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Structure Analysis, Contact Stress Analysis and Fatigue Life Analysis of Spur Gear Assembly by Using Fem

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Abstract- **In this present work a virtual environment has been created to investigate the failure analysis on spur gear assembly in which structural analysis, fatigue failure analysis and contact stress analysis have been performed using finite element method. For this work, a three dimensional cad model has been created and imported to ANSYS workbench for further finite element analysis. Various boundary conditions have been used to perform structural, fatigue failure assessment and contact analysis such as revolute joints is provided with Body Ground connection for 60 rpm for structure analysis, Augmented Lagrange method is set for contact analysis, for fatigue life analysis the fatigue strength factor is used as 0.85 for fully reverse loading and the life of shear stress in cycles and for the contact analysis linear and nonlinear contact are used for both source and target body. It has been observe that contact stress and bending stress not attain their maximum values at the same points, if the contact stress minimize in primary design stage then the failure of gear can minimized by analysis of the problem during the earlier stage of design. It can also be state that by using finite element analysis complex analysis like fatigue and contact analysis can be performed very accurately within a very short time and cost effectively rather than experimental analysis.**

Keywords*:* Spur Gear, Finite Element Method, Structure Analysis, Contact Analysis, Fatigue Analysis, Augmented Lagrange Method Etc.

I. INTRODUCTION

HISTORY OF GEAR: Indian history according to our mythological stories is over 12,000 years old. Since then, people living here have been trying to improve living conditions. We also know that the first humans lived in caves and the cave doors were made of granite. How were these heavy doors opened and closed? They were opened and closed by a transmission, a wheel, a lever and a cable system. However, the documented evidence was lost due to destruction by the invaders and inadequate conservation of palm leaf literature. The guru-kula method of teaching and sharing information through word of mouth and keeping some progress as a well-kept secret has led to poor dissemination of knowledge and documentations. But the knowledge of the gears goes from India to the East through some of the tampons of the world in China from 2600 BC. So they ingeniously used the gears in the carts to measure speed and other mechanisms [43].

DEFINITION OF GEARS: The gears are gears that transmit force / movement between two shafts, forming a mesh without slipping. The gear drives are therefore also called positive drives. In each pair of gears, the smaller one is called pinion and the larger one with respect to the gear from which the other is operated

If the pinion is the driver, this leads to a climb control, where the output speed decreases and the torque increases. On the other hand, if the transmission is the driver, an increase will occur where the output speed increases and the torque decreases.

CLASSIFICATION OF GEARS: The gears are classified according to the shape of the pair of teeth and the arrangement in spur, helical, double helical, spiral bevel, straight bevel spiral bevel and hypoid bevel, worm and spiral gears.

SPUR GEARS: The spur gears have their teeth parallel to the axis and are used to transmit power between two parallel shafts. They are simple in construction, easy to manufacture and at a lower cost. They have maximum yield and excellent precision. They are used in high-speed and high-load applications in all types of trains and in a wide range of ratios. [43 & 45]

Figure 1: Spur Gear

HELICAL GEARS: Helical gear units are used for parallel axis drives. They have teeth inclined to the axis, as shown in

Figure 2. Therefore, their teeth have the same width longer than the cylindrical gears and have a greater load capacity. Their contact ratio is higher than with cylindrical gears and they work quieter and quieter than cylindrical gears. Your accuracy is good. They are recommended for very high speeds and loads. Therefore, these transmissions are widely used in automotive transmissions. Their efficiency is slightly lower than that of cylindrical gears. The angle of the propeller also causes an axial thrust on the shaft. [44]

Figure 2: Helical Gears

DOUBLE HELICAL GEAR OR HERRINGBONE GEAR: Double or Herringbone gears for the transmission of power between two parallel shafts. They have opposite helical teeth with or without clearance, depending on the chosen production method, Figure 3. Two axial shocks face each other and rise. Therefore, the shaft is devoid of any axial force. Although their load capacity is very high, they are more expensive than helical gearboxes due to production difficulties. Their applications are limited to high-capacity drives such as cement factories and crushers. [42]

Figure 3: Double Helical Gear

INTERNAL GEAR: Internal gears are used to transmit power between two parallel shafts. In these gears, the annular wheels have teeth on the inner circumference. This makes the drive very compact Figure 4. In these drives, the pinion and the ring gear rotate in the same direction. Your accuracy is right. They are useful for high load, high speed and high speed reduction applications. The applications of these gears can be seen in the planetary gears of automatic car transmissions, concrete mill gearboxes, windmill wind controls. They are not recommended for precision carpets due to design, manufacturing and inspection limits. They should only be used if an internal function is required. Today, precision maneuverability means that it can also be used in positioning devices such as antenna readers. [45]

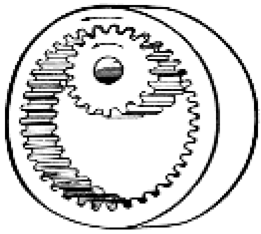

Figure 4: Internal Gear

Rack and Pinion: Rack is a segment of an infinite diameter gear. This type of gear is used to convert a rotary motion into a translational movement or vice versa. Typical example of rack and pinion applications are shown in Figs. 5. [45]

Figure 5: Rack and Pinion

BEVEL GEAR:

(A) STRAIGHT BEVEL GEAR: Straight bevel gears are used to transmit power between intersecting waves, Figure 6. You can work at high speed and high loads. Your accuracy is fine with good. They are suitable for 1: 1 and higher ratios and mesh at right angles to other angles. Your good choice is the right driving angle for very low gear. However, both the shape and the manufacture make accuracy difficult. You should be in one of the least critical parts of the train. A wide range of straight conical transmissions can be found in vehicle differentials. [43]

Figure 6: Straight Bevel Gear

(B) SPIRAL BEVEL GEAR: Spiral bevel gears, shown in Figure 7, are also used to transmit energy between intersecting shafts. Due to the spiral tooth, the contact length is longer and the contact ratio is longer. They work more easily than bevel gears and have a greater load capacity. However, their efficiency is slightly lower than that of a straight conical wheel. [42]

Figure 7: Spiral Bevel Gear

(C) HYPOID BEVEL GEAR: These gears are also used for right-angle guides where the axes do not intersect. This allows lowering the pinion shaft, which is an additional advantage to avoid collisions in the car's power transmission. However, the results do not overlap in a wide sliding movement and the drive requires good lubrication to reduce friction and wear. Their efficiency is lower than the other two bevel gears. These gears are widely used in today's power transmission of motor vehicles. [44]

Figure 8: Hypoid Bevel Gear

WORM GEAR: The worm gear and worm gear pair consists of a worm that closely resembles a worm screw and a worm gear which is a helical gear, as shown in Figure 9. They are used in right angle oblique axes. In these courses, the procedure takes place without any impact. The sliding action that prevails in the system, resulting in quieter operation, generates considerable frictional heat. High reduction percentages from 8 to 400 are possible. The efficiency of these transmissions is low from 90% to 40%. Transmission ratios with a higher transmission ratio are not reversible. Your accuracy is fine with good. You need good lubrication for heat dissipation and to improve efficiency. The disks are very compact. Worm gears are widely used in machinery for handling and transporting materials, machine tools, automobiles, etc. [43]

Figure 9: Worm Gear

NOMENCLATURE OF INVOLUTE SPUR GEARS: The function of a transmission is to function without problems during the transmission of movement or torque. To do this, the angular velocity ratio must remain constant at all times. This aspect is explained here by using various gear-type gear terminologies. Understanding the definitions of these terminologies helps to understand how transmissions and the design of transmissions work. [43 & 44]

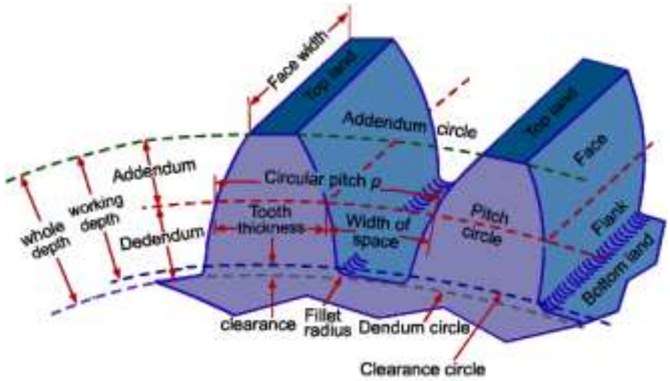

Figure 10: Portion of involute spur gear

Modes of Gear Failure: Gear failure can occur in various modes. In this chapter details of failure are given. If care is taken during the design stage itself to prevent each of these failure a sound gear design can be evolved. The gear failure is explained by means of flow diagram in Figure 11. [42]

Figure 11: Different modes of failure

II. LITERATURE REVIEW

Miryam B. Sanchez et. al [2017] [1] According to this paper the meshing stiffness of spur gear pairs, considering each local contact deflections and global tooth deflections, is evaluated at any point of the path of contact and approximated by an analytical easy operate. With this function, the load sharing ratio is calculated and compared with previous results obtained from the hypothesis of minimum elastic mechanical energy considering the tooth deflections, however neglecting the Hertzian deflections. contact stresses and Critical bending from each models also are compared both for standard and high contact ratio spur gears.

Francesca Curaa et. al. [2016] [2] In this work is to analyze crack propagation paths in planet gears for part applications in order to search out how gears parameters could have an effect on the crack path and, consequently, could give information regarding gears design to avoid catastrophic failures. The analysis activity has been carried on by suggests that of extended finite component models .In explicit, the impact of rim thickness (expressed as backup ratio) and crack initiation point on crack paths has been thought-about. Obtained results are compared with those available for standard gears, to focus on the various behavior in crack propagation.

G. Meneghetti et. al. [2016] [3] In this work, pitting on gear tooth flanks is one amongst the foremost causes of failure in power transmissions. Cracks originate at the surface and propagate at a little depth inflicting the detachment of fabric detritus, which ends in craters. Pitting is damaging because it ends up in vibration, noise, loss of potency and eventually to the gear un-serviceability. The contact fatigue characterization of substances materials needs a good variety of endurance tests on reference gears and isn't cheap for industries.

Newton K. Fukumasua et. al. [2016] [4] Helical gears are subjected to contact fatigue loads, which can lead to the damage of the gear teeth, as an example by pitting-type failure. Casehardening, followed by shot penning processes, are typically carried out to provide a wear-resistant surface with compressive residual stresses established within the gear tooth surface region. This work aims to evaluate, by finite part analyses, the strain distribution through the gear teeth throughout the gear coupling. The results enable the analysis of the strain elements that will result in the roughness failure, indicating the planning variables that are necessary to enhance the reliability of the gear.

Christian Brechera et. al. [2016] [5] The transmission error (TE) could be a criterion within the design process for gears, as, beside a sufficient load-carrying capability and good efficiency, noise performance is a vital client demand. For the micro geometry design, the tooth contact analysis (TCA) together with the simulation of the manufacturing process for the flank topography is important. the target of this paper is to point out potential for the optimization of face-milled bevel gears.

Laxmikant S. Dhamandea et. al. [2016] [6] Gears and bearings are necessary elements of almost each machines utilized in industrial environment. Therefore detection of defect in any of those should be detected in advance to avoid catastrophic failure. This paper aims to deal with the impact of bearing defect on gear vibration signature and impact gear defect on bearing vibration signature. Additionally its purpose is to create vibration analysis of single stage spur gear box, once each gear and bearing is defective.

P. B. Pawara, Abhay A Utpatb [2015] [7] Spur gears are the simplest and wide employed in power transmission. In recent years it's needed to control machines at varying load and speed. Gear teeth usually fail when load is enlarged higher than bound limit. So it's needed to explore alternate materials for gear producing. Composite materials offer adequate strength with weight reduction and that they have emerged as a stronger different for replacing metallic gears.

B. Haefnera et. al.[2015] [8] Nowadays, small motors are used in combination with small transmissions in manifold industrial applications like dental drills or the instrumentation for minimally invasive surgery within the medical industry, hexapod micro positioning systems for wafer process within the field of industrial automation or adjustable automotive parts like fixings of lcd monitors. Small transmissions consist of micro gears that are critical to their functionality. Life analysis is especially important for micro gears, because the influence of their geometric shape deviations on their load rating is considerably higher compared to gears with larger modules.

Shaik Gulam Abul Hasan [2015] [9] Every element or structure is designed based on factor of safety which suggests the element shouldn't fail below the design load. However in actual arena it is not so there's a requirement for an analysis that predicts the lifetime of the element. In this analysis is one such analysis of carrying fatigue check on spur gear using software package ANSYS. The gear fitted within the gearbox of armored tracked vehicle is susceptible to considerable fatigue damage over its life period due to the dynamic excitations caused by the terrain undulations, the rotating wheel and track assemblies.

Ketan Tambolia et. al. [2014] [10] A heavy duty helical gear pair reducer is taken into account for the objective of minimum volume, since the foremost power transmission systems require low weight energy economical and value effective system elements. The various factors for size and strength of gears are computed for gear pure mathematics parameters using DIN normal. The solution is attempted using Particle Swarm optimization (PSO). The results achieved are satisfactory and helps designer to employ for minimum material and value by fulfilling the strength and performance needs. Gears can be individually determined.

III. METHODOLOGY

In this chapter, the stress, fatigue and contact analysis on spur gear assembly ware executed using FEM (finite element method). The mathematical model of a spur gear tooth assembly having the following geometrical data, The number of teeth on gear-1 & gear-2 are 18 & 15, normal module is m = 5 mm, Outer Diameter of Gear-1 & Gear-2 are 100mm & 85mm, Pitch circle diameter of gear-1 & gear-2 are 90mm & 75mm, center distance is = 82.5mm and tooth face width is = 15mm as shown in figure 12.

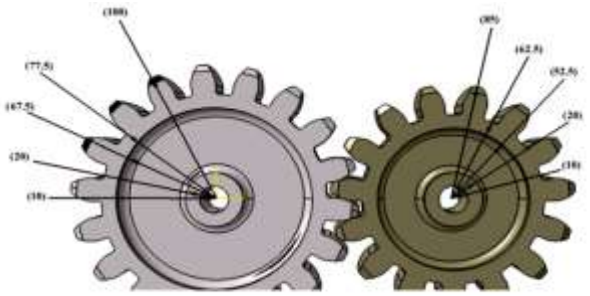

Figure 12: Geometry of the spur gear tooth assembly

The main steps involve conducting the FEM (finite element analysis) on spur gear assembly are as follows:

1. Create a three dimensional Geometrical model of spur gear assembly
2. Generate the meshing to discretize the component into a number of small elements of defined size.
3. Definition of boundary conditions, loading, constraints, and material properties.
4. Calculation of nodal forces, nodal displacements, fatigue life, and contact analysis at spur gear assembly
5. Formation of the results and close the solution.

The Flowchart of Stress, Fatigue failure and Contact analysis spur gear assembly is shown in figure 13.

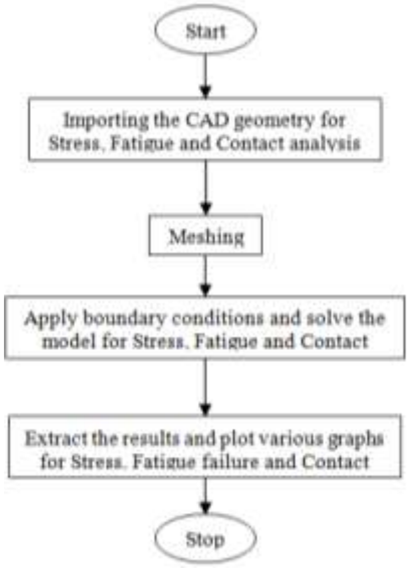

Figure 13: Flowchart of Stress, Fatigue failure and Contact analysis spur gear assembly

The study of deformation of solids which are in contact at one or more points is called Contact Mechanics. When two gears mesh, the region of contact is theoretically a line. The curvatures of the individual mating surfaces at the points of contact will vary according to the given dimensions of the tooth profile of the mating gears as well as to the instantaneous positions of the point of contact on the line of action as the gear tooth surfaces roll and slide during the course of action. The stress pattern developed within this band is quite complicated. According to Dudley as cited in this is what happens when the gear tooth surfaces are in action a point of maximum compressive stress is created in the centre of the hand of contact.

Contact stress is one of the most important deciding factors for the determination of the requisite dimensions of gears. Different research on spur gear action have confirmed that beside contact pressure, sliding velocity, viscosity of lubricant as well as other factors such as frictional stress also influence the formation of pits on the tooth surface. Thus thorough study of contact stress between meshing gears is important in gear design. The German physicist, Heinrich Hertz, developed expressions for the stresses which are created when two curved surfaces are in contact. These surface stresses are globally known as contact stresses or Hertz stresses or Hertzian stresses.

Some assumptions are made in determining the solutions of Hertzian contact problems:

- The strain is small and within the elastic limit.
- The surfaces are linear and non-conforming (implying that the area of contact is much smaller than the characteristic dimensions of the contacting bodies).
- Each and every body can be considered an elastic half-space.
- The tooth surfaces are frictionless.

Some Additional problem arises when all these assumptions are violated and these contact problems are normally known as non-Hertzian.

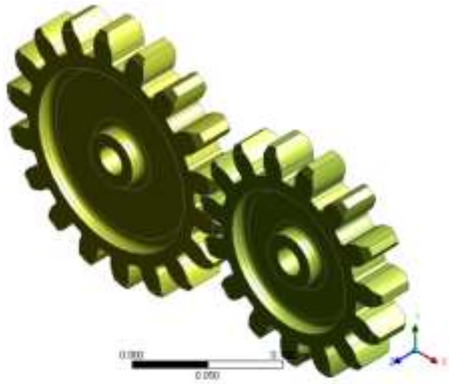

Figure 14: CAD Model of Spur Gear Assembly

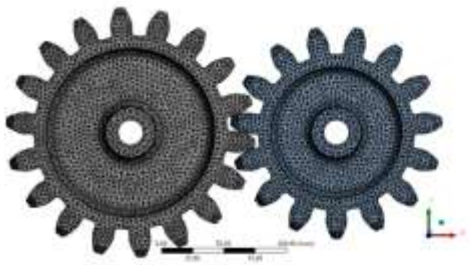

Figure 15: Meshing: Node is generated is 210054 and total elements are 120464

Boundary conditions:

1. Define contacts as a frictional contact with frictional coefficient as 0.1.

2. Augmented Lagrange technique is set for contact analysis.
3. A Revaluated joints is provided to each gears (18Teeth & 15Teeth) with Body- Ground connection.
4. The Mesh refinement is selected for Gear Teeth only.
5. Different kinds of components generated throughout the meshing (SODID187, CONTA174, TARGE170, MPC184 and COMBIN14 etc)
6. Set material as steel for each gears from ANSYS library created throughout Analysis.
7. The revolution of gears is ready as 60 revolutions per minute.
8. For the Fatigue analysis set fatigue strength factor = 0.85
9. Goodman theory is employed with totally reversed loading.
10. Life of Gears set in cycles not in time.
11. For the contact analysis linear and nonlinear contact are used for each source and target body.
12. The problem (solver) used for this FEM analysis is Mechanical APDL solver.

Structural Analysis of Spur gears:

The total deformation of spur gear has been observed in figure 16, its maximum and minimum values are 4.06 mm & 0.4 mm.

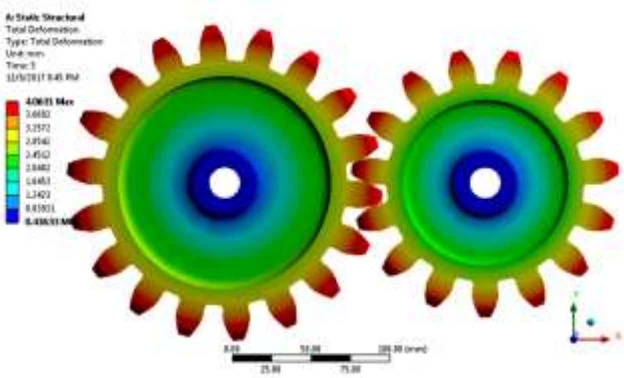

Figure 16: Structural Analysis of Spur gears

The Directional deformation of Spur Gear has been observed in figure 17, its maximum value is 4.0163 mm.

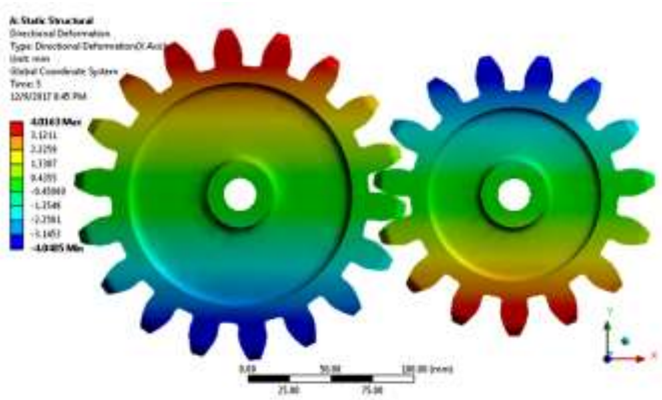

Figure 17: Directional deformation Spur Gear

The Von-mises stress of Spur Gear has been observed in figure 18, its maximum and minimum values are 830.32 MPa & 0.01266 MPa.

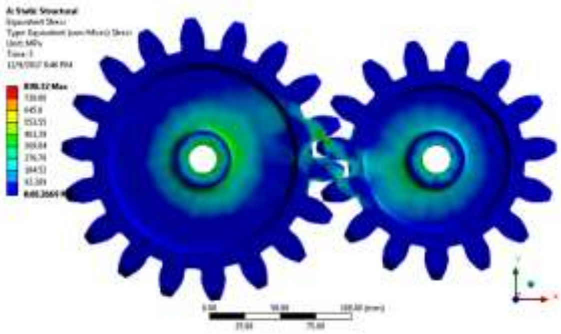

Figure 18: Equivalent stress on spur gear

The maximum principal stress of Spur Gear has been observed in figure 19, its maximum and minimum values are 708.35 MPa & -424.64 MPa.

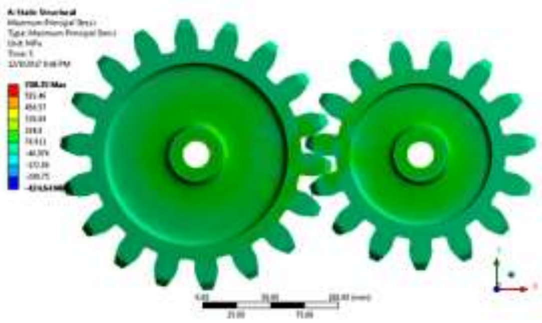

Figure 19: Maximum principal stress on spur gear assembly

The shear stress of Spur Gear has been observed in figure 20, its maximum and minimum values are 394.43 MPa & -345.68 MPa.

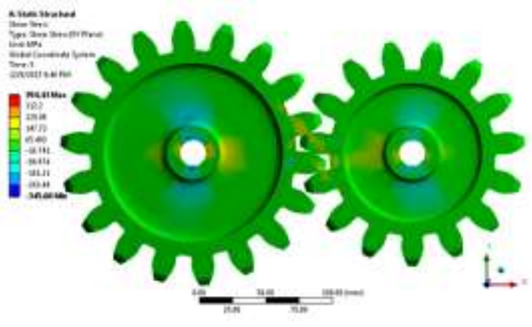

Figure 20: Shear stress on spur gear assembly

Total force on both gears with direction

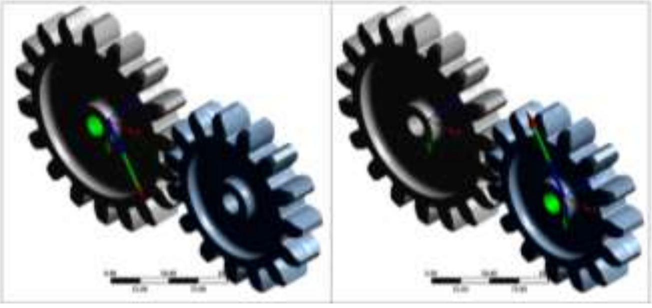

Figure 21: Direction of forces in xyz axies on spur gear assembly

Fatigue analysis:

It has been found through an experiment that once a material is subjected to repeated stresses; it fails at stresses below the yield point stresses. Such sort of failure of a material is known as fatigue. The failure is caused by means of a progressive crack formation that are usually fine and of microscopic size. The failure might occur even with none previous indication. Fatigue analysis includes factor of safety, fatigue stress life, fatigue damage, Bi-axility Indication and Fatigue Sensitivity Chart depending on the fatigue loading history.

The life of Spur Gear has been observed in figure 22, its life come in terms of revolution 1×e7.

Figure 22: Life of spur gear assembly

For calculation of fatigue we calculated damage which is shown in figure 23, its damage on teeth on spur gear has been observed.

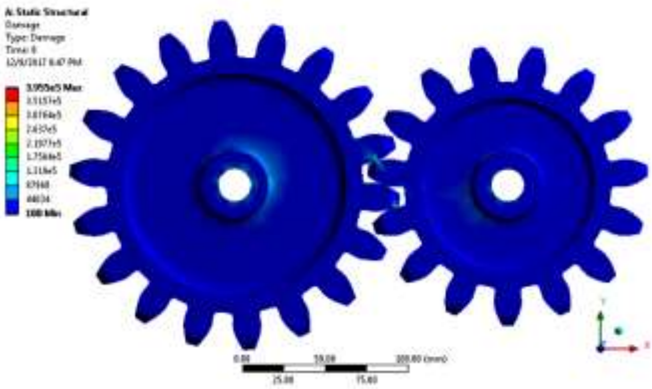

Figure 23: Damage on teeth of spur gear assembly

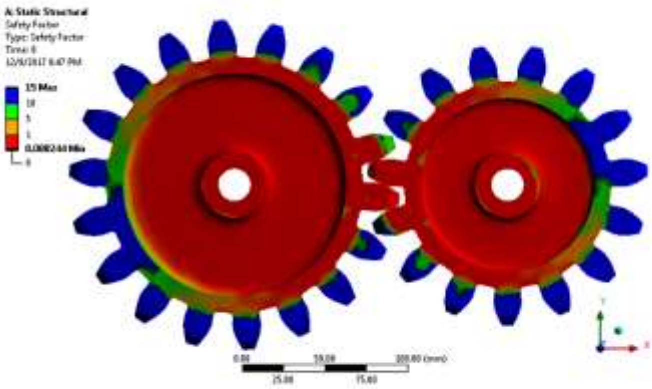

Figure 24: Factor of safety spur gear assembly

The Biaxiality indication of spur gear has been observed in figure 25, its maximum biaxiality is 0.99.

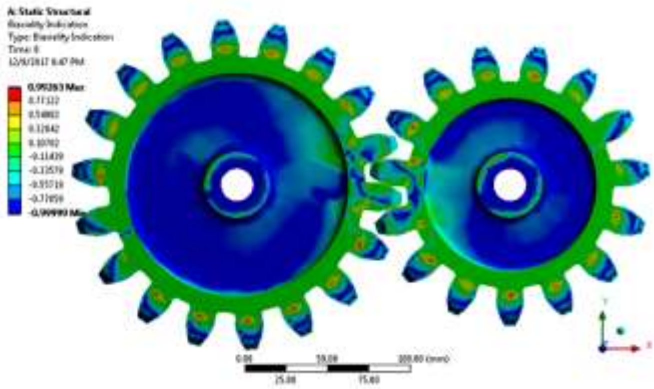

Figure 25: Biaxiality indication of spur gear assembly

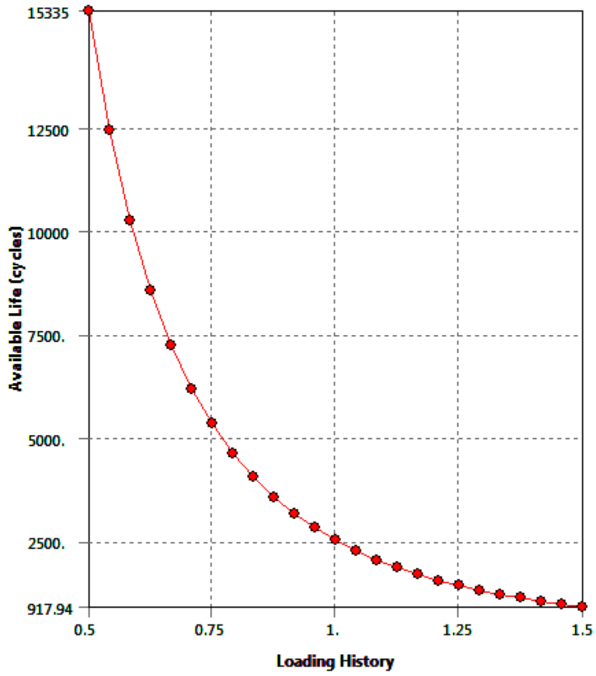

Figure 26: SN curve of spur gear assembly

Contact stress analysis by FEM:

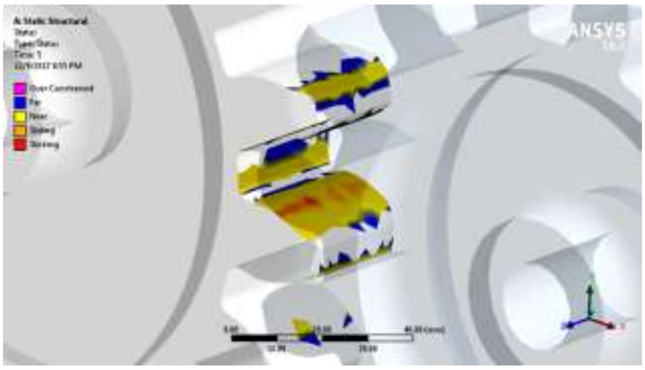

Figure 27: Status of spur gear assembly

The Pressure on teeth of spur gear has been observed in figure 28, its maximum value is 1620.1 MPa.

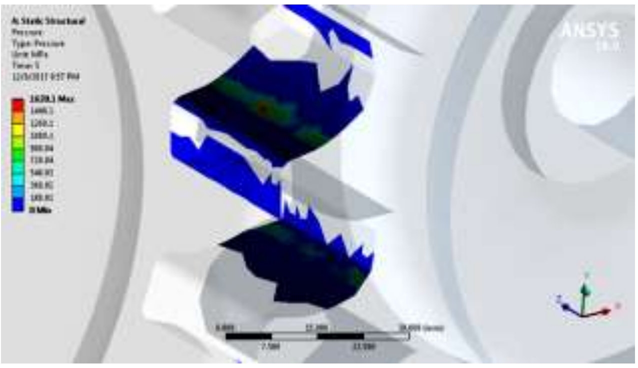

Figure 28: Pressure on teeth of spur gear assembly

The Frictional stress on teeth of spur gear has been observed in figure 29, its maximum value is 162.01 MPa.

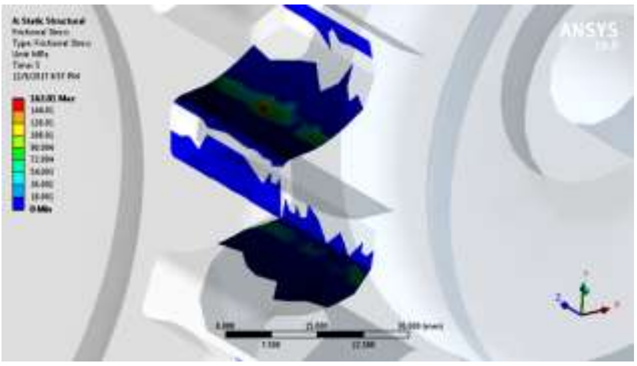

Figure 29: Frictional stress on teeth of spur gear assembly

The sliding distance on teeth of spur gear has been observed in figure 30, its maximum value is 0.79801 mm.

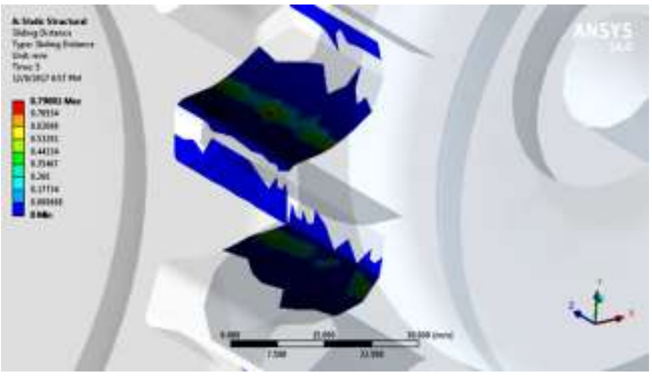

Figure 30: Maximum and minimum sliding distance on teeth of spur gear assembly

The Penetration on teeth of spur gear has been observed in figure 31, its maximum value is 0.0277434 mm.

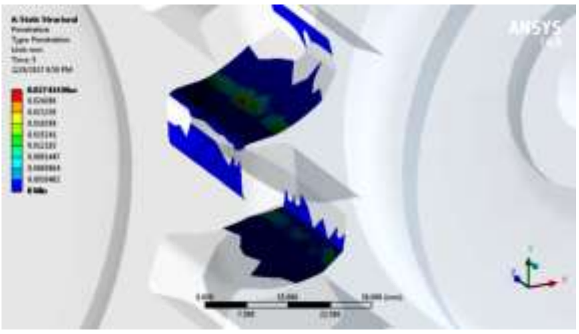

Figure 31: Maximum and minimum Penetration on teeth of spur gear assembly

IV. RESULT ANALYSIS

In this section we study structural stress, fatigue & contact stress on spur gear assembly by using FEM as a tool on ANSYS 16.0. The following graph with respect to our analysis are plotted below:

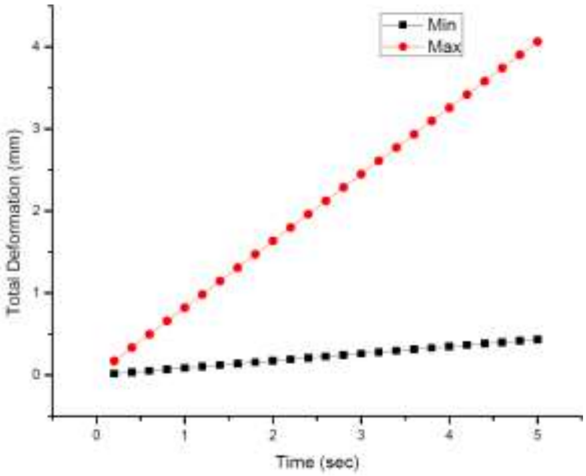

Figure 32: Total deformation of Spur Gear

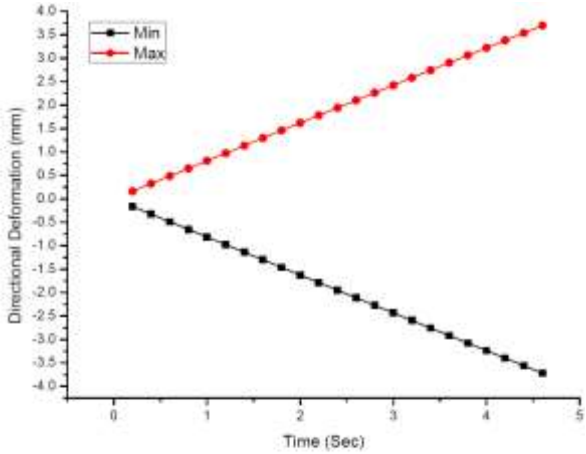

Figure 33: Directional deformation of spur gear

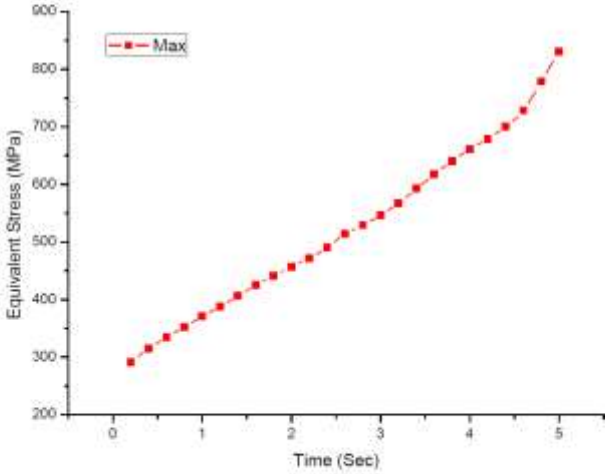

Figure 34: Maximum Equivalent Stress on spur gear.

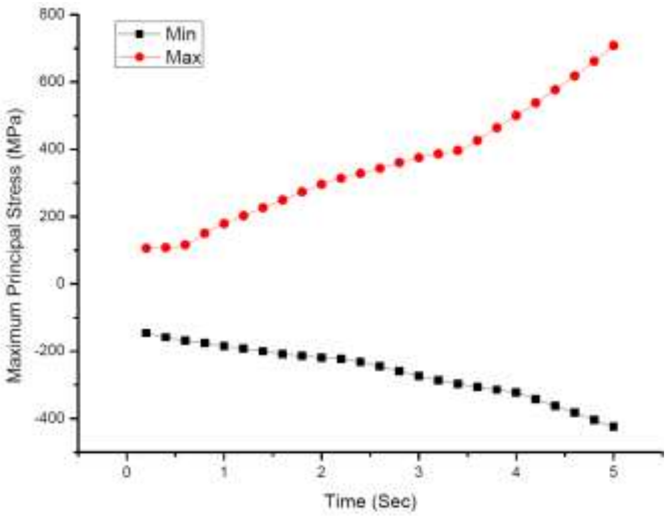

Figure 35: Maximum principal Stress on spur gear

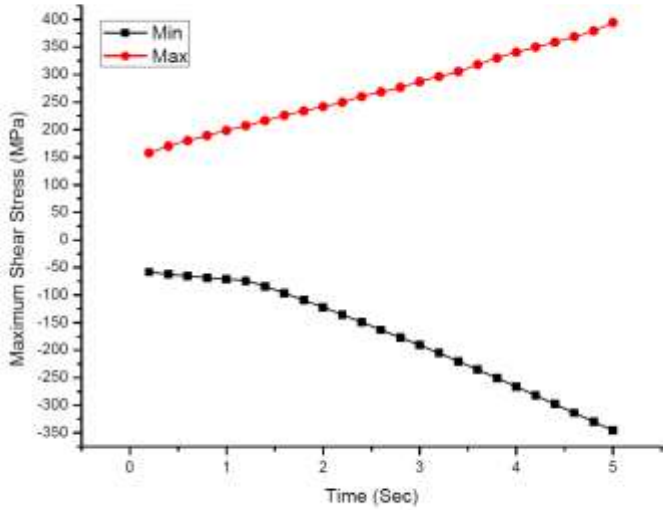

Figure 36: Maximum Shear Stress on spur gear

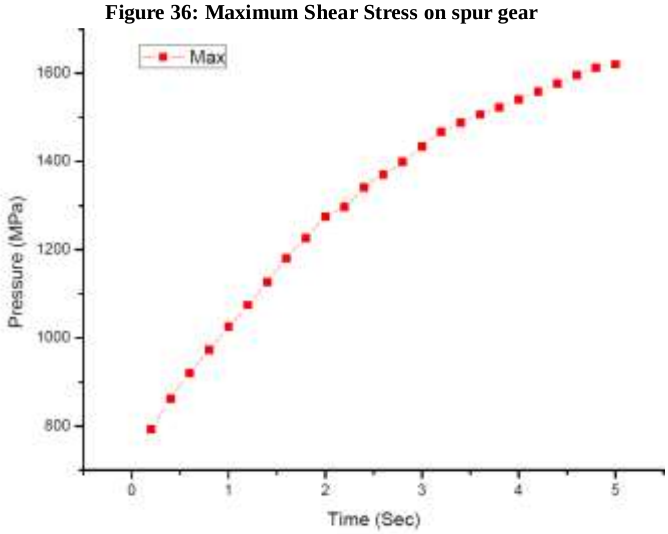

Figure 37: Maximum pressure on spur gear

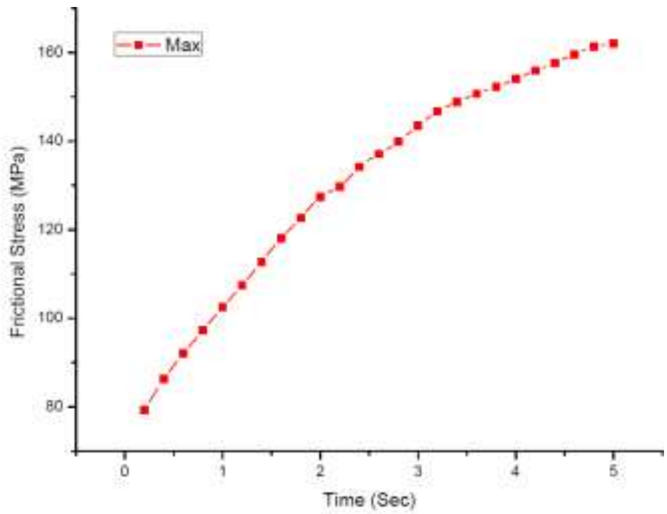

Figure 38: Maximum Frictional stress on spur gear

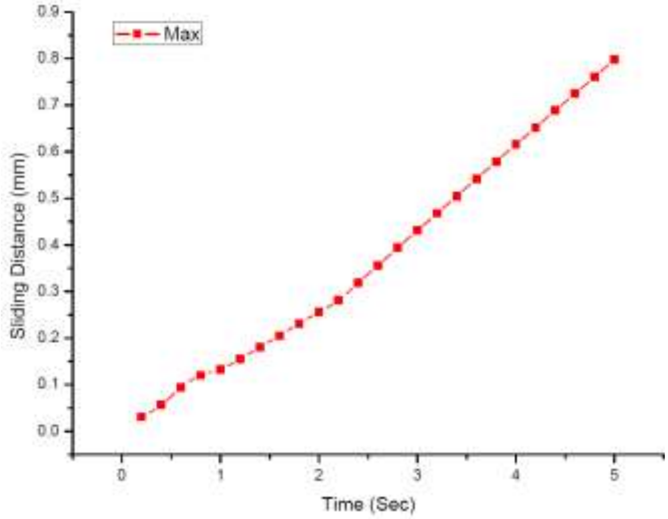

Figure 39: Maximum sliding distance on teeth of spur gear

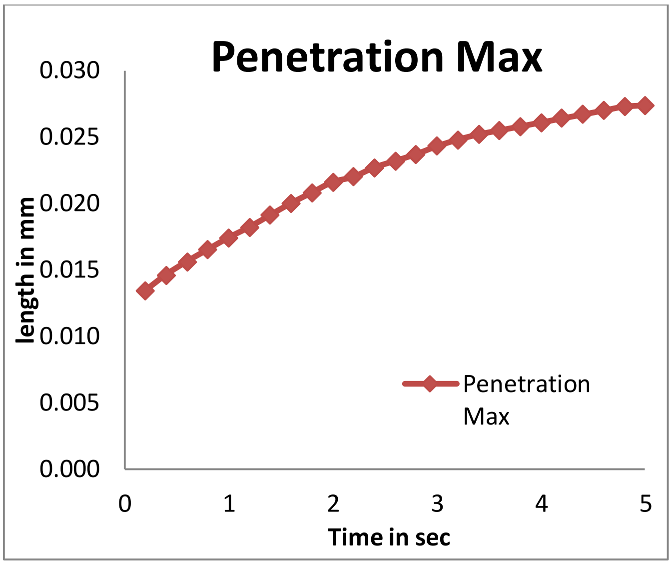

Figure 40: Maximum penetration on teeth of spur gear

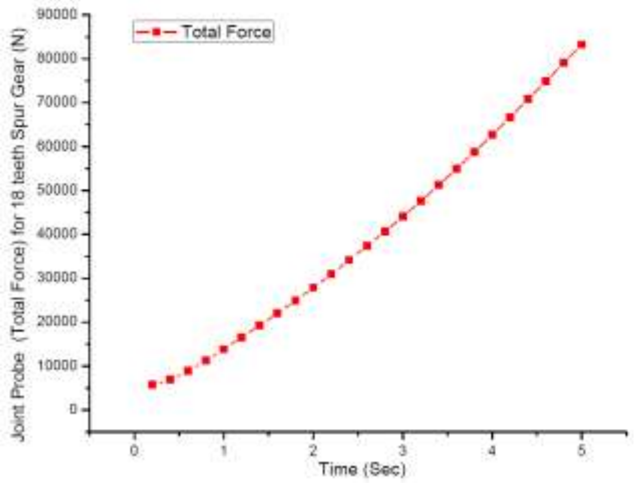

Figure 41: Total forces on 18 teeth of spur gear

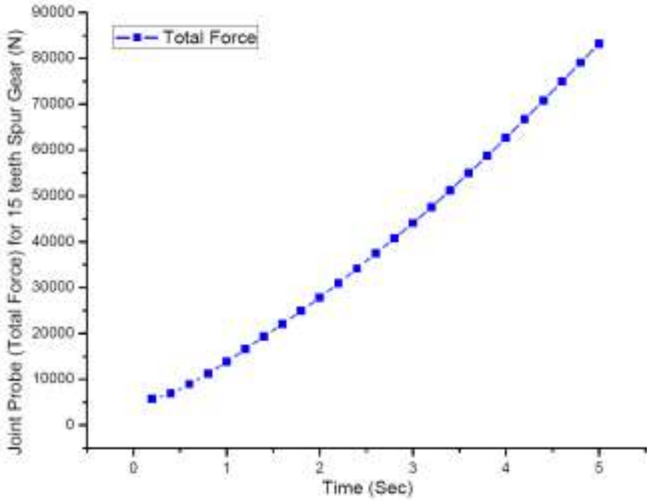

Figure 42: Total forces on 15 teeth of spur gear

V. CONCLUSION

In this dissertation virtual condition are given to gear to study the structural analysis, fatigue analysis and contact stress analysis and to evolutes reaction forces on spur gear assembly by using fem analysis in ansys work bench calculation of the study is presented below.

- The total deformation of Spur Gear assembly has been observed 4 mm.
- The Directional deformation of Spur Gear assembly has been observed, its value is 4.0163mm
- The Equivalent stress(von-mises stress) of Spur Gear assembly has been observed, its maximum value is 830.82 Mpa
- The Maximum principal stress on Spur Gear assembly has been observed, its value is 708.35 Mpa
- The Maximum shear stress on Spur Gear assembly has been observed, its value is 394.43 Mpa
- In contact stress analysis pressure on gear teeth is come as 1620.1Mpa
- In contact stress analysis frictional stress on gear teeth is come as 162.01Mpa
- In contact stress analysis sliding distance on gear teeth is come as 0.79801mm
- In contact stress analysis penetration on gear teeth is come as 0.027434mm
- In calculation of reaction force maximum force on spur gear teeth assembly is come as 83240

To summarize this conclusion, it has been observe that contact stress and bending stress not attain their maximum values at the same points, if the contact stress minimize in primary design stage then the failure of gear can minimized by analysis of the problem during the earlier stage of design. By using Finite element analysis complex analysis like fatigue and contact analysis can be performed very accurately within a very short time and cost effectively rather than experimental analysis.

The present work concerned only the calculation of structural forces, fatigue and contact stress .Further research can also be done by using different tool .

- In our study we are using steel as a material in future different material can be used for better result on chip cost.
- In our study we are not counting lubrication effect on gear .if lubrication effect will come in account results may be improve.

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