Finite Element Analysis to find bending stress analysis of the worm wheel of Winching Machine Gear Box

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ABSTRACT

The worm and worm wheel is used in winch machine gearbox. 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 occurred once within operational period of about 15 days. So the industry had to replace the worm wheel which was not cost effective. The material of worm is hardened steel, and the material of the wheel is phosphor bronze PB2 having approximate composition in percentages as (Cu = 85, Sn = 12, Zn = 0.3, Pb = 0.5, P = 0.4 and other = 2). The calculation of stresses of worm wheel at tooth thickness is a three-dimensional problem. Thus we can analyze the stress pattern by using 3D Photoelasticity techniques and finite Element analysis technique. Breakage is the ultimate type of gear failure. Bending loads on gear teeth usually cause the highest stresses at the root fillets and at the tooth profile/root fillet junctions. A gear tooth is a cantilever plate with tensile stresses on the contact side of the tooth and compressive stress on the opposite side. If the tensile stresses at the critical location are allowed to exceed the endurance strength of the tooth material, fatigue cracks will eventually develop and with continued operation, will ultimately progress to the point where the tooth will break away from the rim material.

Keyword: *FEA, Bending Stress, Three-Dimensional Approach*

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1. INTRODUCTION:

Worm gears are that types of gears which are used to transmit power between two non-intersecting, non-parallel shafts. These gears are generally at right angles to each other. It consists of worm and worm wheel. The worm is threaded screw and worm wheel is toothed gear. The figure shows meshing of worm and wheel. The teeth on the worm wheel envelope the treads on worm. This gives line contact between mating parts. In other types of gears, the drive can be given to any one of the two mating parts. But in worm gears, the drive can be given to only worm. The worm can rotate worm wheel but worm wheel cannot rotate worm.

Fig-1 Worm Gearing

Failure of gears may be classified into four categories:

- Surface fatigue (pitting)
- Wear
- Plastic flow
- Breakage

The appearance of the various distress and failure modes can differ between gears that have through hardened teeth and those that have surface hardened teeth. These differences result from the different physical characteristics and properties and from the residual stress characteristics associated with the surface hardened gearing.

1.1.1. Surface Fatigue

Surface fatigue is the failure of a material as a result of repeated surface or sub surface stresses beyond the endurance limit of the material.

Pitting: Pitting is a surface fatigue which may occur soon after operation begins and it is of three types, initial (corrective), destructive or progressive and normal.

Spalling: It is a term used to describe a large or massive area where surface material has broken away from the tooth. In through hardened and softer material, it appears to be a massing of many overlapping or interconnected large pits in one locality. It is caused by high contact stresses. With surface-hardened gear teeth, surface or subsurface defects or excessive internal stresses from improper heat treatment also can cause spalling.

1.1.2. Wear

Wear is a general term describing loss of material from the contacting surface of a gear. There are varying degrees of wear, which can be measured in terms of thousandths of an inch, per million or 10 million contact cycles, ranging from light to moderate to excessive wear. Wear types can be classified in two major categories:

Abrasive - The abrasive wear, sometimes called cutting wear occurs when hard particles slide and roll under pressure, across the tooth surface. Hard particle sources are dirt in the housing, sand or scale from castings, metal wear particles from gear teeth or bearings.

Adhesive - The adhesive wear results from high attractive forces of the atoms composing each of two contacting, sliding surfaces. Teeth contact at random asperities and a strong bond is formed. The junction area grows until a particle is transferred across the contact interface.

1.1 Problem Definition:

The worm and worm wheel is used in winch machine gearbox. 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 15 days. So the industry had to replace the worm wheel which was not cost effective. The material of worm is hardened steel and the material of the wheel is phosphor bronze PB2 having approximate composition in percentages as (Cu = 85, Sn = 12, Zn = 0.3, Pb = 0.5, P = 0.4 and other = 2).
The calculation of stresses of worm wheel at tooth thickness is a three dimensional problem. Thus we can analyze the stress pattern by using 3D Photoelasticity techniques and finite Element analysis technique.

1.2 Objectives:

Following are the main objectives of dissertation work.

1.To evaluate bending stress distribution at tooth root of wheel using experimental analysis using 3D photo elasticity.

2.To evaluate bending stress distribution at tooth root of wheel using FE Analysis using ANSYS.

3.To validate experimentally obtained results with FEA results and plotting final results.

4.To give design solutions to the Advance Engineer to improve life of worm wheel.

2. Literature Review:

Prashant Patil, Narayan Dharashiwkar, Krishnakumar Joshi and Mahesh Jadhav[1] have discussed about 3D Photoelastic and Finite Element Analysis of helical gear. They have discussed an industrial problem which uses spreading machine to spread bagasse. This spreading machine has Positive Infinite Variable (PIV) gearbox which contains helical gears. In working condition, helical pinion fails due to load coming on the teeth. It seemed that the failure was due to stress concentration and bending stresses at tooth root of gear. The calculation of maximum tensile stress at tooth root was a three dimensional problem. Thus they have analyzed the stress pattern by using 3D Photo elasticity techniques. Also they have verified obtained results with FEA. They have found out 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. In their paper, they have analyzed bending strength of helical gear 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 beggs deformeter, 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 spalling, 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.

3. PRACTICAL AND FEA ANALYSIS

3.1 PRACTICAL APPROACH USING PHOTOELESTIC

If a three dimensional photoelastic model is observed in a polariscope, the resulting fringe pattern cannot be interpreted. The light passing through the thickness of the model integrates the stress difference σ_1-σ_2 over the length of the path of the light so that little can be concluded regarding the state of stress at any point. To avoid this difficulty, the three dimensional model is usually sliced to remove planes of interest which can then be examined individually. In studies of this type it is assumed that the slice should be sufficiently thin in relation to the size of model to ensure that the stresses do not change in either magnitude or direction through the thickness of the slice. The particular slicing plan employed in sectioning a three dimensional photoelastic model will depend upon the geometry of the model and the information being sought in the analysis.

Fig-2 Photograph of Slicing the Model

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

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

Table-1 Fringe order

3.2 FINITE ELECMENT ANALYSIS

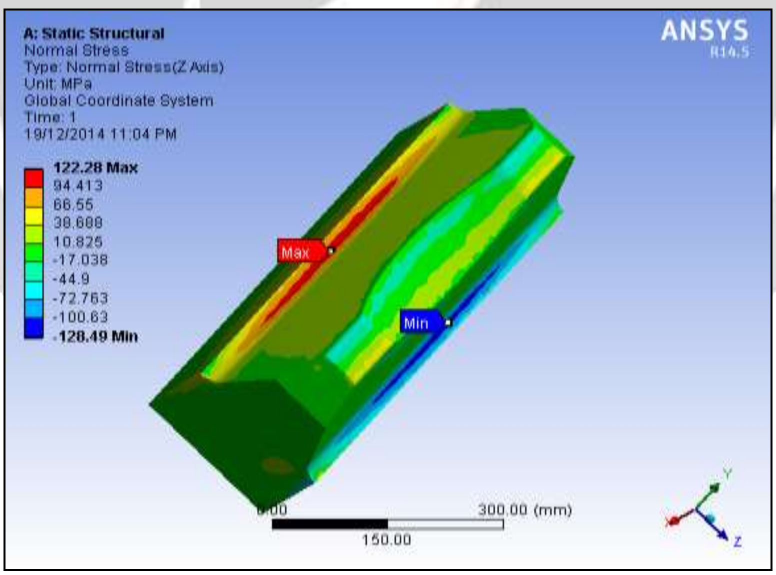

Fig-3 Normal Stresses for Tooth of Worm Wheel

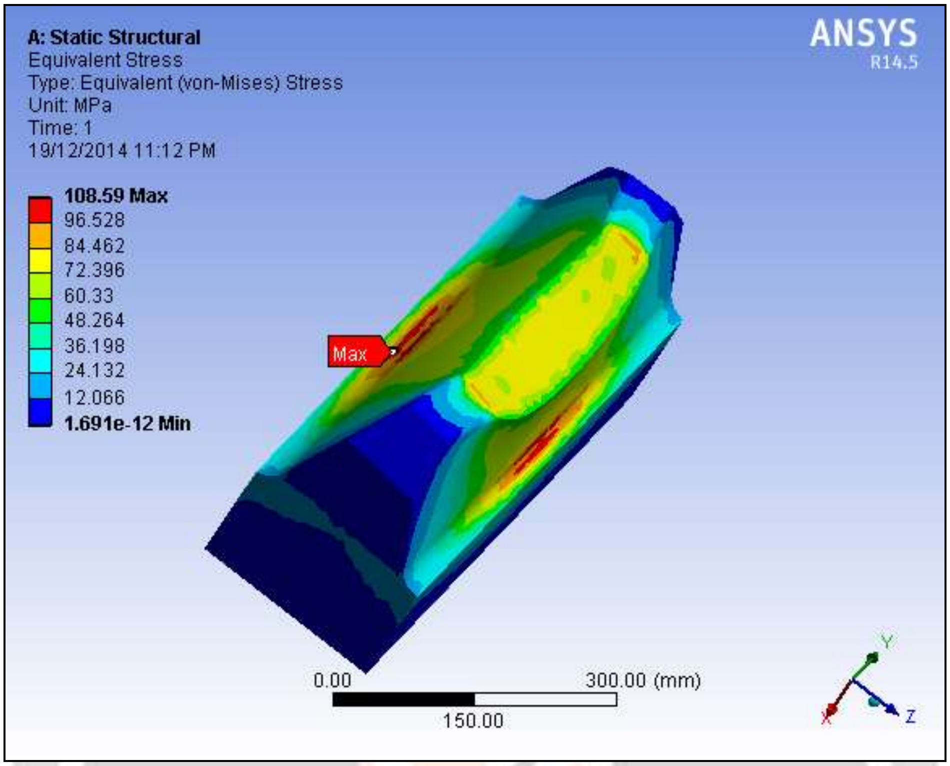

Fig-4 *Von-Mises stresses for Tooth of Worm Wheel*

The bending stress value obtained is 122.28 N/mm^2. This value is far below the ultimate tensile strength of the PB2 material. Hence the design is safe. Also from the obtained results, it can be stated that the ANSYS suits to be best method to validate the experimentally obtained results. The variation of theoretical and FE analysis is about 15 %. The variation is due to reason that the FEM is approximate method of analysis.

4.RESULT AND DISCUSSION

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 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

Table-2 Values of Bending Stresses

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 the hardness of the phosphor bronze PB2 is 110 BH, which is acceptable value, thus it states that the gear material used is suitable for respective application The comparison of experimental analysis and finite element analysis indicates that the variation of results is about 4 % only.

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