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FINITE ELEMENT ANALYSIS OF SPUR GEAR USED IN LATHE HEADSTOCK

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ABSTRACT

One of the important parameter of mating gears design is contact stress. This paper deals with the stress analysis of the spur gear used in headstock of a lathe machine. In this paper the stress analysis of mating gears of the spur gear with three different materials is done to determine the contact stresses generated in the gear theeth. The results obtained from Finite Element Analysis (FEA) using Ansys are compared with the values obtained from theoretical Hertzian equation.The materials of spur gear used for analysis are grey cast iron, high carbon steel and medium carbon steel. On comparing the results after theoretical analysis i.e. by using Hertzian equation and through Ansys, very less and acceptable difference between the values of contact stresses found.

KEYWORDS: Spur Gear, Contact stress, Hertzian equation, Finite Element Analysis, Ansys.

INTRODUCTION

Gears are commonly used for transmitting power. They develop high stress concentration at the root and the point of contact. The repeated stressing on the fillets causes the fatigue failure of gear tooth. A finite element model of Spur gear used in the headstock of Lathe machine for power transmission is considered for analysis
The highest stress occurs at two locations:

1. At contact point where the force F acts
2. At the fillet region near the base of the tooth.

The surface failures occurring mainly due to contact fatigue are pitting and scoring. It is a phenomenon in which small particles are removed from the surface of the tooth due to the high contact stresses that are present between mating teeth. Pitting is actually the fatigue failure of the tooth surface. Hardness is the primary property of the gear tooth that provides resistance to pitting. In other words, pitting is a surface fatigue failure due to many repetitions of high contact stress, which occurs on gear tooth surfaces when a pair of teeth is transmitting power .Gear teeth fails due to contact. Fatigue is a common phenomenon observed.

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.

The Hertz equations discussed so far can be utilized to calculate the contact stresses which prevail in case of tooth surfaces of two mating spur gears. Though an approximation, the contact aspects of such gears can be taken to be equivalent to those of cylinders having the same radii of curvature at the contact point as the load transmitting gears have. Radius of curvature changes continuously in case of an involutes curve, and it changes sharply in the vicinity of the base circle.

METHODOLOGY

In this paper, grey cast iron, high carbon steel and medium carbon steel are used as the spur gear materials. The material properties of steel and grey cast iron are given in Table 1.

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Table 1. Mechanical Properties ofspur gear materials

Property (unit)	Grey cast iron	High carbon steel	Medium carbon steel
Density (Kg/m^3)	7100	7480	7850
Poisson ratio	0.26	0.29	0.29
Young's Modulus (MPa)	110 e^3	197 e^3	203 e^3
Tensile strength (MPa)	195 e^3	800 e^3	685 e^3
Ultimate tensile strength (MPa)	310 e^3	996 e^3	987 e^3

Modeling of Spur Gear

The CAD model of the spure gear is prepared in solid woks software as shown in figure 1. The dimensions of the gear is refered from M. Raja (2014) in which the same headstock spur gear is used and are given in table 2.

Table 2. Dimensions of spur gear

S. No.	Desciption	Symbol	Values	
			Pinion	Gear
1.	Number of teeth on pinion	t_p	22	-
2.	Number of teeth on Gear	t_g	-	56
3.	Pressure Angle		20	20
4.	Module	m	3	3
5.	Pitch Circle Diameter (mm)	D	66	168
6.	Face width (mm)	W	28	28
7.	Bore Diameter (mm)	-	25	30
8.	Input Power (KW)	-	1	
9.	Input Speed (rpm)	-	140	

Theoretical calculations of Contact Stresses by Analytical Method (Hertz equation)

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

$$\sigma_c = \sqrt{\frac{F_t(1+\frac{R_g}{R_p})}{R_g W\pi[(1-\upsilon_1^2)/E_1+(1-\upsilon_2^2)/E_2]sin\phi}} \qquad (1)$$

Figure 1: Part assembly of the spur gear prepared in solid works

Where σ_c = Contact stress in mating teeth of spur gear, F_t is the tangential load, Rg and Rp are the pitch circle radii of gear and pinion, W is the face width, Ø is the pressure angle, υ = poissions ratio, E1 and E2 are the modulii of elasticity of two gears in mesh.

Allowable maximum stress is given by,

$$\sigma_a = \frac{\sigma_c}{FOS} \qquad (2)$$

Here is the Factor of Saftey which can be taken from the ANSYS result or other FOS tables. Equation (2) gives the allowable maximum contact stress in the mating gears. In this paper, factor of safety is taken from ANSYS result. But minimum factor of safety from the ANSYS results is preferred in order to get accurate allowable maximum contact stress at the point of contact of gear teeth.

Now Torque is given by,

$$P = \frac{2\pi NT}{60}$$
$$T = \frac{60*746}{2*3.14*140}$$
$$=50.909 \text{ Nm}$$
$$Force\ (F_t) = \frac{Torque\ (T)}{Radius\ (R)}$$
$$F_t = \frac{50.909*1000}{22}$$
$$= 2314.9 \text{ N}$$

Case I- Grey Cast Iron Spur Gear:
For grey cast iron spur gear, Equation (1) becomes,

$$\sigma_c = \sqrt{\frac{2314.9\ (1+\frac{84}{33})}{84*28\pi[(1-0.26^2)/110\ e3+(1-0.26^2)/110\ e3]sin20}}$$

$\sigma_c = 437.6956$ MPa

From figure, factor of safety for grey cast iron spur gear is 1.8916
.
From (2),
$\sigma_a = \frac{437.6956}{1.8916}$

$\sigma_a = 231.3891$ MPa

Case II- High Carbon Steel Spur Gear:

For high carbon steel spur gear, Equation (1) becomes,

$$\sigma_c = \sqrt{\frac{2314.9\ (1+\frac{84}{33})}{84*28\pi[(1-0.29^2)/197\ e3+(1-0.29^2)/197\ e3]sin20}}$$

$\sigma_c\ =\ 590.998$ MPa

From figure, factor of safety for high carbon steel spur gear is 6.1769.

From (2),

$\sigma_a = \frac{590.998}{6.1769}$

$\sigma_a\ =\ 95.6787$ MPa

Case III- Medium Carbon Steel Spur Gear:

For medium carbon steel spur gear, Equation (1) becomes,

$$\sigma_c = \sqrt{\frac{2314.9\ (1+\frac{84}{33})}{84*28\pi[(1-0.29^2)/203\ e3+(1-0.29^2)/203\ e3]sin20}}$$

$\sigma_c\ =\ 599.93$MPa

From figure, factor of safety for medium carbon steel spur gear is 5.289.

From (2),

$\sigma_a = \frac{599.93}{5.289}$

$\sigma_a\ =\ 113.4297$ MPa

Finite Element Analysis

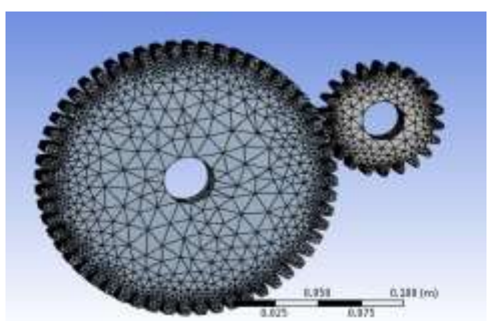

Figure 2: Gear after meshing

Finite Element Method is the easy technique as compared to the theoretical methods to find out the stress developed in a pair of gears. Therefore FEM is widely used for the stress analysis of mating gears. In this paper, finite element analysis is carried out in ANSYS Workbench 12.1 to determine the maximum contact stresses for grey cast iron, high carbon steel and medium carbon steel. Also the deformation is found out for all the three gear.

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Meshing

Fine meshing of tetrahedran type is done to get the accurate results of contact stress.

Boundary Condition

Tangential load of 2315 N is applied at the point of ontact during the mating of the two gears. Frictionless support and the moment of 194.46 N-m to the gear and moment of 76.395 N-m to the pinion in opposite direction is given.

RESULT

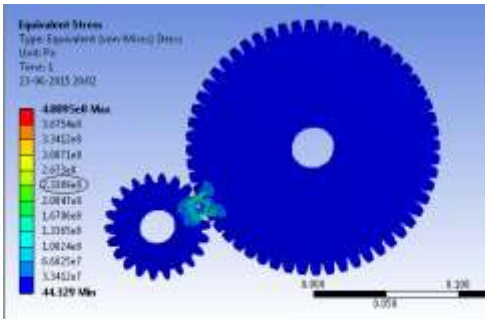

Figure 3: Stress distribution in grey cast iron

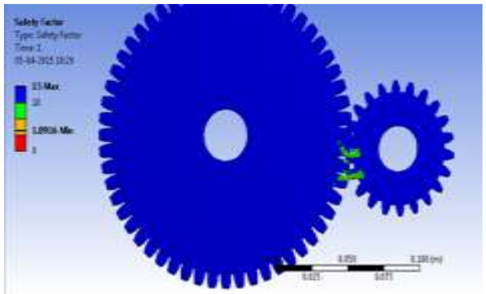

Figure 4: Safety Factor in grey cast iron

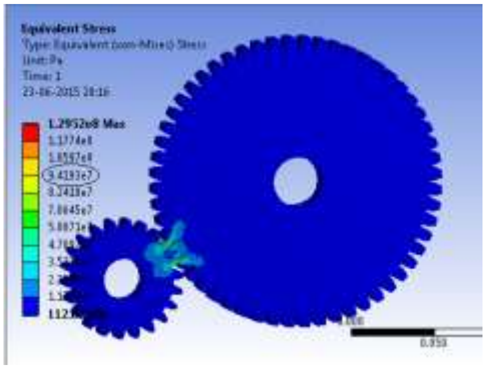

Figure 5: Stress distribution in high carbon steel

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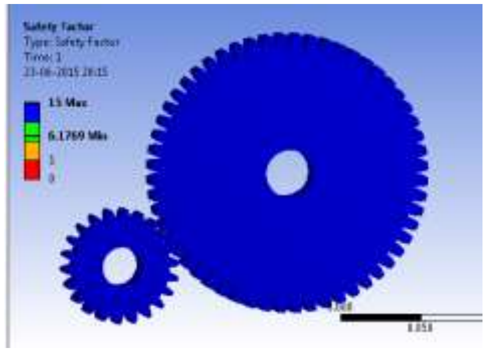

Figure 6 Safety Factor in high carbon steel

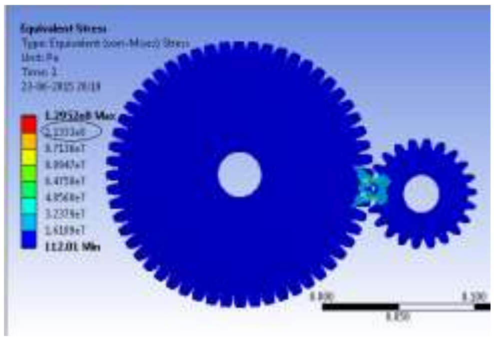

Figure 7: Stress distribution in medium carbon steel

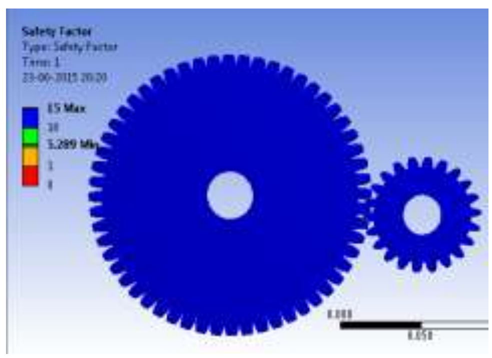

Figure 8: Safety Factor in medium carbon steel

RESULTS AND DISCUSSION

Comparision of maximum contact stresses for the three materials of spur gear i.e. grey cast iron, high carbon steel and medium carbon steel obtained from Hertz equation and ANSYS 12.1 is given in Table 3.

Table 2. Comparision of maximum contact stresses obtained from Hertz equation and ANSYS 12.1

Supr Gear	σ_a (MPa) Hertz Equation	σ_a (MPa) ANSYS 12.1	Difference (%)
Grey Cast Iron	231.58	233.89	0.987
High Carbon Steel	95.785	94.19	1.6
Medium Carbon Steel	113.42	113.33	0.07

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CONCLUSION

The contact stresses of gears of three different materials were calculated by Hertz equation and by ANSYS. It was found that the results obtained by hertz equation and finite element analysis are comparable because the difference between the values of contact stresses obtained by analytical and finite element analysis are negligible.

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