Design and Analysisof Structural Behavior of Spur Gear for Maximum Torque of Off-Road Vehicle

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Abstract: Developing an analytical approach and modeling procedure to evaluate stress distribution under velocity and moment would provide a useful tool to improve spur gear design with high efficiency & low cost. The purpose of this work is to analyze and validate the stress distribution in spur using contemporary commercial FEM program ANSYS coupled with SOLIDWORKS modeler.

The purpose of this work is to design the spur gear set for off road terrain vehicle initial maximum torque. The modelling of the spur gear is developed in SOLIDWORKS and the analysis of spur gear is done in ANSYS 2021R1. Structural analysis has been performed on the spur gear, moment is applied on the driven gear to study the stress and deformation.

KEYWORDS: Spur Gear, FEM - Finite Element Method, ANSYS - Analysis of Systems, SOLIDWORKS.

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I. INTRODUCTION

Spur gears are the simplest and most common type of gear. Their general form is a cylinder or disk. The teeth project radially, and with these straight-cut gears, the leading edges of the teeth are aligned parallel to the axis of rotation. These gears can only mesh correctly if they are fitted to parallel axles. The torque ratio can be determined by considering the force that a tooth of one gear exerts on a tooth of the other gear. Consider two teeth in contact at a point on the line joining the shaft axes of the two gears. The force will have both a radial and a circumferential component. Gears are a very useful simple machine.

A gear is component within a transmission device. Transmit rotational force to another gear or device. A gear is different from a pulley in that a gear is a round wheel. Mesh with other gear teeth, allowing force to be fully transferred without slippage. Depending on their construction and arrangement, geared devices can transmit forces at different speeds, torques, or in a different direction, from the power source. Gears are a very useful simple machine. The most common situation is for a gear to mesh with another gear, but a gear can mesh with any device having compatible teeth, such as linear moving racks.

Fig 1.1. *Spur gear*

II STRUCTURE OF PAPER

The paper is organized as follows: In Section 1, the introduction of the paper is provided along with the structure, important terms, objectives and overall description. In Section 2 we discuss about related work. In Section 3we discuss about spur gear nomenclature. Section 4 tells us about the methodology and the process description. Section 5shows the simulation results obtained. Section 6 tells us about the future scope and concludes the paper with acknowledgement and references.

OBJECTIVES

An automobile runs by transmitting torque to gears which are connected to wheel, when the engaged gear is switched to the next one after obtaining the maximum torque of the gear. the maximum torque of the previously engaged gear will become the minimum torque of the engaged gear, and attaining the maximum torque of the current gear takes time. Our work is to analyze and validate the stress distribution in spur using contemporary commercial FEM program ANSYS coupled with SOLIDWORKS modeler, and to design a spur gear which is capable of obtaining initial maximum torque, suitable for off road terrain vehicles.

II. RELATED WORK

There has been a great deal of research on gear analysis, and a large body of literature on gear modeling has been published. 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.

Pinaknath et al. (2016) analysed the bending stresses characteristics of an involute spur gear tooth under static loading conditions. The tooth profile is generated using Catia and the analysis is carried out by Finite element method using ANSYS software. The stresses at the tooth root are evaluated analytically using existing theoretical models. The theoretical and FEM results are compared. The results obtained theoretically are in good agreement with those obtained from software. Also an attempt is made there to introduce Stress and displacement characteristics of tooth under dynamic loading conditions.

Krishanu et al. (2015) analysed static stresses for spur gear with different pressure angles. The analysed results of a symmetric type involute profiled spur gear pair at different pressure angles are compared. Gears are one of the most important and crucial component in a mechanical power transmission unit and also in most of the industrial rotating machineries. Generally, a spur gear pair in action undergoes two types of stresses: the bending stress and the contact stress. In this paper, both these stresses on the gear tooth pair are analyzed using the finite element analysis and are compared. The stresses on the gear tooth are first analyzed using a finite element software and then those results are validated using the conventional formulae for finding stresses in gear tooth.

Rajaprabakaran et al. (2014) analysed high stress concentration at the root and the point of contact. The repeated stressing on the fillets causes the fatigue failure of gear tooth. The main objective of this study is to add different shaped holes to reduce stress concentration. A finite element model of Spur gear with a segment of three teeth is considered for analysis and stress concentration reducing holes of various sizes are introduced on gear teeth at various locations. Analysis revealed that aero-fin shaped hole introduced along the stress flow direction yielded better results.

Prajapati et al. (2013) analyzed bending stress at critical section of asymmetric spur gear. Bending stress at critical section is most important parameter in gear design. It must be low as low possible. To minimize it by optimize all affected Parameters of asymmetric spur gear tooth to reduce Bending Stress at critical section of tooth. This reduction can translate into Increased Load Capacity, Size and Weight Reduction, Longer Life, Cost Reduction, Increased Reliability, Noise and Vibration reduction, Increased Gear Efficiency and Maintenance Cost Reduction etc. As the pressure angle on drive side increases, the bending stress reduces at critical section of asymmetric spur gear. But Decision on maximum magnitude of drive side pressure angle is constraint by the safe contact ratio and tooth peaking effect. These way parameters are affecting directly or indirectly on performance. There are so many parameters are likes Contact ratio, Top land tip thickness, Pressure angle on drive side profile, Pressure angle on coast side profile, Asymmetry factor, No. of teeth, Interference, Undercut, Centre distance, Gear ratio, Critical section thickness, Profile shift of pinion, Profile shift of gear, Module, Bending stress at critical section, Optimal fillet radius and Balance stress etc. affects the performance.

Rincon et al. (2013) presented the procedure to determine loaded transmission error of a spur gear transmission as well as meshing stiffness and load sharing ratio. The procedure also allows a better representation of load transfer between teeth pairs. The analysis of contact forces and deformations in spur gear transmissions was done using an advanced model. The deformation at each gear contact point was assumed as a combination of a global and a local term. The global term was obtained by means of a finite element model and the local term was described by an analytical approach derived from Hertzian contact theory. The quasi static behaviour of a single stage spur gear transmission was discussed in this study using numerical example, which showed the capabilities of the methodology to obtain the loaded transmission error under several load levels as well as some other related measures such as load ratio or meshing stiffness.

III. SPUR GEAR

NOMENCLATURE OF SPURGEARS

Pitch surface: The surface of the imaginary rolling cylinder (cone, etc.) that the toothed gear may be considered to replace.

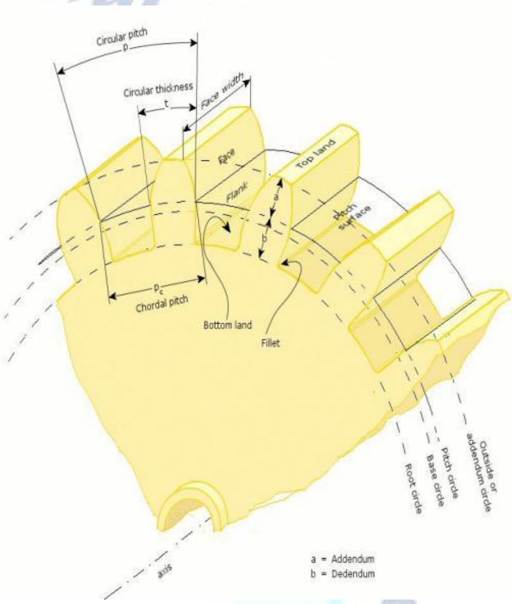

Fig 3.1. *Nomenclature of spur gear*

Pitch circle: A right section of the pitch surface.

Addendum circle: A circle bounding the ends of the teeth, in a right section of the gear.

Root (or dedendum) circle: The circle bounding the spaces between the teeth, in a right section of the gear.

Addendum: The radial distance between the pitch circle and the addendum circle.

Dedendum: The radial distance between the pitch circle and the root circle.

Clearance: The difference between the dedendum of one gear and the addendum of the mating gear.

Face of a tooth: That part of the tooth surface lying outside the pitch surface.

Flank of a tooth: The part of the tooth surface lying inside the pitch surface.

Circular thickness (also called the **tooth thickness**): The thickness of the tooth measured on the pitch circle. It is the length of an arc and not the length of a straight line.

Tooth space: pitch diameter The distance between adjacent teeth measured on the pitch circle.

Backlash: The difference between the circle thickness of one gear and the tooth space of the mating gear.

Circular pitch (Pc) :The width of a tooth and a space, measured on the pitch circle.

Diametral pitch (Pd): The number of teeth of a gear unit pitch diameter. A toothed gear must have an integral number of teeth. The circular pitch, therefore, equals the pitch circumference divided by the number of teeth. The diametral pitch is, by definition, the number of teeth divided by the pitch diameter. That is,

Module (m): Pitch diameter divided by number of teeth. The pitch diameter is usually specified in inches or millimeters; in the former case the module is the inverse of diametral pitch.

Fillet: The small radius that connects the profile of a tooth to the root circle.

Pinion: The smaller of any pair of mating gears. The larger of the pair is called simply the gear.

Velocity ratio: The ratio of the number of revolutions of the driving (or input) gear to the number of revolutions of the driven (or output) gear, in a unit of time.

Pitch point: The point of tangency of the pitch circles of a pair of mating gears.

Common tangent: The line tangent to the pitch circle at the pitch point.

Line of action: A line normal to a pair of mating tooth profiles at their point of contact.

Path of contact: The path traced by the contact point of a pair of tooth profiles.

Pressure angle ( ): The angle between the common normal at the point of tooth contact and the common tangent to the pitch circles. It is also the angle between the line of action and the commontangent.

Base circle: An imaginary circle used in involute gearing to generate the involutes that form the toothpro

IV. METHODOLOGY

InSOLIDWORKS five different models of spur gear were created. Using the assembly option in SOLIDWORKS assemblies were created corresponding to the models. The assembly, which was created in Pro/E, was imported in ANSYS Workbench for further analysis. The other way of importing the assembly is by importing the IGES or STEP file of the assembly. In this the spur gear assembly is subjected to assume driving condition and are analyzed for the bending moment. The dimensions of gear are taken as mentioned in the following table.

Parameters	**Gear 1 (larger)**	**Gear 2**
No. of teeth	36	18
Diameter (mm)	150	75.5
Module(mm)	4.167	4.167
Gear width (mm)	25.4	25.4

Table 4.1.*Gear parameters taken.*

ANSYS is the name commonly used for ANSYS mechanical, general-purpose finite element analysis (FEA) computer aided engineering software tools developed by ANSYS Inc. ANSYSmechanical is a self-contained analysis tool incorporating pre-processing such as creation of geometry and meshing, solver and post processing modules in a unified graphical user interface.

ANSYS is a general-purpose finite element-modeling package for numerically solvingwide variety of mechanical and other engineering problems. These problems include linear structural contact analysis that is non-linear. Among the various FEM packages, in this work ANSYS is used to perform the analysis.

The following steps are used in the solution procedure using ANSYS

- The geometry of the gear to be analyzed is imported from solid works in IGES format this is compatible with the ANSYS.

- The element type and materials properties such as Young's modulus and Poisson's ratio are specified.

- Meshing the three-dimensional gear model. Figure 4.4 shows the meshed 3D solid model of gear.
- The boundary conditions and external loads are applied.
- The solution is generated based on the previous input parameters.
- Finally, the solution is viewed in a variety of displays.

After the assembly is imported in ANSYS Workbench 12, assembly is subjected to the boundary conditions. In this thesis it is assumed that the one gear is fixed and the other gears is given torque along its axis. As both the teeth are already in contact, the main purpose is to study the root bending stress and the contact stresses due to the applied torque.Following are steps followed for the Finite ElementAnalysis.

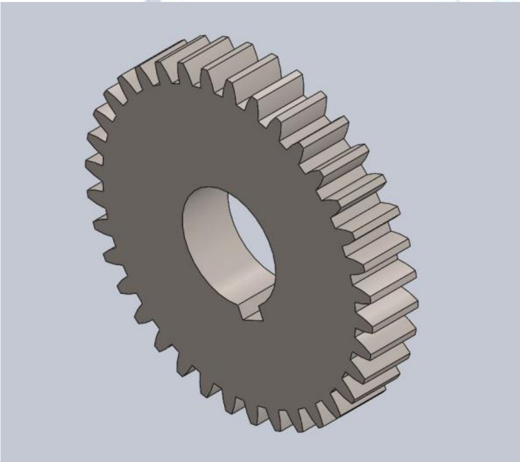

Fig 4.1. *Driven gear.*

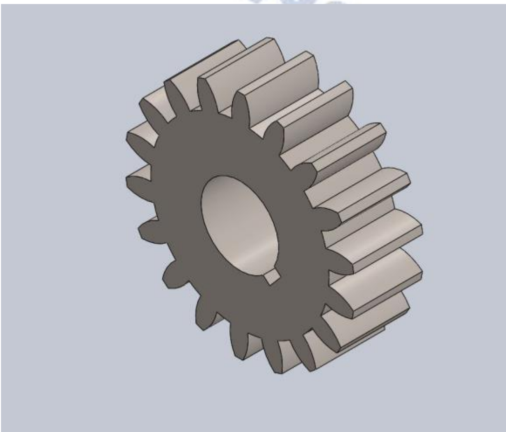

Fig 4.2. *Driver gear.*

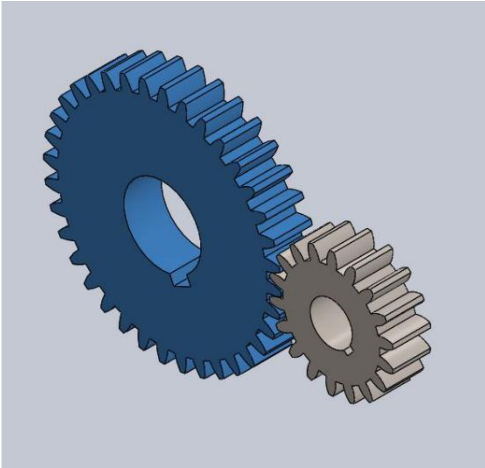

Fig 4.3. *Spur gear assembly.*

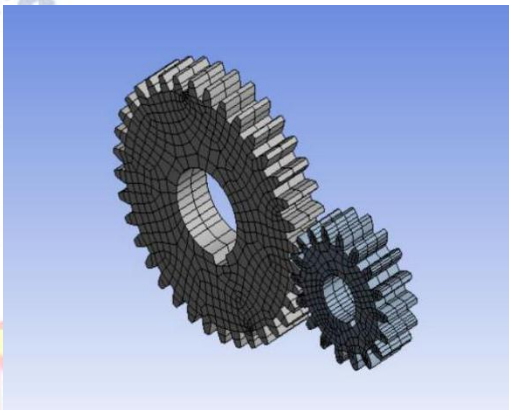

Fig 4.4. *Mesh generation*

THREE-DIMENSIONAL ANALYSIS

ANSYS has many types of analysis, so it is necessary to select the correct type of analysis from the menu bar. As the imported geometry is 3-Dimensional, select 3-D and Static Structural Analysis from menu and connect the geometry to the analysis tab. Then the next step is to enter the Young"s Modulus and Poisson"s ratio of the material. This can be done by selecting the Engineering Data from the analysis tab and inserting the corresponding values.

BOUNDARY CONDITIONS

The lower gear is given a fixed support and the top gear is given frictionless support. The top gear is also given a toque or a moment in clockwise direction. The image below shows how the supports and loads were applied to the gear model.

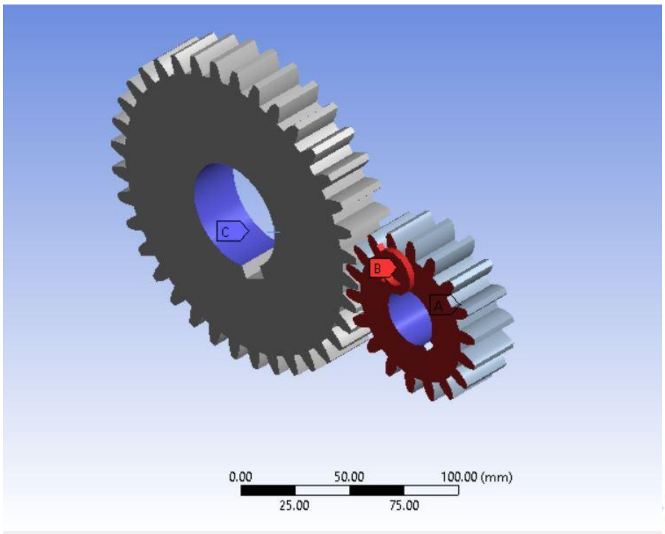

Fig 4.5. *Applied Boundary Conditions.*

Table 4.2. *Loading condition for static load analysis.*

	Loading Condition	Moment(N/mm)
1	Face of gear	3000

V. SIMULATION RESULTS

After performing the structural analysis on the spur gear set for initial maximum torque of terrain vehicle.

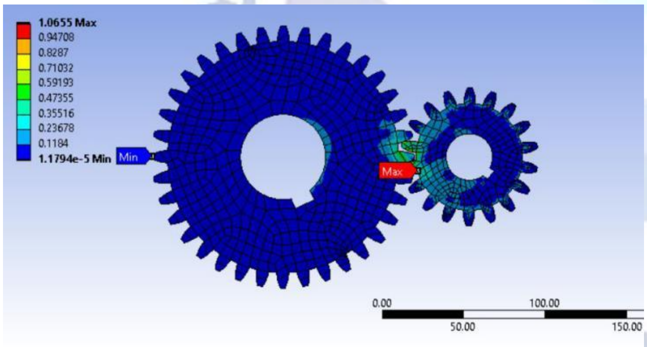

Fig 5.1. *Stress distribution.*

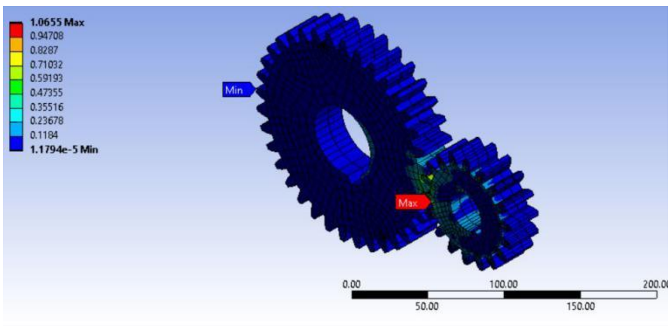

Fig 5.2. *Isometric view of stress distribution.*

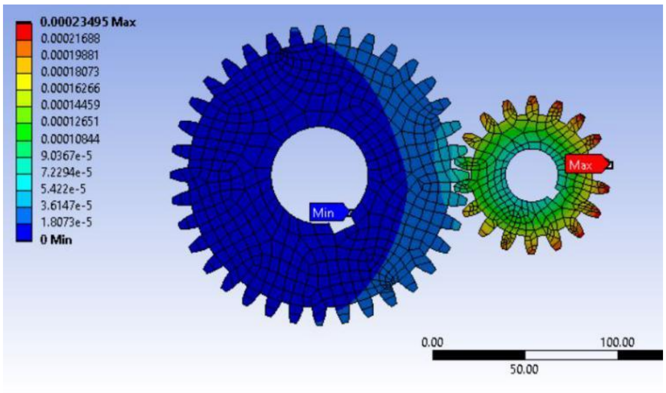

Fig 5.3. *Deformation in spur gear.*

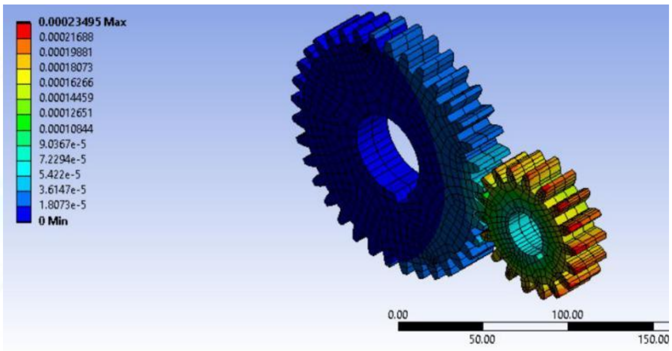

Fig 5.4. *Isometric view of deformation.*

VI. FUTURE SCOPE AND CONCLUSION

In this study a three dimensional deformable-body model of spur gear was developed. The results obtained were then compared with the standard mild steel material properties. The results are in good congruence with the mild steel values, which implies that the model designed is correct. According to the results obtained following conclusions can be drawn.

By using a relational equation modeling in Solid works, one can accurately design complicated parts like involute tooth gears. This process can be very helpful in contact problems as it needs model with high accuracy It also decreases the lead times and improves overall engineering productivity.

A discrete model of spur gear was proposed. The Finite Element results matched well with the numerical results. Thus, this parametric model turns out to be a fast and accurate method of computing stress problem of the spur gear system.

Stress values giving better results and the factor of safety of gear is 2.5. which shows the better life of the gear with better performance.

At the end of this work, it is concluded that solving gear stress problems in design is fairly easy by use of commercial FEM and designing packages available today.

This study can be extended for calculation of accurate contact stresses by using the contact element in ANSYS classic and then it can be analyzed for different types of contact depending on the lubrication used.

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