Review on Tribological Modeling of Worm Gear

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Abstract - *This paper presents study of various wear modeling techniques which are useful for tribological analysis of worm and worm gear to predict wear. Archard wear model is one of the useful wear models. According to Archard's Wear model wear of the each point on the wheel tooth surface is calculated and modify the geometry and the calculation process is repeated in a series of wear steps. Similar condition can be simulated with the help of FEA packages. FEA results are experimentally validated on setup of Pin-on-Disc Tribometer, Ball-on-Disc Tribometer.*

Key Words: **Archard wear model, Friction, Lubrication, Pin-on-Disc Tribometer, Wear, and Worm Gear**

1. INTRODUCTION

Tribology is that the science and engineering of interacting surfaces in relative motion. Tribology is highly interdisciplinary and necessary to study friction, lubrication and wear. All engineering field are affected by friction and wear. In today's world every engineering systems, and biological systems having components such as gears, bearings, hip joint, knee joint etc. which are having relative movement with each other. Due to this relative movement component may facing friction and wear. End result of this phenomenon is the damage to the surfaces, energy wastage, repair, replacement, environmental damage and reduction in overall efficiency.

Worm gearbox is important part of many engineering systems. It is used for various applications like power transmission, motion control, speed reduction and torque multiplication. Advantage of worm gearbox is having large reduction ratio with single stage. Worm gear is harder than the worm wheel. Usually worm gear is made of harder metal like steel and worm wheel made of softer metal like bronze. [1] Wear depends on many parameters including contact pressure, sliding velocity, hardness, surface roughness, and lubricant properties. [1] Meshing action in worm gearbox is having sliding motion. Therefore the tooth friction and also wear are higher than other gear variants. [2] This results in energy wastage and ultimately performance reduction. To improve reliability, reduce life cycle cost it is necessary to study tribology of these systems and for analysis correct modeling of tribological parameter required.

2. STUDY OF TRIBOLOGICAL PARAMETERS

Friction, wear and lubrication are the main tribological parameters affecting efficiency of the worm gear.

i. Friction is the resistance to the relative motion of two parts. When two parts in contact with each other and load is applied then asperities present on the surfaces deformed. Adhesion is found between two surfaces. For relative motion of two surfaces lateral force required to overcome this adhesion. This phenomenon is called as a friction.

ii. Wear means removal of material particle due to relative motion. On micro scale every surface having roughness and asperities. When two surfaces are in relative motion then these asperities wear out. It results in change in shape, replacement of parts, downtime of machine, and increase in energy consumption.

iii. Lubrication is used between two surfaces for reducing the friction. Wear and friction can be drastically reduced by applying proper lubricating film.[15]

3. LITERATURE REVIEW

Dalia Jbily et al: - In this study a numerical model is used to predict the wear of worm gear by using Archard's wear formulation. In this analysis the influence of lubrication and updatation of surface profile due to teeth worn-out is also considered. Updating surface profile helps in accurate contact pressure calculations. The equation of displacement compatibility is solved by using the influence coefficient method for computing the quasi-static load sharing and thus the contact pressures required for the wear model. Result shows that the model predictions presents the same tendencies, but gives more wear. In this model the wear begins once the worm gear runs hence predicted wear is linear and the wear increases with the torque. In actual initially pitting phenomenon is there which forms cracks through sub-surface of tooth flank. Later these cracks reach the surface, they create pits, then the abrasive wear starts and evolves linearly and the two phenomena (pitting and wear) continue successively. Hence it is necessary to do integration of pitting in the wear model. [1]

K.J. Sharif et al:-In this study wear model for worm gear is presented which is based on Archard wear law. Wear model considered the pressure and film thickness generated in the elastohydrodynamic oil film that separates the tooth components. Wear of the each point on the wheel tooth surface is calculated and modify the geometry and the calculation process is repeated in a series of wear steps. Various equations are solved simultaneously like Reynolds equation for calculating the lubricant's hydrodynamic action, elasticity equation for calculating the effect of the lubricant pressure to the elastic deflection and thermodynamic energy equation for considering the effect of heat generation in sliding. To calculate contact area correctly correction to the geometry is introduced by using the semi-infinite body treatment of elastic deflection that is embedded in the EHL analysis. [2]

Fabio Antonio Dorini et al:-To compensate the experimental uncertainties in the identification process of the wear coefficient author worked on a stochastic modeling of the wear process. Here wear coefficient is treated as a random variable which is having only positive values. In the wear process local contact pressure is taken as a constant and the relative sliding velocity is considered to be a known time-dependent function. Also the local contact pressure is constant, and the relative sliding velocity is considered to be a known time-dependent function along the wear process. It is found that by knowing the wear coefficient for a set of information the wear depth at a time can be derived. [3]

K. J. Sharif et al:-Theoretical basis for modelling the contact conditions and elastohydrodynamic lubrication (EHL) of worm gears are presented here. Reynolds equation is developed to incorporate any form of the non-Newtonian relationship between shear stress and strain rate. Semi-infinite body deflections was developed which is based on elastic contact analysis for determining the shape and extent of the dry contact area between the wheel and worm under load. [4]

Nenad Panic et al: - Two simple methods for determining the allowable wear of worm wheels i.e. reduction in the tooth root cross section, and other one is the appearance of tooth tapers are discussed. From experiment relationship between an allowable tooth change and a specific wear can be obtained .It can be calculated by multiplying the volume loss due to wear to the specific weight of the wheel tooth material. [5]

Balazs Magyar et al:- This research explain the method for finding locally changing coefficient of friction along the each contact line for worm gear drives which is operate in mixed lubrication conditions. Author explained how to generate dimensionless Stribeck curves from locally changing tooth friction coefficients determined by such complex calculation which is useful to determine accurately the changing tooth friction coefficient during multibody simulation calculations. Calculated tooth friction coefficients and experimental test results are very close to each other. This tooth friction coefficient is useful for calculating dynamic behaviour of worm gear drives. [6]

Imam Syafaata et al:-This study presented a wear model to calculate the wear of rough sliding contacts. For representing roughness here uniformly distributed spherical asperities are considered. In Finite Element Modelling pin-on-disc contact configuration is considered for wear system. FEA results show that when the sliding distance increases then wear also increases. It is seen that the wear of the asperity at the centre of the contact of the rough surface is higher than the surrounding asperities. Also observed that at initial phase of the sliding process average contact pressure as well as the surface roughness (Ra) are high but in final phase it stabilize because of the conformal shape of the asperities. [7]

Ahmed Hadi Abood et al:-This study focused on contact surface interface, which is important for prediction of the wear depth in contact surfaces. With the help of finite element method the effect of the asperities height, the applied forces and the shape of the contact surfaces on the wear depth and contact pressure are studied. Full Newton Raphson method was used for analysing the contact surfaces. The movement of the surface was defined using a pilot node; this node was also employed to obtain the applied force during the simulation and material nonlinearity, which results from the nonlinear relationship between stresses and strains. The nonlinear behaviour of the contact surface between two surfaces at different times is modelled by using a three-dimensional nonlinear surface-to-surface contact-pair element. It is seen that the wear depth for different asperities increased with increased of contact's time and contact pressure is decreased. Archard's model is used as a base for wear simulation and result showed that wear behaviour can be simulated with the series of discrete models. [8]

F. Al-Bender et al:-Results of modelling and experimental validation of friction, traction and wear are presented in this study. Discussed characterization are concerns with (i) the relationship between the friction (traction) force and the state of sliding of the system (displacement, velocity), at a given normal load; (ii) the relationship between the normal load and coefficient of friction. Pre-sliding behaviour is modelled with the Maxwell-slip structure. For modelling the local friction force at each asperity the Greenwood and Williamson theory is used. It shows that the coefficient of friction decreases with increasing normal load, and decreases with the normal load, ultimately the pre-sliding distance increases with load. Initially generic model is established. To study the wear simulation this generic friction model is further extended with considering asperity population which helps in establishing the correlation between energy dissipation with wear evolution. Here rotational test rig with axes supported on aerostatic bearings is used for experimental analysis. It gives online, simultaneous measurement of normal load, friction force, angular position and normal displacement with high accuracy. Ball-on-disc experiments gave correlation between three process variables and parameters i.e. normal load, wear volume and dissipated energy which are quasi linear. Theoretical results qualitively match with experimentally observed behaviour. [9]

K. J. Sharif et al:-To predict the wear of worm gear wheel teeth the wear model is developed which is based upon a full elastohydrodynamic lubrication (EHL) analysis of the contact between the teeth at various stages of meshing. The EHL results like pressure, film thickness and sliding values helps in calculating wear over the contacting region on the wheel tooth from a modified Archard-type law. The shape of the contacting surfaces is modified by wear which is updated in the EHL solution by an iterative process. In this analysis the point of contact between the teeth at various stages of meshing under zero loads and the direction of the common normal to the surfaces at the contact point is established. These special kinematic conditions are taken care in EHL analysis of such contacts. In this study the differential deflection technique for modelling of the elastic deformation of the surfaces is developed. It show that initially wear concentrated near the centre of the tooth and then towards the root of the wheel. Higher contact pressures due to the higher curvature of the teeth at their roots and a less favourable film geometry responsible for later effect. In actual practice increase in backlash under unloaded conditions is the practical measure of wear in worm gears. This quantity can be obtained from the above analysis and can be used as a means of correlating predicted and measured wear. [10]

Rachit N. Singh et al:- This study discussed various theories which are used to numerically simulating wear in rolling and sliding contacts. A simulation methodology is developed that calculates the wear at a detailed level. Winkler method is used for finding normal pressure. FE modelling of disc on disc analysis is developed for finding change in geometry of contact. It is found that difference in max contact pressure between Hertzian method and FE method are negligible. [11]

Qin Yuan et al: - This study focused on implementation of fluid film lubrication at the contact between the worm and gear teeth to reduce the sliding friction. For this the knowledge of the clearance shape, the relative velocities, and the normal contact force between the meshing worm and gear surfaces are required. Two geometrical properties i.e. pressure angle and apex angle are the main parameter studied in detailed here. It is observed that the lubricant film should withstand normal load whether friction present or not. A smaller pressure angle generates lower normal force. Due to larger pressure angle more number of teeth are meshed which share the load. It is seen that the standard value of normal pressure angle i.e. 20 degree is still a first choice. For desirable contact pattern apex angle can be adjusted. [12]

Tibor Bercsey et al: -This study focuses on collecting information of contact pressure and area between the teeth flanks which is further useful for optimizing tribology conditions. Geometry model is created in ProE software. Further parametric meshing is done using 8 nodes SOLID elements. Here for numerical solution algorithm based upon the coefficient matrix is used. This study helps in calculating the friction condition between the tooth surfaces. It shows that the maximum stresses are caused by the Hertzian contact of the tooth surfaces on the contact line. It also changes depending on the meshing position. [13]

B. Magyar et al: - In this study method for calculating efficiency of worm gearbox is established. Along with tooth friction losses other power losses such as the bearings, oil churnings and seals power losses are considered. To calculate the tooth friction of worm gear drives a tribological calculation method is used. From this simplified tribological model of the tooth meshing of worm gears is created. For worm gear line contact is there. With the help of equation of meshing few points on contact line are calculated. First step of analysis is finding contact. Next step is to find out mixed friction coefficient between a pair of rolls. Shear stress is integrating with penetration surface and method for calculating the frictional force due to hydrodynamic lubrication is defined here. It is observed that average coefficient of the tooth friction is changing with the meshing position of the worm. [14]

4. PROBLEM DEFINITION

1. Literature review shows that many researchers worked on tribological properties of gears. But worm drive is getting lesser attention.
2. Also various wear models are proposed. Different lubrication theories are mentioned. Major focus is given on maximum efficiency, compactness, vibration, thermal efficiency, weight etc.

By using this information we can further work on tribological properties of worm and worm gear. By using advancement of FEA packages we can simulate same operating conditions. Also validate these results experimentally.

This research work will be carried out on worm gear and worm wheel with medium load at medium speed where high sliding friction between the worm and gear teeth during its operation occurs, which causes excessive power loss and reduces the gear efficiency. To realize the power transmission potential of the worm gear, this friction has to be significantly reduced. To optimize this condition it is necessary to use simplified wear model and analyze tribological properties.

5. OBJECTIVES

Objectives of the research work are as follows.

1. To study various wear models.
2. Tribometer for various operating conditions. To perform Design of experiment using Pin-on-Disc
3. To perform FEA analysis of worm gear box for tribological parameters under same operating conditions.
4. Comparison between Experimental results and FEA results.

6. METHODOLOGY

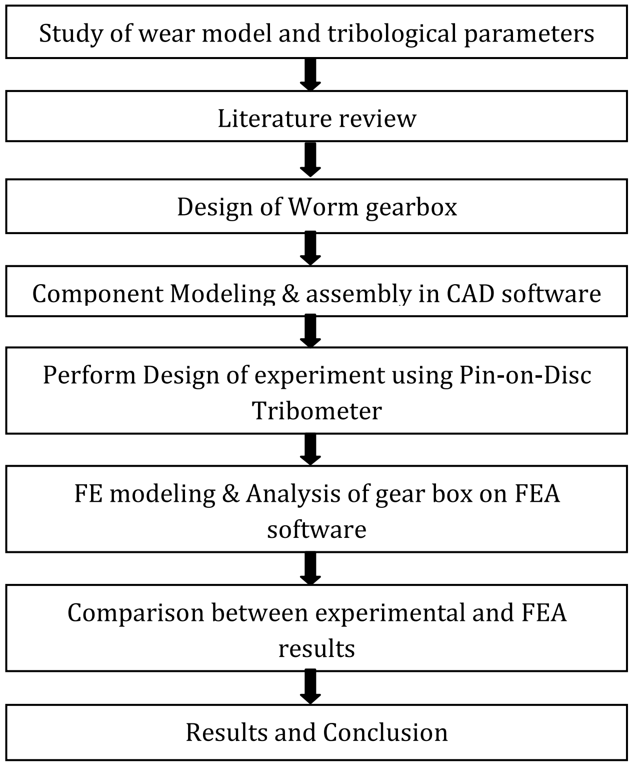

Chart 1: Flow chart of Methodology

7. CONCLUSIONS

From the literature review following conclusions are drawn.

- Due to complex geometry of worm gear drive it is very difficult to lubricate the drive. Reduction in efficiency due to sliding friction is the main concerned in worm and worm gear.
- It is observed that Archard wear model is simple but effective method for studying the tribological parameters.
- By using 3D modeling software geometry of gear can be drawn. Also FEA analysis can be done with advanced FEA packages.
- It is necessary to validate the results obtained from FEA analysis with experimental analysis. Pin on disc set up can be used for experimental validation.
- By comparing Experimental and FEA results various tribological parameters can be studied.

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