Contact Stress Analysis of Asymmetric Spur Gear Using Photoelasticity Experiment

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Abstract – *Gears are an integral and necessary component in our everyday lives. They are present in the automobiles and bicycles we travel with, satellites we communicate with, and computers we work with. Gears have been around for hundreds of years and their shapes, sizes, and uses are limitless. Photoelasticity is an experimental method used for the analysis of stress and stress values of complicated members under loading conditions. A pair of teeth in action is generally subject to contact stresses causing failure of gear tooth. The major purpose of this research is to reduce the contact stress of gear by modifying the pressure angle of gear. In this paper, the material was calibrate for the experiment with the gear. Experiment has carried out for proposed photoelastic material gear. Contact stress for the stressed gear specimen has been calculated using tardy compensation and scaling method. Hence, contact stress reduction take place with the help of experimental method for better performance and increasing pressure angle.*

***Key Words*: Spur gear, Pressure angle, Contact stress, Asymmetry, Photoelasticity experiment etc.**

1. INTRODUCTION

Gears are very important in industrial applications. They are regularly use for transmitting the power from one shaft to another shaft in automobile transmission system as well as machine tools application. The breakdown of the gear in power transmission is major concern in industrial application. The photoelastic phenomenon was first describe by Brewster and extended by the works of Coker and Filon of the University of London. In the year 1853, Maxwell related the birefringence to stress and developed the stress-optical laws. Coker and Filon applied this technique in structural engineering in 1902. Unlike the traditional analytical methods of stress determination, Photoelasticity gives an accurate picture of stress distribution even around abrupt discontinuities during a material. The method is an predominant tool for determining the critical stress points during a material and is usually use for determining the strain concentration factors in irregular geometries.

2. LITERATURE REVIEW

Konstandinos G. Raptis, Theodore N. Costopoulos, Georgios A. Papadopoulos and Andonios D. Tsolakis presented works on the rating of spur gear strength using photoelasticity and the finite element method. Toothed gear is a critical component in machine elements for motion and power transmission between rotating shafts. This fact leads to a need for improved reliability and higher endurance, which require precise and clear knowledge of the stress field during meshing of gear tooth. This study examine the calculation of maximum stress at gear root when the meshing gears are loaded at their most unfavourable contact point (highest point of single-tooth contact - HPSTC), using both numerical and experimental methods. Finite Element Method (FEM) was use for the numerical stress analysis and photo-elasticity has applied for the experimental investigation of the stress field. It has found that the deviation between the results of the applied methods falls between reasonable limits whereas it rises with an increasing number of teeth of the large gear [1].

The mesh stiffness plays an important role geared dynamics. Mostly, analytical expressions were been used to calculate the time-varying mesh stiffness. In 2015, Naresh K. Raghuwanshi and Anand Parey presented a paper in which the photoelasticity technique had used for measuring the stress intensity factor (SIF) for cracked gear tooth. Subsequently, SIF had used to calculate the gear mesh stiffness. The variations in the SIF and mesh stiffness have quantified with angular displacements of the gears. Photoelasticity experiments had performed for different crack lengths at the tooth root of the spur gear pair. Experimental results of mesh stiffness variation were been compared with one of the analytical method i.e. potential energy method, which is widely employed by researchers to calculate gear mesh stiffness [2].

3. EXPERIMENTAL STRESS ANALYSIS USING CIRCULAR POLARISCOPE

Experimental stress analysis has done by the photoelastic method. In the photoelastic method, circular polariscope is used. For determining the perimeter order, a circular disc of same material has employed. The photoelastic model of the spur is prepared from an 8 mm thick sheet cast from epoxy resin (a mixture of Araldite CY 230 and hardener HY 951). In addition, a circular-shaped disc (calibration disc) of 65mm diameter is prepared from the same sheet.

3.1 Casting Procedure for Photoelastic Sheet

When a structural component is subject to loading, the applied photo-elastic material will undergo the stress; so that a stress field is, develop in the photoelastic material. By employing a circular polariscope, the fringe order can be record and then used to determine the difference in the principle stress in the structural component.

The proper selection of photoelastic sheet materials is as important to this method of experimental stress analysis. Although the selection of a photoelastic material is largely a matter of common sense, it is helpful to follow a systematic procedure in order to avoid the omission of one or more important considerations. Naturally, the first desire is to pick a photoelastic material, which will give maximum reliability and accuracy under a given set of test circumstances, and do so with minimum effort and expense. Since there are numerous factors that affect the performance of a photoelastic material and a variety of sometimes-conflicting performance requirements, a compromise is often necessary. The terms of the compromise have usually dictated by the ultimate purpose and conditions of the test.

For the analysis, using Circular Polariscope the photo stress sheet need to prepare on which stress will be observed. The Procedure for preparing the sheet can be divide into the following steps

Determining the amount of resin and hardener

Preparing and pouring the plastic resin and hardener as per the formula-

$W = d \times A \times t$ (1)

Where,

W=Total amount needed (in gm)

d=Plastic density [1.13x10-3 gm/m3]

A=Area of Sheet to be cast (width x length)

t=Desired thickness of the sheet (in mm)

For our test specimen-

W=1.13x10-3 x 210 x100 x 8 = 189.84gm.

The amount of hardener indicated in Parts per hundred by weight, which means that for 100 gm of Type PL-1 Resin the amount of PLH-1 hardener needed as 10gm. For the 189.84 gm of total mixture, the resin and hardener calculations are as follows:

PL-1 Resin: 189.84× 100/110 = 172.59 grams

PLH-1 Hardener: 189.84× 10/110 = 17.26 grams

3.2 Weighing the Calculated Amount of Resin and Hardener

As per the calculated values of Resin and hardener, the exact amount had been take as by weighing of Resin and Hardener on digital weighing pan. 100 parts of Araldite cy-230 mixed with 10 parts of hardener Hy-951 by weight will be used for casting the sheets. Before making a sheet, the resin (Araldite cy-230) was heat in the oven about 80° c to 100° c for about 2 hours. So that all air bubbles, moisture will get remove and it will be then cool slowly at room / ambient temperature. The hardener is add slowly in Araldite. The mixture has stirred in one direction continuously for 15 minutes until it is transparent and clear, the mixture has then poured in the acrylic sheet mould tray in order to cast photoelastic sheet.

Fig -1. Poured mixture of hardener and resin

The disc is make out of photoelastic sheet as described above. This photoelastic disc is subject to compressive load in the circular polariscope set up as shown in the figure 2. Calibration on the disk has been to obtain the material fringe value (Fσ).

The material fringe value Fσ is the number of fringes produced per unit load. The material fringe value is the property of the model material for a given wavelength (λ) and the thickness of the model. Here the circular disc subjected to dimensional compressive load is consider as a calibration model.

Fig -2. Fringe pattern of Calibration disc in white light source

The circular disc of diameter 65 mm and thickness 8 mm was use to find material fringe value. This circular disc was loaded under compression by special fixture. A compressive load was applied to find material fringe value. Viewing through dark-field of circulated Polar scope, the locked isochromatic fringe pattern was observe as shown in figure 2.

Values of fringe order were note at different loads as shown in table 1.

$F_\sigma = \frac{8P}{\pi D N}$ (2)

Where,

P=Load (Kg)

N =Fringe order and

D = diameter of the disc= 65 mm.

Table -1: Determination of Material Fringe Value

Sr. No.	Load in (kg)	Fringe Order (N)			Fringe Value (Fσ)	
		Lower (Nl)	Higher (Nh)	(Nl+ Nh)/2	Fσ	Avg. (Fσ)
1	38.45	1.531	1.669	1.6	9.23	
2	66.36	2.353	2.461	2.407	10.59	10.58 N/mm
3	106.82	3.242	3.642	3.442	11.92	

Figure 3 shows the fringe pattern of calibrated disc in monochromatic light source. The material fringe value is the property of the model material for a given wavelength and thickness of the model.

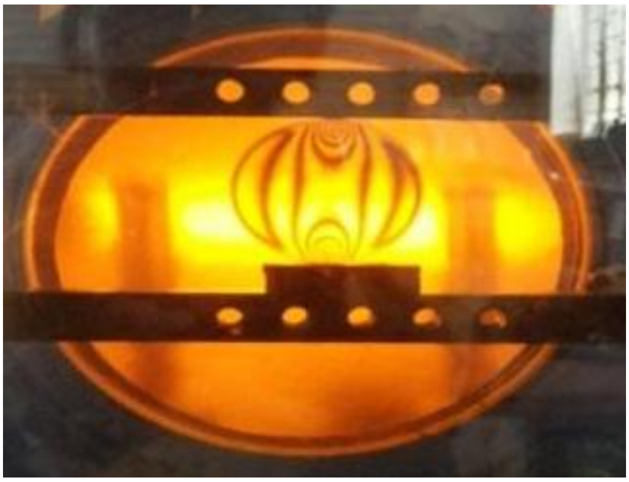

Fig -3. Fringe pattern of Calibration disc in monochromatic light source

3.3 Description of Photoelasticity Setup and Loading Arrangement

Figure no. 4 were inferred as the photoelastic setup for this experiment. Circular polariscope is employ for this experiment. A circular polariscope is constructed by four elements; light source, polarizer, model and analyzer. White light source is used as a light source and a digital camera is used for capturing the images of isochromatic fringes. A special type of fixtures was been designed for loading and mounting of gear. A 300 mm long lever attached to the gear 1.

Fig -4. Photoelastic setup

For applying the torque on gear 1 in an anticlockwise direction. The load had been hanging at the end of this lever. The gear 1 is free to rotate on its axle and gear 2 is fixed at any angle of rotation with the help of nut and bolt. To compensate this D-shape slot provided to mount and fix the gear 2 at fixed angular positions.

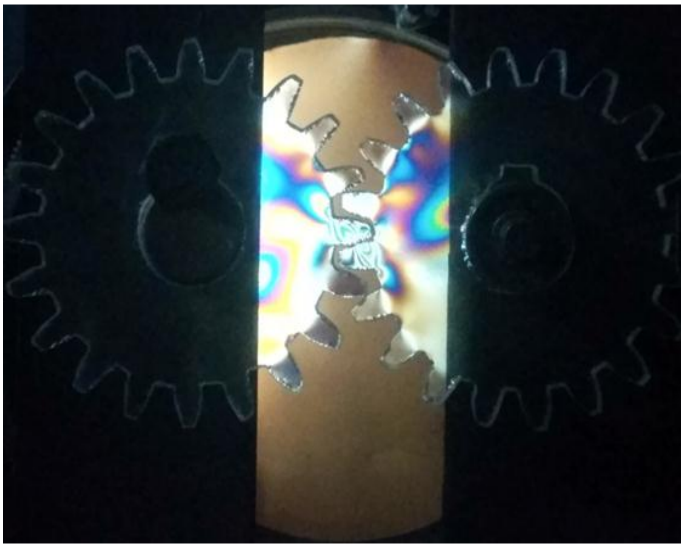

Fig -5. Stress distribution in spur gear pair

An experimentation has been carried out by attaching weights to the liver arm. From the numerical analysis, it is observed that gear with 35^0 drive side pressure angle has less stress as compared to the other gear pairs. Therefore, for experimental analysis we chose two gear pairs, one with standard 20^0-20^0 pressure angles and another with asymmetric 35^0-20^0 gear pair. The isochromatic fringe patterns were develop on test gear as shown in Figure 5.

4. TARDY COMPENSATION METHOD

A plane polarizer (quarter-wave plates removed physically or optically) is first use to find the directions of the principal stresses at any selected point. The polarizer/analyzer pair are then rotate as a unit until their axes had aligned with the birefringent indicial axes, and the quarter plates are then reinsert with their axes oriented at the standard 45-degree angle with reference to the new polarizer axes. The system is now within the standard circular dark-field polariscope condition. Up to this point, the polarizer/analyzer axes has been kept orthogonal to each other; but now the analyzer is rotated separately until one of the fringes moves over the selected point. In rotating the analyzer up to 90 degrees, the polariscope is changing from a dark-field configuration to a light-field configuration. This change will cause a fringe to maneuverer a half-order. For rotations, less than 90 degrees, the ration of a 90 will correspond to a fractional fringe change relative to a half-order. Thus if the angle through which the analyzer has been rotated is divided by 180 degrees, the resulting value a/180 is the fractional-order to be assigned to the selected point. Many polariscope index a half-circle scale in terms of 100 divisions so that the frac0tional order has recorded off directly from the scale. The fringe order (N) given by

$$N = n \pm \beta \quad (3)$$

Where, n-fringe order

β - Angle by which analyzer rotated in radians

Stress in the component given by

$$(\sigma_1 - \sigma_2) = \frac{N \times f_\sigma}{H} \quad (4)$$

5. SCALING

To obtain resultant stress it must be specified how the stress values obtained from observing a plastic model under one load can be scaled up to give the proper results for a real prototype under a different load. By using the following expression i.e.

$$(\sigma_1 - \sigma_2) = \frac{\sigma_P}{\sigma_m} = \frac{P_P}{P_m} \times \frac{D_P}{D_m} \times \frac{H_P}{H_m} \quad (5)$$

Where subscripts *m* and *p* refer to model and prototype, *P* is the load scale factor, D is the dimensional scale factor, and H is the thickness scale factor.

Table -2: Determination of stress using Photoelasticity

Load	Fringe Order, N		Contact stress(σ)(MPa)	
Kg	Symmetric profile	Asymmetric profile	Symmetric profile	Asymmetric profile
3	1.81	0.72	211	83

From the table 1, it has observed that, for the load as contact stress for the asymmetric gear is lower as compare to the symmetric profile gear.

6. CONCLUSIONS

From the research work carried out, hare is the minutes of research

- As the pressure angle on the drive side increases, contact stresses were reduced.
- The decrement in contact stress for the same boundary condition it was observe for all increased values of asymmetry.
- As we increase the pressure angle of the drive side of the gear, it has been observed that there is reduction in contact stress.
- Asymmetric spur gear can bear more load as compared with the symmetric spur gear for the geometrical parameter of the gear except for pressure angle.

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