Design and Analysis of Spur Gear, Helical Gear and Bevel Gear by using Ansys

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Submitted by

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APPROVAL SHEET

This thesis entitled **Design and Analysis of Spur Gear, Helical Gear and Bevel Gear by using ANSYS** by **SWAPNIL KUMAR** & **ANUJ KUMAR SINGH is** approved for the degree of Bachelor of Technology in Mechanical Engineering.

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Abstract

The total deformation and stress generation are taken into consideration because the more the stress is developed high the chance of fatigue failure of gears while designing the gears. Gears fail due to many reasons some are friction, crack generation, or some defect during manufacturing, all these ultimately lead to fatigue of gear. In this paper, the equivalent stress and total deformation are analyzed in three different gears namely Spur gears, Bevel gears, and Helical gears which are of structural steel. A comparative study has been done between these gears considering the same parameters. The selected gears have a 6m module, 30 teeth in gear, and 15 teeth in pinion. Under the torque of 1715 Nm, the three gears are analyzed. From the results, the minimum deformation is experienced by the helical gears of value 0.000030062 m and maximum in case of bevel gears that is of 0.0013472m. And in the case of stress analysis, the bevel gears show the maximum formation of stress near teeth 2.2088*e9 Pa which is nearly the same as in spur gears. The helical gears show the least stress formation among these three gears. So, better results are obtained for helical gears in both the analysis.

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CHAPTER - 1

INTRODUCTION

1.1 Preface

Gears are solely used for power/motion transfer in any apparatus from one part to another part in an apparatus. They are like a disk chipped at its outer periphery like teeth. Power transmission is the prime application of a gear pair or simply a gear when they are built up on rotating shaft. Spur gears, helical gears, bevel gears are some of the different types of gears. A further classification into these categories of gears gives spur gear, single helical, double helical, straight bevel, spiral bevel. Usually a set of gears which is a pair for most of the time performs the task for power transmission when they are locked internally with each other, this is called a gear set, the smaller gear is usually called a "pinion" where the larger gear can be called as a "gear" or "wheel" and the position in which their teeth are coupled or linked are called a mesh.

The performance of gears are measured or somewhat depend on significantly important criteria's which are pure rolling and uniform motion, low weight and high speed and high efficiency.

1.2 Classification of gears

Gears are classified into different types according to the orientation of gear tooth against the face width of gear and their direction with respect to the longitudinal axis of the gear.

They are as follows –

1. Spur gear
2. Helical gear
3. Bevel gear
4. Worm gear.

- Spur gear – “Spur gears or straight-cut gears are the simplest type of gears. They consist of a cylinder or a disk with teeth projecting radially. The edge of each tooth is straight and is aligned parallel to the axis of rotation”. [1] The tooth of a spur gear are projected in a radial direction to the centre of the face of the gear or centre of the base circle of gear and always parallel to the axis of the shaft on which the gear is mounted. Each teeth is located on the basic circle of the gear where each point on the circumference is away from the central axis by the same perpendicular distance. These gears mesh together correctly only if fitted to parallel shafts. “Spur gears are excellent at moderate speeds but tend to be noisy at high speeds”. [1]

There are two types of spur gear on the basis of the direction of the tooth face whether it is pointing towards/away from the axis of the shaft.

Internal spur gear - When the direction of tip is towards the central axis of the shaft, the gear is called a internal spur gear.

External spur gear - When the direction of tip is pointing away from the central axis of the shaft, the gear is called a external spur gear.

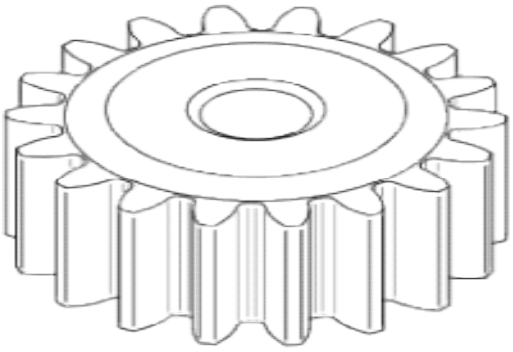

Fig 1.1 - A spur gear

Fig 1.2 - A spur gear and spur pinion in mesh

2. Helical gear – Helical or “dry fixed” gears provides some refinement over a spur gear; The leading edges of the teeth are nonparallel to the axis of rotation, but are set at any arbitrary angle, helical gears can be meshed in parallel or crossed orientations, The former is the most common orientation for helical gears. [1]

In the latter, the shafts are non-parallel, and in this configuration the gears are sometimes known as "skew gears", With parallel helical gears, every pair of teeth initially makes contact at a single point at one side of the gear wheel; a moving curve of contact then grows gradually across the tooth face to a maximum, then deceases until the teeth break contact at a single point on the counter side, In spur gears, teeth abruptly meet at a line contact across their entire width, causing stress and noise. Spur gears make characteristic noise at high speeds, however, this matter can be turned into a leverage when using a double helical gear, which has no axial thrust - and also provides self-aligning of the gears; This ends in less axial thrust than a comparable spur gear. [1]

Fig 1.3 - Helical gears, Top - parallel configuration; bottom - Crossed configuration

3. Bevel Gear – “Bevel gears are the highest efficient means of transmitting rotation between angularly disposed shafts”. [2] There are different types of bevel gears. The straight bevel gears and spiral bevel gears are widely used for nonparallel shafts, “A bevel gear is carved like a right circular cone with most of its tip cut off.; when two bevel gears mesh, their imaginary vertices must attain the same point”. [1] The same point is also the intersecting point of the shaft axes, making a random non-straight angle between the shafts, “The angle between the shafts can be anything except zero or 180 degrees”. [1]

Fig 1.4 – A bevel gear

1.3 Gear Nomenclature

1.3.1 General

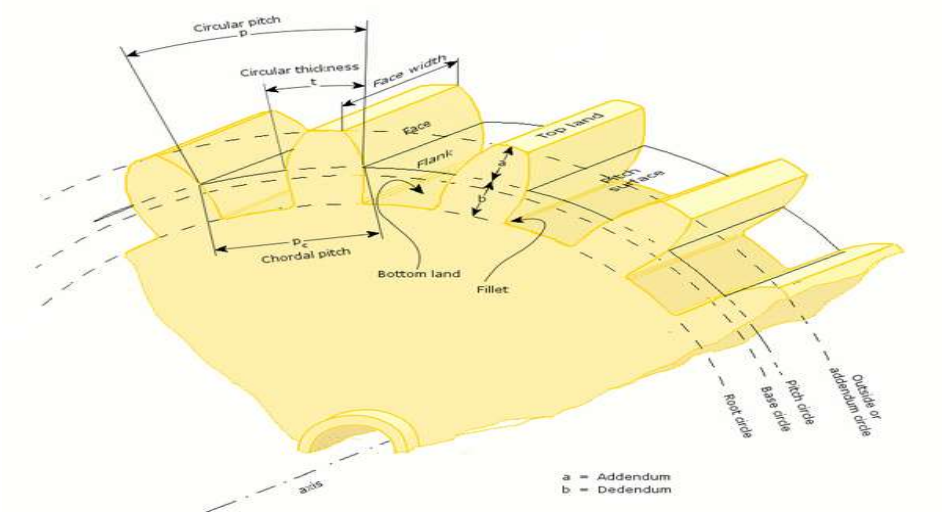

Figure 1.5 - A schematic diagram of a part of a gear

1. "Gear, wheel – The larger of the two interacting gear or a gear on its own,
2. Pinion – The smaller of the two interacting gear,
3. Path of contact – The Path followed by point of contact between two meshing gear teeth,
4. Axis – Axis of revolution of the gear, centre line of the shaft,
5. Pitch point - Point where the line of action crosses a line joining the two gear axes,
6. Pitch circle - Circle centered on and perpendicular to the axis, and passing through the pitch point,
7. Pressure angle - The complement of the angle between the direction that the teeth exert force on each other, and the line joining the centers of the two gears,
8. Root diameter - Diameter of the gear, measured at the base of the tooth,
9. Addendum, a - Radial distance from the pitch surface to the outermost point of the tooth,

10. Dedendum, b - Radial distance from the depth of the tooth trough to the pitch surface,
11. Circular pitch, p - Distance from one face of a tooth to the corresponding face of an adjacent tooth on the same gear measured along the pitch circle,
12. Base circle - In involute gears, the tooth profile is generated by the involute of the base circle; The radius of the base circle is somewhat smaller than that of the pitch circle,
13. Base pitch, normal pitch - In involute gears, distance from one face of a tooth to the corresponding face of an adjacent tooth on the same gear, measured along the base circle". [1]

1.4 Project Background

Gears are the mechanical component used to transmit power to the system. It's a rotating element having many cut tooth known as teeth, these teeth mesh with teeth of another gear to transmit power and torque. Gears are used in a variety of apparatus, some tiny as a wristwatch to heavy machines like automobiles, the aircrafts and many components in the aerospace industry, marine and many more. Furthermore, there is a huge rising demand for enhancement in gear design.

Although gears are simple but designing gear is a more complex and complicated task, which is done by engineers. The vibration and noise produced by the gear affects the transmission of power between shafts.

For several years, several measures are adopted to minimize these effects and strengthen the service lifetime of gears like heat treatment or adjusting micro geometry. The main aim of design improvement is to increase the life of components. Fatigue occurs in components fail the machine and can sometimes be led to an accident. Fatigue is generally understood as the breaking of material due to constant cyclic or continuous loads. The fatigue starts when there are some impurities in the structure of manufacturing defects or near fillet sections, initial a small crack is developed will eventually become bigger and bigger over time. [3], [4]

The aim of this paper to design and analysis of the spur gear, bevel gear, and helical gear in solid works and compare the results using different methods in ANSYS.

Basically, by design we mean modeling of these gears of given dimensions and properties and the comparison of the values for the output parameters for these gears where the value of the input parameters remains the same.

For many years gears are being studied by the designer to understand the precision and to reduce the error in power transmission. ISO, DIN, AGMA are some of the standards followed in the industry to develop gears. These standards are made by taking special care in factor of safety, that's why they provide high safety towards any accident. ANSYS is the most widely used software in industries for analysis, but there are many software that can be used.

1.5 Area of Application & Utilities of gears

Aeronautics, mining and manufacturing chains in the automotive sector, medicine and drug industry, textiles the fields in which you can find machines that use different types of gears are abundant. [5]

Gears, whose basic operation is based on the coupling between a crown and a pinion as sprockets, are manufactured in various materials and with various tooth widths, face width, head circumference and circular pitch.

1.5.1 Gear types for different applications

1. "Internal or Ring Gears - They are similar to spur gears, although their teeth are not ground on the outside, but on the inside of a wheel or rimmed ring. A pinion drives the inner gears and maintains the direction of angular velocity,
2. Planetary gears – They are also called epicyclic gears, it is a gear train in which a central gear has one or several external gears around it. They are commonly used for automobile transmissions,

3. Rack and Pinion – They are used in lathes to control the movement of longitudinal carriage; they do not have a transmission ratio, but a length ratio. In this case, it is referred to as the distance between axes, since the rack falls within the category of gears of infinite diameter". [5]

1.5.2 Utilities of gears

1. "Hydraulic Pump - It converts rotary mechanical energy into hydraulic energy; It consists of a pair of coupled gears and has the driven shaft and the driver, which is driven by the motor shaft; This one, due to the displacement caused by the contact between the teeth of the gears, rotates the driven shaft;
2. Speed Reducer - They use circular and toothed gear pairs to lower the motor speed efficiently and safely, In addition, they use gears with very different diameters to reduce the speed of rotation;

3. Differential – They are widely used in the automotive sector, it makes it easier for the two driving wheels of a vehicle to turn at different speeds than the others; A differential is made up of two planetary gears attached to the ends of the semi-axles of the wheels, and two other satellites or conical pinions located at the ends of their satellite-carrying axle".[5]

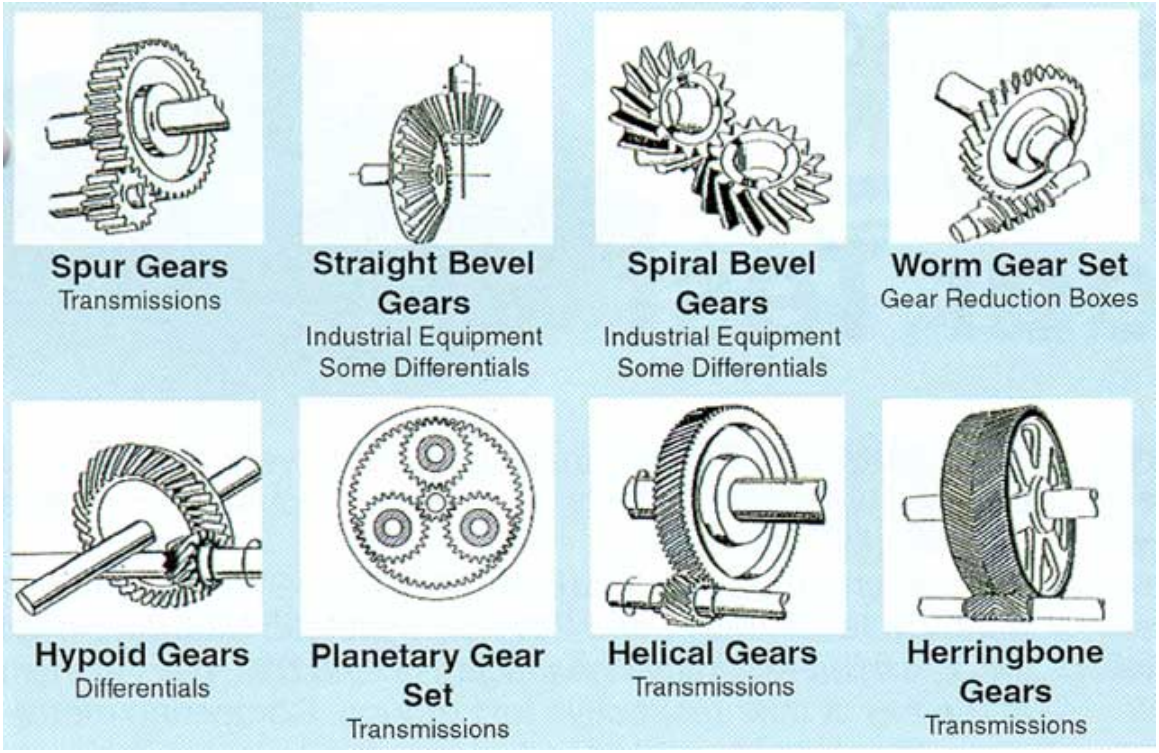

Fig 1.6 - Different types of gears with their applications

1.6 Material Selection for gears

Numerous non-ferrous alloys, cast iron alloys and powder-metallurgy and plastics are used in the production of gears. However steels are most commonly used because of high strength to weight ratio and low cost. Plastic is commonly used where cost or weight is a concern. “A properly designed plastic gear can replace steel gear in many places because it has many desirable properties, including dirt tolerance, low speed meshing, and the ability to be made with materials that don't need additional lubrication, the ability to "skip" quite well”. [1]

“Manufacturers have used plastic gears to lower down the cost in consumer entities including copy machines, optical storage devices, cheap dynamos, consumer audio equipment, servo motors, and printers; Another advantage of the use of plastics, formerly

(such as in the 1980s), was the reduction of repair costs for certain expensive machines. In cases of severe jamming (as of the paper in a printer), the plastic gear teeth would be torn free of their substrate, allowing the drive mechanism to then spin freely (instead of damaging itself by straining against the jam), This use of "sacrificial" gear teeth avoided destroying the much more expensive motor and related parts. This method has been superseded, in more recent designs, by the use of clutches and torque- or current-limited motors". [1]

1.7 Failure theory for gears

There are various ways through which the failure of a gear can be possible. Yet the only sign of a gear's failure is the noise level and vibration. Unlike different mechanical components, the failure can only be acknowledged when the part has broken completely.

The most probable failure zone of a gear is the region near its leading edge of the tooth or its tip. Still the strength and durability of material and the gear structure must be taken into account while analyzing theory of failure of a gear.

There are five common failure modes -

- "Bending fatigue - Bending fatigue failure is the result of cyclic bending stress at the tooth root,
- Pitting - Pitting or macro-pitting is a type of surface damage from cyclic contact stress transmitted through a lubrication film that is in or near the elasto-hydrodynamic regime. Pitting is one of the most common causes of gear failure,
- Micro-pitting – Micro-pitting is the formation of small craters on the tooth surface, often in the region of negative sliding below the pitch line,
- Scuffing - Scuffing, also termed "scoring" (incorrect according to gear standards), is a severe type of adhesive wear which instantly damages tooth surfaces that are in relative motion,
- Wear - Wear is a continuous, abrasive process of material removal from mating gear teeth that happens with or without abrasive particles in the oil".

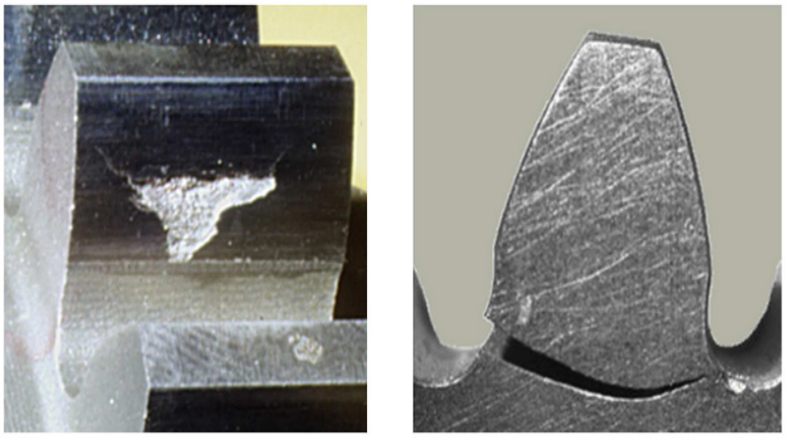

Fig 1.7 - Typical surface gear failure examples – pitting (left) and tooth root breakage (right)

Fig 1.8 - Traditional Failure modes for gears

CHAPTER – 2

LITERATURE REVIEW

2.1 Introduction

This literature review comprises of excerpts from published papers which provides some deep and detailed insights into the field of materials science of engineering in context of advancement in gear performance by development in gear design methods. Since, our project includes the comparison of three gear types which are spur gear, helical gear and bevel gear. The introduction to this chapter and this chapter will include the theoretical papers published related to these gears during previous decades

1. The simplest and most widely used gear for a power transmission system is spur gear. Apparently, most of the times a spur gear is subjected to bending stress which becomes the reason for teeth failure. However, the efficiency of spur gear in certain applications is quite limited and unsatisfactory. Therefore, there births a need for improvement for alternative materials for spur gear. Composite materials provide sufficient strength added with weight reduction, In this work, A metallic gear of Alloy Steel is replaced by the composite gear of 30% Glass filled Poly-ether-ether- ketone (PEEK). Such Composites material provides much improved mechanical properties such as better strength to weight ratio, more hardness, and hence less chances of failure. [6]
2. A gearbox is a collection of mechanical components which is deliver maximum power from the engine by managing various gear ratios that in turn operates a transmission. In this paper, the analysis of characteristics of spur gears is done using finite element method. This project is focused to carry out design and analysis of two stage spur planetary gearbox2P17. [7]

3. In this project, an attempt was made to design, model and do the finite element analysis of spur gear using composite material. Conventional spur gears are made of cast iron and mild steel only. An alternative of these two conventional gear materials could be composite materials which could provide fine performance with weight reduction, less rust formation and maintenance. The modeling of spur gear was done on solidworks and finite element analysis is done in ansys. Based on the analysis results it is suggested that short carbon reinforced (SCF) nylon to be used in place of cast iron or mild steel for limited load applications under 1500 watts. [8]
4. Engineering components made of composite materials are finding increasing applications in the field of spacecraft to miniaturized instruments. It is highly appreciable that gears are going the most effective and the first option for power transmission in future machines due to high degree of reliability and compactness in the design and structure of components. The main objective of this work was to perform the stress analysis of spur gear for different materials in ansys software.
   "A review has been taken for case-I purpose is to design the spur gear and study the weight reduction and stress distribution for cast steel and composite materials and results are observed. And in case-II Static analysis is performed to determine the deformation and Von-mises stresses. Analysis is done by considering different materials for gears like Structural Steel, Gray Cast Iron, Aluminium Alloy and Epoxy E Glass UD, and results are compared". [9]

5. The potential applications of hybrid composite materials in aerospace and automotive space are very high. Hybrid composite materials are a type of composite material made up of more than single reinforcement fibers. So we can gather that even composite materials have high variety in properties and strength to weight ratio and several others. The scope of potential applications of composite materials grows by the day. Owing to their high strength to weight ratio and temperature resistance, they might be the dominant material used in many other fields of engineering as well. The widespread adoption of particulate metal matrix composites for engineering applications has been hindered by the high cost of producing components."Achieving a uniform

distribution of reinforcement within the matrix is one such challenge, which affects directly on the properties and quality of composite material, This paper discuss the Spur Gear model made by Aluminium wire and palm,e-glass fiber composite material and to evaluate the Hardness, Impact Strength of the Composite Material". [10]

2.2 Review of papers

2.2.1 MODELING AND STRESS ANALYSIS OF COMPOSITE MATERIAL FOR SPUR GEAR UNDER STATIC LOADING CONDITION

"The purpose of the paper is to examine the load capacity of PC/ABS spur gears and investigation of gear damage. Further in this study usability of PC/ABS composite plastic material as spur gear was investigated and was defined that PC/ABS gears were tested by applying three different loading at two different numbers of revolutions on the FZG experiment set. The experiment result summarized that the usage of PC/ABS materials brings an advantage in many industrial area because such materials are durable against flame, air, ultraviolet lights and holding lower moister than PA66 GFR 30 materials. The other result of this study was that good operating conditions are comprised at low numbers of revolution and the tooth loads. Further the suitable environmental condition must be revolutions and the tooth load for gears. PC/ABS gear should be preferred at low tooth and unwanted high power transmission". [11]

"This paper describes design and analysis of spur gear and it is proposed to substitute the metallic gears of sugarcane juice machine with polymer gears to reduce the weight and noise, A virtual model of spur gear was created in PRO-E, Model is imported in ANSYS 10.0 for analysis by applying normal load condition, The main purpose of this paper to analysis the different polymer gears namely nylon, polycarbonate and their viability checked with counterpart metallic gear like as cast iron. Concluding the study using the FEA methodology, it can be proved that the composite gears, if well designed and analyzed, will give the useful properties like as a low cost, noise, Weight, vibration and

perform its operation similar to the metallic gears; Based on the static analysis Nylon gear are suitable for the application of sugarcane juice machine under limited load condition in comparison with cast iron spur gears". [12]

This paper presents the stress analysis of mating teeth of the spur gear to find maximum contact stress in the gear tooth , The results obtained from finite element analysis are compared with theoretical Hertz equation values, The spur gear are modeled and assembled in ANSYS DESIGN MODELER and stress analysis of Spur gear tooth is done by the ANSYS 14.5 software, It was found that the results from both Hertz equation and Finite Element Analysis are comparable, From the deformation pattern of steel and grey cast iron, it could be concluded that difference between the maximum values of steel and grey CI gear deformation is very less. [13]

2.2.2 A REVIEW ON ANALYSIS OF SPUR GEAR IN TWO STAGE PLANETARY GEARBOX USING FINITE ELEMENT APPROACH

"Yi Guo and Robert G. Parker worked on study of the nonlinear tooth wedging behavior and its correlation with planet bearing forces by analyzing the dynamic response of an example planetary gear, The results show significant impact of tooth wedging on planet bearing forces for a wide range of operating speed; To develop a physical understanding of the tooth wedging mechanism, connections between planet bearing forces and tooth forces are studied by investigating physical forces and displacements acting throughout the planetary gear; A method to predict tooth wedging based on geometric interactions is developed and verified, The major causes of tooth wedging relate directly to translational vibrations caused by gravity forces and the presence of clearance-type nonlinearities in the form of backlash and bearing clearance". [14]

"Zhipeng Feng had studied Fault diagnosis of planetary gearboxes. They proposed a simple yet effective method to diagnose planetary gearbox faults based on amplitude and frequency demodulations, They use the energy separation algorithm to estimate the amplitude envelope and instantaneous frequency of modulated signals for further demodulation analysis, by exploiting the adaptability of Teager energy operator to

instantaneous changes in signals and the fine time resolution; With the proposed method, both the wear and chipping faults can be detected and located for a sun gear of the planetary gearbox test rig". [15]

"A. Kahraman had a main objective of study is to investigate the dynamic effects on gear stresses as a function of gear rim thickness parameters and the number of planets in the system, A deformable body dynamic model is used to simulate a typical automotive automatic transmission planetary unit, A new rim thickness parameter will be introduced that takes into account the size of the gears; The model will be used to quantify the impact of the gear rim flexibilities on dynamic gear stresses, The relationship between the bending modes of the gears and the number of planets in the system is also demonstrated quantitatively". [16]

"Chien-Hsing Li worked on batch module called integration of finite element analysis and optimum design by taking gear systems as testing examples, A simple and practical method was developed, by which this module was enabled to search for contact nodes and elements and to automatically define the contact surfaces for contact analysis, The module will automatically construct the geometrical model, analyze contact stress and solve for the optimal solutions when gearing parameters are input; The results are expected to enhance the technology of gear system design". [17]

2.2.3 Finite element analysis of composite spur gear

"Zhong Hu & Mohammad Robiul Hossan: Strength Evaluation and Failure Prediction of Short Carbon Fiber Reinforced Nylon Spur Gears by Finite Element Modeling: In this paper, short carbon fiber reinforced nylon spur gear pairs, and steel and unreinforced nylon spur gear pairs have been selected for study and comparison; A 3D finite element model was developed to simulate the multi-axial stress–strain behaviors of the gear tooth, Failure prediction has been conducted based on the different failure criteria, including Tsai-Wu criterion; The tooth roots, where has stress concentration and the potential for failure, have been carefully investigated, The modeling results show that the short carbon fiber reinforced nylon gear fabricated by properly controlled injection molding processes can provide higher strength and better performance". [18]

“Stress Analysis of Composite Spur Gear: This paper investigates the static stress characteristics of an involute composite spur gear system including bending stresses and contact stresses of gears in mesh and comparing it with the existing involute cast iron spur gear system. The aim is to replace the cast iron spur gear with Carbon fiber epoxy composite spur gear due to its high strength, low weight and damping characteristics. A pair of involute spur gear is modeled in a CAD system (SOLIDWORKS) and FEA is done by using finite element software ANSYS 13. The bending stresses in the tooth root and contact stresses were examined using a 3-D FEM model. The bending stress obtained by finite element analysis method is compared with bending stress obtained by Lewis equation and the contact stress obtained by finite element analysis method is compared with contact stress obtained by Hertzian equation”. [19]

“Prashanth Banakar, H.K. Shivananda : Preparation and Characterization of the Carbon Fiber Reinforced Epoxy Resin Composites: The objective of this research was to gain a better understanding of Mechanical properties of epoxy resin composites reinforced with carbon fiber, The effect of fiber orientation of laminates has been investigated & experimentation was performed to determine property data for material specifications, the laminates were obtained by hand layup process; The laminates were cut to obtain ASTM standards, This investigation deals with the testing of tensile and flexural strength on a universal testing machine, The graphs that are obtained from the tests are documented. This research indicates that the mechanical properties are mainly dependent on the fiber orientation of laminated polymer composites”. [20]

“M. Nayeem Ahmed, Dr. P. Vijaya Kumar, Dr. H.K. Shivanand, Syed Basith Muzammil: A Study on Effect of Variation of Thickness on Tensile Properties of Hybrid Polymer Composites (Glass fiber – Carbon fiber – Graphite) and GFRP Composites: Increase in demand of advanced materials to satisfy the requirements of aerospace and automotive industry viz. high modulus to density ratio, leads to the research in composite materials where an attempt is made to study the properties of composite materials by composing the different materials together to obtain the desired properties by reducing the weight as much as possible; Here an attempt is made to study the behavior and tensile properties of Hybrid polymer composite material by composing E-glass fiber, carbon fibers and

graphite with epoxy resin 5052, By the variation of thickness, Tensile strength of hybrid composite is observed for each thickness and is optimized and compared with the properties of standalone glass fiber reinforced composites for the same variation of thickness, The comparison represents the enhancement of tensile strength and cost effectiveness by the introduction of multiple materials (Hybrid composites)". [21]

2.2.4 Stress Analysis of Spur Gear by using Different Materials: A Review

"M Jebran Khan et al. proposed, Finite Element Analysis is one such method which has been ex tensively used in analysis of components used in various mechanical systems, He reported the contact stress analysis of 14.5 degree full depth involute stainless steel spur gears during the transmission of power of 10kW by theoretical method using Hertz theory and by FEA using ANSYS Workbench 14.0.He concluded that FEA provides results that are comparable with theoretical analysis results as was in the contact stress analysis of spur gears in the present study, FEA can predict whether a product will break, wear out, or work the way it was designed; Hence, FEA can prove very helpful in the product development process by forecasting its behavior in operation". [22]

"Putti Srinivasa Rao studied that the contact stress in the mating gears is the key parameter in gear design , Deformation of the gear is also another key parameter which is to be considered. The study in this paper shows that the complex design problem of spur gear which requires fine software skill for modeling and also for analyzing, The project aims at the minimization of both contact stress as well as deformation to arrive at the best possible combination of driver and driven gear". [23]

"In this process of spur gears mating, 3 different materials were selected and the software program was performed for 9 different combinations to get the best result possible, 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 Hertz's equation and ANSYS agree with each other with each other with a maximum error of 4% which is acceptable, The lowest contact stress is recorded when aluminum is used as both driver as well as driven gear". [23]

"Bharat Gupta studied that the gear tooth failure takes place if contact stresses in the gear are higher than the wear strength of the gear, For research purpose selecting one spur gear train for contact stress analysis, The contact stress can calculate by analytical method using hertz's contact stress theory for different value of module, The contact stresses can also calculated by FEA method; The model of gear train is formed in the Pro-E software and imported in the ANSYS for calculates the contact stresses, The result found by two methods are compared and concluded that difference is within reasonable limit, He observed the result and concluded that maximum contact stress decreases with increasing module of gear, The contact stresses are higher at the pitch point of the gear". [24]

"Sachindra Kumar presented that Gears analysis in the past was performed using analytical methods, which required a number of assumptions and simplifications; In general, gear analyses are multidisciplinary, including calculations related to the tooth stresses and to tribological failures such as like wear, Designing highly loaded spur gears for power transmission systems that are both strong and quiet requires analysis methods that can easily be implemented and also provide information on contact and bending stresses, along with transmission errors, The finite element method is capable of providing this information; The finite element method is very often used to analyze the stress state of an elastic body with complicated geometry, such as a gear. The finite element method with special techniques, such as the incremental technique of applying the external load in the input file, the deformation of the stiffness matrix, and the introduction of the contact element were used; It was found that initial loading using displacements as inputs was helpful in reducing numerical instabilities". [25]

2.2.5 Design and analysis of spur gear by using palm fiber and e-glass composite material and evaluate the mechanical properties

"The history of natural fiber reinforced polymer composites can be traced back to the advent of synthetic polymers in the early twentieth century, In 1850s, shellac was compounded with wood flour, Research on natural fiber composites has existed since the early 19^{th} century but has not received much attention until late in the 1980's.During

1920s, 1930s and early 1940s, a good deal of research was carried out on natural fiber reinforced composites; Caldwell and Clay carried out their research work on natural fiber reinforced composites for lighter materials to be used in aircraft primary structures. Composites, primarily glass but including natural reinforced composites are found in countless consumer products like boats, agricultural machinery and cars, A major goal of natural fiber composites is to alleviate the need to use expensive glass fiber, which has a relatively high density and is dependent on non-renewable sources; Recently, car manufacturers have been interested in incorporating natural fiber composites into both interior and exterior parts". [26]

"This serves a two-fold goal of the companies that is to lower the overall weight of the vehicle thus increasing fuel efficiency and to increase the sustainability of their manufacturing process , Many companies such as Mercedes Benz, Toyota and DaimlerChrysler have already accomplished this and are looking to expand the uses of natural fiber composites, The gear stress analysis, the transmission errors, and the prediction of gear dynamic loads, gear noise, and the optimal design for gear sets are always major concerns in gear design; The polymer gear wear rate will be increased, when the load reaches a critical value for a specific geometry". [26]

"The gear surface will wear slowly with a low specific wear rate if the gear is loaded below the critical one, The possible reason of the sudden increase in wear rate is due to the gear operating temperature reaching the material melting point under the critical load condition, Actual gear performance was found to be entirely dependent on load; A sudden transition to high wear rates was noted as the transmitted torque was increased to a critical value; This is to be associated with the gear surface temperature of the material reaching its melting point, that is for a given geometry of actual gear, a critical torque can be decided from its surface temperature calculation". [26]

"The detailed analysis of the flash temperature for polymer composite gears and the heat partition between gear teeth problem is treated as an unsteady one where the intensity distribution and velocity of heat source changes as meshing proceeds; A numerical approximation is adopted using finite different method and the results are shown to be

close to those found using semi-analytical method assuming no internal hysteresis and the material properties are constant, Blok's solution can be used to provide a quasi-steady approximation that is for mean flash temperature estimation". [26] "A numerical method has been developed in the current paper for polymer composite gear flash temperature prediction". [27]

"Load carrying capacity and occurring damages of gears which are made of PC/ABS blends were investigated. PC is hard material and ABS is soft material, The usage of materials limits these drawbacks; However PC and ABS polymers combine each other, the PC/ABS blends have suitable mechanical properties for gear applications in the industrial areas, In this study, usability of PC/ABS composite plastic materials as spur gear was investigated; PC/ABS gears were tested by applying three different loading at two different numbers of revolutions on the FZG experiment set". [26]

2.2.6 REVIEW ON DESIGN AND ANALYSIS OF SPUR GEAR TO OVERCOME GEAR STUCKING AND SCUFFING

"By Xiang yang Jin (2012) [1] studied on utilize the coordinate transformation method to establish the surface equation for gear tooth; Techniques such as feature modeling, parametric driving, two-dimensional and three dimensional full dynamical correlation are also used to process the tooth surface and add features according to the relationship between individual features and creating order, A number of rotation and duplication is also utilized to obtain all the cogging, finally completing the detail design for each feature, This method has avoided the shortcomings of traditional three-dimensional dynamic assembly and excessive motion simulation computing, greatly improved the operational efficiency, reduced the size of storage file and decreased requirements for computer hardware Use Pro / E software to create three-dimensional model for each component of reducer, This model is based on some advanced techniques such as feature modeling, parameter-driving, single database, 2D and 3D full dynamical correlation, so it is a kind of complete model which can express and process three dimensional objects, To improve the efficiency of the system's modeling, the component should be analyzed

before the design and examine it from the overall look to form the general idea about it, determine the composition, creating order and improvement of its features 1; Complete the three-dimensional solid modeling of components of reducer, summarize the modeling techniques, and introduce the modeling process of components taking the shell of inner gear as an example. 2; Component modeling is a process from course to fine. First create the rough model for components, and then add features according to the relationship between the various features and the creating order, finally complete the details. For each individual feature, its relationship with others should be cleared and the internal link also needs attention". [28]

"S. Jyothirmaia, et al (2014) - Describes that in the face of extensive research into the theoretical basis and performance characteristics of helical gear design, a complete mathematical description of the relationship between the design parameters and the performance matrices is still to be clearly understood because of the great complexity in their interrelationship, The objective of this work is to conduct a comparative study on helical gear design and its performance based on various performance metrics through finite element as well as analytical approaches, The theoretical analysis for a single helical gear system based on American Gear Manufacturing Association (AGMA) standards has been assessed in Mat lab, The effect of major performance metrics of different helical gear tooth systems such as single, herringbone and crossed helical gear are studied through finite element approach (FEA) in ANSYS and compared with theoretical analysis of helical gear pair; Structural, contact and fatigue analysis are also performed in order to investigate the performance metrics of different helical gear systems". [29]

"Mrs. C.M. Meenakshi et al (2012) [4]: The objective of paper is to study the various stress state of spur gear, They calculated the tangential and radial forces which acts on various point upon that basis we can analyze by applying the forces; By using ansys software bending stress and contact stress on the tooth of spur gear drive is found, Gears are machine elements used to transmit power between rotating shafts by means of engagement of projection called teeth, Gears are most common means of transmitting power in the wooden mechanical world, They vary from a tiny size used in watches to

larger gears used in massive speed reducers, bridge lifting mechanism and rail road turn table drive; The gears are vital elements of main and auxiliary mechanism in many machines such as automobiles, tractors, metal cutting machine tools rolling mills hosting and transmitting and transporting machinery, massive engines ” . [30]

CHAPTER – 3

METHODOLOGY

3.1 Objective

The different types of gears are used for specific functions according to the strength, efficiency and material properties of the gear. Different types of gears are utilized in different machines. The selection of any gear is focused on some fixed yet important such as stress and deformation criteria. A comparative study of three types of gears has been done in the paper to find out the stress generation and total deformation generated on the gears imposed by the given load.

3.2 Gear properties and parameters

The comparative analysis of three gears which are spur gear, helical gear and bevel gear is done. The material selection for the gears was done on the basis of high strength criteria in terms of fatigue strength when subjected to high temperature during operation as well large amount of stress generation at the meshing region of the gear. High-strength structural steel has the ability to work under a high dynamic load.

3.2.1 Materials properties for the high strength steel

1. Coefficient of thermal expansion - 1.2201*10^(-5) C^-1
2. Density of material - 7.85001*10^(-6) kg mm^-3
3. Specific Heat - 4.3399*10^(5) m J kg^-1 C^-1
4. Compressive Yield Strength - 250 MPa
5. Thermal Conductivity - 6.05021*10^(-2) W mm^-1 C^-1
6. Tensile Ultimate Strength - 460 MPa
7. Resistivity - 1.69857*10^(-4) ohm mm

3.2.2 Characteristic parameters for the three gears shown in the table drawn below.

	Spur gear	Helical Gear	Bevel gear
Module	6	6	6
No. Of Gear teeth	30	30	30
Pinion teeth	15	15	15
Pressure angle (degrees)	20	20	45

3.3 Tools used for modeling and analysis of gears

3.3.1 Modeling of gears

The modeling of these gears was done on solidworks. “Solidworks is a solid modeling computer aided design (CAD) and computer aided engineering (CAE) computer program published by Dassault systems that runs basically on Microsoft windows”. In general, the modeling of any component whether it be a mechanical component (gears, bearings, beam etc.) or any electrical components such as electric circuits, capacitors and resistor or any electronic component can be modeled on the program. The quality of work on the program however, depends on the skill of the programmer.

Finite element analysis is used as a tool to analyze the behavior of gears under load. It is a numerical method to analyze mechanical parts which are under load that do not vary with time. It is used to solve the majority of engineering problems because of its flexibility and diversity and many techniques provided by it to customize the problem parameter and results. It calculates an approximate result which s quite satisfactory. As an exact solution cannot be achieved by the mathematical equation and need the experimental result, this method is nearly accurate to analyze material under static load. One can view results at a specific position, draw the graph, visualize animation, and many more in the finite element analysis.

The gears were modeled on solidworks in a specific manner :

- The gears (both pinion & wheel) were modeled for the three gear types. The pinion and wheel for all the gear types were modeled in the same space for each gear types.
- Then the process of mating of pinion (the smaller of two gears) & wheel (the larger of the two gears) was followed and the mating parameters were fed into the program and the mating parameters were fixed and the mating of gears was done for each of the gear types.

3.3.2 ANSYS Meshing

Meshing is the property of ANSYS to divide the element into smaller sections or regions. More the division in the model high will be accuracy. “Meshing is an integral part of computer-aided engineering (CAE) simulation process”. [31] The mesh affects the accuracy, convergence and speed of the solution. ANSYS provides many different techniques to mesh the model. Each has its area of application. Since the gear have teeth in it and the body of gear has many curvatures in it, therefore, proximity and curvature type of meshing is done in this paper. This type of method does not mesh the face properly but the curvature region is highly meshed. Since the stress develops at the teeth and area near it. So, the curvatures present in the teeth need to be meshed properly to obtain accurate results and the mesh at the middle can be ignored. The meshed model of spur gear is shown below to show how proximity and curvature function meshes the model.

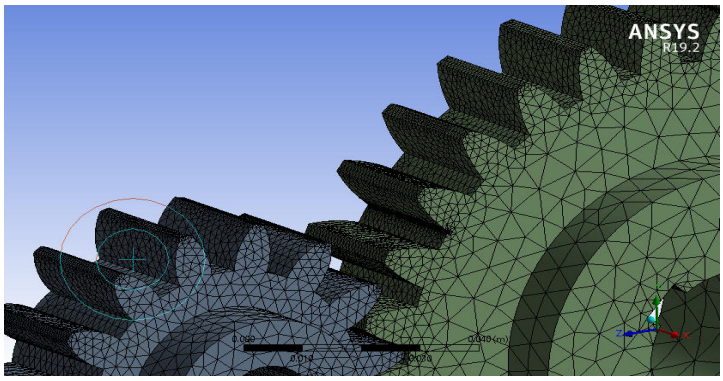

Fig 3.1 - A meshed spur gear

3.3.3 Analysis Parameters

The moment of 1715 Nm is applied at the center of bigger gear and frictionless supports are given at the center of two gears to stop the motion in the x direction. Similarly, frictionless supports are given at the face of gears to limit the movement of gears in the z direction. Table 1 shows the analysis parameters.

Table 2: Analysis Parameters

Loads/Support	Frictionless Support1	Frictionless Support2	Moment
State	Fully defined		
Suppressed	No	No	No
Defined by		Component	
Magnitude		1715 N m (ramped)	
Direction		Z axis	

CHAPTER – 4

RESULTS & DISCUSSIONS

4.1 Introduction

In this chapter both analyses (equivalent stress & total deformation) have been done for comparative study among three gear pairs (pinion & the wheel). The analysis of the results obtained by the simulation of the gears is done. The results obtained are in the form of equivalent stress and total deformation induced in the gear pairs. The stress distribution obtained in different gear pairs differs with each other as well as for the strain distribution (total deformation).

4.2 Results

The results for each gear types are presented in different subsections. The result contains stress distribution and total deformation over the surface of gears. The stress distribution for each gear type is followed by total deformation for each gear and then the zoom-in representation of stress distribution is shown as the magnitude of stress distribution does not varies continuously over the gears, it is remarkably high at certain region and low at minimum at most of the regions.

4.2.1 Spur gear (pair)

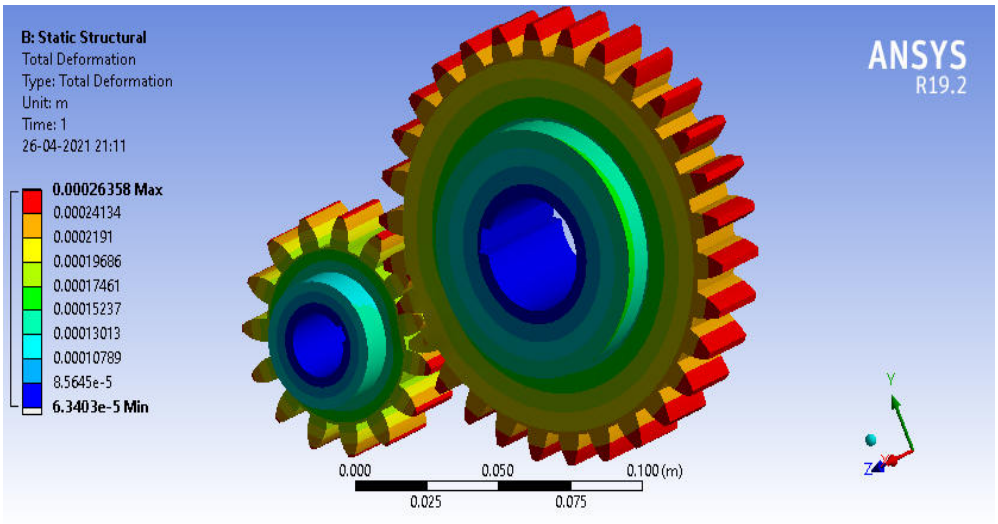

Fig 10 – Total deformation in spur gears

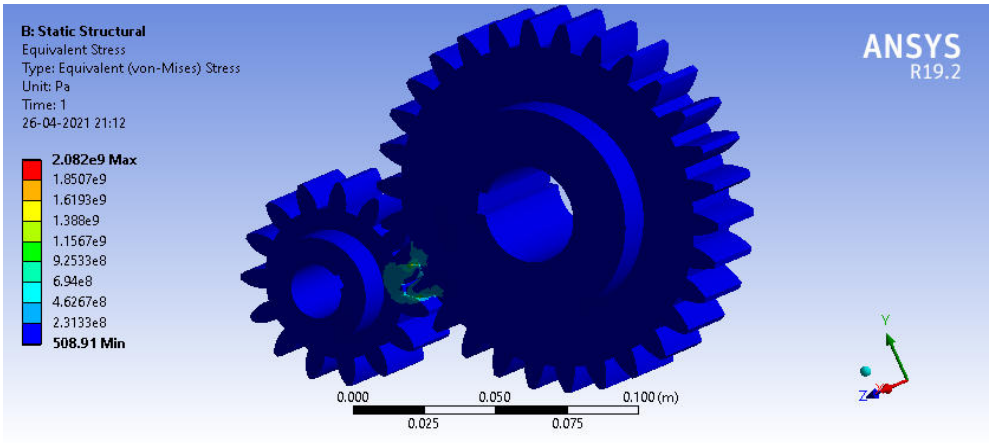

Fig 11 – Stress distribution in spur gears

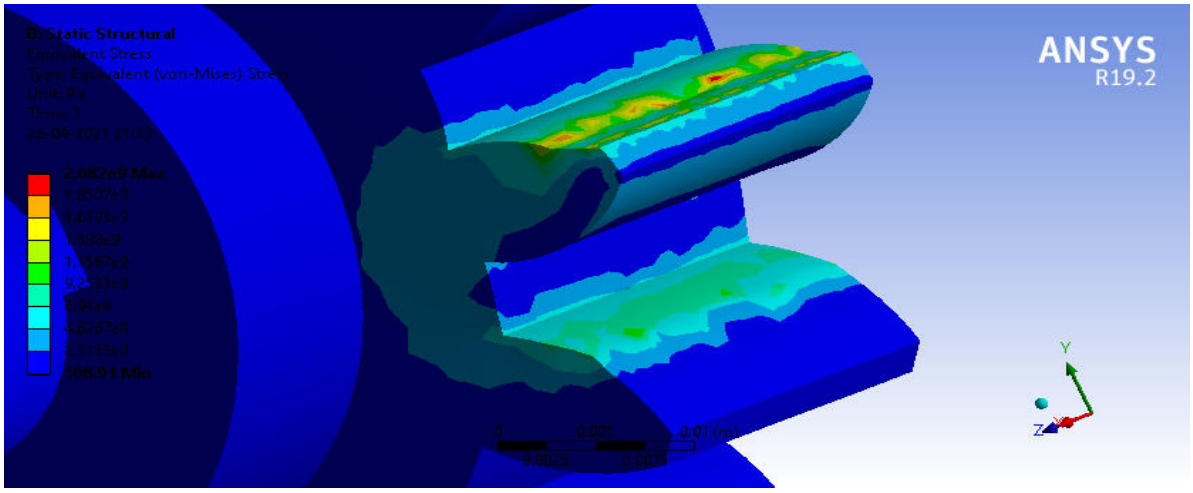

Fig 11 - Stress distribution in spur gear

4.2.2 Helical gear

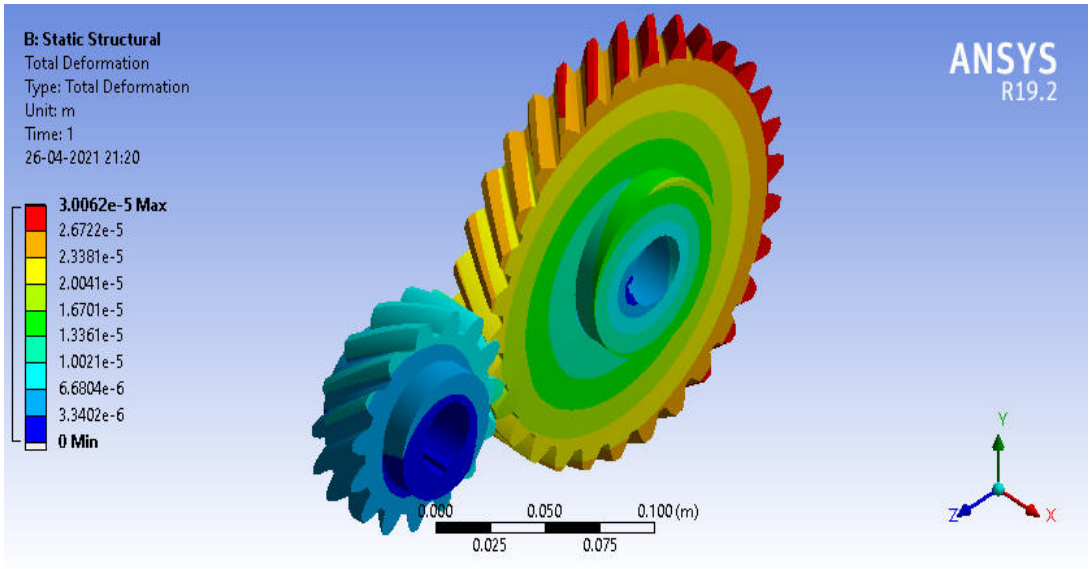

Fig 12 – Total deformation in helical gears

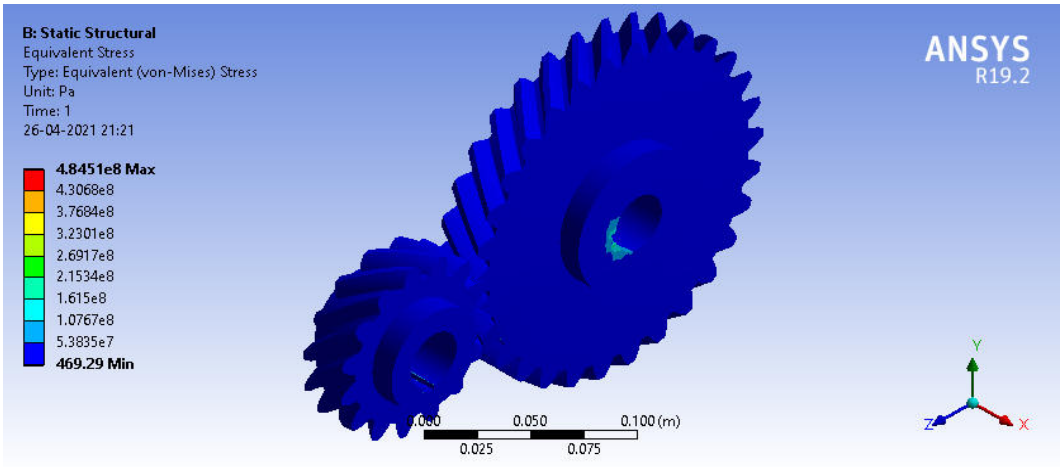

Fig 13 – Stress distribution in helical gears

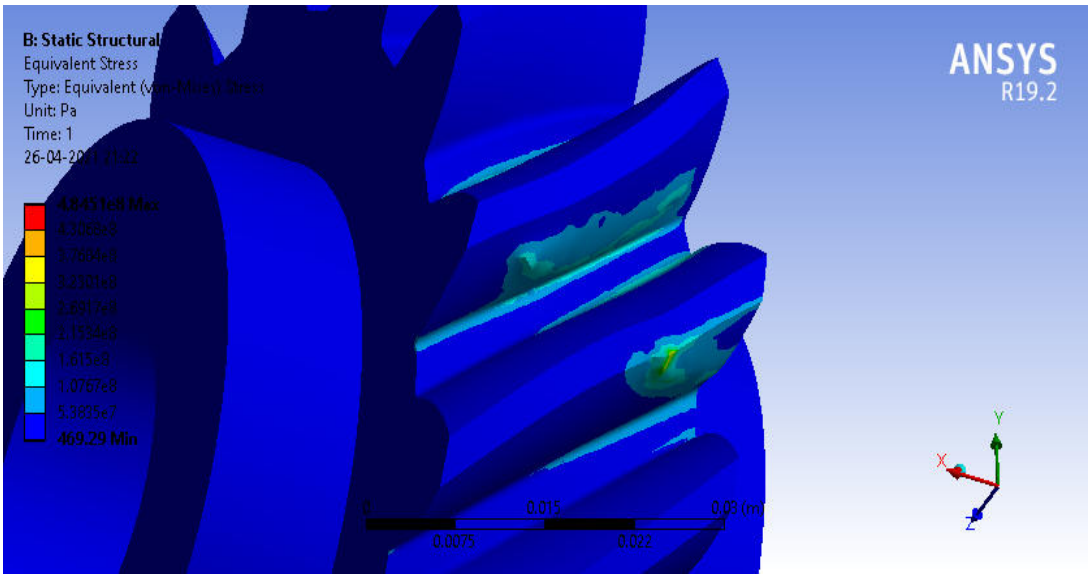

Fig 14 – Stress distribution in helical gears

4.2.3 Bevel gear

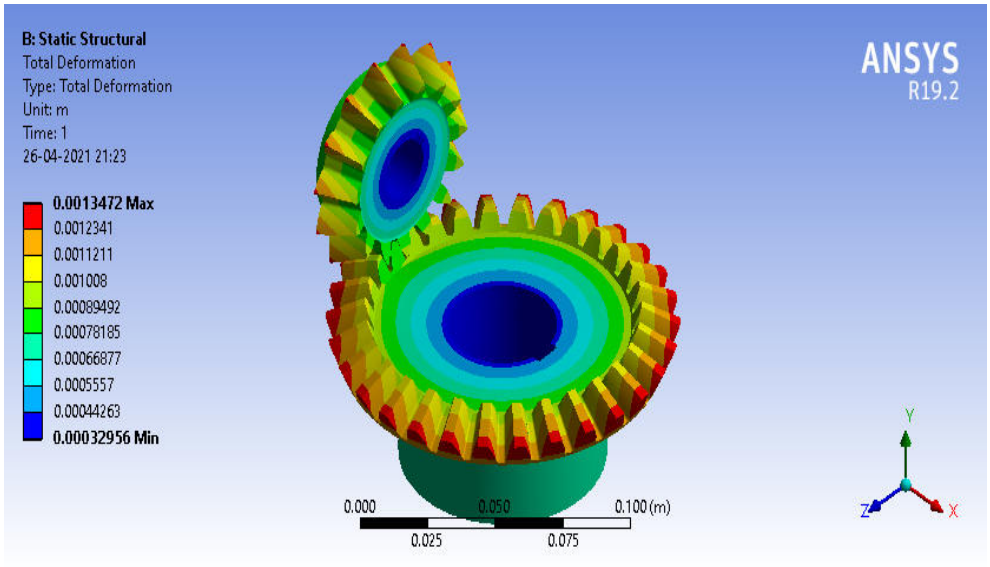

Fig 15 – Total deformation in bevel gears

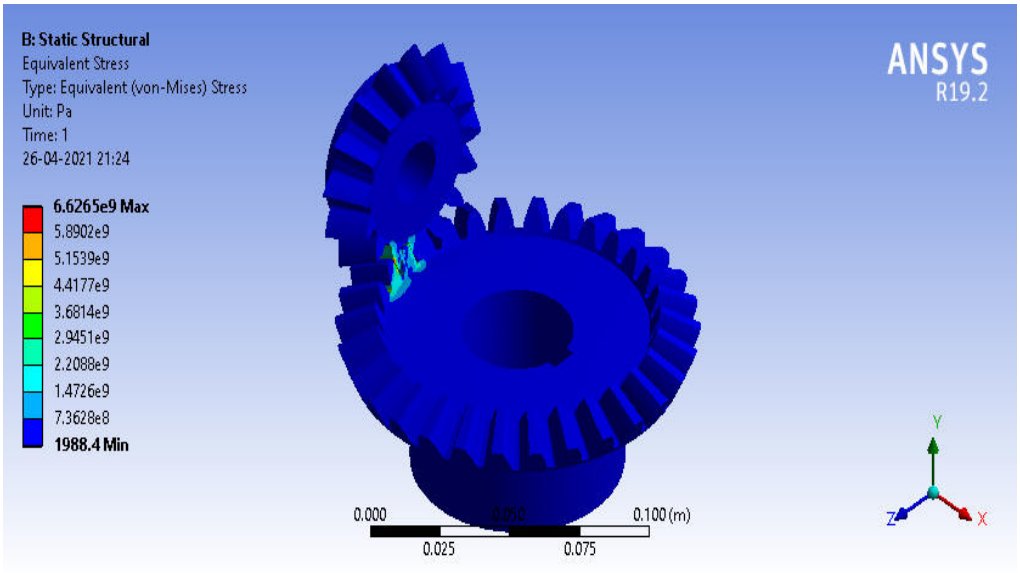

Fig 16 – Stress distribution in bevel gears

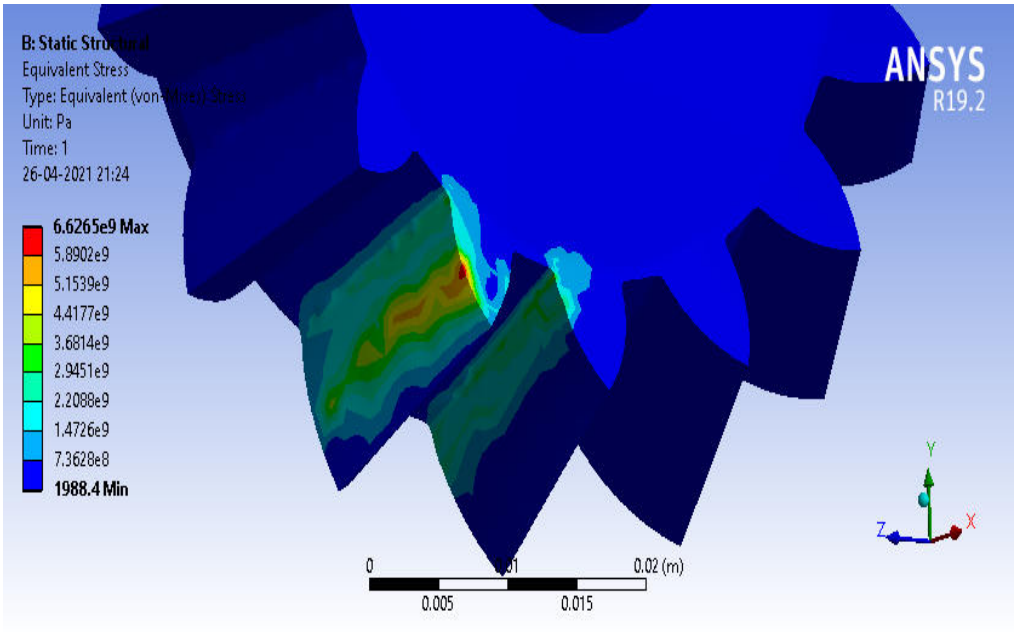

Fig 16 – Stress distribution in bevel gear

4.3 Discussions

The result obtained from the simulation of each of the gear types presents some obvious and fascinating behavior of these gears.

The variation of output parameters such as equivalent stress (stress distribution) over each gear is different for variation of total deformation for each of the gear types. For instance, the meshed gear tooth experience high stress generation and maximum total deformation and is most crucial part of a gear while life of the gear is considered for design perspective.

From the results obtained it can be seen that the deformation occurred at the contact region that is the teeth area and the center of the face shows minimum deformation which is right because the main work of transferring power is done by the teeth.

4.3.1 Analysis of the Results for Total deformation on Gear types

The results obtained by the simulation for the criteria of total deformation over the gear region shows the following behavior -

1. From Figure 10, the max deformation is at the tip of teeth that is 0.00026358 m in spur gears. While the minimum is at the center.
2. In the case of helical gears, the max deformation is less than the spur gears which is at the teeth 0.000030062 m, and same as the spur gear the center area has the least deformation as seen in Figure 13.
3. From Figure 16, it is cleared that the deformation in bevel gears is highest among the three that is 0.0013472 m.
4. The range of values for total deformation for different gear types obtained are given below –
    1. Spur gear : (0.000063403 – 0.00026358) m
    2. Helical gear : (0 – 0.000030062) m
    3. Bevel gear : (0.00032956 – 0.0013472) m

4.3.2 Analysis of the Results for Equivalent stress on Gear types

The results obtained by the simulation for the criteria of total deformation over the gear region shows the following behavior –

1. It is clear from figure 11, the stress developed in spur gears in the contact region is maximum.
2. Figure 12, shows the magnified view of the contact region, and the stress value is calculated as 2.082e+9 Pa in spur pinion teeth.
3. From Figure 14, a small amount of stress developed at the center approx. 5.3857e+7 to 1.675e+8 in helical gears.
4. Figure 15 shows that the contact region experiences the stress of 4.851e8 Pa maximum at some small point of helical pinion teeth but the major portion of the contact region has the stress of approx. 5.385e7 to 1.615e8 Pa.

5. The bevel pinion teeth have experienced the stress of 6.6265e9 Pa as maximum and the major portion has developed the stress of approx. 7.3628e8 Pa to 2.2088e9 Pa (Figure 17 and Figure 18) which is very close to spur gear stress value.
6. The range of values for total deformation for different gear types obtained are given below –

1. Spur gears: (508.91 – 2.082e9) Pa
2. Helical gears: (469.29 – 4.851e8) Pa
3. Bevel gears: (1988.4 – 6.265e9) Pa

CHAPTER – 5
CONCLUSION

1. Gears are the mechanical component used to transmit power to the system. Due to its compact size and a high degree of reliability, gears are a major choice of designer is present. Furthermore, enhancement in gear design is a major demand of industry because of its wide range of uses and to development of more lightweight and high-performance gears.
2. Fatigue occurs in components, breaks the machine and can sometimes be led to an accident. Fatigue is generally understood as the breaking of material due to constant cyclic or continuous loads.
3. There is much reason for a gear failure like low strength material used in gears, crack generation in fillet region, impurities during gear making, etc. All these features ultimately lead to gear failure.
4. This paper compares the results of three different gears under similar conditions. The model is prepared through Solidworks and exported to ANSYS for further analysis. Solid works assembly feature is used to mate the gear and pinion before sending to the ANSYS.
5. From the results, conclusions are as follows:

1. It is clear that minimum deformation is experienced by the helical gears of value 0.000030062 m, however the maximum deformation occurs in case of bevel gears that are of 0.0013472m.
2. The bevel gears show the maximum formation of stress near teeth with 2.2088e9 Pa which is nearly the same as in spur gears.
3. The helical gears show the least stress formation among all three gears. So, helical gears performed better in both the analysis.

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