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Experimental Stress Analysis of Worm Gear using 3D Photo Elasticity and its Validation through Finite Element Analysis

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ABSTRACT

One of the very important component of mechanical system involving motion transmission is gear assembly is Worm and pinion gear pairing is necessary to convert rotary motion into linear motion. The life of gear is important factor and the stresses developed on the tooth of the gear are one of the tedious task. Here, in the current work the stresses are analyzed using 3D photoelastic technique which is one of the promising techniques in stress analysis. The synthetic rubber material and the experimental stress analysis are conducted using polariscope in the laboratory. The result obtained shown promising approach to analyses the stresses in the 3D structure.

Keywords- *Component, Gear, Stress, 3d Photoelastic, Rubber Material, Structure.*

1. INTRODUCTION

Worm gears are that types of gears which are used to transmit power between two non-intersecting, non-parallel shafts. The figure shows meshing of worm and wheel. The teeth on the worm wheel envelope the threads on worm. This gives line contact between mating parts

Figure 1:- Worm Gearing

1.1 Problem Statement

During operation it was observed that the worm wheel fails due to load coming on the teeth. The failure starts at the central thickness of tooth and continues up to the root of the tooth. At the initial stage of failure, the tooth was going in plastic deformation and then crack was occurring at the central thickness. The failure was occurring once within operational period of about 15days. A 3D Photoelasticity method to find out stresses in worm wheel and comparison with results obtained using Finite Element Analysis (FEA).

2. OBJECTIVES

Following are the main objectives of dissertation work

- To evaluate bending stress distribution at tooth root of wheel using experimental analysis using 3D photo elasticity.
- To evaluate bending stress distribution at tooth root of wheel using FE Analysis using ANSYS.
- To validate experimentally obtained results with FEA results and plotting final results.
- To give design solutions to the Advance Engineer to improve life of worm wheel.

3. LITERATURE SURVEY

In spite of the wide use of worm gear drives, only few papers have been published on analysis and load distribution calculation of worm gears. Previous works addressing worm gear analysis published by some authors is as follows.

Prashant Patil, Narayan Dharashiwkar, Krishnakumar Joshi and Mahesh Jadhav [1] have discussed about 3D Photoelastic and Finite Element Analysis of helical gear. In working condition, helical pinion fails due to load coming on the teeth. The results obtained were verified with FEA. It was found that the failure of helical gear of PIV gear box may be due to improper alignment or due to improper heat treatment process during teeth hardening.

Bhosale Kailash C. and Dongare A. D. [2] have discussed about an experimental and finite element method of analysis. Bending strength of helical gear is analyzed using Photoelasticity technique. The experimentally obtained results are verified with finite element results. The conclusion of their work have proved that the error in maximum bending stress calculated by both, experimental and finite element technique, is only about 2.02%. Thus it clears that these both methods are best suitable for bending stress analysis of gears.

W. T. Moody and H. B. Phillips [3] have published various techniques of analysis of mechanical component in Photoelastic and Experimental Analog Procedures Engineering Monograph No. 23. Along with the theory of technique, they have explained all details including material requirement, instrument used for analysis, calibration techniques, the polariscope, nature of light and plane polarization, 3D Photoelasticity, the Photoelastic interferometer, the babinet compensator, the beggsdeformeter, the electrical analogy tray, the membrane analogy, photoelastic materials and model preparation, photoelastic model loading frame assembly.

Rexnord Industries, LLC, Gear Group [4] has given all the details regarding gear distress and failure modes, surface fatigue i.e. pitting and spilling, wear, degrees of wear, types of wear, miscellaneous wear modes, plastic flow, breakage, failure associated with processing along with reasons for failures and preventive action to be taken so as to avoid the failures in their publication named Failure Analysis Gears-Shafts-Bearings-Seals.

Dr. V. B. Sondur and Mr. N. S. Dharashivkar [5] have discussed about theoretical and finite element analysis of load carrying capacity of asymmetric involute spur gears. In this paper, they have presented a method for investigating the bending stress at the critical section of "Asymmetric Involute spur Gear". Initially results were obtained theoretically and verified by using ANSYS. It was found that bending stress can be minimized up to 20% by increasing pressure angle from 20° to 35°.

Pravin M. Kinge, Prof. B.R. Kharde and Prof. B.R. Borkar [6] have analysed gearbox used in sugar industry. The main objective of analysis was to improve the life of the gear. The reason found for failure of the gear was due to wear of gear teeth edges. This is caused due to high stress concentration along gear teeth edges. To relieve these stress concentration three modifications in the design were done using ANSYS and again stress analysis of the modified gears carried out.

Gavril Ion [7] has discussed tooth's tensions analysis of face worm gears with cylindrical pinion development of FEA. He has proposed tooth's tension in lapping process for worm face gear. In this paper, the stress analysis of the gear drive is performed using a three-dimensional finite element analysis. The developed simulation is illustrated with numerical examples.

William L. Janninck [8] has discussed about the contact surface topology of worm gear teeth. In a mating worm and warm. Gear set, the inspection of the worm member is accomplished by available analytical inspection procedures. The mating enveloping worm gear with its distorted tooth surfaces is generally accepted by the contact pattern developed while running the gear with a qualified worm. A mathematical modeling procedure has been developed to predict the initial contact pattern.

4. EXPERIMENTAL ANALYSIS 3D PHOTOELASTICITY

4.1 Principle of Photoelasticity

Photoelasticity is an experimental technique for analysis of stress and strain that is particularly useful for components having complicated geometry, complicated loading conditions, or both. For such cases, analytical methods may be difficult or impossible, and analysis by an experimental approach maybe more correct. Problems involving three-dimensional geometry, multiple-component assemblies, dynamic loading and inelastic material behavior can be experimental analyzed.

4.2 Procedure for 3D Photoelasticity [1, 2]

The general procedure followed for carrying out 3D **Photoelasticity** is listed below. Each of these activities is explained in detail along with actual dissertation work.

a) Preparation of Model
- Preparation of Pattern.
- Preparation of Rubber Mold.
- Casting photoelastic material model.
- Casting of calibration disc

.

b) Designing and developing the loading frame to simulate actual loading conditions.
c) Stress freezing.
d) Slicing of model.
e) Stress analysis

4.2.1 Preparation of Model: The preparation of a model is a sort of technique which needs not only great care, but a lot of experience and practice.

A] Preparation of Pattern

The wheel itself has been used as pattern as the dimensions can be acceptable. The following figure (a) shows the photograph of actual worm wheel.

Figure 4.1 (a): - Worm Wheel as a Pattern

B] Preparation of Rubber Mold

The mold is generally prepared out of synthetic rubber material.

Figure 4.1 (b): - Curing of Rubber Mold And Split Mold

C] Casting Photoelastic Material Model

There are several photoelastic materials those can be used for this work. The casting of photoelastic model out of rubber mold is very tedious task. The rubber mold was divided into three parts. Therefore for casting photoelastic model out of it, the wooden box was rejoined. Then petroleum jelly was applied on inner surface of total rubber mold for easy removal of model after curing. The joined rubber mold was placed in wooden box and the box was tightened assuring leak proof joints.

Then epoxy resin ARALDITE CY-203-1 IN was taken for casting photoelastic model. The following figure 4.1 (c) shows the actual photograph of photoelastic model.

Figure 4.1 (c): - Photograph of Photoelastic Model

4.3 Stress Analysis

The table 1 shows the values for the colors produced in a dark field white light source polariscope.

Table1. Fringe order

Colors	Fringe Order
Black	0
Grey	0.28
White	0.45
Yellow	0.60
Orange	0.79
Red	0.90
Tint of passage	1.00
Blue	1.06
Blue green	1.20
Green Yellow	1.38
Orange	1.62
Red	1.81
Tint of passage 2	2.00
Green	2.33
Green Yellow	2.50
Pink	2.67
Tint of passage 3	3.00
Green	3.10
Pink	3.60
Tint of passage 4	4.00
Green	4.13

By using following equation, material fringe value (F_σ) at critical temperature was found out.

$$F_\sigma = \frac{8 \times P}{\pi \times D \times N} \qquad (1)$$

P=Load applied = 2Kg = 19.60 N

D=Diameter of disc = 50 mm

N= Fringe order observed at the center of the disc = 2.66

On the figure 4.2 (a and b) the fringe pattern is shown which is obtained experimentaly.

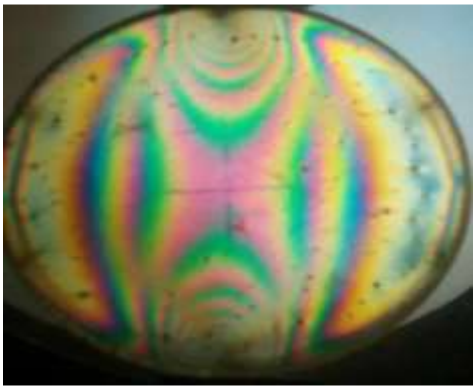

Figure 4.2 (a): -Stresses Developed in Disc

Substituting these values in above equation,

$$F\sigma = \frac{8 \times 2 \times 9.81}{\pi \times 50 \times 2.66}$$

Fσ= 0.37 N/mm

4.4 Evaluation of Stress at Root of Tooth

According to stress optic law,

$$\sigma_1 - \sigma_2 = \frac{N \times f_\sigma}{t} \qquad (2)$$

Where,

σ_1=Major principal stress.

σ_2= Minor principal stress.

N=Fringe order or fractional fringe order.

F_σ=Material fringe order.

t =Thickness of slice.

The isochromatic near a free boundary give the values of non-vanishing principal stress σ_1.

$$\sigma_1 = \frac{N \times f_\sigma}{t} \qquad (3)$$

Following is the photograph of slice for which analysis of stresses is done.

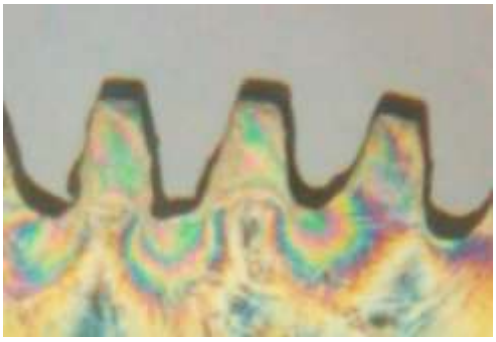

Figure4.2 (b): -Fringe Pattern at the Tooth Root

According to Tardy's method of compensation, fractional fringe order N is calculated as,

$$N = n \pm (\gamma/180)$$ -------------

where n is fringe order.

$$N = 2.33 + (70/180)$$

$$N = 2.718$$

Therefore for one slice, the model stresses are calculated as below.

$$\Sigma_1 = \frac{2.718 \times 0.37}{3} = 0.3353 \text{ N/mm}^2$$

Now, as the load was given throughout the face width, the value of stresses produced in total model is derived as below.

$$\sigma_m = \frac{0.3353 \times 25.08}{3}$$

$$\sigma_m = 2.80 \text{N/mm}^2$$

4.5 Scaling Model to Prototype

Scaling the stresses from model to prototype was carried out as follows.

We have,

$$\sigma_p = \sigma_m \times \left(\frac{T_p}{T_m} \times \frac{h_m}{h_p} \times \frac{L_m}{L_p}\right) \quad (4)$$

Where,

T_p = Torque on a prototype.

T_m = Torque on a model.

σ_p= Stresses produced in prototype.

σ_m = Stresses produced in a model.

h_m = thickness of prototype.

h_m = thickness of model.

L_m =typical lateral dimensions of prototype.

L_m =typical lateral dimensions of model.

As model and prototype have same dimensions.

$h_m = h_p$ and $L_m = L_p$

Therefore,

$$\sigma_p = \sigma_m \times \left(\frac{T_p}{T_m}\right) \quad (5)$$

We have,

Torque on prototype = 33157.27N-mm

Torque on model = (4×9.81×20) = 784.8 N-mm

Stresses produced in a prototype,

$$\sigma_p = 2.80 \times \left(\frac{33157.27}{784.8}\right)$$

$$\mathbf{= 118.29 N/mm^2}$$

The bending stresses of worm wheel obtained by this method are 118.29 N/mm^2.

5. FINITE ELEMENT ANALYSIS

The analysis was carried out using following steps.

Each step is explained below.

- Modeling of worm wheel
- Selection of proper element for meshing.
- Applying boundary conditions and constraints.
- Carrying out the Post Process in ANSYS to solve the problem.

5.1 Modeling

The tooth of the worm wheel is modeled in Creo 2.0 software from the given 2D drawing and shown in figure 5.1. Creo is user friendly software so it is best tool for drawing 3D model.

The image shows the model of the tooth of worm wheel.

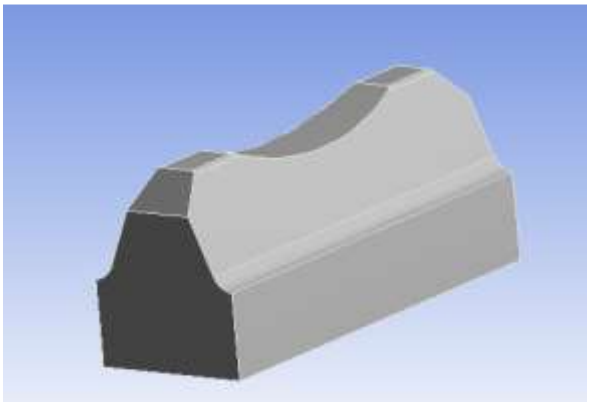

Figure 5.1:- Creo Model of Tooth of Worm Wheel

5.2 Selection of Proper Element for Meshing

Out of several kinds of elements, solid elements are used for meshing a 3D component as shown in figure 5.2. The shape of solid elements can be a Hexahedron, Wedge, Tetrahedron or a Pyramid as per requirements. For meshing a tooth, linear tetrahedron is used. Very fine meshing is used so as to get very accurate results. The size of the element is chosen to be 1 mm. Number of nodes generated is 1991152 and number of elements generated is 1180999.

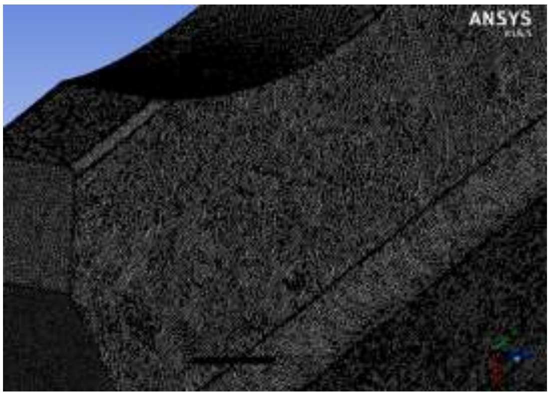

Figure 5.2:- Meshing of Tooth of Worm Wheel

5.3 Loading and Boundary Condition

The tooth is fixed at remaining surfaces and load of 16732.5 N is applied at the edge of tooth. Following figure 5.3 shows fixed supports and the load applied to the tooth at the tip surface.

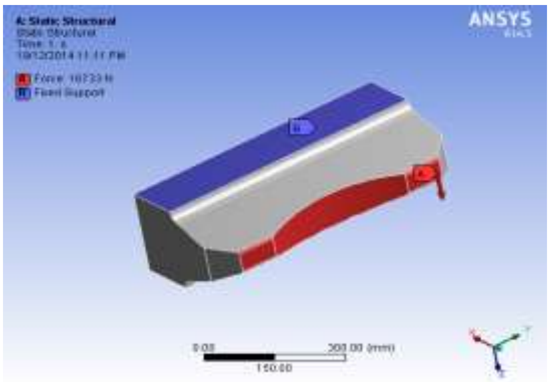

Figure 5.3:- Deformation for Tooth of Worm Wheel

The total deformation, normal stresses and equivalent stresses and are shown in figures 5.3 (a, b and c) respectively.

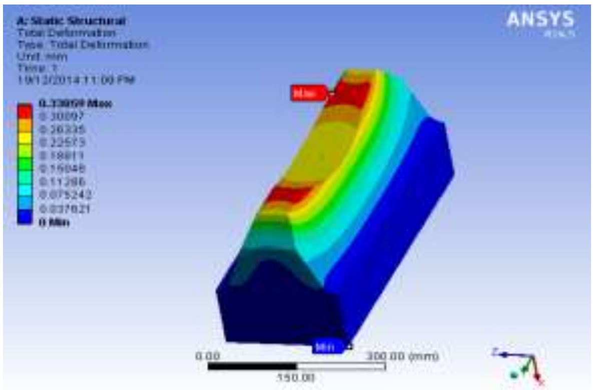

Figure 5.3. (a):- Total Deformation for Tooth of Worm Wheel

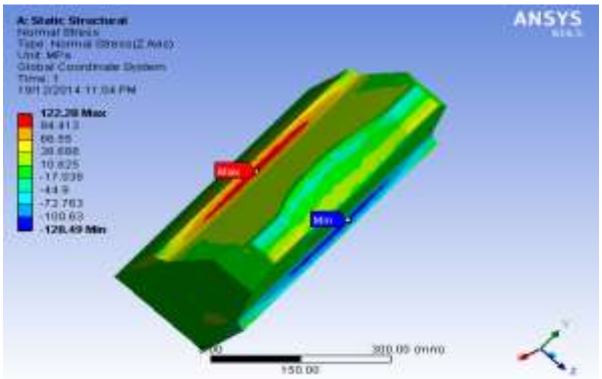

Figure 5.3 (b):- Normal Stresses for Tooth of Worm Wheel

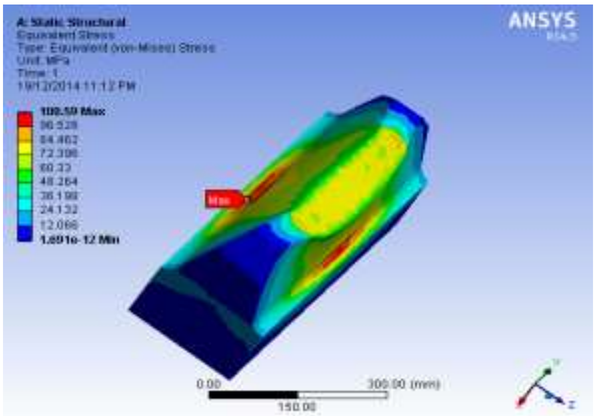

Figure 5.3 (c):- Von-Misses stresses for Tooth of Worm Wheel

The bending stress value obtained is 122.28 N/mm^2.

6. RESULT

6.1 Results of 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.

Bending Stresses by Theoretical Analysis = 144.64 N/mm^2

Bending Stresses by Experimental Analysis =118.29 N/mm^2

Bending Stresses by FE Analysis=122.28 N/mm^2

7. CONCLUSION

By determining the stress analysis by three methods i. e. theoretical, experimental and FE analysis, the following conclusions are made.

1. Though the worm wheel fails during working, the design of worm wheel is safe. Hence the reason for failure may be production method of the mating worm.
2. FEM and experimental method gives the actual visualization of stress pattern of the component under study.
3. Before going directly for failure analysis of any component, every possible reason should be checked out on primary basis.

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