's leg to obtain the proper shim adjustments. This is known as the trial and error method, and it is useful for early installation and erratic alignment [18].

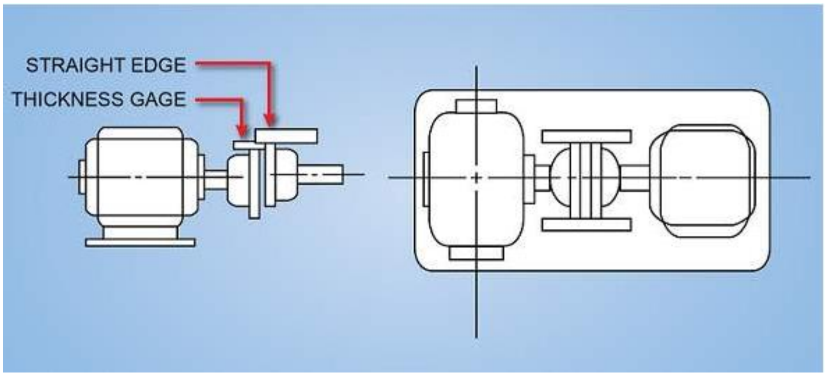


Figure 2.4 Example of straightedge process **[18]**.

2.6.1.2 Dial indicator

Dial indicators are another traditional method of alignment. Despite the fact that the dial indicator has a higher degree of precision, the technician must have a high level of technical ability to operate it, which takes a long time [13]. The installation of a dial indicator is depicted in Figure 2.5.

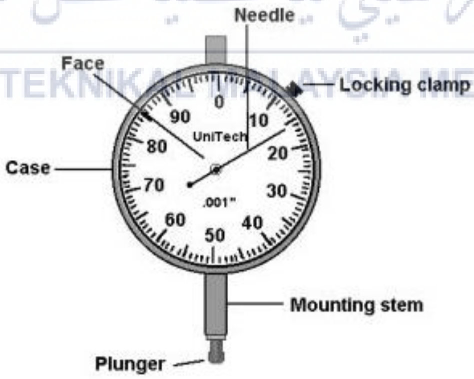


Figure 2.5 Dial Indicator **[19]**.

There are two methods for aligning machine shafts using a dial indicator. A dial indicator is a measurement device that is used to determine relative location [19]. The rim and face method and the reverse indicator method are the two most popular methods of dial indicator alignment [20].

2.6.1.2.1 Rim Face Method

The Rim Face method is one of the oldest alignment techniques. This technique can be used in a variety of ways, including straight edge and feeler gauge approaches, single dial rim-face, two dial rim-face, and trial and error rim-face. The rim-face approach is depicted in Figure 2.6.

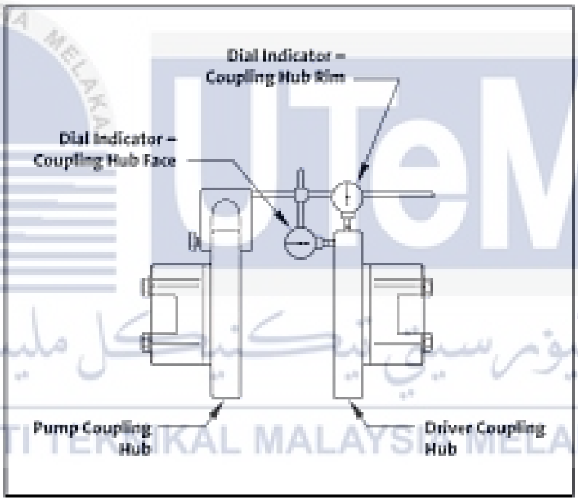


Figure 2.6 Rim and Face Indicator Setup **[21]**.

To evaluate the relative position of the movable shaft with respect to the stationary shaft, two dial indicators are used. The offset in one plane along the shaft lengths is measured using the rim dial. The face dial, on the other hand, tests the angularity or angle between the shafts [22].

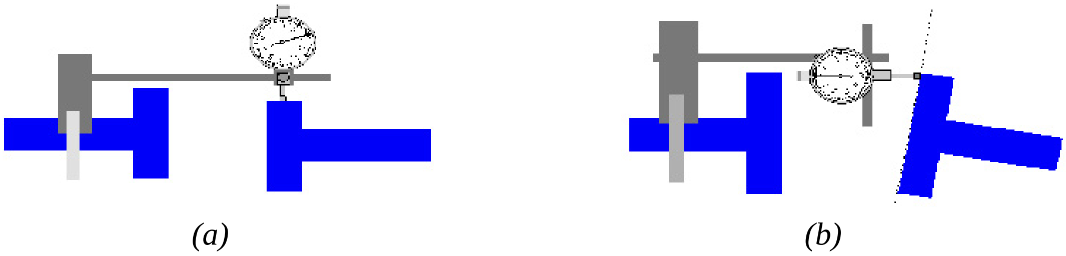


Figure 2.7 Offset measurement technique (a) Trim dial indicator (b) Face dial indicator **[23]**.

This method uses an axial indicator to calculate angularity and a radial indicator to determine offset [20]. Shaft offset is calculated by taking a single measurement on the coupling's rim.

While the angularity is measured by taking a single measurement on the coupling's forehead. The machines must be uncoupled when performing this process [24]. The offset is estimated at two different points along the shaft axis, and the angularity is determined in reverse indicator [20].

2.6.1.2.2 Reverse Dial Indicator Method

The reverse dial indicator method involves taking two measurements on the coupling rims to calculate offset at two different locations. Furthermore, the angularity is determined by summing the slopes of the two offset measurement positions. To use this technique, the system must be coupled [24].

The reverse rim method is commonly recognized as the preferred shaft alignment method. At two planes along their length, two rim dial indicators are used to determine the relative location of the portable shaft with respect to the motionless shaft. Figure 2.8 depicts the reversed rim alignment process [23].

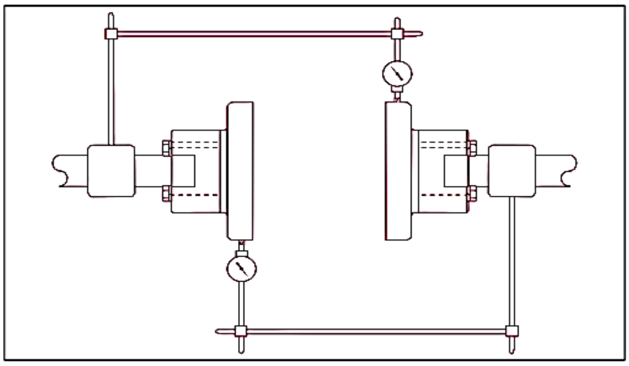


Figure 2.8 Reverse Dial Indicator Method **[21]**.

2.6.1.3 Laser alignment

Laser Alignment is the most user-friendly and accurate method, requiring only a single installation. This technique also provides more reliable precision than dial indicators, where specific technician skills are not needed to obtain accurate results every time. This method is made up of two units, each of which has a handheld control device capable of emitting an accurate laser beam and locating a laser beam from its mate [25]. The description of laser alignment is shown in Figure 2.9 below.

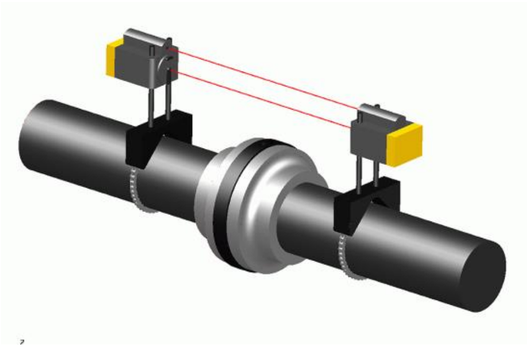


Figure 2.9 The overview of laser alignment **[4]**.

The laser's accuracy is higher than that of dial sensors, resulting in significant time savings. Laser alignment uses a variety of methods, including those that use a single laser and detector configuration. Others, on the other hand, used a reflected beam approach and a dual laser configuration that works on the same principle as the reverse dial indicator method. The advantage of this technique is that the machine's foot is corrected, and the alignment data at the couple is given.

The machine's life cycle is therefore greater than a dial indicator. However, the main drawback is the cost, as this technique consumes a few expenses from running the alignment method. However, this strategy can minimize downtime and increase equipment life, lowering maintenance costs [20]. Figure 2.10 depicts an industrial laser measurement device.

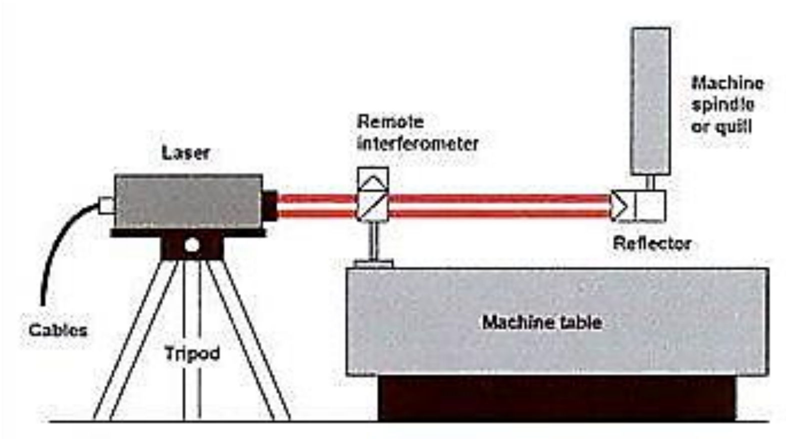


Figure 2.10 Scheme of a laser measuring system **[19]**.

2.6.2 Current method

There are few methods for correcting misalignment shown below. The current method is mainly used by industry. The following sub-topic shows the current method of correcting misalignment.

2.6.2.1 Shim

According to Nick et al., (1980), shim plates may be used to solve the problem of misalignment. Shims are widely used to change the clearance or gap between two parts by adjusting the shim thickness.

The shims come in a variety of sizes and are arranged in a pack shape to meet a variety of modification requirements. The unit would be aligned in both directions as a result of this (vertical and horizontal). Shims are used in the shaft alignment method to correct misalignment in the vertical location of a portable machine. As a result, the machine will be in a line with a stationary machine. Shim material can be cut from brass or stainless steel shim stock, but this process takes a long time and requires a lot of labor. The sharp burr caused by cutting shims can be identified as a safety problem that can cause errors in shim stacking.

As a result, the best approach is to use precut Stainless Steel shims with safety tabs and rounded edges without burrs that allow you to easily keep the shim while positioning it under the machine feet, as shown in Figure 2.11. This will reduce the safety concern associated with shims cut from stock. The number of shims used to position beneath the machine feet is limited to five or less [26].

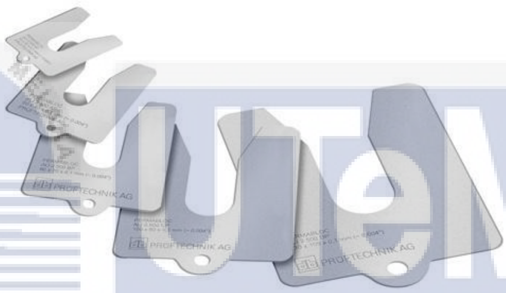


Figure 2.11 Exhibits a Precut Stainless Steel Shim **[4]**.

Lawton Industries pioneered pre-cut stainless steel shims in a variety of sizes. Table 2.1 displays the size of different forms of shims as well as the slot for both.

Table 2.1 Size of Shim **[4]**.

Type	**A**	**B**	**C**	**D**	**G**	**H**
Size (mm)	50 x 50	75 x 75	100 x 100	150 x 127	178 x 178	203 x 203
Slot (mm)	16	20	30.5	31.75	44.45	57.15

2.6.2.2 Shimless alignment

A shimless alignment is a product developed by Anwar (2011) that is used as an insert between the machine feet and the base to straighten the foot relative to the base, removing the prefabricated shim packets and resolving all of the long feeling unsatisfied needs depicted in Figure 2.12. It allows for the machine's normal alignment for the least amount of downtime while also accommodating what are known as "step-shims" for the correction of bent feet. Although realignment is sought, the system does not need to be shut down.

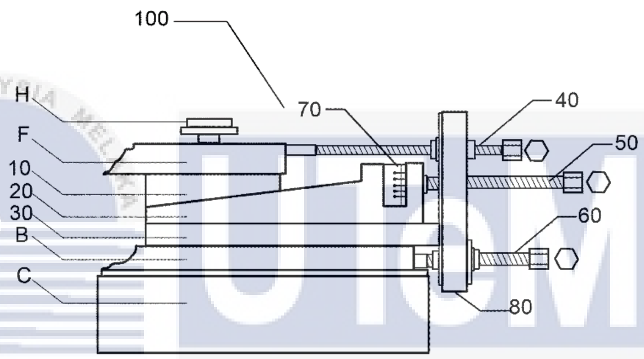


Figure 2.12 Shimless aligner **[27]**.

The inventor believed that the foot and base are held together by a hold-down bolt that extends between the foot and base. The aligner consists of a top plate with a sloped bottom surface, a taper wedge with a sloped top surface engaging the slanted bottom surface involving the tilt bottom surface, a bottom plate underneath the taper wedge, and a back plate mounted significantly perpendicularly at one end of the bottom plate. The bottom and upper plates share a hole, while the taper wedge has a slot. The back plate has a hole for the vertical alignment rod to engage, preventing the taper wedge from rotating during vertical alignment action and ensuring bent foot corrections.

Since the scale of this invention is compact, the installation would be susceptible into equipment that is already in operation or supplied with the manufactured equipment, causing this invention to potentially become machinery normal.

2.7 Alignment Tolerance

The perfect alignment of the shafts can increase the reliability and life span of equipment, especially high-speed equipment. The tolerance table that is most commonly accepted as the industry standard for short couplings. The excellent and agreed values are shown in Tables 2.2 and 2.3 [4].

Table 2.2 Shaft alignment tolerances (Offset) **[4]**.

Motor RPM	Offset Misalignment (mm)	
	Excellent	**Acceptable**
600	0.127	0.2286
900	0.0762	0.1524
1200	0.0632	0.1016
1800	0.0508	0.0762

Table 2.3 Shaft alignment tolerances (Angular) **[4]**.

Motor RPM	Angular Misalignment (mm)	
	Excellent	**Acceptable**
600	1	1.5
900	0.7	1
1200	0.5	0.8
1800	0.3	0.5

According to Gubran and Sinha (2014), the higher the speed of a machining operation, the lower the permissible tolerance for misalignment. The relationships between the two aspects are depicted in Figure 2.13. If the technician is aware of the allowable tolerances, he or she can easily perform the alignment without wasting time or effort in order to achieve precise alignment [10].

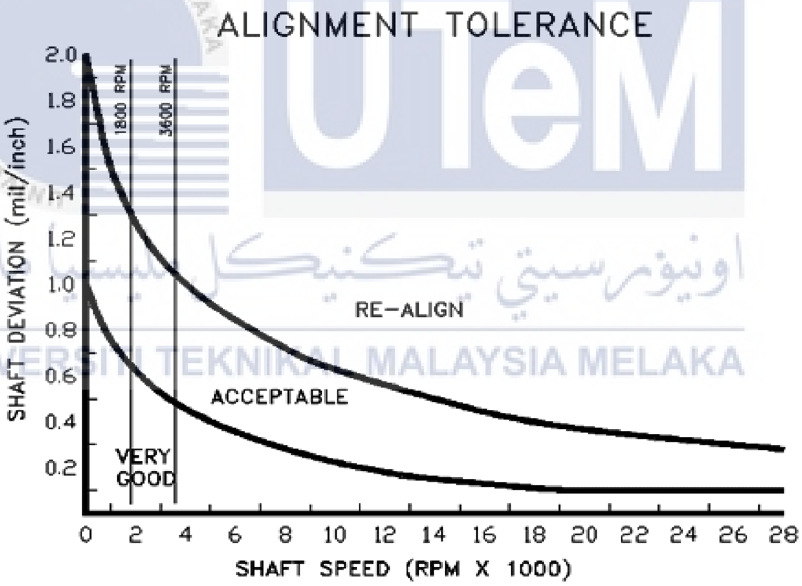


Figure 2.13 Alignment tolerance chart **[3]**.

2.8 Coupling

A coupling is a system used to connect two or more machine shafts in order to transmit power. Many factors influence coupling design, including horsepower, load, real gravity, head strain, torque, shaft sizes, and safety factors [28].

Couplings are mechanical elements used to link two or more drive machines, allowing motion to be transferred from one to the other [29]. It transmits power and torque between two shafts that are either precisely aligned or slightly misaligned. There are two types of coupling that are widely used in industry: rigid and flexible coupling.

Rigid couplings are often used when the two shafts are parallel to each other. It is appropriate for use when the produced torque is high and there is no zero change in the axial positions of the coupled shafts. Rigid coupling is commonly used in the application of large turbine generators and exact standard timing of operation for specific system processes.

It is less costly and typically takes up less room than flexible coupling. However, if there are any dynamic changes in the system, such as thermal growth, the machine can be damaged. They should be precisely matched with virtually no misalignment. In rotary machines, rigid couplings come in two varieties.

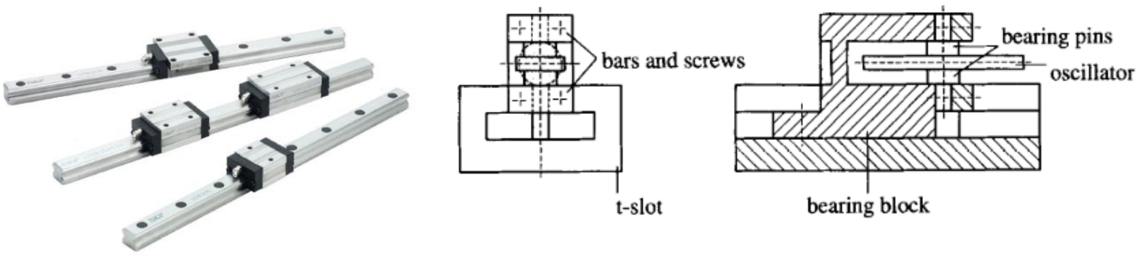
Flexible coupling was commonly used in places where the alignment of two shafts was not always assured and where there was the risk of shock occurring during the transmission process. This form of coupling is also known as elastic couplings because it has elastic behavior when connecting two machines. Flexible couplings have a significant advantage in that they can flex slightly, allowing for minor misalignment.

The degree of misalignment tolerated by a flexible coupling is heavily dependent on the coupling's nature [17].

Figure 2.14 Shaft coupling

2.9 Linear Bearing

Bearings are critical for machine load balancing and provide a very convenient low friction for the mechanism [30]. Bearings come in a variety of shapes, styles, sizes, and slots [31].Tiwari et al. studied different types of bearings in order to set and recommend appropriate bearing specifications for design and production. As shown in Figure 2.15, a bearing with a t-slot guide was used for a built machine to support the mechanism and improve load balancing. The key characteristics are high load carrying capacity in a compact design, resulting in high performance rigidity and accuracy.



(a) *(b)*

Figure 2.15 (a) Linear Bearing **[32]**.

(b) Bearing with a T-Slot guide **[32]**.

2.10 Backlash Free Screw

Backlash is a degree of interaction between components of a mechanism. Backlash can affect machine motion and trigger a great deal of vibration, lowering overall efficiency [33]. As a result, designing the machine with a backlash-free mechanism is critical. . Screw mechanisms are one of the most common mechanisms for converting rotary motions into linear motions, as well as their ability to handle heavy loads [34]. Jones et al. attempted to design a screw mechanism with less backlash using rollers, as seen in Figure 2.16.

Figure 2.16 Backlash Free Screw **[34]**.

2.11 Type of Vibration

Vibration is the periodic back-and-forth motion of the particles of an elastic body or medium that occurs when practically any physical system is moved from its equilibrium condition and allowed to respond to forces that tend to restore equilibrium

2.11.1 Torsional Vibration

Torsional vibration is defined as the angular motion (rotation) of an oscillation that occurs along the spinning component seen in Figure 2.17. Torsional vibrations are typical in power transmission components such as crankshafts, camshafts, alternator shafts, and gearboxes. Torsional vibrations can cause damage, such as shaft rupture, if not regulated [35].

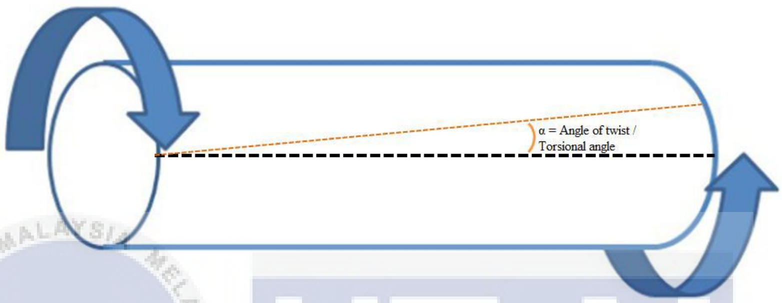


Figure 2.17 Basic principle of a twisted shaft **[35]**.

There are several methods for measuring torsional vibration:

i. Direct measurements (e.g., strain gages, linear accelerometers, dual-beam laser interferometers).

ii. Coder-based techniques (e.g., magnetic pick-ups, optical sensors, zebra tapes).

The output quantities can be angular position, velocity and acceleration, twist angle, twist speed and torque, or a combination of these. The quantities are determined by the methods of measurement [35]. Mass forces (e.g., oscillating, and rotating masses) and gas forces are common excitation sources (e.g., pressure in cylinder).

2.11.2 Rotational Vibration

The dynamic divergence from the shaft's rotation speed is referred to as rotational vibration. Rotational vibration is measured by subtracting the direct current component from the rotation speed or angle. There are always deviations from the rotation speed when a shaft is rotating. Depending on the rotation speed, the variances may get too large in particular places, causing issues.

Figure 2.18 depicts a rotational vibration measurement in which a shaft begins at 0 RPM (revolutions per minute), accelerates to 3000 RPM, and then returns to 0 RPM. The upper curve represents the spinning speed (RPM), and the lower curve represents the variation in degrees (rotation angle). The graph demonstrates that the rotation angle deviates significantly during the shaft's run up and coast down. The two red arrows in the graph represent the rotation angle's high variance. This is due to the angular vibration crossing the angular natural frequency of the shaft, which means that the resonance of the shaft is higher than typical at this point in the RPM range [35].

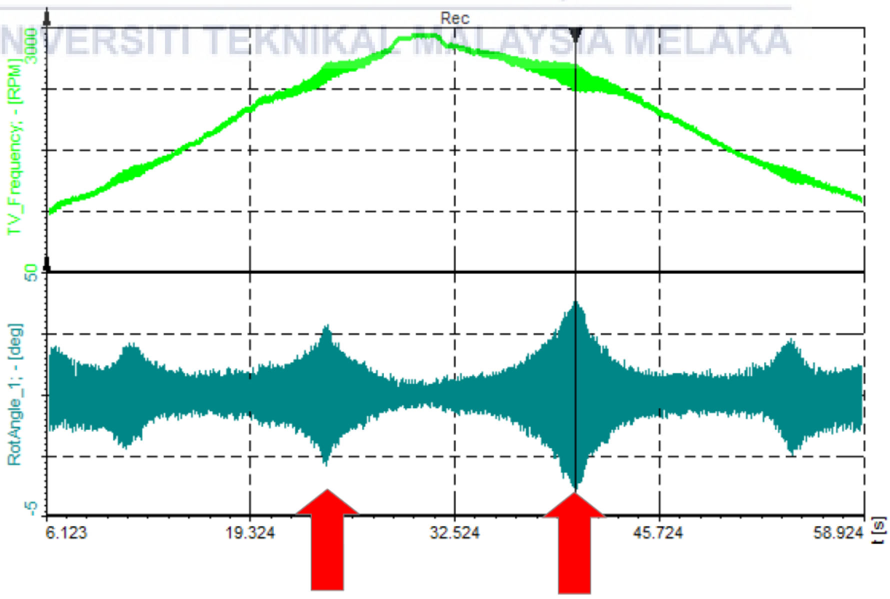


Figure 2.18 Example measurement of rotational vibrations **[35]**.

2.12 Vibration Measurement

Experimental approaches have advanced in tandem with the advancement of the electronics sector. As a result, vibration measurement is becoming more reliable. Furthermore, it is the best and most realistic technique to determine vibration intensity is through experimental methods.

2.12.1 Measurement Devices

To determine the vibration level, acceleration, velocity, displacement, strain, force, and mechanical impedance are measured in a vibration experiment. Critical speeds, natural frequencies, mode shapes, and shaft bearing behavior can all be acquired with these devices.

2.12.1.1 Accelerometers

An accelerometer is a sensor that monitors the acceleration of a structure's vibratory movement to which it is attached. It generates an electrical signal based on the vibratory level. The accelerometer data can be shown as a velocity waveform or a velocity spectrum. If it is represented as a waveform, it can be changed to a velocity spectrum using the fast Fourier transform [35].

Accelerometers are classified into two types: AC-response and DC-response. They can, however, be categorized as described below.

Types of accelerometers

- Piezoelectric
- Tri-axial
- Laser
- Low frequency
- High gravity
- High temperature
- Magnetic induction
- Optical
- Shear mode

2.12.1.2 Velocity Gauges

A velocity gauge is a sensor that detects the velocity of a structure's vibratory movement. For low to medium frequency measurements, velocity gauges (sensors) are ideal. When compared to accelerometers, they have a decreased sensitivity to high frequency vibrations. They are typically used on spinning machines to monitor vibration and balance operations [35].

Types of velocity gauges:

- electromagnetic (coil and magnet) sensor
- piezoelectric velocity sensor

Historically, velocity transducers with coils and magnets have been frequently employed to measure velocity parameters. However, as technology advances, piezoelectric velocity sensors become more popular.

2.12.1.3 Proximity Probes

A proximity probe is a sensor that measures distance as a result of the structure's vibratory movement. They are non-contact sensors that are frequently used to measure static and dynamic distances. Radar, laser, capacitance, and eddy current are all examples of proximity probes. They are widely utilized for shaft vibration, radial and axial shaft position, shaft fracture detection, shaft misalignment, and rotor imbalance.

Types of proximity sensors:

- Capacitive
- Eddy-current
- Doppler effect
- Radar
- Inductive
- Laser
- Magnetic
- Optical
- Thermal infrared

CHAPTER 3

METHODOLOGY

In this section, it will explain about project flowchart, work procedure, working principle, system overview, inside box, main components, and concept of operation. Generally, the phrase ‘technical design’ refers to project activities that take place after the detailed design (or 'developed design' or 'definition') has been completed, but before the construction contract is tendered or construction begins.

3.1 Project Flowchart

A flowchart is a type of diagram that represents an algorithm, workflow, or process, showing the steps as boxes of various kinds, and their order by connecting them with arrows. Flowcharts are used in analyzing, designing, documenting, or managing a process or program in various fields. Below is our workflow starting from planning of the project until the end of the project.

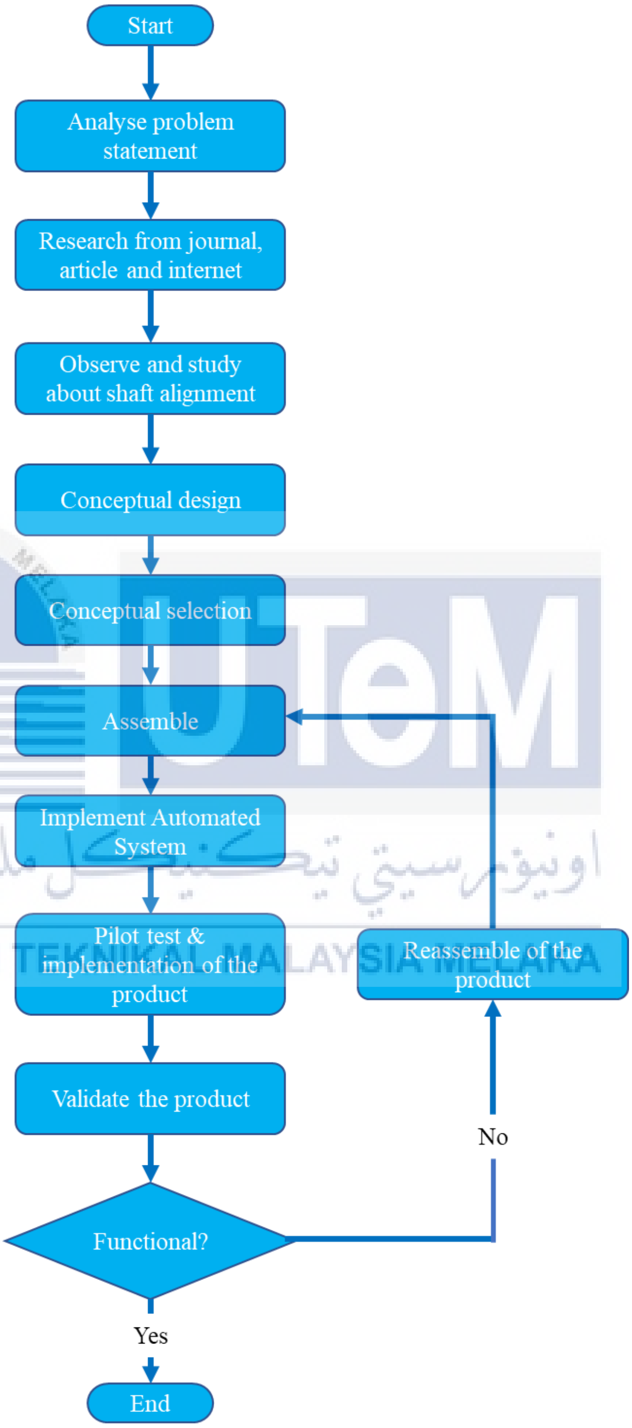


Figure 3.1 Project flowchart.

3.2 Work Procedure

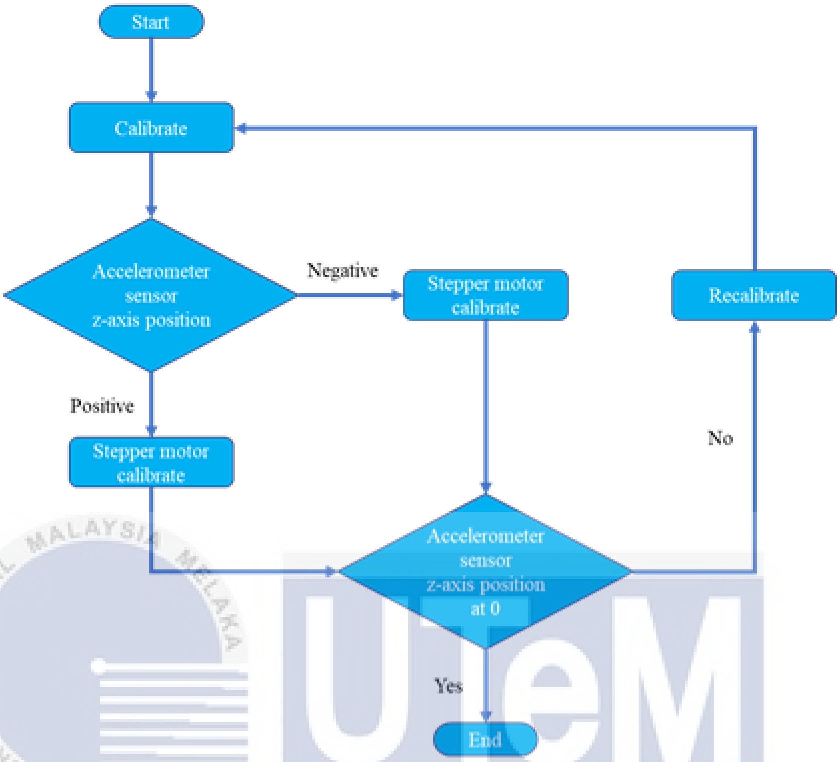


Figure 3.2 Overall flow chart of the project.

3.3 Gantt Chart

The Gantt chart is designed as a guideline to describe the time required to plan, perform, and complete a work. It is a strong chart that can help an individual complete a task in a timely manner. The Gantt chart is separated into two semesters, which include problem identification, introduction, literature review, methodology, results, and discussion, presenting poster and report, and conclusion. Gantt chart is shown in Appendix A respectively.

3.4 Working Principle

This project uses Node MCU ESP32 as microcontroller for the development of automatic self-alignment system that can sense vibration **[RO1].** For the working principle, the objective is to integrates an accelerometer sensor, motor driver and stepper motor into a single microcontroller (NodeMCU ESP32) **[RO2]** and to analyze the vibration reading during the shaft alignment process at different speed. **[RO3].** The accelerometer sensor will analyze the origin position of the shaft. When the shaft is misalignment at positive z-axis or negative z-axis, it will trigger the stepper motor to recalibrate the alignment of the shaft.

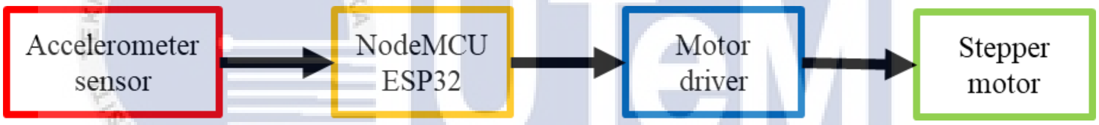


Figure 3.3 Block diagram of the project.

3.5 System Overview

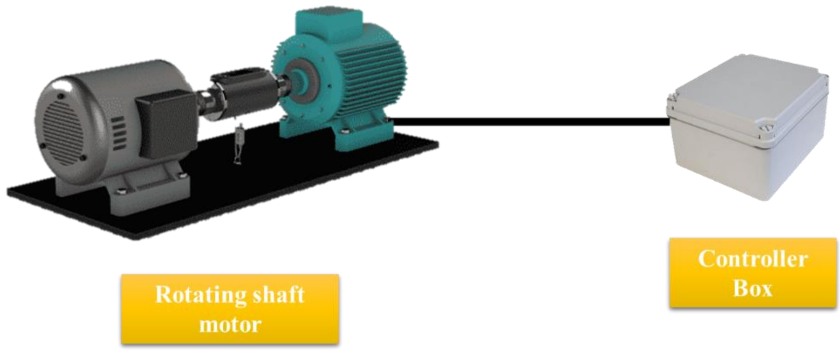


Figure 3.4 System overview of the project.

3.6 Inside Box

Figure 3.5 Inside Box.

3.7 Main Components

For this project, the work procedure is done step by step in a systematic plan called methodology. This section will explain the method adopted by this project. This section will mention every component involved in conducting this project.

3.7.1 Node MCU ESP32

Figure 3.6 Node MCU ESP32.

ESP32 is capable of functioning reliably in industrial environments, with an operating temperature ranging from –40°C to +125°C. Powered by advanced calibration circuitries, ESP32 can dynamically remove external circuit imperfections and adapt to changes in external conditions.

Engineered for mobile devices, wearable electronics and IoT applications, ESP32 achieves ultra-low power consumption with a combination of several types of proprietary software. ESP32 also includes state-of-the-art features, such as fine-grained clock gating, various power modes and dynamic power scaling.

ESP32 is highly integrated with in-built antenna switches, RF balun, power amplifier, low noise receiver amplifier, filters, and power management modules. ESP32 adds priceless functionality and versatility to the applications with minimal Printed Circuit Board (PCB) requirements.

ESP32 can perform as a complete standalone system or as a slave device to a host MCU, reducing communication stack overhead on the main application processor. ESP32 can interface with other systems to provide Wi-Fi and Bluetooth functionality through its SPI / SDIO or I2C / UART interfaces.

3.7.1.1 Block Diagram

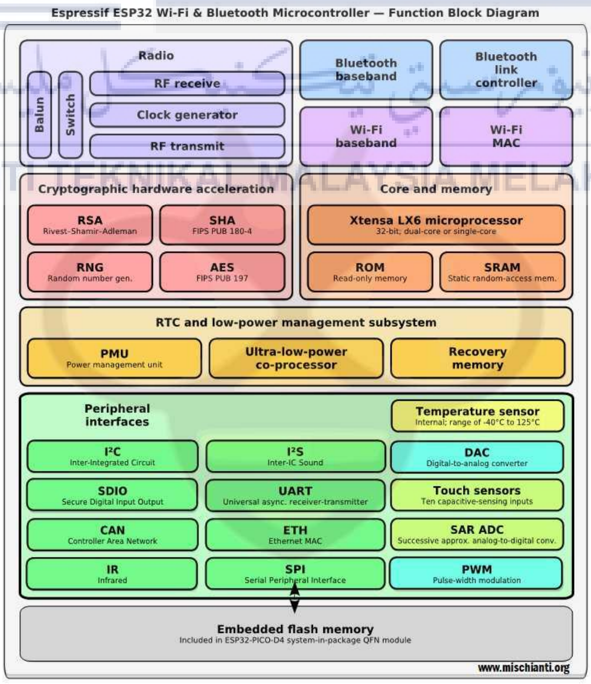


Figure 3.7 Block Diagram of Node MCU ESP32.

3.7.1.2 Pin Configuration

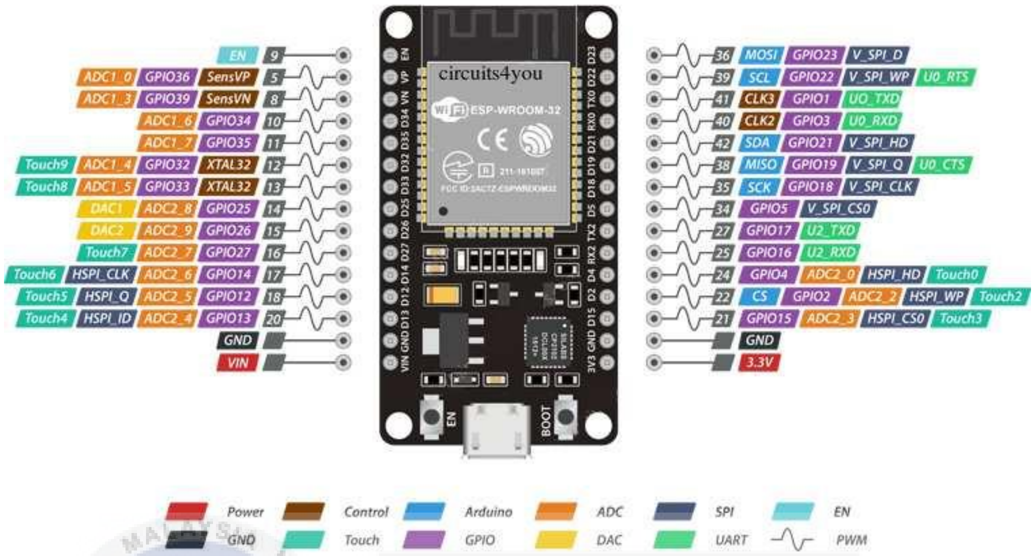


Figure 3.8 Node MCU ESP32 Pin Configuration.

Table 3.1 Pin Configuration of Node MCU ESP32.

Pin Category	Pin Name	Details
Power	Micro-USB, 3.3V, 5V, GND	**Micro-USB:** ESP32 can be powered through USB port. **5V:** Regulated 5V can be supplied to this pin which is we be again regulated to 3.3V by on board regulator, to power the board. **3.3V:** Regulated 3.3V can be supplied to this pin to power the board. **GND:** Ground pins.
Enable	En	The pin and the button resets the microcontroller.
Analog Pins	ADC1_0 to ADC1_5 and ADC2_0 to ADC2_9	Used to measure analog voltage in the range of 0-3.3V. 12-bit 18 Channel ADC
DAC pins	DAC1 and DAC2	Used for Digital to analog Conversion
Input/Output Pins	GPIO0 to GPIO39	Totally 39 GPIO pins, can be used as input or output pins. 0V (low) and 3.3V (high). But pins 34 to 39 can be used as input only
Capacitive Touch pins	T0 to T9	These 10 pins can be used a touch pins normally used for capacitive pads
RTC GPIO pins	RTCIO0 to RTCIO17	These 18 GPIO pins can be used to wake up the ESP32 from deep sleep mode.
Serial	Rx, Tx	Used to receive and transmit TTL serial data.
External Interrupts	All GPIO	Any GPIO can be used to trigger an interrupt.
PWM	All GPIO	16 independent channel is available for PWM any GPIO can be made to work as PWM though software
VSPI	GPIO23(MOSI), GPIO19(MISO), GPIO18(CLK) and GPIO5 (CS)	Used for SPI-1 communication.

3.7.1.3 Technical Specification

Table 3.2 Technical Specification of Node MCU ESP32.

Microprocessor	Tensilica Xtensa LX6
Maximum Operating Frequency	240MHz
Operating Voltage	3.3V
Analog Input Pins	12-bit, 18 Channel
DAC Pins	8-bit, 2 Channel
Digital I/O Pins	39 (of which 34 is normal GPIO pin)
DC Current on I/O Pins	40 mA
DC Current on 3.3V Pin	50 mA
SRAM	520 KB
Communication	SPI(4), I2C(2), I2S(2), CAN, UART(3)
Wi-Fi	802.11 b/g/n
Bluetooth	V4.2 – Supports BLE and Classic Bluetooth

3.7.2 MPU 6050 Accelerometer Sensor

Figure 3.9 MPU 6050 Accelerometer sensor.

An accelerometer is an electronic sensor that measures the acceleration forces acting on an object, in order to determine the object's position in space and monitor the object's movement. Acceleration, which is a vector quantity, is the rate of change of an object's velocity (velocity being the displacement of the object divided by the change in time).

There are two types of acceleration forces: static forces and dynamic forces. Static forces are forces that are constantly being applied to the object (such as friction or gravity). Dynamic forces are "moving" forces applied to the object at various rates (such as vibration, or the force exerted on a cue ball in a game of pool) [6].

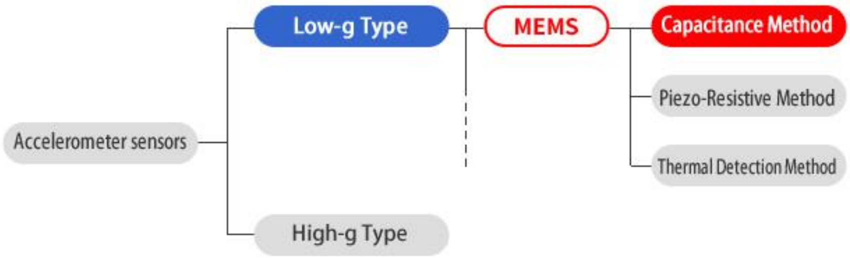


Figure 3.10 Accelerometer sensor classification based on measurement range.

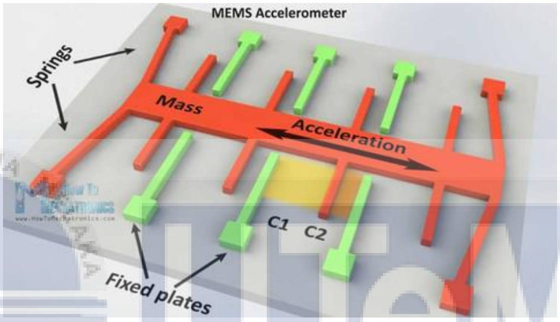


Figure 3.11 MEMS capacitive accelerator diagram.

The sensor element consists of a fixed electrode comprised of Si, a working electrode, and spring. In a state with no acceleration, the distance between the fixed and movable electrode is the same.

When acceleration is applied, the movable electrode is displaced. This causes a change in the positional relationship with the fixed electrode, changing the capacitance between the electrodes. The capacitance change is converted to voltage by an ASIC and used to calculate acceleration [36].

3.7.2.1 Schematic Diagram

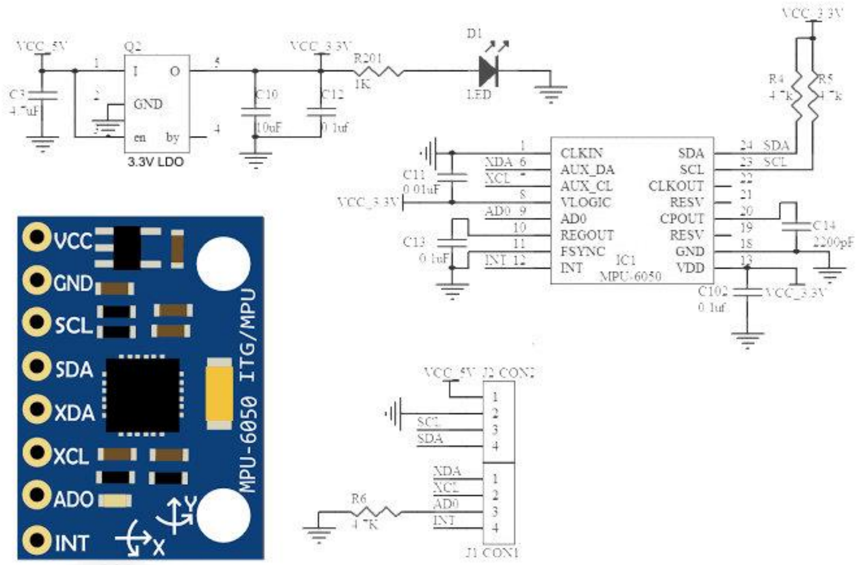


Figure 3.12 Schematic diagram of MPU6050.

3.7.2.2 The Principle of Operation of the Gyroscope

MEMS devices, such as single-chip integrated circuits, are made on silicon substrates, therefore their sizes range from tens of microns to millimeters. MEMS gyroscopes come in a variety of shapes and sizes, each with its own internal construction, but they are all predicated on the utilization of Carioles force to function. They each have a functional body that moves in a reciprocal fashion.

When the substrate on which this body is located is rotated, the Carioles' force, which is directed perpendicular to the axis of rotation and the direction of motion of the body, begins to work on it. Figure 3.13 shows an illustration to help you grasp the principle of this force.

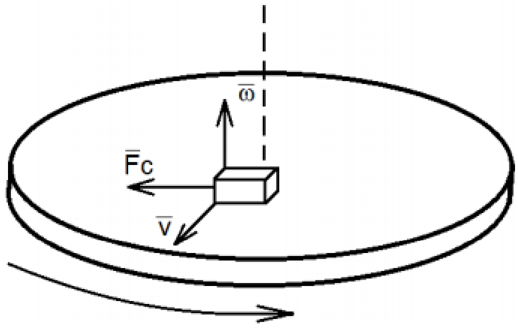


Figure 3.13 The mechanism of the Coriolis force. **[37]**

The angular velocity can be calculated using the linear velocity and the Carioles' force. One proposed gyroscope implementation is as follows: a frame placed on flexible hangers, within which a mass undergoes translational oscillatory oscillations. Figure 3.14 depicts the structure of such a sensor.

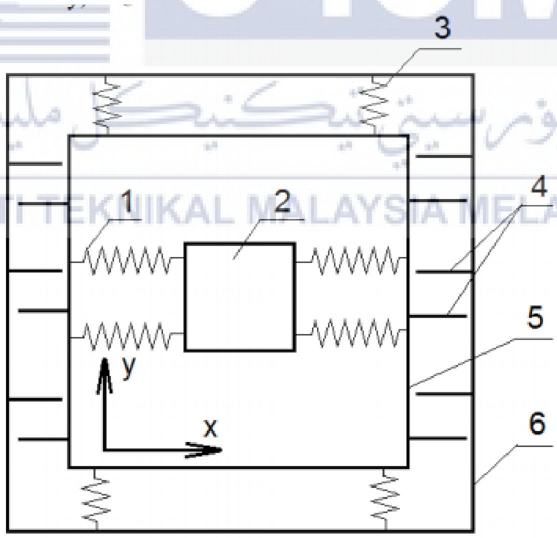


Figure 3.14 The internal structure of the gyroscope: 1 – fastening mass, 2 – working weight, 3 – fastening the inner frame, 4 – sensors moving the inner frame, 5– inner frame, 6 – substrate **[37]**

Electrostatic forces cause working mass oscillations along the X axis, but internal frame oscillations are only conceivable along the Y axis. Plates of flat capacitors (displacement sensors) are placed between the inner and false frames, detecting their capacity; the frame movement relative to the substrate can be fixed.

However, oscillations of the inner frame can be induced by linear accelerations acting along the Y axis as well as Carioles' force. The challenge is solved by assembling two frames on a single substrate, each containing the operational mass. Because both masses oscillate in anti-phase, the Carioles force acting on the first mass is directed opposite to the force operating on the second at any given instant in time. The signals produced by Carioles' force will be added, while the in-phase component produced by linear acceleration will be deleted. [37]

3.7.2.3 Technical Specification

Table 3.3 Technical Specification of MPU6050.

Supply voltage	2.3 – 3.4 V
Current consumption	3.9 mA max
Accelerometer ranges	± 2 g ± 4 g ± 8 g ± 16 g
Gyroscope ranges	± 200/500/1000/2000 °/sar
Operating temperature	-40 °C to +85 °C

3.7.3 TB6600 Motor Driver

Figure 3.15 L289N Motor driver.

The motor drive serves as a connection point between the motor and the control circuit. The motor demands a lot of current, but the controller circuit just needs a little bit. A motor driver's function is to transform a low current control signal into a higher current signal capable of driving the motor [7].

The motor drive gets the signal from the microprocessor and then converts it before sending it to the motor. It contains two voltage pins (VCC1 and VCC2), one for turning on the motor driver and the other for applying voltage to the motor via this motor IC. This motor IC will continually transform the output signal based on the microprocessor's input wave.

The tiny IC transmits the received signal but does not change its value. For instance, if the CPU delivers a high input (1) to the Drive IC, the Drive IC will pass the same High (1) even though it is an output pin. As shown in the diagram below, the H bridge circuit will look like this. Four switches make a "H" shape and are used to enable/disable the supply [11].

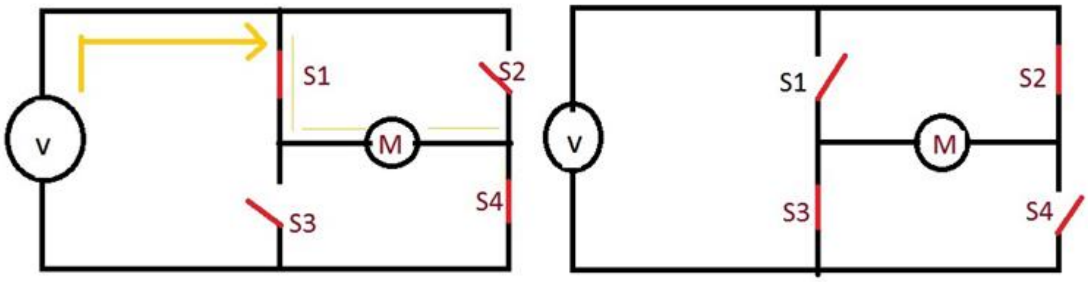


Figure 3.16 H-bridge circuit.

3.7.3.1 Schematic Diagram

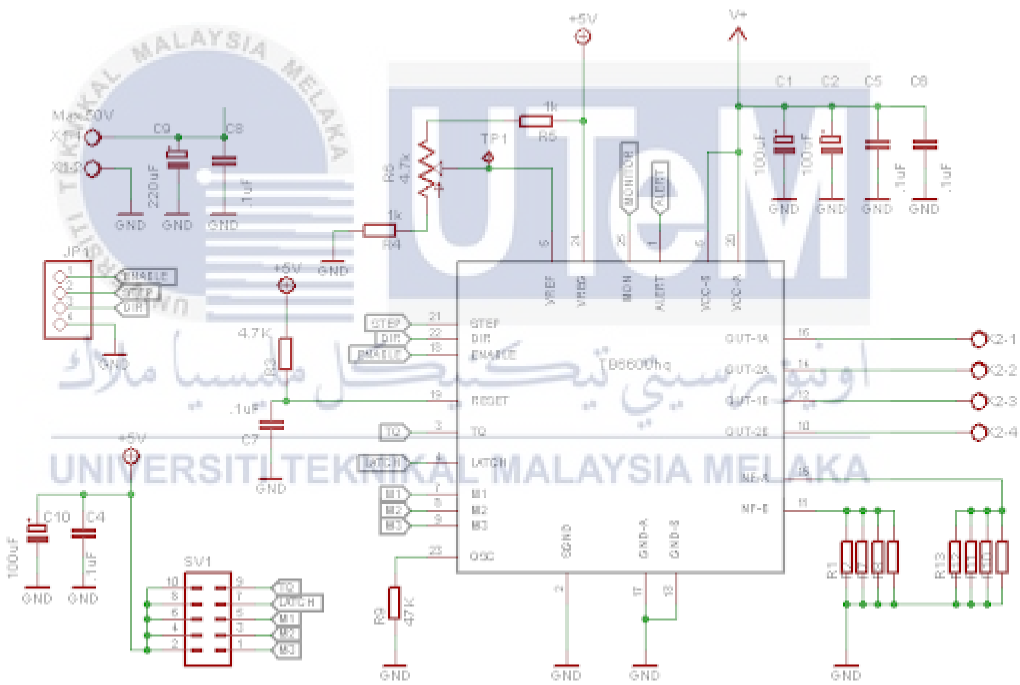


Figure 3.17 Schematic diagram of TB6600.

3.7.3.2 Technical Specification

Table 3.4 Technical specification of TB6600.

Step angle	1.8 deg
Rated current	1.8A
Phase resistance	1.8 Ω
Phase inductance	3.2 mH
Holding torque	52 N.cm

3.7.4 NEMA 23 Stepper Motor

Figure 3.18 NEMA 23 Stepper motor.

The stepper motor consists of a stationary (stator) and a moving portion (rotor). The coils are wired through teeth on the stator, while the rotor is either a permanent magnet or a changeable repulsive iron core.

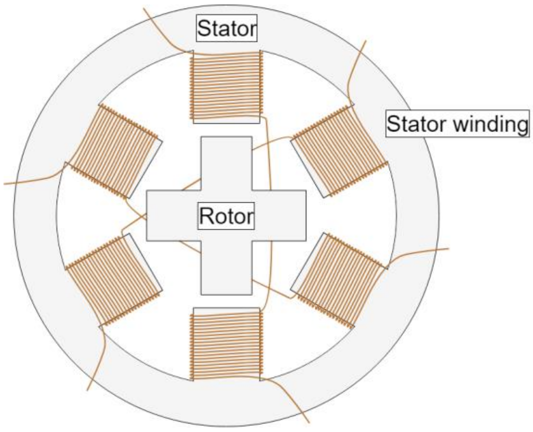


Figure 3.19 Cross-section of a stepper motor.

The basic working principle of the stepper motor is the following: By energizing one or more of the stator phases, a magnetic field is generated by the current flowing in the coil and the rotor aligns with this field. By supplying different phases in sequence, the rotor can be rotated by a specific amount to reach the desired final position. Figure below shows a representation of the working principle. At the beginning, coil A is energized, and the rotor is aligned with the magnetic field it produces. When coil B is energized, the rotor rotates clockwise by 60° to align with the new magnetic field. The same happens when coil C is energized. In the pictures, the colors of the stator teeth indicate the direction of the magnetic field generated by the stator winding [38].

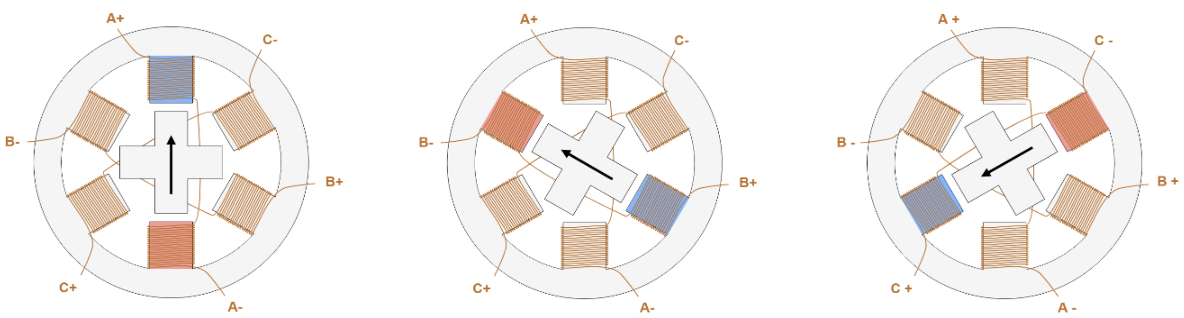


Figure 3.20 Stepper motor steps.

3.7.4.1 Schematic Diagram

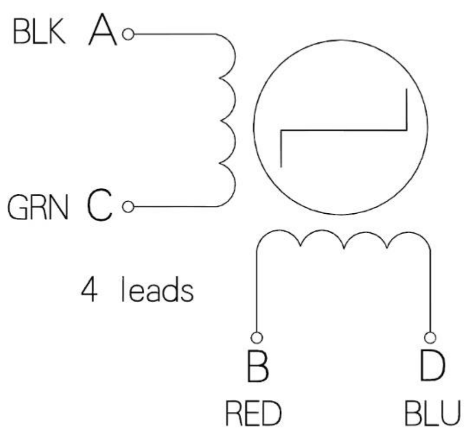


Figure 3.21 Schematic diagram of NEMA 23.

3.7.4.2 Technical Specification

Table 3.5 Technical specification of NEMA 23.

Voltage rating	3.2V
Current rating	2.8A
Step angle	1.8 deg
Step per revolution	200
Number of phase	4

3.7.5 Nextion Touch Display

Figure 3.22 Nextion touch display.

Nextion is a unified Human Machine Interface (HMI) system that serves as a control and visualisation interface between humans and processes, machines, apps, or appliances. The latter is largely employed in the field of IoT or consumer electronics. It is the finest replacement for classic LCD tubes and Nixie LEDs. Nextion is more than simply a touch screen; it also features a well-developed hardware and software component for HMI applications.

The Nextion display has a resolution of 400*240 and is a TFT display. This display's touch panel is a resistive touch panel. Nextion only offers one series (TTL) for power supply or connecting to external devices such as Arduino or Raspberry Pi boards. The following display includes an MCU with a frequency of up to 48MHz. This display has a large storage capacity for HMI programming thanks to its 4MB flash, 3584Byte RAM, and SD card connection. [39].

Figure 3.23 Hardware overview.

3.7.5.1 Technical Specification

Table 3.6 Technical specification of Nextion Touch Display.

Color	64K 65536 colors
Layout size	95(L) x 47.6(W) x 4.6(H)
Resolution	400 x 240 pixel
Touch type	Resistive
Backlight	LED
Brightness	200 nit
Weight	35.5 gram

3.8 Software Implementation

Software implementation is the segmentation of software development activity into different phases (or stages) that contain activities for better planning and administration. It is frequently seen as a component of the systems development life cycle.

3.8.1 Arduino IDE

Arduino is a computer hardware and software open source corporation, project, and user community that designs and manufactures single board microcontrollers and microcontroller kits for making digital devices and interactive things that can sense and control physical items. The Arduino boards are self-contained kits.

The boards have analogue and digital input/output pins. It supports serial transmission. USB connectors are provided on certain boards for code dumping. The programming language is highly influenced by C and C++. As a result, Arduino offers an integrated development environment (IDE).

The IDE is a JAVA-based cross-platform application. Copy, paste, find and replace, automated indenting, brace matching, and syntax highlighting are all included in the code editor. A simple single-click technique compiles and uploads programs. It also has a message area, a text terminal, a toolbar with buttons for common functions, and an operation menu hierarchy. A *sketch* is a program created with the Arduino IDE. Sketches are saved as text files with the file extension *.ino* on the development computer, whereas Arduino Software (IDE) pre-1.0 saved sketches with the extension *.pde*. [40]

3.9 Concept of Operation

This chapter defines the concept of operations management, the characteristics of a dependable system for operations management, and the actions an organization can take to formalize operations management.

3.9.1 Schematic Diagram of Project

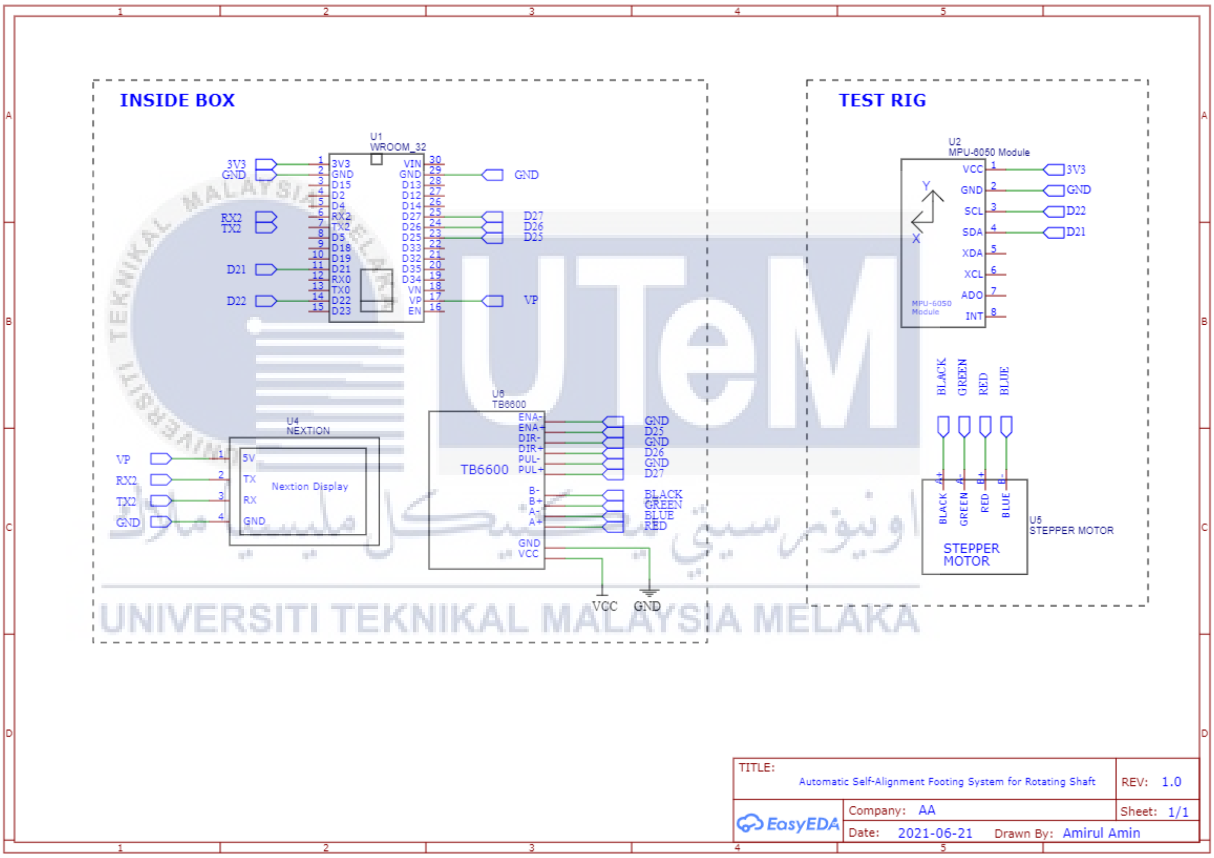


Figure 3.24 Schematic Diagram of Project

The system is made up of a single sensor that is linked to the NodeMCU ESP32. The 5V micro-USB cable linked to the 3 pin socket serves as the ESP32's power source. The ESP32 powers each component via GPIO RAW. The MPU 6050 accelerometer sensor is powered by a 3V3 pin supply, while D21 and D22 serve as pin signals. The TB6600 motor driver is then utilized to control the stepper motor. The ENA+ is wired to D25, the DIR+ to D26, and the PUL+ to the ESP32's D27 pin signal. This motor driver gets its power from the VCC 3 pin socket. While the stepper motor's BLACK wire was linked to B-, GREEN wire was attached to B+, BLUE wire was connected to A-, and RED wire was connected to A+. Finally, the Nextion touch display is included to display the shaft's status position. The Nextion is powered by a 5V power supply and uses TX2 and RX2 as pin signals.

3.10 Validation of Project

Mechanical vibration severity is the evaluation of vibration measurement performed for shaft vibration in accordance with ISO 7919 and ISO 10816. The standards are divided into small, medium, large rigid, and large soft machines. This section of ISO gives particular recommendations for evaluating the severity of vibration observed on rotor dynamic pump bearings, as well as some general information about shaft vibration.

Figure 3.25 depicts an ISO 7919 mechanical vibration severity graph. This section of ISO is utilized as a standard for determining whether or not the displacement result is within the standard by comparing it to the displacement error. Zone A in the zone description suggests that newly commissioned machinery is in good condition. Zone B, on the other hand, demonstrates that it is suitable for both unrestricted and long-term operation. Zones C and D suggest that they are unsuitable for long-term operation and may harm the device. [41]

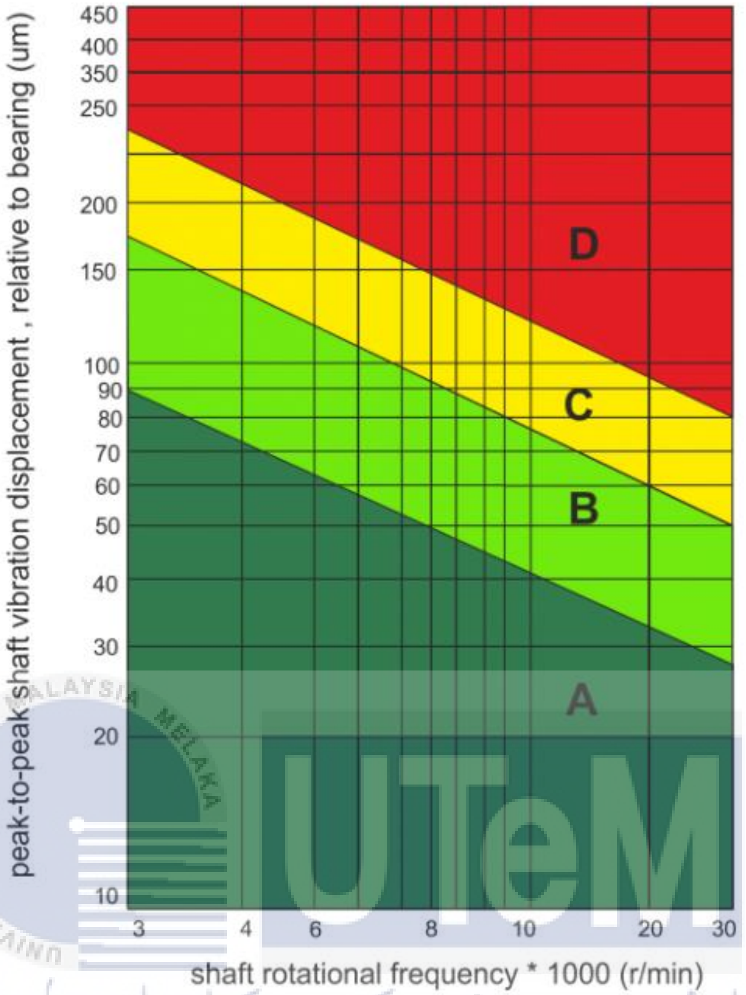


Figure 3.25 Graph of ISO 7919 Mechanical vibration severity.

The vibration severity of ISO 10816 is shown in Table 3.7. This section of ISO is utilized as a standard for determining whether or not the results of vibration testing are suitable for usage. The green color indicates that the vibration is safe to use, whereas the red color indicates that the vibration is dangerous and could damage the device. This project makes use of the Class I small machine. The acceptable severity range is less than 1.12 mm/s. The danger level is greater than 7.10 mm/s. [41]

Table 3.7 Vibration Severity per ISO 10816.

<table>
<tr><th>RMS Overall Velocity Level Measured in 1000 Hz Bandwidth</th><th colspan="4">Vibration Severity Criteria</th></tr>
<tr><th>mm/s</th><th>Class I</th><th>Class II</th><th>Class III</th><th>Class IV</th></tr>
<tr><td>0.28</td><td rowspan="3">Good</td><td rowspan="4">Good</td><td rowspan="5">Good</td><td rowspan="6">Good</td></tr>
<tr><td>0.45</td></tr>
<tr><td>0.71</td></tr>
<tr><td>1.12</td><td rowspan="2">Satisfactory</td></tr>
<tr><td>1.80</td><td rowspan="2">Satisfactory</td></tr>
<tr><td>2.80</td><td rowspan="2">Unsatisfactory</td><td rowspan="2">Satisfactory</td></tr>
<tr><td>4.50</td><td rowspan="2">Unsatisfactory</td><td rowspan="2">Satisfactory</td></tr>
<tr><td>7.10</td><td rowspan="5">Unacceptable</td><td rowspan="2">Unsatisfactory</td></tr>
<tr><td>11.20</td><td rowspan="4">Unacceptable</td><td rowspan="2">Unsatisfactory</td></tr>
<tr><td>18.00</td><td rowspan="3">Unacceptable</td></tr>
<tr><td>28.00</td><td rowspan="2">Unacceptable</td></tr>
<tr><td>45.00</td></tr>
</table>

Where:

Class I : Small sized machine (Powered from 0 – 15 kW)
Class II : Medium sized machine (Powered from 15 – 75 kW)
Class III : Large sized machine (Powered > 75 kW)
: Mounted on "Rigid Support" structure and foundation
Class IV : Large sized machine (Powered > 75 kW)
: Mounted on "Flexible Support" structures.

3.10.1 Tachometer

Figure 3.26 shows a tachometer used to measure the RPM of any shaft. This tachometer is a device that measures the rotational speed of a shaft or disc, such as that found in a motor or other machine. The tachometer does not required to come into physical touch with the revolving shaft. The operating principle is to target the laser beam from the gadget towards the reflective sticker that we stacked on the rotation shaft, and then the RPM measurement will appear in the digital display.

Figure 3.26 Tachometer device.

3.10.2 Vibration Meter

A vibration meters is a portable instrument that measures the amplitude of vibration during the operating process and stores the results in memory. It communicates with the equipment to provide and display digital vibration rates. The vibration meters illustrated in Figure 3.27 will be used to validate the performance of the self-alignment for the footing system. The measurement will be translated into numbers that the technician can read during the process of improvement.

Figure 3.27 Vibration meter.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter is discussed the result of the experimental data collection. The testing of vibration, response time and displacement error is analyzed. The validation and the functionality of the product also been discussed.

4.1 Vibration Testing

The value of vibration meter reading after correction is tabulated as shown in Table 4.1. The vibration meter is taken in the unit of mm/s.

Table 4.1 Data of vibration meter reading (after correction).

No.	Shaft speed (RPM)	Vibration meter reading (after correction) (mm/s)
1	100	**0**
2	200	**0**
3	300	**0**
4	400	**0.2**
5	500	**0.4**
6	600	**0.4**
7	700	**0.7**
8	800	**0.7**
9	900	**1.0**
10	1000	**1.5**
11	1100	**1.5**

Figure 4.1 shows the graph correction of vibration against shaft speed. The vibration meter reading increases in tandem with the shaft speed. The vibration of the machine is only detected when the shaft speed is 400 RPM or higher. The maximum value of vibration is recorded when the shaft speed is set to 1100 RPM, which is 1.5 mm/s. The vibration meter is increased from 0.2 to 0.4 mm/s at 500 RPM. This is most likely due to a lack of machine maintenance, which influenced the machine's smooth performance.

The vibration meter reading is also influenced by the probe's incorrect position. All data are compared to the ISO 10816 standard, and the data are in a satisfactory vibration severity that is less than 2.80 mm/s for small machines (Class 1) where the controller manages to reduce the vibration occur. As expected, the vibration meter data after correction that exceeds 1500 RPM would achieve unacceptable vibration severity because the speed is relatively high and cannot support this level of machine reliability.

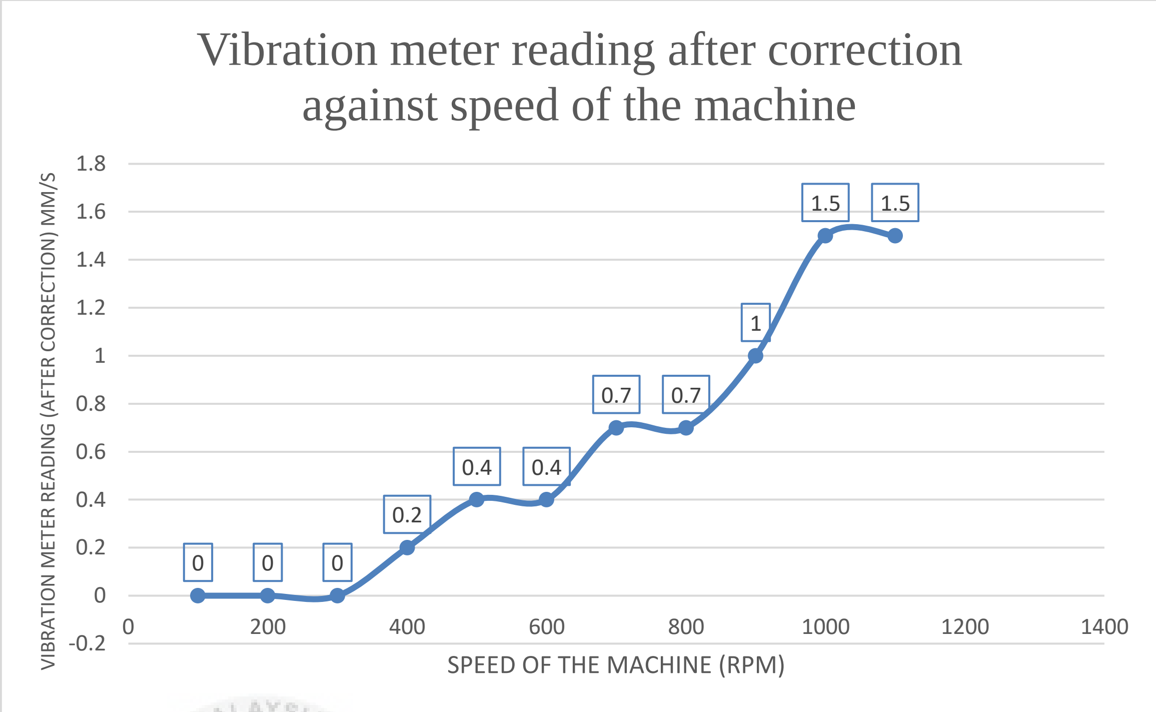


Figure 4.1 Graph correction of vibration against shaft speed.

4.2 Response Time

The response time that corresponding to the increasing of the shaft speed is tabulated in Table 4.2.

Table 4.2 The response time data corresponding to the shaft speed.

No.	Shaft speed (RPM)	Vibration meter reading (after correction) (mm/s)	Response time (s)
1	100	0	7
2	200	0	11
3	300	0	14
4	400	0.2	19
5	500	0.4	29
6	600	0.4	23
7	700	0.7	32
8	800	0.7	43
9	900	1.0	67
10	1000	1.5	86
11	1100	1.5	55

Figure 4.2 depicts a graph of response time during correction against shaft speed. The response time for the system to produce the best vibration meter reading increases as the shaft speed increases. The machine has a response time of 7 seconds because it is running at the slowest speed of 100 RPM. When the shaft speed is set at 900 RPM, the response time is 55 seconds.

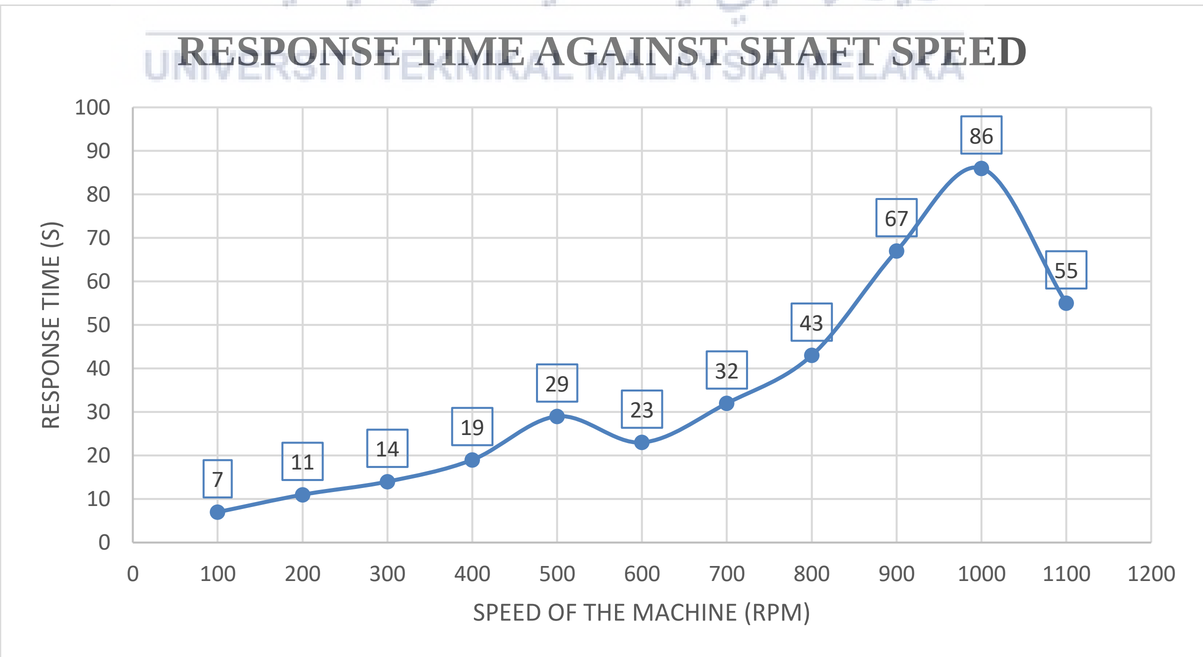


Figure 4.2 Graph of response time against shaft speed.

4.3 Vibration Validation

The vibration efficiency of the automated self-alignment system must be validated. The vibration sensor is used to measure vibration during the shaft alignment process at various shaft speeds. The measurement was carried out in the manner depicted in Figure 4.3.

Figure 4.3 Validation of product

The data are validated based on the results of vibration reading correction by comparing the data to the mechanical vibration standard, Vibration Severity ISO 10816. Because the step motor's output is less than 15 KW, the system is classified as a small machine (Class 1). All of the vibration values that compare to ISO 10816 are in satisfactory condition, with the greatest vibration value of 1.5 at 1100 RPM.

4.4 System Functionality

The automated self-alignment system is installed on the shaft alignment testing ring. The testing is performed to determine whether the system is capable of being fine-tuned and decreasing vibration, as shown in Figure 4.4. The vibration meter measures the vibration produced by the shaft machine. The shaft speed is set to 1100 RPM, and the vibration meter probe is mounted to the upper head of the block bearing house. The vibration as well as the response time are recorded. The system corrects the vibration throughout the outcome within the specified time. As indicated, the vibration result was decreased to the best condition as confirmed by the standards. The result validated within the satisfactory vibration severity and within the 'Zone A' limit. This demonstrates that the system is practical and functional.

Figure 4.4 Correction of vibration

CHAPTER 5

CONCLUSION AND FUTURE WORKS

This chapter closes the research study and the research's future work, with the objectives and scope of the study serving as the primary reference for the conclusion of the findings. Recommendations for future work enhancements are also provided.

5.1 Conclusion

This research study proposes the most innovative concept design of an automated self-alignment device for misalignment correction. The problem statement serves as the foundation for product development. The problem statement was derived from journal, article, and previous research study research. The main issue that the company encountered was misalignment, which was primarily caused by vibration. The misalignment issue might cost the corporation billions of dollars in maintenance costs. Due to machine failure, the company's output would also be delayed.

Based on the problem statement investigated in the previous research, this research study has achieved the study's purpose of developing an automated self-alignment system that reduces vibration. The product can be fine-tuned while the shaft alignment process is being carried out.

Vibration testing is performed on the product to ensure that it works properly. As the shaft speed was increased, the vibration increased. As the shaft speed is set to 1100 RPM, the highest vibration reading is 1.5 mm/s. Furthermore, the product has been evaluated by comparing the vibration testing results to the Vibration Severity per IS0 10816. In vibration testing, all of the corrected vibration data have a vibration severity of less than 2.80 mm/s.

5.2 Recommendation

At this point, the self-alignment system's recommendations for improvement will be described. Further research in the related topic can be carried out to gain a better understanding of this study, as shown below:

i. To demonstrate that the automated system is superior to the manual system, the controller should correct the system's position in less than one minute during the shaft alignment procedure.

ii. Further testing of this project should be developed for commercialization in order to assess the accuracy and precision of this product and verify the testing with certain ISO.

iii. In the future, IOT will be used to control multiple stations at the same time utilizing a smart phone.

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APPENDIX A

A. PERANCANGAN PROJEK
PROJECT PLANNING (GANTT CHART)

	SEM I																			SEM BREAK					SEM II															
Aktiviti Projek *Project Activities*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Find the Supervisor	X																																							
Title selection	X	X																																						
Project discussion	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X						X	X	X	X	X	X	X	X	X	X	X	X	X			
Literature Review understanding of the project		X	X	X																																				
Research of misalignment issues		X	X	X																																		SEMINAR PSM II		
Proposal preparation		X	X	X																																				
Product purchasing					X																																			
Start assembling the circuit						X	X	X	X	X	SEMINAR PSM I	X	X	X	X	X	X	X	X																					
Start programming the coding						X	X	X	X	X		X	X	X	X	X	X	X	X						X	X	X	X	X	X										
Project testing						X	X	X	X	X		X	X	X	X	X	X	X	X						X	X	X	X	X	X										
Analysis the result of the project						X	X	X	X	X		X	X	X	X	X	X	X	X						X	X	X	X	X	X										
Thesis writing		X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X						X	X	X	X	X	X	X	X	X	X	X	X	X			
Thesis submission																																							X	
Project presentation																																							X	

APPENDIX B

Full Coding

```
#include <AccelStepper.h>
#define dirPin 26
#define stepPin 27
#define motorInterfaceType 1
#include <Adafruit_MPU6050.h>
#include <Adafruit_Sensor.h>
#include <Wire.h>

Adafruit_MPU6050 mpu;
AccelStepper stepper = AccelStepper(motorInterfaceType, stepPin, dirPin);

int maxspeed = 0;
int setspeed = 0;
int utkcase = 0;
int i =0;
int b = 10000;
int k = 100;

void setup(){

  Serial.begin (115200);
  stepper.setMaxSpeed(maxspeed);
  stepper.setSpeed(setspeed);
  stepper.runSpeed();
  while (!Serial) {

  }

  if (!mpu.begin()) {
    Serial.println("Failed to find MPU6050 chip");
    while (1) {
    delay(10);
    }
  }

  mpu.setGyroRange(MPU6050_RANGE_250_DEG);
  mpu.setFilterBandwidth(MPU6050_BAND_21_HZ);
  Serial.println("");
  delay(100);
}

void loop(){

  long positions;
  utkcase = 1;
  sensors_event_t a, g, temp;
  mpu.getEvent(&a, &g, &temp);
  Serial.print(a.acceleration.z);
  Serial.print(" m/s^2");

  if (a.acceleration.z < 8.30 ){
    utkcase = 0;
  }
```

```
 else if (a.acceleration.z > 12.30){
   utkcase = 2;
 }

 switch (utkcase)
   {
     case 0:
        Serial.println("lowerrange");
        stepper.setMaxSpeed(7000);
        stepper.setSpeed(7000);
        positions = b;
        stepper.moveTo(positions);
        stepper.runSpeedToPosition();
        i++;
        goto ilebih;
       break;

     case 1:
       Serial.println("inrange");
       break;

     case 2:
       break;

ilebih:
    if (i > k)
    {
   Serial.println("i more than 50");
   b = b*-1;
   k = k+500;
   Serial.print("value b: ");
   Serial.println(b);
   Serial.print("value k: ");
   Serial.println(k);
   if (k >8000)
   {
    k= 100;
    b=250;
    }
   i= 0;
   break;
      }


}}
```