Parametric Stress Analysis of Spiral Bevel Gear using ANSYS

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Abstract— *Gears are the chief component for Transmitting power from one shaft to another. Moreover, they are also required to transfer power from the horizontal engines to the vertical rotor shaft. Spiral bevel gears used in this capacity, are typically essential to carry high loads and operates at very high rotational speeds. Therefore the efficient design of these components is very significant.*

In this paper Investigate the parametric analysis of a Spiral Bevel Gear have done in order to improve the transmission performance, since the bending and surface strength of the gear tooth are considered to be one of the main contributors for the failure of the gear in a gear set. Therefore, evaluation of stresses has become popular as an research on gears to minimize or to reduce the failures and for optimal design of gears. The whole research has completed in two phase 1st phase modeling of gear in which gear parameter such as number of teeth, spiral angle, face width, Bearing load (W) as altered. And in 2nd phase analysis in which model gear is analyzed with the help of ANSYS 14.5 and the bending and contact stress are evaluated

AGMA gear Equations are used to calculate gear contact stresses which are derived for contact between two gears analytically and compared with FEM results. The obtained theoretical value shows good agreement with the FEA result. From this we can conclude that the proposed gear model of Spiral bevel gear is accurate and some case study also have been done and discussed.

Key Words: Spiral Angle, Face Width, Stress.

I. INTRODUCTION

A gear is a mechanical device frequently used in transmission systems which allows rotational force to be transferred to another gear or device. The gear teeth, or cogs, allow force to be effusive transmitted exclusive of slippage and depending on their arrangement, can transmit forces at different speeds, torques, and even in a singular direction. Throughout the mechanical industry, many types of gears exist with each type of gear possessing explicit benefits for its intended applications. Bevel gears are widely implemented in usage because of their suitability towards transferring power between nonparallel shafts at almost any angle or speed. Spiral bevel gears have curved and sloped gear teeth in relation to the surface of the pitch cone. As a result, an oblique surface is formed during gear mesh which allows contact to begin at one end of the tooth (toe) and smoothly progress to the other end of the tooth (heel), as shown below in Figure 1 with various applications. Spiral bevel gears, on comparison with straight or zerol bevel gears, had further overlapping tooth action which crafts a smoother gear mesh. This smooth transmission of power along the gear teeth facilitate to reduce noise and vibration that increases exponentially at higher speeds. Therefore, the ability of a spiral bevel gear to alter the direction of the mechanical load, coupled with their ability to aid in noise and vibration reduction, make them a prime candidate for adopting in the helicopter industry.

Since 19th century American Gear Manufacturing Association (AGMA) has developed standards for the design, analysis, and manufacture of bevel gears. The first step in any general design employing gears is to first predict and understand all of the conditions under which the gears will operate. Most importantly are the anticipated loads and speeds which will affect the design of the gear. Additional concerns are the operating environment, lubrication, anticipated life of operation, and assembly processes, just to name a few.

In earlier period gear analyses was done with the help of analytical methods which includes lots of assumptions and simplifications. In general, gear analyses are flexible including computations related to the tooth stresses and the failures. In this thesis, bending stress, contact stress and parametric analyses are performed, with the main aim of designing Spiral gears to resist bending failure.

Nowadays advancement in computer technology is becoming more and more influential, and that is the motivation to peoples to use numerical approach to expand theoretical models to predict the effects. Due to less restraining assumptions numerical methods are employed since they provide more accurate and precise solution. However the imperative thing is to choose the correct model and the solution methods to get the perfect results and also reasonable computational time

II. LITERATURE REVIEW

In 1979 Konstantinov and Djamdjiev presents a state-of-the-art Wholly automated forging systems in which problems associated with the application of automatic loading equipment to the handling of forgings to insure continuous operation of the integrated manufacturing system, object of this research study, are examined by arguments and various types of handling devices are considered The manufacturing system is under direct numerical control (DNC) and is centered on chipless forming which, as a final product, yield bevel gears and similar parts with ready-to-mount teeth.

Weck et. al 1980 applied multiple-coordinate measuring technique to measure manufacturing deviations on bevel gears with great precision. The techniques helips in detail analysis of bevel-gear toothing geometry to be made and found that the obtained results prerequisites for methodically influencing the stting data of the bevel-gear cutting machine, with a view to obtaining the desired flank geometry

Nalluveettil and muthuveerappan 1993 perform finite element modelling and the analysis of a straight bevel gear tooth in order to evaluate bending stresses. isoparametric brick element is selected for FEA. The obtained stress distribution at the root of the tooth is compared with the experimental results existing in the literature and the tooth behaviour at the root is studied by changing the various parameters such as torque, pressure angle, shaft angle, rim thickness and face width of the gear pair

Lim et. al 1993 presents A transient elastohydrodynamic lubrication (EHL) analysis for spiral bevel gears. On considering the effect of the rate of change of contact parameters the time dependent Reynolds equation is solved and the fundamental characteristics of the dynamic loading are investigated in detail and are compared with the Grubin's approximations.

Vijayarangan and ganesan 1994 studied the behaviour of composite bevel gear from a static load distribution in a 3D finite element method. The performance of composite gear are compared and found that the static strength of glass epoxy bevel gear is found to faintly closer to a carbon steel bevel gear than a boron/epoxy bevel gear. The displacement of glass/epoxy deviates in comparison with carbon steel even more than boron/epoxy, and revealed that the bron/epoxy is more better as compared to steel.

Vaidyanathan et. al 1994 use Rayleigh-Ritz method to determine the flexural behavior of a cantilevered annular sector plate of variable rigidity, including the effects of shear deformation and root stresses in a straight bevel gear is demonstrated. And the numerical result is compared and found good agreement with the published fea results.

Rao and Shunmugam proposed a mathematical modelling of the tooth surface geometry of spiral bevel gears by implementing theory of conjugate surfaces and principles of differential geometry. A comparison has been made with involute spiraloid surface computationally and theoretically with actual surface.

Zhang et. al 1995 proposed a advanced design methodology face-milled spiral level gears with modified tooth surface geometry that helps in reducing noise level and have better stability . Local synthesis of gear is been done and the meshing and contact of the gear drive is synthesized and analyzed by a computer program. Synthesis approach are based on the application of a predesigned parabolic function for absorption of unwanted transmission errors caused by misalignment and the direct relations between principal curvatures and directions for mating surfaces.

In 1997 Lin and Tsay develop a mathematical model based on grinding mechanism and machine-tool settings of the Gleason modified roll hypoid grinder for spiral gear and hypoid gear.it is found that the all the machine-tool settings and machine constants involved in the mathematical model shows outstanding correlation between the mathematical model and actual manufacturing machines. In order to validate the mathematical model an example is been illustrated and bearing contact and kinematic errors in spiral bevel gear are analyzed.

Shunmugam et. al 1998 present a method for deterring the normal deviation bevel gears. With this method exact spherical involute is outlined and straight tooth and spiral tooth bevel gears are considered for the validation. Effectiveness of the proposed scheme for obtaining normal deviation is instituted by considering spiral bevel gear geometry based on circular arc.

Suh et al 2002 present an indirect measurement technique based on the virtual gears model (VGM), obtained by NUBS fitting of the surface points measured by CMM. In spiral gear, direct measurement with the physical part is not possible accurately due to presence of complexity. On comparing CAD and VGM model various errors such as tooth profile, tooth trace errors are automatically detected. The main attribute of this model is robust and does not required any special device. This model is further incorporated in the CAM-CNC and tested, the obtained results shows good agreement with the experiment and gets validated.

Li and hu 2003 perform dynamic analysis of a spiral bevel-geared rotor-bearing system. spiral bevel gear pairs constraint equation are described briefly which having relation between general displacement. The dynamic behavior and the vibration characteristics of the system are investigated with the other parameters such as critical speeds in journal supports, stability threshold speed and unbalanced responses in hydrodynamic journal bearings are well analyzed analytical and compare with experimental result.

Wang and fong 2005 proposed a technique to determine the machine settings with modified radial motion (MRM) correction at specified contact point with programmed motion curve and contact path bias on pinion tooth surface. Parameters of MRM correction are evaluated according to the equations of meshing and correlation between mating curvatures at specified contact point. In order to verify the proposed method numerical examples are stated con revealed that, the bias of contact pattern and the motion curve were powered separately.

Litvin et. al 2006 implement local synthesis algorithm for design, manufacturing, stress analysis of spiral bevel gears and perform experiment and the obtained results are compared aiming to reduce levels of noise and vibration and increased endurance. The optimized spiral bevel gear is presented by improving the bearing contact, and give parabolic function of transmission errors which helps in increasing the endurance limit of the gear drives.

Tsai and Hsu 2008 use cup-shape grinder or milling cutter for manufacturing the spiral bevel gear sets. In their previous publication the general meshing constraint equation is presented for designing and constructing solid model and in present work they derive meshing constraint equation of bevel gear sets with having point-contact characteristics and conclude that a novel approach for manufacturing spiral bevel gear is present and having major attribute that spiral bevel gear have single axis motion and it can be controlled during the cutting process.

Pio et al 2013 propose a novel method for kinematic and power flow analysis of bevel epicyclic gear train with having gyroscopic complexity. A new formula have been deduced and replaced spur gear trains with bevel gears and the willis equation are further modified with new power ratio expressions and the equation is been validated with bevel gears.

Bahrami et. al 2014 develop a model for straight bevel gear which predict the film thickness and friction coefficient under the mixed-lubrication regime. Using Tred gold approximation each pair straight bevel gear teeth is replaced with multiple pairs of spur gear teeth and evaluates the transmitted load and radii of curvature. The effect of load, roughness, hardness, and rolling speed parameters are investigated in the gear sytem which helps in understand the concept of load sharing with consideration of elastic, elasto-plastic and plastic deformation for asperities.

III. Mathematical Model

The calculation of bevel gear-tooth-bending and surface fatigue strengths (Contact Stress) is even more complex than for SpiralBevel gears. The treatment given here is very brief. The serious student wishing to pursue this subject further should consult appropriate AGMA publications and other specialized literature, such as that published by the Gleason Machine Division

The equation for bevel gear-bending stress is the same as for spur gears:

$$\sigma_b = \frac{F_t}{bmJ} k_v k_o k_m$$

Where, Ft =Tangential load in N

m = module at the large end of the tooth in mm

b = Face width in mm

J = Geometry form factor based on virtual number of teeth

Kv = Velocity factor,

Ko = Overload factor,

Km= Mounting factor, depending on whether gears are straddle mounted (between two bearings) or overhung (outboard of both bearings), and on the degree of mounting rigidity.

$$\sigma_c = \sqrt{0.35 \frac{F_t E}{b d_m} \frac{u_v + 1}{u_v} \frac{1}{\cos^2 \phi \tan \phi_w}} \quad (1)$$

$$u_v = u^2 = \frac{z_2}{z_1} \quad (2)$$

Putting material coefficient

$$y_m = \sqrt{0.35E} = \sqrt{0.35 \frac{2E_1 E_2}{E_1 + E_2}} \quad (3)$$

Where, E_1 and E_2 are the modulii of elasticity of the pinion and the gear material and pitting the pitch point coefficient.

$$y_p = \sqrt{\frac{1}{\cos^2\phi \tan\phi_w}}$$

(4)

On inserting the above terms we get Contact Stress,

$$\sigma_c = y_m y_p \sqrt{\frac{F_t}{bd_m}\frac{\sqrt{u^2+1}}{u}}$$

(5)

Since ϕ_n =20^o ψ=35^o and $\Sigma=\gamma_1+\gamma_2$= 90^o

IV. Methodology

The equation of motion of Spiral bevel gear is solved using FEA tool (ANSYS) as the equation of motion for a gear is difficult to visualize therefore some FEM tool is the solution method for analyzing stress of gear with various aspect ratio.

The ANSYS 14.5 finite element program was used for stress analysis. For this purpose, the key points were first created and then line segments were formed. The lines were combined to create an area. Finally, this area was extruded a We modelled the gear with a different no. of Teeth .A three-dimensional structural solid element was selected to model the gear. The gear was discretized into 35359 elements with 63404 nodes. Gear boundary conditions can also be modelled by constraining all degrees of freedoms of the nodes located on the left end of the gear. For bending and contact stress analysis the spiral bevel and straight gear pair with the properties given in table 5.1 was chosen to model. To minimize computation time, meshed gear with one tooth is imported to ANSYS Workbench 14.5 for analysis.

Table 1: Spiral Bevel Gear parameters

1	**Modulus of Elasticity**	202 Gpa
2	**Poission ratio**	0.3
3	**Type of Gear**	Standard Involute, Full depth
4	**Module**	4.5 mm
5	**Pressure Angle**	20^o
6	**Spiral Angle**	35^o
6	**Face width(F)**	40 mm
7	**No of teeth(N)**	9, 36-45
8	**Pitch Diameter**	162 mm
9	**Transmitted load(W)**	3000 N
10	**Revolution Per Minute(RPM)**	3000
11	Torque	150 Nm
12	Material	SCM420

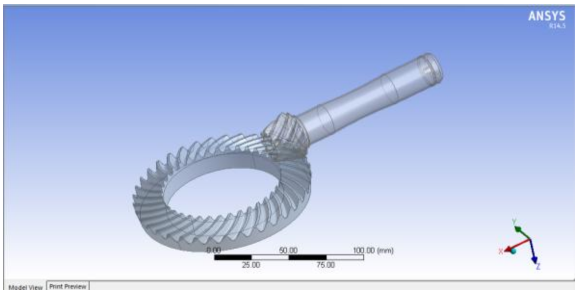

Figure 1 Modelled Geometry

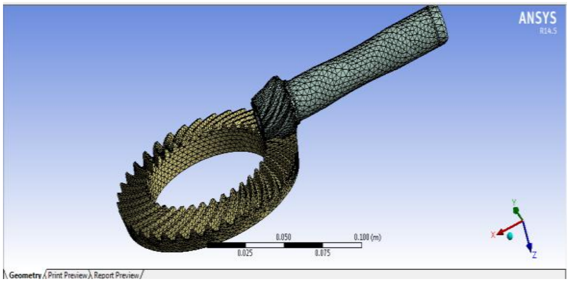

Figure 2 Mesh Model

V. Result and Discussion

Stress analysis of Spiral Bevel gear with using ANSYS and Analytical calculation. The parametric study of effect of face width, varying load, no. of teeth on Bevel gear is carried out.

The FEM results are validated with literature Faydor [23, 36] and by Analytical calculation for a few cases are also illustrated.

Table 2 Validation of Von-Mises Stresses for Spiral Bevel gear Models

Stresses		**Gear**	**Pinion**
Bending Stress	**FEM Reference [18]**	143	102
	FEM Present (ANSYS)	144.1	103.1
	Faydor (Expt.)	167	110.3

	[14]		
	FEM Present (ANSYS)	168.9	111.1
Contact Stress	**Faydor (Expt.) [14]**	377.4	29.410
	FEM Present (ANSYS)	379.2	30.8

Table 3: Von-Mises (Bending) Stresses for Bevel gear Models

No of teeth(N)	**AGMA Stresses(MPA)**	**3D Stresses (ANSYS)(MPA)**
36	219.2988	220.57
38	203.4563	203.21
40	184.2228	184.28
42	168.4495	168.86
44	155.1232	154.94

For the number of teeth (Z) = 36

$$\sigma_b = \frac{F_t}{bmJ} k_v k_o k_m = \frac{3000}{36 \times 4.5 \times 0.35185} \times 1.22 \times 1.3 \times 1.4 = 219.29 MPa$$

For number of teeth (Z) = 38

$$\sigma_b = \frac{F_t}{bmJ} k_v k_o k_m = \frac{3000}{36 \times 4.5 \times 0.2021} \times 1.2 \times 1.3 \times 1.4 = 203.45 MPa$$

For number of teeth (Z) = 40

$$\sigma_b = \frac{F_t}{bmJ} k_v k_o k_m = \frac{3000}{36 \times 4.5 \times .2232} \times 1.22 \times 1.2 \times 1.4 = 184.22 MPa$$

For number of teeth (Z) = 42

$$\sigma_b = \frac{F_t}{bmJ} k_v k_o k_m = \frac{3000}{36 \times 4.5 \times 0.2441} \times 1.22 \times 1.3 \times 1.4 = 168.449 MPa$$

For number of teeth (Z) =44

$$\sigma_b = \frac{F_t}{bmJ} k_v k_o k_m = \frac{3000}{36 \times 4.5 \times 0.26507} \times 1.22 \times 1.3 \times 1.4 = 155.123 MPa$$

From Table 6.1, 6.2 shows the stress distribution in Spiral Bevel Gear 3-D models and Shows the comparison of results for different 3-D models and the corresponding AGMA stress values and Present FEM values. From this it can be revealed that on comparing Analytical result with computational result shows good agreement. And it can also be concluded that on increasing number of teeth of Bevel gear Von-Mises (Bending) Stresses decreases.

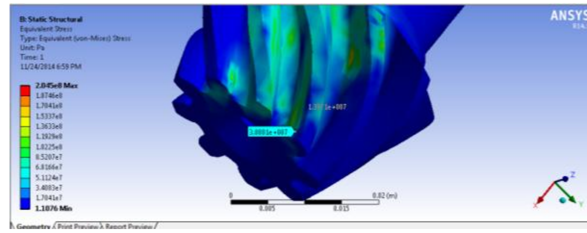

Figure 3 Validation of Contact Stress for Spiral Bevel Pinion

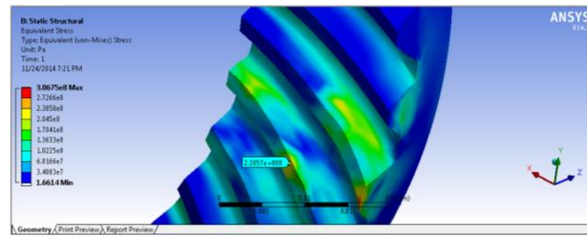

Figure 4 3-D Von-Mises Stress for Spiral Bevel Gear with 36 Teeth

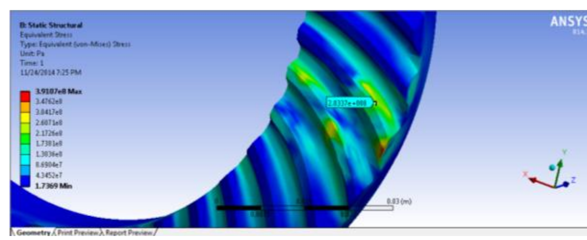

Figure 5 3-D Von-Mises Stress for Spiral Bevel Gear with 38 Teeth

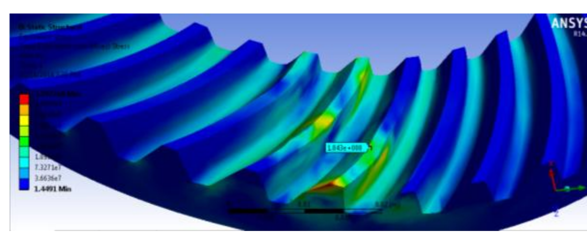

Figure 6 3-D Von-Mises Stress for Spiral Bevel Gear with 40 Teeth

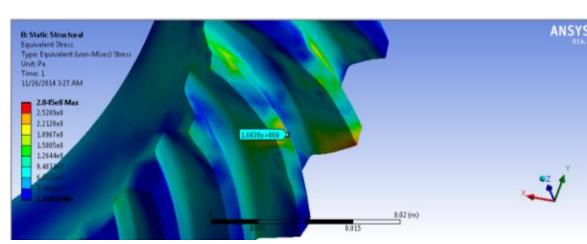

Figure 7 3-D Von-Mises Stress for Spiral Bevel Gear with 42 Teeth

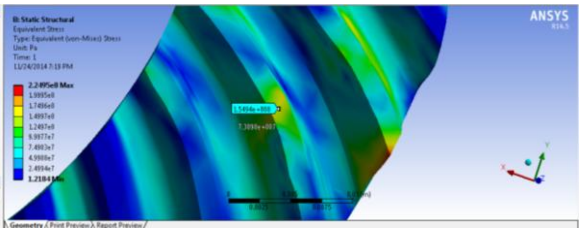

Figure 8 3-D Von-Mises Stress for Spiral Bevel Gear with 44 Teeth

Figure 3-8 shows the validation of bending stress of spiral bevel gear in which different configuration of spiral bevel gear are tests and compared with analytical result. It is found that the obtained result from FEA is near to the Analytical one. Since the variation in FEA result is due to the element and node sizing.

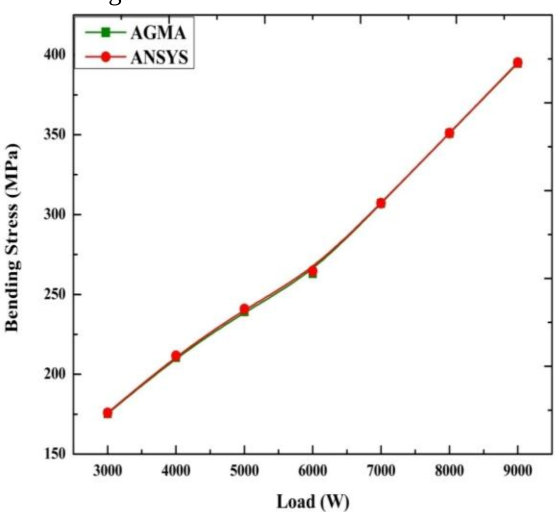

Figure 9 Variation of Bending Stress with respect to Load

Figure 9 show the Variation of Bending Stress with respect to Load. It is seen that on increasing load (Ft) the bending stress of Spiral Bevel gear linearly increases. On increasing load the bending stress increases from 16.63% - 9.53% form initial. An interesting fact is noticed that this percent deviation significantly decreases as load increases.

It can also be concluded the significance of load and bending stress played crucial role in material selection for gear design.

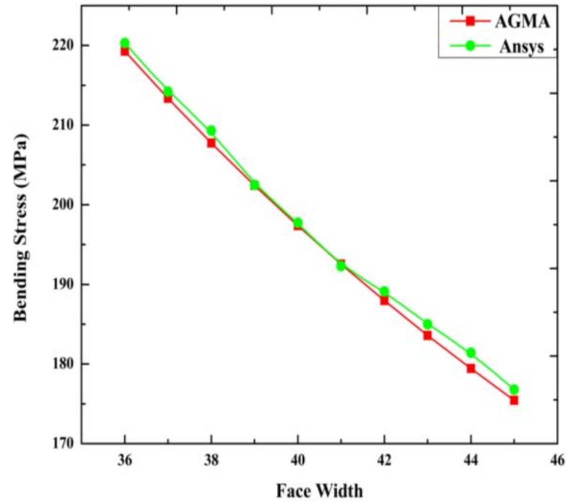

Figure 10 Variation of Bending Stress with respect to Face width

Figure 10 shows the Variation of Bending Stress with respect to Face width. From the figure it has seen that the bending stress linearly goes on decreasing as the gear face width increases. It can also be revealed that the decline trend even shows good and remarkable agreement with the FEA result.

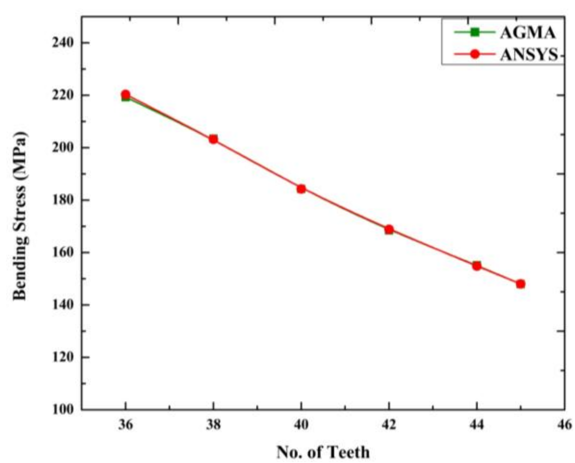

Figure 10 Variation of Bending Stress with respect to Number of Teeth

Figure 10 shows the Variation of Bending Stress with respect to Number of Teeth. It is seems that as the number of teeth increases of spiral bevel gear bending stress significantly goes on decreasing. And the FEA result very less deviation with the analytical (AGMA) result.

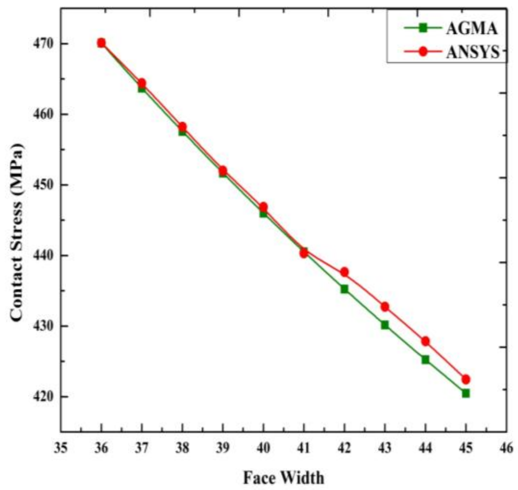

Figure 11 Variation of Contact Stress with respect to Face width

Figure 11 shows the Variation of Contact Stress with respect to Face width. From the figure it can be concluded that on increasing face width of spiral bevel gear linearly goes on decreasing. It has been also seen that the FEA (ANSYS) result also following the same trend and 0.61759% variation has seen from face width 42mm to 45mm.

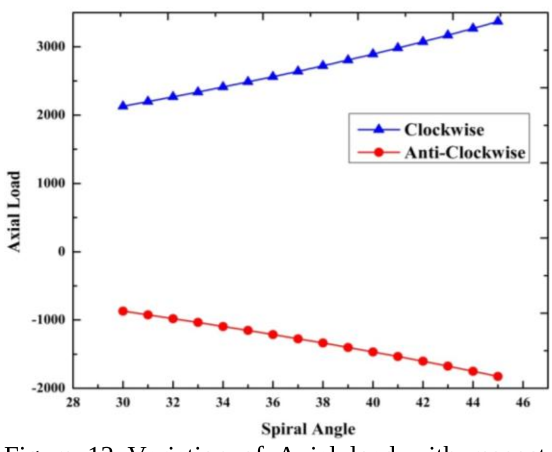

Figure 12 Variation of Axial load with respect to spiral angle (Constant load)

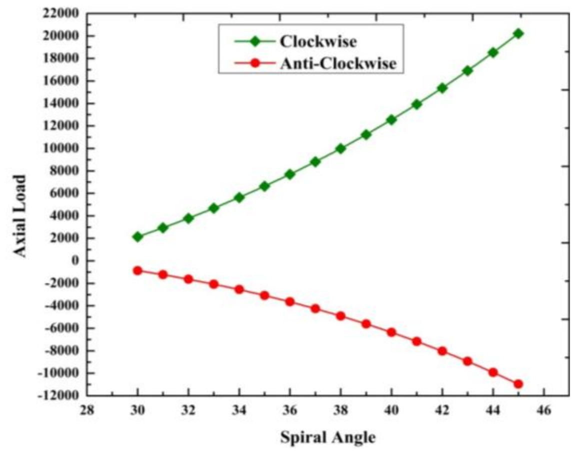

Figure 13 Variation of Axial load with respect to spiral angle (varying load)

Figure 12-13 Shows the Variation of Axial load with respect to spiral angle for constant and varying load. It cane concluded that on increasing spiral angle the magnitude of axial load(Thrust) on clockwise direction and decrease in anti clock wise direction since it depends upon the driver and driven member and also with hand of spiral.

It can also be conclude that on increasing tangential load (ft) with spiral angle the axial load acting of gear increase vigorously in clockwise direction.

VI. Conclusion

It was observed that the stresses generated on Spiral bevel gear teeth changes with the number of teeth.

It has observed that on increasing face with contact and bending stress decreases.

Spiral angle also play a crucial role the axial force acting on bevel gear.

A comparison of the results obtained from the FEM with those using the AGMA (maximum bending stresses) and (maximum contact stresses) reveals that that the maximum stresses predicted by the FEM are slightly higher than those predicted by the AGMA.

The height of the tooth is an important criterion and should be changed only if There are Space restrictions. A shorter gear tooth will produce more concentrated areas of stress which is ideally avoided, and should only be done if space is a major constraint.

Hardness of a tooth profile can improved can be prevented from pitting failure .i.e. a phenomenon in which a small particles are removed the surface of the tooth. This is due to high contact stress occurred between teeth during mating

In spiral Bevel gear spiral angle is main attribute in design consideration. Since spiral angle varies along with face width. Traditionally, a spiral angle β varies from 30^o to 45^o and it is implemented in order to assure a smooth tooth action as well as it also influence gear ratio, tooth load and bearing load

In Spiral bevel gears the pressure angle general made with 17.5^o and 20^o. But most commonly 20o is preferred to design.

The face width of spiral bevel gear is dependent upon the kind of application of the gearing and the cone distance at the back cone.

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