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Design and Analysis of Helical Gear Pair using ANSYS, FEM and AGMA Standards for Calculating a Bending and Contact Stress on Gear Profiles: A Review

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Abstract
Gear failure can be controlled by their tooth surface strength; the bending effects and wear effect are major parameters, affected in any gear system to minimize or reduce the failure. The following paper aims to provide information on the bending and contact stress analysis of helical gear pair. Thus, the analysis of stress, bending effects and contact effects to minimize or reduce the failure of gears. Therefore, present paper focuses on the theoretical and finite element method to calculate bending and contact (Root and Flank safety) stresses on the tooth geometry of major effected parameters on helical gear pair. Authors have to use the various approaches to calculate the wear and bending effects of gear failure cause in static condition using finite element analysis, AGMA standard and ANSYS. This review paper contains theoretical, numerical and analytical methods for the helical gear pair analysis.

Keywords: *Helical gear pair, AGMA, ANSYS, contact stress, bending stress, bending strength, surface fatigue strength, tooth surface strength of gear*

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INTRODUCTION

Gears are needful to the modern global economy and are used in almost all applications where power transmission is required, such as industrial equipment, automobile industry, marine vessels, aerospace industry, aircraft industry, automotive industry and other industries. Gears with involute teeth are widely used in industry because of the low cost of manufacturing. For transmitting power and motion from one shaft to another shaft, gears are used. Gears are mostly used to transmit torque and angular velocity.

Helical apparatus are vital parts for any transmission (Figure 1). In present times, helical gears are being utilized as a power transmitting gears because of their moderately smooth and quiet Operation, huge load conveying limit and higher working velocity and smoother engagement of teeth; power can be exchanged between two non-parallel shafts, they are highly effective and so on. Their tooth twisting anxiety and surface contact push had dependably been one of the explorations engaged, and numerous researchers have done a considerable measure of work on it. The tooth bending stress and surface contact stress of these gears had always been one of the major areas of research for scholars. The designing of a helical gear pair is a complex process. Generally, it needs a large number of iterations and datasets. Helical gear can fail due to excessive bending stress at root of gear tooth or surface contact stress. This can be changed by minimizing bending stress and contact stress or by modifying the geometry or parameters of the gear tooth.

The large helix angle provides a smoother operation than the spur gears to these helical gears as it increases the length of the contact lines. But the stresses occur when the two gears come in contact during the process of power transmission. Due to meshing between two gears, contact stresses are evolved, which is calculated by using ANSYS, software used for this kind of analysis.

LITERATURE REVIEW

In order to have the detailed knowledge of developments in the field of bending and contact stress analysis of helical gear pair a literature review was carried out.

Jyothirmai *et al.* mentioned comparative study on helical gear design and its performance based on various performance metrics through the finite element analysis and theoretical analysis by AGMA standard in their study "A Finite Element Approach to Bending, Contact and Fatigue stress Distribution in Helical Gear Systems" [1] (Figure 5 ad 6). Then after, the FEA and theoretical results were compared with each other. Models were created by the proE engineer by CAD software (Figure 2 and 3). The benefit of paper is that comparisons are quick in estimating stress distribution for new design without carrying complex theoretical analysis, and FEA gives less scope for manual errors. Processing time was reduced and final flexibility in design is increased. This analysis is calculated in three gear systems signal helical gear pair, double helical gear pair and crossed helical gear pair (Figure 4). In FEA calculation of bending stress is done by vonmiss stress, and principal stress theory and hertz theory are used for calculating the contact stress in helical gear systems.

Fig. 1: *The Helical Gear.*

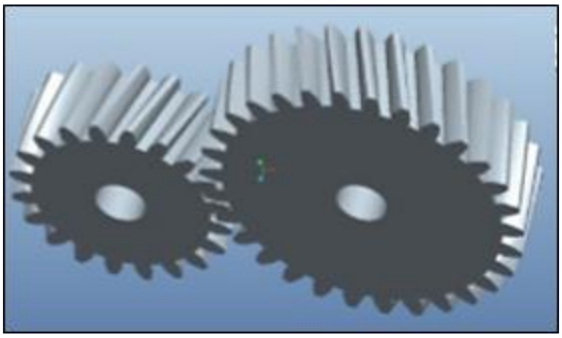

Fig. 2: *Modeling of Single Helical Gear in Pro/E.*

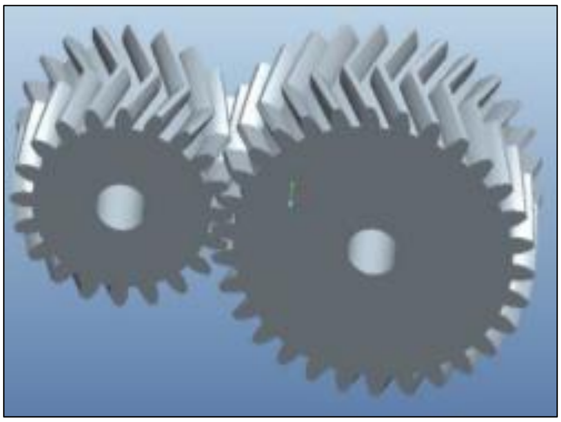

Fig. 3: *Modeling of Double Helical Gear in Pro/E.*

Fig. 4: *Modeling of Crossed Helical Gear in Pro/E.*

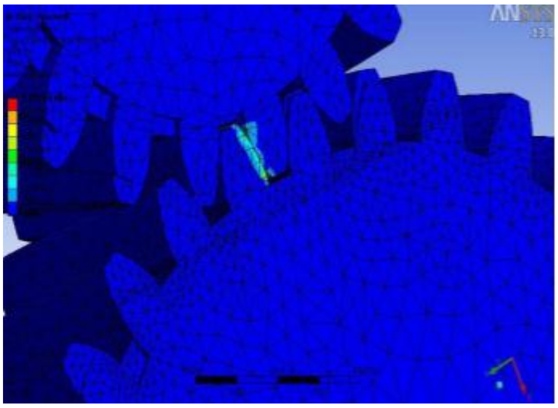

Fig. 5: *Tooth Bending Stress Distribution for Single Helical Gear.*

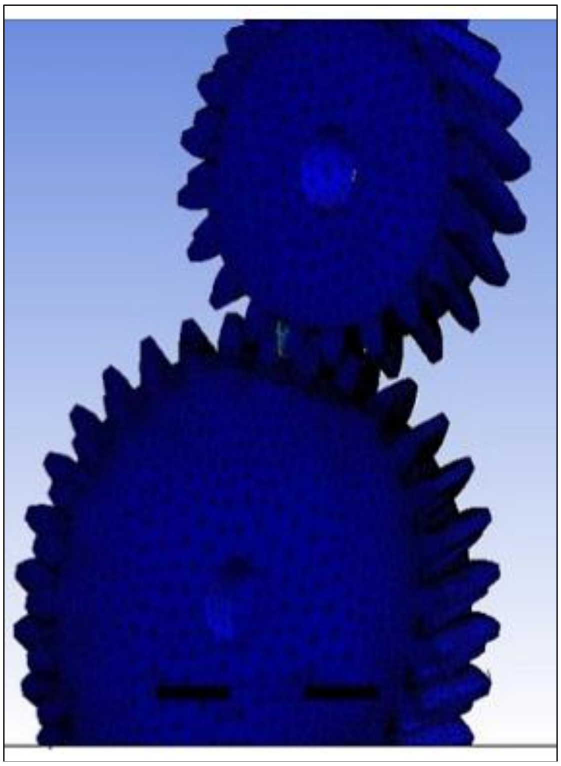

Fig. 6: *Fatigue Stress Distribution for Single Helical Gear.*

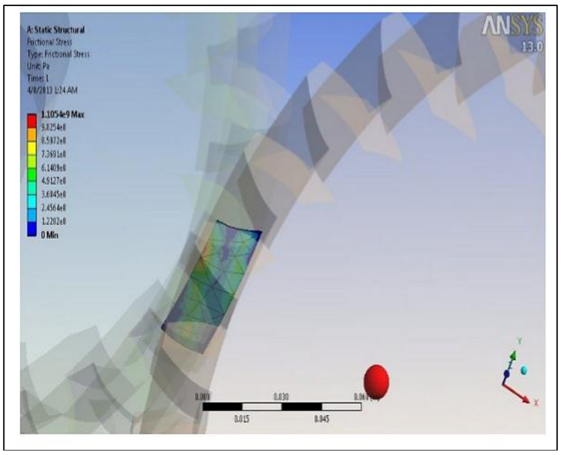

Fig. 7: *Contact Analysis for Double Helical.*

Venkatesh and Murthy also stated the methods that were used to calculate the bending and contact stresses of involute helical gear pair [2]. The 3-D solid modeling of helical gear pair was done with the help of Pro-E software (Figure 8), whereas Lewis beam strength equation and ANSYS were used to calculate bending stress. Contact stresses are calculated by using AGMA contact stress equation and ANSYS software, and in the last, the results of bending and contact stress are compared with each other.

Achari *et al.*, in their study "A Comparison of Bending Stress and Contact Stress of a Helical Gear as Calculated by AGMA Standards and FEA" revealed that the design of gear, the surface and tooth root strength of the gear contribute to the failure in gear pair [3]. Stress analysis in gear has turned out into a trending topic of research to lessen or to limit the failure and for ideal design of gear sets. In this paper, bending stress and surface contact stresses at the root of the helical gear tooth were calculated by utilizing hypothetical technique and also FEA. Lewis beam strength method was used to appraise the bending stress at the tooth root. 3D solid model (Figure 9) of helical gear was created using modeling software, NX CAD 8.5 and the bending stress of gear tooth root was examined by NX Nastran 8.5. Contact stresses were computed as per the guidelines set by AGMA. Finally, the outcomes of tooth root bending stress and contact stress were compared (Figure 14).

Fig. 8: *Solid Model of Helical Gear by Pro-E.*

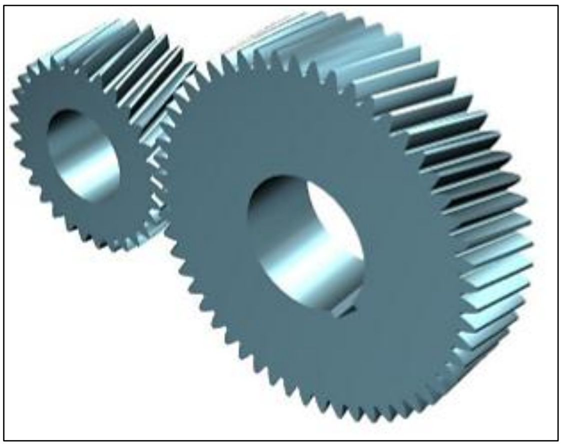

Fig. 9: *3D Solid Model of Contact Gear Pairs.*

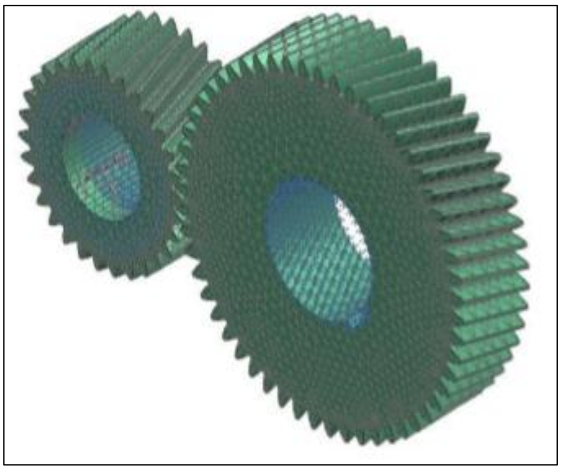

Fig. 10: *FEM Model with Boundary Conditions Applied.*

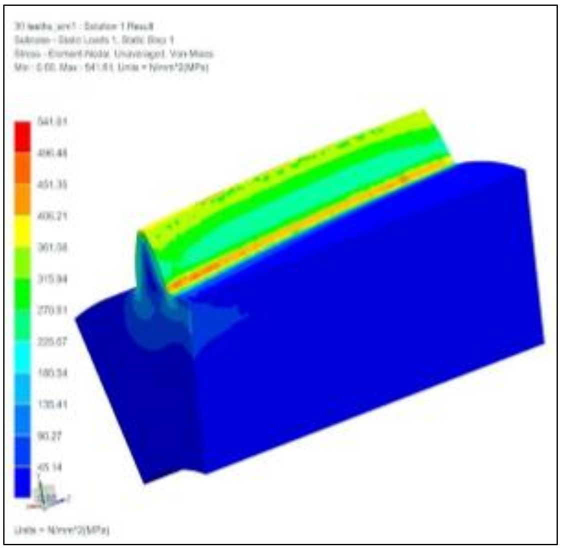

Fig. 11: *Bending Stress of the Pinion.*

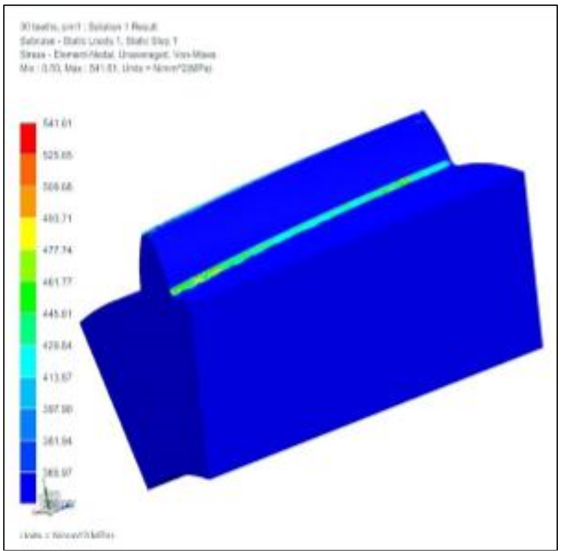

Fig. 12: *Bending Stresses of Pinion by Specifying Ranges from 300 N/mm2 to Maximum Von-mises Stress (541.61 N/mm2).*

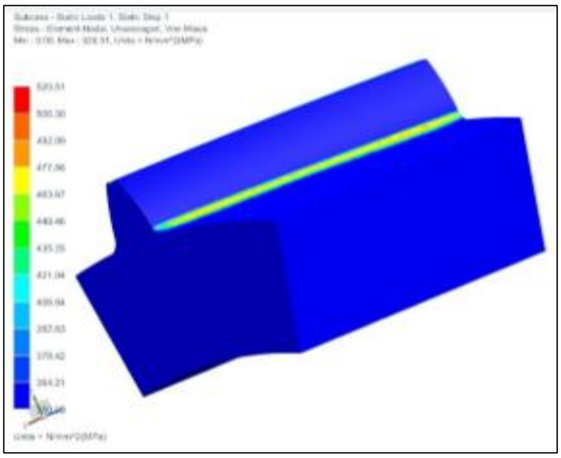

Fig. 13: *Bending Stress of Gear by Specifying Ranges from 350 N/mm2 to Maximum Von-mises Stress (520.51 N/mm2).*

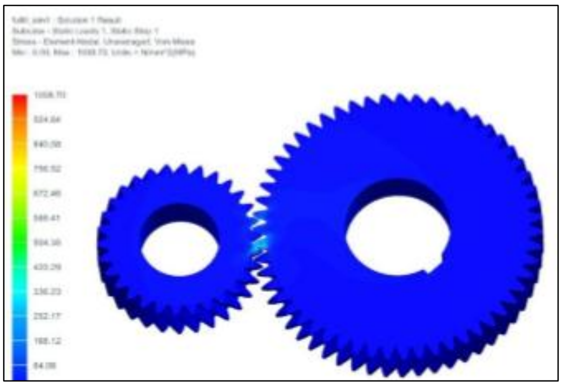

Fig. 14: *Contact Stress of the Helical Gear Pair.*

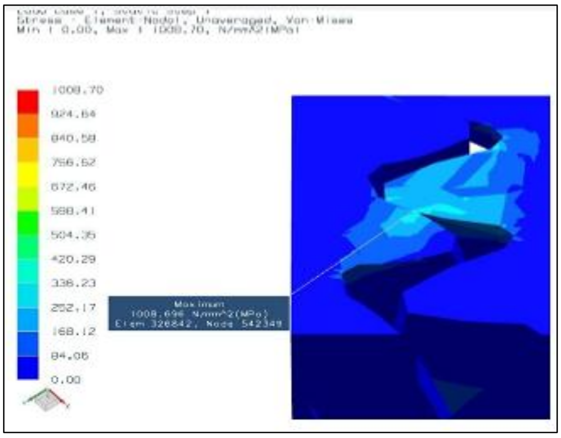

Fig. 15: *Contact Stress of the Helical Gear Pair.*

Malek revealed in their study, a concise survey of plan, modeling and analysis of high speed helical gears utilizing AGMA and ANSYS from different width and helix point [4]. They found their impact because of bending and contact stress and its value was compared with ANSYS and AGMA (Figure 15).

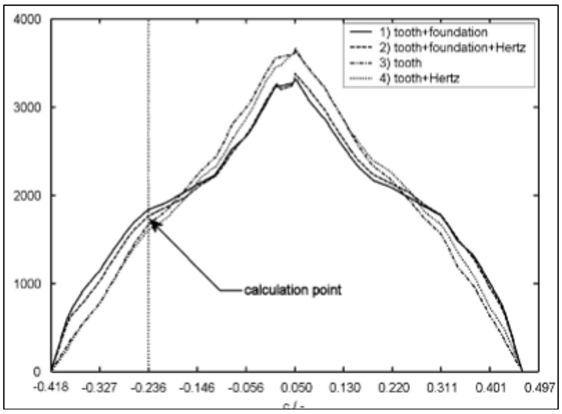

Fig. 16: *Single Tooth Contact Force along the Line of Action.*

Hedlund and Letovaara presented a paper, "Modeling of helical gear contact with tooth deflection"; in this paper, mostly helical gears are used in industry, focuses on the modeling of helical gear contact with tooth deflection [5]. A calculation model for helical gear contact analysis for construction of tool geometry by simulating the hobbing process, was presented. The model used three-dimensional finite elements for the calculation of tooth deflection including tooth bending, shearing and tooth foundation flexibility. The model combined contact analysis (Figure 7) with structural analysis to avoid large meshes. Tooth foundation was found to have an essential role in contact load sharing between the meshing teeth, whereas contact flexibility played only a minor role.

A study by Anusha *et al.* proved that the bending and contact stress of gear tooth were considered to be causing the failure in gear pair [6]. Experiments were conducted to utilize the helical gear by evaluating the contact stress at different pressure angles (14.5, 16, 18 and 20˚), helix angles (15, 20, 25 and 30˚) and face width (80, 90, 100, 110 and 120 mm). A three-dimensional solid model was generated by Pro-E modeling software and calculation was done by finite element analysis software, ANSYS. This discrete approach was used to determine the contact stress between two gears which was based on contact stress equation. The results obtained were thus compared with the theoretical values available.

Mao mentioned a gear tooth contact analysis and its application in the reduction of fatigue wear through micro-geometry modification method [7]. He mentioned that a wear is produced by the shaft misalignment and assembly deflection effects on gear surface. The tooth profile was generated mathematically by using the finite element analysis (FEA) software instead of importing from other computer aided design (CAD) software in order to achieve high accuracy of the gear pair. Real rolling and sliding contact simulations have been achieved by the use of latest non-linear FEA techniques.

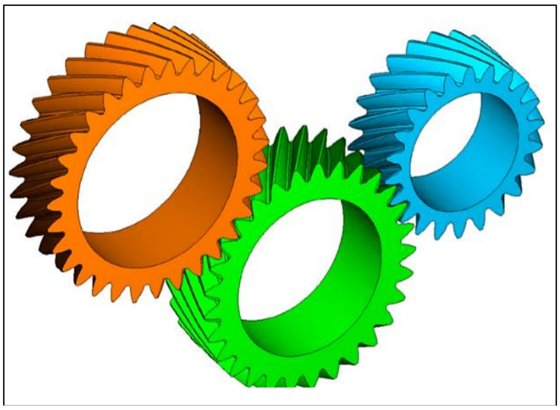

Fig. 17: *Generated Helical Gears and their Assembly.*

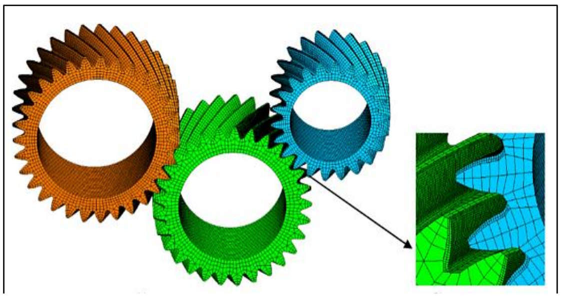

Fig. 18: *Three Gear Mesh Assembly and Details of their Local Mesh.*

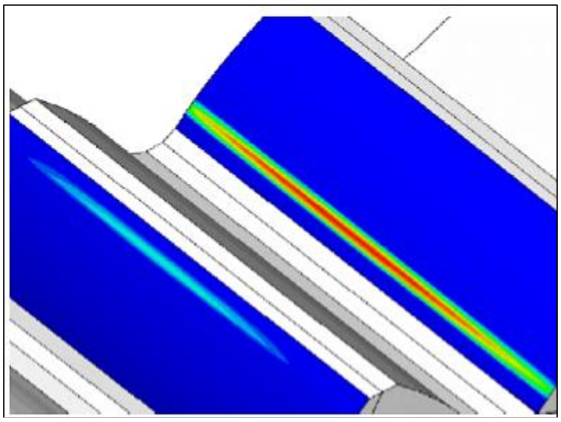

Fig. 19: *Tip Relief for the Original Design.*

Venkatesh *et al.*, the authors mentored that in this paper "Investigate the combined effect of gear ratio, helix angle face width and module on bending and compressive stress of steel alloy helical gear" the work is to focus on investigating the combined effect of gear ratio, helix angle, face width and normal module on bending and compressive stress of high speed helical gear as shown in the Figures 20–23, relation between bending stress and gear ratio, helix angle face width and module [8]. Figure 20 shows that when the gear ratio are increased from 4 to 8, then bending stress is constant and other parameters are is also constant (Figure 21). The helix angles, gear ratio, and module are kept constant, when face width is increased from 41 to 49, the bending stress decreases linearly from 580 kgf/cm^2. Figure 22 shows that the face width, gear ratio, corresponding to optimum earlier and module is constant, when helix angle is increased from 15 to 35 the bending stress was decreased from 580 to 492 kgf/cm^2 (Figure 23). The values of face width, gear ratio and helix angle are constant, when module is increased from 16 to 24 mm, the corresponding bending stress was decreased from 580 to 258 kgf/cm^2, thereby giving the maximum bending stress 580 kgf/cm^2 for input parameters viz. gear ratio=6, face width=41, helix angle=15 and module=16.

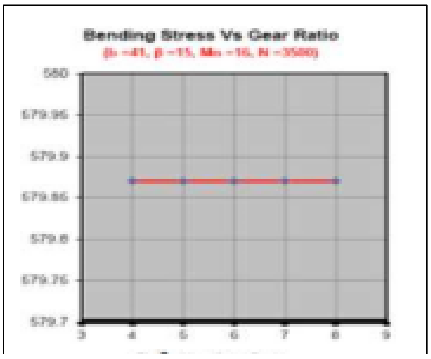

Fig. 20: *Gear Ratio.*

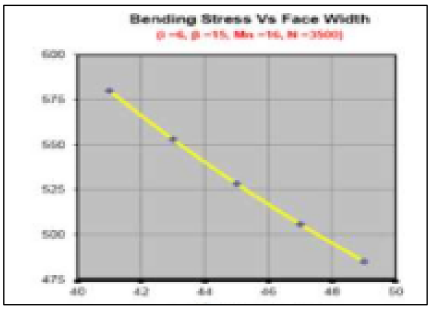

Fig. 21: *Face Width.*

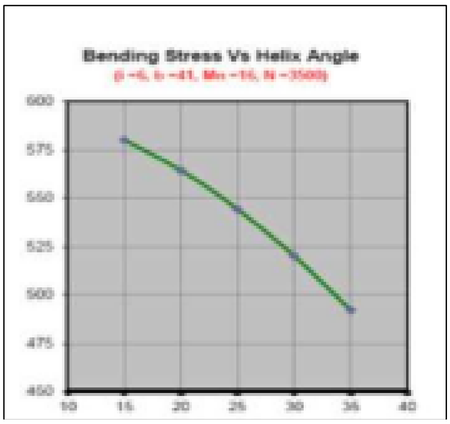

Fig. 22: *Helix Angle.*

Fig. 23: *Module.*

Figs. 20,21,22,23: *Variation of Bending Stress for Different Input Variables.*

Vishwakarma and Joshi studied the finite element model for observing the stress lured of tooth flank, tooth fillet during meshing of gears [9]. The helical gear pairs have to pass through the bending and contact stress for estimation by generating 3D models using CATIA V5 and simulation by finite element software ANSYS 14.0. Lewis and AGMA bending equations were used for analytical calculation of bending stress of gear. And Hertz and AGMA were used for contact stress respectively. Face width was varied to study its impact on bending stress of helical gear and it was concluded that maximum bending stress decreases when the face width is increased (Figure 19).

Chen and Tsay proposed a helical gear pair consisting of an involute pinion and a double crowned gear, in their study mentioning the stress analysis of a helical gear pair with localized bearing in contact [10]. Mathematical models based on the theory of gears followed by the standards have been calculated for pinion and gear (Figure 11-13).

The distribution of stress on gear was estimated by ABAQUS, FEA software and was calculated after the mesh was generated.

Asi had mentored a fatigue failure of a helical gear in a gearbox [10]. A failure analysis of a helical gear used in gearbox of a bus, which is made from AISI 8620 steel, was done. Evaluation of the failed helical gear was undertaken to assess its integrity that included a visual examination, photo documentation, chemical analysis, micro-hardness measurement, and metallographic examination. The failure zones were examined with the help of a scanning electron microscope equipped with EDX facility. Results indicate that teeth of the helical gear failed by fatigue with a fatigue crack initiation from destructive contact and bending region at one end of tooth in the pitch line because of misalignment of shaft.

Sameer and Srikanth conducted a parametric study to interpret the effect of contact stress analysis on helical gears using CATIA and ANSYS [11]. Strength of the gear tooth was a crucial parameter to withstand failure. Results obtained from ANSYS through varying geometries were compared to determine the methods which can improve and withstand pitting failure during the wearing effects produced by contact analysis of two gear pairs.

Achari *et al.* presented "A comparison of bending stress and contact stress of helical gear as calculated by AGMA standards and FEA" [12].

Singh and Parvez conducted a study primarily focused on the calculation of bending and contact stress and their comparison with the results obtained by hypothetical and finite element analysis [13]. A 3D model generated using Pro/Engineer was created according to the number of teeth, and ANSYS was used for calculation. The study was carried out by varying face width and helix angle and their impact on bending stress on sets of helical gear.

Bhosale had done the analysis of bending strength of helical gear by FEM and bending stress was calculated using 3D photo elasticity [14] (Figure 10). The parameters were as follows:
Helical gearbox with 2.2 kW power transmission at 760 rpm and number of teeth=30 mm, pitch circle diameter=60 mm, module=2 mm, pressure angle=20°, helix angle=12, Addendum=64 mm, base circle diameter=56.38 mm, Dedendum=55 mm. A solid model was created using CATIA and thereafter meshing was done with hypermesh. ANSYS Workbench 12.1 performed the analysis. Lewis equation was interpreted to calculate bending equation for a pair of helical gear and subsequently the results were compared (Figure 17, 18).

Stress analysis of helical gears by finite element method was conducted by Sarkar *et al.* to analyse the involute gear pair with transmission ratio [15]. The properties of gear pair were, number of teeth T1 and T2=25, Std. tooth profile, face width b=72.86 mm. Module mn=5 mm, pressure angle=20°, rotational speed of gear=1440 rpm, gear torque=132.63 Nm, material steel E=21000 N/mm2, Poison ratio v=0.3, gear with right and left inclination of teeth was to be modeled. Ft=tangential force (N), b=face width, mn=normal module, fi=pressure angle, E=young's modulus, neu=poison ratio, i=module. Where Ka=Application factor, KS=Size factor, Km=Load distribution factor, KV=Dynamic factor, Ft=Normal tangential load, J=Geometry factor. AGMA, Lewis equation and Hertz equation were used to calculate bending and contact stresses respectively. Thereafter, an FEA model was created and meshed to apply the bending and contact stress and the theoretical results and the results obtained from software were compared.

CONCLUSION

This paper was a brief review of bending and contact stress analysis of helical gear pair using AGMA and ANSYS software with different width and helix point and diverse gear geometry to increase its efficiency. Helix angle is a significant geometrical parameter in deciding the condition of stress during the gear designing.

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