STRESS ANALYSIS OF COMPOSIT SPUR MESH GEAR USING FEM

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Abstract— *Spur mesh Gear is one of the most important critical components in a mechanical power transmission system, and most industrial Dynamic machinery. Spur gears teeth in action are generally subjected to two types of Dynamic cyclic stresses are: bending stresses inducing bending fatigue and contact stress causing contact fatigue. Both these types of Dynamic stresses may not attain their maximum values at the same point of contact fatigue. Recently worm & worm wheel in gear box of Winch machine for lifting sand buckets of approximate weight of 270 kg & at height 27 feet. The motor used to drive the worm has power of 3 Hp & speed of 1440 rpm. The speed reduction is 62:1. In working condition of gear box, worm wheel fails due to load coming on the teeth. The crack is initiated at central thickness of tooth. Hence the tooth breaks at the central thickness. The failure occurs once within operational period of about 16 days. So the industry has to replace the worm wheel which is not cost effective. Calculation of stresses of worm wheel at tooth thickness is a 3D problem. This paper represents the analysis of stresses using theoretical, experimental and FEM analysis. Experimentally obtained results are verified with the finite element analysis (FEA) results.*

Keywords— Worm Gear; Photoelastictiy; Polariscope; Stress Freezing; FEA

1. INTRODUCTION

The material of worm wheel is Phosphor Bronze PB2.Some important parameters of existing worm

gear are,	
Number of Starts	1
Number of Teeth	65
Pitch Circle Diameter (Wheel)	178.54 mm
Pitch Circle Diameter (Worm)	36.34 mm
Module	2.72
Pressure Angle	25°
Lead Angle	4.48°
Max. Torque Transmitted	32175.25 N.mm

2. THEORETICAL ANALYSIS

The bending stresses for wheel are calculated using Lewis equation,

Pt = Cv b π mn Y

Pt = Permissible tangential tooth load or beam strength of gear tooth = 16732.57

N =Bending stresses.

Cv = Velocity factor. = 0.9658

b = Face width. = 25.08 mm

mn = Normal module=3.878 mm

Y= Tooth form factor or Lewis factor = 0.392

= Pt / (Cv b π mn Y)

= 144.64 N/mm2

Ultimate tensile strength of the Phosphor Bronze (PB2) material is 320 N/mm2. Therefore it can be stated that, the design of worm wheel is safe.

3. THREE DIMENSIONAL PHOTO ELASTICITY

Out of various analysis techniques, Photo elastic stress analysis is a technique which provides full field analysis of stress distribution for complex components. The name photo elasticity itself explains that technique is based on photo i.e. light and theory of elasticity. This technique is based on the property of birefringence possessed by some transparent materials when loaded. A stress freezing method is used to find out fringe pattern of the model. In this paper, bending strength of worm wheel is found out using three dimensional photo elasticity. In practice,

many problems are three dimensional in nature. Thus it becomes quite difficult to analyze 3D geometry than the 2D. Hence there arises a need of getting 3D stress pattern. The most powerful way for achieving this is the stress freezing method. Certain photo elastic model materials, such as epoxy resins, exhibit the stress freezing phenomenon. When the photo elastic material is heated to its stress annealing (or stress freezing) temperature under loading, the secondary bonds breaks down and primary bonds carries the entire applied load undergoing deformation. Now if temperature is lowered while maintaining the load, the secondary bonds will reform between the highly elongated primary bonds and serve to lock them into their extended positions. Thus we get locked stresses. The optical response of material related to the mechanical stress remains fixed in the material even after the removal of the loads at room temperature. Furthermore, the optical response is not disturbed even when the material is cut into thin slices. These slices are then analyzed on polar scope.

4. EXPERIMENTAL WORK & ANALYSIS

Experimental results and analysis requires finding the material fringe value of photo elastic material for calibration, finding the stresses developed in a model and scaling model to prototype. The accuracy of photo elastic model has got the major effects on the results obtained thus the preparation of the model bears its own importance in the whole problem of photo elastic stress analysis.

4.1 Preparation of Model

Following are the steps in casting photo elastic models. a) Pattern making. For casting 3-dimensional model, it is necessary to make pattern either of wood or metal . In present case, prototype of a worm gear itself is used as a pattern.


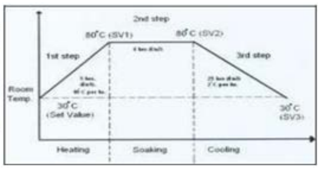

Fig.1 Preparation of Model b) Preparation of Rubber Mould

The pattern was placed in wooden frame. The rubber mould was made out of Sylartivi-11 & catalyst in proportion of
100: 2.4.Silicone rubber vulcanizing at room temperature (fig.1a).
101: As the geometry of wheel is not symmetric, the mould was cut into three parts (fig.1 b.)
c) Casting of model & calibration disc
The model was prepared out of epoxy resin Araldite CY-203-1 IN mixed with HY-951 hardener in proportion of 100:7 (fig.1 c). So as to find out material fringe value, calibration disc was also casted in the same manner.

4.2 Designing & Developing Loading Frame

The loading frame should be designed and developed so as to simulate the actual loading conditions. With the help of loading frame, the required torque can be transferred by loading worm & wheel and fringe pattern can be obtained. The following figure shows the loading frame. Here the worm shaft is provided with lever, fitted for application of load and the rotation of the wheel is restricted by providing a stopper. Thus torque will be transferred from worm to worm wheel & as the rotation of wheel is stopped, stresses will get locked in the wheel. The loading frame for loading the calibration disc was also designed & developed. Following are the several parameters required while designing loading frame & for prediction of load to be given to the model. The speed of worm wheel (n) = 1440 rpm Torque transmitted by worm gear = 33157.27 N.mm Power transmitted by gear box (P) = 5 kW Tangential component acting on wheel,=16732.57 N The load of 2kg was required to produce adequate no. of fringes.

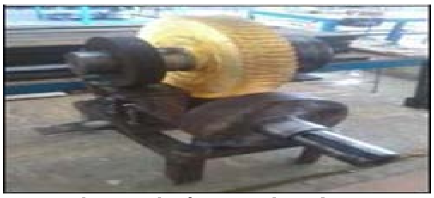

Fig 2.Photograph of Designed Loading Frame

4.3 Stress Freezing

After mounting a model on a loading frame, a model & calibration disc along with loading frames were placed in a stress freezing oven. A typical stress freezing cycle is shown in fig 5. Temperature rise rate was kept 10° C/hr up to soaking temperature of 80°C, the soaking time was kept 4 hrs and natural cooling was done. The model was loaded by4 kg mass. The total stress freezing cycle was observed to be of 38 hr.

4.4 Slicing

The slices were cut by employing horizontal milling machine with high speed (1500 rpm) and slicing saw of 1.5 mm thickness. Because of symmetrical shape of the model and symmetrical loading, it was decided to slice longitudinal. Cutting oil was spread at the time of cutting as coolant. Slice thickness was kept 3 mm. After cutting the slices, the surface of each slice was finished manually with the help of zero number polish paper.

4.5 Material Fringe Value

The material fringe value Fσ is defined as number of fringes produced per unit load. The material fringe value is the property of the model material for a given wavelength (λ) and thickness of the model (h). Here the circular disc of diameter 50 mm and thickness 6 mm was used to find material fringe value. This circular disc was loaded under compression by special fixture. A compressive load of 2Kg was applied to find material fringe value. This circular disc was also subjected to same stress freezing cycle as that for the model. Viewing through dark-field of circulated polar scope, locked is chromatic fringe pattern was observed. By using following equation, the material fringe value Fat critical temperature was found out. F
P =Load applied = 2Kg = 19.60 N D=Diameter of disc = 50mm
N= Fringe order observed at the center of the disc = 2.66 Substituting these values in above equation,F=0.37 N/mm

4.6 Stress Analysis

At root of marked tooth on the each slice, the isoclinic and is chromatic fringes were observed by using plane and circular Polariscope. All the values of fringe orders were noted down. The figure 3 shows the observation of fringe pattern at the tooth root slices using polar scope.

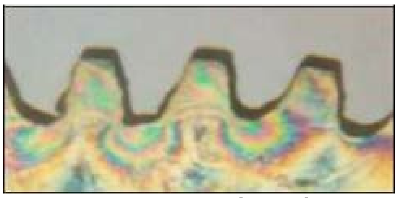

Fig 3.Fringe Pattern at the Tooth Root

The stresses developed in each slice at root of marked tooth point have been calculated as follows
Specimen Calculations:
Slice No. 1
$N = n \pm (\gamma/180)$
$N = 2.33 + (70/180)$
$N = 2.718$
We have material fringe value = 0.37 N/mm
Slice thickness = 3 mm Slice thickness = 3 mm

σ1 = = 0.3353 N/mm2 Slice thickness = 3 mm
Now, as the load was given throughout the face width σm = 2.80 N/mm2
σm = 2.80 N/mm2

4.7 Scaling Model to Prototype

The actual value of stress obtained in model should be calibrated with the prototype by following equation.

Tp=Torque on prototype
Tm=Torque on model
σp=Stresses produced in prototype
σm=Stresses produced in model .
We have
Torque on prototype = 33157.27 N-mm
Torque on model = (3×9.81×20) = 784.8 N-mm
Stresses produced in a prototype,=118.29 N/mm2

5. FINITE ELEMENT ANALYSIS

Finite Element Analysis (FEA) is a computer-based numerical technique for calculating the strength and behavior of engineering structures. We have analyzed worm wheel using ANSYS software. The analysis is done in relation with the Lewis equation, according to which, the tooth of gear is considered as cantilever beam fixed at one end. Very fine meshing is done so as to achieve more accurate results. The tooth is fixed and loaded as shown in figure 4.

The following figure 6 shows bending stresses for worm wheel.

Fig. 5 Bending Stresses for Tooth of Wheel From FEA results, it can be stated that the maximum stresses are at the root of the tooth and magnitude of bending stress is 123.45N/mm2 .Thus the design is safe.

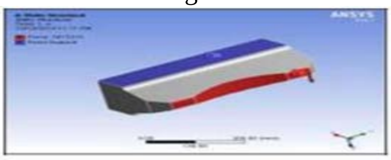

Fig. 4 Loading and Boundary Conditions

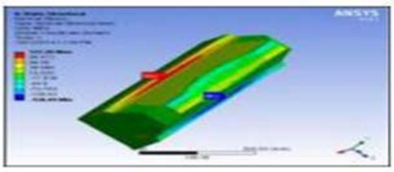

Fig. 5 Bending Stresses for Tooth of Wheel

6. EXPERMENTAL ANALYSIS

The worm wheel is analyzed using theoretical, experimental and finite element method. The following table shows the values of bending stress for each of the analysis. Table 1: - Values of Bending Stress From the above table it is clear that the design of worm wheel is safe as the ultimate tensile strength of wheel material PB2 is 335 N/mm2. All the values obtained from each analysis are far below the ultimate tensile strength of wheel material having factor of safety more than 2. Therefore it is clear that the failure of wheel is not due to design parameters but due to some other reasons. Also comparison of experimental analysis and finite element analysis indicates that the variation of results is about 4.4 % only.

BENDING STRESSES BY USING THEORETICAL ANALYSIS N/mm^2	BENDING STRESSES BY EXPERIMENTAL ANALYSIS N/mm^2	BENDING STRESSES BY USING FEM ANALYSIS N/mm^2
155.54	125.35	120.36

7. CONCLUSION

It is clear that the design for worm wheel is safe. But in actual working, the wheel fails. Thus this indicates that there is other reason of failure. Hence possible reasons of failures and their remedial actions are discussed with engineers of company. There can be several failure reasons but the more specific reason that came after discussion was the production procedure of the worm. For production of both worm and worm wheel, special production processes are required which are carried out on the special milling machines with special tools. The production of gears on milling machine is costly but the accurate geometry of tooth is achieved. It was found that, the company orders worm wheels from other company but they were producing worms on lathe machine using special tool. Advance Engineers were doing so for saving production cost of the worm. But this production practice was faulty as the geometry of tooth was not achieved on lathe machine. Thus as a primary solution, it was decided that the worm should be produced on the milling machine. After production of worm on the lathe machine it found that there is variation in the surface finish as well as geometry of the worm. Hence company accepted the solution on a primary

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