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DESIGN AND ANALYSIS OF STRAIGHT CUT GEAR USING FINITE ELEMENT METHOD (FEM)

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Abstract*—Gear drives transmit motion and power by tooth mesh mostly in the form of involutes profiles, gear tooth mesh is a complex process involving multi tooth engagement, multipoint contact and varying load conditions. To achieve improved static and dynamic characteristics of gear drives and enhanced load carrying capacity and reliability, a complete study about gear drive design and analysis is carried out. The contact stress and fatigue analysis are examined for spur and helical gear drive in static and dynamic condition. The contact stresses were examined using 3-D FEM model. The gears are modeled by using PRO-E WILDFIRE 5.0 and analyzed by ANSYS 12.1. In the present work an attempt is proposed to find the contact stress, fatigue analysis at the point of gear tooth engagement under static and dynamic loading conditions through finite element software.

***Index Terms*—Spur gear, contact stress, Fatigue, Ansys, Static and Dynamic analysis.**

I. INTRODUCTION

Gears are toothed members which transmit power / motion between two shafts by meshing without any slip and the power is usually transferred in such a way velocity ratio remains constant. In any pair of gears, the smaller one is called pinion and larger one is called gear immaterial of which is driving the other. When pinion is the driver, it results in step down drive in which the output speed decreases and the torque increases. On the other hand, when the gear is the driver, it results in step up drive in which the output speed increases and the torque decreases. Gears are classified as spur, helical, double helical, bevel, worm and spiral gears. The contact stress and fatigue analysis of both spur and helical gear drive are examined in this research and it will be useful for further investigators to improve gear behaviors on various aspects.

II. IMPORTANCE

It is difficult to accurately predict the contact stress and fatigue using conventional methods. On the contrary, the contact stress and deformation can be accurately predicted using the finite element method for contact problems with proper definition of gear geometry, loading and boundary conditions. The material for both pinion and wheel is C45 carbon steel. The contact of the spur gear tooth starts in 95°(pinion) and 68.07 °(wheel) and ends in 61°(pinion) and 90.71°(wheel) in wheel. This contact is called contact region. The pinion values are decreasing from 95° to 61° and the wheel values are increasing due to clockwise and anticlockwise rotation of pinion and wheel.

Table 1 Properties of carbon steel

Material	C45
Young's modulus in N/MM^2	2.15E^5
Poisson ratio	0.3
Yield strength in N/MM^2	400
Tensile strength	680

Table 2 Symbol and descriptions

Symbol	Descriptions
α	Pressure angle
O.D	Outside Diameter
P.C.D	Pitch circle diameter
B.C.D	Base circle diameter
R.D	Root diameter
m	Module
b	Face width
N	Number of teeth
R_f	Fillet radius
Dp	Diametral pitch

Table 3 Specifications of spur gear

Specifications	Pinion	Wheel
α	20^0	20^0
O.D	64mm	92mm
P.C.D	56mm	84mm
B.C.D	52.62mm	76.93mm
R.D	46mm	74mm
m	4mm	4mm
b	10mm	10mm
N	14	21
R_f	1.50mm	1.50mm
Dp	56.02mm	56.02mm

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III. Static Analysis

Static analysis is concerned with determination of response of a gear to steady loads whose response remains unchanged with time. The response of the gear is expressed in terms of stress, strain, displacement. The tool used in the static analysis is Static structural. The finite element analysis procedure of the spur gear was given below:

- A three-dimensional model of the spur gear was created using the pro/engineer CAD software.
- The material properties were defined for gears.
- The model was meshed using finite element software.
- Boundary conditions for ANSYS Workbench as mentioned below.
  - Fixed displacement constraint was applied on gear
  - Moment was applied on gear
  - In order to arrest the displacement on x, y, z directions and rotations on x, y directions remote displacement constraint is applied on pinion surface.

Figure 1 show the meshed finite element model of the spur gear which had been utilized for the analysis.

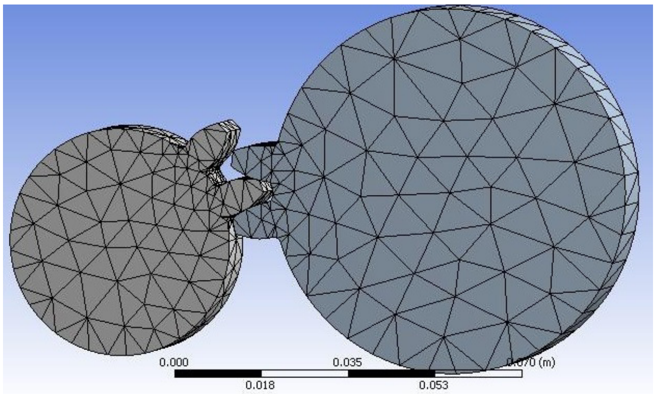

Figure 1 Meshed model of spur gear

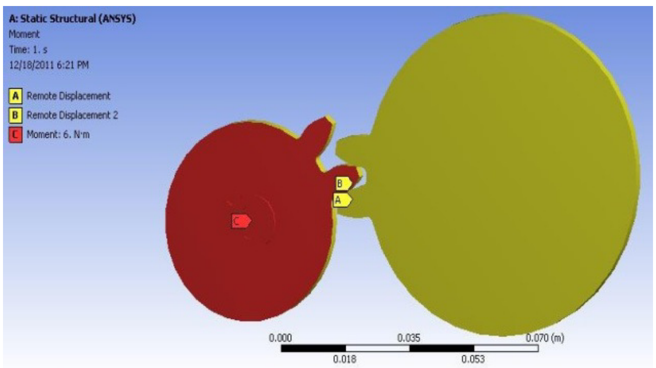

Figure 2 Spur gear with imposed loads and boundary conditions

IV. Dynamic Analysis

Dynamic analysis is concerned with determination of response of a gear to fluctuating loads whose response changes with time. The response of the gear is expressed in terms of stress, displacement etc. Using the finite element analysis software the dynamic responses of the spur gear drive under speed impact condition is obtained. The ansys tool used in dynamic analysis is Transient structural.

The finite element analysis procedure of the spur gear was given below.

- A three-dimensional model of the spur gear was created using the pro/engineer CAD software.
- The model was meshed using finite element software.
- Boundary conditions were given on the finite element model through Ansys workbench (Transient structural) as mentioned below.
  - The material properties were defined for both gears.
  - Moment is applied in pinion with respect to time.
  - Both gears are allowed to rotate with reference to Z-Axis in opposite direction.
  - Translation motions are arrested and rotations about X and Y axis are arrested.

The meshing diagram is same as indicated in static analysis.

V. Results and Discussions

A. *Static Analysis*

The below figure shows contact stress on tooth meshing area made up of carbon steel with hardening and tempering. The maximum and minimum von-mises stress values found in the 5 cases are 168.94 N/mm2 and 0.004035 N/mm2 respectively which is lower than maximum allowable stress 266 N/mm2 ,from this result it is well known that the gear design is safe and there is a possibility to increase the speed of spur gear until the contact stress reaches 255 N/mm2 .The contact stress in static for all 5 cases of spur gear drive is shown in Table 4, the diagram for first case are given below,

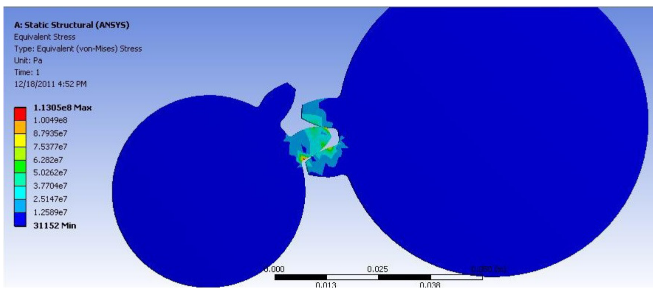

Figure 3 Von-mises stress for Case 1

Table 4 Contact stress in static condition

Case	Min. stress in N/mm^2	Max. stress in N/mm^2	Allow. stress in N/mm^2
Case 1	0.031152	113.05	266
Case 2	0.029111	124.77	266
Case 3	0.009951	71.70	266
Case 4	0.004035	52.52	266
Case 5	0.010137	168.94	266

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B. Dynamic Analysis

Here the contact stress of the spur gear is identified for five cases by 4, 6 and 8 seconds. Following plots shows the contact stresses on tooth meshing area of a spur during various time dependent operating conditions.

The maximum and minimum von- mises stress values found in all five cases were 174.64 N/mm2 and 0.003921 N/mm2 respectively which is lower than maximum allowable stress 190.47 N/mm2 from this result it is well known that the gear design is safe and there is a possibility to increase the speed of spur gear until the contact stress reaches 185 N/mm2. The contact stress in dynamic for all 5 cases of spur gear drive is shown in Table 5,6 and 7 the diagram for first case for 4 second is given below,

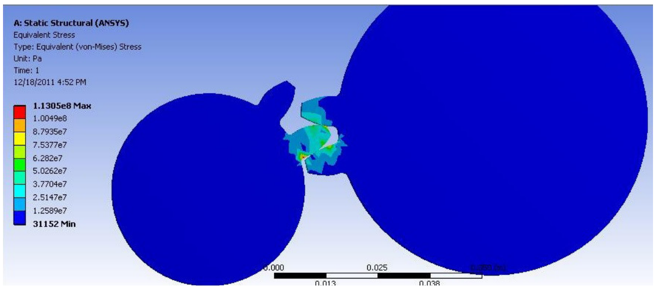

Figure 4 Von-mises stress in 4 seconds-Case 1

By following the same procedure the contact stress in dynamic conditions for rest of the cases are given below, here the maximum stress is 174.64 N/mm2 and minimum stress is 0.003921 N/mm2.

Table 5 Dynamic Contact stress for 4 seconds

Case	Min stress in 4 sec	Max. stress in 4 sec
Case 1	0.031288	109.86
Case 2	0.028969	126.46
Case 3	0.009159	71.964
Case 4	0.003921	52.813
Case 5	0.010345	169.55
Allowable stress in N/mm^2	**190.47**	**190.47**

Table 6 Dynamic Contact stress for 6 seconds

Case	Min stress in 6 sec.	Max stress in 6 sec.
Case1	0.032071	112.61
Case2	0.029693	129.62
Case3	0.009388	73.764
Case4	0.004019	54.139
Case5	0.010604	173.79
Allowable stress in N/mm^2	**190.47**	**190.47**

Table 7 Dynamic Contact stress for 8 seconds

Case	Min stress in 8 sec.	Max stress in 8 sec.
Case1	0.032462	113.98
Case2	0.030056	131.20
Case3	0.009503	74.660
Case4	0.004068	54.794
Case5	0.010656	**174.64**
Allowable stress in N/mm^2	**190.47**	**190.47**

The comparison of both static and dynamic conditions of spur gear is given below,

Table 8 Static Vs Dynamic stress

Case	Max. static stress in N/mm^2	Max. Dynamic stress in N/mm^2
Case 1	113.05	113.98
Case 2	124.77	131.20
Case 3	71.70	74.660
Case 4	52.52	54.794
Case 5	168.94	174.64

VI. CONCLUSION

This project work focuses three dimensional spur gear analyses under both static and dynamic conditions. The purpose of three-dimensional analysis is to predict the gear behavior on real operating conditions. In the static analysis, gear is fixed and rotational load is applied on pinion. From this analysis it is proven that the gear pairs are subjected to minimal von-mises stress and deformation during starting period of meshing as per theory. In dynamic analysis of gear both gear and pinion are allowed to rotate in opposite direction on time basis. From analysis it is proved as per theory that once the gear meshes and stars to rotate they are subjected to maximum von-mises stress and deformation.

Thus the three dimensional static and dynamic analysis of spur gear was performed under various operating conditions. Results shows that the contact stress is more in gear tooth meshing and it can be reduced with the increased in contact area and tooth profile modification. And the maximum von-mises stress obtained from the finite element analysis for both static and dynamic 168.94 N/mm2 and 174.64 N/mm2 is which is lower than the allowable stress 266 N/mm2 and 190.47 N/mm2 hence the design is within the safe limit and the gears can endure safe operation until the von-mises stress reaches 255 N/mm2 and 185 N/mm2.

Variation in center distance results in cyclic stress, vibration and noise, which can be reduced with proper assembly. Thus the three dimensional spur gear drive is used to find the contact stress in static and dynamic behavior and it will be useful for further investigators and industrial people to improve gear behaviors on various aspects.

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