A REVIEW ON INVESTIGATION ON RECENT ADVANCE IN THE ANALYSIS OF SPIRAL BEVEL GEARS

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ABSTRACT

The theory of generating-line method has been discussed in this study. It is a new theory of manufacturing spiral bevel gears of which tooth surfaces are formed by exact spherical involutes. The tooth surface of spiral bevel gears is obtained by the pure-rolling motion between the base cone and the great circular plane of the fundamental sphere. Based on the cutting motions the equations to describe tooth surfaces have been derived by using theory of gearing, and the equation of meshing of spiral bevel gears with spherical involutes tooth surface is obtained in the text. This study can provide some fundamentals for manufacturing and contact analysis of spherical involutes spiral bevel gears.

Keywords: Equations of meshing, generating-line, spiral bevel gears.

INTRODUCTION

The purpose of gears is to transmit motion and torque from one shaft to another. That transmission normally has to occur with a constant ratio, the lowest possible disturbances and the highest possible efficiency. Tooth profile, length and shape are derived from those requirements. Gearing is one of the most critical components in a mechanical power transmission system, and in most industrial rotating machinery.

SPIRAL BEVEL GEAR

A spiral bevel gear is a bevel gear with helical teeth. The main application of this is in a vehicle differential, where the direction of drive from the drive shaft must be turned 90 degrees to drive the wheels. The helical design produces less vibration and noise than conventional straight-cut or spur-cut gear with straight teeth. A spiral bevel gear set should always be replaced in pairs i.e. both the left hand and right hand gears should be replaced together since the gears are manufactured and lapped in pairs.

Bevel gears classification

Bevel gears are classified in different types according to geometry:

- **Straight bevel gears** have conical pitch surface and teeth are straight and tapering towards apex.
- **Spiral bevel gears** have curved teeth at an angle allowing tooth contact to be gradual and smooth.

- **Zerol bevel gears** are very similar to a bevel gear only exception is the teeth are curved: the ends of each tooth are coplanar with the axis, but the middle of each tooth is swept circumferentially around the gear. Zerol bevel gears can be thought of as spiral bevel gears, which also have curved teeth, but with a spiral angle of zero, so the ends of the teeth align with the axis.

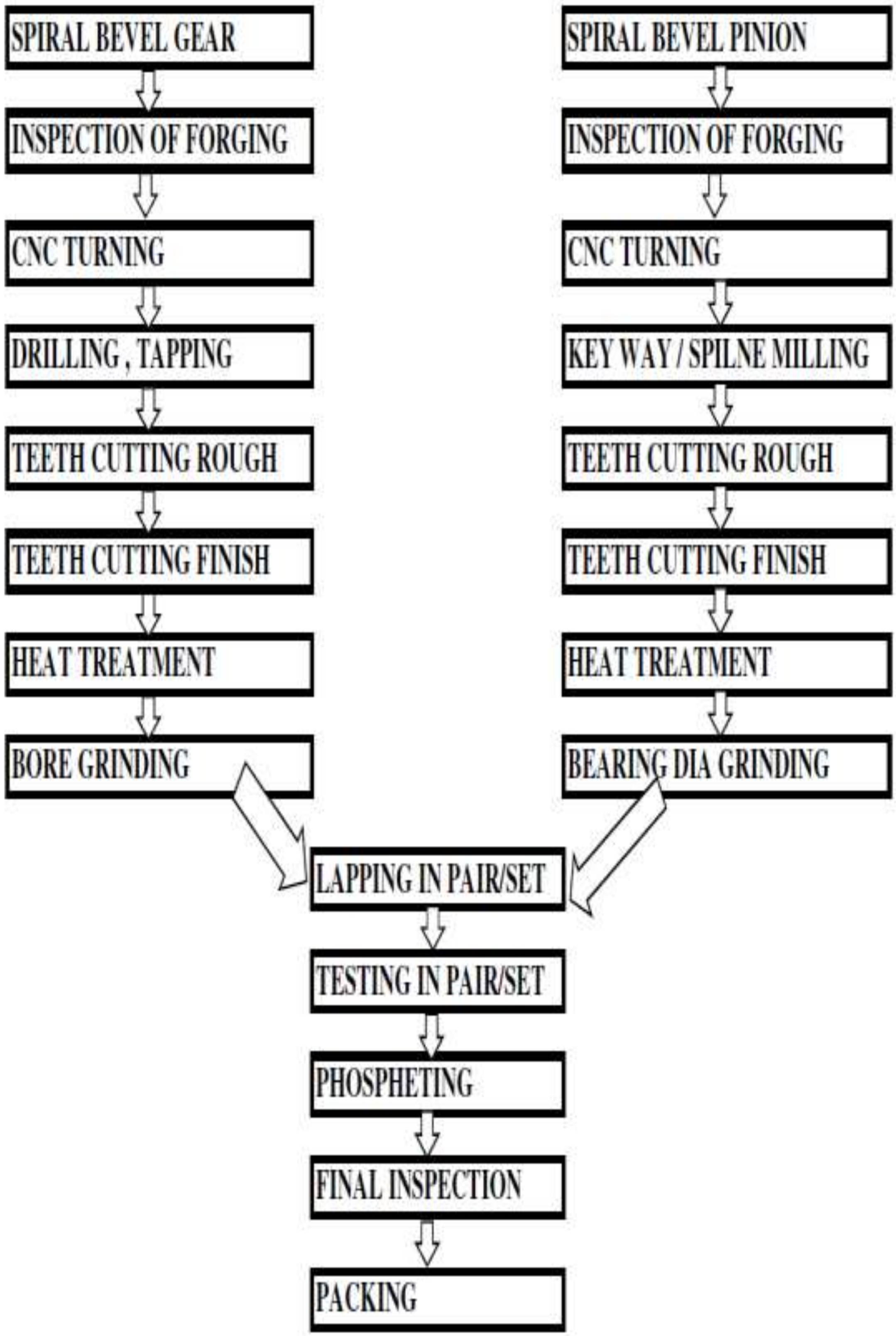
- **Hypoid bevel gears** are similar to spiral bevel but the pitch surfaces are hyperbolic and not conical. Pinion can be offset above, or below, the gear centre, thus allowing larger pinion diameter, and longer life and smoother mesh, with additional ratios e.g., 6:1, 8:1, 10:1. In a limiting case of making the "bevel" surface parallel with the axis of rotation; this configuration resembles a worm drive. Hypoid gears are widely used in automobile rear axles.

Spiral bevel gears are used to transmit power between shafts that are typically at a 90-degree orientation to each other. The teeth on spiral bevel gears are curved and have one concave and one convex side. They also have a spiral angle. The spiral angle of a spiral bevel gear is defined as the angle between the tooth trace and an element of the pitch cone, similar to the helix angle found in helical gear teeth. In general, the spiral angle of a spiral bevel gear is defined as the mean spiral angle.

Because spiral bevel gears do not have the offset, they have less sliding between the teeth and are more efficient than spiral and produce less heat during operation. Also, one of the main advantages of spiral bevel gears is the relatively large amount of tooth surface that is in mesh during their rotation. For this reason, spiral bevel gears are an ideal option for high speed, high torque applications.

The American Gear Manufacturing Association (AGMA) has developed standards for the design, analysis, and manufacture of bevel gears.

The driving and driven gears are the most important components of the Gear box of any automotive. Modelling allows the design engineer to let the characteristic parameters of a product drive the design of that product. During the gear design, the main parameters that would describe the designed gear such as module, pressure angle, root radius, tooth thickness and number of teeth could be used as the parameters to define the gear.



Manufacturing of Bevel Gear

Transmission Error

Gear noise and vibration divided into three parts, “Transmission error”, “Dynamic models” and “Noise and vibration measurement”.

Transmission error (TE) is considered to be an important excitation mechanism for gear noise and vibration. The definition of transmission error is “The difference between the actual position of the output gear and the position it would occupy if the gear drive were perfectly conjugate”.

Gearing transmissions have a long history dating back since the time of the first engineering systems. Their practical usage in the present day modern engineering system is enormous. In accordance with a contemporary development of mechanical engineering techniques ever growing requirements and working specifications. Along with modern high speed manufacturing industry development, gears are used widely in many applications ranging from automotive transmission to robot and aerospace engines. Different kinds of metallic gears are currently being manufactured for various industrial purposes. Seventy-four percent of them are spur gears, fifteen percent helical, five percent worm, four percent bevel, and the others are either epicyclical or internal gears. The main purpose of gear mechanisms is to transmit rotation and torque between axes. The gear is a machine element that has intrigued many engineers because of numerous technological problems arises in a complete mesh cycle. If the gears were perfectly rigid and no geometrical errors or modifications were present, the gears would result in a constant speed at the output shaft. The assumption of no friction leads to that the gears would transmit the torque perfectly, which means that a constant torque at the output shaft. No force variations would exist and hence no vibrations and no noise could be created. Of course, in reality, there are geometrical errors, deflections and friction present, and accordingly, gears sometimes create noise to such an extent that it becomes a problem.

LITERATURE REVIEW

A final gear design is proposed and analyzed to show that proper margins of safety have been included in the design. Upon completion of the design phase of the gear, analysis was conducted to ensure appropriate margins of safety had been implemented into the design. Calculated values of Hertz stress and bending stress are less than the allowable stresses as per AGMA Robert. Spiral bevel gears are often generated by spiral generated modified (SGM) roll method. In this style, pinion tooth surface modified generation strategy has an important influence on the meshing and contact performances.

F Handschuh [1] et al.discussed the experimental and analytical studies was conducted with respect to the behavior of spiral bevel gears. The experimental effort was conducted on aerospace quality spiral bevel gears. Also an analytical modeling method was developed to analyze the thermal behavior via the finite element method.
S H Gawande et al. [2] presented the mechanical design of crown wheel and pinion in differential gear box. Detailed modeling, assembly and analysis of tooth of crown gear and pinion was performed in Pro-E. Finite element analysis was performed to analyse the crown gear tooth for working load. Induced equivalent stress was less than allowable stress. From this it was concluded that design was safe.

As per base paper “The Equation of Meshing of Spiral Bevel Gears Manufactured by Generating-Line Method”, Yankun Wang, Zhaojun Yang, Linan Li and Xuecheng Zhang, the theory of generating-line method was discussed in the study. It was a new theory of manufacturing spiral bevel gears of which tooth surfaces were formed by exact spherical involutes. The tooth surface of spiral bevel gears was obtained by the pure-rolling motion between the base cone and the great circular plane of the fundamental sphere.

Simulation software is based on the process of modeling a real phenomenon with a set of mathematical formulas. It is, essentially, a program that allows the user to observe an operation through simulation without actually performing that operation. Simulation is used when conducting experiments on a real system would be impossible or impractical: for example, because of the high cost of prototyping and testing, or because the fragility of the system will not support extensive tests, or because of the duration of the experiment in real time is impractical.
The work done on bevel gears involved straight bevel, spiral bevel gears. Tsai and Chin proposed a model to generate the geometry of the straight and spiral bevel gears using the spherical involutes which is created from the envelope of the tangents to the base cone of the gear. The straight bevel gears manufactured by the two tool generation process are defined by the octoid tooth form using the crown rack and the tool kinematics.

Figliolini and Angeles [3] formulated an algorithm for generation of exact spherical involute and octoid bevel gears. The above research was mainly focused on developing the geometry for further analysis of the gears.
Sentoku et al. [4] performed the study on transmission error of bevel gears of Gleason type including the effect of shafts and manufacturing errors. The current work was aimed at developing a full finite element model for the analysis of straightbevel gears for the prediction of load distribution, transmission error and stress and also to include the effect of surface deviations in the load distribution.

Wilcox, et al [5] for bevel and hypoid gear for calculating the stress. Conry et al. [6] worked on elastic bodies in contact and Windows LDP with the basis for the solver for the load distribution of gears.

Petry-Johnson et al. [7] conducted experiments on gears under high speeds and various torque values to measure the influence of parameters such as gear module, tooth surface roughness amplitudes and operating conditions on spin and mechanical losses of a gear pair. Handschuh and Kilmain [8] carried on both experimental and analytical investigations on high-speed gear. Their results showed that increasing speed has a negative effect on the efficiency. Various approaches were employed in investigating tooth contact friction and load-dependent (mechanical) power losses of parallel-axis gears.

Benedict and Kelley [9] performed experiments with cylindrical rollers to investigate the gear tooth friction. They presented their results as an empirical formula to predict the instantaneous friction coefficient. However, a very limited range of variables within which the experiments were run around the validity of this equation.

Diab et. al. [10] derived a semi-empirical traction formula based on experiments on a disk test rig at low rotational speeds. Xu et al. used an EHL model along with a multiple regression analysis to obtain a new friction coefficient formula which they used in predicting mechanical efficiency of parallel axis gear pairs and used mechanical efficiency model together with a gear design optimization model to show that measures to maximize the mechanical gear efficiency often impacts the other noise and durability.The final design must be a compromise that delivers reasonable efficiency levels with reasonably low vibration excitations and contact and bending stresses.

Boness [11] performed experiments on a disc and a gear operating partially submerged in lubricant to measure drag torque and estimate churning losses. Based on these experiments, he obtained empirical relations for churning losses within the ranges of the experiments and also conducted experiments on individual and meshed spur gears to measure the churning losses. Their results were used to show certain discrepancies formulae.

Changenet and Velex [12] also predicted churning losses in a single and a pair of gears. Their study was based on results from a dimensional analysis andcompared well with the experiments they conducted for validation and proposed a physics-based model oto predict spin losses of a spur gear pair including drag and pocketing loss components. They investigated the impact of static oil level, speed, module and face width on the load independent losses.

Dawson [13] performed experiments on large spur and helical gears to measure the windage losses and quantify the effects of speed, gear size and geometry as well as the shape ofthe enclosure. Research on power losses of cross-axis gears goes all the way back to Buckingham [14-15] who proposed an approximation of hypoid gear efficiency by assuming that a conjugate action between the gear teeth that was taken to equivalent to that of spiral bevel gears and the sliding action of the pitch surfaces is equivalent to that of worm gears. He then approximated the power loss of a hypoid gear as the sum of power losses of a spiral bevel and a worm gear.

Geometric Approach

Envelope surface is mentioned as the boundary surface of the swept volume formed by object moving in a space. The surface of the object and envelope surface are also called as generating surface and generated surface, respectively. The whole process is called as generating process. Envelope surface has been widely used to simulate the machined surface in many fields of current manufacturing industry. While a product is machining, the machined surface is obtained by removing a certain amount of material from the stock. Subsequently, the machined surface can be calculated as part of the envelope surface of the cutter moving along the given tool path. The details about the envelope surface are introduced as follows. Assume a generating process is related to a generating surface continuously moving in the three dimensional Euclidean space E3. With the generating process, a family of surfaces is formed with respect to all configurations of the generating surface at every moment.

4.2 Basic derivatives

The derivatives of the unit normal of the envelope surface can be calculated with Eqs.

$$n.\left(T \times V_q\right)^2 = \cos\alpha - V_q^2.T-(T.\ V_q).\ \cos\alpha.\ V_q \pm\sqrt{\left(T \times V_q\right)^2 - \cos^2\alpha.V_q^2}.(T X V_q) \quad 4.1$$

Assume

$$F1 = \left(T \times V_q\right)^2,$$

$$f2 = \cos\alpha - T \times \frac{\partial V_q}{\partial h}.$$

$$F3 = -\cos(T.\ V_q),$$

$$f4 = \pm\sqrt{\left(T \times V_q\right)^2 - \cos^2\alpha.\ V_q^2} \quad 4.2$$

Submitting Eq. 4.40 into Eq. 4.39 , Eq. 4.39 can be derived as

$$F1.n = f2.T + f3.\ V_q + f4.(T\ X\ V_q) \quad 4.3$$

Taking the derivatives of both sides of Eq. 2.41 with respect to h, we have

$$\frac{\partial f1}{\partial h}.n + f1.\frac{\partial n}{\partial h} = \frac{\partial f2}{\partial h}.T + \frac{\partial f3}{\partial h}.V_q + f3.\frac{\partial Vq}{\partial h} + \frac{\partial f4}{\partial h}.(T \times V_q) + f4.\frac{\partial (T \times V_q)}{\partial h} \quad 4.4$$

Then the derivative of n with respect to h is given as

$$n_h = \frac{\partial n}{\partial h} = \frac{1}{f1}.\left[-\frac{\partial f1}{\partial h}.n + \frac{\partial f2}{\partial h}.T + \frac{\partial f3}{\partial h}.V_q + f3.\frac{\partial Vq}{\partial h} + \frac{\partial f4}{\partial h} + \left(T\ X\ V_q\right) + f4\ \frac{\partial (T \times V_q)}{\partial h}\right] \quad 4.5$$

Where

$$\frac{\partial f1}{\partial h} = 2.\left(T\ X\ V_q\right) + \frac{\partial (T \times V_q)}{\partial h} = 2.\left(T\ X\ V_q\right).\left(T \times \frac{\partial V_q}{\partial h}\right)$$

$$\frac{\partial f_2}{\partial h} = -\sin,\ \frac{d\alpha}{dh}.\frac{d\alpha}{dh} + 2.\cos\alpha.V_q.\frac{\partial V_q}{\partial h}$$

$$\frac{\partial f_3}{\partial h} = \sin,\ \frac{d\alpha}{dh}.\left(T\ .V_q\right) - \cos\alpha.\frac{\partial (T.V_q)}{\partial h}$$

$$\frac{\partial f_4}{\partial h} = \frac{1}{2-f4}.\left(\frac{\partial f1}{\partial h} + \sin 2\alpha.\frac{d\alpha}{dh}.V_q^2 - 2.\cos^2\alpha.V_q.\frac{\partial f1}{\partial h}\right)$$

Similarly, the derivative of n with respect to $\emptyset$ is given as

$$n\emptyset = \frac{\partial n}{\partial \phi} = \frac{1}{f1}.\left[-\frac{\partial f1}{\partial \phi}.n + \frac{\partial f2}{\partial \phi}.T + f2.\frac{dT}{d\phi}.Vq + f3\frac{\partial Vq}{\partial \phi} + \frac{\partial f4}{\partial \phi}.(T\ X\ Vq) + f4.\frac{\partial (T \times Vq)}{\partial \phi}\right] \quad 4.6$$

where

$$\frac{\partial f1}{\partial \phi} = 2 . (T \text{ x } Vq) . \frac{\partial (T \text{ x } Vq)}{\partial \phi} = 2. (T \text{ x } Vq) . \left(\frac{dT}{d\phi} \text{ X } Vq + T \text{ X } \frac{\partial Vq}{\partial \phi}\right)$$

$$\frac{\partial f2}{\partial \phi} = 2. \text{ Cos } . Vq. \frac{\partial Vq}{\partial \phi}$$

$$\frac{\partial f3}{\partial \phi} = - \cos. \frac{d(T.Vq)}{d\phi}$$

$$\frac{\partial f4}{\partial \phi} = \frac{1}{2-f4} . \left(\frac{\partial f1}{\partial \phi} - 2. \cos^2 \alpha. Vq. \frac{\partial Vq}{\partial \phi}\right)$$

With the derivatives of the unit normal, the derivative of envelope surface can be calculated according to Eq. 4.34 as

$$rh = \frac{\partial r(h,\phi)}{\partial h} = T\phi + \frac{dp(h)}{dh}.n(h,\phi) + p(h).nh \qquad 4.7$$

$$R\phi = \frac{\partial r(h,\phi)}{\partial h} = Vq\ (h,\phi) + p(h).n\phi \qquad 4.8$$

Experimental Procedure

The most conclusive test of spiral bevel gears is their operation under normal running conditions in their final mountings. Testing not only maintains quality and uniformity during manufacture, but also determines if the gears will be satisfactory for their intended applications.

MASTA is an automated designing soft-ware that creates an optimized model of the gear tooth profile just by inputting the basic parameters. A mathematical model of an ideal spiral bevel gear-tooth surfaces based on the Gleason gear generator mechanism is used.

Using this mathematical model, the tooth surface sensitivity matrix to the variations in machine–tool settings are investigated. Surface deviations of a real cut pinion and gear with respect to the theoretical tooth surfaces are also investigated. An optimization procedure for finding corrective machine–tool settings is then proposed to minimize surface deviations of real cut pinion and gear-tooth surfaces.

The results are revealed that surface deviations of real cut gear-tooth surfaces with respect to the ideal ones are reduced. Therefore, the proposed method for obtaining corrective machine–tool settings improves the conventional development process and can also be applied to different manufacturing machines and methods for spiral bevel gear generation.

First of all, to get the relative position of contact pattern and tooth profile of the boundary, we need to locate tooth profile and contact pattern as well as their respective centric. In the meanwhile, it requires the guide, which can help to check whether the tooth profile on which the spiral bevel gear meets with the contact pattern is on its right position.

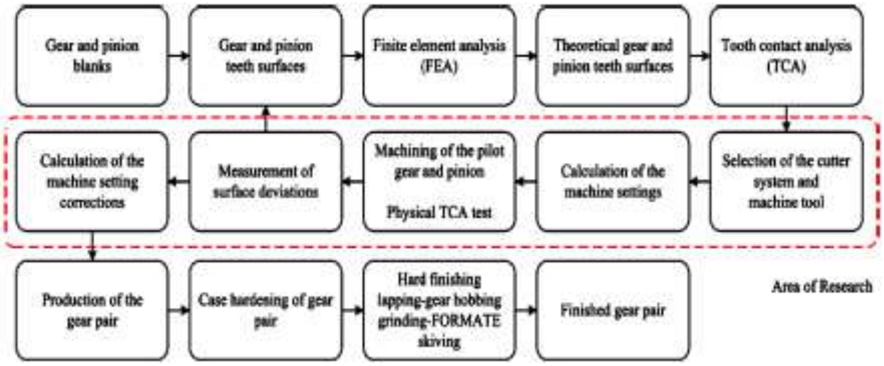


Fig 4.1 Analysis and machining cycle of spiral bevel bevel gears

CONCLUSION

The design of complex systems has become a more global, integrated problem. Complex systems comprise of various disciplines and analyses. Many design decisions are a compromise based on these disciplinary objectives. To facilitate design decisions in a concurrent manner, information transfer between these systems need to be streamlined and processes developed for improved integration. Amount of interfaces are subject to the extent of interaction anticipated. For most systems the level of interaction between subsystems and disciplines can vary greatly depending on the overall system objectives and the fidelity of the analyses. Efficient information transfer and change propagation is essential for multidisciplinary trade studies, needed to achieve the system's global objectives.

FUTURE SCOPE

There is a possibility to study in future to improve the life of gear.

1. Tooth Contact Analysis can also be determined for hypoid bevel gear; presently the study was for spiral bevel gear only.

2. Because of the high torque and high loads during operation, considerable amounts of heat is also dissipated. So the heat transfer condition can also be considered in the future analysis of the spiral bevel gear.

3. Next generation of standards and practices in gear industry is one that will demand reliability, high levels of engineering excellence and precision manufacturing. Over the coming years,

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