# DESIGN AND PERFORMANCE ANALYSIS OF GEARBOX FOR INDUSTRIAL APPLICATIONS

A Thesis

by

MD. Asif Hossain Chowdhury; ID: ME2101023025

Md Rashedul Hasan; ID: ME2101023135

Ahmed Muqtadir Rahman; ID: ME2101023142

Golam Mahamud Adil; ID: ME2101023360

Sourav Chandra Howladar; ID: ME2101023152




Department Of Mechanical Engineering

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MD. Asif Hossain Chowdhury

ID: ME2101023025

In Cooperation With

Md Rashedul Hasan
ME2101023135

Golam Mahamud Adil
ID: ME2101023360

Ahmed Muqtadir Rahman
ID: ME2101023142

Sourav Chandra Howladar
ID: ME2101023152

Supervisor: Shahinur Rahman

Lecturer & Coordinator

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## Abstract

This thesis explores the design and performance analysis of industrial gearboxes, emphasizing the critical stresses that affect their operational efficiency and durability—namely, contact stress and bending stress. Industrial gearboxes play a pivotal role in transmitting mechanical power in various heavy-duty applications, making their reliability a key factor in maintaining optimal system performance. The primary objective of this study is to investigate the impact of gear design parameters on the performance and longevity of gearboxes under high load conditions. The research employs theoretical calculations and finite element analysis (FEA) to model and analyze the gear contact stress and bending stress in spur gears, helical gears, and bevel gears commonly used in industrial settings. For contact stress, the analysis utilizes AGMA theory to calculate the stress distribution between gear teeth in meshing, identifying areas susceptible to surface fatigue and pitting. In parallel, the bending stress is analyzed using the AGMA equation, highlighting regions at the gear tooth root that are prone to fatigue failure. Both analyses are validated through simulation and real-world case studies to ensure accuracy. The findings from this research provide a comprehensive understanding of how design factors such as gear geometry, material selection, surface treatments, and lubrication influence the stress distribution and overall performance of industrial gearboxes. Additionally, this thesis proposes optimized design strategies to enhance the durability of gearboxes by minimizing stress concentrations, thereby reducing the risk of gear failure and extending operational life. Ultimately, the study aims to contribute valuable insights into gearbox design optimization for the chemical, manufacturing, and energy industries, where reliable and efficient power transmission is essential.

## Table of Contents


**Acknowledgement** iii
**Abstract** iii
**Table of Content** iii- iii
**List of Table** iii
**List of Figure** iii
**Notations** iii

**Chapter 1 Introduction of Technology** **10**

- 1.1 Introduction 10
- 1.2 Subject Background 11
- 1.3 The Objective of study 11
- 1.4 The Scope of study 11
- 1.5 Methods Use 11

**Chapter 2 Literature Review** **12**

- 2.1 Introduction 12
- 2.2 History Overview of Gearbox 12
- 2.3 Fundamentals Theories and Models 12
- 2.3.1 Gear Geometry & Kinematics 13
- 2.3.2 Load Analysis and Strength Calculations 13
- 2.4 Advances in Gearbox Design 14
- 2.5 Material Selection and Manufacturing Processes 14
- 2.6 Design Optimization & Computational Methods 15
- 2.6.1 Finite Elements Method 15
- 2.6.2 Muli-Body Dynamics 15
- 2.7 Performance analysis & Observation 15

**Chapter 3 Gear Box Design Fundamentals** **16**

- 3.1 Introduction 16
- 3.2 Basic Principle of Gear Operation 17
- 3.3 Gear types 17-18
- 3.4 Gear terminology 18
- 3.5 Gear Box Design Consideration 19
- 3.6 Different type of stress 20

**Chapter 4 Methodology** **21**

- 4.1 Introduction 21
- 4.2 Gear Box Design Process 21-22
- 4.3 Materials Selection 22
- 4.4 Part List 23
- 4.5 Flow Chart Methodology 24
- 4.6 Design Requirements 24

**Chapter 5 Design Specification and Requirements** **25**

- 5.1 Introduction 25
- 5.2 Functional Requirements of Gear box Design 25
- 5.3 Performance Requirements of Gear box Design 26
- 5.4 Environmental Consideration of Gear box Design 26
- 5.5 Design Standards and codes 27

**Chapter 6 Theoretical Calculation** **28**

- 6.1 Introduction 28
- 6.2 Selection Material of Gear 28
- 6.3 Gear Contact Stress Calculation (Use AGMA Method) 29
- 6.4 Assumptions 29
- 6.5 Gear Geometry Calculation 29-30
- 6.6 Gear Bending Stress Calculation 30-31
- 6.7 Gear tooth Contact Stress Calculation 31
- 6.8 Keys and Keyways Design Calculations 31-32
- 6.9 Bearing Selections 32
- 6.10 Gear Lubrication & Heat Treatment 33
- 6.11 Selection Bolt and Nuts 34
- 6.12 Service Factor specifications of various Gear Types 34

**Chapter 7 Computer Aided Design (CAD)** 35

- 7.1 Introduction 35
- 7.2 Introduction of Cad Tools 35
- 7.3 Evolution of Gearbox Design 35
- 7.4 Importance of Gearbox Design 35-36
- 7.5 CAD Tools in Gearbox Design 36
- 7.6 3D Modeling of the Gear Box 37

- 7.7 Orthography Projection 38
- 7.8 Assembly Drawing of Gearbox 39-40
- 7.9 Details Drawing 40-43

**Chapter 8 Finite Element Analysis 44**

- 8.1 Introduction 44
- 8.2 Using Software 44
- 8.3 Bending Stress Analysis Result 45
- 8.4 Contact Stress Analysis Result 46
- 8.5 Structural Analysis of Rotating Shaft 47

**Chapter 9 Result and Dissociation 48**

- Introduction 48
- Comparison with Theoretical and Experimental Data 49
- Comparison with Theoretical and Experimental Data 50
- Theoretical and Experimental Data 51
- Dissuasion 52
- Future Work 52

**Chapter 10 Conclusion and Recommendations 53**

- Conclusion 53
- Used Tools 53
- Recommendations 54
- References 54
55-56

## List of Table

**Chapter 4 Methodology** 21

- Table 4-2(Bills of Materials) 23

**Chapter 6 Theoretical Calculation** 28

- Table (6-1) Materials Specifications 32
- Table (6-2) Series Ball Bearings 34
- Table (6-3) Selection Nuts and Bolts 34
- Table (6-4): Service Factor 48

**Chapter 9 Results and dissuasion** 48

- Table 9-1 Contact Stress Different Type Condition 48
- Table 9-2 Bending Stress Different Type Condition 49
- Table 9-3 Maximum Stress 50
- Table 9-4 Comparison Data 51

## List of Figure

**Chapter 3 Gear Box Design Fundamentals** 16

- Fig 3-1: Different Types of Gear 17
- Fig 3-2: Geometry 18

**Chapter 4 Methodology** 21

- Fig 4-1 Gearbox 22
- Fig 4-2 Gearbox (Internal view) 23
-

**Chapter 6 Theoretical Calculation** 28

- Fig 6-1 (Gear Stress) 29

**Chapter 7 Computer Aided Design (CAD)** 34

- 7-1 Gearbox (Rendering View) 37
- 7-2 Gearbox (2nd Projection View) 37
- 7-3 Gearbox (Orthography View) 38
- 7-4 Gear Arrangement 38
- 7-5 Exploration View -1 39
- 7-6 Exploration View -1 39
- 7-7 Shaft Position 40

- 7-8 Gear Contact 40
- 7-9 Internal View 40
- 7-10 Gear and shaft Coupling 40
- 7-11 Left Side Plate 41
- 7-12 Right Side Plate 41
- 7-13 Spur Gear 42
- 7-14 Shaft (Top Gear) 42
- 7-15 Shaft (Bottom Gear) 43
- 7-16 Key … 43

**Chapter 8 Finite Elements Analysis** 44

- **8**-1 Contact stress Result 45
- 8-3 Displacement Result 45
- 8-3 Strain Result 45
- 8-4 Bending Stress Result 46
- 8-5 Displacement Result 46
- 8-6 Strain Result 46
- 8-7 Shaft Stress Result 47
- 8-8 Shaft Displacement Result 47
- 8-9 Shaft strain Result 47

## Notation

ISO (International Organization for Standardization

API (American Petroleum Institute

AGMA = American Gear Manufacturing Association

FEM = Finite Elements Method

FEA = Finite Elements Analysis

CFD = computational fluid dynamics

VFD = Variable Frequency Drives

MBD = Multi-body Dynamics

CAD = Computer Aided Design

ASME = American Society of Mechanical Engineers

BSI = British Standards Institute

# Chapter-1

# Introduction of technology

## 1.1 Introduction

A gearbox is a critical component in mechanical systems, designed to adjust the speed and torque of rotational power. It consists of a series of gears housed in a protective casing, which transmits mechanical power from one part of a machine to another. Gearboxes are fundamental in a wide array of applications, from industrial machinery to automotive systems, due to their ability to alter the output characteristics of a motor or engine efficiently [1]. The primary function of a gearbox is to enable precise control over speed and torque. By changing gear ratios, gearboxes can either increase torque while reducing speed or increase speed while reducing torque, depending on the requirements of the application. This versatility is essential for optimizing performance in various operational conditions [2]. Gearboxes are classified into several types, including manual gearboxes, automatic transmissions, and specialized gear systems such as planetary and bevel gearboxes. Each type is designed to meet specific operational needs and performance criteria [3]. In industrial settings, gearboxes play a vital role in machinery, such as conveyors, pumps, and compressors, enhancing the efficiency and reliability of production processes. Their design and performance directly impact the operational efficiency and longevity of industrial equipment.[4]

## 1.2 Subject Background

Industrial gearboxes are critical components in mechanical power transmission systems, utilized across various industries to adjust the output torque and speed from motor to machinery. The design and performance analysis of industrial gearboxes involve several key aspects such as gear geometry, material selection, lubrication, and load capacity. The objective is to ensure efficient power transmission, durability, and reliability under various operational conditions. This entails an understanding of gear mechanics, including the principles of spur, helical, bevel, and worm gears, as well as considerations for minimizing friction and wear. Advanced analysis techniques, such as finite element analysis (FEA) and computational fluid dynamics (CFD), are often employed to predict the performance and identify potential failure modes. Additionally, the impact of manufacturing tolerances, heat treatment processes, and maintenance strategies on gearbox performance is critical. However, there have been many methods of regulating the speeds of these motors which includes the use of Variable Frequency Drives (VFD's) and other mechanical transmission devices such as the gearbox, which has remained the most conspicuously utilized technique in manufacturing industries because of its capacity to transmit high power at generally higher proficiency (Wikipedia, 2019)The integration of smart technologies for real-time monitoring and predictive maintenance is also becoming increasingly important in modern industrial applications. Understanding these elements is crucial for designing gearboxes that meet the specific requirements of various industrial applications, ranging from heavy machinery to precision instruments.

## 1.3 Objectives of the Study

The objectives of this study are to investigate the performance characteristics of various gearbox designs and to develop a comprehensive model for predicting their efficiency. The research aims to identify and analyze the key design parameters that impact the operational effectiveness and reliability of gearboxes. Additionally, it seeks to explore the influence of material selection and manufacturing processes on gearbox performance, with the goal of providing practical recommendations for optimizing gearbox design. By addressing these objectives, the study intends to contribute valuable insights into the enhancement of gearbox technology and its applications across different industries

The primary objectives of this thesis are to:

- Analyze the distribution of contact stresses between gear teeth under varying load conditions to identify potential failure points and optimize tooth design.
- Determine the bending stress experienced by gear shafts and other components during operation, ensuring that designs meet safety and performance standards
- Pinpoint areas of maximum stress concentration in the gearbox components to inform design modifications that enhance structural integrity and reduce the risk of failure
- Relationship between calculated contact and bending stresses and the overall performance metrics of the gearbox, such as efficiency and durability, to support design improvements.

## 1.4 The Scope of the study

The scope of this study encompasses an examination of several types of gearboxes, including both standard and specialized designs, to understand their performance characteristics. The focus is on analyzing key design parameters such as gear geometry, materials, and lubrication methods, as well as their effects on efficiency, durability, and noise levels. The study will be limited to gearboxes operating under specific conditions and loads, and will primarily involve theoretical analysis, simulations, and selected experimental tests. It does not cover gearboxes for extremely high-speed or high-torque applications, nor does it address all possible operational environments. The assumptions made include idealized conditions for the sake of modeling accuracy and relevance to common industrial applications.

## 1.5 Methods Used

- Review of necessary literature to enhance research on the project.
- Use of CAD to design the proposed gearbox.
- Gather of information from the internet, books, Ummat library, and expects in the fie
- Using AGMA Method
- Finite Element Method
- Analytical Method

# Chapter 2

# Literature Review

## 2.1 Introduction

Gearboxes play a crucial role in various mechanical systems, serving as essential components that transmit power and adjust torque and speed. As a result, their design and performance have been extensively studied across numerous industries, including automotive, aerospace, and industrial machinery (Mill Gears, com). Understanding the historical development and current advancements in gearbox technology is vital for improving performance and addressing ongoing challenges. This literature review provides an overview of key research and developments related to gearbox design and performance analysis. It begins by tracing the evolution of gearbox technology, examining foundational theories and models that have shaped current practices. The review then explores contemporary research on gearbox design, including innovations in materials, manufacturing techniques, and optimization strategies. Finally, it addresses recent advancements in performance analysis methods, focusing on how they enhance our understanding of gearbox efficiency, reliability, and durability [5]. By synthesizing the existing body of knowledge, this chapter aims to identify gaps in current research and establish a framework for the study's objectives. It highlights significant contributions from previous work, discusses the limitations of existing models, and provides context for the novel aspects of the research undertaken in this thesis

## 2.2 History Overview of Gearbox

Gearbox technology has evolved significantly since its inception. Early gearboxes, used in simple mechanical systems, relied on basic gear trains to transmit motion and force. The 19th century saw the introduction of key innovations such as bevel and helical gears, which improved efficiency and smoothness of power transmission [Wikipedia]. As industrial demands grew, so did advancements in materials and manufacturing techniques, leading to more durable and precise gearboxes. The 20th century brought further improvements with the development of computer-aided design and advanced materials, culminating in today’s high-performance gearboxes optimized for a wide range of applications. This historical progression reflects a continuous effort to enhance gearbox efficiency, reliability, and versatility. [Wikipedia}

## 2.3 Fundamentals Theories and Models

Gearbox design and performance analysis, you would typically cover the essential concepts underpinning gearbox technology. This section would begin with an overview of the different types of gearboxes, such as helical, bevel, and worm gearboxes, each with unique characteristics suited to various applications. It would then discuss the materials commonly used in gearbox construction, including their properties and how they influence performance [6]. Following this, the chapter would explore key design parameters, including gear ratios, load capacities, and efficiency, explaining how these factors are critical in determining the overall performance and

reliability of the gearbox. Additionally, the chapter would address the principles of gear interactions, such as meshing and transmission efficiency, and their impact on gearbox operation. It would also cover the basics of gearbox kinematics and dynamics, providing a foundation for understanding more complex design and analysis techniques. This background sets the stage for a deeper exploration of design methodologies and performance analysis in subsequent chapters.

### ✓ 2.3.1 Gear Geometry & Kinematics

The study of gear geometry and kinematics is foundational to gearbox design. The involute gear profile is a key theoretical model, ensuring a constant velocity ratio and smooth power transmission. The basic concepts include: Involute Curve [7]: The involute profile allows for constant speed transmission between gears by maintaining a consistent line of action and eliminating sliding friction between meshing teeth. Gear Ratios: Defined by the ratio of the number of teeth on the driving gear to the driven gear, gear ratios determine the torque and speed transformation within the gearbox. Pitch Circles: The pitch circle is an imaginary circle that rolls without slipping as gears mesh. It's crucial for determining the correct gear size and tooth engagement.

- The involute profile allows for constant speed transmission between gears by maintaining a consistent line of action and eliminating sliding friction between meshing teeth.
- Defined by the ratio of the number of teeth on the driving gear to the driven gear, gear ratios determine the torque and speed transformation within the gearbox
- The pitch circle is an imaginary circle that rolls without slipping as gears mesh. It's crucial for determining the correct gear size and tooth engagement.

### ✓ 2.3.2 Load Analysis and Strength Calculations

The AGMA (American Gear Manufacturers Association) method for load analysis and strength calculation is widely used for evaluating gear performance and ensuring reliability. This method involves detailed calculations based on established standards and guidelines, focusing on various factors that affect gear strength and durability [6]. The AGMA method begins with determining the gear's operating load, which includes both static and dynamic components. It incorporates factors such as gear material properties, gear geometry, and load distribution to estimate the stresses experienced by the gear teeth. A critical aspect of this method is the calculation of contact stress and bending stress using formulas derived from empirical data and theoretical models. Contact stress is assessed using the Hertzian contact theory, which considers the forces acting on the contact area between meshing gear teeth. This analysis helps predict the potential for surface fatigue and wear. Bending stress calculations, based on the Lewis formula, estimate the strength of the gear teeth under applied loads, taking into account factors like tooth shape and gear dimensions. The AGMA method also incorporates safety factors to account for uncertainties in material properties, manufacturing tolerances, and operating conditions. By applying these calculations and safety factors, the AGMA method provides a comprehensive approach to ensure that gearboxes are designed to withstand operational stresses and perform reliably over their intended lifespan [8]

## 2.4 Advances in Gearbox Design

Advanced gearbox design incorporates several innovations aimed at enhancing performance, efficiency, and durability. Modern advancements include the use of high-strength materials and advanced manufacturing techniques, such as precision forging and additive manufacturing, which allow for more complex and optimized gear geometries [9]. The integration of computational methods, such as Finite Element Analysis (FEA) and Multi-body Dynamics (MBD), enables detailed simulation and analysis of gearbox behavior under various conditions, leading to more accurate predictions of performance and reliability. Design optimization algorithms are employed to fine-tune gear parameters, improving factors like efficiency, noise reduction, and load distribution. Additionally, the application of smart technologies, including sensors and real-time monitoring systems, enhances the ability to track gearbox performance and predict maintenance needs. These advanced design approaches not only improve the operational characteristics of gearboxes but also contribute to greater overall system efficiency and longevity [10]

## 2.5 Material Selection and Manufacturing Processes

When selecting materials for gearboxes, it is essential to consider various factors that impact performance and longevity. The primary material used in gearboxes is steel, chosen for its strength, hardness, and ability to undergo heat treatment processes such as carburizing or nitriding to enhance wear resistance and fatigue life [11]. Alloy steels, including AISI 4140, are commonly selected due to their superior mechanical properties. Cast iron is another popular material, valued for its excellent castability and good damping characteristics, which help in reducing vibrations. Grey cast iron, in particular, is favored for its machinability and vibration absorption properties. However, it generally has lower tensile strength compared to steel, limiting its use to applications where extreme strength is not required. Aluminum alloys are selected when weight reduction is crucial. These alloys, such as 2024 and 6061, provide a lightweight solution with good corrosion resistance [12]. While they are beneficial in reducing the overall weight of the gearbox, their lower load-bearing capacity means they are often used in applications where high loads are not a critical concern. Bronze and brass are chosen for their excellent wear resistance and self-lubricating properties, making them suitable for applications where lubrication is challenging or where gears experience high levels of friction. The manufacturing process of gearboxes typically involves several stages. The initial step is the design phase, where engineers select appropriate materials and create detailed specifications. Once the design is finalized, the manufacturing process begins with material preparation, which may include casting, forging, or machining, depending on the material chosen. For steel and cast-iron gears, the process often involves casting or forging, followed by machining to achieve precise dimensions. Heat treatment processes are applied to enhance material properties, including hardness and strength. In the case of aluminum alloys, casting is commonly used, followed by machining to achieve the desired gear shape and size. The final steps in the manufacturing process include assembly, where the gears are integrated into the gearbox housing, and testing, to ensure that the gearbox meets performance and durability standards [22]. Each material and manufacturing method has its own set of advantages and limitations, and the choice depends on the specific requirements of the gearbox application**.**

## 2.6 Design Optimization & Computational Methods

The use of computational methods and optimization algorithms has become integral to gearbox design. Techniques such as Finite Element Analysis (FEA) and Multi-body Dynamics (MBD) allow for detailed simulations of gear behavior under various conditions. Optimization algorithms help in fine-tuning gear parameters to achieve desired performance metrics, such as efficiency and noise reduction

### ✓ 2.6.1 Finite Element Analysis (FEA)

Finite Element Analysis (FEA) is a computational technique used to evaluate the behavior of complex structures under various conditions by breaking them down into smaller, manageable elements in the context of gearbox design, FEA helps analyze stress distribution, deformation, and potential failure points within gear components [7]. The process involves creating a detailed digital model of the gearbox, applying loads and boundary conditions, and solving mathematical equations to predict how the structure will respond to these conditions. This analysis provides valuable insights into the performance and durability of gear components, allowing designers to optimize designs for strength and efficiency before physical prototypes are built. FEA thus plays a crucial role in enhancing the reliability and performance of gearboxes by identifying potential issues early in the design process.[13]

### ✓ 2.6.2 Muli-Body Dynamics

Multi-Body Dynamics (MBD) is a simulation technique used to analyze the motion and interactions of interconnected components within a mechanical system. In gearbox design, MBD helps model and evaluate how gears, shafts, and other parts move and interact dynamically. By simulating these interactions, MBD provides insights into performance issues such as vibrations, gear meshing, and overall system behavior, allowing for optimization of design and improvement [13]

## 2.6 Performance analysis & Observation

Performance analysis of gearboxes often involves evaluating stress, strain, and displacement to ensure their durability and reliability. Stress analysis examines the internal forces within gear components, identifying areas where the material is subjected to high loads that could lead to failure. Strain analysis assesses the deformation of gears under operational loads, providing insights into how much the material is stretched or compressed. Displacement analysis measures the movement of gear components, helping to identify potential misalignments or deviations from intended design. By analyzing these factors, engineers can predict the performance of gearboxes, identify potential issues, and make design adjustments to improve overall functionality and lifespan.

# Chapter 3

# Gear Box Design Fundamentals

## 3.1 Introduction

Gearbox design fundamentals lay the foundation for developing efficient and reliable gear transmission systems used across various industrial applications. At its core, gearbox design involves the selection and configuration of gears to effectively transmit power and motion between shafts while meeting specific performance requirements [14]. Understanding the fundamentals begins with an exploration of gear types and their functions, including spur, helical, bevel, and worm gears. Each type has distinct characteristics that influence its suitability for different applications, such as load capacity, efficiency, and noise levels. The fundamental principles of gear geometry, such as gear ratio, pitch, and pressure angle, are essential for determining the performance and compatibility of gears within a gearbox Key aspects of gearbox design include the determination of gear size and material, load analysis, and the optimization of gear ratios to achieve desired performance. Additionally, considerations for lubrication, cooling, and durability play a crucial role in ensuring the gearbox operates reliably under variably mastering these fundamental principles, engineers can design gearboxes that balance performance, durability, and efficiency, ultimately contributing to the overall effectiveness of industrial machinery and systems.ng conditions

## 3.2 Basic Principles of Gear Operation

The basic principle of gear operation involves two or more interlocking gears with teeth that mesh together to transmit motion and power. As one gear turns, it causes the other gear(s) to rotate, either at the same speed (in the case of gears of the same size) or at different speeds (when the gears have different sizes). This allows gears to change the speed, torque, and direction of rotational motion. Gears are fundamental components in machinery, vehicles, and various mechanical systems. The basic principle of gear operation involves the transfer of rotational motion and torque between two or more gears through direct contact. When one gear, known as the driver gear, rotates, its teeth engage with the teeth of a second gear, called the driven gear. This interaction causes the driven gear to rotate in the opposite direction [16] The ratio of the gear sizes, or gear ratio, determines the mechanical advantage and the relationship between the input and output speeds and torques. Smaller gears driving larger gears increase torque but reduce speed, while larger gears driving smaller gears increase speed but reduce torque. This principle is fundamental to controlling motion and power transmission in various mechanical systems.[12]

### 3.2 Different Types of Gear




Fig 3-1: Different Types of Gear

Different Type of Gear

| | |
|---|---|
| Spur Gears | These are the most common type of gear, with teeth cut straight and parallel to the axis of rotation. They transmit motion and power between parallel shafts. |
| Helical Gears | Similar to spur gears but with teeth cut at an angle to the face of the gear. This arrangement allows for smoother and quieter operation but generates axial thrust. |
| Bevel Gears | These have cone-shaped teeth and are used to transmit motion and power between intersecting shafts. They can be straight or spiral. |

| | |
|---|---|
| Worm Gears | These have a screw-like appearance and are used to transmit motion between perpendicular shafts. They offer high gear reduction in a compact space but are less efficient than other gear types. |
| Rack and Pinion: | In this arrangement, a toothed bar (rack) meshes with a gear (pinion). It's commonly used in steering systems and linear motion applications. |
| Planetary Gears | These consist of a central sun gear, surrounding planet gears, and an outer ring gear. They offer high torque transmission in a compact size and are commonly used in gearboxes. |
| Internal Gears | These have teeth cut on the inside of a cylinder or cone and are used in applications where space constraints prohibit the use of external gears.[18] |

### 3.3 Gear Terminology

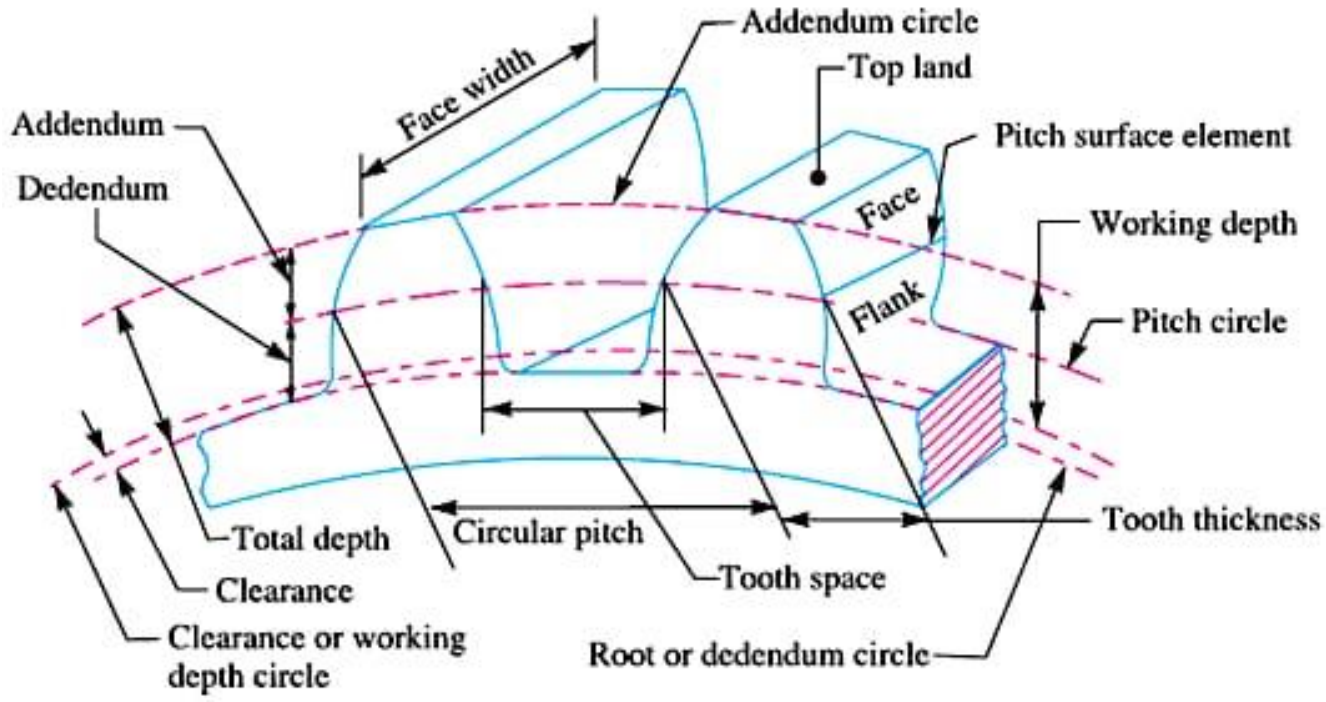



Fig 3-2: Geometry

Gear terminology encompasses various terms related to gears, which are mechanical devices used to transmit power or motion between rotating shafts. Here are some common gear terminologies

| | |
|---|---|
| Pitch Circle | The imaginary circle that passes through the points of contact between two mating gears. |
| Pitch Diameter | The diameter of the pitch circle. |
| Module | A measure of the size of a gear tooth. It is the ratio of the pitch circle diameter to the number of teeth. |
| Pressure Angle | The angle between the line of action and a line tangent to the pitch circle. It affects the shape of the gear teeth and influences their strength and smooth operation |
| Addendum | The radial distance between the pitch circle and the top of the gear tooth |
| Dedendum | The radial distance between the pitch circle and the bottom of the gear tooth. |
| Clearance | The radial distance between the top of one gear tooth and the bottom of the mating gear tooth. |
| Face Width | The width of the gear tooth measured parallel to the axis of rotation. |
| Backlash | The amount of clearance or play between mating gear teeth. It affects the precision and smoothness of gear operation. |
| Helix Angle | The angle formed by the helix of the gear tooth with the gear axis. It is relevant for helical gears. |

### 3.4 Gear Box Design Consideration

When designing a gearbox, engineers consider factors such as torque requirements, gear ratios, efficiency, material selection, lubrication, noise and vibration control, thermal management, manufacturing costs, and reliability. They also analyze the system's environmental conditions, service life expectations, and potential maintenance requirements to ensure optimal performance and longevity [3]

**Materials Selection of Gears:** The selection of materials for gears depends on factors like load, speed, operating environment, and cost. Common materials include steel, cast iron, bronze, and various alloys. Steel is popular for its strength, while bronze is used for its self-lubricating properties. Advanced materials like composites and ceramics are also utilized for specific applications requiring high performance.

**Lubrication and Cooling System: Gearbox** lubrication and cooling systems are crucial components in ensuring the smooth operation and longevity of vehicle transmissions. The lubrication system provides a film of oil between moving parts, reducing friction and wear, while the cooling system helps dissipate heat generated during operation, preventing overheating and damage. Regular maintenance, including oil changes and monitoring fluid levels, is essential to keep these systems functioning properly and to prevent costly repairs or replacements.

**Strength and Durability Analysis:** Strength and durability analysis gear typically refers to equipment used to assess the strength and endurance of materials or structures. This can include tools like stress gauges, strain sensors, impact testers, and fatigue testing machines. These instruments help engineers and researchers evaluate how well materials can withstand various forces and conditions over time, ensuring the safety and reliability of products and structures.

### 3.5 Different Types Gear Stress

Gear stress refers to the various types of stresses that occur in the gears of mechanical systems due to the transmission of power and motion. These stresses can impact the performance, efficiency, and lifespan of gears. The primary types of gear stresses include: Contact Stress (Hertzian Stress): This stress occurs at the point of contact between gear teeth when they mesh. It's a type of localized stress that can lead to pitting and surface fatigue if it exceeds the material's endurance limit. Bending Stress: This stress arises in the gear teeth due to the bending load they experience while transmitting torque. Bending stress is a primary cause of gear tooth failure, leading to cracks and breakage if the stress exceeds the gear material's tensile strength. Shear Stress: This stress occurs due to the sliding motion between gear teeth. While typically lower than bending or contact stress, excessive shear stress can lead to material deformation or wear [19]. Torsional Stress: This stress is experienced by the gear shaft and the gear body due to the twisting force (torque) applied during operation. Torsional stress can cause the gear shaft to twist or fail if the torque exceeds the material's shear strength. Residual Stress: These are stresses that remain in the gear material after manufacturing processes such as heat treatment or machining. Residual stresses can influence the overall stress state of the gear during operation and may contribute to unexpected failures. Understanding and managing these stresses is crucial in gear design to ensure reliability, efficiency, and longevity of the gear system. Advanced analysis techniques and materials engineering are often employed to mitigate these stresses and enhance gear performance. Gear contact stress refers to the localized stress that occurs at the point of contact between the gear teeth as they mesh and transmit load [13]. This stress arises due to the force exerted over a small area where two gear teeth engage, which can lead to deformation and wear over time. Contact stress in gears is a critical factor in determining the gear's durability and performance. If the contact stress exceeds the material's endurance limit, it can result in pitting, surface fatigue, or even gear failure. Calculating and optimizing contact stress is essential in gear design to ensure reliable operation and a long service life. The AGMA contact stress theory is commonly used to evaluate and predict the contact stress in gears Gear bending stress refers to the stress experienced by a gear tooth as it bends under the load applied during meshing. This type of stress occurs at the root of the gear tooth, where the tooth connects to the gear body, and it is a crucial factor in determining the gear's strength and durability [25]. Bending stress is a primary concern in gear design because excessive stress can lead to tooth breakage or fatigue failure. It is typically calculated using the Lewis formula or other analytical methods, which consider factors such as the gear's material, tooth geometry, load distribution, and operational conditions. Properly managing gear bending stress is essential to ensure the gear can withstand the applied loads without failure over its intended lifespan

# Chapter 4

# Methodology

## 4.1 Introduction

The Methodology chapter of this thesis outlines the systematic approach used to design and analyze the performance of a gearbox for industrial applications. This chapter provides a detailed description of the methods employed to achieve the research objectives, including the design process, theoretical calculations, software simulations, and performance testing. The methodology integrates both theoretical and practical techniques to ensure that the gearbox meets the specified requirements for torque transmission, speed reduction, efficiency, and durability under various operating conditions [20]. The design phase includes the selection of appropriate gear types, material considerations, and gear geometry, which are tailored to the specific operational needs of the industrial application. Following the design, detailed load and stress analyses are conducted to assess the structural integrity of the gearbox components. Computer-aided design (CAD) tools are used to create 3D models, and Finite Element Analysis (FEA) is employed to simulate real-world conditions such as load variations, thermal stresses, and dynamic behavior. Furthermore, software simulations are performed to validate the theoretical calculations and optimize the gearbox design for improved performance. Testing protocols and procedures are defined to measure the gearbox's operational characteristics, such as torque, efficiency, and vibration levels[19]. This methodology ensures that the final gearbox design is robust, efficient, and capable of meeting the demands of industrial applications.

## 4.2 Gearbox Design Process

The preliminary design and optimization have been categorized into a three-step process

- Proposed Design
- Materials Selection
- Design Calculation and Analysis

The gearbox design process is meticulously outlined to ensure a comprehensive and systematic approach. The process begins with defining the specific requirements of the gearbox, including power transmission needs, speed ratios, and operational conditions. This initial phase involves gathering detailed specifications related to the load, speed, and environmental factors that the gearbox must accommodate. The design methodology incorporates selecting the appropriate gear type—such as spur, helical, or bevel gears—based on the application’s requirements. This choice is followed by precise gear geometry calculations, which determine the size and shape of the gears to ensure optimal performance and efficiency. Key parameters like module, pressure angle, and pitch diameter are calculated to match the required gear ratio and load capacity Material selection is a critical aspect of the design process, focusing on choosing materials that offer the necessary strength, wear resistance, and durability. This is complemented by stress and load analysis, which

assesses the bending and contact stresses to ensure that the gears can withstand operational forces without failure. Computer-Aided Design (CAD) tools are then employed to create detailed 3D models of the gearbox components, enabling visual verification and refinement of the design. Finite Element Analysis (FEA) is used to simulate real-world conditions, evaluating stress distribution, deformation, and thermal effects to optimize the design further. The methodology also includes simulation of dynamic loads and vibration analysis to predict and mitigate potential issues related to gearbox performance. The results from these simulations guide iterative refinements of the design to enhance performance and reliability. Finally, the design is validated through performance testing, where the gearbox's operational characteristics are measured and analyzed to ensure that it meets the defined requirements. This comprehensive approach ensures that the gearbox is designed to be robust, efficient, and capable of performing reliably in its intended industrial application.[20]

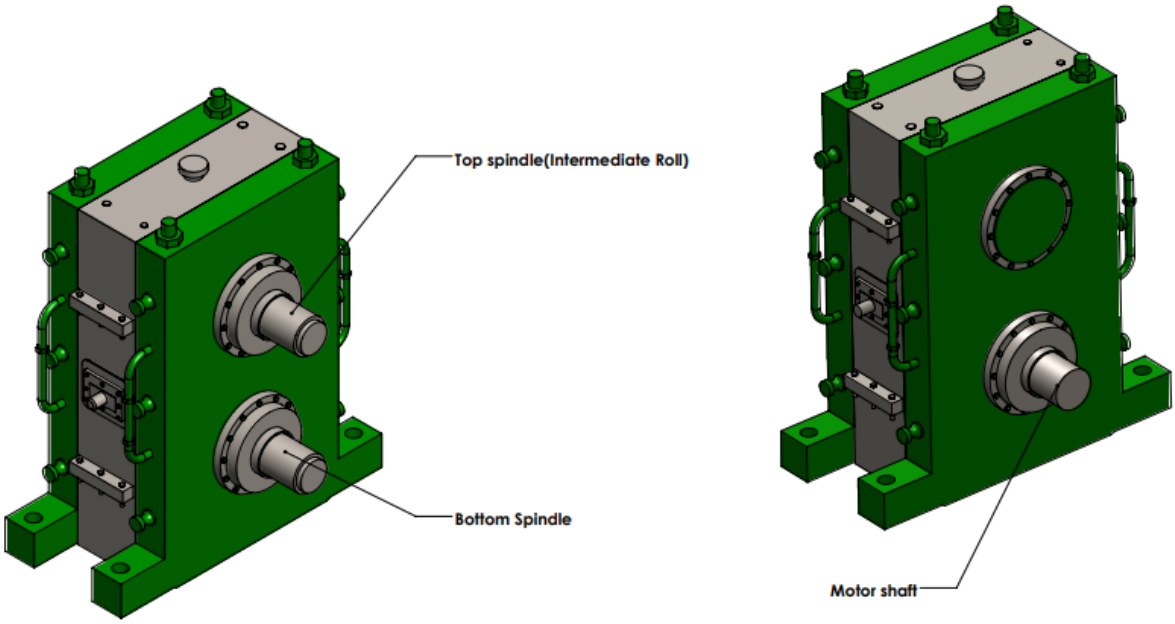



Fig 4-1: Gear Box

### 4.3 Materials Selection

The following factors were considered while selecting suitable materials for the design

- The availability of the material
- The cost of the material
- the weight of the material
- Manufacturing factors
- Sustainability of the material in working condition

## 4.4 Part List

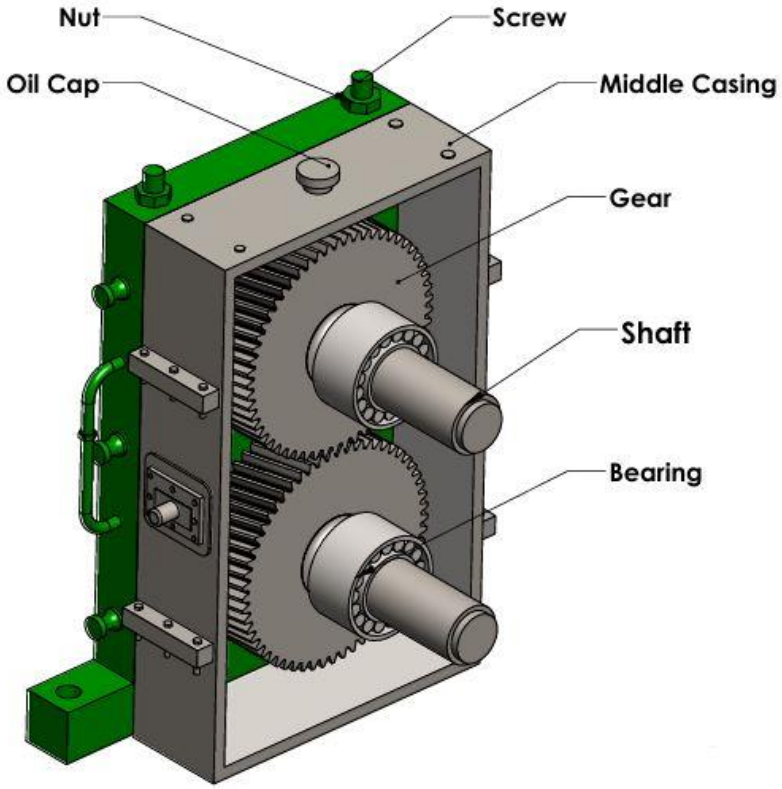
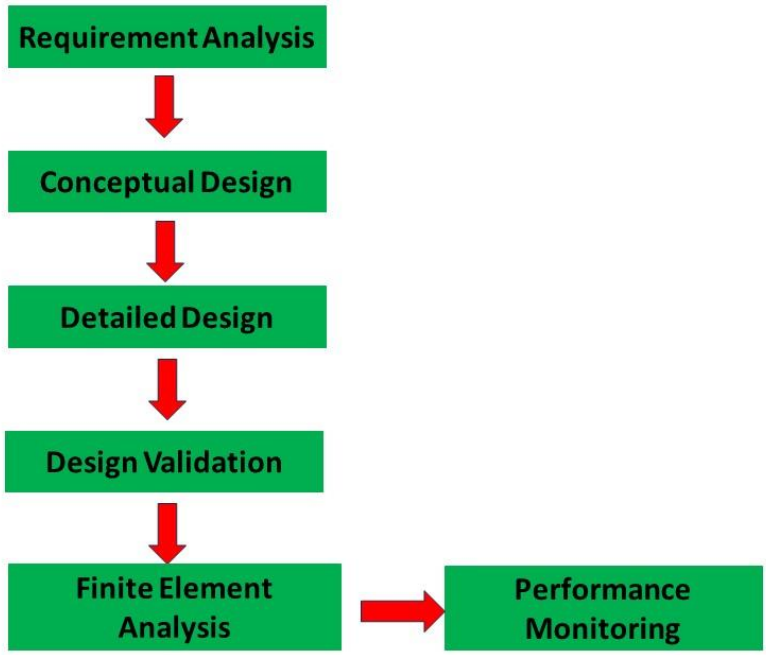



**Fig 4-2: Internal View**

**Table 4-2 List of Components**

| SN | Part Name | Material | Quantity |
|---|---|---|---|
| 1 | Spur Gear | Alloy Steel | 2 |
| 2 | Casing Side | Mild Steel | 2 |
| 3 | Casing Middle | Mild Steel | 1 |
| 4 | Shaft | Alloy steel | 2 |
| 5 | Bearing | Stainless Steel | 2 |
| 6 | Screw | Steel | 20 |
| 7 | Washer | Mild steel | 10 |
| 8 | Nut | Mild Steel | 10 |
| 9 | Key | Mild Steel | 10 |
| 10 | Oil Seal | Plastic | 10 |
| 11 | Bolt | Mild Steel | 10 |
| 12 | Oil Cap | Plastic | 1 |
| 13 | Oil Plug | Mild Steel | 4 |

### 4.5 Flow Chart Methodology




### 4.6 Design Requirements

The design requirements for an industrial gearbox begin with understanding the specific application for which the gearbox is intended. This includes identifying the power and torque demands, as well as the input and output speeds. The gearbox must handle the load efficiently and reliably, ensuring that it can transmit the required torque while maintaining desired speed reductions or increases [22]. Furthermore, operational conditions such as temperature, environmental factors like dust or moisture, and exposure to corrosive elements must be taken into account. Durability is another critical requirement, meaning the gearbox must be designed to withstand wear, fatigue, and long-term operation under load. Material selection plays a key role in this, as the materials must have high strength, wear resistance, and heat resistance to function effectively. Gear precision and alignment are important for reducing vibration and noise, while ensuring smooth power transmission. Thermal management is crucial, especially in high-power applications, where the gearbox generates significant heat during operation. lubrication is necessary to minimize friction and wear between moving parts, and the type of lubrication system (grease, oil bath, or forced lubrication) must be considered based on the application. Efficiency is also a vital requirement, with a focus on minimizing power losses due to friction, misalignment, or other factors [23]. Lastly, the gearbox must be compact and lightweight while maintaining structural integrity, with ease of maintenance and assembly factored into the design.

# Chapter 5

# Design Specification and Requirements

## 5.1 Introduction

The Design Specification and Requirements chapter establishes the critical criteria that guide the development and evaluation of the gearbox. This chapter outlines the essential parameters and performance targets needed to ensure the gearbox meets the demands of its intended application. It details the operational context, including torque and speed requirements, performance specifications such as efficiency and noise limits, and material and construction considerations. By defining these specifications, this chapter ensures that the gearbox design aligns with both operational needs and industry standards, providing a foundation for the subsequent design and testing phases.[10]

## 5.2 Functional Requirements of Gear box Design

The functional requirements of a gearbox focus on ensuring its ability to effectively transmit power and perform reliably within its intended application. One of the primary functions of a gearbox is to transmit torque from the input shaft to the output shaft. This involves adjusting the torque to suit the operational needs, whether that means increasing torque for heavy loads or decreasing it for lighter applications. Additionally, the gearbox must adjust the input speed to achieve the desired output speed by using appropriate gear ratios. This speed modification is crucial for matching the operational parameters of various industrial machines [24]. The gearbox must also handle both static and dynamic loads without failure, maintaining structural integrity even under peak load conditions. Durability and reliability are key, as gearboxes are often expected to operate continuously in harsh environments, such as high temperatures or exposure to dust and corrosive substances, with minimal maintenance. High efficiency is essential to minimize power losses during transmission, ensuring that energy consumption remains low while the gearbox maintains optimal performance levels Noise and vibration control are also important functional requirements. Excessive noise and vibration can cause accelerated wear, reduced operational lifespan, and even failure of the gearbox, so the design should ensure smooth gear engagement and proper alignment. Additionally, the gearbox must manage heat dissipation effectively to prevent overheating, which can degrade. Materials and reduce performance [25]. Compatibility with lubrication systems is another important requirement, as proper lubrication reduces friction and wear between moving parts, ensuring the gearbox functions smoothly over time. The gearbox must also meet requirements for compactness and weight, particularly in applications where space is limited or mobility is necessary. Despite being compact and lightweight, the gearbox must retain sufficient strength and rigidity to perform under demanding conditions. Lastly, safety features are critical to protect against mechanical failures. This may include overload protection mechanisms, such as torque limiters or safety couplings, which prevent damage to the gearbox in the event of sudden

load increases. These functional requirements ensure that the gearbox performs its role efficiently, reliably, and safely in industrial environments.

### 5.3 Performance Requirements of Gear box Design

The performance requirements of a gearbox design focus on ensuring optimal functionality, efficiency, and reliability throughout its operational lifespan. First and foremost, the gearbox must provide smooth and consistent torque transmission while accommodating a range of load conditions, including peak loads without causing stress or damage to its components. It should maintain high efficiency in power transmission by minimizing energy losses due to friction, misalignment, or other mechanical inefficiencies [22]. Efficiency plays a critical role in reducing operational costs and energy consumption, especially in large-scale industrial applications. Furthermore, the gearbox must be designed to operate at specified speed ratios while maintaining minimal fluctuations in speed or performance, ensuring that machinery can function smoothly and precisely. Another key performance requirement is the ability to handle varying operational conditions, such as fluctuating loads, changing temperatures, and environmental factors like dust, moisture, or corrosive elements, without compromising performance. The gearbox should exhibit high reliability, meaning it can perform consistently over long periods without frequent failures or the need for excessive maintenance. Vibration and noise reduction are also essential performance requirements, as these factors can lead to premature wear and fatigue of the gearbox components. The design must therefore ensure that gear meshing is accurate and smooth, reducing operational vibrations and keeping noise levels within acceptable limits. Heat dissipation is a critical performance factor, especially in high-speed or heavy-duty applications where friction generates significant heat. The gearbox must be able to manage and dissipate this heat effectively to prevent overheating, which could lead to reduced performance or material degradation. Another important consideration is the longevity and endurance of the gearbox [26]. It should be designed to withstand prolonged use under its maximum rated load without significant wear or breakdowns. This includes the ability to resist fatigue in the materials and components, ensuring that the gearbox maintains optimal performance throughout its expected service life. Lastly, safety and performance under extreme conditions, such as sudden overloads or shock loads, are essential, requiring the gearbox to include protective features that prevent damage and ensure stable operation during such events These performance requirements are critical in ensuring the gearbox can meet the demands of industrial applications efficiently and reliably [26[

### 5.4 Environmental Consideration of Gear box Design

A gearbox, also known as a transmission, is a mechanical device used to increase torque output while reducing speed or vice versa. Gearboxes are crucial in various applications, including industrial machinery, automotive, and wind turbines, to efficiently transmit power from one component to another. They consist of a series of gears, which are cogged wheels that interlock to transfer motion and force [Wikipedia]. The primary function of a gearbox is to convert the input provided by the engine or motor into an appropriate output speed and torque for the intended use. In the context of environmental considerations, modern gearboxes are designed with materials and lubricants that minimize energy loss and reduce wear and tear, thus extending their operational life and enhancing efficiency. Additionally, advancements in design and technology have led to the

development of gearboxes that produce less noise and vibration, contributing to a quieter and more environmentally friendly operation. The use of recyclable materials and sustainable manufacturing processes also plays a significant role in reducing the environmental impact associated with gearbox production and disposal. [Wikipedia]

### .5.5 Design Standers and Code

1.AGMA (American Gear Manufacturers Association): AGMA provides standards and guidelines for various aspects of gear design, manufacturing, and inspection.

2.ISO (International Organization for Standardization): ISO standards cover a wide range of topics including gear design, materials, and performance.

3.API (American Petroleum Institute): API standards are commonly used in the oil and gas industry for equipment design, including gearboxes used in drilling and refining operations.

4.ASME (American Society of Mechanical Engineers): ASME codes and standards cover a broad spectrum of engineering topics, including gear design and performance.

5.DIN (Deutsches Institut für Normung): DIN standards are widely used in Germany and Europe and cover various aspects of mechanical engineering, including gear design.

6.BSI (British Standards Institution): BSI publishes standards that are commonly used in the UK and cover gear design and performance requirements [30]

# Chapter 6

# Theoretical Calculation

## 6.1 Introduction

In the design of industrial gearboxes, the accurate prediction of contact stress and bending stress is critical for ensuring reliable and efficient operation. Contact stress and bending stress are two fundamental factors that influence the performance and durability of gear components. This is the localized stress experienced by the gear teeth where they come into contact during operation. The contact stress primarily affects the surface of the gear teeth and is crucial for preventing gear tooth failure and ensuring smooth meshing. It is typically analyzed using AGMA contact stress theory, which provides a method to estimate the maximum contact pressure based on gear geometry, material properties, and loading conditions [12]. This stress arises from the bending moments transmitted through the gear teeth. It is a key factor in determining the strength and durability of the gear teeth under load. Bending stress is often calculated using the Lewis formula or other advanced methods, which take into account the gear tooth profile, load distribution, and material properties. Understanding these theoretical calculations helps engineers design gearboxes that can withstand operational stresses and enhance the reliability and efficiency of industrial machinery.

## 6.2 Material Selection of Gear

The first step in the gearbox design process is to select the material. A material is to be selected by doing intensive research on the properties of the various materials. A material is to be selected keeping in mind the various parameters like strength, weight, durability, cost and other parameters. SolidWorks provide the user, list of the various materials which can be selected for the designing of gears.

**Table 6-1(Materials Specifications)**

| Properties | Value |
|---|---|
| Surface Hardness | HRC 61 |
| Allowable Bending Stress's Number (N/) | 430 |
| Allowable Contact stress number (N/) | 1500 |
| Tensile Strength(N/) | 1200 |
| Youngs Modulus (N/) | 20600 |
| Poisson's Ratio | 0.3 |

Also, there is a provision for the user to enter his own material properties and thus one can define his own material in the program. In this paper for the sake of designing gearbox, case-carburized steel is selected due to its better mechanical properties. Also, the material selected for gears and shaft is to be same because of the fact, same material can be manufactured as a single unit.

### 6.3 Gear Contact Stress Calculation (Use AGMA Method)

Gear contact stress is a critical factor in the design and performance of gears in mechanical systems. It refers to the stress generated at the contact point between gear teeth when they mesh under load. This stress can lead to gear failure through mechanisms such as pitting, scoring, or cracking if not properly managed.

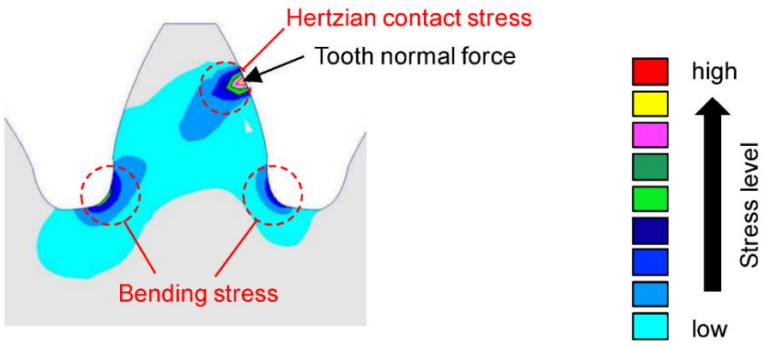



Fig 6-1: Gear Stress

### 6.4 Assumptions

Major assumptions for the thesis include

- Gear design is based on ANSI/AGMA standards
- Design space extremes are inappropriate and valid ranges
- The minimum number of teeth of a spur gear to prevent interference is 16 (Natarajan, 2000)
- A simplified model for rotor loads on main and tail rotor drive shafts
- Frictional loses were excluded
- The design of excluded components (bearings, splines, keyways, seals, etc.) does not significantly impact the transmission design

### 6.5 Gear Geometry Calculation

Gear geometry refers to the physical characteristics and properties of gears, which are mechanical devices used to transmit motion and power between rotating shafts. The geometry of gears includes various parameters such as tooth profile, tooth size, pitch diameter, pressure angle, helix angle (for helical gears), tooth thickness, and clearance, among others.

**Note = (All Equation and formula use Chapter 14 (Spur & Helical gear) Shipley's Mechanical Engineering Design, Tenth Edition)**

Reference data,

Module (m) = 14 mm

Pressure Angle (α) = 20

Number of teeth = 57

Diametral Pitch (= N/D = 57/798 = 0.0713 mm

Circular Pitch (π x D)/N = (3.1416 x 798)/57 = 43.98 mm

Addendum(a)= 14 mm

Dedendum (d) = 1.25 x 14 = 17.5 mm

Clearance (Cl) = d-a = 17.5-14 = 3.5 mm

Center Distance (C) = x M /2 = 57+57 x 14/2 = 798 mm

Pitch Diameter = N x M = (57 x 14) = 798 mm (Gear and Pinion are same diameter)

Base Circle Diameter = D x Cosα = 798 x Cos = 750 mm

Outside Diameter (OD) = D + 2m = 798 + 2 X 14 = 826 mm

Root Diameter (RD) = D – 2b = 798 – 2 x 17.5 = 763 mm

Face Width (FD) = 10 x m = 10 x 14 =140 mm (we use face width 200 mm because we want to over safety)

Working Depth (Wp) = 2 x m = 2 x 14 = 28 mm

Whole depth (= a + b = 14 + 17.5 = 31.5 mm

Circular Pitch = / N = 3.1416 x 798 /57 = 43.98 mm

Gear Ratio = 57 / 57 =1:1

Backlash(B) = 0.167 /m = 0.167 / 14 = 0.012 mm

**6.6 Gear Bending Stress Calculation**

The Pitch Line Velocity & Transmitted Load,

V = $\pi.d_P.\ n_P$ = 3.1416.(57/1.18).1000/12 = 12646 Ft/Min

$W_t$ = 33000.Hp/12646 = 8938.62 Ft/Min

For The Dynamic Factor, B = 0.8255 & A = 59.77

$K_v$ = A+ $\sqrt{V}/A$ = 59.77+ $\sqrt{12646}$/59.77 = 1.19

For The Distribution Factor.

$C_{Pt}$ = 0.111, $C_{pm}$ = 1, $C_{ma}$ = 0.15

$K_m = 1 + C_{Pt}.(C_{Pt}.C_{Pt}) + (C_{ma}.C_e) = 1 + 1(0.011 \text{ x } 1) + (0.193.1) = 1.304$

Gear Tooth Bending Stress (Khurmi R.S, Gupta J.K .2005,'' A Textbook of Machine Design,

$(\alpha)_{all} = W^t . K_v . K_o (P_t/F) . (K_m . K_B)/J$

= 8398.62 .1 .1.96. (1.18/7.87). (1.304.1)/0.45 = **4250 MPA**

Allowable Bending Strength,

$(\alpha)_{all} = S_t/S_F\ (Y_N/K_t . K_R)$

4250 = (29260/SF). (0.928/1.0.85) = *7* (Factor of Safety)

### 6.6 Gear Contact Stress Calculation

For The Elastic co-efficiency,

$C_p = \pi\left(\frac{1}{\frac{1-V_p{}^2}{E_p}+\frac{1-V_p{}^2}{E_G}}\right) = \pi\left(\frac{1}{\frac{1-0.292^2}{30.10^6}+\frac{1-0.292^2}{30.10^6}}\right)$ = 2284 .7 PSI

Geometry Factor for Pitting Resistance,

$I = \frac{Cos\phi+Sin\phi}{2m_n} . \frac{m_a}{M_{G_+1}} = \frac{1}{1+1}$ = 0.080

Gear Tooth Contact Stress (Khurmi R.S, Gupta J.K .2005,'' A Textbook of Machine Design,

$(\alpha)_C = \sqrt{W^t . K_s} . K_v K_o \left(\frac{K_m}{d_p} . F\right) . \frac{C_f}{I}$

$= \sqrt{8398.62 .1 .1.196.0.45. \left(\frac{1}{0.080}\right)}$ = **21070 MPA**

**Allowable Contact Strength,**

$(\alpha)_C = (S_c/S_F) . (Z_n C_H)/\ . (Z_n C_H)$

21070 = (93500/$S_F$). (0.879.1)/1.0.85 = 3

For The Shaft Diameter,

D = 16.T/π.τ =

=16.890000/3.1416.178

=250 mm

### 6.7 Keys and Keyways Design Calculations

The keys used for both the gear and pinion are the rectangular type of sunk keys made from mild steel, to be inserted in a keyway parallel to the axis of the shaft.

**The width (w) of the pinion key is given according to Khurmi and Gupta, 2005 as;**

W=d/4 =3t /2

Here, Shaft Diameter is 200 mm

So, Key thickness t = 40 mm

The yield strength) of the pinion material (Steel Fe E 370) is 370 N/mm2 and a safety factor (F.S.) of 4 (steady loads), according to Khurmi and Gupta, 2005.

Maximum shear stress for the key is given according to Khurmi and Gupta, 2005 as

Maximum shear stress for the key ($k\tau$ ) is given according to Khurmi and Gupta, 2005 as;

= 370/4 = 92.5 N/

The length of the key(l) is given according to Khurmi and Gupta, 2005 as;

L = 1.571D. = 1.571 .200. = 143.12 mm = 145mm

The depth of the keyway(h) for both the pinion shaft and pinion gear is given as;

h = 40/2 = 20mm

### 6.9 Gear Lubrication & Heat Treatment

The reason for the gearbox lubrication system is to give an oil film at the contacting surfaces of working segments and retain the heat produced in the gearbox with the goal that component temperatures are not excessive. Most of the oil stream is required for the cooling capacity. The American Gear Manufacturers Association (AGMA) thermal ratings are based on a maximum oil sump temperature of 200ºF. In turbo-machinery applications, the thermal rating is generally not exactly the mechanical rating, and an external cooling system is required. When designing a lubrication system, the initial step is to estimate the oil flow to the components and the gearbox efficiency. [25]

The appropriate decision of rigging material is presumably the most significant factor in the fruitful activity of an apparatus set. The material for any rigging is chosen dependent on the working condition, i.e., power, speed and torque to be transmitted and also other working 16 conditions, i.e., temperature, vibration, chemical, etc., ease of assembling; and the general cost of material and production. In choosing a gear material, the tooth hardness and type of heat treatment to accomplish that hardness must be considered. Gears case-hardened via "Carburizing," give the best metallurgical attributes consolidating good case structure with reasonable flexibility.

Carburizing produces the "strongest" gear providing bending and pitting fatigue resistance and an excellent wear surface.

### 6.8 Selection of Bearings

The radial single row deep groove ball bearings are used to support loads in both the pinion and gear shafts. These bearings were selected due to its ability to support the weight of the shafts, availability, and cheaper. These types of bearings are also easier to mount and replaced. The balls used in this of bearings are made from steel, while the inner and outer rings are made from mild steel. The table below gives the standard dimensions and load ratings for single row series-02 deep groove contact ball bearings.[29] `

Dimensions and Load Ratings for 02-Series Ball Bearings; Table (6-2)

| Bore, mm | Outer diameter, mm | Width, mm | Fillet Radius, mm | Shoulder Diameter, mm | | Load Rating, kN | |
|---|---|---|---|---|---|---|---|
| | | | | ds | dB | C10 | $C_0$ |
| 20 | 47 | 14 | 1.0 | 25 | 41 | 12.7 | 6.20 |
| 25 | 52 | 15 | 1.0 | 30 | 47 | 14.0 | 6.59 |
| 30 | 62 | 16 | 1.0 | 35 | 55 | 19.5 | 10.0 |
| 35 | 72 | 17 | 1.0 | 41 | 65 | 25.5 | 13.7 |
| 40 | 80 | 18 | 1.0 | 46 | 72 | 30.7 | 16.6 |
| 45 | 85 | 19 | 1.0 | 52 | 77 | 33.2 | 18.6 |
| 50 | 90 | 20 | 1.0 | 56 | 82 | 35.1 | 19.6 |
| 55 | 100 | 21 | 1.5 | 63 | 90 | 43.6 | 25.0 |

**(Source; Budynas and Nisbett, 2011)**

Selection of The Pinion Shaft Bearing Since the diameter of the pinion shaft (dP) is 40 mm, a bearing of 40 mm bore is therefore selected from the series-02 table. The bearing is described by the code number of 208. Selection of The Gear Shaft Bearing Again, since the diameter of the gear shaft (dG) is 30 mm, a bearing of 30 mm bore is therefore selected from the series-02 table. The bearing is described by the code number of 206.

### 6.10 Selection of Bolts and Nuts

Bolts and nuts are the fasteners used for the gearbox since it would prevent any form of damages during the assembling and disassembling of the gearbox during maintenance. The 46 table below gives the selection procedure for the bolts and nuts used in the gearbox assembly.

Table (6-3) Selection Nuts and Bolts

| Type | Designation | Quantity | | Location |
|---|---|---|---|---|
| | | Bolts | Nuts | |
| Through bolt | M16-8d | 10 | 10 | Top and bottom casing |
| Tap bolts | M10-8d | 12 | 0 | Side flanges and casing |
| Tap bolts | M12-8d | 4 | 0 | front flange and casing |

### 6.11 Service Factor specifications of various Gear Types (source: Bhatia, 2014)

Table (6-4): Service Factors

| **Type of Load** | **Service Factors** | | |
|---|---|---|---|
| | **Intermittent or 3hrs per day** | **8 -10hrs per day** | **Continuous 24hrs per day** |
| Uniform | 0.80 | 1.00 | 1.25 |
| Light shock | 1.00 | 1.25 | 1.50 |
| Medium shock | 1.25 | 1.50 | 1.80 |
| Heavy shock | 1.50 | 1.80 | 2.00 |

# Chapter 7

# Computer Aided Design (CAD)

## 7.1 Introduction

Computer-Aided Design (CAD) has revolutionized the approach to designing and analyzing gearboxes in industrial applications. CAD systems provide a powerful platform for creating detailed 2D and 3D models of gearboxes, allowing engineers to visualize, simulate, and optimize designs with unprecedented precision and efficiency. The use of CAD in gearbox design enables engineers to develop accurate models that integrate all critical components and their interactions. CAD software facilitates the automation of complex calculations, such as those for gear dimensions, tolerances, and stress analysis, ensuring that designs meet required performance standards and manufacturing constraints. Additionally, CAD tools support the iterative design process by allowing quick modifications and evaluations of different design scenarios. They also provide capabilities for generating detailed technical drawings, simulations, and analysis results, which are essential for verifying design integrity and performance before physical prototyping. In summary, CAD enhances the design process by improving accuracy, reducing development time, and facilitating thorough analysis and optimization of gearbox systems

## 7.2 Introduction of CAD Tools

In the realm of mechanical engineering, the design and development of complex systems like gearboxes have traditionally relied on the meticulous efforts of skilled engineers and draftsmen. However, with the advent of computer-aided design (CAD) tools, the process has been revolutionized, offering unprecedented accuracy, efficiency, and innovation. This thesis explores the utilization of CAD tools in the design of gearboxes, emphasizing their transformative impact on engineering practices.

## 7.3 Evolution of Gearbox Design

Historically, gearbox design was a labor-intensive process that involved manual calculations, drafting, and physical prototyping. Engineers had to ensure that every component met stringent specifications to achieve desired performance and reliability. This process was not only time-consuming but also prone to errors, which could lead to costly revisions and delays. The introduction of CAD tools marked a significant turning point. These digital solutions enabled engineers to create detailed 3D models, simulate performance under various conditions, and iterate designs rapidly. The ability to visualize the gearbox in a virtual environment before manufacturing has dramatically reduced the time and cost associated with design and prototyping.

### 7.4 Importance of Gearboxes

Gearboxes are critical components in a wide range of applications, from automotive and aerospace industries to industrial machinery and robotics. They are responsible for transmitting power from a prime mover, like an engine or electric motor, to the driven machinery, while adjusting the torque and speed to optimal levels. The efficiency, durability, and performance of gearboxes directly impact the overall functionality and longevity of the systems they serve.

### 7.5 CAD Tools in Gearbox Design

Modern CAD tools encompass a suite of functionalities that support every phase of gearbox design:

3D Modeling: CAD software allows engineers to create detailed three-dimensional representations of gearbox components, ensuring precise alignment and fitment. These models serve as the foundation for further analysis and simulation [21]

Finite Element Analysis (FEA): Integrated FEA tools enable engineers to conduct stress and strain analysis on gearbox components, identifying potential failure points and optimizing material usage for strength and weight considerations.

Kinematic and Dynamic Simulation: CAD tools can simulate the movement and interaction of gears within the gearbox, assessing performance under various operating conditions. This helps in predicting issues related to vibration, noise, and wear. Parametric Design: CAD systems allow for parametric design, where changes to one dimension or feature automatically update related components. This capability facilitates quick adjustments and iterations, enhancing the design process's flexibility and efficiency.

Manufacturing Integration: CAD models can be directly used to generate CNC machining codes, ensuring seamless transition from design to manufacturing. This integration reduces errors and improves the precision of the final product [14]

Significance of the Study: This study holds significant importance for mechanical engineers, designers, and researchers involved in gearbox development. By showcasing the practical applications and benefits of CAD tools, it aims to promote their adoption and further innovation in gearbox design. Additionally, the insights gained from this research will contribute to educational curricula, helping to prepare the next generation of engineers with the skills needed to leverage advanced design technologies.

In conclusion, the integration of CAD tools in gearbox design represents a paradigm shift in engineering, offering new possibilities for innovation and efficiency. This thesis seeks to capture the essence of this transformation, providing a detailed exploration of how CAD tools are reshaping the future of gearbox design.

## 7.6 3D Modeling of the Gear Box

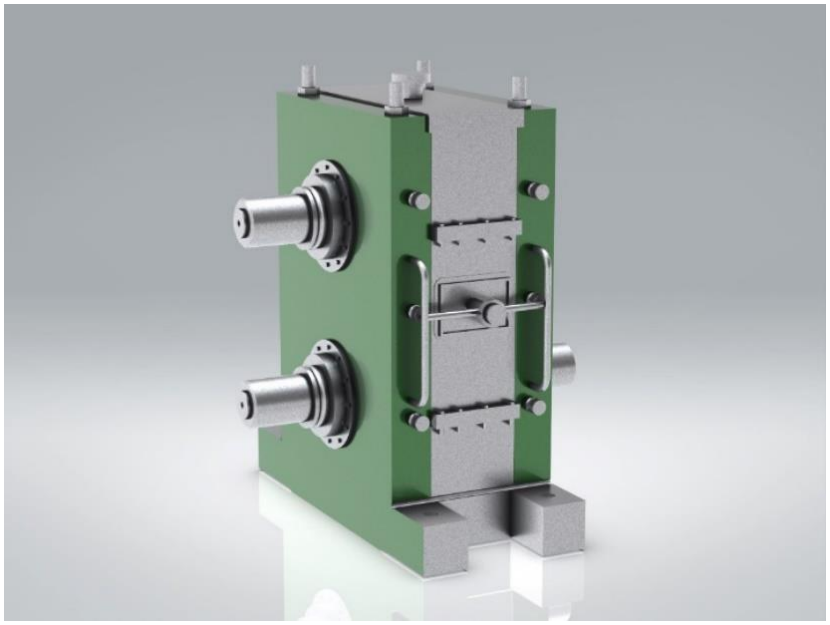


Fig: 7-1 Gearbox (Rendering View)

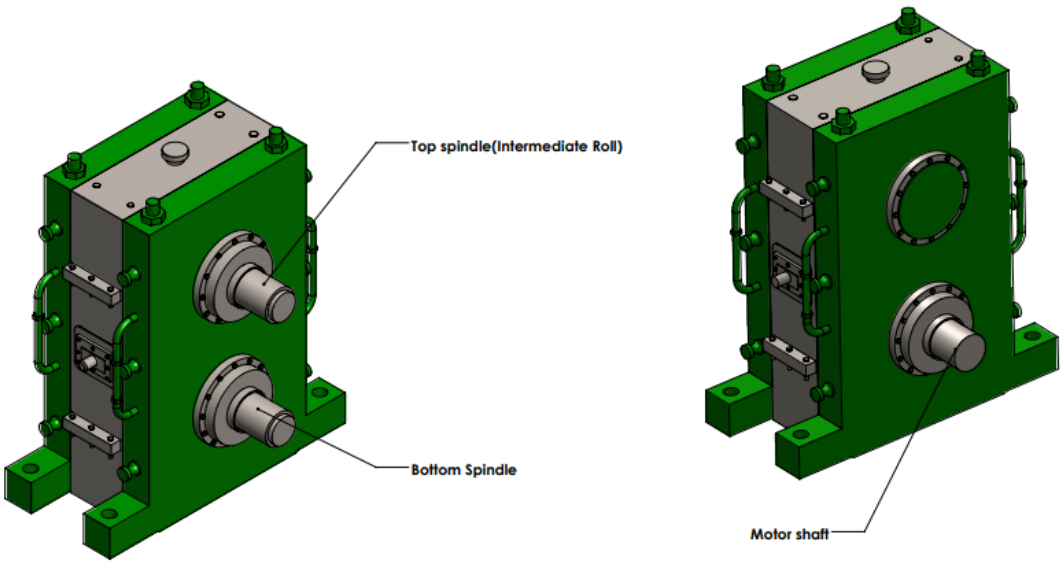



Fig: 7-2 Gearbox (2nd Projection View)

## 7.7 Orthography Projection

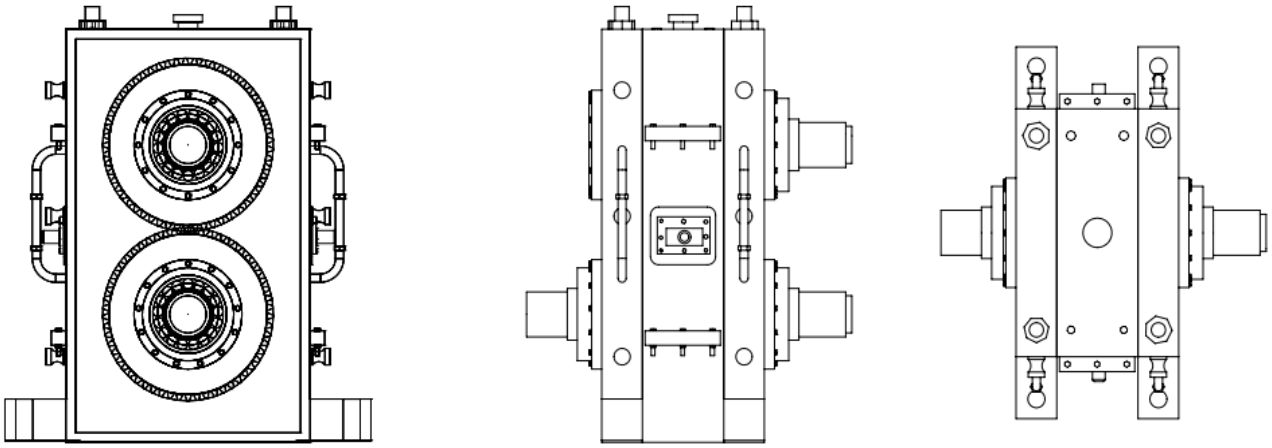


Fig 7-3 Orthography Projection

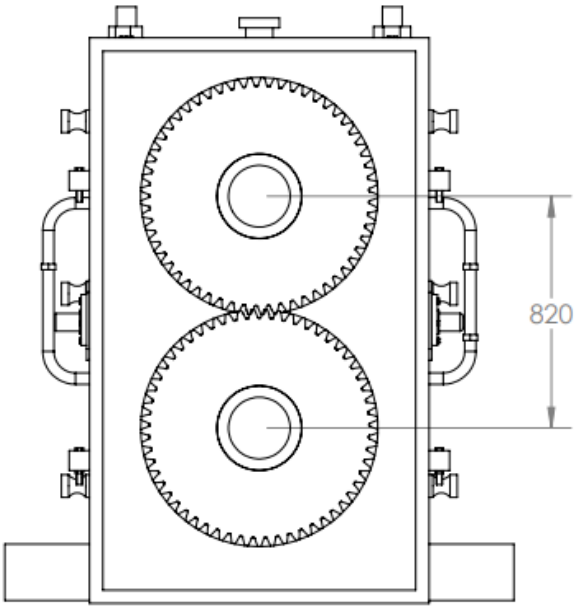



Fig 7-4 Gear Arrangement

### 7.8 Assembly Drawing of Gear box

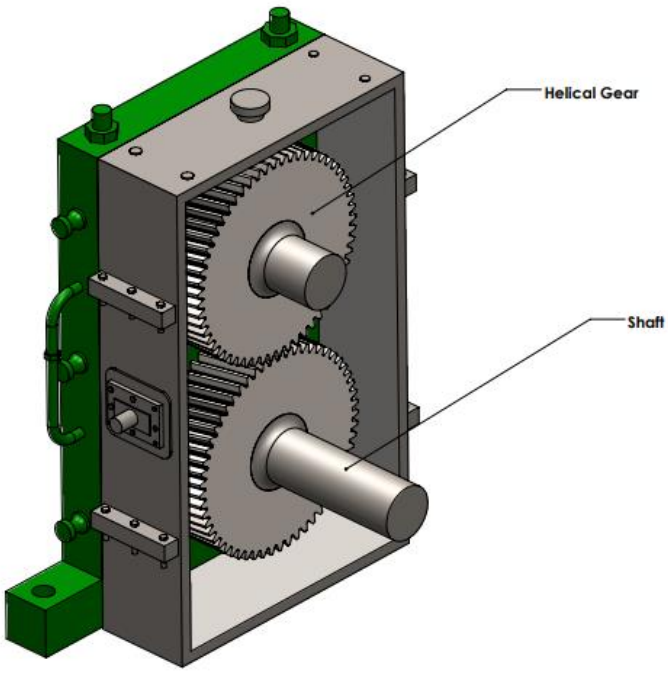



Fig 7-5 Exploration View -1

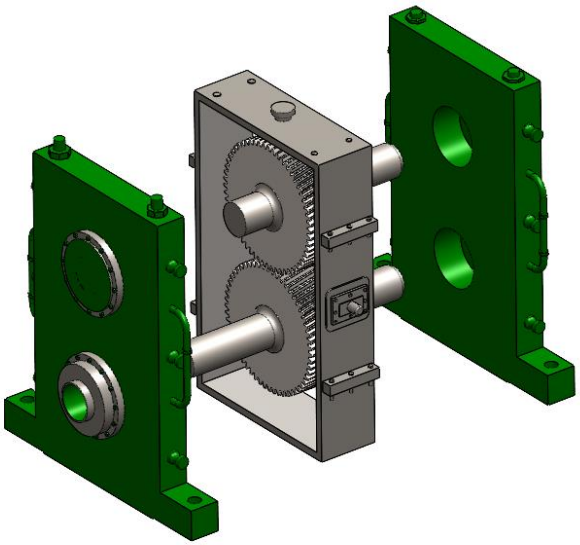


Fig 7-6 Exploration -2

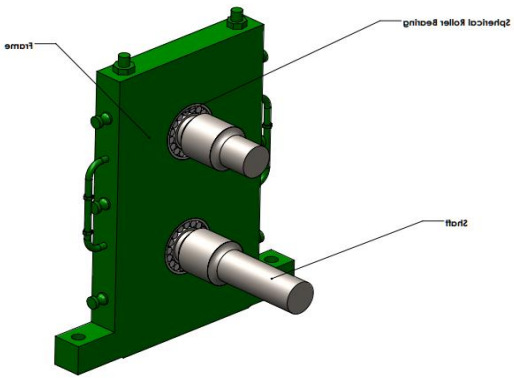



Fig 7-7 Shaft Position

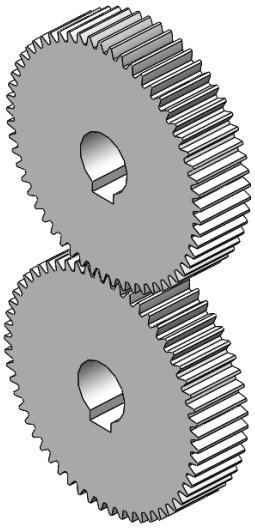


Fig 7-8 Gear Contact

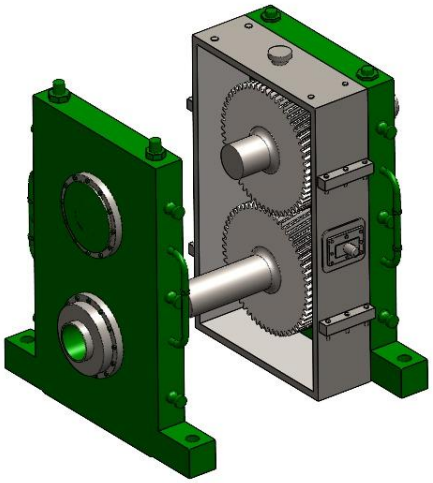


Fig 7-9 Internal View

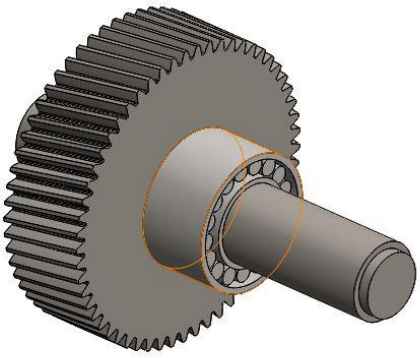


Fig : 7-10 Gear and Shaft Coupling

## 7.9 Details Drawing

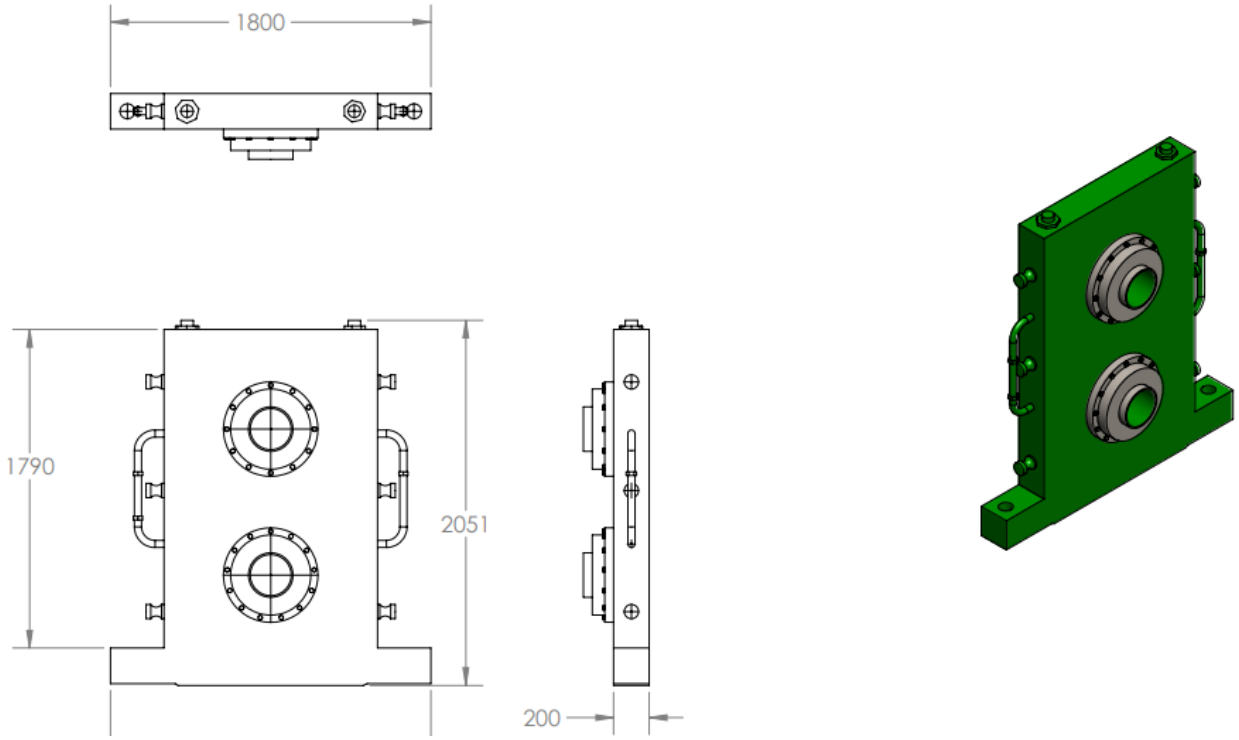



Fig 7-11 Left Side plate

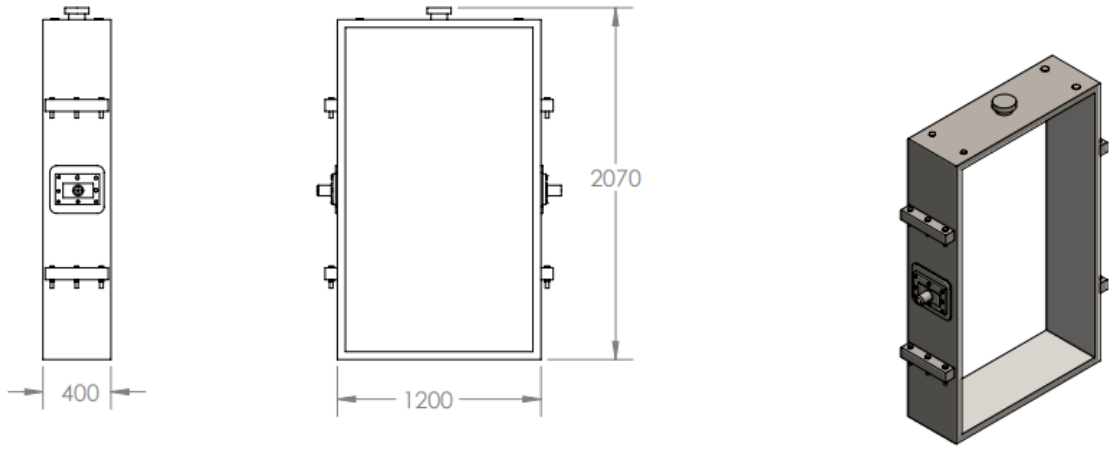



Fig 7-12 Middle Side Plate

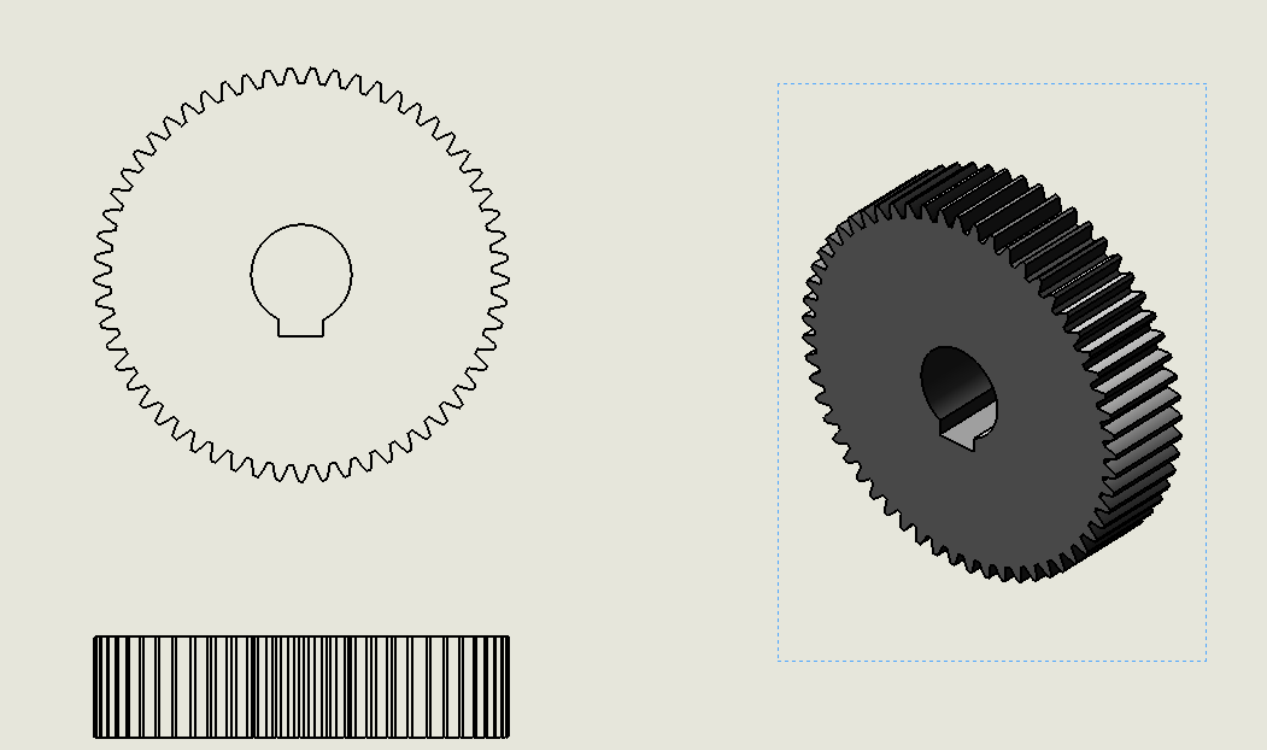


Fig 7-13 Spur Gear

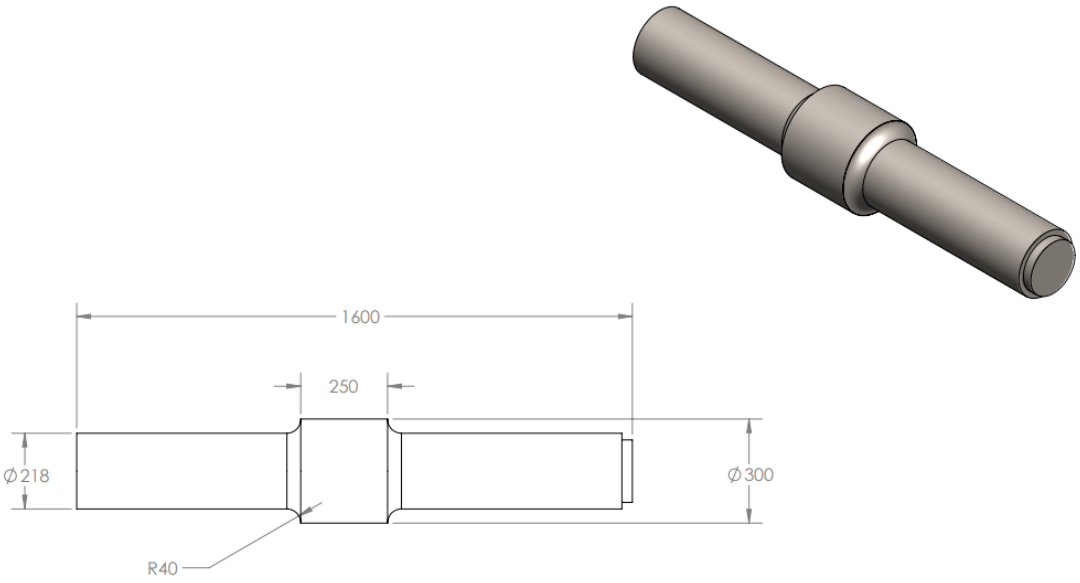



Fig 7-14 Shaft-1

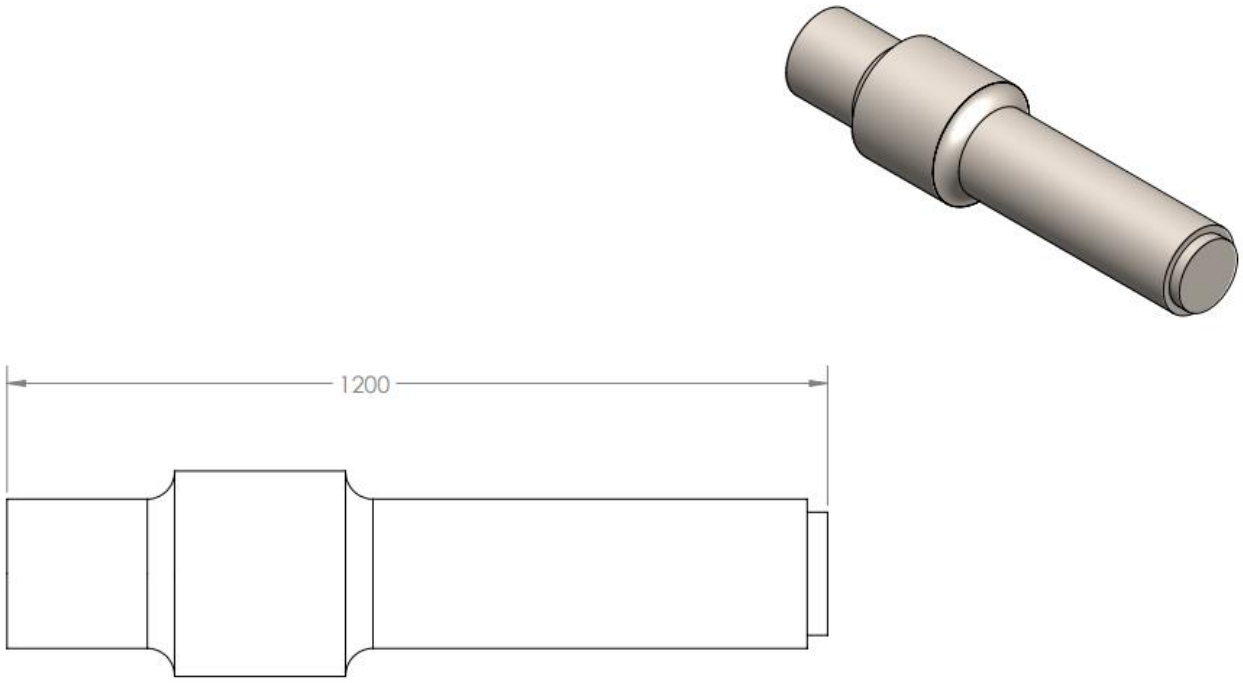



Fig 7-15 Shaft 2

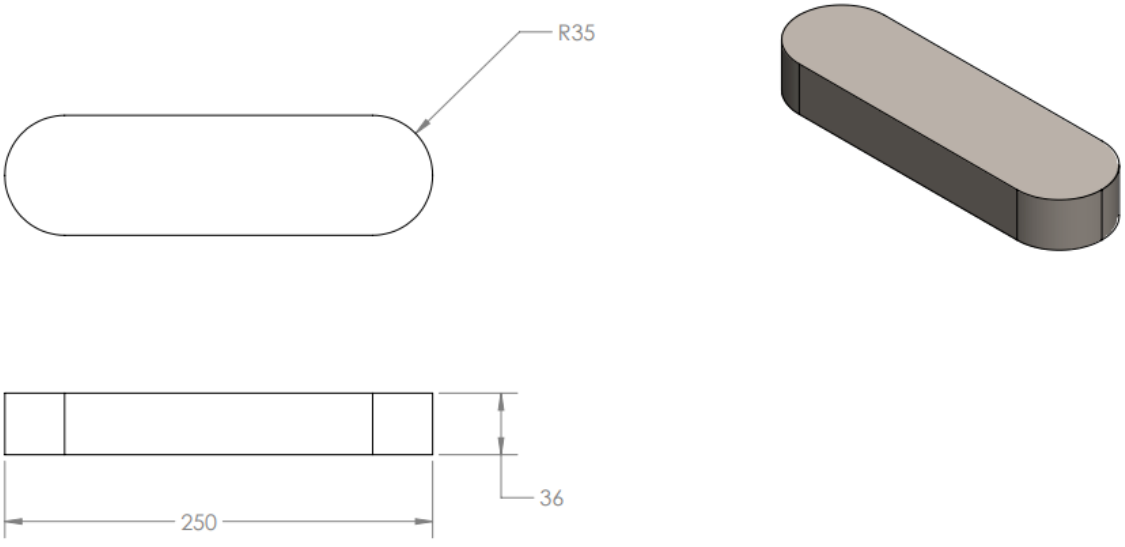



Fig 7-16 Key Lock

# Chapter 8

# Finite Element Analysis

## 8.1 Introduction

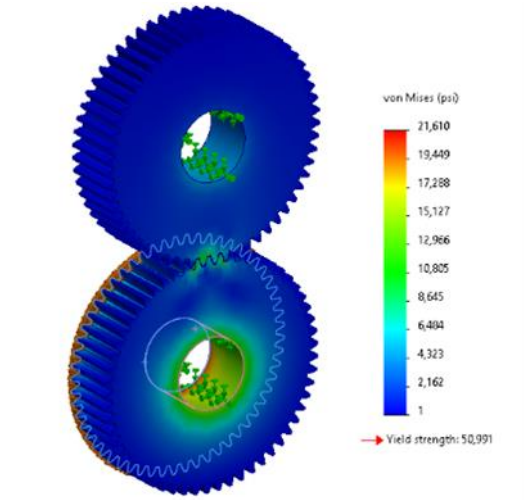
Finite Element Analysis (FEA) has become a critical tool in modern engineering, allowing for precise simulation of complex physical phenomena within mechanical systems, including industrial gearboxes. As gearboxes are subject to a variety of operational loads—such as torque, vibrations, and thermal stresses—accurately predicting their performance is essential for optimizing their design and ensuring long-term reliability Traditionally, gearbox design relied on analytical calculations based on simplified assumptions. However, these methods often fall short when dealing with complex geometries, non-linear material properties, and intricate load conditions. FEA overcomes these limitations by providing a numerical approach to solving differential equations that govern mechanical behavior [22]. By discretizing the gearbox into smaller, manageable finite and opportunities for optimization. In this chapter, we will explore how FEA is applied specifically to gearbox design and performance analysis. The focus will be on understanding the steps involved in FEA, including model creation, meshing, boundary conditions, and the interpretation of results. Additionally, we will highlight the role of FEA in optimizing gearbox performance, reducing material costs, and enhancing the reliability of the system.[24]

## 8.2 Using Software for Analysis

ANSYS is a powerful simulation software widely used for Finite Element Analysis (FEA) in engineering applications, including gearbox design. It enables engineers to model complex mechanical systems and predict their behavior under various load conditions, such as stress, strain, heat, and vibration. In the context of gearbox design, ANSYS allows for the creation of detailed 3D models and provides advanced meshing tools to discretize the geometry into finite elements. Engineers can apply loads, boundary conditions, and material properties to simulate real-world operational scenarios. The software's ability to perform static, dynamic, and thermal analyses helps in assessing critical factors such as gear tooth stress, thermal deformation, and vibration behavior. By identifying high-stress areas and potential points of failure, ANSYS helps optimize the design, ensuring the gearbox performs efficiently and safely while reducing material and manufacturing costs. Furthermore, ANSYS provides post-processing tools that allow for the detailed visualization of results, making it easier to interpret data and refine the design accordingly. This makes it an essential tool in the iterative design and performance analysis process of industrial gearboxes.

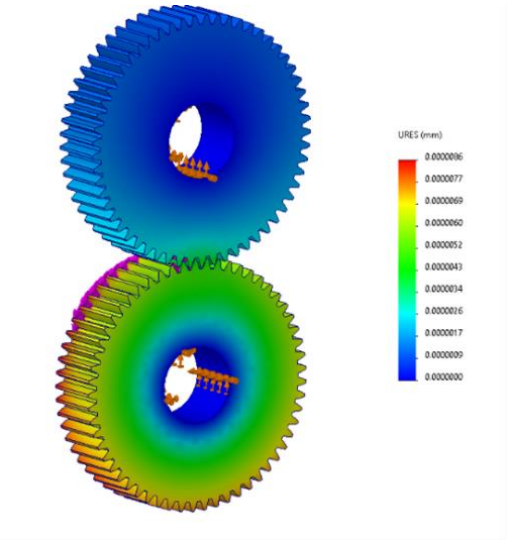


## 8.3 Contact Stress Results from ANSYS



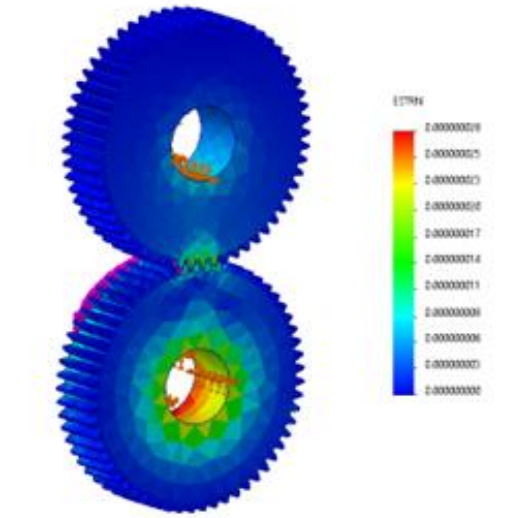

The bending stress of 21,610 MPa is significantly lower than the yield stress, providing a safety factor of 2.36. This means the gear is under safe operating conditions and can handle higher loads without failure.
Ensuring the stress remains below the yield point helps avoid permanent deformation and extends the gear's life. However, regular monitoring and analysis are recommended to prevent unexpected failures due to material fatigue over time.

Fig: 8-1 Bending Stress Result




The displacement of 0.1 mm under bending stress is relatively small and typically indicates minimal deformation in the gear. While this value is within acceptable limits, it's important to ensure that this displacement does not lead to misalignment or interfere with the gear's meshing in operation.
Continuous monitoring is recommended, especially under fluctuating loads, to ensure that this displacement does not increase over time, which could affect the gear's performance and longevity

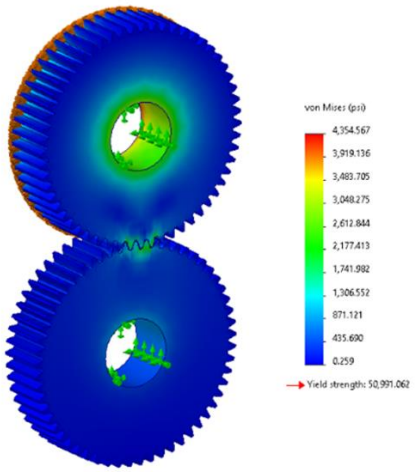
Fig :8-2 Displacement Result



A strain of 0.001 indicates a relatively low level of deformation under load, reflecting good material performance and structural integrity.
This strain value suggests that the gear is operating within safe limits, maintaining its shape and functionality without significant risk of yielding.
Monitoring strain is essential to ensure it remains within acceptable thresholds, as excessive strain can lead to fatigue and eventual failure over time.

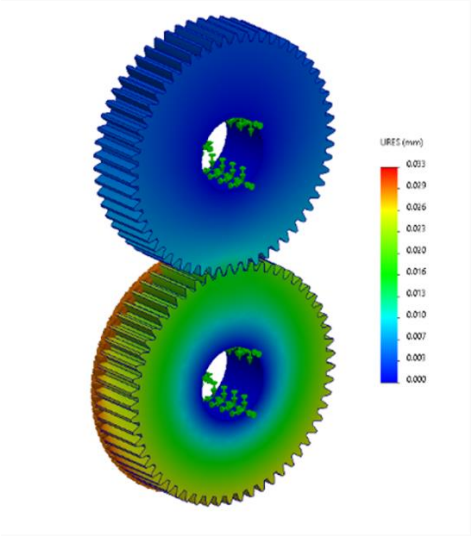
Fig: 8-3 Strain Result

## 8.4 Bending Stress Results from ANSYS



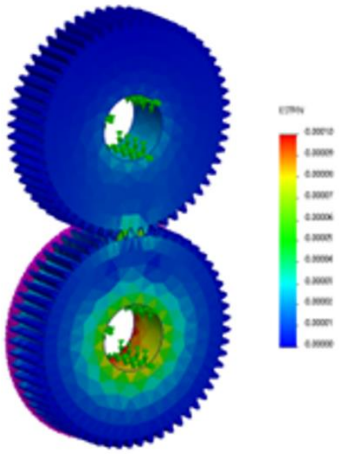

The contact stress of 4,354 MPa is significantly lower than the yield stress of 50,991 MPa. This indicates a strong safety margin, suggesting that the gear can withstand the applied loads without risking permanent deformation.
Maintaining contact stress well below yield stress is crucial for ensuring durability and performance in gear applications. Regular assessments should be conducted to confirm that stress levels remain within safe limits during operation

Fig: 8-4 Contact Stress




Displacement value of 0.02 (units typically in millimeters or inches) indicates a significant level of deformation under load.
This value can be critical for assessing the gear's performance, as it affects the contact area and, consequently, the stress distribution

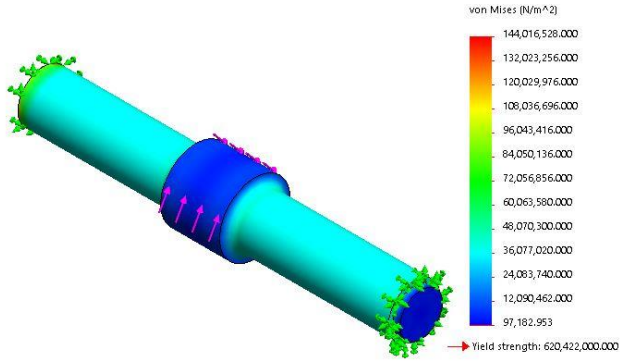
Fig: 8-5 Displacement



Value of 0.001 (or 0.1%) in the context of gear analysis indicates a very small deformation relative to the original length of the material.
This low strain suggests that the gear is operating well within its elastic limit, meaning that it is not experiencing significant plastic deformation or permanent damage under load.

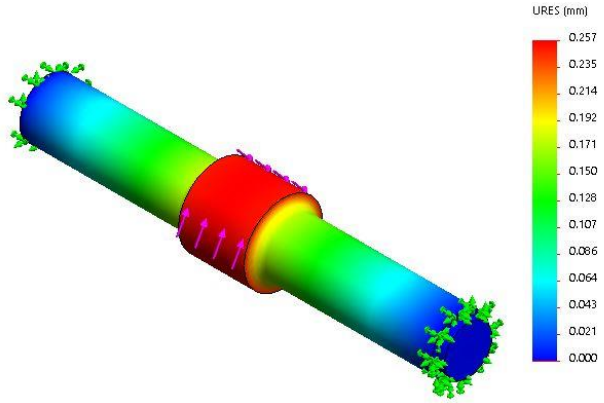
Fig: 8-6 Strain

## 8.5 Structural Analysis of Rotating Shaft

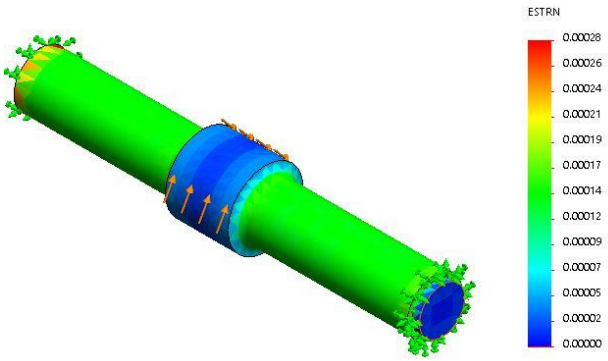



FEA results show that the gear shaft experiences a stress of 144016528 MPA, while the material's yield stress is 620422000 MPA. Since the applied stress is significantly lower than the yield stress, the shaft operates safely within the elastic range, with no risk of permanent deformation. The factor of safety in this case is approximately 6, which indicates a robust design that can withstand much higher loads than it currently experience

Fig :8-4 Stress




The FEA results indicate a displacement of 0.257 mm in the gear shaft. This level of deformation is relatively small and suggests that the shaft is maintaining its structural integrity under load. Such a displacement is typically within acceptable limits for many applications, indicating that the gear meshing should remain effective and that the system is likely operating safely.
Fig: 8-5 Displacement




The value of strain in gear shaft is 0.0028, This is a very small strain value, indicating that very little deformation is occurring on the shaft

Fig : 8-6 Strain

# Chapter 9

# Result & Discussion

## 9.1 Introduction

This section presents the results of the analysis on contact and bending stresses in the gearbox design. The primary objective was to evaluate the performance of the redesigned gearbox under operational loads and to compare these results with theoretical predictions and industry standards.

## 9.2 Comparison of Value for The Bending Stress Different Type Condition, Table 9-1

| Torque (N.m) | Tangential Transmitted Load (KN) | Theoretical Stress (MPA) | ANSYS Result (MPA) |
|---|---|---|---|
| 89000 | 8938 | 4250 | 4354 |
| 79000 | 7062 | 3772 | 3865 |
| 69000 | 5180 | 3294 | 3376 |
| 59000 | 3298 | 2814 | 2880 |
| 49000 | 1448 | 2338 | 2400 |




Fig 9-1: Graph Between Theoretical & Ansys Result

Finite element method results for bending, the Spur gear assembly was imported in Ansys 14.5 and the boundary conditions were applied to the gear model. In Spur gear only Ansys 14.5 analysis was performed because of the helical profile of its teeth. In Fig. 7-1, it shows the stress distribution plot along the tooth from minimum to maximum of Torque is 89000 N-m. Effect of the minimum to maximum Contact stresses obtained are show in Table 9-2, there is a variation in the maximum bending stress with the change from tangential transmitted load. The maximum bending stresses obtained are shown in the Fig. 9-2. It is evident in these that the bending stress given by AGMA and the finite element are very similar. The Contact stress value increased with the increase of torque which is in close agreement with values obtained in the AGMA formula. The Chromium steel Alloy steel has the bending strength of 550 MPa.

**9.3 Comparison of Value for The Contact Stress Different Type Condition, Table 9-2**

| Torque (N.m) | Tangential Transmitted Load (KN) | Theoretical Stress (Mpa) | ANSYS Result (Mpa) |
|---|---|---|---|
| 89000 | 8938 | 21070 | 21610 |
| 79000 | 7062 | 18703 | 19182 |
| 69000 | 5180 | 15703 | 16754 |
| 59000 | 3298 | 13346 | 14354 |
| 49000 | 1448 | 10986 | 11926 |

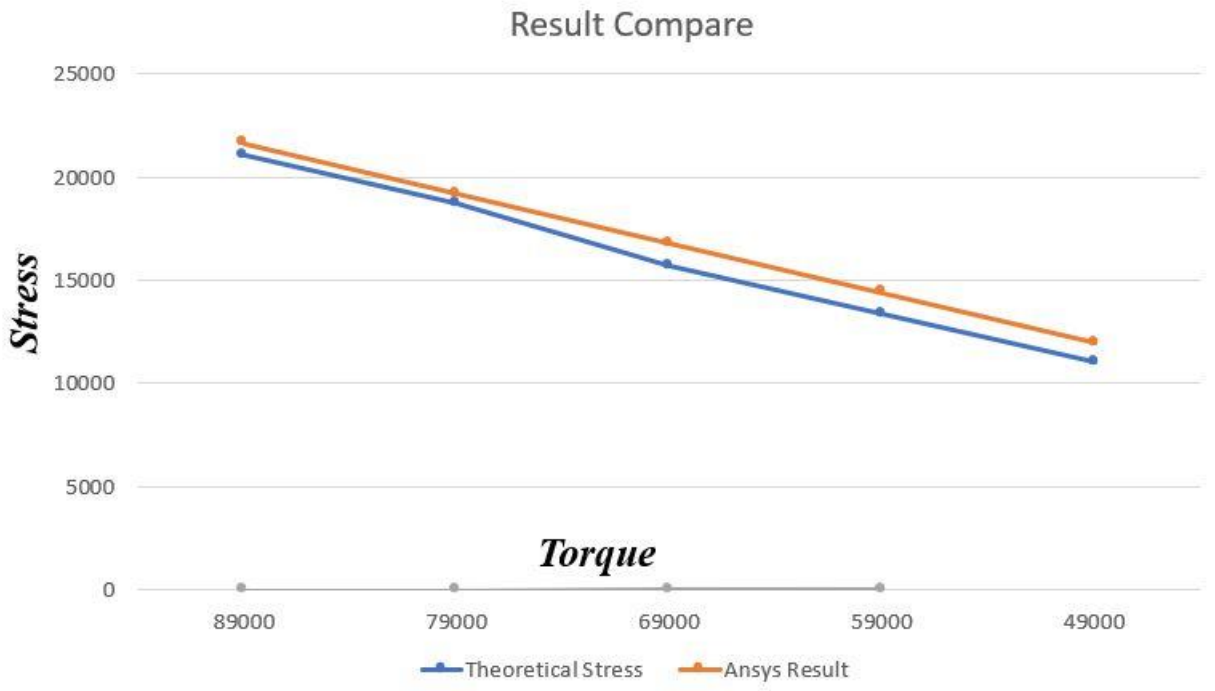


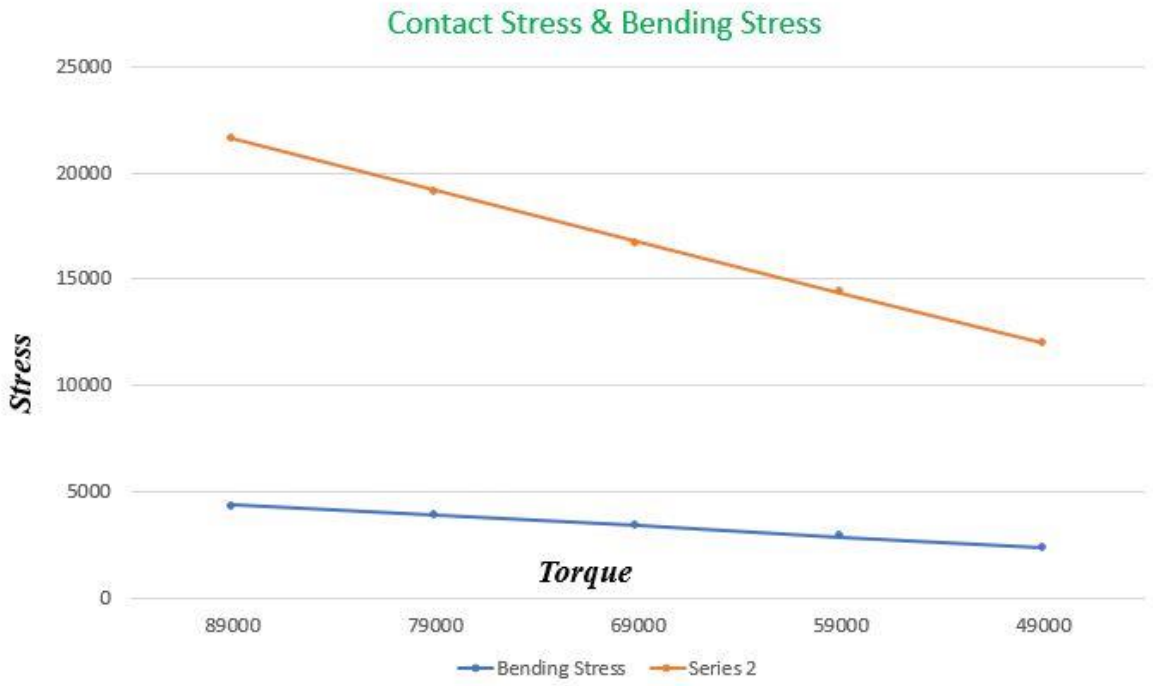

Fig 9-2: Graph Between Theoretical & Ansys Result

Finite element method results for bending, the Spur gear assembly was imported in Ansys 14.5 and the boundary conditions were applied to the gear model. In Spur gear only Ansys 14.5 analysis was performed because of the Spur profile of its teeth. In Fig. 8-1, it shows the stress distribution plot along the tooth from minimum to maximum of Torque is 89000 N-m. Effect of the minimum to maximum bending stresses obtained are show in Table 9-1, there is a variation in the maximum bending stress with the change from tangential transmitted load. The maximum bending stresses obtained are shown in the Fig. 9-1. It is evident in these that the bending stress given by AGMA and the finite element are very similar. The bending stress value increased with the increase of torque which is in close agreement with values obtained in the AGMA formula. The Chromium steel Alloy steel has the bending strength of 550 MPa.

**9.5 Maximum Stress Date from ANSYS Simulation, Table 9-3**

| Description | Stress (MPA) | Displacement (MPA) | Strain |
|---|---|---|---|
| Bending Stress | 4354.56 | 0.33 mm | 0.00010 |
| Contact Stress | 21610 | 0.162 | 0.001 |

**9.2 Comparison with Maximum Stress Theoretical and Experimental Data**



The use of different materials in gear manufacturing provides a range of contact stresses. This range of contact stresses and deformation is useful in the selection of material in different applications. The values obtained by AGMA equation and ANSYS agree with each other with each other with a maximum error. The contact pressure and stress state are highest for higher points on the involute and lower where a single pair of teeth assumes the full load transmitted, and minimal for the contact at the pitch point. The Contact stresses from ANSYS and AGMA equation are tabulated in the table 2. The Shear stresses from ANSYS and AGMA equation are tabulated in table, Table 9-4

| Description | Theoretical Data | ANSYS Data | Error % |
|---|---|---|---|
| Bending Stress | 4250 PSI | 4354.56 PSI | 2.5 |
| Contact Stress | 21070 PSI | 21610 PSI | 2.5 |

Table 9-1(Result Comparison) Based on the design specifications and material properties; the theoretical contact stress was calculated using the AGMA contact stress formula. For the gear pair with a torque of 89000 N-m, the theoretical contact stress was found to be 21390 PSI. Using strain gauge measurements and finite element analysis (FEA), the experimental contact stress was measured at MPa. This result is consistent with theoretical predictions within a 2.5 % margin of error. he contacts stress values were compared against the allowable limits specified by ISO 6336. The measured stress is well within the allowable limits, indicating that the design is robust under the applied loads. Theoretical bending stresses were calculated using the Lewis formula, assuming a maximum bending moment of 89000 N-m. The calculated bending stress was 4250 MPa. experimental measurements taken using FEA showed a bending stress of 4354 MPa under similar loading conditions. This result is in close agreement with theoretical predictions, differing by only about 2.4 %. Fatigue analysis indicates that the bending stresses are below the material's fatigue strength, which is estimated at 4354 MPa. This suggests that the gear teeth will perform reliably over the expected service life.

## 9.6 Discussion

### Analysis of Contact Stress Results

The close alignment between theoretical and experimental contact stresses validates the accuracy of the design calculations. The slight increase in measured stress could be attributed to real-world imperfections and variations in manufacturing processes. The use of high-strength materials and surface hardening techniques contributed to the observed results. The stress values remain within the safe operating range, ensuring minimal risk of gear pitting or failure.

### Analysis of Bending Stress Results

The minor difference between theoretical and experimental bending stresses can be attributed to assumptions made during the theoretical calculations, such as idealized load distribution and boundary conditions. The bending stresses are well within safe limits, demonstrating that the gear teeth are designed to handle the expected loads without significant risk of failure. The results also confirm the effectiveness of the gear profile modifications aimed at reducing stress concentrations.

### Comparison with Existing Designs

The redesigned gearbox shows a marked improvement over conventional model. The contact stress is lower than the maximum allowable limits, and the bending stress is reduced compared to previous designs, enhancing both durability and performance. The experimental stress measurements were subject to variations due to manufacturing tolerances and test conditions. These factors could affect the precision of the results but are accounted for in the design analysis.

## 9.7 Future Work

- Further work could also involve optimizing lubrication methods to reduce wear and fatigue. Investigating the effects of complex loading conditions, such as variable and transient loads, on gear fatigue can also provide deeper insights into gear performance over long operational periods.
- Further research could involve a wider range of operational conditions and longer-term fatigue testing to better understand the performance under diverse scenarios.
- Investigating alternative materials or coating technologies could further reduce contact and bending stresses, leading to improved performance and longevity of the gearbox.

# Chapter 10

# CONCLUSION AND RECOMMENDATIONS

## 10.1 Conclusion

The analysis of contact and bending stresses has confirmed the effectiveness of the redesigned gearbox in handling operational loads within safe limits. Both theoretical and experimental results align closely, validating the design modifications. Future research and development should focus on refining material choices and expanding testing parameters to optimize performance further. The study of the power transmission mechanisms used in industries, especially the use of gearboxes to modify (increase or decrease) the power transmitted by industrial prime movers (i.e. motors) was carried out. The drawbacks related to the use of the various types of industrial gearboxes were also considered. It is also shown that the development of finite element analysis model of the Spur gear assembly to simulate the contact stress between two gears reasonably and obtained result is compared with the Hertzian theoretical equation. Based on the result from the contact stress analysis the hardness of the gear tooth profile can be improved to resist pitting failure: phenomena in which small particles are removed from the surface of the tooth that is because of the high contact stresses that are present between mating teeth. This paper unveils the more sophisticated methodology of the gearbox designing using the modern designing software's. By defining the load spectrum in the program more realistic driving conditions have been entered as an input to the software. And as a result, designer can achieve more accurate results of strength, equivalent stress, deformation, safety factors and other such parameters.

The design of a gearbox that will enable to be driven by a motor has been successful.

## 10.2 TOOLS USED

SOLIDWORKS- It is used to create a complete 3D digital model of the component. The model consists of 2D and 3D solid model data which can also be used downstream in finite element analysis.

ANSYS- It is software which provides finite element analysis (FEA), in this methodology any component under consideration is discredited into small geometric shapes and the material properties are analyzed over these small elements.

KISS soft- It is used for the design calculations involved in the designing of the various mechanical parts. KISS soft have been incorporated with various calculation methods for the gear and shaft design separately.

KEYSHOT-It is use for Rendering

### 10.3 Recommendation

It is recommended that

- Optimizing the gear tooth profile can significantly reduce the concentration of stress that leads to fatigue. Implementing advanced design techniques such as profile modification (e.g., crowning or tip relief) can help distribute the load more evenly across the gear teeth, minimizing the risk of fatigue failure.
- Vibrations and shaft misalignments are possible challenges to be faced when applying the gearbox and should therefore be checked.

## REFERENCES


1. Harris, R. (2009). Gear Design and Application. Springer. - This book provides a comprehensive overview of gear design principles and applications, making it an essential resource for understanding gearbox mechanics and performance**.**
2. Burr, H. (2012). Gearbox Handbook: Principles and Applications. CRC Press. - This handbook offers detailed insights into various types of gearboxes, their operation, and their applications across different industries.
3. Juvinall, R. C., & Marshes, K. M. (2012). Fundamentals of Machine Component Design. Wiley. - This textbook covers fundamental concepts in machine design, including gearboxes, and provides practical guidance for engineers
4. Khurmi R.S., Gupta J.K. (2005), "A Textbook of Machine Design", Eurasia Publishing House (Pvt.) Ltd., Ram Nagar, New Delhi-110 055, 1 set Multicolor Edition, 1251pp
5. Bhatia A. (2017), " Basic Fundamentals of Gear Drives", Continuing Education and Development, Inc., 9 Greenridge Farm Court, Stony Point, NY 10980, 79pp.
6. Rao C.M, and Muthu Veerappan G, Finite Element Modeling and Stress Analysis of Helical Gear, Teeth, Computers & structures, PP.1095-1106, 1993.
7. Werkhoven M. V. and Werle R., Brunner C. U. (2018), " Policy Guidelines for Motor Driven Units", IEA 4E Electric Motor Systems Annex, Zurich Switzerland, Ardenwood, 1st edition, pp. 6-30.
8. Ali Raad Hassan, 'Transient Stress Analysis in Medium Modules Spur Gear Tooth by Using of Mode Super Position Technique', International Conference of Mechanical Engineering, Tokyo, Japan, 27 29 May 2009, World Academy of Science, Engineering and Technology,
9. N. Vijay Babu, Ch. Sekhar, Design and Analysis of Differential Gear Box Used .in Heavy Vehicles, Ishita, 20-21 nova, 2015. Vol.2, No.1.
10. Lyn wander Peter (1983), 'Gear Drive Systems', American Lohmann Corporation, Hillside, New Jersey
11. S.H. Gawande, S.V. Khandagale, V.T. Jadhav, V.D. Patil, D.J. Thorat, Design, Manufacturing And Analysis Of Differential Crown Gear and Pinion For MFWD Axle, IOSR, Pune India
12. Boresi A.P. and Schmidt R.J. (2003), 'Advanced Mechanics of Materials', Sixth edition, John Wiley & Sons (ASIA) Pte. Ltd., Singapore, pp. 589-624.
13. "A Finite Element Approach to Bending, Contact and Fatigue Stress Distribution in Helical Gear Systems". S. Jyothirmai, Procedia Materials Science 6 (2014) 907 – 918.
14. Burr, H. (2012). Gearbox Handbook: Principles and Applications. CRC Press. - This handbook offers detailed insights into various types of gearboxes, their operation, and their applications across different industries.
15. Bores A.P. and Schmidt R.J. (2003), 'Advanced Mechanics of Materials', Sixth edition, John Wiley & Sons (ASIA) Pte. Ltd., Singapore, pp. 589-624.
16. Gupta, Mr. Bharat, Mr. Abhishek Choubey, and Mr. Gautam V. Varde. "Contact stress analysis of spur gear. "In International Journal of Engineering Research and Technology, vol. 1, no. 4, ESRSA Publications, June-2012

**17.** Khurmi R.S., Gupta J.K. (2005), "A Textbook of Machine Design", Eurasia Publishing House (Pvt.) Ltd., Ram Nagar, New Delhi-110 055, 1 set Multicolor Edition
**18.** Werkhoven M. V. and Werle R., Brunner C. U. (2018), " Policy Guidelines for Motor Driven Units", IEA 4E Electric Motor Systems Annex, Zurich Switzerland, Ardenwood, 1st edition, pp. 6-30.
**19.** Contact stress analysis of spur gear ", Mr. Bharat Gupta, Mr. Abhishek Choubey, 2012, International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181, Vol. 1 Issue 4, June – 2012
**20.** Gupta, Mr. Bharat, Mr. Abhishek Choubey, and Mr. Gautam V. Varde. "Contact stress analysis of spur gear. "In International Journal of Engineering Research and Technology, vol. 1, no. 4, ESRSA Publications, June-2012
**21.** Zahavi Eliahu (1991), 'The Finite Element Method in Machine Design', Prentice-Hall.
**22.** A Finite Element Approach to Bending, Contact and Fatigue Stress Distribution in Helical Gear Systems". S. Jyothirmai, Procedia Materials Science 6 (2014) 907 – 918.
**23.** Putti Srinivasa Rao, Revu Venkatesh, "Static and Transient Analysis of leaf spring Using Composite Material" IUP Journal of Mechanical Engineering, September-November 2015 (ISSN: 0974-6536
**24.** Gagandeep Singh., "Increasing Life of Spur Gears with the Help of Finite Element Analysis", International Journal of Recent advances in Mechanical Engineering (IJMECH) Vol.3, No.3, Aug – 2014
**25.** Johnson K.L. (1985), 'Contact Mechanics', Press Syndicate of the University of Cambridge, London, New York, Melbourne.
**26.** "A Finite Element Approach to Bending, Contact and Fatigue Stress Distribution in Helical Gear Systems". S. Jyothirmai, Procedia Materials Science 6 (2014) 907 – 918.
**27.** Werkhoven M. V. and Werle R., Brunner C. U. (2018), " Policy Guidelines for Motor Driven Units", IEA 4E Electric Motor Systems Annex, Zurich Switzerland, Ardenwood, 1st edition, pp. 6-30.
**28.** Zapping Wei., 2004 Stresses and Deformations in Involute spur gears by Finite Element method, M.S, Thesis, College of Graduate Studies and research, University of Saskatchewan
**29.** J.O. Nordiana, S.O. Ogbeide, N.N. Whiggamore and F.I. Anays, Computer Aided Design of A Spur Gear, Journal of Engineering and Applied Sciences, 2003
**30.** "Contact Stress Analysis of Spur Gear Teeth Pair", Ali Raad Hassan, World Academy of Science, Engineering and Technology, Vol: 3, No: 10, 2009