INVESTIGATION IN RECENT ADVANCE IN THE ANALYSIS OF SPIRAL BEVEL GEARS

[1]Md.Nadimul Haque, **[2]Anil Verma,[3]Dr.G.R.Selokar, [4]Dhananjay Yadav**

[1] M.tech Schlor, Mechanical Department, SSSUTMS, M.P.India
[2] Assistant Professor, Mechanical Department, SSSUTMS, M.P.India
[3] Professor, Mechanical Department, SSSUTMS, M.P.India
[4] Assistant Professor, Mechanical Department, SSSUTMS, M.P.India

ABSTRACT

The theory of generate-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.

LITERATURE REVIEW

Benedict and Kelley [1] 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. [2] 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 [3] 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 [4] 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 [5] 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 [6-7] 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.

Handschuh and Kicher [8] developed a method to analyze the thermal behavior of spiral bevel gears. They assumed an elliptical Hertzian contact and used a simplified expression for friction coefficient as a function of slide-to-roll ratio and rolling velocity. Then they employed a finite element model to determine the heat generated as a result of the relative sliding of the tooth surfaces. In terms of hypoid gear power losses, Simon [9] used an EHL lubrication formulation along with a hypoid gear a finite-element load distribution model to predict mechanical power losses.

Jia et al [10] used a multilevel-mutligrid technique to solve the implement the same EHL equations with accelerated convergence. Taking these preliminary studies on cross-axis gears one step further, Xu and Kahraman developed a model to predict load dependent power losses in hypoid gear pairs.

They utilized a finite element based hypoid analysis software package [11] for contact analysis and a deterministic EHL model proposed by Cioc et al. [20] to predict the friction distributions. They performed experiments and validated the proposed EHL based model. Later, Kolivand et al [12] extended this study by utilizing the contact model developed by Kolivand and Kahraman, in the process removing the dependency of the load distribution computation on a FE package. Investigating the components of the rear axle including cross axis gearing, experimental studies were performed measuring overall axle power losses.

Johnson et al. [13] conducted experiments to investigate the effects on windage power loss of a single spiral bevel gear and showed that optimally placed shrouds could reduce windage as much as 70%. Then, Johnson et al. [14] extended this study to a shrouded spiral bevel gear pair and presented their results concluding that gear windage becomes a significant contributor to spin losses at high speeds.

Gabiccini et al. [15] presented an automatic procedure to optimize the loaded tooth contact pattern of face-milled hypoid gears with misalignments varying within prescribed ranges. Through the formulation of an appropriate nonlinear optimization problem,
Artoni et al. [16] proposed a novel methodology to systematically define optimal ease-off topography to simultaneously minimize the loaded transmission error and tooth contact pressures, while concurrently confining the loaded contact patterns within a prescribed allowable region on the tooth surface to avoid any edge- or corner-contact conditions.

Artoni et al. [17] presented a novel methodology to restore the designed functional properties of hypoid gear sets whose teeth deviate from their theoretical models due to inevitable imperfections in the machining process.

Ozel et al. [18]. For the spiral bevel gear machining by using CNC milling machine, people don't need to invest huge money on specific bevel gear machine since the general CNC milling machine are used, but the accuracy is difficult to achieve, and takes longer time compared to the specified cradle machining method.
Suh et al. [19] proposed a virtual gear model. In this model, the sampling points were measured by using CMM, and fitted by NURBS surface. Compare the virtual gear model to the theoretic model, the geometric error was evaluated. Weimin developed accurate way to measuring the spiral gear tooth by optimize the measuring process parameters.

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.

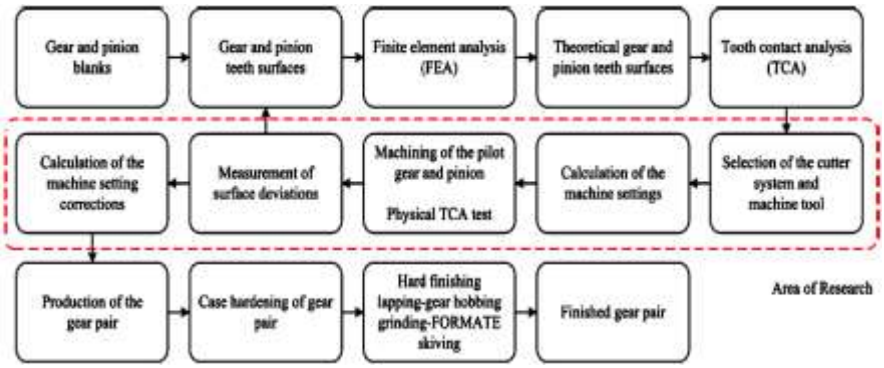

Fig 4.1 Analysis and machining cycle of spiral bevel bevel gears

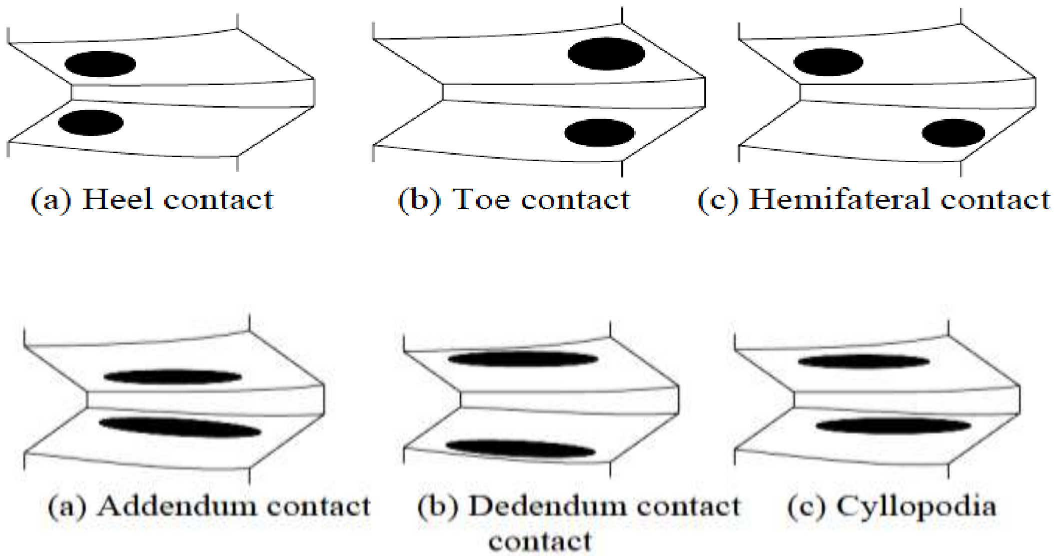

Fig 4.2 Various Contact Positions

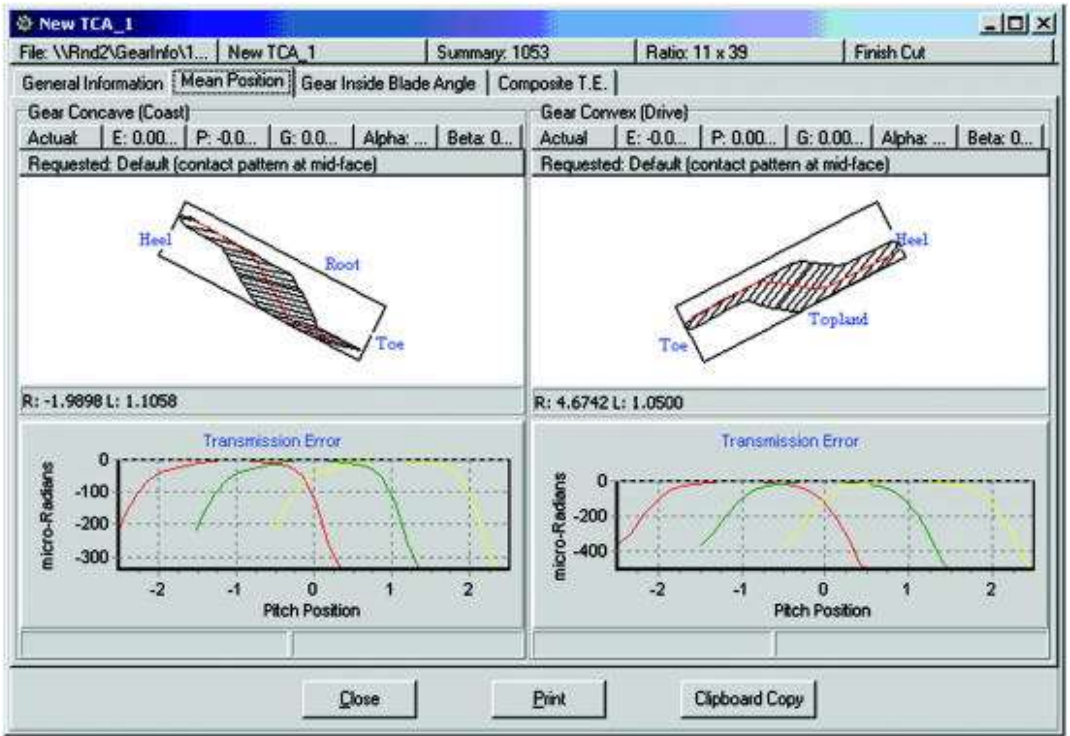

Fig 4.3 Trial 1

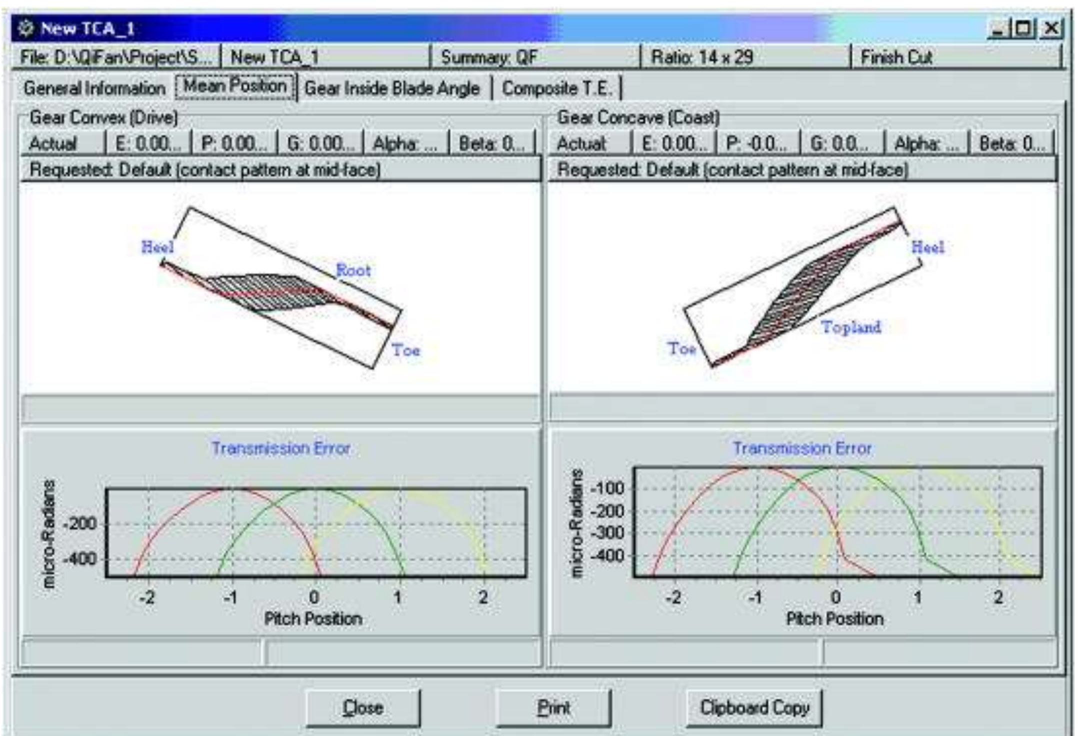

Fig 4.4 Trial 2

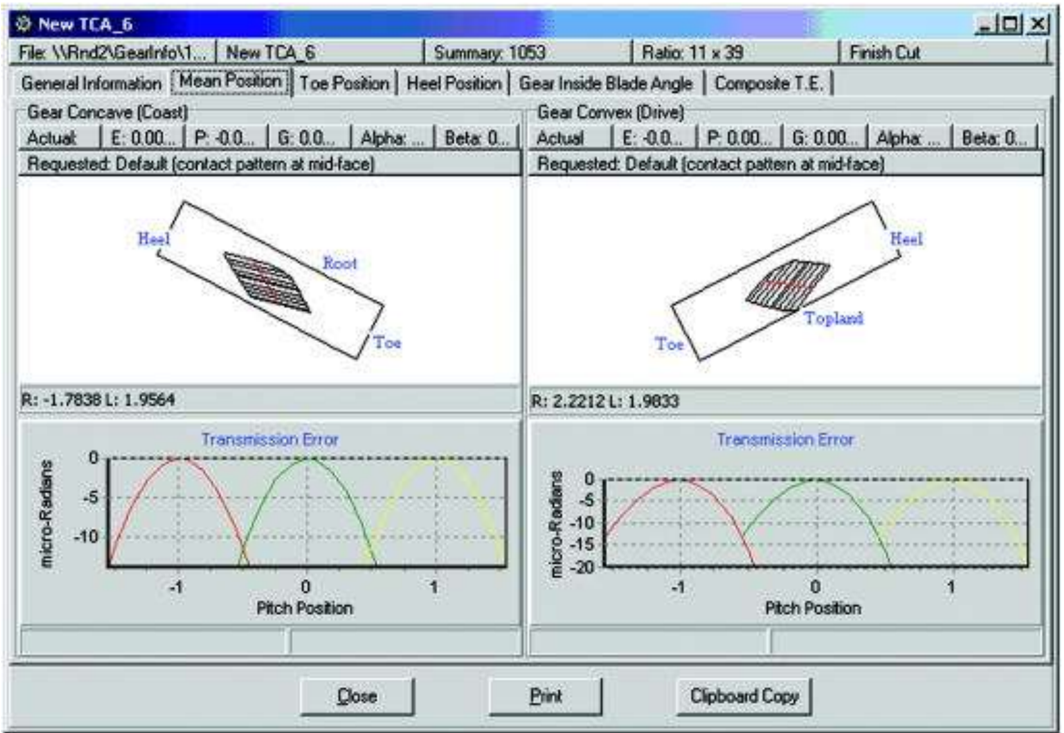

Fig 4.5 Trial 3

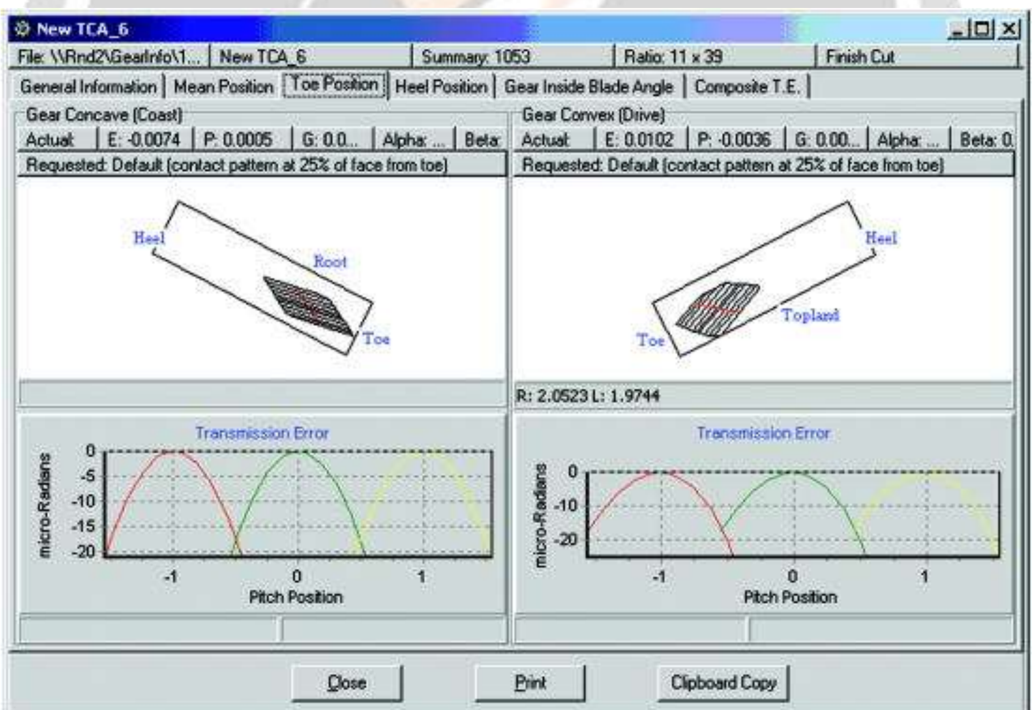

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Fig 4.4 Trial 4

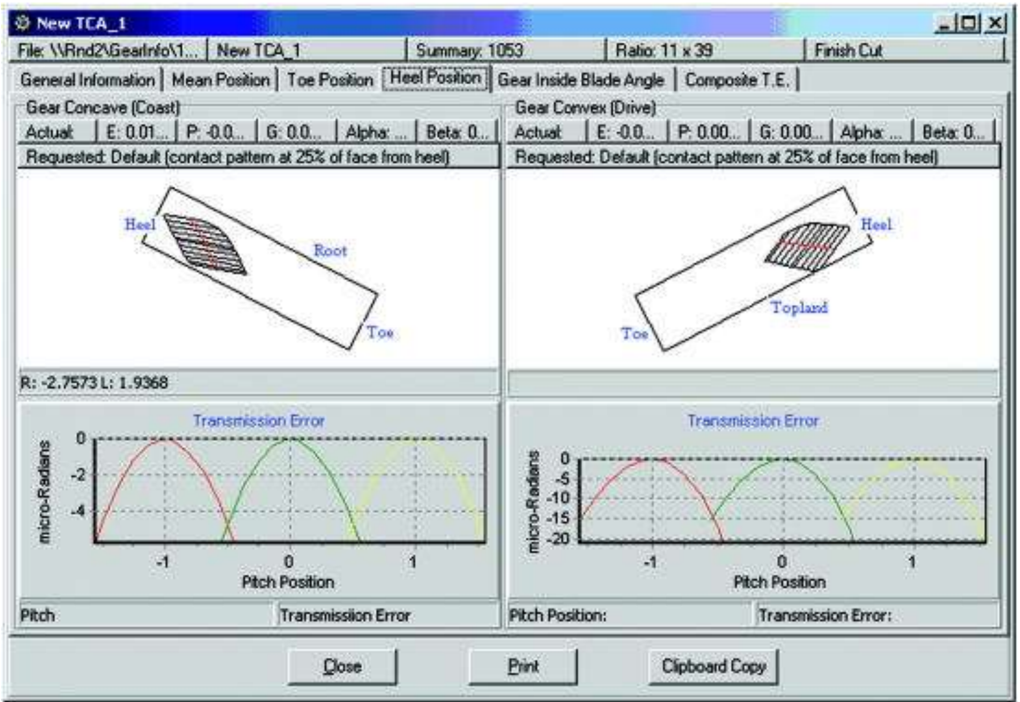
- 

Fig 4.7 Trial 5

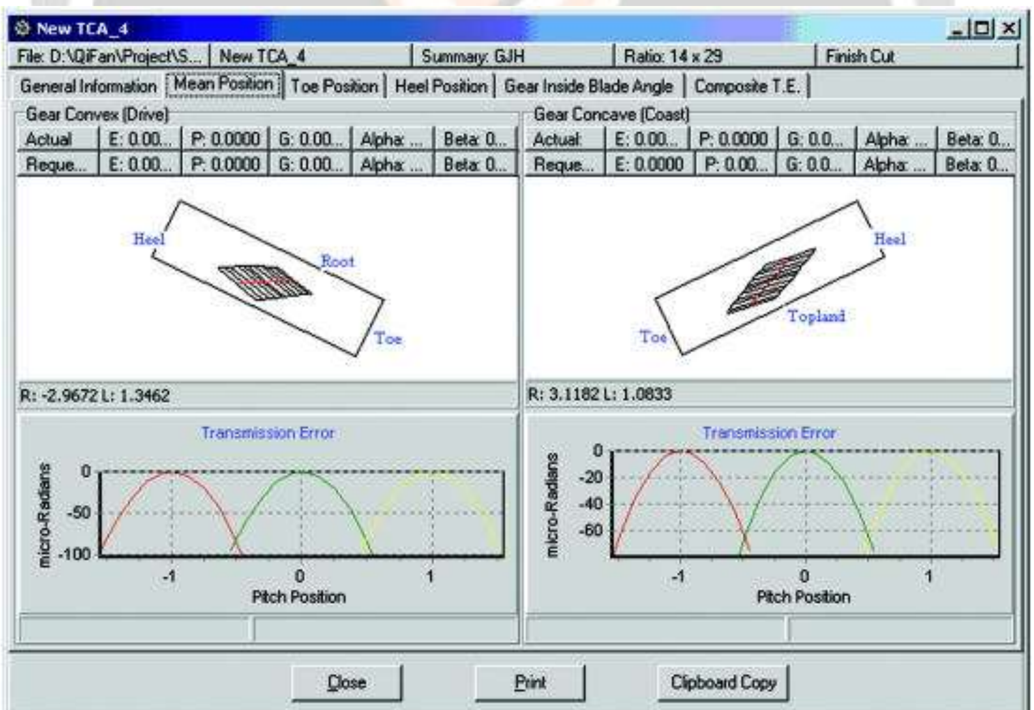
- 

Fig 4.8 Trial 4

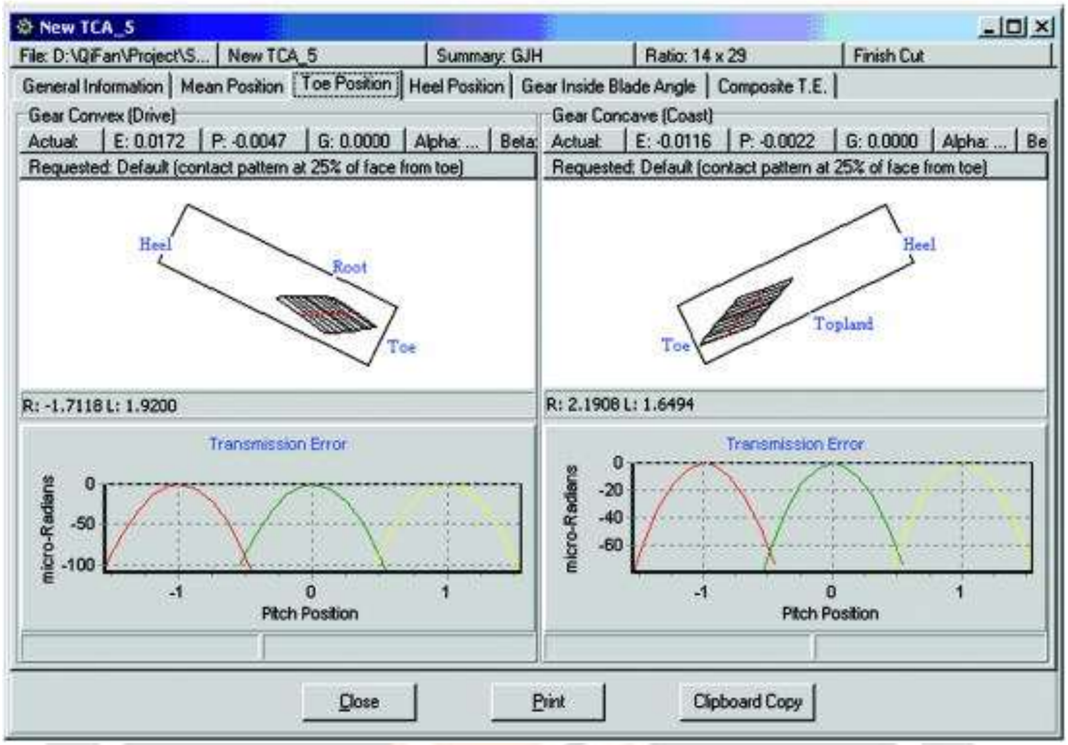


Fig 4.9 Trial 7

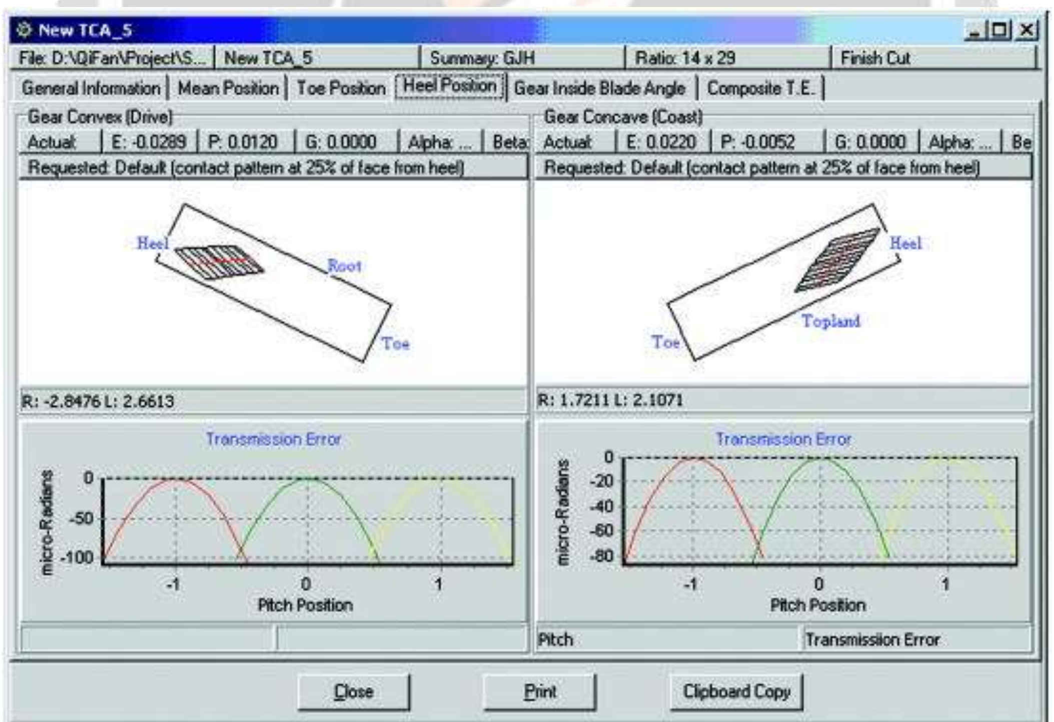


Fig 4.10 Trial 8

RESULTS AND DISCUSSION

To study the overall methodology, a sound system design techniques developed. Based on literature survey and research done in the area of spiral bevel gear design and development, the following design framework **Error! Reference source not found.**was developed.

MASTA

MASTA is capable of modelling a variety of gear types. Instructions for the creation spiral bevel gear pair models is found in the MASTA. This describes to use to input and design face milled spiral bevel gear sets.

Following MASTA modules functionality were used in this thesis.

- MC302 – AGMA/Gleason Spiral Bevel Gear Design and Rating
- MC303 – AGMA/Gleason Spiral Bevel Gear Macro Geometry Optimisation
- MC401 - AGMA / Gleason Spiral Gear Design and Rating
- MC402 - AGMA / Gleason Spiral Gear Macro Geometry Optimisation

Spiral Bevel/Spiral Gear Sets in a MASTA Design

Adding a Spiral Bevel Gear Set to the Design

1. Select **Design** mode.

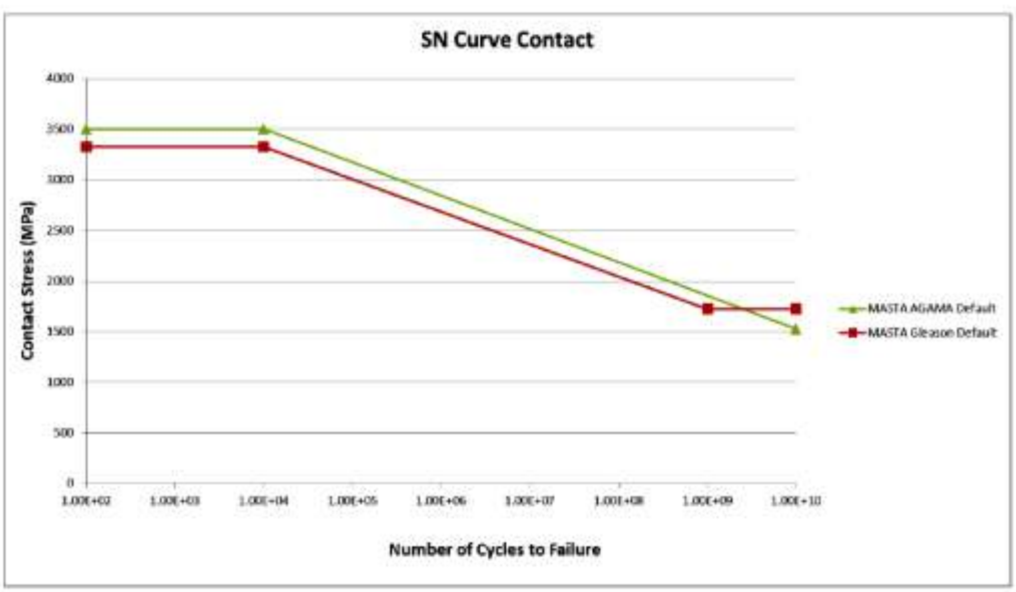
2. Right click in the Assembly View.

3. Click **Add** >**Gear Sets** >**Spiral Bevel Gear Set**.

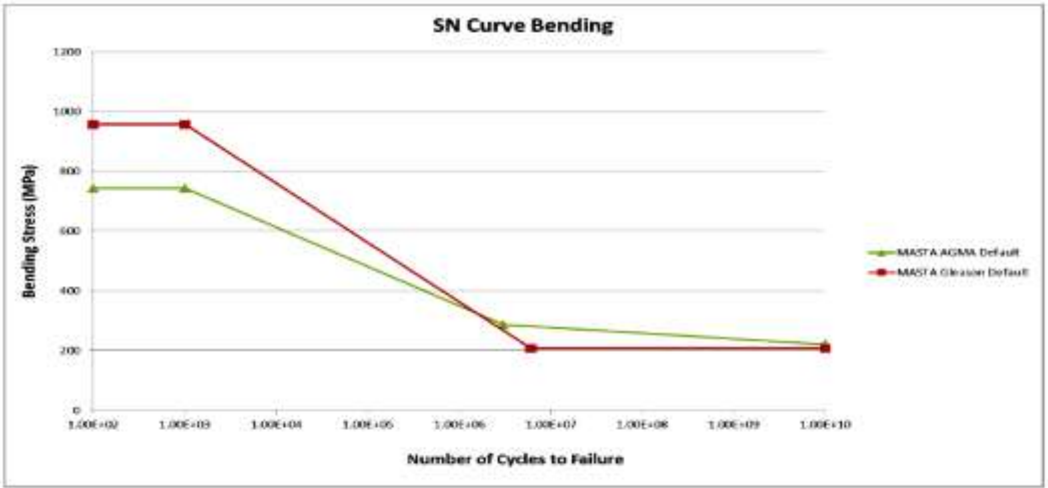
4. A window will open allowing input of some of the main macro geometry parameters for the spiral bevel gear pair to be created. These properties may be entered at this stage but they may also all be entered or edited at any time once the gear pair has been created via the Properties Grid:

For AGMA the relevant life factor expressions can be found in, Figures 5 and 6 p 21 of ANSI/AGMA 2003-C10. Note that the corresponding AGMA Technical Report for Spiral Gears, AGMA 932-A05, also refers to the 2003-C10 graphs.

This above process leads to the following default S/N curves for contact:



and the following default S/N curves for bending:



Notes:

- There is a significant difference between Gleason and AGMA S/N curves for Bending due to the significant differences in the Life Factor charts. Default materials cannot be edited or deleted but they can be duplicated.

Optimisation Results

Status | Report | Rating | Gear Teeth | Optimisation

Searching for 1 initial designs
Found 1 initial designs

Iteration	Progress	Pressure Angle (°)	Mean Spiral Angle (°)	Circular Thickness Factor	Wheel Addendum Multiplier	Whole Depth Factor
5	8.61 %	20	35	0.084	0.4263	1.9729
4	8.61 %	20	35	0.08401	0.4262	1.973
3	8.6 %	20	35	0.08401	0.4262	1.972
2	8.51 %	20	35	0.08301	0.4272	1.971
1	7.75 %	20	35	0.07489	0.4354	1.9629
Initial Optimisation	0 %	20	35	0	0.5103	1.888

While the optimisation is running the Status tab provides information on the progress of the optimisation. Each row of the table displays values for an iteration of the optimisation. The Progress percentage displays a percent improvement as compared to the initial optimisation step. The other columns display the values of the input variables for that iteration.

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