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Design, Modelling and Analysis of Herringbone Gear Using Ansys

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ABSTRACT
Herringbone gears, also called as double helical gears are the gear sets designed to transmit power through either parallel or less commonly perpendicular axes. The unique tooth structure of a herringbone gear consists of two adjoining opposite helixes that appear in the shape of the letter 'V'. Herringbone gears usually mate via the use of smooth, precisely manufactured V-shaped teeth. Like helical gears multiple teeth are engaged during rotation, distributing the work load and offering a quiet operation. However, due to their tooth structure, herringbone gears nullify the axial thrust unlike helical gears. The gear set's teeth may be manufactured so that tooth-tip aligns with the opposite tooth-tip or the opposite gear's tooth trough. In this project, herringbone gears that are used in a rolling mill gear box is designed using a 3D modelling software called Solid works. Static, Modal and Fatigue Analysis has been carried out on herringbone gears using ANSYS tool. Alloy Steel, GRP and Carbon fiber materials have been analysed and studied for comparison. The selection of better material for herringbone gear is determined out of this analysis. This Paper is the result of the analysis carried out by using ANSYS 14.5 on a 3D model of Herringbone gear which was generated using Solid works tool. The results are then compared with the help of graphs.
Keywords:- Design, Modelling, Helical, Herringbone Gear, Solid works, Ansys, Static, Modal and Fatigue analysis.

I. INTRODUCTION

A gear is a rotating machine part having cut teeth, or cogs, which mesh with another toothed part in order to transmit torque. Two or more gears working in tandem are called a transmission and can produce a mechanical advantage through a gear ratio and thus may be considered as a simple machine. Geared devices can change the speed, magnitude, and direction of a power source. The most common situation is for a gear to mesh with another gear, however a gear can also mesh a non-rotating toothed part, called a rack, thereby producing translation instead of rotation. The gears in a transmission are analogous to the wheels in a pulley. The advantage of gears is that the teeth of a gear prevent slipping. When two gears of unequal number of teeth are combined a mechanical advantage is produced, with both the rotational speeds and the torques of the two gears differing in a simple relationship. In transmissions which offer multiple gear ratios, such as bicycles and cars, the term gear, as in first gear, refers to a gear ratio rather than an actual physical gear. The term is used to describe similar devices even when gear ratio is continuous rather than discrete, or when the device does not actually contain any gears, as in a continuously variable transmission. The earliest known reference to gears was circa 50 A.D. by Hero of Alexandria, but they can be traced back to the Greek mechanics of the Alexandrian school in the 3rd century BC and were greatly developed by the Greek polymath Archimedes (287-212 BC).

The finite element method is proficient to supply this information but the amount of time required to generate proper model is large. Therefore to reduce the modelling time, a pre-processor method that builds up the geometry required for finite element analysis may be used, tools such as Solid works or Pro/Engineer. These tools can generate 3Dmodels of gears so quickly. The model geometry generated using Solid works is saved as an IGES file and then import it to ANSYS 14.5 for conducting the analysis.

Zhonghong Bu, et.al [1], produced a generalized dynamic model for herringbone planetary gear train (HPGT) is developed to investigate its modal properties. The model includes the axial vibration of two helical ring gears in addition to three planar degrees of freedom for the carrier and all gears. Four stiffness coefficients are applied to describe the asymmetry and the interaction of the oil film stiffness of journal bearings for supporting the planets. Vibration modes are classified into rotational and axial mode, translational mode, planet mode, rotational and axial ring mode and translational ring mode. For each type of mode, the reduced-order eigen value problems are derived according to the modal properties. The formulae for calculating the modal strain and kinetic energy distributions are also given for each mode. The proposed dynamic model and analysis methods can be applied to HPGT with any number of planets. Only when the asymmetric interaction exists in journal bearings, will the dramatic change of mode shape for translational mode occur. The new relations between deflections of planets in translational mode are also derived in this research.

Sachin M. Kamble, et.al[2], explained that Herringbone gears are extensively used in numerous engineering applications including gearboxes. Premature failures of such gears could lead to many serious consequences such as process downtime and late delivery which are critically important in this day and age of intense competition. This paper presents the results of an investigation into the premature failure of a herringbone gear used in a gearbox of a steel million wardha. The gear failed after about 9,000 hrs of service which was much shorter than the normal service life of 20,000 to 30,000 hrs. It was concluded the herringbone gear subsequently failed due to random fracture initiated by surface and subsurface damages resulting from excessive bending stress. Structural analysis on herringbone gear used in rolling mill gearbox has been carried out. The stress generated on gear tooth have been analysed theoretically as well as by using Finite Element analysis. Finally the results obtained by theoretical analysis and finite element analysis are compared to check the correctness.

Mr. Chirag R Patel, et.al[3], presents characteristics of a helical gear in dynamic condition involving meshing stiffness and other stresses produce. The main purpose of this thesis is by using numerical approach to develop theoretical model of helical gear and to determine the effect of meshing gear tooth stresses by taking material C-45. To estimate the meshing stiffness, three-dimensional solid models for different number of teeth are generated by Pro/Engineer and the numerical solution is done in ANSYS, which is a finite element analysis package.

Changzhao Liu, et.al[4], showed a dynamic model that includes friction and tooth profile error excitation for herringbone gears is proposed for the dynamic analysis of variable speed processes. In this model, the position of the contact line and relative sliding velocity are determined by the angular displacement of the gear pair. The translational and angular displacements are chosen as generalized coordinates to construct the dynamic model. The friction is calculated using a variable friction coefficient. The tooth profile error excitation is assumed to depend on the position along the contact line and to vary with the angular displacement of the driving gear. Thus, the proposed model can be used in the dynamic analysis of the variable speed process of a herringbone gear transmission system. An example acceleration process is numerically simulated using the model proposed in this paper. The dynamic responses are compared with those from the model utilizing a constant friction coefficient and without friction in cases, where the profile error excitations are included and ignored.

Chao Lin, et.al[5], suggested a new narrow herringbone gear, a new kind of transmission, is derived from traditional herringbone gear and broadens its application range. Based on the theories of differential geometry and gear meshing principles, the author describes the tooth and the transmission characteristics of the gear and deduces the equations of tooth face and fillet. According to the theories of material mechanics and gear strength check, the author deduces the equations of gear fatigue strength calculation, contact ratio and restriction of addendum sharpening. Based on the basic theories deduced before, a kind of software is developed which can achieve optimization design, modelling and analysis. ADAMS is used to simulate the contact forces of the gear and the result is compared with the theoretical mechanical calculation to confirm the axial force of the gear is lower than the helical gear. Finite element analysis is carried out to confirm the equations of gear fatigue strength are practical and correct.

According to Mayur S. Shelke, et.al[6], The history of rolling machines is very ancient. The first rolling machine was made in the late 17th century. The steel rolling machines are generally used in various sectors like Transmission Line Towers, Communication Tower, Wind Mill Tower, Ship Building, Railways, Industrial Infrastructural Projects and other Nation Building Infrastructure like Bridges, Electrification Projects etc. The steel rolling and forging is the part of metal working processes in which rolling machines are used for constructing long and continuous sections of metal. In this paper we are discussing steel rolling use for hot metal working process. This paper is focused on presenting the calculation of rolling load and the forces acting on the gears of steel rolling machine. After that power and torque required is calculated for the rolling load and the gear forces simultaneously which is further useful in designing and analysis of the gears used in gearbox of a hot rolling machine.

Wang Feng, et.al[7], aiming at effectively analyzing on power transmission processing of herringbone gear trains system, reasonably estimating the gearbox structure vibration and noise, finite element model is put forward considering fluid-solid coupling of gearbox. Time-varying dynamic loads calculating are applied on each center coupling point of bearing holes. Dynamic response analysis is carried out on the gearbox by the transient dynamic analysis module of ANSYS software, and structural vibration acceleration of the gearbox investigation nodes is estimated. Tooth dimensional optimization design with multiple dynamic targets is carried out by the adaptive genetic algorithm. Optimization results show the vibration acceleration of teeth meshing line direction and gearbox machine feet are both significantly reduced under given load condition. Herringbone gear transmission experiment testing system with closed power flow is set up to verify the theoretical analysis. In order to verify herringbone gear dynamic systems vibration transmission theory and tooth surface modification effects, teeth meshing line direction vibration is measuring through high precision angle encoders of Heidenhain, and vibration acceleration of bearing seat and machine feet are measured by accelerometer.

WANG Feng, et.al[8], also discussed that Teeth meshing stiffness was calculated using tooth contact analysis and load tooth contact analysis. A 12-DOF nonlinear double helical gear vibration model was established considering excitations of time-varying meshing stiffness, corner mesh impact, and backlash. With a ship transmission system as an example, the vibration characteristics of the left end meshing gear pair under multi-load were studied. The results showed that the system vibrations under excitations of meshing stiffness and corner mesh impact increase with increase in load torque; a corner mesh impact excitation is more sensitive to changes of load than a meshing stiffness excitation; however, the vibrations of the system decrease with increase in external load under backlash excitation; meanwhile, a corner mesh impact has a growing effect on the system vibrations with increase in the load while a meshing stiffness and a backlash excitation have diminishing effects.

Wu Liyan, et.al [9], explained that Meshing stiffness and stress are essential for vibration and strength analysis which become the key concerns in the application of herringbone gears. A parametric method for meshing stiffness and stress analyses based on finite element method (FEM) is proposed in this paper.A three dimensional model of herringbone gear structure is established based on the curve equations for true involute profile and transition curve. The curve equations for external and internal gears are generated according to the hobbing and shaping techniques respectively. The model can be easily changed in terms of the basic geometry parameters.

It is commonly known that the total deformation of each contact point at the same meshing position along the load direction must be the same to ensure the continuity of the meshing process. An automatic program to determine the meshing positions and the coordinates of each contact point is developed firstly. The flexibility factors for gear flank are computed by using FEM. The whole process is implemented by using FEM commands of ANSYS which are managed by the APDL program language and macros technique.

The program constructing the flexibility matrixes and solving out the meshing stiffness and load distribution is developed. By using the progam, the meshing stiffness and load distribution along the contact lines and load sharing ratio of each gear tooth during the whole meshing period can be obtained simultaneously.

Based on the load distribution, the gear stresses are analyzed by the finite element model of whole gear structure. The stress and deformation contours are displayed using the post-treatment of ANSYS.

In the end, techniques developed in this paper are used to analyze the meshing stiffness and stresses of herringbone gears used in encased planetary gear trains (PGTS). The 3D models of every parts of PGTS are established and used to assemble the virtual prototype which simulates the movement of the PGTS. The meshing stiffness of sun gear wheel with planet gear pairs and planet gear pairs with ring gear pairs, and the stresses of sun gears, planet gears and ring gears are calculated to highlight the capabilities of the developed techniques.

According to ZHOU Jianxing, et.al[10], the structure characteristics of herringbone gear transmission the dynamic response of the gearbox is researched in consideration of the excitation (such as: time-varying mesh stiffness, gear errors), herringbone gears axial positioning and sliding bearing. The model is solved by using the New mark integrals method, then the time history of system dynamic force is obtained. Taking bearing force as excitations the gearbox noise radiation characteristics are researched. The distribution of sound pressure and frequency spectrum for noise of the field points are obtained, then the spatial distribution and frequency components of the noise are analyzed. The effect of the gear parameters (including helical angle, face width, addendum coefficient, tip clearance coefficient and pressure angle), connection stiffness of left and right sides of herringbone gears and axial support stiffness on the gear reduce noise radiation are discussed. The study provides useful theoretical guideline to the design of the gearbox.

II. DESIGNING OF GEAR

Considering the module =5, number of teeth = 18 and 20^0 full depth
Power transmitted = 15 KW
Torque, $T = (P \times 60) / 2\pi N$
For 10000 rpm ,
$T = (15 \times 1000 \times 60) / (2 \times \pi \times 10000)$
$= 143.3$ N-m
From A Text Book of
MACHINE DESIGN by R.S.khurmi & J.K.GUPTA
From Table no : 28.7
For m=5
Precision gear error = 0.015
From table 28.6 --- for 0.015 –
Pitch line velocity v = 20 m/sec
Velocity factor $C_v = 0.75 / (0.75 + \sqrt{v}) = 0.75 / (0.75 + \sqrt{20}) = 0.14361$
Number of tooth on gear $T_g = 3 \times T_p = 3 \times 18 = 54$
Diameter of gear $D_g = m \times T_g = 5 \times 54 = 270$ mm
Circular pitch = (3.14 x D) / T = (3.14 x 270) / 54 = 15.7 mm
Face width $b = 4\pi m = 4 \times 3.14 \times 5 = 62.8$ mm
Tangential force calculation:
Tangential force $W_t = 2000\ T / D_g$
$= 2000 \times 143.3 / 270$
$= 1061.41$ N

III. MODELING OF GEAR

The most complicated part in any gear modelling is the involute profile of its teeth. There are various ways of creating involute profile of a herringbone gear. In this paper the herringbone gear model was designed in Solid works design
modeller. DS Solid works is a suite of programs, which are basically used in designing and manufacturing range of products. This paper basically deals with the solid modeling feature of Solid works [11] by varying the face width.The parameters and the materials properties used for gearmodeling are tabulated below:

TABLE I GEAR PARAMETER

Sl.no	**Variable Name**	**Description**	**Values**	**units**
1	Z	No.of teeth	54	-
2	M	Module	5	mm
3	D	Pitch diameter	270	mm
4	PHI	Pressure angle	20	degree
5	β	Helix angle	15	degree
6	F	Face width	62.8	mm
7	A	Addendum	5	mm
8	B	Deddendum	6.25	mm
9	P	Power	15	kW
10	N	Speed	1000	RPM

Solid works is a 3D mechanical CAD (computer-aided design) program that runs on Microsoft Windows and is being developed by Dassault Systems Solid works Corp., a subsidiary of Dassault Systems, S. A. (Vélizy, France). Parameters refer to constraints whose values determine the shape or geometry of the model or assembly. Parameters can be either numeric parameters, such as line lengths or circle diameters, or geometric parameters, such as tangent, parallel, concentric, horizontal or vertical, etc. Numeric parameters can be associated with each other through the use of relations, which allow them to capture design intent. Operation-based features are not sketch-based, and include features such as fillets, chamfers, shells, applying draft to the faces of a part, etc.

Building a model in Solid works usually starts with a 2D sketch (although 3D sketches are available for power users). Dimensions are added to the sketch to define the size and location of the geometry. Relations are used to define attributes such as tangency, parallelism, perpendicularity and concentricity. The parametric nature of Solid works means that the dimensions and relations drive the geometry, not the other way around. The dimensions in the sketch can be controlled independently, or by relationships to other parameters inside or outside of the sketch.

Solid works also includes additional advanced mating features such as gear and cam follower mates, which allow modelled gear assemblies to accurately reproduce the rotational movement of an actual gear train. Finally, drawings can be created either from parts or assemblies. Views are automatically generated from the solid model, and notes, dimensions and tolerances can then be easily added to the drawing as needed. The drawing module includes most paper sizes and standards (ANSI, ISO, DIN, GOST, JIS, BSI and SAC).

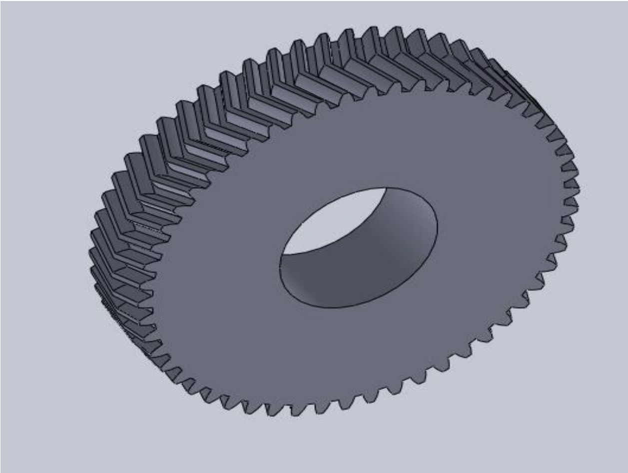

Fig.1 Herringbone Gear Modelled

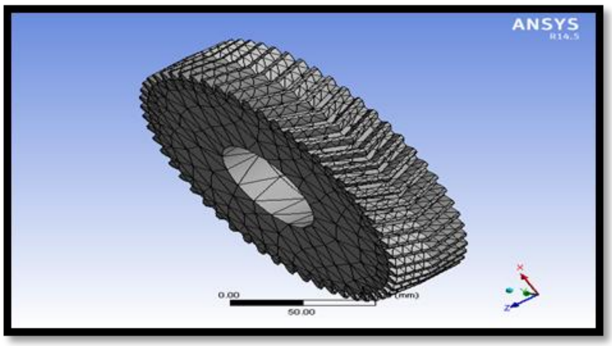

Fig.2 meshed 3D gear model

FEM Package

ANSYS is the name commonly used for ANSYS mechanical, general-purpose finite element analysis (FEA) computer aided engineering software tools developed by ANSYS Inc. ANSYS mechanical is a self contained analysistool incorporating pre-processing such as creation of geometry and meshing, solver and post processing modules in a unified graphical user interface. ANSYS is a general purpose finite element-modeling package for numerically solving a wide variety of mechanical and other engineering problems. These problems include linear structural and contact analysis that is non-linear. Among the various FEM packages, in this work ANSYS is used to perform the analysis[11]. The following steps are used in the solution procedure using ANSYS. 1. The geometry of the gear to be analyzed is imported from solid modeling Pro/Engineer in IGES format this is (fig.2 &3) Compatible with the ANSYS.

IV. RESULTS

The static analysis, modal analysis and fatigue analysis was carried out on 3 different materials. The analysis results, i.e.,ANSYS solution for CFRP material has been presented in figures 3 to 7.

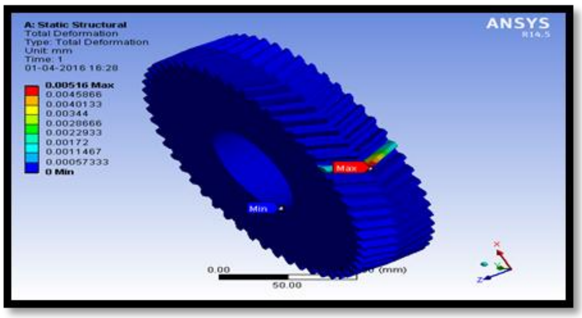

Fig.3 Deformation-CFRP

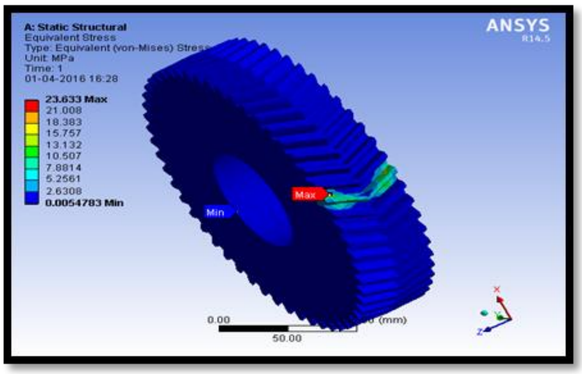

Fig.4 Stress-CFRP

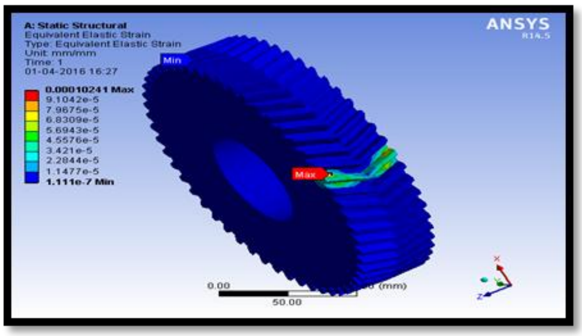

Fig.5 Strain-CFRP

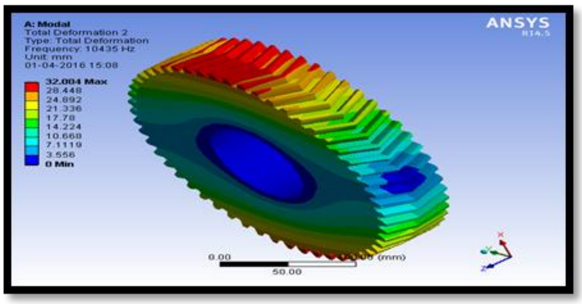

Fig.6 Dynamic deformation-CFRP

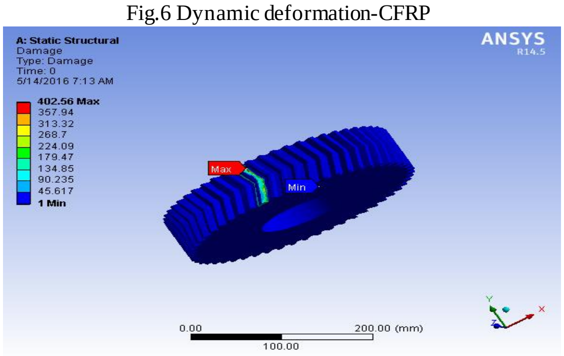

Fig.7 Damage period –CFRP

The results are depicted in the table 2.

TABLE 2

S.No.	Property	Alloy steel	GRP	Carbon FRP
1	Deformation, mm	0.006	0.034	0.005
2	Stress, MPa	23.34	23.60	23.63
3	Strain	0.0001	0.0007	0.0001
4	Dynamic Deformation, microns	15.28	31.49	32.00
5	Damage, hrs	231	402	403

During the analysis, it can be learned that the deformation of the gear wheel for carbon reinforced plastic material is smaller when compared to that of the other materials. The stress induced is almost same as that of the other two. Even though the dynamic deformation is little more, the life of the gear is much longer at the same load.

The cost of the carbon reinforced plastic material is much lowerthan steel.

Keeping the above facts in view, the carbon reinforced plastic material is very much suitable to be used for making the herringbone gears.

V. CONCLUSIONS

From the modeling, design and analysis, it is found that the herringbone gears can be made with carbon fibre reinforced plastic material for better performance and results.

REFERENCES

[1] Zhonghong Bu, Geng Liu, Liyan Wu; "Modal analyses of herringbone planetary gear train with journal bearings Mechanism and Machine Theory", Volume 54, August 2012, Pages 99–115

[2] Sachin M. Kamble, Abhishek Chaubey; "Stress Analysis of Herringbone Gear by Using FEA", www.ijert.org, Vol.2 - Issue 10 (October - 2013), e-ISSN: 2278-0181

[3] Mr. Chirag R Patel, Mr. Samir D. Jarivala, Mr. Charmis Rajput; "Meshing Stiffness and Stress Analysis of Helical Gear of C45 in Dynamic Condition using Analysing Software", International Journal for Research in Technological Studies| Vol. 1, Issue 6, May 2014 | ISSN (online): 2348-1439

[4] Changzhao Liu, Datong Qin and Yinghua Liao, J. Mech. Des 136(4); "Dynamic Model of Variable Speed Process for Herringbone Gears Including Friction Calculated by Variable Friction Coefficient", 041006 (Feb 26, 2014) (12 pages)

[5] Chao Lin, Zheng Guo, Bingkui Chen and Caichao Zhu; "Study of New Type Herringbone Gear with Narrow Tooth Width and Beveloid Teeth Journal of Applied Sciences", Year: 2013 | Volume: 13 | Issue:23 | Page No.: 5584-5593

[6] Mayur S. Shelke, Prof. S.D. Kshirsagar; "Methodology for Calculation of Rolling Load and Forces Acting On Herringbone Gear Using Hot Rolling Theory", International Journal of Research in Aeronautical and Mechanical Engineering, Vol.2 Issue.1, January 2014, Pgs: 27-34

[7] WANG Feng, FANG Zongde, LI Shengjin, LI Jianhua, JIANG Jink; "Analysis Optimization and Experimental Verification of Herringbone Gear Transmission System", Journal of Mechanical Engineering, 2015-01

[8] WANG Feng,FANG Zong-de,LI Sheng-jin;"Dynamic characteristics of a double helical gear under multi-load Journal of Vibration and Shock", 2013-01

[9] Wu Liyan, Liu Geng and Bu Zhonghong; "Meshing stiffness and stress analyses of herringbone gears 5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)", June 30 – July 5, 2008

[10] ZHOU Jianxing, Sun Wenlei, Cui Quanwei; "Vibration and Noise Characteristics of The Herringbone Gear Transmission System Journal of vibration and shock",2015, 34(5): 213-219.

[11] ANSYS&Solid worksuser manual