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WORM WHEEL ANALYSIS OF WINCH MACHINE GEARBOX USING EXPERIMENTAL & FEA

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ABSTRACT

The Worm & worm wheel in winch machine gearbox is used for lifting sand bucket in the foundry. During its operation of lifting, the worm wheel fails due to load coming on the teeth. This failure occurs due to stress concentration. The crack appears at central thickness of tooth. Hence the tooth breaking starts at the central thickness. The failure of wheel occurs within period of about 20 days. So the foundry has to replace the worm wheel which is not cost effective. The calculation of stresses of worm wheel at tooth thickness is a three dimensional problem as the thickness of wheel is considerable. This paper represents the analysis of stresses of wheel using theoretical, experimental and FEA. In this work, the experimentally obtained results are verified with the finite element analysis (FEA) results. Also proper solution has been provided to the foundry.

KEYWORDS- Worm Gear, Photo elasticity, Polari scope, Stress Freezing, FEA.

INTRODUCTION

The worm wheel is made of Phosphor Bronze PB2.Some important parameters of existing worm gear are,

z_1/ z_2/ q/m	1/60/12.18/2.82
Pitch Circle Diameter (Wheel)	168.84 mm
Pitch Circle Diameter (Worm)	34.36 mm
Pressure Angle	20°
Max. Torque Transmitted	33157.27 N.mm

THEORETICAL ANALYSIS

The bending stresses for wheel are calculated using Lewis equation,

$$P_t = \sigma_b C_v b\, \pi\, m_n Y$$

P_t = Permissible tangential tooth load or beam strength of gear tooth = 16732.57 N
σ_b=Bending stresses.
C_v= Velocity factor.= 0.9658
b = Face width. = 25.08 mm
m_n= Normal module=3.878 mm
Y= Tooth form factor or Lewis factor = 0.392

$$\sigma_b = 144.64 \text{ N/mm}^2$$

As the ultimate tensile strength of the Phosphor Bronze (PB2) material is 320 N/mm^2, the design of worm wheel is safe.

THREE DIMENSIONAL PHOTOELASTICITY

Photoelastic stress analysis is an experimental technique which provides full field analysis of stress distribution for complex geometry. The name 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 they are loaded.

In this paper, bending strength of worm wheel is found out using three dimensional photoelasticity. There arises a need ofgetting 3D stress pattern as model is 3 dimensional in nature. Thiscan beachieved by the stress freezing method. Certain photoelastic model materials, such as epoxy resins, exhibit the stress freezing phenomenon. If the photoelastic material is heated to its stress freezing temperature under loading, the secondary bonds breaks down and primary bonds carries the entire applied load undergoing deformation. If temperature is now lowered while maintaining the load, the secondary bonds reform between highly elongated primary bonds and 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 at room temperature even if the load is removed. Also the optical response is not disturbed if the material is cut into slices. These slices are then analyzed on circular polariscope.

EXPERIMENTAL WORK & ANALYSIS

In the experimental results and analysis, the material fringe value of photo elastic material (for calibration) and the stresses developed in a model has to be found out. Finally analysis contains scaling model to prototype. The accuracy of casting of photoelastic model severely effects on the results obtained thus the preparation of the model has its own importance in the photo elastic stress analysis.

A. PREPARATION OF MODEL

Casting of photoelastic models.

i. Pattern making, the pattern can be made of wood or metal. Here, prototype of a worm gear itself is used as a pattern.

(a) (b) (c)

Fig.1 Preparation of Model

ii. 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. The geometry of wheel is not symmetric, so the mould was cut into three parts (fig.1 b.)

iii. Casting of model & calibration disc, The model was casted out of epoxy resin Araldite CY-203-1 IN mixed with HY-951 hardener in proportion of 100:7 (fig.1 c). for finding material fringe value, calibration disc was also casted in the same manner.

B. DESIGNING & DEVELOPING LOADING FRAME

Loading frame has to be designed and developed so as to simulate the actual loading conditions. Using loading frame, the required torque can be transferred and fringe pattern can be obtained. The figure shows the developed loading frame. The worm shaft is provided with lever for load application and wheel rotation is restricted by providing a stopper. Thus stresses will get locked in the wheel as load is transferred. The calibration disc was also loaded with respective loading frame. After several trials and from reference it was found that the load of 2kg was required to produce adequate no. of fringes

Fig 2.Photograph of Designed Loading Frame

C. STRESS FREEZING

A model & calibration disc with loading frames were placed in a stress freezing oven. A typical stress freezing cycle was followed.

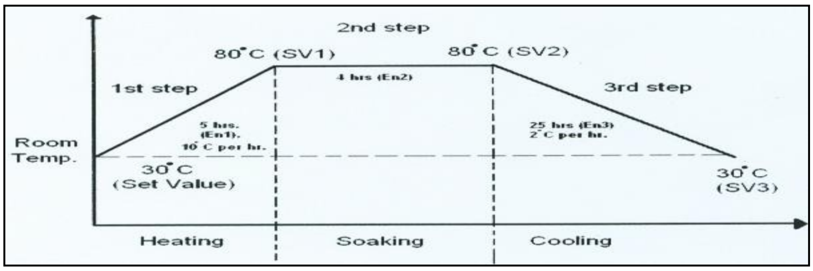

Fig 3.Stress Freezing Cycle

D. SLICING

Using horizontal milling machine, slices were cut with high speed. Cutting oil was used at during cutting as a coolant. The thickness of slice was kept about 3 mm. After cutting, the surface of each slice was finished manually using zero number polish paper.

E. MATERIAL FRINGE VALUE

Material fringe value Fσ is the number of fringes produced per unit load. It is the property of the model material for a given wavelength (λ) and thickness of the model (h). Here for finding material fringe value the circular disc of diameter 50 mm and thickness 6 mm was used. This circular disc was loaded under compression by special fixture and load of 2Kg was applied. This circular disc was also followed through same stress freezing cycle. Using dark-field arrangement of circulated polariscope, locked isochromatic fringe pattern was observed.
The material fringe value Fσ at critical temperature is,

$$F\sigma = \frac{8\times P}{\pi\times D\times N}$$

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,

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

$$F\sigma = 0.37 \text{ N/mm}$$

F. STRESS ANALYSIS

A tooth of worm wheel was marked which was in engagement with worm thread. At root of marked tooth on the each slice, the isoclinic and isochromatic fringes were observed by using circular Polariscope. All the values of fringe orders were noted down. The figure 4 shows the observation of fringe pattern at the tooth root slices using Polariscope.

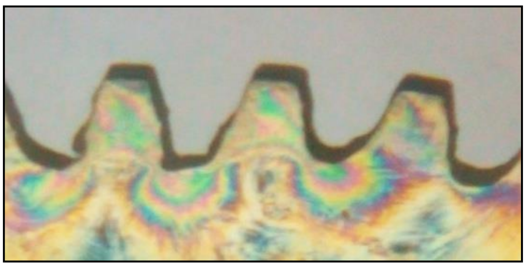

Fig 4.Fringe Pattern at the Tooth Root

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

$$\sigma_1 - \sigma_2 = \frac{N \times f_\sigma}{t}$$

(As σ_1 = bending stress and $\sigma_2 = 0$)

$$\sigma_1 = \frac{2.718 \times 0.37}{3} = 0.3353\ \text{N/mm}^2$$

Now, as the load was given throughout the face width,

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

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

G. Scaling Model to Prototype

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

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

Where,

Tp=Torque on prototype

Tm=Torque on model

σ_p=Stresses produced in prototype

σ_m=Stresses produced in model

As model and prototype have same dimensions, hm=hp and Lm=Lp

Therefore, $\sigma_p = \sigma_m \times \left(\frac{T_p}{T_m}\right)$

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

$$\boldsymbol{\sigma_p = 118.29\ \text{N/mm}^2}$$

From experimental obtained bending stress value, it can be again stated that the worm wheel design is safe.

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 5.The following figure 6 shows bending stresses for worm wheel.

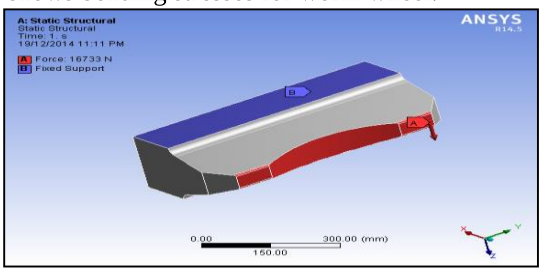

Fig. 5 Loading and BoundaryConditions

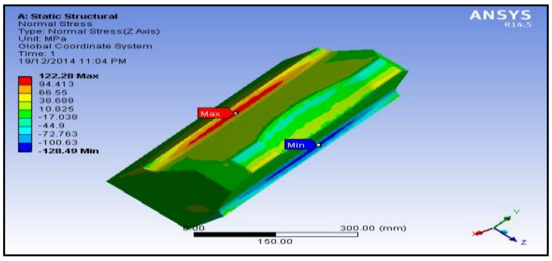

Fig. 6 Bending Stresses for Tooth of Wheel

From FEA results, it can be stated that the maximum stresses are at the root of the tooth and magnitude of bending stress is 122.28 N/mm^2 .Thus the design is safe.

RESULT 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.

I.TABLE
Values of Bending Stress

Bending Stresses by Theoretical Analysis N/mm^2	Bending Stresses by Experimental Analysis N/mm^2	Bending Stresses by FE Analysis N/mm^2
144.64	118.29	122.28

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 320 N/mm^2. 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 % only.

CONCLUSION

From all three analysis, it is clear that the design for worm wheel is safe. But in actual working, there is failure of wheel. This indicates of having other reason of failure. The possible reasons of failures and their remedial actions are discussed with engineers of company. The more specific reason that came after discussion was the production procedure of the worm.

The company orders worm wheels from other company and themselves 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 accurate geometry of tooth was not achieved on lathe machine.

So it was decided that the worm should be produced on the milling machine. After production of worm on the milling 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 basis.

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