International
Journal
Of Advanced Research in Engineering & Management (IJAREM)

Design, Optimization and Finite Element Shrink Fit Analysis of Helical Gears for High speed operations

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ABSTRACT: Present paper is fretful with the design and analysis of some of the input elements of a gearbox that is used for high speed operations. Since the pinions swivel at high speeds the complete gear system is subjected to noise and ambiance. The gear system is composed of one bull gear and two pinions. The helical gears are designed as per American Gear Manufacturing Association standard procedure. Conventional parallel axes helical gears with Involute profile teeth are insensitive to center distance assembly errors and possess line contact under design assembly condition. Involute helical gear is very sensitive to axial misalignments, causing discontinuous transmission error and edge contacts. To reduce this effect, the teeth of helical gears are thinned at the tip by an amount that is estimated to exceed the sum of deflections of a pair loaded teeth and a maximum sum of spacing error of adjacent teeth this is known as tip relief or profile crowning. It is eased off down the profile so that when the gears are running, the readjustment of relative position on engaging teeth is effected in a longer time than would be the case with unrelieved profiles therefore the impact on engagement is reduced. The contact analysis of helical gear tooth is done using finite element software, ANSYS.

Keywords— Helical Gear, AGMA standards; profile crowning

I. INTRODUCTION

Helical Gears are toothed wheels with inclined helix angle which transmit power and motion from one shaft to another by means of successive rendezvous of teeth. Gear drive is a positive drive and maintains constant velocity ratio. It can transfer very high power. As the necessities are broad and are of varying difficulties, gearing is a complex and diversified engineering field. Therefore modifications on the design of gear are suggested depending upon the different applications. The purpose of modification is to improve the performance of the gear. In helical gears, the contact between meshing teeth begins with a point on the leading edge of the tooth and gradually extends along the diagonal line across the tooth. There is a gradual pick up of load by the tooth, resulting in smooth engagement and quiet operation even at high speeds. Compared to spur gears of the same size, helical gears can transmit more power and are less noisy. In views of this, helical gears are more efficient and are usually desired for high power transmission. During the gear manufacturing, the error such as total composite error, tooth-to-tooth composite error and position error, etc. are introduced. Therefore, close tolerances are required. Helical gears are widely used in high power transmission between parallel shafts. One such example is compressor gearbox unit. In this compressor gearbox, power is transmitted to four compressors through one bull gear and two high speed pinions. Bull gear receives the power from external electrical motor. It transmits the torque to two pinions. The main constraint in the design is that the center distance between the two pinions and bull gear is fixed. Basic data such as power rating, speed, module, face width and helix angle are given. The following are the compressor gearbox details

	Rated power (KW)	Centerline distanc (mm)	Speed (Rpm)
Driver electric motor	640	-	2,970
Pinion 1 (HS1) Driven shaft 1	392	496.5	24,322
Pinion 2 (HS2) Driven shaft 2	248	483	32,140

Table 1 Technical Detail of Gears

2.0 LITERATURE SURVEY

Yi-Cheng Chen[1], Chung-Biau Tsay (2002) has investigated the contact stress and bending stress of a helical gear set with localized bearing contact, by means of finite element analysis. The helical gear set comprises an involute pinion and a double crowned gear. The result shows the effect of crowning on the contact stresses. The tensile and compressive bending stresses along the pinion's fillets under different contact conditions were investigated. The mesh generation program is developed to discretize FEA models of gear. Litvin [2], Fuentes, Gonzalez-Perez, Carvenali, Kawasaki and Handschuch (2003) have presented paper on modified involute helical gear. It contains enhanced stress analysis of modified involute helical gear. The approaches proposed for modification of conventional helical involute gear. Double crowning of pinion is provided for study. It is shown that the pinion-gear tooth surfaces are in point contact, the bearing contact is localized and oriented longitudinally and edge contact is avoided. They have shown the influence of errors of alignment on the shift of nearing contact and vibration and noise are reduced substantially. It shows the advantages of the gear drives of modified geometry in comparison with conventional helical involute gears. Litvin and Kim[3] (March 1997) proposed modification of geometry of gears that enable to localized the bearing contact and reduce the level of transmission errors. Methods for generation of spur gears with the modified geometry are proposed as well. Litvin, Chen, Lu[4] and Handschuch (December 1996) has presented a paper on FE analysis application for determination of load share, real contact ratio, precision motion and stress analysis of gears. A loaded gear drive with point contact between tooth surfaces is considered. This gives the deep focus on determination of the contact force and its distribution over the contact ellipse. The tooth deflection under load, the load sharing and real contact ration has been determined. The distribution of bending stresses is determined by finite element method. Simon (in June 1991) has given a method for the determination of load and stress distribution along the contact lines of the instantaneously engaged teeth of spur and helical gears. This method includes the tooth profile modification and crowning, manufacturing and alignment error of gears, tooth deflections, local contact deformations of the teeth. The influence of gear parameters on the load and stress distributions is discussed. Litvin (in June 1995)"Applied theory of Gearing: State of the art." covers a brief history of some concept of theory of gearing and new developments in this area such as theory of enveloping curves and surfaces, simulation of meshing determination of direct relations between the curvatures of contacting surfaces, and avoidance of singularities, transfer from line contact of tooth surfaces to point contact, and design and manufacturing of gears with compensated transmission errors caused by misalignment. Zhang and Litvin [5](September 1994) presented a model for analysis of helical gear under load. The model accommodates the modification of the tooth surfaces, gear misalignments and the deformation of tooth surfaces caused by contact load. In this model, the gear contact load is assumed to be nonlinearly distributed along the direction of the relative principal curvature between the two contacting tooth surfaces. The proposed model is applied to a pair of helical gears in the numerical example. Rama Mohana Rao [6] and Muthuveerappan (June 1992) studied the 3D stress analysis of helical gear teeth for calculating root stresses. Root stresses are evaluated for different positions of the contact line when it moves from the root to the tip. A parametric study is made by varying the face width and the helix angle to study their effect on the root stresses of the helical gears. The three dimensional way of calculating the root stresses of the helical gear gives realistic results.

3.0 MODEL PREPARATION

Involute helical gear is very sensitive to axial misalignments, causing discontinuous transmission error and edge contacts. For any power gearing application it is essential that perfect tooth contact is obtained. To allow for any misalignment in the mountings of the gear, or heat treatment distortion, it is usual to crown the tooth form; i.e. produce elliptical teeth, thus, eliminating any chance of end loading of the gear teeth. End loading of a gear tooth is a very prolific cause of tooth failure and gear noise, as this causes a concentration of stress at the ends of the teeth there are most vulnerable to shock and fatigue failures with tooth crowning there is a reduction in surface contact therefore the teeth of helical gears are usually modified to attain localized point contact and to avoid edge contacts. Recently Litvin proposed the concept of tooth surface modification to obtain a pre designed parabolic transmission error as well as a localized bearing contact of the gear set. The proposed helical gear set is composed of two modified helical pinions and one modified bull gear. The modified helical gear processes both profile crowning and length wise/ longitudinal crowning it is also known as double crowning means deviation of cross profile from an invalid one and deviation in longitudinal one from a hellocid surface By using the parametric equations of involute profile, helical is modeled using CATIA software. The modeled figures of gear and pinion assembly are shown in following figures

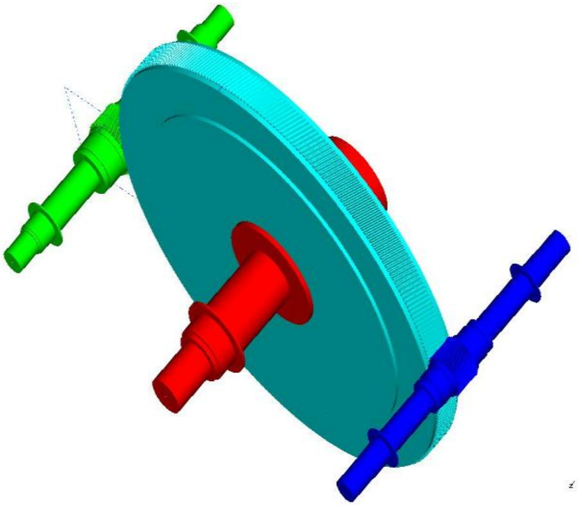

Figure 1 Gear and Pinion Assembly

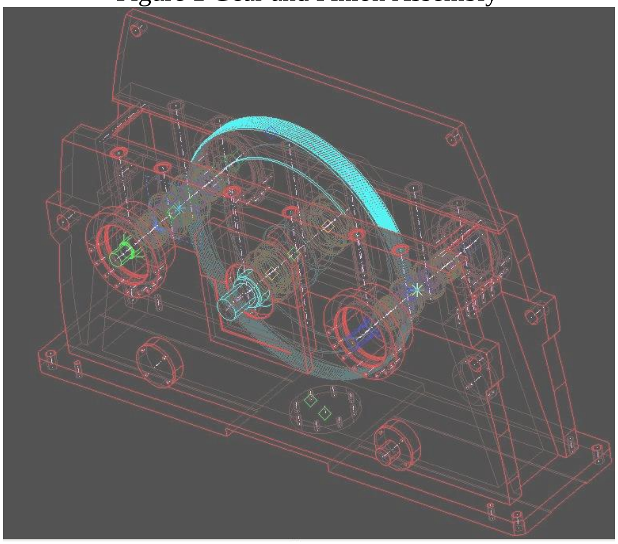

Figure 2 Isometric view of gear box assembly

4.0 FINITE ELEMENT ANALYSIS

The term “Finite Element” distinguishes the techniques from the use of the infinitesimal “differential equations” used in calculus, and partial differential equations. The method is also distinguished from finite difference equations, for which although the steps into which space is divided are finite in size, there is a little freedom in the shapes that the discreet steps can take. Mmaterial properties such as Modulus of elasticity were taken as 207GPa. The element type was taken as 20 node solid 45

Contact Analysis

For 3D contact analysis, the modeling of helical gear and pinion is done in IDEAS. The meshing and boundary conditions are applied in FEA package, ANSYS. A linear brick element, SOLID45, having eight nodes and six faces, is employed to discretise the geometric models of the pinion and the gear tooth surfaces. The regions where stress concentration may occur such as fillets and possible contact area are discretized by a finer mesh. More over the contact points on the tooth surfaces under light load can be predicted by TCA. The deformable gear tooth surface and target surface are meshed by TARGET170 elements. The shape of the surface is described by a sequence of triangles, quadrilaterals, cylinders, cones and spheres. The deformable contact surface is meshed by using CONTAC173. The contact surface is defined by the set of contact elements that comprise the surface of the deformable body. These contact elements have the same geometric characteristics as the underlying elements of the deformable body. The contact surface elements are of the same order as the underlying elements (lower or higher order), with compatible nodes along the edges. The CONTAC173 is 3D, 4-node, lower order quadrilateral element that can be located on the surfaces on 3D solid. CONTAC175 is 2-D/3-D point-to-surface and edge-to-surface contact element. CONTA175 is used to represent the contact and sliding between two surfaces, in two or three dimensions. The element is capable to two or three-dimensional structural contact analysis the element is located on the surface of solid, beam and shell elements. The TARGET169 is 2-D element used as target surface. The input data for the element is as follows.

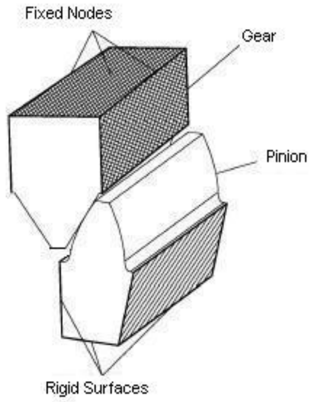

Figure 4 contact pairs

Bending Stress Analysis

The FE model of pinion is divided into 20 transverse sections and the gear is divided into 10 transverse sections. Generally, the bending stresses in the fillet of the two contacting tooth side are considered tensile stresses and those in the fillets of the opposite, unloaded tooth side, are considered compressive stresses. The fillet stresses are determined at four pinion's rotational angles 0°, 3°, 7° and 9°. It is shown in the figure6. The variation of bending stress on the tensile side and compressive side along the path of contact has shown in the figure5

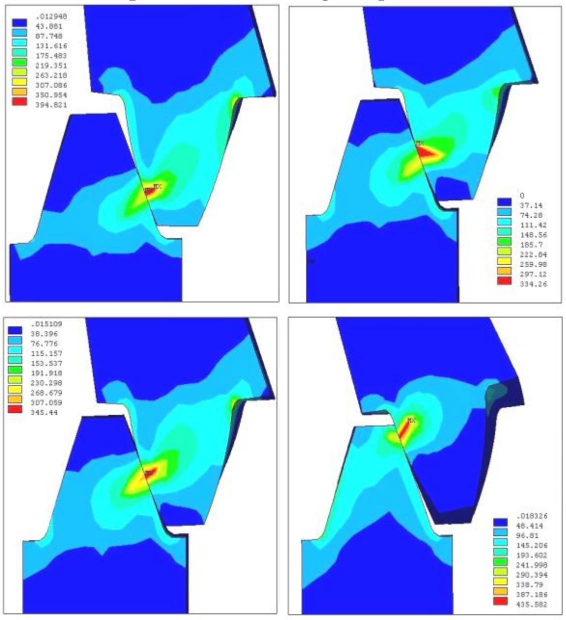

Figure 5 Contact stresses and bending stresses in pinion and gear during the different angle of pinion rotation – 3^0, 0^0, 3^0 and 7^0 respectively

5.0 RESULTS AND DISCUSSION

In this study, finite element stress was performed to investigate the contact stresses and the bending stresses of an un-modified and modified helical gear set as mentioned above. The geometrical model of a helical gear was generated using parametric equation of involute curve. Commercial FEA software, ANSYS, capable of contact analysis was used to evaluate the stress distribution on the tooth. The analysis results leads to the following conclusions.

1. The different models with one tooth of each pinion and gear, as shown in figures are investigated. It shows there is no variation in the contact analysis of the gears.
2. The contact stresses of an unmodified helical gear calculated by FEA is close to the Hertzian contact stress obtained from Hertzian stress formula and the contact stress obtained from the contact analysis of two equivalent cylinders. The contact stresses are below the allowable contact stress. Hence the gear is safe in contact stress.
3. The tensile and compressive bending stresses along the pinion's fillets under different contact positions were investigated. The maximum fillet stress occurs near the middle section of the tooth flank, below the contact points as seen from the figure 6 the bending stresses are below the allowable bending stresses. Hence the gear is safe in bending stress.

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