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# Bending Stress Analysis of Worm Wheel of Winch Machine Gearbox Using Experimental and FE Analysis

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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 was occurring once within operational Bending Stress Analysis of Worm Wheel of Winch Machine Gearbox Using Experimental and FE Analysis 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 Photo elasticity techniques and finite Element analysis technique.

## I. INTRODUCTION

Worm Gearing:

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.

The advantages of worm gear drives are as follows:

- High speed reduction can be obtained as high as 100:1 with single pair of worm.
- These are compact with small dimensions compared with other types of gears.
- The operation is smooth and silent.
- As motion is transmitted only from worm to wheel, provisions can be made for self-locking in case of cranes and lifting devices.
- There are also several drawbacks of worm gear drives as mentioned follows :
- The efficiency is low as compared with other types of gears.
- Worm wheel is generally made of phosphor bronze, which increases the cost.
- Lubrication is required as considerable heat is generated.
- The power transmitting capacity is low up to 100 kW.

There are four major areas of application of worm gear drives. They are as follows:

- Manually operated intermittent mechanisms.
- Motorized operated intermittent mechanisms.
- Motorized continuous operations.
- Motorizes speed increasing applications.

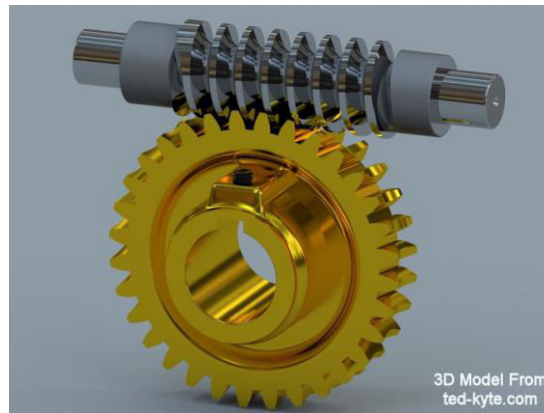


Fig1: Worm Gearing

## II. LITERATURE SURVEY

**1. Prashant Patil, Narayan Dharashiwkar, Krishnakumar Joshi and Mahesh Jadhav** have discussed about 3D Photo elastic 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.

**2. Bhosale Kailash C. and Dongare A. D.** have discussed about an experimental and finite element method of analysis. In their paper, they have analyzed bending strength of helical gear using photo elasticity 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.

**3. W. T. Moody and H. B. Phillips** have published various techniques of analysis of mechanical component in Photo elastic and Experimental Analog Procedures Engineering Monograph No. 23. Along with the theory of technique, they have explained all details Bending Stress Analysis of Worm Wheel of Winch Machine Gearbox Using Experimental and FE Analysis including material requirement, instrument used for analysis, calibration techniques, the polariscope, nature of light and plane polarization, 3D photo elasticity, the photo elastic interferometer, the cabinet compensator, the beggs deforester, the electrical analogy tray, the membrane analogy, photo elastic materials and model preparation, photo elastic model loading frame assembly.

**4. Rextord Industries, LLC, Gear Group**, 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.

**5. Dr. V. B. Sondur and Mr. N. S. Dharashivkar** 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". The gears with different pressure angle have been modeled by using CATIA software and analysis was carried out. The results obtained by theoretical method have been verified by using ANSYS. From their work they have proved that bending stress can be minimized up to 20% by increasing pressure angle from 20° to 35°. Thus from their work it is clear that FEA can be the best technique for designing and analyzing mechanical component.

**6. Pravin M. Kinge, Prof. B.R. Kharde and Prof. B.R. Borkar** have analyzed 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. The three design modifications were done as first, the edges of the gear teeth were tapered by an angle of 200, second, making groove in the gear wheel and third, making holes at the roots of the gear teeth. They have proved that the expected increase in life of the gears of the gearbox would be three years. Bending Stress Analysis of Worm Wheel of Winch Machine Gearbox Using Experimental and FE Analysis

**7. Gavril Ion** 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. This complex and intuitive simulation was created with CAD-CAM, MATH-CAD and FEM support.

**8. William L. Janninck** has discussed about the contact surface topology of worm gear teeth. In a mating worm and worm 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. These patterns will only show that area with a minimal separation between the worm and worm gear tooth surfaces and the actual separation beyond the contact area are unknown. A mathematical modeling procedure has been developed to predict the initial contact pattern. As well as the surface separation topology over the entire worm gear tooth surface equations and procedures are presented to permit an analysis for any gear set. He has also explained about production ways of gears. There are five popular ways to make a worm-Thread chasing, Thread milling, Thread grinding, Hobbining and Roll forming. The Worm gear Member can be made by gear hobbling processes i.e. Radial feed and Tangential feed.

**9. Gitin M. Maitra, V.B. Bhandari**, PSG College of Technology, Norton, P. C. Gope, M. F. Spotts & etal have explained all the details of every type of gear including geometry, gear related parameters, force calculations, deflections, effect of heat generation, stress concentration, design criterion, load rating and efficiency of gears, friction in worm gears, material selection and strength rating of worm gears in their respective books.

**10. James W. Dalley and William F. Raily** have explained various experimental techniques which can be used for analysis including fracture mechanics, strain measurements with electrical strain gauges and strain gauge circuits, Moiré method, Bending Stress Analysis of Worm Wheel of Winch Machine Gearbox Using Experimental and FE Analysis theory of photoelasticity and brittle coating methods in the book 'Experimental Stress Analysis', McGraw-Hill Inc.

**11. L. S. Shrinath and etal** have given all the detailed procedure regarding nature of light, 2D photo elasticity and 3D photo elasticity. They also have given various experimental analysis techniques like holography, Moiré method, brittle coating method, strain measurement, strain gauges etc. in their book named 'Experimental Stress Analysis', Tata McGraw-Hill Publishing company.

**12. Nitin S. Ghokhale and etal** have explained the finite element method in detail. They have explained about introduction, history of FEA, types of analysis, meshing, elements, material properties, boundary conditions, nonlinear analysis, thermal analysis, dynamic analysis, CFD etc. in the book named 'Practical Finite Element Analysis', Finite to Infinite Publications, Pune. According to the literature survey from above mentioned references, it is clear that 3D photo elasticity technique can be used for analysis of worm gears to find out stresses at the tooth root as this techniques has been used by authors and their results are very much fine. It is also clear that the 3D photo elasticity gives stress concentration areas and magnitudes of stresses. Also FEA can be effective technique which can be used to validate the experimentally and theoretically obtained results. The references from books give details about the worm gearing and details of methods of analysis. Also from several published papers, we get the literature about the various kinds of failures of gears, their failure reasons and preventive actions as well as corrective actions to be taken.

### III. THEORETICAL ANALYSIS

A pair of worm gears is specified and designated by four main quantities as follows.

$z_1 / z_2 / q / m$

The existing gear has designation as follows, 1/60/12.18/2.82



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- $z_1$  = number of starts on the worm
- $z_2$  = number of teeth on the wheel
- $q$  = diametral quotient
- $m$  = module

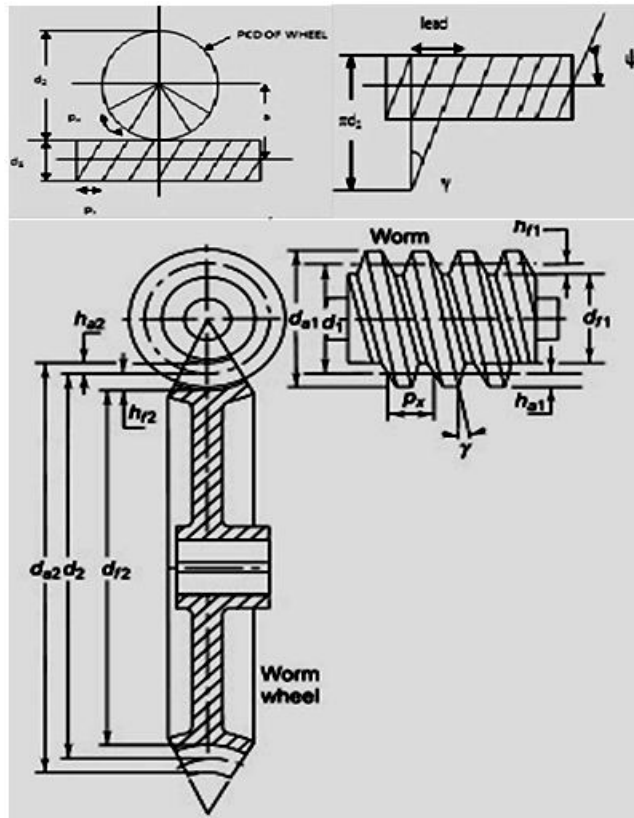


Fig2: Worm and Worm Wheel Geometry.

IV. SCREENSHOTS ANALYSIS

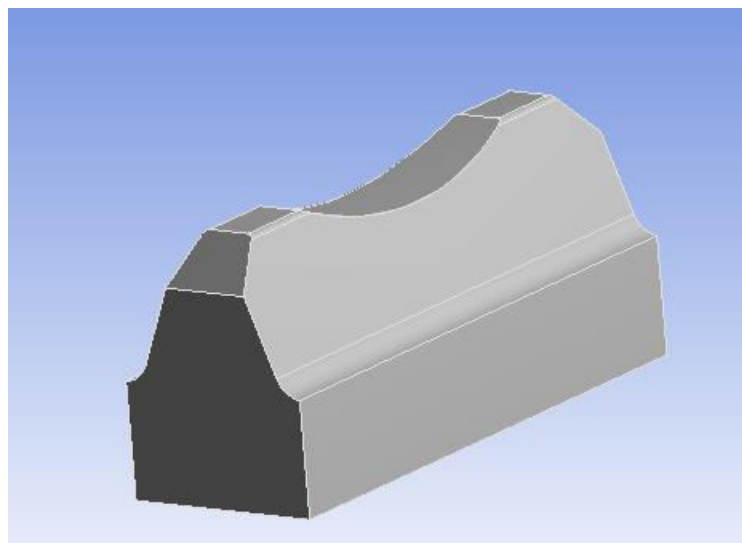


Fig3.Creo Model of Tooth of Worm Wheel

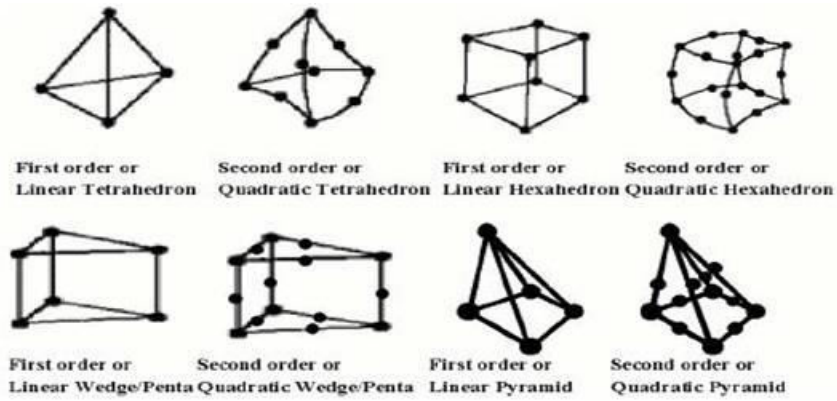


Fig4: Solid Elements

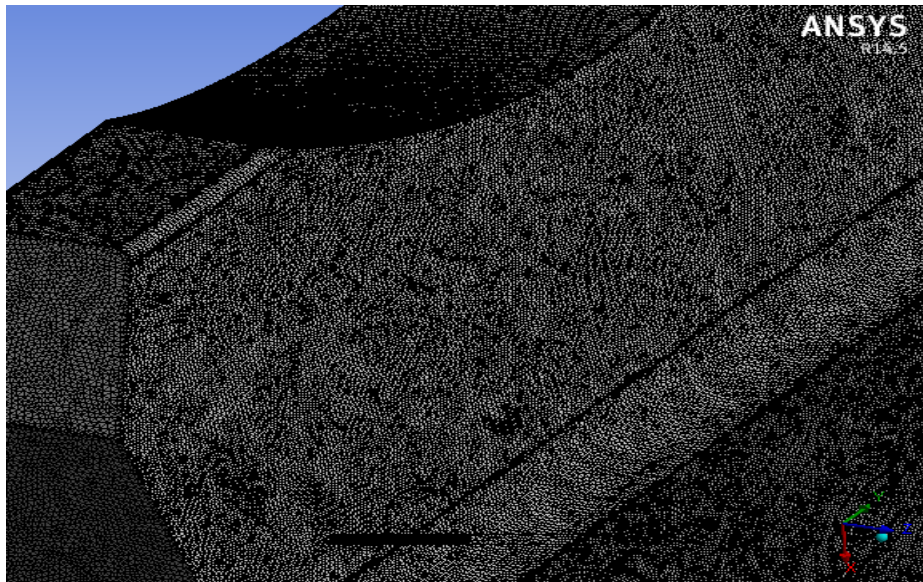


Fig5: Meshing of Tooth of Worm Wheel

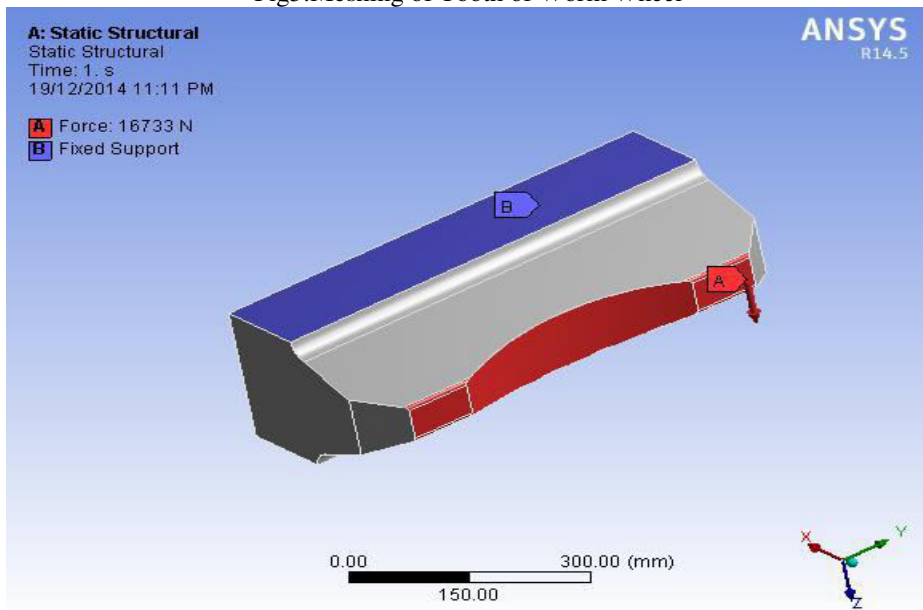


Fig6: Loading and Boundary Conditions



## V. RESULTS & 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 <sup>2</sup>	Bending Stresses by Experimental Analysis N/mm <sup>2</sup>	Bending Stresses by FE Analysis N/mm <sup>2</sup>
144.64	118.29	122.28

Table1: 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<sup>2</sup>. 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.

## VI. DISCUSSION

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 the Engineers of 'Advance Engineers', MIDC, Shirol and 'Hind Gears', MIDC, Shirol.

## VII. 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. Among the three methods used for stress determination, the result obtained from FEA are closure to theoretical than experimental results.
3. Designing and developing a loading frame is very important factor in 3D photo elasticity so as to simulate actual loading conditions.
4. FEM and experimental method gives the actual visualization of stress pattern of the component under study.
5. Before going directly for failure analysis of any component, every possible reason should be checked out on primary basis.

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