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The Failure Analysis of Worm Wheel for Ash Brick Factory – A Case Study

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***Abstract*: Gears are machine elements that are used to transfer motion and power by the help of engagement of teeth with another toothed wheel or with a rack. If gear fails to perform its work before its expected service life the whole assembly will stop working and it is a major issue for any industry or factory. In this paper A stacker arrangement of an Ash Brick factory is working through the help of Worm & Worm wheel and the worm wheel are failing to perform their expected work before its service life Worm gear is used to transfer power among two non-intersecting, non-parallel shafts. Worm gears are usually at right angles to each other. It is made up of worm and worm wheel. The worm looks like a threaded screw and worm wheel are toothed gear, Worm Wheel arrangement are used where large speed reduction is required. In this paper a case study of fail Worm wheel have been prepared and investigated with the help of Finite Element software ANSYS to determine the various cause of failure so that it can be minimized in future.**

***Keywords*: Worm wheel, Finite Element Method, ANSYS tool, Mode of failure, Cause of failure, Ash brick factory.**

1. Introduction

A necessary part of an industry is always being a Gear drive. Gears are machine elements that are used to transfer motion and power by the help of engagement of teeth. Gear is such device which can be used to change torque, power, speed and direction of power source. The Gear fails when any of the two fails to perform their expected work in time. A Worm & Worm Wheel is shown in figure 1. It is used where large amount of speed reduction is required.

Fig. 1. Worm and worm wheel

In this paper a real case study of Worm & Worm wheel arrangement of Ash Brick Factory is being investigated where the Worm wheel fails to perform their work before its expected service life. Failure of Gear is a critical problem or any industry as changing of gear is not an economical process and it will affect the return on investment and changing of gear may take one or two days which will shut down the whole system which is a big concern for any industry/factory.

A. Various modes of gear failure

The various modes of failure is broadly classified below,

- *Wear:* It is a surface occurrence in which upper layers of metal are eliminated mostly from the contacting surfaces of the mating gear teeth.
- *Pitting:* A surface fatigue failure which occurs when the endurance limit of the material is exceeded, a failure of this nature depends on surface contact stress and number of stress cycles.
- *Scoring:* Rapid wear resulting from a failure of the oil film due to overheating of the mesh, permitting metal to metal contact; this contact produces alternate welding and tearing which removes metal rapidly from the tooth surfaces.
- *Fracture:* Whenever a gear tooth bears overload and if it goes beyond its endurance limit then it may cause breakage of whole tooth or a portion of a tooth.
- *Plastic Flow:* Cold working if the tooth surfaces, caused by high contact stresses and the rolling and sliding action of the mesh; it is a surface deformation resulting from the yielding of the surface and subsurface material, and is usually associated with the softer gear materials- although it often occurs in heavily loaded case-hardened and through-hardened gears.

2. Literature reviewed

A. Lanzutti, A. Gagliardi, A. Raffaelli, M. Simonato et. al [1], Failure analysis of Gear, shaft and keys of centrifugal washers failed during life test. In this paper failure analysis of a transmission gearbox used in a motor of a food centrifugal dryer tested with a life test procedure developed by Electrolux Professional. The test apparatus consisted in a prototype of the centrifugal dryer, where some aluminum cylinders were installed on the drying basket in order to simulate the maximum loads. The gear and the shaft analyzed in this work are made of low-alloyed steel heat treated by induction quenching followed

by tempering. Permanent failures occurred during life test are considered in this work. In particular failure of the gear's teeth or the keys used to transfer force from the shaft to the gear. The failure of these components was observed after about 3000 ON-OFF cycles.

K Stahl, B. R. Hohn, J. Hermes & A. Monz et. al. [2] Pitting resistance of worm gears- advance model for contact pattern of any size position flank type, Gear technology. In this paper a precise knowledge of pitting of Worm & Worm wheel is being discussed, Worm gear shows a reduced contact pattern at the outset. The local high Hertzian stress combined with the low wear rate of larger center distance leads quickly to localized pitting however requires a completely run in contact pattern between worm and worm wheel, On the basis of experimental and theoretical investigation of the tooth contact of worm gearing a new method for calculating pitting lifetime is presented. The Hertzian stress in the tooth contact between worm and worm wheel is assessed as signified load accordingly the result of previous research in this field with complete contact pattern can be compared and calculated as well.

Vrushali Wable, D. M. Mate et. al. [3] "An investigating study of spur gear failure by FEA & Photo-elastic method". In this paper pitting failure has been studied for a gear. The gear is being modelled in CATIA V5 by parametric formulation and then analyzed in ANSYS for calculating deformation and max contact stress which causes pitting. Photo- Elastic Apparatus is used for Experimental Analysis.

3. Methodology

Traditional Methodology of Machine Design is being followed in this research paper. At first An Ash brick factory Owner approached with Two failed Worm Wheel shown in figure 2, then we went to Ash brick factory where the stacker assembly is mounted as shown in figure 3, through which the bricks were lifted are running through the help of Worm & worm wheel arrangement and the main concern of factory is the failure of Worm wheel continuously. We take various measurements through which we have generated the model of Worm wheel and then the analysis has been done on ANSYS to find out the various causes due to which the gear is failed.

Fig. 2. Two different modes of failure in gear, one is due to wear and other is due to misalignment

Fig. 3. Stacker assembly of ash brick factory

4. Boundary conditions

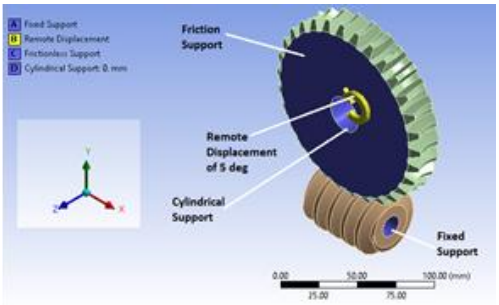

Fig. 4. Boundary condition representation of the modeling of Worm and Worm wheel

The figure shows the degree of freedom provided to the model. Fixed support is applied on the worm to restrict the worm in X Y Z Rotational and linear direction. Cylindrical support is applied on gear wheel to restrict the wheel in X and Y rotation and to be free in Z-axis. The frictionless support is providing on two face of gear wheel to restrict Z- direction motion. The load applied is given by remote displacement boundary condition. 5-degree rotation about Z-axis. It is calculated by converting 3000 rpm to degrees and calculating the time required for 5deg rotation. The element taken is 20-node tetra-hedral element. Meshing method is patch conforming method. The number of element is below 100000 elements due to the restriction of machine RAM capacity

5. Data analysis & results

A. Contact stress analysis

Point contact or line contact are being replaced to area contact when the two bodies having curved surfaces are pushed together. Three-dimensional stresses originate in two contact bodies. Problems of contact stress arises in the contact surfaces between the wheel and rail, in automobile engine in parts like valve cam and tappet, between mating gear teeth and in the action of rolling bearing. Few typical failures that occur in contact stress are Cracks, flaking or pits in the surface material. The most general case of contact stress provides that each contacting body have double radius of curvature. Or we can say that, the radius of the plane of rolling is different as compared

to the radius in the perpendicular plane. Both these planes are taken together as the axis of contacting forces. In this research we are considering only two special cases for contacting spheres and contacting cylinders. The results which come out here are due to Hertz and so are generally known as Hertzian stresses. In analytical analysis we can determine contact stress, fatigue life, penetration, with the help of Hertzian stresses.

Deploying the Hertz's theory to obtain the expression for surface contact stress.

$$p_{max} = \frac{2f}{\pi b l} \quad (1)$$

and half – width b is obtained,

$$b = \sqrt{\frac{2F\left[\frac{(1-v_1^2)/E_1]+[(1-v_2^2)/E_2]}{\left(\frac{1}{d_1}\right)+\left(\frac{1}{d_2}\right)}\right.}{\pi l}} \quad (2)$$

To adapt these relations to the notation used, we replace F by $W^1/cos\text{ø}$,d by 2r, and l by the face width F. With these changes, we can substitute the value of b as given by eq. (2) in eq. (1) .replacing P_{max} by σ_c, the surface compressive stress (Hertzian stress) is found from the equation

$$\sigma_c^2 = \frac{W^2}{\pi F cos\,\emptyset} \frac{\left(\frac{1}{r_1}\right)+\left(\frac{1}{r_2}\right)}{[(1-v_1^2)/E_1]+[(1-v_2^2)/E_2]} \quad (3)$$

B. Worm and worm wheel arrangement for penetration analysis

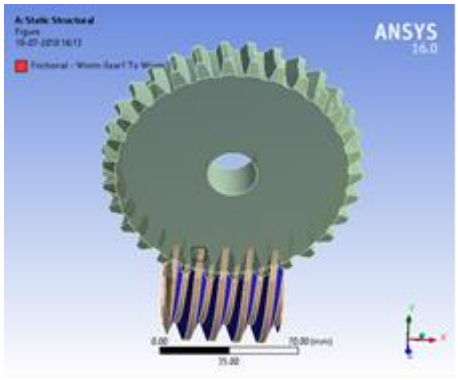

Fig. 5. Worm and worm wheel for penetration analysis

C. Analyzing contact stress results

By means of simulation, the contact change status can be got such as contact stress, penetration & fatigue life of the worm and worm arrangement. The bigger contact stress mainly concentrated on the inner part of the pitch circle of the worm and worm contact. Specifically, the worm is made by steel whereas the worm wheel is made by gun metal, which is softer and weaker then worm. We can also know that the contact area has an approximate liner in contact area along the worm wheel PCD that is consistent with the Hertzian contact theory.

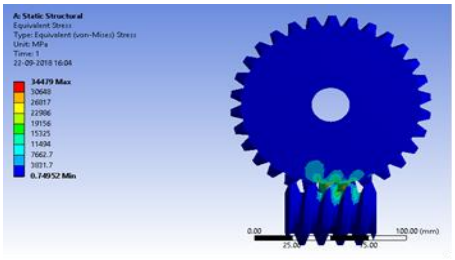

Fig. 6. Extreme condition analysis of the worm and worm wheel

As the displacement increases with the friction the magnitude of the contact stresses reaches at the critical level and this is the main problem with the worm wheel. The actual reason behind the worm wheel wear is pitting and erosion of the contacting surface due to interstitial and substantial impurity of the oil (SAE90).

Table 1
Result of stress analysis

Coefficient of friction	Displacement (in mm)	Contact stress in MPa
0.025	0.01	5890 (SAFE)
0.05	0.01	7212 (SAFE)
0.025	0.03	8462(SAFE)
0.05	0.03	16056(UNSAFE)
0.025	0.045	18234(UNSAFE)
0.05	0.045	22547(UNSAFE)
0.025	0.06	27825(UNSAFE)
0.05	0.06	34476(UNSAFE)

D. Misalignment analysis

The application of this assemble shown in figure 7, is to converted the rotation velocities of the motor to the translation velocity of the stacker. The stacker caries approximately 18 bricks pallet and 3 pallets at a time and misalignments and uneven slope of the long stacker leads the large resisting force over the transmission devices, specially worm and worm wheel.

Fig. 7. Stacker assembly

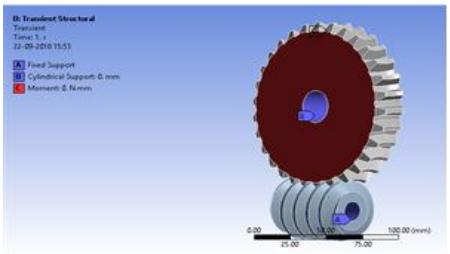

Fig. 8. Boundary condition for analysis

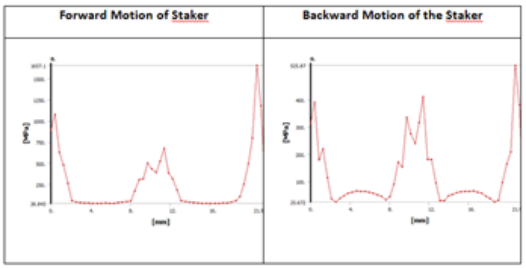

Fig. 9. Contact line stress distribution of the worm wheel

Actually the staker is moving forward with around 162 to 200kg (18 Brick*3kg/Brick*3 Pallets at a time) load and came back with no load conditions. Figure 9 is the stress distribution plot over the contact line along the Pitch Circle Diameter that varies Up-Down-Up-Down-Up, as per expectation as the pressure angle varies. The peak values of the forward contact stress is 1657 MPa due to loaded staker and it reduced up-to 560 MPa due to no load on staker.

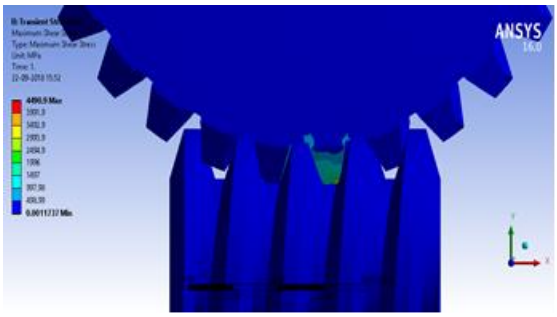

Fig. 10. Shear Stress profile of the Worm Wheel

Fig. 10, shows Contacting shear stress reaches up-to 4490 MPa which is very large for the gun material and is the basic reason the material is dissolved in the lubricating oil gradually and the gear system failed.

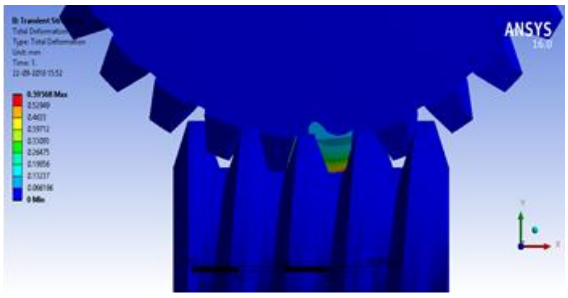

Fig. 11. Deformation profile of the worm wheel

Fig. 11, Shows the deformation profile of the worm wheel, when the misalignment is available with the staker. The deformation is very large and material is permanently deformed when that much of deformation is introduced.

6. Conclusion

The work presented here is a consultancy work and a real case study of an Ash brick factory's Gear failure issue where I represent the overview of an important role of the mode and cause f failure in worm and worm wheel assembly

During the research, I found that the gear is failed because of two reasons

1. The Gear fails due to Wear because of Higher contact stress generally name as Hertzian stress includes lower lubrication film between two mating gears, As the contact is metal to metal the massive amount of wear and heat is generated in the interface of the mating gear leads to oil burning and as a result as Worm wheel is made up of Gun metal it starts wearing.
2. The staker is moving forward with around 162 to 200kg (18 Brick*3kg/Brick*3 Pallets at a time) load and came back with no load conditions and as due to this much load a slight misalignment causes a huge amount of deformation which leads to tooth breakage or fatigue.

7. Future scope

After looking to the conclusion we determined that the Gear fails due to Wear and Misalignment in our case so to avoid such condition in future.

1. By providing proper Rubber seal in the lubrication system and regular checkup of Oil will lead to reduce the Wear condition in the gear system.
2. Regular checkup of staker assembly is required with water level so that the condition of misalignment can be reduced and will avoid tooth breakage.

Acknowledgment

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