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Contact Stress Analysis of Spur Gear (EN 8) of PTO drive using Finite Element Analysis

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Abstract — *In this paper the contact stress over the lower addendum of the spur gear and shrear stresses by using the software tools like Creo and ANSYS are used to design and analysis. The spur gear is sketched and modeled in ANSYS design modular and the contact stress analysis is done in mechanical ANSYS multi-physics. In this, we found the contact stress analysis of EN8 spur gears by theoretical method using Hertz equations and by finite element analysis using FEA software ANSYS 15.0 workbench. The ANSYS software avoids monotonous calculations presumably impending in the design procedure and uses ultimate numerical tool to approximate the solution of the partial differential equations associated with continuity, momentum and energy phases of a flow problem in a 3-D model. This intricate feature of ANSYS enables designer to optimize the design procedure in an iterative manner based on the final plots of post-processing phase of gear.*

Keywords- *Spur gear, Contact stress, ANSYS, Finite Element Analysis*

I. INTRODUCTION

Spur gears have been used since ancient times. Gears are the most common means of transmitting power in mechanical engineering. With the moving wheel of science and technology the use of gears has become more common in all the upcoming industries and Automobiles. Spur gears or straight-cut gears are the simplest type of gear. Spur gears use no intermediate link or connector and transmit the motion by direct contact. The two bodies have either a rolling or a sliding motion along the tangent at the point. No motion is possible along the common normal as that will either break the contact or one body will tend to penetrate into the other. Modern gears are a refinement of the wheel and axle. Gearing is one of the most critical components in a mechanical power transmission system, and in most industrial rotating machinery. The advantage of spur gear is their simplicity in design, economy of manufacture and maintenance, and absence of end thrust. Spur gear is a component with in a transmission device that transmits rotational torque by applying a force to the teeth of another gear or device.

Putti Srinivasa Rao, Nadipalli Sriraj, Mohammad Farookh et al (2015) [1] shows that the complex design problem of spur gear which requires fine software skill for modeling and also for analyzing. The project aims at the minimization of both contact stress as well as deformation to arrive at the best possible combination of driver and driven gear. In this process of spur gears mating, 3 different materials were selected and the software programme was performed for 9 different combinations to get the best result possible. The results of the two dimensional FEM analysis
from ANSYS are presented. These stresses were compared with the theoretical Hertz's equation values. Both results agree very well. This indicates that the FEM model is accurate.

VIVEK KARAVEER et al (2013) [2] presents the stress analysis of matting teeth of spur gear to find maximum contact stress by theoretical Hertizian's equation and by finite element analysis. For the analysis steel and gray cast iron are used as the materials of the spur gear. FEA is done in finite element software ANSIS 14.5 and also deformation for steel and gray cast iron is obtained as efficiency of the gear depends on its deformation. The result show that the difference between maximum contacts stresses obtained from Hertz's equation and finite element analysis is very less and it is acceptable.

M. RAJA ROY et al (2014) [3] calculated gear contact stress by the Hertz's equation originally derived for contact between two cylinder and then analytically these contact stresses are calculated for different modules and these results are compared with results obtained in modeling analysis in ANSIS. A result shown that with increase in module, contact pressure decreases for per of spur gear. Likewise factor of safety is also increase with increasing in module. Both analytical and ANSIS results follow same trend.

Vijay Bhaskar Sudarsi and T.B.S.Rao et al (2013) [4] worked with the finite element analysis of deformation on spur gear teeth by applying static load on teeth. the feasibility of the project is investigated and the results of the FEM analyses from ANSYS are presented. By theoretical and FEM analysis they found that in both the cases tooth is safe at predefined load. Hence they conclude that FEA can be applied for effective calculation of stress and deformation of a spur gear. Tooth for stresses have done several studies. In detail study of the contact stress produced in the mating gears is the most important task in design of gears as it is the deciding parameter in finding the dimensions of gear.

Mr. Bharat Gupta et al 2012 [5] Sushil Kumar Tiwari [6] found out the contact stress and bending stress for involute spur gear teeth in meshing by finite element method.

DhavaleA.S., Abhay Utpat [7] paper explores when gear is subjected to load, high stresses developed at the root of the teeth, Due to these high stresses, possibility of fatigue failure at the root of teeth of spur gear increases.

Research article on Modeling and Finite Element Analysis of Spur Gear is done by Vivek Karaveer, Ashish Mogrekar and T. Preman Reynold Joseph [8] in which the contact stresses of gears is found out by ANSYS and HERTZ equation which is for finding contact stress in gears.

T. Shoba Rani et al. [9] have used cast iron, nylon and polycarbonate as the materials used for the project of spur gear for finite element analysis.

II. SPUR GEAR SPECIFICATIONS AND MATERAIL PROPERTIES

rpm of the gear ng = 540
rpm of pinion np = 1686

Now, no. of teeth for pinion is taken Zp = 18,

No. of gear $= \frac{Zg}{Zp} = \frac{np}{ng}$ so, $Zg = \frac{1686}{540} \times 18 = 56$

Pitch circle dia. of gear d'p = mZp = 3 × 18 = 54mm
d'g = mZg = 3 × 56 =168mm
Addendum (ha) = m = 3mm
Dedundum (hf) = 1.25m = 1.25 × 3 =3.75mm
Tooth thickness = 1.5708m = 4.71mm
Buttom clearance (c) = 0.25m = 0.75mm

Table 1. Gear Specification

Description	Specifications	Specifications
No. of teeth(Z)	Zp = 18	Zg = 56
Module(m)	3	3
Pitch circle diameter(D)	dp = Zp × m = 54	dg = Zg × m = 168
Face gear width(b)	b = 20m	
Pressure angle(ϕ)	20°	
Addendum(ha)	ha = 3mm	
Dedendum(hf)	hf = 1.25m = 3.75mm	
Shaft radius	Rs = 16mm	

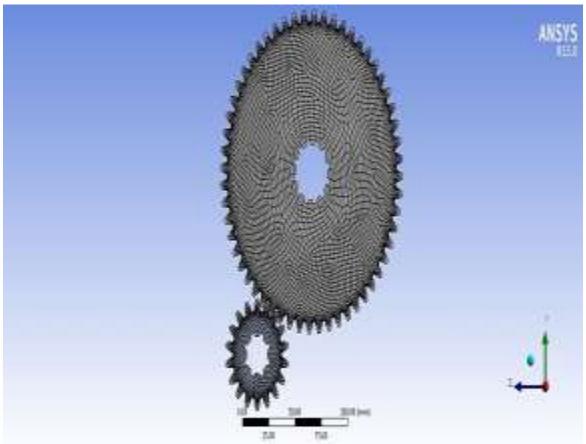
III. MODELING OF SPUR GEAR

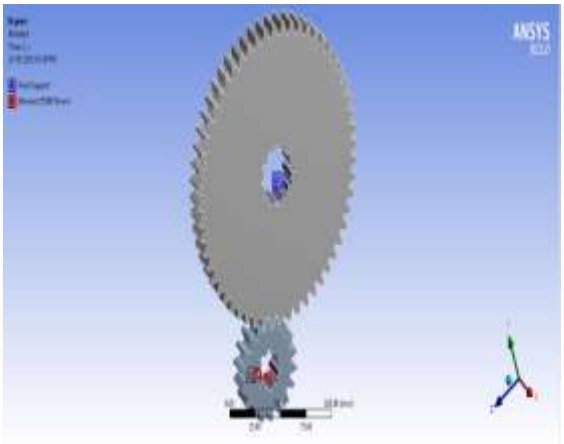
To determine maximum contact stress during the transmission of torque of 68.53Nm by EN8 using finite element analysis we sketched and modeled helical gear in the ANSIS design modeler. The dimension of gear is given table 1.

Figure 1. Spur Pinion

Figure 2. Spur Gear

3.1 Meshing and Boundary Condition





Nodes	138485
Elements	26228

IV. THEORETICAL CALCULATION OF CONTACT STRESSES FOR SPUR GEAR BY ANALYTICAL METHOD (HERTZ EQUATION)

One of the main gear tooth failure is pitting which is a surface fatigue failure due to many repetition of high contact stresses occurring in the gear tooth surface while a pair of teeth is transmitting power. Contact failure in gears is currently predicted by comparing the calculated Hertz contact stress to experimentally determined allowable values for the given material. The method of calculating gear contact stress by Hertz‟s equation originally derived for contact between two cylinders. Contact stresses between cylinders are shown in figure 1 and figure 2.

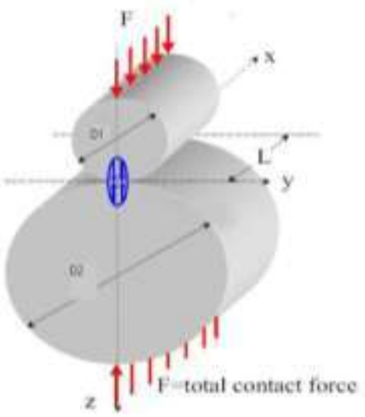


Figure 1.Contact stress between cylindrical surface

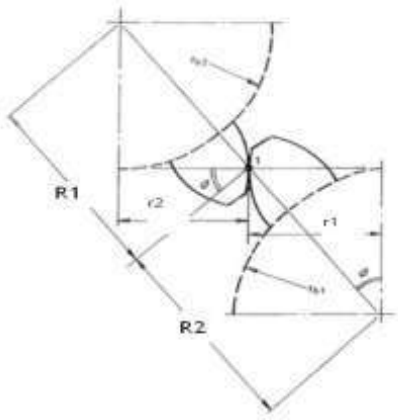


Figure 2. Mating Gear Geometry

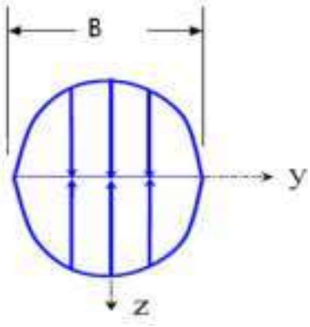


Figure 3. Stress across the width

In machine design, problems frequently occurs when two members with curved surfaces are deformed when pressed against one another giving rise to an area of contact under compressive stresses of particular interest to the gear designer is the case where the curved surfaces are of cylindrical shape because they closely resemble gear tooth surfaces. In Fig.1 two gear teeth are shown in mating condition at the pitch point. Referring to Fig.3, the area of contact under load is a narrow rectangle of width B and length L the stress distribution pattern is elliptical across the width as shown in figure.

Hertz equation is used to determine the contact stresses in the mating teeth of gear. Hertzian equation for contact stress in the teeth of mating gears is given by,

$$\sigma_c = \sqrt{\frac{F(1+{R_1}/{R_2})}{R_1 B\pi[{(1-\vartheta_1{}^2)}/{E_1}+{(1-\vartheta_2{}^2)}/{E_2}]\sin\emptyset}}$$

Where σ_c is the contact stress in mating teeth of spur gear, F is the force, and R1 and R2 are pitch radii of two mating gears, B is the face width of gears, ϕ is the pressure angle,

υ_1, υ_2 are the Poisson ratios and E1,E2 are the modulii of elasticity of two gears in mesh.

Allowable maximum stress is given by,

$$\sigma_a = \frac{\sigma_c}{FOS}$$

Here FOS is the factor of safety which can be taken from the ANSYS results or other FOS tables. Above equation gives the allowable maximum contact stress in the mating gears.

V. ANALYTICALY CALCULATION FOR CONTACT STRESS FOR SPUR GEAR

Power P = 2πNT/60$\frac{2\pi NT}{60}$

$$\therefore T = \frac{60P}{2\pi N}$$

= 68.53N

Torque = Force * Radius

68530 = F * 16 => F = 4283.13N

Now, Contact stress,

$$\sigma_c = \sqrt{\frac{F(1+{}^{R_1}/_{R_2})}{R_1 B\pi[{}^{(1-\vartheta_1{}^2)}/_{E_1}+{}^{(1-\vartheta_2{}^2)}/_{E_2}]\sin\emptyset}}$$

Putting the values,

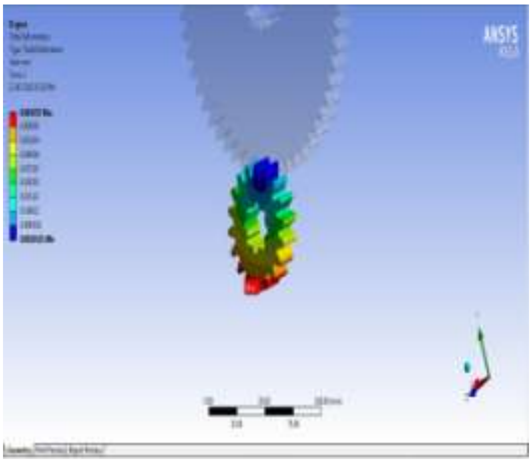
For EN8

$$\sigma_c = \sqrt{\frac{4283.12(1+\frac{27}{84})}{27\ \times 20\ \times 3.14\left[\frac{1-0.3^2}{2\ \times 10^5}+\frac{1-0.3^2}{2\ \times 10^5}\right]Sin\ 20}}$$

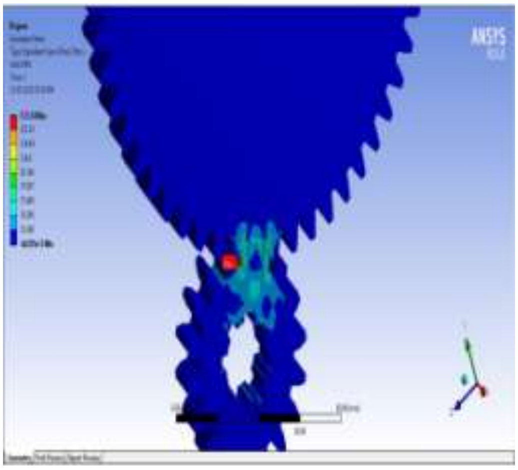
σ_c = 1210.12 MPa

VI. FINITE ELEMENT ANALYSIS RESULT

Total Deformation

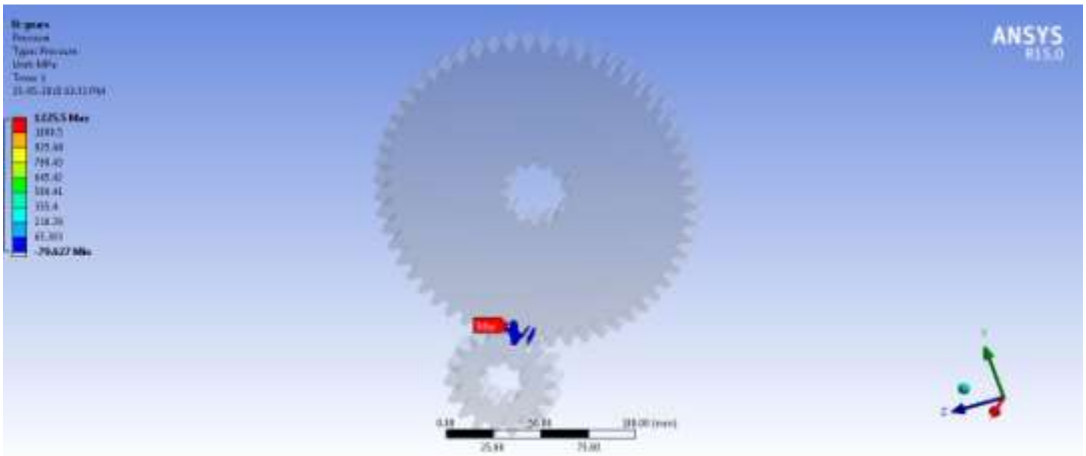


Von-Mises Stresses for Spur Gear



Max. deformation is 0.065655 mm. Von mises stresses are maximum 172.34 MPa and Minimum 4.6335e-5 MPa.

Contact Stress of Spur Gear for EN8



Contact Stress at tooth is1225.5MPa.

Table 2 Result comparision

Material	Contact Stress Analytical Results (MPa)	Contact Stress ANSYS Results (MPa)
EN 8	1210.12	1225.5

VII. RESULTS AND DISCUSSIONS

The analytical and structural analysis of spur gear is carried out using the FEA in ANSYS 15. The load applied at the tooth of the gear by applying the analysis over the tooth which is facing the load we get the stress distribution in the numerical as well as in the form of color skim. Results of theoretical and ANSYS are closure therefore the designs are accepted. The contact stress is analyzed by FEA analysis is the real contact region between the two matting gears.

VIII. CONCLUSION

The designed model of PTO drive shaft i.e. helical gear, spur gear and shaft is applied onto FEA software ANSYS 15. Analysis results were compared and confirmed by the theoretical calculated data. According to those results we can draw the conclusion; design is safe and it was found out that the numerically obtained values of stress distribution were in good agreement with the theoretical results. contact stresses and deformation is useful in the selection of material in different applications. The values obtained by Hertz's equation and Ansys agree with each other with a maximum error of 4% which is acceptable. It shows that the simulation done in ANSYS is compatible and copes up with the hertz equation for a materials used. The values are compared to practical values and the two analysis validate each other.

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