Stress Analysis of Bevel Gear Tooth using FEA: A Review

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Abstract— Gears are the device used to transmit motion from one shaft to another shaft by direct contact. Tooth of the gear is most important device in a gear system and has focused in the current study. A detailed study about the earlier work conducted on the design and stress analysis of tooth of bevel gear using ANSYS and other simulating software is presented. Discussion about the types of materials being used for manufacturing of tooth of bevel-gear and the stress acting on the surface of tooth of bevel gear and its parts has presented. Tool geometry has represented for the nomenclature used during its bevel-gear design and manufacturing. Literature shows that helical bevel gear is best and can be manufactured on the same unit that of spur gears with same precision. Tooth of the gear is the most important part as they goes under high load and stress which are the reasons of the failure of gear. A design of the bevel gear is presented in the paper. 20 number of tooth has considered at the profile of the gear.

Key words: Stress Analysis, FEA

I. Introduction

Every shaft has gears which are connected to each other by teeth. The two bodies have either roiling or sliding motion along the tangent at the point of contact. Along the common normal no motion is possible because in this case either one body will pierce into another body or a contact between them will break.

There are wide ranges of gears utilized by industry, yet every one of these gears has the same reason, which is to transmit motion starting from one shaft to other. Gear can be classified as Parallel shaft which are spur and helical gears, while the other one are intersecting shaft which are bevel and spiral gears. This study focuses on the bevel gears tooth analysis. They are widely used in aircrafts, automobiles, and heavy engineering machines. They can be classified as, Straight bevel gears, Spiral bevel gears, Zerol bevel gears and Hypoid gears.

A. Straight Bevel Gear

In these type gears teeth of the gears are straight and radial to the intersection point of the shafts shown in figure 1. Teeth vary in cross section throughout their length. When two bevel gears connected to each other perpendicularly (at 90°) they also called Mitre gears.

Fig. 1: Straight-Bevel Gear

Fig. 2: Spiral-Bevel Gear

B. Spiral Bevel Gear

When teeth of the gears are inclined at an angle to the face of the bevel they are known as spiral bevel or helical bevel gear shown in figure 2. Same as helical gears they also have gradual load and low impact stress.

C. Zerol Bevel Gear

They are the types of spiral bevel gears with curved teeth. But they have zero degree spiral angle.

Fig. 3: Zerol-Bevel Gear

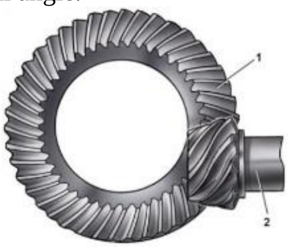

Fig. 4: Hypoid Gear

D. Hypoid Gear

In automotive differential applications, need to have gearing similar to bevel gears but with shafts offset these gears are called hypoid gears shown in figure 4, because of their hyperboloids of revolution of pitch surfaces.

1) Materials Selection For Tooth And Gear

The gear material should have high tensile and endurance strength to prevent failure against static load and dynamic load respectively. They also have low coefficient of friction and good manufacturability. Different materials used for gear manufacturing are, Steel, Carbon steel, Brass, Aluminium, Cast iron and Plastics.

E. Tooth Geometry

- Addendum of pinion (gear) AP (AG):It is defined as the height projected by the tooth above the pitch cone.
- Clearance (c): It is defined as the distance exceeds by the Dedendum of a gear by the addendum of meshing gear.
- Backlash (B): It is the difference between the space width and tooth thickness along the pitch circle.
- Cone distance, mean (Am): It is the distance measured from the pitch cone apex to the middle of the face width.
- Cone distance, outer (Ao): It is the distance measured from the pitch cone apex to the outer end of teeth.
- Cutter radius (rc): It is the radius of the wheel used to cut the spiral-bevel gear.
- Pitch diameter (pm): It is the diameter of the pitch circle; gears are usually specified on the basis of pitch circle diameter.
- Shaft angle (∑): It is the angle between the axis of pinion and gear shaft.

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- Root angle of pinion (γR): It is the angle between the root element and its axis.
- Pressure angle (ϕ): It is the angle between the line joining the centres of the two gears and the common tangent to the base circles.
- Crown Point of pinion (gear) xo (Xo): It is the distance measured in the axial direction in an axial section from the crown of the corresponding point.
- Face width (F): It is the length of the teeth measured along the pitch-cone element.
- Dedendum angle of pinion (gear) δP (δG): It is the angle between the root cone and pitch cone elements

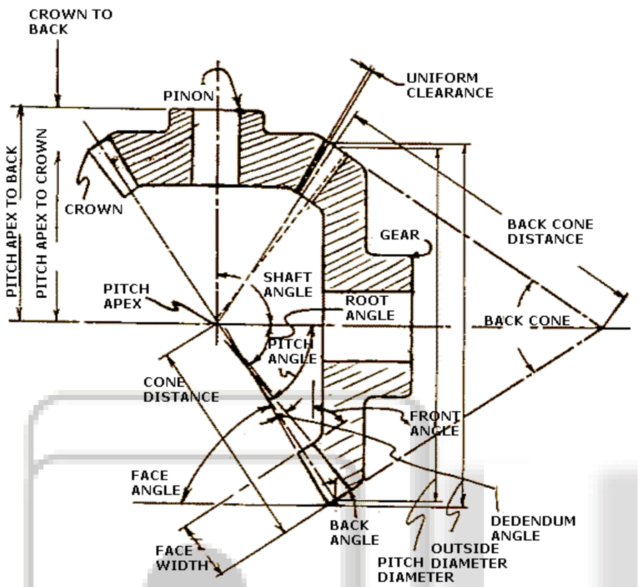

Fig. 5: Bevel-Gear Geometry

II. LITERATURE REVIEW

Chen B. et al in 2015 conducted study on spatial curve meshing and its application for logarithmic spiral bevel gear.[1] They targeted their study for the curve theory of gear transmission meshing for high performance applications. They studied different gear geometries and space curve meshing kinematics for design of a gear. From the space curve detailed study they discuss about the conjugate curve theorem and their meshing. They used logarithmic spiral bevel gear theory and conjugate curve information and developed a mathematical model for conical-helix bevel gears. They have used ANSYS to validate their results developed by their mathematical model for specific profiles. They concluded known curve normal vector must be determined before finding the conjugate of space curve. Norma vector helps in determining the pressure angle for the tooth surfaces drawn. Relative curve magnitude acts as constraints for drawing proper meshing of tooth surfaces with arbitrary cross-sections from conjugate curve and known curve details.

Fong Z-H and Lin C-H in 2015 numerically studied the tooth contact analysis of a bevel gear set by using measured tooth geometry data.[2] They developed a numerical tooth contact analysis (NCTA) for single flank simulation by data measured on gear meshing centre. The contact pattern and corresponding transmission error been calculated by the position vector from their developed NCTA. The residual error for the surface fitting is almost around 100μm but residual error calculated by them is around 0.2μm. The bevel gear tooth surface measured by them by B-spline method was more effective. They compared contact pattern theoretical results with QT (Qua-tree) search algorithm and with TE (Transmission error) by LRA (Least rotation angle) and found good agreement.

Kawasaki K et al in 2015 studied the method for manufacturing large-sized skew bevel gears using CNC machining center.[3] They proposed a method for remanufacturing pinion member using CNC machining of skew-bevel gear of large size. They modelled the skew bevel gear tooth surfaces numerically and mathematically.CMM has been used by them to measure the real gear tooth surface. They compared the CMM measured results with the simulation results. They formulated a polynomial expression for the deviation between the real and simulation results. Transmission error and tooth contact pattern shows the deviation has been designed and analyzed. Swarf cutting CNC machine has been used to produce pinion member. They also compared the deviation results with the analytical results for the pinion member manufactured by CNC.

Lopatin B. A. et al in 2015 studied the involute helical-bevel gearing.[4] In this study they dictated about the aspects during helical-bevel gear design. They concluded that involute gears can be designed for any shaft-axes position, parallel, intersecting or skew. For small interaxal angles less than 20° and taper angles less than 15° helical-bevel gear (HBG) are most efficient they depends on the displacement coefficient of its faces. They concluded that HBG main advantage is that they can be manufactured on the same unit that of spur gears with same precision.

Kawasaki K. and Shinma K. in 2014 designed and manufactured a straight bevel gear for precision forging die by direct milling.[5] They targeted their study towards the increasing the production rate and reducing the cost of gear production. A quasi-complementary crown gear has been introduced by them instead of a conventional crown gear for generating the gear tooth profile. 3D-CAD has been used to model the gear tooth profile. First they calculated the co-ordinates of the straight bevel gear tooth surfaces then the CNC milling machine has been used to generate the straight bevel gear by precision die casting. From their results they found that precision die casting helps in improvement of cost reduction and in increment in production rate.

Xuemei C. et al in 2008 studied the design of pinion machine tool-settings for spiral bevel gearsby controlling contact path and transmission errors.[6] For their study they give three control points on the tooth surface and their study was based on the contact condition on the tooth surface of these given points. These three control points have been chosen based on the parabolic function of transmission errors. Magnitude of transmission errors and contact path orientation has been designed. They have also designed the blank offset which gives no effect on the transmission errors. A spiral bevel gear has also been designed on the Phoenix grinding machine to represents the calculated values from results.

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Wang and Howard in 2005 conducted FEA for high contact ratio gears in mesh.[7] The numerical model has been developed under quasi-static conditions when gears in mesh. Other consideration are tooth root stress against various input loads over a complete mesh cycle, load-sharing ratio, contact stress, transmission error, combined torsional mesh stiffness. Numerous modifications in tooth profile have been presented and comparisons between the results suggest optimal profile modification to gain the maximum benefit of high contact ratio gears.

Wang P-Y and Fong Z-H in 2005 mathematically model the face-millingspiral bevel gear with modified radial motion (MRM) correction.[8] They told that conventional machine setting calculation for spiral and bevel gear by face-milling based on the mean appoint local synthesis. They proposed a method for finding the accurate machine setting with MRM (modified radial motion). This method has been developed at the particular contact points on the pinion tooth surface with contact path bias and defined motion. Equation of meshing and mating curvature relationship at the specific contact points have been used to calculate the MRM (modified radial motion) parameters. They concluded that by giving the radial distance as a DOF parameter one can easily control the bias and kinematic error separately.

BaroneS. et al. in 2003 targeted at finding the behaviour of a face gear transmission with respect to contact path under loads and stresses, for an unchanged gear set with shaft arrangement and amendment on pinion profile. 3D CAD system with a FEA code by simulating the meshing of gear with three teeth and pinion, using meshed elements and an algorithm has been studied.[9] The concluded that the load influenced the theoretically calculated contact paths, contact areas, contact length and load sharing. They also noted that usefulness of numerical approach on meshing problem with complex geometry. Other considerations are surpluses loads due to pinion disarrangement and change of contact areas.

Argyris J. et al in 2002 generated a computerized integrated approach for design and stress analysis of spiral bevel gears.[10] They have proposed a new approach for spiral bevel gear stress analysis and synthesize. They simulated the meshing, contact of the gear tooth surface and local synthesis computerized. The modelled develop by them give less noise and vibration. They completed their study in four stages.Obtainment of desired shape and path contact, obtainment of transmission errors shape function and magnitudes for low-noise gear drive, adjustment and reductionof the bearing contact shift because of the misalignment, stress analysis of gear drive and enquiry of bearing contact during meshing.

Howard I. et al. in 2001 discover the friction effects on the resultant gear case vibration utilizing a simple gear dynamic model.[11] The model comprises development of a FEA (Finite Element Analysis) to see the consequence of deviations in gear tooth torsional mesh stiffness as gears mesh. A dynamic equation has been developed for frictional force between teeth. Frequency spectrum displays single tooth crack effects. They indicate the influence of the tooth crack for all dynamic variables in the time waveforms neglecting friction.

A. Outcomes of Literature Review

1) Manufacturing of bevel gear is one of the most crucial stages.
2) Helical bevel gears are found to be most advantageous.
3) There is no specific method available for analysis of bevel gear.
4) Manufacturing of bevel gear should include the where the gear is going to be used based on the loading conditions.
5) Fatigue life need to be studied in detail so that the some steps could be taken before the failure of bevel gear.

B. Objective of Research

1) To find out the stress generated in the tooth of bevel when it gets loaded.
2) To study the fatigue life of tooth and bevel gear.
3) To study the different methods used for meshing in FEA.

C. Problem Formulation and Proposed Research Work

Finite element (FE) tool ANSYS will be used for the mathematical modelling of the bevel gear.Different loading conditions which represent the actual physical scenario will be applied.Stress and strain generated will be studied based on the loading condition.Fatigue life will also be studied using the ANSYS.Effect of different gear materials will also be studied.Geometry of the bevel gear has been modelled. A total of 20 numbers of teeth has been drawn on the circumference of the bevel gear. Figure 6 illustrates the geometry drawn of the bevel gear in a FE tool.

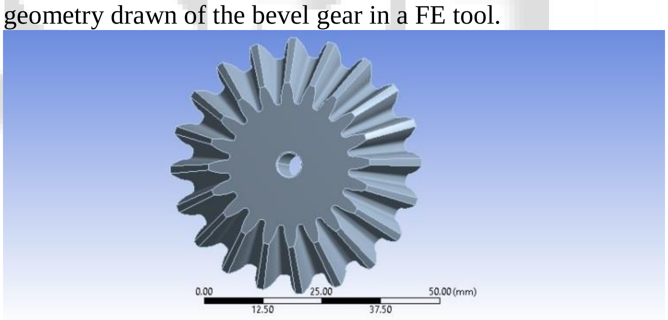

Fig. 6: Geometry of the Bevel Gea

III. CONCLUSION

1) Known curve normal vector must be determined before finding the conjugate of space curve. Normal vector helps in determining the pressure angle for the tooth surfaces drawn.
2) The bevel gear tooth surface measured by them by B-spline method was more effective.
3) Swarf cutting CNC machine can be used to produce pinion member.
4) HBG (Helical Bevel Gear) main advantage is that they can be manufactured on the same unit that of spur gears with same precision.
5) Precision die casting helps in improvement of cost reduction and in increment in production rate of bevel gear.
6) Phoenix grinding machine can be used for spiral bevel gear.

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7) Radial distance as a DOF parameter can easily control the bias and kinematic error separately.

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