A CONDITION MONITORING ON GEAR BOX USING VIBRATION SIGNAL ANALYSIS

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DEDICATION

To my beloved parents, Rohati Binti A. Jalil and my late father, Mohd Noor Bin Ghani, thank you for raising me with love and patience. Thank you for giving me the upportunity to further my degree even one of you didn’t get to see me succeed.

ABSTRACT

Analysis of Vibration Signals Performed on Gearboxes Allows for Condition Monitoring. In a wide variety of industrial contexts, it is essential for gearboxes to function in an effective and dependable manner. On the other hand, the deterioration and failure of gearboxes can result in unanticipated downtime, expensive repairs, and sometimes even safety issues. As a result, putting into practice efficient strategies for condition monitoring is vital if one want to identify early indicators of degradation and make it possible for prompt maintenance actions.In recent years, vibration signal analysis has become a major tool for condition monitoring of gearboxes. This trend is expected to continue. This method takes advantage of the innate sensitivity of vibration signals in order to discover numerous fault types, such as wear on the gear teeth, misalignment, defective bearings, and lubrication problems. An in-depth understanding of the gearbox's current state of health can be obtained by carefully examining the vibration signals for their frequency content, amplitude, and any other relevant properties.This abstract provides a summary of condition monitoring on gearboxes through the use of vibration signal analysis. The most important stages of the process, such as signal capture, preprocessing, feature extraction, and defect identification, are broken down and investigated in this chapter. Several different strategies for processing signals, including time-domain analysis, frequency-domain analysis, and statistical methods, are dissected in great detail, along with the benefits and drawbacks of each strategy in its own right.In addition, this abstract emphasizes the significance of selecting suitable sensors and measuring locations in order to acquire accurate and representative vibration signals. In addition to this, it highlights the need of gathering baseline data and designing efficient defect detection algorithms that are suited to the particular gearbox configurations and operating conditions at hand.In addition, the abstract places an emphasis on the benefits of using vibration-based condition monitoring, which include improved maintenance planning, enhanced operational efficiency, and reduced downtime. Potential failures can be avoided and proactive maintenance techniques can be implemented, which leads to cost savings and an increased lifespan of the equipment. This can be accomplished by the early detection and diagnosis of gearbox defects.To summarize, vibration signal analysis is an effective method for condition monitoring of gearboxes. This technology makes it possible to detect and diagnose flaws in a timely manner by capitalizing on the diagnostic potential of vibration signals. This, in turn, facilitates the development of effective maintenance strategies and ensures the dependable and optimal operation of gearboxes in a variety of industrial settings.

ABSTRAK

Analisis Isyarat Getaran yang Dilakukan pada Kotak Gear Membolehkan Pemantauan Keadaan. Dalam pelbagai konteks perindustrian, kotak gear adalah penting untuk berfungsi dengan cara yang berkesan dan boleh dipercayai. Sebaliknya, kemerosotan dan kegagalan kotak gear boleh mengakibatkan masa henti yang tidak dijangka, pembaikan yang mahal, dan kadangkala masalah keselamatan. Akibatnya, mempraktikkan strategi yang cekap untuk pemantauan keadaan adalah penting jika seseorang ingin mengenal pasti petunjuk awal kemerosotan dan membolehkan tindakan penyelenggaraan segera. Dalam beberapa tahun kebelakangan ini, analisis isyarat getaran telah menjadi alat utama untuk pemantauan keadaan kotak gear. Trend ini dijangka berterusan. Kaedah ini mengambil kesempatan daripada sensitiviti semula jadi isyarat getaran untuk menemui pelbagai jenis kerosakan, seperti haus pada gigi gear, salah jajaran, galas yang rosak dan masalah pelinciran. Pemahaman yang mendalam tentang keadaan kesihatan semasa kotak gear boleh diperoleh dengan memeriksa isyarat getaran dengan teliti untuk kandungan frekuensi, amplitud dan sebarang sifat lain yang berkaitan. Abstrak ini menyediakan ringkasan pemantauan keadaan pada kotak gear melalui penggunaan analisis isyarat getaran. Peringkat proses yang paling penting, seperti penangkapan isyarat, prapemprosesan, pengekstrakan ciri, dan pengecaman kecacatan, dipecahkan dan disiasat dalam bab ini. Beberapa strategi berbeza untuk memproses isyarat, termasuk analisis domain masa, analisis domain frekuensi dan kaedah statistik, dibedah dengan sangat terperinci, bersama dengan faedah dan kelemahan setiap strategi dengan cara tersendiri. Selain itu, abstrak ini menekankan kepentingan memilih penderia yang sesuai dan mengukur lokasi untuk memperoleh isyarat getaran yang tepat dan mewakili. Di samping itu, ia menyerlahkan keperluan untuk mengumpul data garis dasar dan mereka bentuk algoritma pengesanan kecacatan yang cekap yang sesuai dengan konfigurasi kotak gear tertentu dan keadaan operasi yang ada. Di samping itu, abstrak memberi penekanan pada faedah menggunakan pemantauan keadaan berasaskan getaran, yang termasuk perancangan penyelenggaraan yang lebih baik, kecekapan operasi yang dipertingkatkan dan masa henti yang dikurangkan. Potensi kegagalan boleh dielakkan dan teknik penyelenggaraan proaktif boleh dilaksanakan, yang membawa kepada penjimatan kos dan peningkatan jangka hayat peralatan. Ini boleh dicapai dengan pengesanan awal dan diagnosis kecacatan kotak gear. Ringkasnya, analisis isyarat getaran adalah kaedah yang berkesan untuk pemantauan keadaan kotak gear. Teknologi ini memungkinkan untuk mengesan dan mendiagnosis kecacatan tepat pada masanya dengan memanfaatkan potensi diagnostik isyarat getaran. Ini, seterusnya, memudahkan pembangunan strategi penyelenggaraan yang berkesan dan memastikan operasi kotak gear yang boleh dipercayai dan optimum dalam pelbagai tetapan industri.

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CHAPTER 1

INTRODUCTION

1.1 Background

A mechanical device used to transmit and control power between rotating shafts is a gearbox, which is often referred to as a gear train or gearbox. It is made up of a number of gears that mesh together to transmit rotational motion and a torque from one shaft to another. The gears range in size and tooth design.

A gearbox's main function is to offer a mechanical advantage by enabling the change of the output shaft's rotational speed, torque, and direction with respect to the input shaft. A gearbox can adjust speed or torque to suit the application by varying the gear ratio between the input and output shafts.

Numerous industries and applications, including as automotive, industrial machinery, power generation, aerospace and others, employ gearboxes extensively. They are essential for minimizing the effectiveness and efficiency of machinery because they make it possible to modify power transmission to satisfy particular needs.

Based on its structure and intended use, gearboxes can be divided into various categories. Each gearbox type has advantages of its own, and the best one is chosen based on the torque demands, speed ranges, size constrains, noise, restrictions, and efficiency requirements. In many mechanical systems, gearboxes play a crucial role in the efficient and precise transfer of motion and power.

1.2 Problem Statement

Every type of machine will produce vibration when operating. The machine will produce either normal vibration or abnormal vibration. When problem occur in the machine, it will show an abnormal vibration. To detect the abnormal vibration, condition monitoring is needed using vibration signal analysis. Vibration analysis is an effective method for identifying and treating mechanical problems. Without it, possible problems such as bearing wear, imbalance, or mechanical looseness could go undetected. These flaws can get worse over time, resulting in unanticipated failures, shortened machine lifespans, and expensive repairs.

Machine are more prone to unexpected breakdowns when defects go unnoticed. Increased unplanned downtime may emerge as a result of the need of repairs or replacements. Downtime has a negative effect on productivity, interrupts corporate operations, and costs company's money.

In the absence of vibration signal analysis, maintenance stops being proactive and starts being reactive. In comparison to planned or preventive maintenance, reactive maintenance is frequently more expensive and less efficient. Maintenance efforts are concentrated on fixing breakdowns after they happen rather on preventing possible problems from leading to substantial damage, which results in increased expenses and extended downtime.

1.3 Research Objective

a) To monitor vibration from normal and abnormal gear.
b) To measure the data between the normal and abnormal gear using Vibration Signal Analysis.

1.4 Scope of Research

This project is focusing on the vibration of the normal and abnormal gear. Recognizing the condition of the machine is necessary to avoid major machine damage and to schedule maintenance appropriately. The type of a machine's vibrations are often good indicators of how well a machine or its components are functioning. The equipment diagnostic system can be employed to explain certain damage types and research how it affects the vibration spectrum. This project is using the PT 500 base unit from GUNT Hamburg to measure the vibrations.

CHAPTER 2

LITERATURE REVIEW

2.1 Condition Monitoring

In order to detect potential failure early on, complex, expensive, and important machinery must be continuously monitored as part of a systematic and continuing process called condition monitoring. The main goals of condition monitoring are to guarantee optimum performance, maintain operational safety, and stop serious problems from developing.

Condition monitoring enables the early discovery of flaws that, if left unattended, could result in catastrophic failures by continuously monitoring the functioning of machinery. This proactive strategy reduces repair expenses and averts unplanned breakdowns. Additionally, it makes it possible to adopt condition-based maintenance, which involves carrying out maintenance tasks in accordance with the machine's real condition rather than just depending on planned maintenance or waiting for a failure to happen.

The main objective of condition monitoring is to gather thorough information about the machinery's current state and how it has changed over time. Data from the machine's many sensors and instruments must be gathered and analysed for this. These sensors take measurements of a variety of variables, including temperature, vibration, pressure, fluid levels, and electrical signals. The performance and behaviour of the machine are continuously monitored, and this data is analysed to identify any deviations or anomalies.

Unplanned downtime and breakdowns are avoided thanks to condition monitoring, which foresees and prevents possible faults. Due to the huge time and resource savings, this is advantageous for various sectors. Maintenance tasks can be planned and scheduled more effectively, increasing productivity and lowering costs by finding and resolving problems before they become more serious.

In industries where machinery is important, condition monitoring is a key procedure. It offers useful information about the condition of the equipment, makes proactive maintenance methods possible, and eventually helps to increase operational effectiveness, safety, and cost-effectiveness.

2.1.1 Condition-Based Monitoring (CBM)

Condition-Based Monitoring (CBM) is a method for continuous monitoring and evaluation of equipment and systems. Data is collected, and asset performance is assessed using wired or wireless monitoring devices. CBM's major goals are to diagnose equipment's current state, predict probable failures, and implement preventative maintenance measures like repairs or replacements.

Critical equipment, including gas compressors, pumps, turbines, and compressors, used in many sectors, including the oil and gas sector, can be detected using CBM. CBM uses sensors and other monitoring systems to detect deviations from normal operating conditions early.

CBM helps schedule maintenance before failures occur by detecting anomalies. Since equipment can be taken out of operation for maintenance or repair at a suitable time, this proactive strategy reduces downtime. CBM saves maintenance costs by addressing potential issues before they become severe problems.

Vibration, temperature, pressure, flow rates, and other data factors are collected and analysed for CBM. These data points are regularly checked and compared to normal operation thresholds or trends. Alerts or notifications notify maintenance staff of deviations.

There are many benefits of CBM. Maintenance may be planned and scheduled more efficiently with early anomaly identification, reducing downtime and increasing equipment availability. By reducing the danger of sudden equipment failures that could cause accidents or injuries, this proactive strategy improves safety. Instead of following a fixed timetable for all assets, CBM optimises maintenance expenses by focusing resources on the equipment that needs it.

CBM is a useful tool for equipment and system monitoring. It allows early anomaly detection, failure prediction, and maintenance. Industries can reduce downtime, improve dependability, safety, and maintenance costs by using CBM.

2.2 Vibration

The term "vibration" refers to a mechanical phenomenon that includes the oscillatory motion of a structure or item with respect to a reference point. Vibration can be caused by a number of different factors. The term "vibration related to the mechanical vibration" refers to the mechanical vibrations that are generated by both machines and structures. These vibrations can be examined to monitor and diagnose the condition of the machinery and determine how well it is performing. Analysis of vibration signals is one method that may be used to identify any flaws and issues with machinery, and it can also provide proper maintenance strategies to prevent machinery breakdown and downtime.

2.2.1 Basic Concept of Vibration

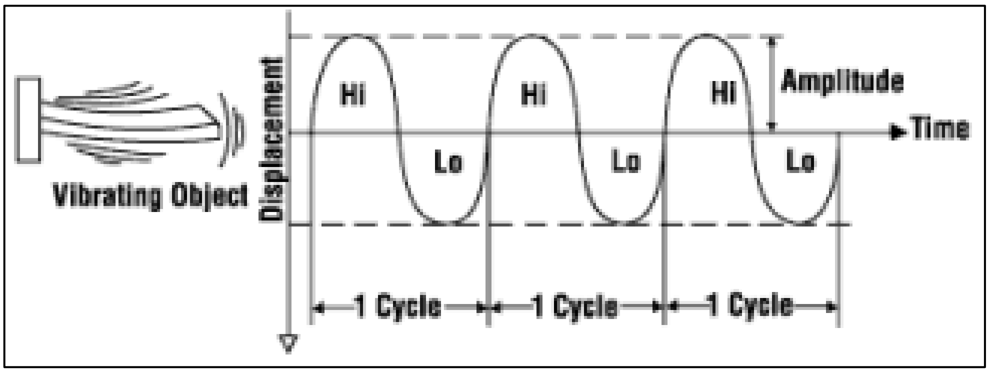


Figure 2-1 Basic Concept of Vibration

Sinusoidal waves, to put it another way, are the fundamental building pieces that make up vibration signals. They exhibit oscillations that are both smooth and periodic. Sinusoidal waves are characterised by three primary qualities: amplitude, frequency, and phase. Amplitude refers to the amount of the oscillation, frequency refers to the rate of oscillation, and phase refers to the position of the wave within its cycle. Through the examination of these waves, we are able to comprehend the operation of vibrating systems and locate any problems or irregularities that may exist. Sinusoidal waves enable us to obtain significant information from vibration signals and build effective ways for effectively managing vibrations. (Alfonso Fernandez, 2017)

2.2.1.1 Amplitude

When an object vibrates, the maximum distance that it moves away from its position of rest is referred to as the object's amplitude of vibration. This value, which is expressed in terms of the vibration's strength or intensity, is measured in metres (m). When the amplitude is larger, it indicates that the object is moving further and that the vibrations are stronger. Monitoring and managing the amplitude of vibration is essential for determining how vibrations are perceived, determining the impact of vibrations on structures, and ensuring that machinery and systems are operating as intended.

2.2.1.2 Frequency

When something vibrates, it shifts back and forth from the position in which it was originally resting. A cycle of vibration refers to the whole movement from one extreme position to the other and back again. The number of times during which an object goes through a complete cycle in one second is referred to as the object's frequency of vibration. It is expressed as one cycle for every one second, which is denoted by the unit hertz (Hz). A higher frequency indicates faster vibrations since it means more cycles are occurring in the same amount of time. grasp sound perception, music, as well as the ability to analyse vibrations in machinery and buildings all require a grasp of frequency.

2.2.1.3 Phase

When performing vibration analysis, the timing difference between two signals is referred to as phase. It is the angle that is obtained by measuring backwards from the highest point of a vibration signal to a reference point. Engineers are able to pinpoint the position of imbalances on a rotor by analysing the phase of the rotor. It is common practise to use the pulses of a tachometer as reference trigger points. The condition of the machinery can be evaluated and prospective problems identified with the use of phase measurement.

2.2.2 Main Component of Vibration

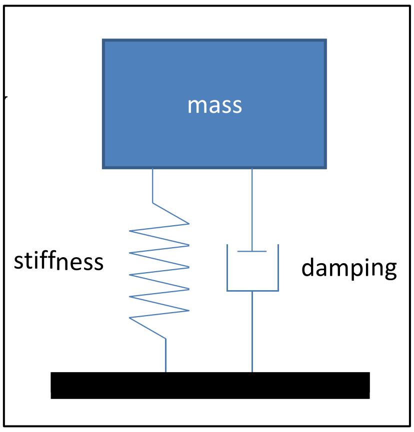


Figure 2-2 Main Component of Vibration

2.2.2.1 Damping

The technique of minimising vibrations by distributing energy more evenly is referred to as damping. It is employed in the regulation of oscillations in mechanical systems, as well as noise and electrical currents. The purpose of damping devices is to prevent excessive vibrations by absorbing and dissipating energy. Depending on the particular application, many types of damping, including as friction, viscous damping, fluid damping, hysteresis damping, and electric or magnetic damping, may be utilised. In many different types of systems, damping is a key component for achieving stability and reducing the detrimental effects of vibrations. (Britannica, 2020)

2.2.2.2 Stiffness

The degree to which an object or structure is resistant to being deformed or shifted as a result of the application of a force to it is referred to as its stiffness. When compared to an object with less stiffness, a more rigid one takes a greater force to cause it to deform. In the context of vibrations, stiffness has an effect on the natural frequency of a vibrating system; more specifically, the correlation between stiffness and natural frequency is positive: the higher the stiffness, the higher the natural frequency. When it comes to engineering and design, stiffness is a crucial component since it ensures that objects and structures can bear forces without undergoing undue distortion.

2.2.2.3 Mass

The capacity of an object to accumulate potential or kinetic energy as a result of its oscillatory motion is referred to as the mass in vibration property. The greater the mass, the greater the amount of kinetic energy that can be stored in it. Both the amplitude and the frequency of a vibration are affected by an object's mass, with heavier items exhibiting bigger amplitudes and lower frequencies. In layman's terms, an object's mass is what dictates how much energy it can carry during vibration, and it also affects the features of how it moves.

2.3 Vibration Analysis

The health of machinery can be monitored and evaluated with the help of a technique called vibration analysis. It helps detect any changes or abnormalities that could suggest possible problems or failures by continuously measuring and evaluating the vibration levels of equipment over time. This is done over the course of the process. Because of this proactive strategy, maintenance teams are able to plan and prioritize their maintenance efforts, which helps to minimize unanticipated machine failures and improves both the performance and the dependability of the equipment. In essence, vibration analysis assists in the early identification of issues, which enables these issues to be handled before they might result in costly damage or interruptions to operations.

2.3.1 Vibration Signal Analysis (VSA)

Mechanical engineers frequently use Vibration Signal Analysis to assess rotating machinery. This method checks the machinery's vibration signals for abnormalities that could affect its safety and reliability. Non-linear and non-stationary vibration signals make analysis difficult.

Vibration signals are used to detect flaws or anomalies in a machine or building. The machine's vibration signals might reveal its condition and efficiency. These signals can detect misalignment, imbalance, bearing wear, and other mechanical difficulties.

Vibration signal analysis comprises several procedures and methods. First, sensors are strategically installed on machinery to gather vibration signals. Accelerometers, proximity probes, and other sensors can correctly measure vibrations in various directions and frequencies.

Vibration signals are processed and analysed. Signals are analysed using mathematical algorithms, statistical approaches, and signal processing. Identify patterns, frequencies, and amplitudes that depart from normal operating circumstances.

Vibration signals help engineers find machinery problems. Excessive vibration amplitudes at specific frequencies may indicate misalignment or unbalance, while variations in vibration patterns over time may indicate bearing wear or structural concerns. Early detection allows maintenance to prevent further damage or catastrophic collapse.

Vibration signal analysis benefits greatly. It is non-invasive and cost-effective for rotating machinery health and performance evaluation. Engineers can prevent downtime, safety hazards, and maintenance costs by monitoring vibrations. Vibration analysis also permits predictive maintenance, which schedules maintenance based on equipment status rather than fixed intervals or reactive fixes.

Finally, mechanical engineering uses vibration signal analysis to monitor and diagnose spinning machines. Engineers can increase dependability, operating efficiency, and equipment performance by analysing vibration signals and taking corrective action.

Benefits of using Vibration Analysis

1. It can be used to identify the type of fault that is present in a machine.
2. It can be used to detect faults in rotating machinery before they cause a failure.
3. It can be used to track the progress of a fault over time.
4. It can be used to assess the severity of a fault.

Limitations of using Vibration Analysis:

1. It can be difficult to identify the source of a vibration signal if the machine is complex.
2. It can be difficult to interpret vibration signals if the machine is noisy or if there are multiple faults present.
3. It can be difficult to use vibration analysis to diagnose faults in machines that are not rotating.

2.3.1.1 Theoretical Calculations of Feeders

The TL in distribution feeder is caused by heat generated due to current flow through feeder resistance. This are sometimes referred to as “I^2 R losses” (also known as “copper losses” or “joule losses”). The fact that this type of TL depends on the square of the current, means that demand profiles containing large peaks lead to significantly more TL than flat demand profiles, even if the average power usage is the same.

The power losses (MW) of the feeder in Figure 2.9 at any time t can be described based on Equation 2.3 and Equation 2.4 (Abdullah and Rodzi, 2011; Rahman, Abdullah and Kamarudin, 2012). The total TL for the entire feeder is then calculated as the sum of all energy losses in all feeder section using Equation 2.5.

2.4 Sensors

2.4.1 Vibration Sensors

Plant maintenance relies on vibration sensors, also known as vibration transducers, to measure equipment and system vibrations. These sensors detect machinery or building vibrations and measure their amplitude and frequency.

Vibration sensors are used to measure spinning machinery like pumps, compressors, steam turbines, and pipelines. Engineers can assess these devices' operation and identify imbalances or flaws that may lead to failures by monitoring their vibration levels.

To evaluate the system, vibration sensor data is analysed. This data helps engineers predict equipment failures. They can use vibration patterns to perform root cause analysis and decide whether repairs or maintenance are needed.

Vibration-measuring equipment and systems require vibration sensors. They provide real-time equipment health and dependability data. Maintenance staff can identify issues early and avert breakdowns and costly shutdowns by monitoring and measuring vibration. Avoiding unexpected breakdowns and downtime minimises operational costs and enhances equipment reliability and durability.

Industrial vibration sensors are beneficial. Root cause analysis helps identify vibration issues and solve them. It also aids in data-driven repair and maintenance decisions. Engineers can optimise plant performance and reduce downtime by continuously monitoring vibration levels. Vibration sensors prevent costly shutdowns and optimise maintenance, lowering operating costs. (Anup Kumar Dey, 2022)

2.4.2 Application of Vibration Sensors

Vibration sensors are important in all businesses that require to monitor vibration for asset performance. In general, the following industries find a wide application of vibration sensors:

- Oil and Gas
- Mining
- Aerospace
- Food and beverage
- Pulp and paper
- Refining, Chemical, Petrochemical, and other Processing Industry
- Metalworking
- Automotive and Transportation
- Power generation
- Certain Manufacturing Industries
- Wind power and other Renewable Power

- Cement
- Research and development

There are several industry standards that govern vibration measurement for industries. Some of those are:

- ISO 4866
- ISO 20816
- AS 2625.1

2.4.3 Working of Sensors

Vibration sensors, which are often referred to as vibration transducers, can be wirelessly utilised to monitor systems or fixed directly on the apparatus being monitored. Vibrations can have their displacement, velocity, or acceleration measured by these devices. These sensors make use of either mechanical, electromagnetic, or optical principles in order to detect vibrations. They have a high degree of sensitivity and can detect vibrations with an amplitude of as little as 10 mV/g. Piezoelectric crystals and seismic masses are the two components that make up vibration sensors. An electrical signal is produced by the crystal as output data whenever the crystal is subjected to mechanical stress in the form of vibrations. These sensors are long-lasting, dependable, and offer consistent readings over the course of their use. Figure below provides the major components of a typical vibration sensor.

Figure 2-3 Working Sensor

If the vibration sensors are placed for a longer duration of time, it will provide the following information:

- How frequently vibration occurs
- The intensity of vibration

To determine if that vibration needs attention, these data can be compared to equipment maker or code and standard data.

2.4.4 Types of Vibration Sensors

Industry uses three main vibration sensors:

- Accelerometers or Acceleration Transducers

Figure 2-4 Accelerometer

Accelerometers measure system acceleration through vibration. Piezoelectricity converts mechanical vibrations into electrical signals. High- and low-impedance accelerometers exist. High impedance accelerometers detect bearing, gear, and other component failures with a larger frequency range. They detect imbalance, misalignment, and broken pieces. Accelerometers detect industrial vibration and prevent equipment failure.

- Velocity sensors

Figure 2-5 Velocity Sensor

Velocity sensors measure vibrations and monitor rotating and reciprocating equipment. They translate mechanical vibrations into electronic signals without power. Velocity sensors are cost-effective and straightforward to install for medium-frequency measurements. They aid equipment evaluation and fault detection.

- Displacement sensors or Displacement Transducer

Figure 2-6 Displacement Sensor

Displacement transducers are vibration sensors that measure displacements. Radial vibrations, axial movements, eccentricity, internal clearances, and differential expansion are captured well by them. These low-frequency sensors measure minor movements accurately. Displacement sensors monitor machinery and structures for safe and effective operation.

2.4.5 Selecting of Vibration Sensors

Application determines vibration sensor or transducer type. The main factors that contribute to the selection of vibration sensors are:

- Range and accuracy of the vibration transducer
- Environmental conditions where it will be mounted
- The shape of the measuring surface

Displacement sensors work for vibration frequencies of 0 to 10Hz, velocity sensors for 10 to 100Hz, and accelerometers for greater than 100Hz. The following table provides the selection of vibration transducers based on the frequency of vibration.

Table 2.1 Type of Vibration Sensor and Frequency

Frequency Range	**Type of Vibration Sensor**
0 to 10 Hz	Displacement Sensors
10 to 100 Hz	Displacement or Velocity Sensors
100 to 1000 Hz	Displacement, Velocity, or Acceleration Sensors
1000 to 2000 Hz	Velocity or Acceleration Sensors
Greater than 2000 Hz	Accelerometers

2.5 Data Processing

2.5.1 Time Domain

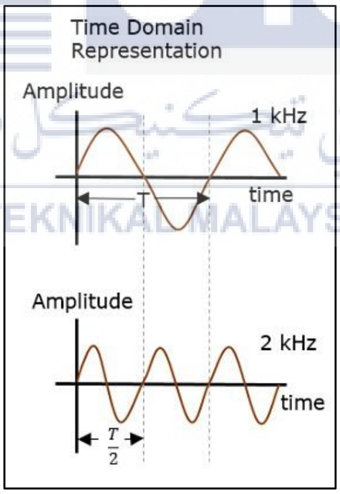


Figure 2-7 Time Domain

During the process of vibration analysis, the vibration signal is observed on an oscilloscope in the form of a waveform. On the waveform, the amplitude is plotted along the vertical axis, while time is plotted along the horizontal axis. This allows one to see how the vibration alters itself through time. Waveform analysis makes it possible to do a direct visual assessment of the vibration signal in the time domain. This makes it easier to spot unusual patterns and transient occurrences, both of which could be signs of problems with the vibration. It offers a straightforward and easy-to-understand method for understanding the nature of the vibration and identifying any irregularities or shifts in the manner in which the vibration behaves.

2.5.2 Spectrum Analysis

The examination of the frequency components of a signal can be done through the process of spectral analysis. In this process, the signal is changed from being in the time domain to being in the frequency domain by utilizing mathematical procedures such as the Fast Fourier Transform (FFT). We are able to determine the main frequencies that are contained in the signal as well as the amplitudes that correlate to those frequencies by doing an analysis on the resulting frequency spectrum. This enables us to have a better understanding of the vibration patterns and sources that are present within a machine. It is common practice to do spectral analysis in order to ascertain vital information such as rotational speeds or particular mechanical problems associated with vibrations in machinery.

2.5.3 Frequency Domain

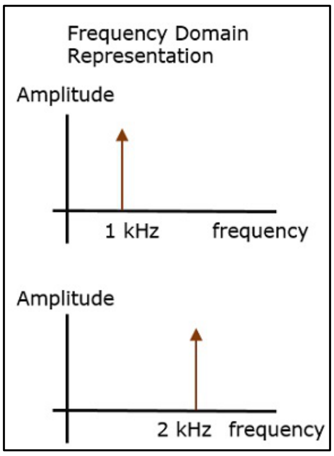


Figure 2-8 Frequency Domain

The many frequencies that are present in a vibration signal can be analyzed through a process called spectrum analysis. Experts are able to have a better understanding of the exact frequencies that contribute to the vibration of a machine as a result of this. They are able to spot any unique patterns or peaks by studying the spectrum, which allows them to determine whether or not there may be problems with the apparatus. This data is provided in a graphical fashion, with the frequency displayed along one axis and the amplitude displayed along the other. Spectrum analysis is a helpful tool that may be used to diagnose issues and make maintenance decisions based on accurate information.

2.5.4 Fast-Fourier Transform (FFT)

The Fast Fourier Transform (FFT) is a mathematical approach that helps evaluate vibration signals by translating them from the time domain to the frequency domain. This process is called the frequency domain transformation. It does this by decomposing the vibration signal into its separate frequency components, which in turn enables us to recognize particular frequencies that are linked to machine problems such as misalignment and unbalance. Engineers are able to swiftly assess vibration data with the help of the FFT, which enables them to determine the cause of vibration and execute the relevant maintenance activities. It is a strong instrument that helps guarantee that operations run smoothly and helps prevent breakdowns in machinery.

2.6 Gear

2.6.1 Definition of Gear

Toothed gears transmit power and motion between spinning shafts. These toothed wheels transfer torque and angular velocity by interlocking. Gears change power source speed, torque, and direction. "Transmission" or "gear set" refers to synchronised gears. Gears are elementary machines because they provide mechanical advantage, which amplifies force or torque.

Two gears of different sizes with matching teeth (the larger gear has more teeth) acquire a mechanical advantage. The gears have different rotational speeds and torques. Speed and torque ratios are inversely related, assuming equal input and output power (ignoring friction losses). The smaller gear has a higher speed and lower torque, while the larger gear has a lower speed and higher torque.

Gears and gear set change speed, torque, rotation, power supply, and motion. Most gears engage with each other. Gears can also engage with "racks," non-rotating toothed components, to produce translational motion. Car steering systems use "rack and pinion" to transform steering wheel rotation into linear motion.

Gears are essential to many mechanical systems and machines, from industrial to every day. They transmit and change electricity and motion, making mechanical devices efficient. (Dr. Ala Hijazi, 2023)

2.6.2 Types of Gear

There are a few different types of gear.

1. Spur Gears

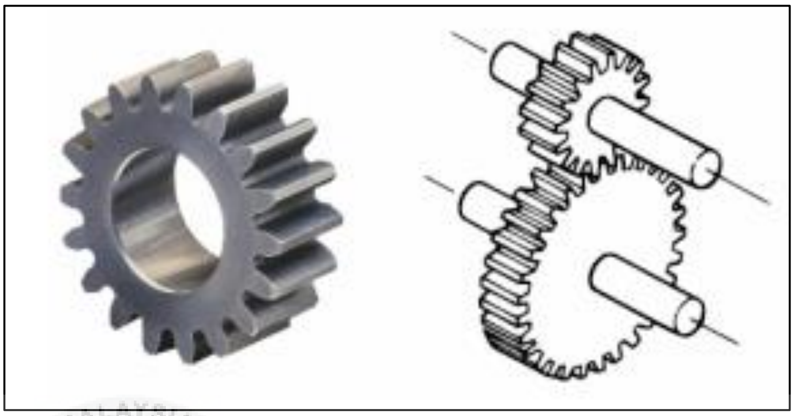


Figure 2-9 Spur Gear

Due to their simplicity and versatility, mechanical systems use spur gears. These gears are designed to transfer power between parallel shafts. Spur gears have straight teeth parallel to the rotation axis. This simple architecture enables widespread use in numerous industries and mechanical equipment, from small domestic appliances to massive industrial gear.

Spur gears transfer power by interlocking their teeth. The driven and driving gears rotate synchronously when their teeth touch. This contact transfers torque and angular velocity between parallel shafts smoothly.

Spur gears transfer power efficiently, but their direct teeth interaction causes noise and vibration. Gear tooth profile, precision manufacture, and lubrication improve performance and reduce wear.

Spur gears can be customised by size, material, and configuration. The gear ratio—the number of teeth on each gear—determines the speed and torque relationship between the driving and driven gears. Depending on load capacity, working conditions, and cost, spur gears are made from metals, polymers, and other materials.

Spur gears are essential to many mechanical systems. Power transmission between parallel shafts is easy with their simple design and parallel alignment. Spur gears help many electronics and industrial processes run smoothly despite their simplicity.

The characteristic of Spur Gear

The features of spur gears can be succinctly described as follows:

- Spur gears are the easiest to make. They have parallel-cut teeth. Spur gears are cheaper to build due to their simple design.
- Spur gears are cheaper to build because of their simplicity. Their straight teeth and parallel alignment make them easier to machine.
- Spur gears can achieve gear system speed ratios. Spur gears can attain speed ratios up to 8 for a single reduction (one-step) design. In extreme circumstances, they can reach 20. Two-step designs with several gears can achieve 45-speed ratios. Complex three-step designs can achieve speed ratios exceeding 200.

The speed ratio shows the relationship between the driving gear and the driven gear(s). It controls how gears in a gear system change speed. Gear sizes, gear teeth, and gear arrangement determine speed ratios.

Spur gears are simple, cost-effective, and can reach specified speed ratios based on the gear configuration. Spur gears are often used in cost-efficient and moderate-speed ratio applications due to these qualities.

Limitation of Spur Gear

Spur gears provide advantages, but their restrictions require careful application. Noise and direction change are these restrictions.

Spur gears' parallel teeth prevent direction change. These gears cannot transmit power along a curved path, making them unsuitable for 90-degree turns. In such instances, bevel or worm gears are better.

Spur gears generate noise from quick collisions and vibrations caused by mating teeth. Gear design, tooth profile, manufacturing precision, and lubrication affect noise. Noise-reducing gear or methods are recommended in essential situations.

Spur gears are used in numerous applications because their benefits outweigh their shortcomings. Simple, cost-effective, modest speed ratio and straight-line power transmission systems suit them well. Noise-dampening materials, optimised gear tooth shapes, enhanced gear meshing precision, and proper lubrication can reduce spur gear noise.

Understanding spur gear restrictions is crucial to choosing the right gear type. Consider different gear types for direction changes and noise reduction. Spur gears remain attractive in many applications where their characteristics match system requirements.

2. Helical Gears

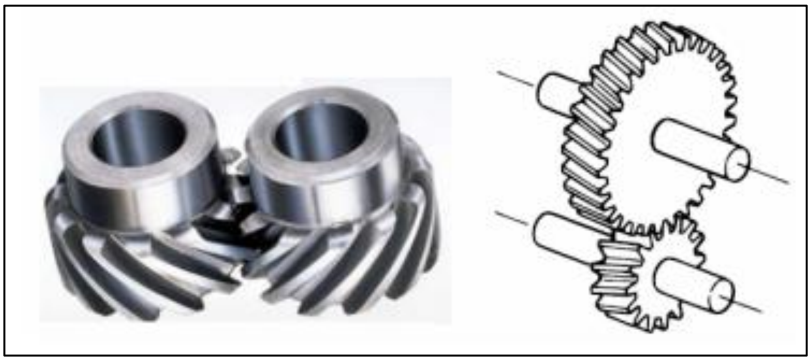


Figure 2-10 Helical Gear

Helical gears look like spur gears but have different teeth. Helical gears contain helical teeth, unlike spur gears, which have straight teeth that run parallel to the shaft axis. Helical gears benefit from their unique tooth design.

The Helix angle determines the gear tooth angle. Shaft design and gear position affect the helix angle. Effective functioning and tooth engagement depend on the helix angle.

When the helix angle is right, one gear tooth's end progressively contacts the other. Smooth tooth engagement decreases noise, vibrations, and impact loads. Gradual contact evenly distributes the load across the tooth face, reducing wear and enhancing load-carrying ability.

Parallel shafts should have a helix angle below 20 degrees. Due to the teeth's helical form, end thrust along the shaft axis is limited by this constraint. End thrust can cause premature bearing and shaft failure.

Manufacturers can benefit from helical gears with the right helix angle over spur gears. These benefits include smoother and quieter operation, increased load-carrying capacity, efficiency, and axial force resistance. Helical gears are regarded for their benefits in automotive, industrial machinery, power generating, and marine applications.

Helical gears feature teeth cut at the helix angle, unlike spur gears, which have parallel teeth. Efficiency and tooth engagement depend on the helix angle. Following the appropriate helix angle limitations reduces the detrimental consequences of excessive end thrust, improving gear performance and smoothness.

The Characteristics of Helical Gear

Helical gears possess various attributes that distinguish them from other gear types, particularly spur gears. These characteristics include:

- Helical gears have longer teeth than spur gears with the same pitch diameter. Elongated teeth have more contact surfaces, which strengthens them. Helical gears can handle bigger loads and transmit more torque than similar-sized spur gears due to their larger surface contact area. Helical gears are ideal for heavy-duty and high-load applications because of this.
- Improved Load-Carrying Capacity: Helical teeth allow numerous teeth to engage simultaneously along the gear's contact zone. Increased contact area distributes the load across more teeth, improving load-carrying capacity. Helical gears can bear heavier loads and transmit power efficiently due to distributed stress and wear.
- Helical gears can connect non-parallel and non-intersecting shafts. Helical gears mesh easily, even with inclined shafts, due to their angled teeth. Helical gears can be used in applications with non-parallel shafts due to their flexible shaft connection.
- Helical gears are silent, especially at high speeds. Helical gears improve power transmission and reduce noise due to their inclined tooth profile. Helical teeth reduce impact and shock loads, lowering vibrations and gear system durability.

- Durability: Helical gears' larger tooth contact area improves load distribution and reduces wear. Elongated tooth profiles gradually transfer forces, reducing stress concentrations and improving gear life. Helical gears can take higher weights and transmit more torque, making them durable in demanding situations.

Helical gears are popular in many industries due to their tooth strength, load-carrying capability, versatility, reduced noise and vibration, and durability. They efficiently transmit power and manage big loads due to their teeth design and performance advantages.

Limitations of Helical Gear

Helical gears have drawbacks that must be considered while using them. Limitations include axial thrust forces during operation and higher expense.

The helical tooth profile generates axial thrust forces in meshing gears. These forces press along the shaft axis and load gear bearings and shafts. Gear system design and bearing and support structure selection must accommodate these thrust forces.

Helical gears cost more than spur gears because they require specialised equipment and processes to create properly angled teeth. For best performance, the inclined tooth shape may require precision machining and alignment, increasing production costs.

Helical gears have benefits and applications despite these limits. Engineers and designers analyse these constraints against the gear system's needs to find the best gear type for an application.

Limitations can be mitigated. Thrust bearings or thrust washers can handle helical gears' axial forces, minimising gear system strain. Helical gears may get cheaper due to manufacturing advances.

Helical gears are employed in many industries because their benefits outweigh their shortcomings. Reliable and precise gear systems, they can withstand heavier loads, operate smoothly, and transmit power efficiently.

In conclusion, helical gears generate axial thrust forces and are more expensive than spur gears, but careful design and additional components can overcome these drawbacks. Thus, to choose a gear, one must assess the application's needs and limits to determine if helical gears' benefits outweigh their drawbacks.

3. Bevel Gears

Figure 2-11 Bevel Gear

Bevel gears are used to transmit power between right-angled shafts. Bevel gears contain cone-shaped teeth, unlike spur or helical gears, which have cylindrical teeth.

Bevel gear tooth configurations vary. Straight-tooth bevel gears have teeth cut across the face. Spiral-tooth bevel gears are comparable to helical gears. Application requirements, operating circumstances, and gear system design determine straight or spiral teeth.

Below 1000 fpm, straight-tooth bevel gears are recommended. Straight-tooth bevel gears produce excessive noise at higher speeds. These gears' straight teeth mesh abruptly, causing impact and noise. Thus, for peripheral speeds over 1000 feet per minute, spiral-tooth bevel gears or other gear layouts may be better for noise reduction and smooth operation.

The 1000-foot-per-minute speed limit is a rough guideline based on gear design factors. Gear design, tooth geometry, lubrication, and other factors affect speed restrictions. To optimise performance, durability, and noise within the operating range, engineers and gear designers consider these parameters during gear selection.

Finally, cone-shaped bevel gears distribute power between right-angled shafts. Straight or spiral teeth. For peripheral speeds below 1000 feet per minute, straight-tooth bevel gears reduce noise. To reduce noise and mesh at greater speeds, alternate gear types or arrangements may be utilised.

The characteristic of Bevel Gear

The characteristics of bevel gears can be expounded upon in greater detail as follows:

- Bevel gears are designed for power and motion transmission between intersecting shafts. When power is transferred from a vertical shaft to a horizontal shaft, they excel at changing rotation direction. Hand drills use bevel gears to convert handle rotation to horizontal chuck revolution.
- To ensure gear tooth meshing and alignment, bevel gear system assembly changes can be done. Assembly flexibility allows gear system fine-tuning for the best performance and minimal misalignments. Bevel gears also account for load-induced deflection. Gear shafts and housing deflect due to applied forces. The

load distribution is optimised by calculating potential deflection and allowing for it. This feature ensures gear system longevity.

Bevel gears are available in many designs and configurations for varied uses. Tooth shape, size, and inclination angle are chosen based on load capacity, speed, torque transfer, and motion conversion. Bevel gear design includes backlash (clearance between meshing teeth), lubrication, noise reduction, and efficiency.

Where power transfer and direction change are crucial, bevel gears are widely utilised. They convey emotion and power in machines and mechanical systems because they can tolerate intersecting shafts, assembly flexibility, and deflection.

4. Miter Gears

Figure 2-12 Miter Gear

Miter gear pairs always have the same number of teeth. The number of teeth in classic bevel gears can vary.

Miter gears have the same number of teeth, so the input and output shafts have the same rotational speed and torque. Miter gears are ideal for applications that require direction change without speed or torque change. The power gearbox is seamless because the gears interlock.

Right-angle drives often use miter gears. Two miter gears at a 90-degree angle can redirect rotational motion without changing speed or torque. Woodworking equipment, automotive differentials, and mechanical clocks use these gears to transmit power between perpendicular shafts.

Miter gears are made like bevel gears. Straight teeth are the most prevalent. However, spiral teeth are possible. The tooth profile is carefully developed to promote correct meshing and minimise backlash for reliable power transfer.

Miter gears have drawbacks despite their 1:1 gear ratio and right-angle power gearbox. Miter gears cannot change gear ratios or speed amplification due to their symmetrical tooth shapes. The mating gears must also have the same module (tooth size) and pitch diameter, which limits their application versatility.

Miter gears are specialised bevel gears with equal teeth in both ratios. Right-angle power gearbox without changing rotational speed or torque is frequent. Miter gears are durable and efficient for power transmission and perpendicular shaft connections, although gear ratio flexibility is limited.

The Characteristics of Miter Gear

The attributes of miter gears can be further expounded upon in the following manner:

- Miter gears, like bevel gears, provide a consistent gear ratio. Since miter gears have the same number of teeth, their gear ratio is 1:1. The input and output shafts have the same rotational speed and torque. This constant gear ratio helps maintain speed and torque.
- Miter gears resemble bevel gears in many ways. They're conical, with teeth cut at an angle to the gear's axis. Miter gear teeth are designed for effective meshing

and power transfer. Depending on the application, they might have straight or spiral teeth. Lubricating miter gears, like bevel gears, reduces friction and wear.

- Miter gears are widely used in industrial applications that demand reliable and precise power transfer at right angles. They're crucial in conveyors, lifts and kilns. Miter gears can be used in conveyor systems to change direction at a right angle. They connect the motor to the hoisting mechanism of lifts. Miter gears help kiln drums or vessels rotate.

Miter gears benefit these applications. Their constant gear ratio maintains speed and torque throughout the system. Miter gears allow compact power transfer in confined places. Miter gears also enable accurate motion control for conveying, lifting, and rotating heavy items.

Miter gears, like bevel gears, have a constant gear ratio. Conveyors, lifts, kilns and other systems that need reliable and precise power transmission at right angles use them. Miter gears maintain speed and torque for precise motion control in industrial processes.

Limitation of Miter Gear

Due to equal teeth on each gear, miter gears have a 1:1 gear ratio. This means the input and output shafts rotate at the same speed, which is good for steady gear ratios but bad for speed changes.

Miter gears cannot change gear ratios to change input and output shaft speeds; hence they are not appropriate for speed reduction or amplification. Instead, they retain a constant speed and torque, making them less adaptable for variable-speed applications.

Spur, helical, and worm gears may be better for speed-changing applications. These gear types offer greater gear ratios for speed reduction or amplification to satisfy application needs.

Consider application gear requirements before choosing miter gears. If speed variation or adjustable gear ratios matter, try other gear types. Miter gears can efficiently transmit power if a 1:1 gear ratio and right-angle gearbox are sufficient.

Miter gears' main drawback is their 1:1 gear ratio. They're unsuitable for variable-speed applications. When changing speed, consider an application's speed needs and gear possibilities.

5. Hypoid Gears

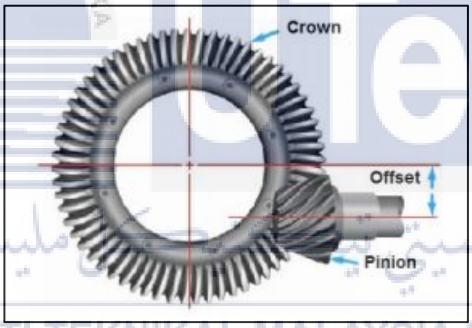


Figure 2-13 Hypoid Gear

Hypoid gears are spiral bevel gears with an offset axis. Hypoid gears' pinion and ring gear shafts continue past each other, unlike bevel gears. In non-intersecting shaft applications like vehicle drivetrains, this design has many advantages.

Hypoid gears have larger pinion diameters than bevel gears. The gear's strength and torque capacity increase with the pinion diameter. This strength allows high gear ratios for efficient power transmission in situations that need significant torque multiplication or reduction.

Hypoid gears' offset axis provides mechanical advantages. The offset design lowers the drive shaft in cars, improving packaging and freeing up space. Sports cars and SUVs with low centres of gravity must optimise space and weight distribution.

Hypoid gears run smoother and quieter than bevel gears due to their offset axis. A misaligned gear axis reduces gear teeth sliding contact and friction, reducing noise and improving efficiency.

Many industries employ hypoid gear. Rear-wheel drive and all-wheel drive systems use them. They efficiently transfer engine power to the rear wheels while accommodating the offset needed for the driveshaft to pass under the car. Hypoid gears are also used in heavy machinery, industrial equipment, and domestic appliances for non-intersecting shafts and high torque.

Hypoid gears are spiral bevel gears with a pinion-ring gear offset axis. They allow high gear ratios, non-intersecting shaft arrangements, and greater pinion diameter for strength. In automotive applications, offset design improves vehicle packaging and lowers drive shafts. Hypoid gears reduce noise and increase torque capacity for power transmission in many industries.

6. Worm Gears

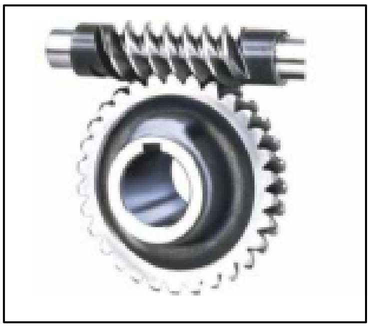


Figure 2-14 Worm Gear

Worm gears distribute power between two shafts at a straight angle without intersecting. The worm gear's spiral thread-like structure and meshing teeth on the mated gear resemble screws.

Worm gears are distinguished by their high gear reduction ratio in a compact construction. The worm gear's helical teeth slide against the worm wheel's teeth at a small angle. This sliding movement gives the worm gear a high reduction ratio, allowing the input shaft to rotate numerous times while the output shaft rotates only a portion. Worm gears are ideal for conveyor systems, lifts and heavy-load machinery that require a large speed reduction.

Worm gears self-lock due to worm-worm wheel sliding contact. The gear design inhibits output shaft backward rotation, giving great mechanical holding strength. Worm gears are ideal for lifting machinery and safety devices since they self-lock.

Worm gears are small, high-gear reduction, and self-locking. They're also limited. Their efficiency is lower than other gears. Heat losses from worm-worm wheel friction reduce efficiency. Lubrication and careful design reduce friction and maximise efficiency.

Worm gears can provide significant axial thrust forces. Worm gear helical teeth provide axial stresses along the worm shaft. These axial forces must be supported and borne to ensure gear reliability.

In conclusion, worm gears distribute power between right-angled shafts. They're compact, gear-reduced, and self-locking. Automotive, industrial machinery, and robotics use worm gears for precision speed reduction and locking systems. Worm gear systems should account for their decreased efficiency and axial thrust forces.

The Characteristics of Worm Gear

Worm gears' unique properties make them ideal for certain applications. The worm's angle makes them self-locking. Due to friction between their teeth, the worm can easily rotate the gear, but the gear cannot. Worm gears are ideal for safety-critical systems like conveyor belts because their self-locking characteristic prevents the output shaft from rotating backwards.

Worm gear input gears are also common. Torque is applied directly to the worm shaft input end, commonly via a driven sprocket or electric motor, providing compact and efficient power transfer. Worm gears are also suitable for high gear reduction between the driving and driven shafts. Heavy machinery, automotive systems, and industrial equipment can regulate speed and torque with high gear ratios from 20:1 to 300:1 or greater.

Worm gears are useful for safety, compactness, and precise motion control applications due to their self-locking capability, input gear arrangement, and high gear ratios. Worm gear system design and operation should include lubrication, efficiency, and axial thrust forces.

Limitation of Worm Gear

Worm gears' limits need careful use. Worm gears' low efficiency limits them. Due to the worm and worm wheel teeth's sliding contact, friction losses increase. The heat from friction reduces gear system efficiency. Consider this decreased efficiency while developing and selecting worm gears for efficiency-critical applications.

In high-torque situations, friction between the worm and worm wheel teeth causes wear and erosion. Constant sliding motion and strong contact pressures can damage surfaces and degrade gear components. Gears need proper lubrication and maintenance to last longer. Selecting high-wear materials can also help.

High sliding velocities and heat generation limit worm gear speed ratios. High rotational speeds without sacrificing gear system efficiency and durability are difficult. Spur or helical gears may be better for a wide speed ratio range.

Due to their helical teeth, worm gears create large axial thrust forces. The gear system must be supported and regulated to handle these axial forces along the worm shaft. These axial forces require thrust bearings and gear design to prevent excessive wear and failure.

Consider these limits while choosing worm gears for certain applications. Proper lubrication, maintenance, and design can help the gear system operate and last longer.

7. Racks (Straight Gears)

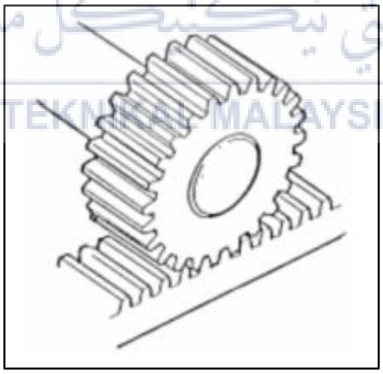


Figure 2-15 Racks Gear

The rack converts rotating motion to linear motion. It has a straight bar with an infinite-diameter gear tooth profile. The rack and pinion, a tiny gear, converts rotary motion to linear or linear to rotary.

The rack's teeth contact with a pinion gear to start a linear movement. Linear motion has many uses. In an automobile's rack and pinion steering system, the steering wheel's rotational motion is converted into linear motion along the rack, which turns the wheels.

The rack can also rotate in linear motion. Linear actuators and positioning systems use the rack's movement to rotate a shaft or operate a machine.

Rack and pinion have many benefits. It efficiently converts linear motion to rotational motion with a direct and exact input-output relationship. The rack and pinion teeth mesh precisely, minimising slippage and friction losses and ensuring maximum mechanical efficiency.

Automotive, robotics, manufacturing, and linear motion systems use rack and pinion mechanisms. Its adaptability and dependability make it a popular choice for direct and effective motion conversion.

The Characteristics of Rack Gear

The practicality and widespread application of rack gears are further emphasised by their various characteristics. Additional elaborations on these characteristics are presented below:

- Racks with machined ends can be joined to form any length, demonstrating their modularity and versatility in constructing systems with longer linear motion. Conveyor systems, CNC machines, and gantry systems can be customised and adapted with this feature.
- Rack gears in car steering systems reliably and efficiently convert steering wheel rotation into linear motion along the rack. Modern automobiles use rack and pinion steering due to their fine control, quickness, and compact design.

- The rack and pinion mechanism is used in windscreen wiper systems and steering systems. This device is reliable and synchronised and clears the windscreen of rain, snow and debris.

Rack gears can join racks, are widely used in steering systems and are used in windscreen wiper systems. Rack gears efficiently transform rotational motion to linear motion, providing reliable and precise movement in mechanical systems.

8. Herringbone (Double Helical Gears)

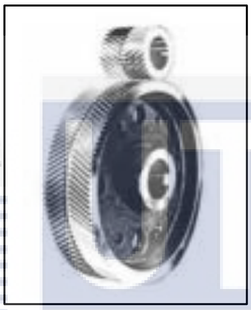


Figure 2-16 Herringbone Gear

Double helical gear, commonly known as Herringbone, is utilised to transfer energy between two parallel axes. The double helical gear mechanism provides minimal noise and vibration, in addition to a complete absence of net axial thrust.

The attributes of double helical gears, commonly referred to as Herringbone gears, underscore their distinctive merits in the transmission of energy between parallel axes. The following discourse provides further elaboration on these traits:

- Double helical gears decrease noise and vibration better than other gear designs. Double helical teeth produce a V-shaped pattern. This arrangement reduces axial stresses and vibrations in single helical gears. Double helical gears reduce noise and vibration in high-precision machinery and automotive and industrial gearboxes by cancelling axial thrust forces.

- No net axial thrust: Single helical gears generate axial thrust due to their slanted teeth, but double helical gears do not. The net axial thrust is annulled by forces from the two sets of teeth's opposing helix angles. In high-speed gearboxes and gear systems, where axial forces can enhance wear, efficiency, and equipment damage, this feature is especially useful.
- Herringbone gears' double helical design increases load-carrying ability. Two sets of teeth with opposite helix angles improve gear face weight distribution. Double helical gears can manage more torque and power due to their distributed load-sharing capacity, making them excellent for heavy-duty applications that demand reliable gear systems.
- Axial symmetry facilitates double helical gear production. Teeth are the same but angled differently. The same cutting tools and machining methods can be used for both gear surfaces, simplifying manufacturing. Axial symmetry allows balanced loading, which distributes forces evenly across gear teeth and improves gear system performance and lifetime.

To summarize, Herringbone gears, or double helical gears, have low noise, vibration, and net axial thrust. These gears perform better and carry more in parallel axis applications. Their symmetrical form makes them suited for a wide range of industries and applications where smooth and efficient power transfer is needed while maintaining mechanical integrity and reducing noise and vibration.

Limitation of Herringbone Gear

Herringbone gears possess certain limitations despite their advantages. These limitations are outlined below:

- Herringbone gears are more complicated and expensive to create than other gears due to their extensive manufacturing process. To work properly, double helical teeth need precision machining and alignment. Specialised equipment and expert labour increase manufacturing costs. Herringbone gears cost more than simpler gears.
- Herringbone gears are noisier than similar single helical gears. A Herringbone gear's two helical sets cause axial shuttling. To offset net axial force loading, the double helical pinion oscillates. This movement increases vibration and noise during gear operation. Herringbone gears have a somewhat higher noise level than single helical gears, even with good gear construction and maintenance.

Despite these difficulties, Herringbone gears are used in many industrial applications due to their distinct advantages. Herringbone gears are used depending on load capacity, noise tolerance, and cost. Manufacturers and engineers carefully weigh the pros and cons of Herringbone gears to assess their viability for a certain application.

9. Internal Gear

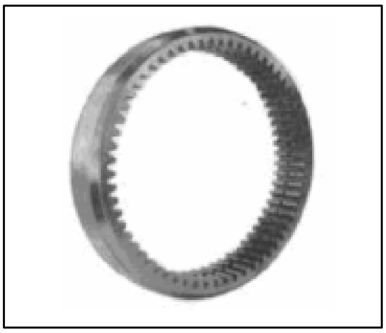


Figure 2-17 Internal Gear

Internal gears have teeth on the interior. Internal gears are modified to prevent tooth interference. These gears are used when space is limited or design requirements need gears with teeth on the inside. They work smoothly without teeth contact. Gearboxes and machines with compact and reliable power transfer use internal gears.

The Characteristics of Internal Gear

The distinctive features of internal gears can be concisely presented as follows:

First, two external gears in mesh reverse rotational direction, but two inside gears do not. Second, internal gears are safer and have more weight-bearing capacity than external gears since the teeth are enclosed. Thirdly, parallel shaft axes allow compact designs and reductions in limited space, making internal gears appropriate for space-restricted applications. Fourthly, when utilised with a pinion, internal gears distribute the load uniformly across more teeth, reducing pressure intensity on individual teeth and improving durability and longevity. Fifthly, internal gears have a reduced centre distance between gears, making them more compact than external gears and employed in planetary gear systems to achieve large reduction ratios.

Finally, the internal gears' convex profile surface works against a concave surface to prevent wear and ensure long-term performance.

Internal gears give steady rotation, safety, compact construction, even weight distribution, huge reduction ratios, and superior surface endurance. However, internal gears are harder to find and may require bespoke fabrication.

Applications of the Internal Gear:

- Planetary gear drive of high reduction ratios, clutches, etc.

Limitation of Internal Gear

The constraints of internal gears can be delineated as follows:

First, internal gears have more complex housing and bearing supports than external gears. The external gear embeds within the internal gear, making the gear system more complicated. The housing's gear location and support, and alignment can be more difficult.

Second, interference difficulties may make low-gear ratios impossible with internal gears. The internal gear teeth on the gear blank might limit meshing space, especially at lower gear ratios. This limits internal gear ratios.

Thirdly, internal gears are harder to make. Specialised tools and production methods are needed for gear blank internal teeth geometry and precision machining. Custom tooling may be needed to shape and position the teeth, increasing production cost and complexity.

Selecting internal gears for specific applications requires consideration of these limits. Internal gears offer continuous rotational direction and compact design, but housing complexity, limited gear ratios, and manufacturing challenges should be considered throughout design and implementation.

2.6.3 Gear Fundamental

Gear can be defined in terms of its pitch, pressure angle and number of teeth. Gears have a few terms, such as:

- **Pitch Circle Diameter (D):**

  Gear design and measurement use the pitch circle, a conceptual circle where gear teeth contact. Pitch diameter determines gear tooth size and positioning. The pitch diameter is crucial for gear ratio, clearance, gear meshing, and power transfer.

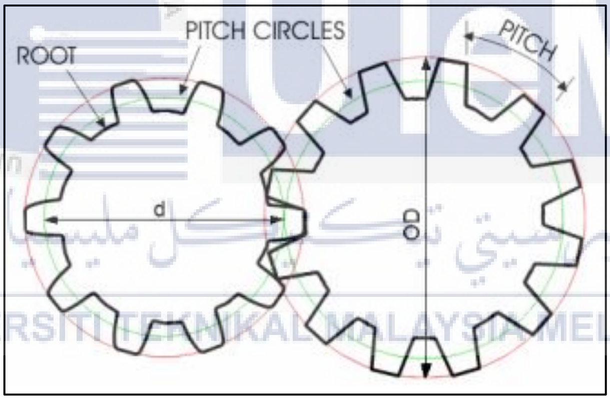


Figure 2-18 Pitch Circle Diameter

- **Outside Diameter (OD):**

  The gear's outside circle, or peripheral, is the circular border of gear teeth. The gear's outer diameter, which determines its size and system fit, is crucial. This critical measurement calculates clearance requirements, gear spacing, and gear system dimensions. The outside diameter is essential for gear manufacturing, assembly, and application.

- **Root:**

The root is the bottom part of a gear wheel.

- **Pitch:**

The pitch circle in gear measures tooth spacing. This measurement indicates tooth-to-tooth distance. Gear design and manufacturing depend on the pitch, which determines gear tooth size and engagement. Pitch is inversely proportional to gear teeth. Engineers can ensure power transmission via smooth meshing gear systems with pitch information. It is expressed in the following forms:

  - Diametral Pitch (Pd) is the number of teeth per inch of the pitch diameter and is also an index of tooth size. Given:

$$Pd = \frac{Z}{d}$$

Where;

Pd = diametral pitch

Z = number of teeth

d = pitch circle diameter in inches

A significant diametral pitch signifies a diminutive tooth and conversely. To reiterate, grander gears possess a reduced number of teeth in an inch of diametral pitch.

- **Module (m):**

The module quantifies gear tooth size and dispersion. It's calculated by dividing a gear's pitch diameter by its tooth count. Higher module values indicate larger gear teeth. The metric system relies on the module to standardise gear dimensions and ensure gear mechanism compatibility. Meshing gears must have the same module:

$$m = \frac{1}{Pd} = \frac{d}{Z}$$

- **Circular Pitch (Pc):**

The distance between corresponding points on consecutive gear teeth along the pitch circle determines gear tooth size and spacing. Gear teeth are directly related to circular pitch. In particular, a lesser number of teeth results in a larger circular pitch. Circular pitch ensures gears mesh well. This smooths the power and motion gearbox, emphasising its importance in gear technology. Calculated in inches, the circular pitch equals the pitch circle circumference divided by the number of teeth:

$$Pc = \frac{Circumference\ (\pi d)}{Number\ of\ teeth\ (Z)}$$

Due to the direct proportionality of the circular pitch to the module and the inverse proportionality to the diametral pitch, it is imperative that meshing teeth exhibit a uniform circular pitch.

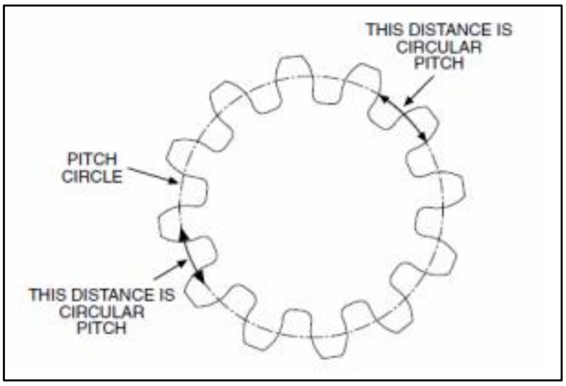


Figure 2-19 Relationship between Circular Pitch and Diametral Pitch

Relationship between Circular Pitch and Diametral Pitch:

$$Pc = \frac{\pi d}{Z} \text{ and } Pd = \frac{Z}{d}$$

We have,

$$Pd\ Pc = \pi$$

The product of the circular pitch and the diametral pitch is equal to pi (π).

- **Number of Teeth (N):**

  The number of teeth is related to the diametral pitch and the pitch circle diameter by the equation:

$$Z = d \times Pd$$

- **Tooth Size:**

  Diameter, module, and circular pitch indicate tooth size. These ratios determine a gear's pitch diameter-dependent tooth count. A gear set's tooth count is crucial. Teeth should be large and few for severely loaded gears and small and many for smooth operation. Mesh teeth must have the same circular pitch since the module is directly proportional to the circular pitch and inversely proportional to the diametral pitch.

- **Center Distance (CD):**

  The centre distance of two spur gears is crucial. This essential measurement determines gear position. For two spur gears, the centre distance equals the total of their pitch diameters divided by two. This approach aligns gears for optimal meshing. The centre distance affects gear ratio and tooth interlocking, making it essential for smooth gear functioning.

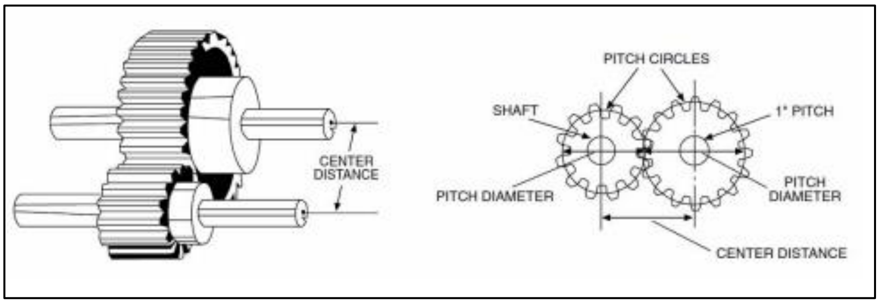


Figure 2-20 Center Distance

- **Pitch Point:**

  The pitch point is where two gears engage during rotation. "P" marks it on the gear centre line. The gears converge to transmit power and motion at this point. Engineers may create gears that mesh and work well by understanding the pitch point.

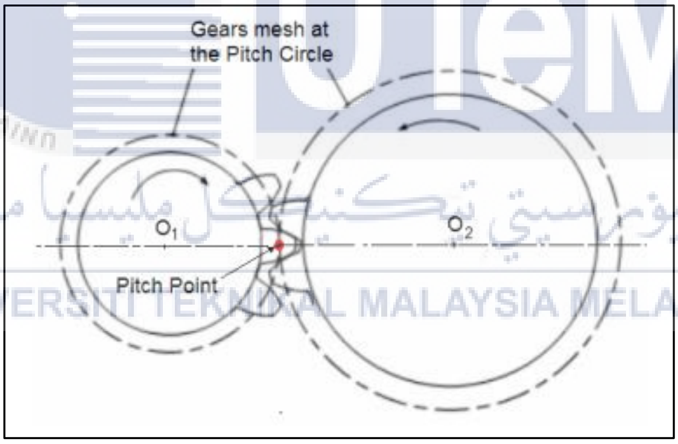


Figure 2-21 Pitch Point

CHAPTER 3

METHODOLOGY

3.1 Introduction

3.2 Proposed Methodology

This project is carried out using two types of gear in two conditions which is normal and abnormal gears. This project is using the equipment PT 500, Machinery Diagnostic system from gunt HAMBURG to analyse the result. The sensor is mounted to the gearbox while the software will process the data through PT500.04, Computerised Vibration Analyser.

3.2.1 Experimental Setup

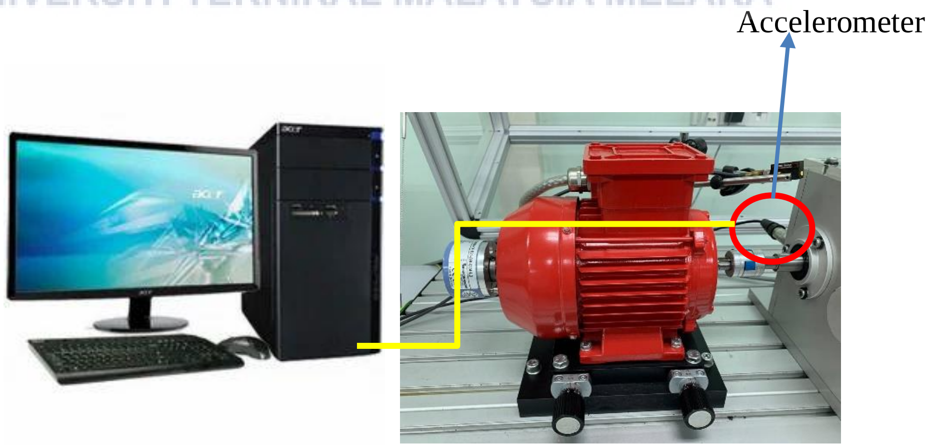


Figure 3-1 Experimental Setup

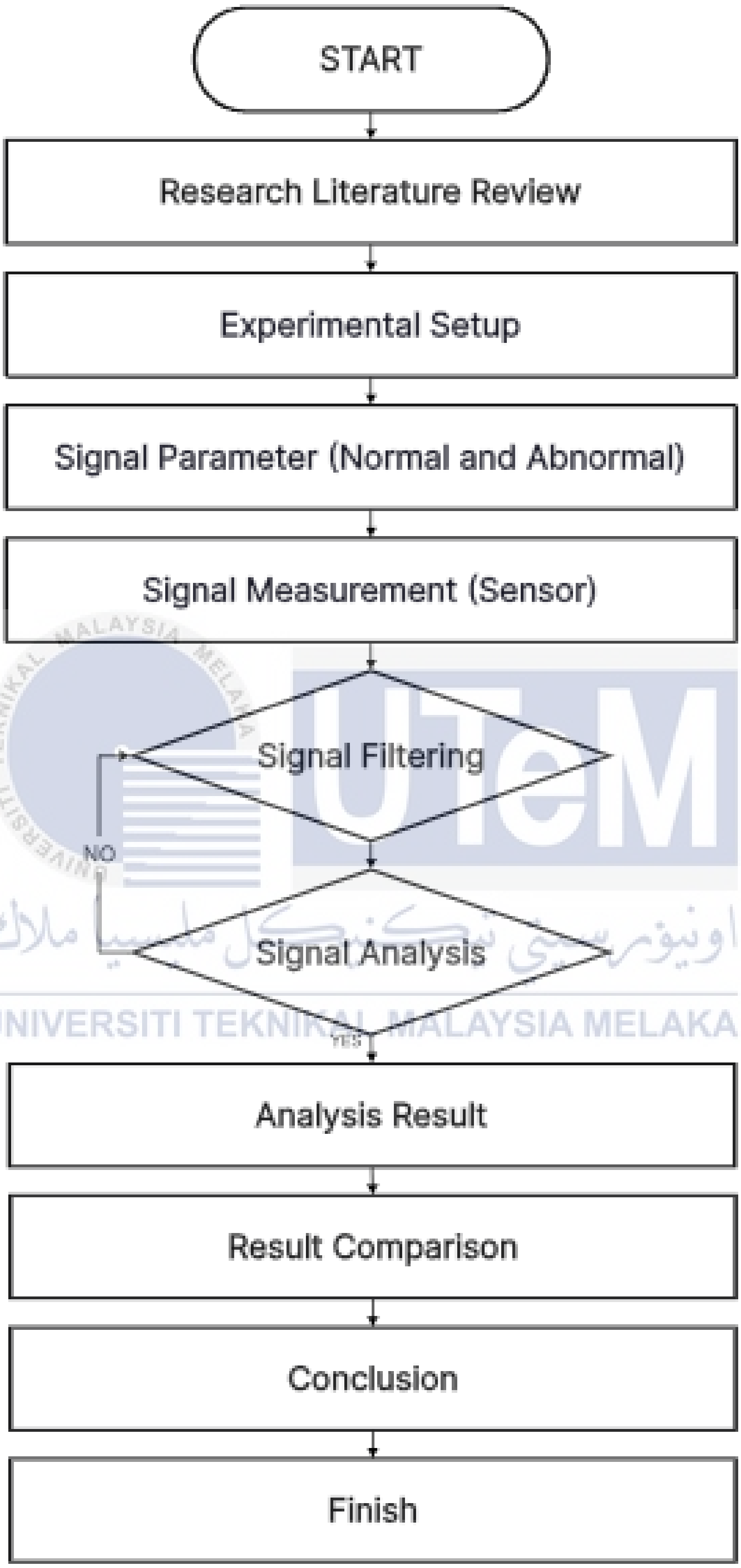


Figure 3-2 Project Flow Chart

3.2.2 Parameter

The signal parameter is a component used to conduct this experiment. The main component of this project is Spur Gear and Helical Gear. Both of gear are in two condition which is normal and abnormal gear. The figure shows the two conditions of gear.

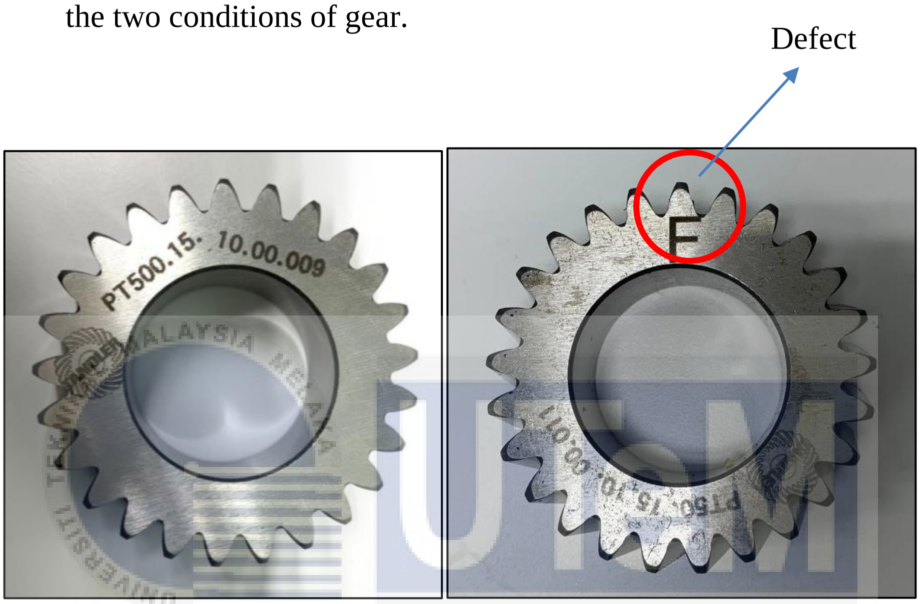


Figure 3-3 Normal and Abnormal Gear

3.2.3 Equipment

The table below shows list of the equipment used to conduct this project.

Equipment	Specification	Quantity
Machinery Diagnostic System	PT500	1
Computerised Vibration Analyzer	PT500.04	1
Brake and Load unit	PT500.05	1
Elastic Shaft Kit	PT500.10	1
Crack detection in rotating shaft kit	PT500.11	1

Couplings kit	PT500.13	1
Belt Drive Kit	PT500.14	1
Damage to gears kit	PT500.15	1
Crank mechanism kit	PT500.16	1
Displacement Sensors	PT500.41	2
Computer	-	1

Table 3.1 The Equipment Used

3.2.4 Signal Measurement

The Computerized Vibration Analyzer, PT500.04 was developed specifically to enable analysis of machinery diagnostic experiments that were conducted using the PT 500 series. The analyzer has several further applications, including its usage in various vibration investigations. Two acceleration sensors, a measuring amplifier that has an adjustable gain, a USB box, and analysis software all make up the components of the system. The software provides the capability to apply many analytical methods to a vibration signal and analyze the effectiveness of these approaches against one another.

3.2.5 Signal Analysis

The signal produced by sensor will shows in the Fast-Fourier Transform (FFT). The result will be compared based on the speed and the condition of the gear.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In the pursuit of understanding gear performance and diagnosing potential faults, this chapter delves into the comprehensive analysis of vibration signals through Fast Fourier Transform (FFT) graphs obtained from an experimental setup. The experimental configuration involved the examination of vibration signals with frequency as the x-axis and acceleration as the y-axis. Three types of gear pairs were scrutinized: normal big gear with a normal small gear, normal big gear with a defective small gear, and defective big gear with a normal small gear. This analysis extended to encompass both helical and spur gear configurations, exploring their distinct characteristics under varying speeds ranging from 500 to 2500 revolutions per minute (rpm). The intricacies of these FFT graphs serve as the cornerstone for unveiling the nuances in gear behavior and identifying potential irregularities, laying the groundwork for a comprehensive exploration of gear performance and fault detection.

4.2 Process of collecting data

The chart below shows the process of collecting data to obtain the FFT graph.

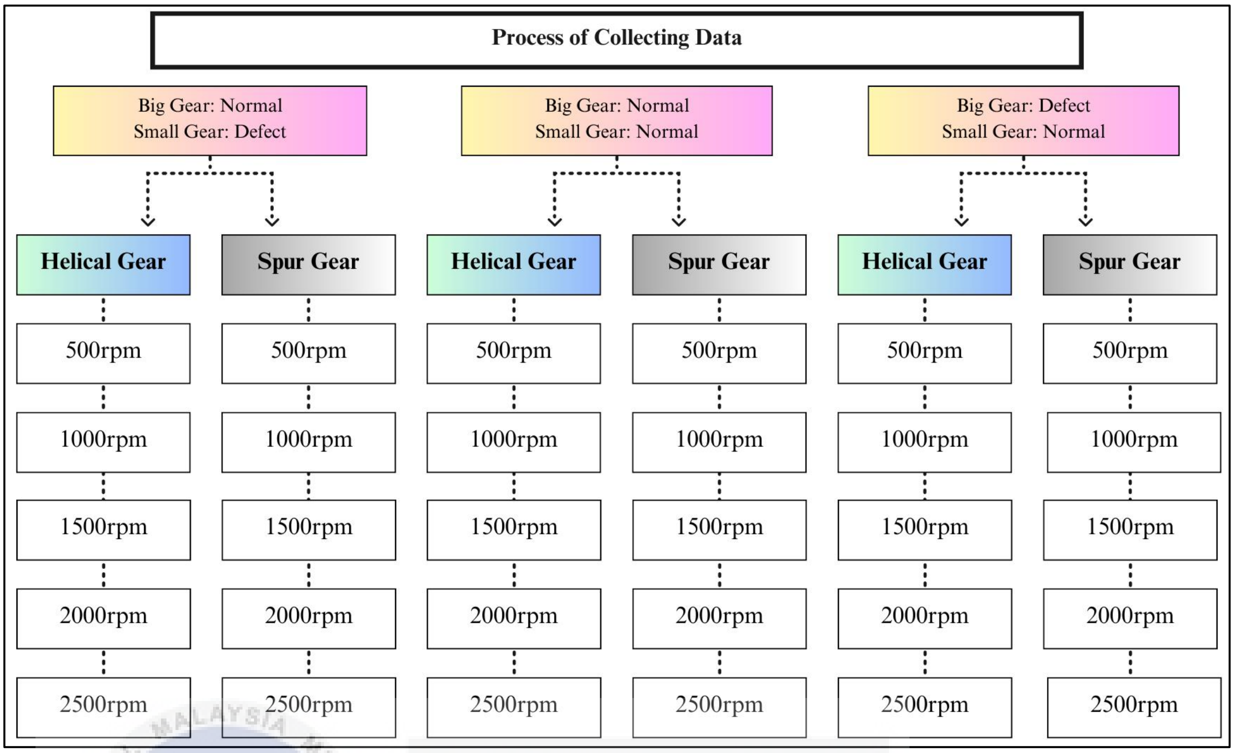


Figure 4-1 Process of collecting data

4.3 Results and analysis

4.3.1 Helical Gear

i. Normal big gear paired with normal small gear.

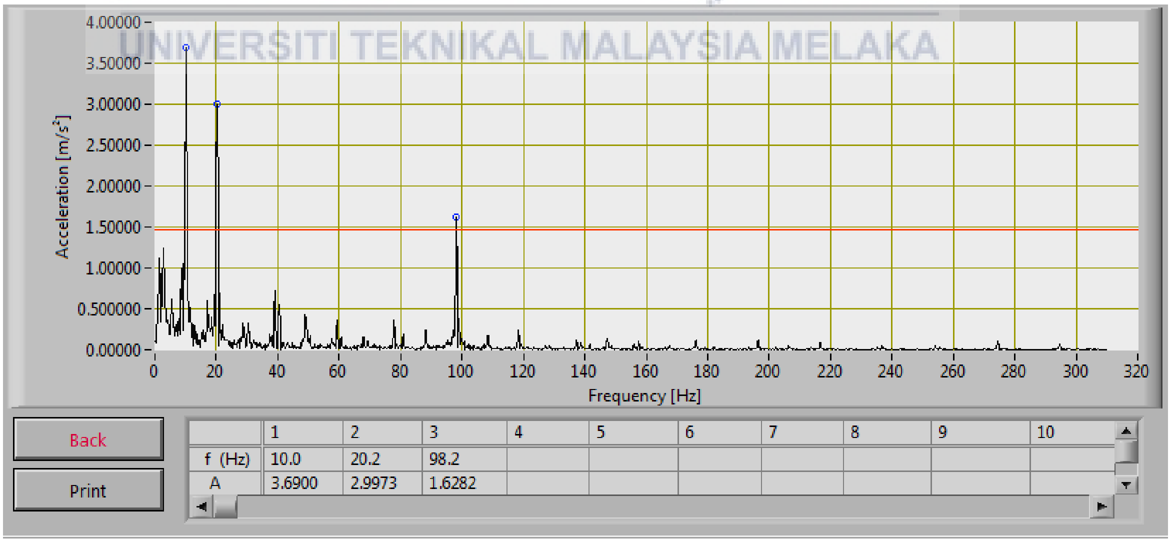


Figure 4-2 Helical gear – Normal big gear paired with normal small gear.

In the graph, there are several notable peaks at frequencies of 10 Hz, 20.2 Hz, and 98.2 Hz, with the corresponding accelerations of 3.6900 m/s², 2.9973 m/s², and 1.6282 m/s², respectively. These peaks may represent key vibrational modes within the gear system, including the gear mesh frequency (GMF) or its harmonics. The GMF is the frequency at which the gear teeth contact one another and is determined by the number of teeth and the rotational speed.

When creating a formal report, one would address these specific frequencies and their associated vibration levels, considering the gear teeth numbers and the operational RPM. Since both gears are reported to be normal, without defects, the peaks could be indicative of the inherent vibration characteristics of the gear system. The high acceleration values could also be due to resonance phenomena within the gear system or the structure to which it is mounted.

To simplify, this FFT graph shows the vibration signature of a gear system that is presumably functioning as expected. The graph helps to identify the vibration frequencies that are most significant for this particular setup, which is crucial for monitoring the health and performance of the gears. Any deviations from these patterns in future tests could indicate the development of defects or changes in the gear system's condition

ii. Normal big gear paired with defect small gear.

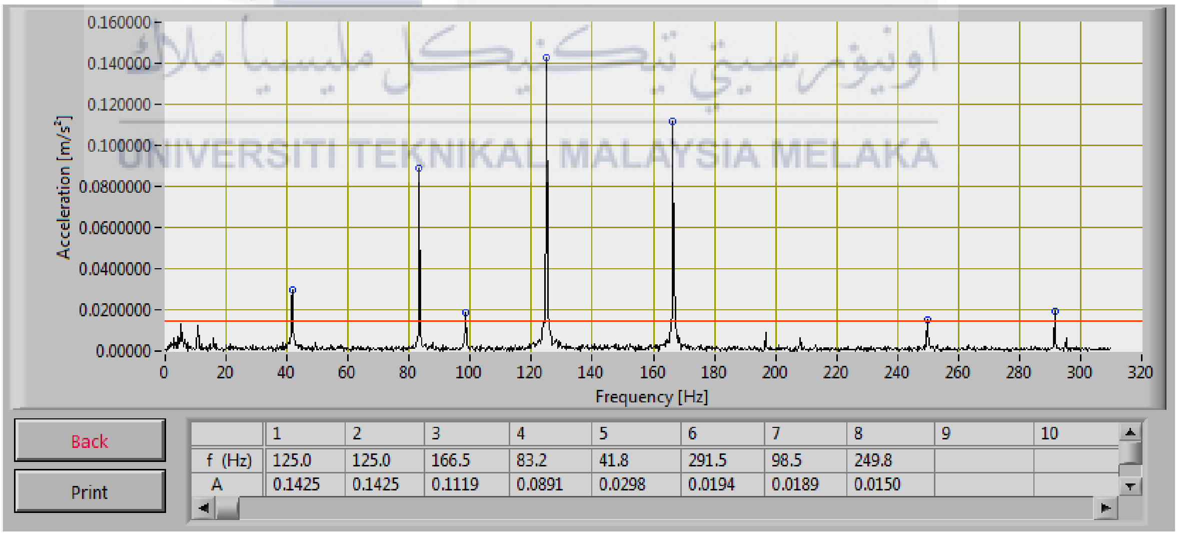


Figure 4-3 Helical gear – Normal big gear paired with defect small gear.

From the graph, we can observe distinct peaks at certain frequencies – specifically at 125.0 Hz and 166.5 Hz, with acceleration amplitudes of 0.1425 m/s² and 0.1119 m/s², respectively. These peaks likely correspond to the gear mesh frequency (GMF) and its harmonics, which is the frequency at which the teeth of the gears engage with each other.

Since the gears are in a 3:1 ratio and the system is running at 2500 RPM, we would expect the GMF to be present in this range, and the harmonics would be integer multiples of this frequency.

The presence of such peaks in the vibration analysis is a clear indication of the interaction between the gears. The fact that there is a defect in the small gear can alter the vibration signature, resulting in variations in the amplitude at these critical frequencies.

In summary, this FFT graph is used to identify the significant frequencies and amplitudes of vibrations arising from a gear system under analysis, which in this case includes a defective small gear. The results of this analysis can guide maintenance actions, such as inspections or repairs, to address the identified defect and ensure the proper functioning of the gear system.

iii. Defect big gear paired with normal small gear.

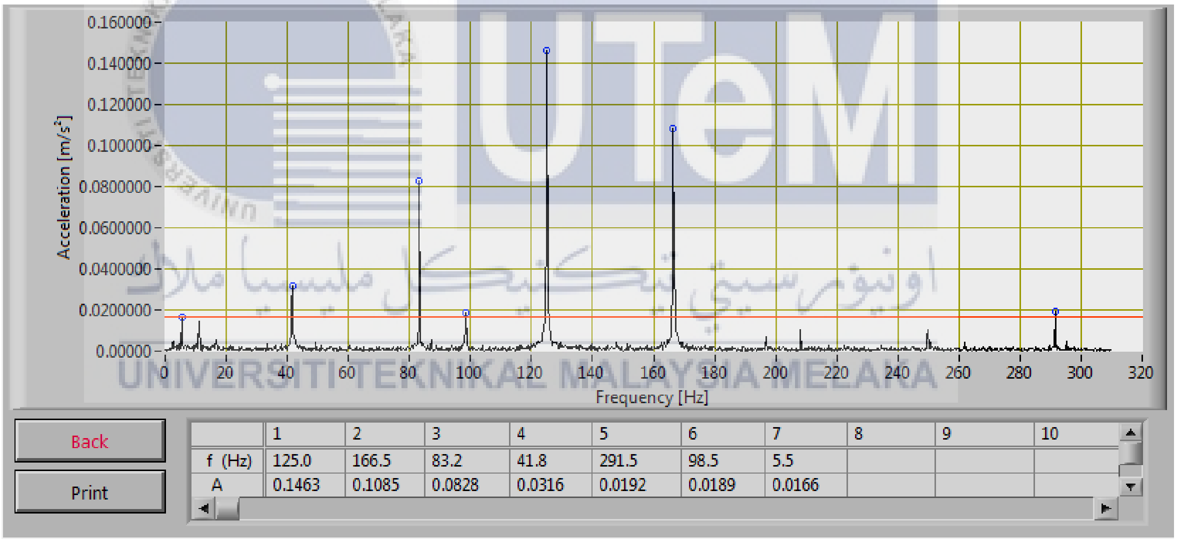


Figure 4-4 Helical gear – Defect big gear paired with normal small gear.

Upon examination of the graph, we can observe several peaks that are of particular interest at frequencies of 125.0 Hz, 166.5 Hz, and 291.5 Hz with their respective acceleration amplitudes of 0.1463 m/s², 0.1085 m/s², and 0.0192 m/s². These frequencies are significant because they may correspond to the gear mesh frequency (GMF)—the rate at which the teeth of the gears come into contact—as well as its harmonics and sidebands, which are influenced by the speed of the gears and the number of teeth on each gear.

These peaks potentially represent the vibrational characteristics of a gear system with a known defect in the larger gear. The defect could be impacting the gear mesh dynamics, leading to the observed peaks at these frequencies. It is also important to note that the largest amplitudes in the graph suggest that the defect in the big gear may be causing significant vibration at the gear mesh frequency and its harmonics.

To simplify, this FFT graph serves as a tool for identifying the prominent frequencies and the intensity of vibrations that arise from the gear assembly during operation. The presence of a defect in the big gear appears to affect the vibration signature of the system, particularly at the gear mesh frequency and its harmonics, which can be critical for understanding the health of the gear train and informing maintenance decisions.

4.3.2 Spur Gear

i. Normal big gear paired with normal small gear.

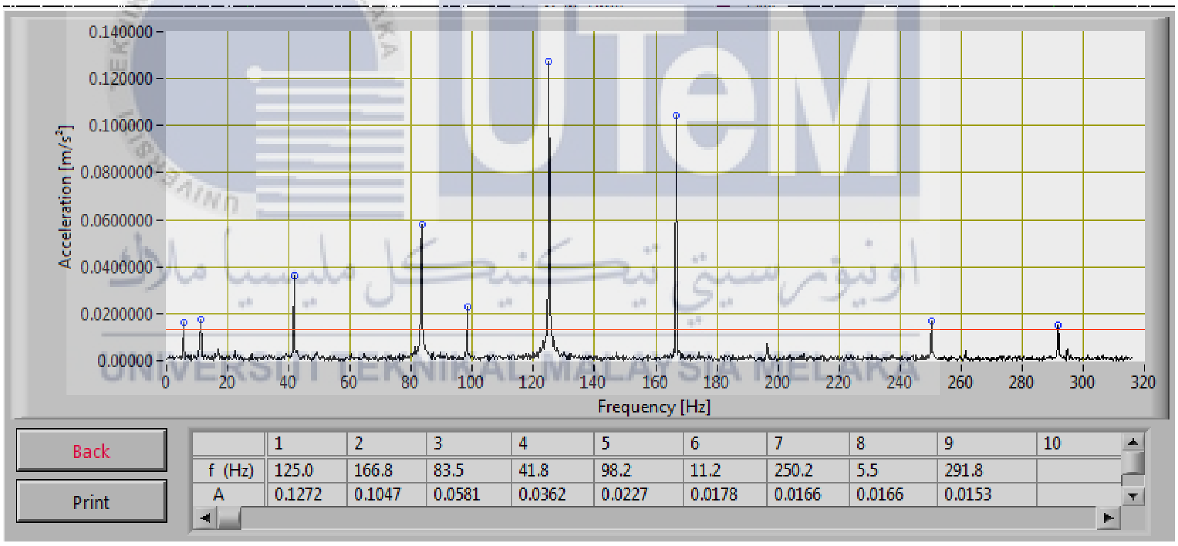


Figure 4-5 Spur gear – Normal big gear paired with normal small gear.

The peaks on the graph are indicative of the vibrational frequencies inherent in the gear system during its operation at a speed of 2500 revolutions per minute (RPM). Notable peaks at frequencies of 125.0 Hz, 166.8 Hz, and 83.5 Hz, with corresponding acceleration values of 0.1272 m/s^2, 0.1047 m/s^2, and 0.0581 m/s^2, suggest the gear mesh frequencies and possibly their harmonics. These frequencies are important as they indicate the rate at which the gear teeth interact with each other.

For a well-functioning gear system, such as the one described, these peaks should correspond to the gear mesh frequency (GMF) which is calculated by multiplying the number of teeth on the gear by the rotational speed of the shaft and converting this to hertz. The presence of peaks at integer multiples or divisions of this GMF is expected and signifies normal operation.

In simpler terms, this FFT graph shows the vibration 'fingerprint' of a normally operating gear set at the given speed. The presence of consistent and predictable peaks in vibration at certain frequencies is an indicator of a healthy gear system. This analysis would be used to confirm that the gears are functioning as expected, without any apparent defects or issues.

ii. Normal big gear paired with defect small gear.

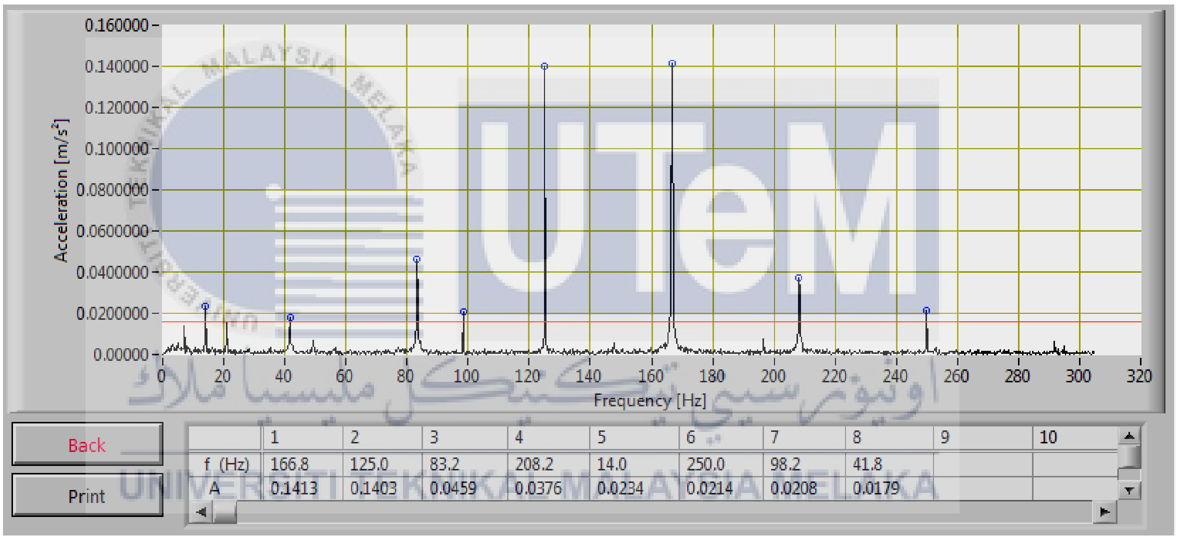


Figure 4-6 Spur gear – Normal big gear paired with defect small gear.

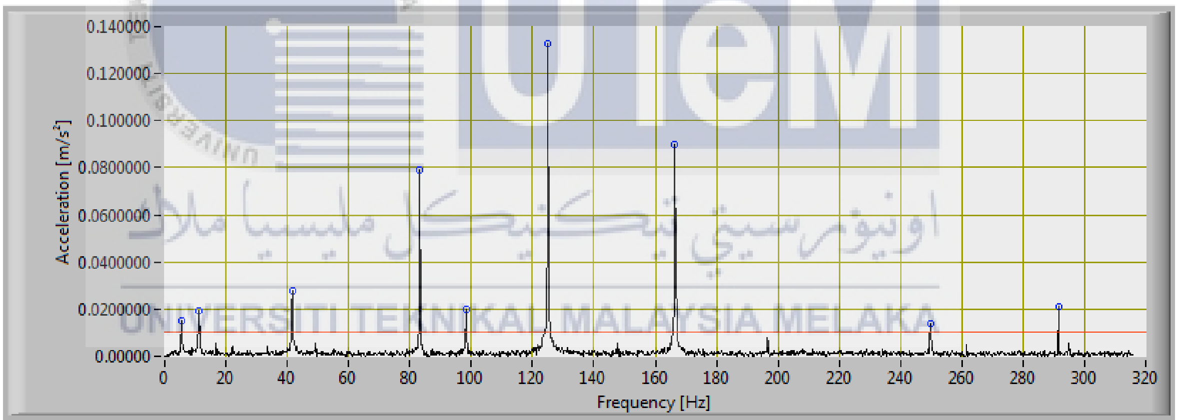
From the graph, significant peaks at various frequencies are observed, which are likely to be associated with the gear system's operating dynamics. The most pronounced peaks occur at 166.8 Hz and 125 Hz, with acceleration values of 0.1413 m/s² and 0.1403 m/s², respectively. These could represent the fundamental gear mesh frequency and its harmonics, which are generated by the rotation of the gears in conjunction with the number of teeth they possess.

Considering the rotational speed of 2500 RPM, it can calculate the gear mesh frequency (GMF) by multiplying the number of teeth on one gear by the number of revolutions per minute and then converting that figure to hertz. This GMF is the frequency at which the teeth of one gear engage with the teeth of the other gear. The presence of additional peaks at frequencies such as 83.2 Hz, 208.2 Hz, and 250 Hz suggests the appearance of harmonics and sidebands, which are typical in the presence of gear defects

The peaks on the FFT graph are indicative of the vibrations caused by the defect in the small gear. When a gear has a defect, such as a chipped or worn tooth, it can cause an impact or a change in the load distribution each time the defective tooth engages with the other gear, resulting in vibrations at specific frequencies that can be observed in the FFT analysis.

To simplify, the graph shows that there is a pattern of vibrations that are not expected in a perfectly functioning gear system, pointing to a problem with the small gear. These findings would be critical for maintenance teams to prioritize inspection and to address any issues to avoid potential failures or further damage to the gear system.

iii. Defect big gear paired with normal small gear.



	1	2	3	4	5	6	7	8	9	10
f (Hz)	125.0	166.5	166.5	83.2	41.8	291.5	98.2	11.2	5.5	249.8
A	0.1330	0.0898	0.0898	0.0791	0.0277	0.0211	0.0200	0.0192	0.0152	0.0138

Figure 4-7 Spur gear – Defect big gear paired with normal small gear.

The spikes in the graph at specific frequencies are critical, as they indicate the presence of vibrations that could be linked to the gear defect. For instance, a spike at 125 Hz with an amplitude of 0.1330 m/s² is prominent, which may be indicative of the gear mesh frequency, where one gear tooth passes another. The presence of a defect in the big gear can alter the vibration signature of the gear mesh, leading to such noticeable peaks in the FFT analysis.

With the system operating at a high rotational speed of 2500 RPM, the vibration characteristics are essential in diagnosing the condition of the gears. The speed of the gears and the number of teeth directly influence the gear mesh frequency, which for this setup can be calculated. The harmonics of this fundamental frequency, or integer multiples of it, should also appear in the vibration spectrum, which can be seen in the additional peaks at 166.5 Hz, 83.2 Hz, and so on.

In simpler terms, the graph is a visual representation of the vibrations emanating from the gears during operation. It helps in identifying the specific frequencies at which these vibrations are most pronounced, pointing to potential issues with the gear teeth interaction due to the defect in the big gear. Regularities in the vibration pattern are key to determining the nature of the defect and the overall health of the gear system

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study's extensive analysis of vibration signal analysis in monitoring gear systems has provided profound insights into the health and functioning of machinery. The detailed examination of helical and spur gears under different conditions—normal and defective states—reveals the nuanced capabilities of vibration analysis as a diagnostic tool. In normal gear pairings, the vibration patterns observed were consistent and within expected parameters, indicating stable and efficient operation. These patterns, characterized by specific frequencies and amplitudes, align with theoretical models of gear behavior, reinforcing the reliability of vibration analysis in confirming the soundness of machinery.

Conversely, the presence of defects in gears, as reflected in the FFT graphs, introduced notable deviations in vibration patterns. These deviations were not merely random fluctuations but were indicative of specific issues related to gear meshing. Peaks at certain frequencies and their corresponding amplitudes shifted, suggesting alterations in gear dynamics due to physical deformities. This aspect of the study is particularly crucial as it showcases the sensitivity of vibration analysis in detecting early signs of wear, misalignment, or damage—factors that, if left unaddressed, could lead to catastrophic failures and costly downtimes.

The research underscores the fact that machinery, despite being robust, is prone to wear and tear and subject to operational stresses that can lead to defects. The ability to identify these defects early, through a non-invasive and efficient method like vibration analysis, is invaluable. It provides a window into the internal workings of machinery, often invisible to the naked eye, and allows for preemptive action.

Moreover, the study highlights the importance of understanding the baseline vibration signatures of different gear types and configurations. By establishing a clear reference of what constitutes 'normal' operation, any deviations become more pronounced and easier to diagnose. This approach, coupled with continuous monitoring, forms the backbone of predictive maintenance strategies.

In summary, the research not only reaffirms the importance of vibration signal analysis in the maintenance of gear systems but also expands our understanding of its potential applications. It demonstrates how subtle changes in vibration patterns can be deciphered to reveal underlying mechanical issues, allowing for timely interventions. This proactive approach to maintenance, informed by detailed analysis and continuous monitoring, is a significant step forward in ensuring the longevity, efficiency, and reliability of machinery in various industrial settings.

5.2 Recommendations

Several key recommendations emerge, aimed at enhancing the effectiveness of maintenance practices in industrial settings:

i) Integration of Regular Vibration Analysis: Industries utilizing gear-driven machinery should incorporate vibration analysis as a cornerstone of their maintenance programs. Regular monitoring of vibration signatures can serve as an early warning system for potential issues. This proactive approach, compared to the traditional relative methods, can significantlu reduce unplanned downtime and maintenance costs.

ii) Continuous Monitoring Systems: The implementation of continuous monitoring systems, such as the PT500 base unit from GUNT Hamburg, is highly advised. These systems can provide real-time data on gear performance, allowing for immediate detection of anomalies in vibration patterns. The continuous stream of data will enable maintenance teams to respond swiftly to changes, potentially averting equipment failures.

iii) Develepment of a Vibration Signature Database: Creating a comprehensive database of vibration signatures for various types of gears under different operational conditions is crucial. Such a database would serve as a reference point for identifying deviations from normal operation. It can enhance the accuracy of diagnostics and facilitate quicker decision-makin in maintenance processes.

iv) Advance Diagnostic Tools: Investment in advance diagnostic tools that can capture more subtle changes in vibration patterns is recommended. These tools can provide more detailed analysis gear health and are particularly useful in detecting early stages of wear or damage that might not be apparent with basic monitoring equipment.

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APPENDICES

APPENDIX A PSM 1 PLANNING GANTT CHART

PSM 1 PLANNING GANTT CHART															
2023															
NO	**TASK**	**W1**	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**	**W8**	**W9**	**W10**	**W11**	**W12**	**W13**	**W14**
1	PSM 1 briefing							MID SEMESTER BREAK							
2	Thesis tittle verification														
3	Meeting supervisor														
4	Write thesis Chapter 1														
5	Discuss thesis problem statement and objective														
6	Study the purpose of the study														
7	Literature review														
8	Write thesis Chapter 2														
9	Journal study related to vibration analysis														
10	Journal study related to bearing faulty analysis														
11	Experimental parameter study														
12	Study the experimental set up														
13	Write thesis Chapter 3														
14	PSM 1 report submission														

APPENDIX B PSM 2 PLANNING GANTT CHART

PSM 2 PLANNING GANTT CHART																	
2023 / 2024																	
NO	**TASK**	**PLAN / ACTUAL**	**WEEK**														
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Project Briefing	PLAN								MID SEMESTER BREAK						
		ACTUAL														
2	Experimental Setup	PLAN														
		ACTUAL														
3	Data Collection	PLAN														
		ACTUAL														
4	Result Analysis	PLAN														
		ACTUAL														
5	Result Verification	PLAN														
		ACTUAL														
6	Conclusion and Recommendation	PLAN														
		ACTUAL														
7	Weekly BDP Reporting (logbook)	PLAN														
		ACTUAL														
8	Project Reporting	PLAN														
		ACTUAL														
9	4 Pages Summary	PLAN														
		ACTUAL														
10	Presentation and poster	PLAN														
		ACTUAL														