ID: 2016-ISFT-256

Finite Element Analysis (FEA) and Modelling of Twin-Disc Contact

Akash Sharma[1], Harish Dakshana Moorthy[2], Paras Kumar[3]

[1,2]Student, Mechanical Engineering Department, Delhi Technological University, Delhi, India
[3]Assistant Professor, Mechanical Engineering Department, Delhi Technological University, India
[1]sharma.akash3008@gmail.com

Abstract: *In this present work, gear tooth contact is modelled as two discs in contact. Three different combinations of disc materials (structural steel - structural steel, cast iron-cast iron, and structural steel-cast iron) are modelled and analyzed using Finite Element Analysis (FEA). To analyze the contact problems in ANSYS, special contact elements need to be created during meshing to obtain accurate results. The contact element used in the present simulation is CONTA174, which is associated with the TARGE170 element on the target side.*

The maximum shear stress and von Mises stress are evaluated and compared for different combination of disc materials assuming frictionless contact. Since the yielding in ductile materials are usually caused by the slippage *of crystal planes along the maximum shear stress. The value of maximum shear stress and its location play an important role in crack initiation and prorogation. The maximum shear and von Mises stresses are 204 MPa and 396 MPa for discs made of structural steel. The cast iron discs show least value of the stresses. The maximum chance of crack initiation starts in steel discs at 103.5 μm depth. The FEA results are in close agreement with the theoretical calculation.*

Keywords: *Spur Gears, FEM, Twin Disc, ANSYS*

1. INTRODUCTION

Due to high power transmission efficiency, compact size, constant velocity ratio and higher reliability spur gears are used in a variety of applications such as metal cutting machines, marine engines, gear motors and gear pumps, automobile gear boxes and steel mills. Gear teeth experience a large amount of stress and thus their performance is evaluated on the basis the magnitude of stresses developed. The tooth interior fatigue fracture depends on the alternating stresses developed in the gear and the residual tensile stresses. The FE- Analysis of which is carried out in two stages: 1) calculation of the state of stress history in the tooth during the load cycle, including residual stresses 2) evaluation of the risk of crack initiation. The risk of crack initiation can be analyzed using twin disc setup in which spur gear profiles are approximated by cylinders with the same radius of curvature as the gear teeth at the instant contact point. This provides the basis of the twin-disc test devices, which typically represents only a single point along the line of action in real gears at constant load and speed conditions. Twin-disc test devices are widely used to study the influence of surface roughness on friction, lubricant rheological properties, development of coatings and different kinds of surface failures in gears.

Influence of speed on friction-force has been studied using the twin-disc setup by J. Sukumaran et al [1]. A twin disc set-up can also be used to investigate the surface failure, influence of lubrication and wear in gear contact [2, 3]. Similar experiments have been carried out to investigate the effect of surface roughness, lubricant type and surface treatment on micro-pitting performance of two case hardening steels by T. Ahlroos et al [4]. Twin-disc test device focusing on the friction coefficient and on temperature and lubrication conditions along the line of action have been performed by Jaakko Kleemola et al [5]. A fracture mechanical analysis of a tooth interior fatigue fracture crack has been performed utilising Finite Element Analysis for varying crack lengths by [6] by M. Mackaldener et al.

The effect of different materials and their combination on the maximum shear stress and hence the crack initiation for tooth interior fatigue failure in the gears has not been performed. In the following study, variation of maximum shear stress in spur gears of different material combinations has been performed using Finite Element Analysis on an equivalent twin-disc setup using ANSYS.

2. METHODOLOGY

Reducing gear noise plays an important role in the material selection for gears. Cast iron gears have exceptional vibration dampening characteristics though they are believed to be weak and brittle. Gray cast iron is often used for manufacturing gears as they provide a good choice for reducing gear noise. In the present study, gear pairs made of structural steel and grey cast iron have been simulated to compare their performance.

Twin-disc measurements are quicker and cost effective to implement than real gear measurements. The twin-disc simulation give more local information which is essential for evaluation of gear failures. Gear pitting tests cannot provide all that local information. Modelling the gear mesh in a twin disc setup gives an opportunity to test materials at different velocities corresponding to different contact points along the line of action. Two cylinders equivalent to the radii of curvature [7] of the gear tooth and pinion are used for evaluating the stresses in the gear tooth, where the radius of each gear is given by

$$R = \frac{d \sin \varphi}{2} \qquad (i)$$

R= Equivalent radius of cylinder

d= Pitch circle diameter of the gear

φ= Pressure angle

2.1 THEORETICAL CALCULATIONS

For cylinders in contact the contact patch is rectangular whose half width (b) [8] is given by

$$b = \sqrt{\frac{2F(1-v_1{}^2)/E_1 + (1-v_2{}^2)/E_2}{\pi l(\frac{1}{d_1}+\frac{1}{d_2})}} \qquad (ii)$$

Where:

l=length of contact area

F = force pressing the two discs together

d_1 and d_2 = diameters of the two discs in contact

E_1, v_1, E_2, v_2 = respective elastic constants of the two discs

The maximum contact pressure is

$$p_{max} = \frac{2F}{\pi bl} \qquad (iii)$$

The values of principal stresses are obtained as follows:

$$\sigma_x = -2\, v\, p_{\max}(\sqrt{1+\frac{z^2}{b^2}} - \left|\frac{z}{b}\right|) \qquad (iv)$$

$$\sigma_y = -\, p_{\max}(\frac{1+2\frac{z^2}{b^2}}{\sqrt{1+\frac{z^2}{b^2}}} - 2\left|\frac{z}{b}\right|) \qquad (v)$$

$$\sigma_z = -\frac{p_{\max}}{\sqrt{1+\frac{z^2}{b^2}}} \qquad (vi)$$

$$\tau_{max} = \frac{\sigma_1 - \sigma_3}{2} \qquad (vii)$$

The various parameters of the gear and the pinion used for the geometrical modelling are as follows:

TABLE 1: Gear parameters

S. No.	Parameters	Pinion	Gear
1.	Module	2	2
2.	Pitch diameter (mm)	54	106
3.	Number of teeth	27	53
4.	Outer Diameter(mm)	58	110
5.	Face width (mm)	33	33
6.	Pressure angle (degrees)	20	20
7.	Contact Ratio	1.697	1.697

Automotive gears are being converted to grey cast iron for its damping capacity and cost reductions. To evaluate the performance of such gears, the following three combinations of twin-discs have been considered.

TABLE 2: Combinations of disc materials considered

Case Number	Pinion Material	Gear Material
Case 1	Structural Steel	Structural Steel
Case 2	Grey Cast Iron	Grey Cast Iron
Case 3	Structural Steel	Grey Cast Iron

3. FINITE ELEMENT ANALYSIS

Contact problems are highly nonlinear and require significant computer resources to solve. Thus, it becomes important to understand the physics of the problem. In Finite Element Analysis (FEA) contact problem can be described by two bodies that get in contact because of the action of an external force. One of these bodies is defined as a contact body, and the other as a target body. In the case of a flexible-to-flexible body contact, the FEA procedure is complex and it needs to be analyzed carefully to obtain desired results. The contact forces that appear when the bodies are in contact prevent mutual penetration of bodies, the result of which is deformations around the contact patch. For twin-disc setup the surface to surface contact is used for the FEA.

The Augmented Lagrange method is used as the formulation which is very similar to the penalty method. The augmented Lagrange method should produce less penetration than the pure penalty method, but it might take more iterations to converge. The program-controlled default formulation for contact between flexible bodies is augmented Lagrange. One important decision is to select an asymmetric or symmetric contact. The asymmetric contact is defined as having all contact elements on one surface and all target elements on the other surface. This is usually the most efficient way to model the surface-to-surface contact problem like in case of the twin-disc setup. The meshing has been improved by making use of the contact sizing to increase the number of elements.

The gear equivalent disc is fixed and the normal load is applied on the upper pinion equivalent disc after constraining it to move only in the vertical direction. The value of the normal force is 2760 N at 70 N-m pinion torque. The modeling has been performed on SolidWorks and the gears have been modeled as two cylinders of radii equal to R in contact at the pitch point.

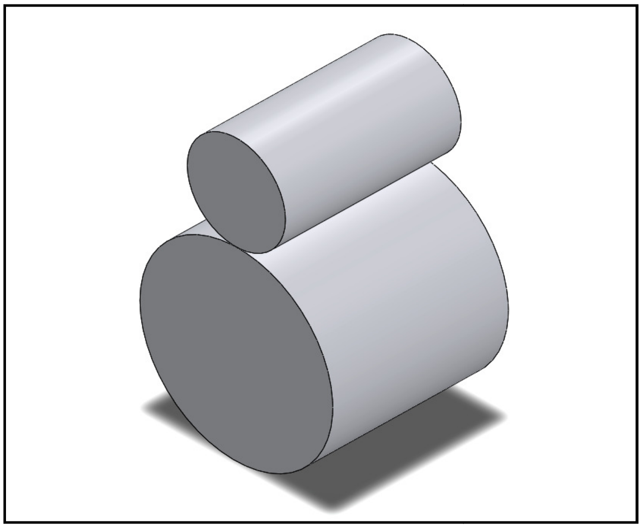

Fig. 1. SolidWorks model for the twin-disc in contact

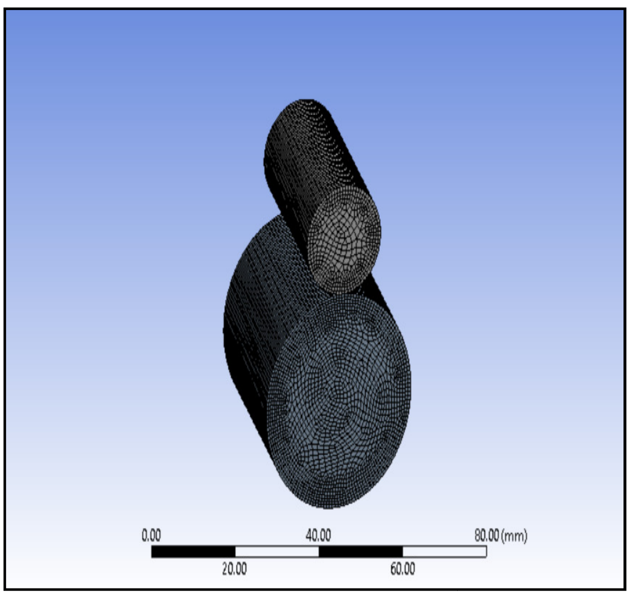

Fig. 2. Meshing of the twin-disc setup in ANSYS

4. RESULTS AND DISCUSSION

In the present study, the stress analysis is done on the smaller disc as it represents the pinion and is more prone to failure during operation. The stress distribution across the width is constant, as seen in Fig. 4, since the contact patch is uniform throughout the face width. Stress analysis has been done at the pitch point only.

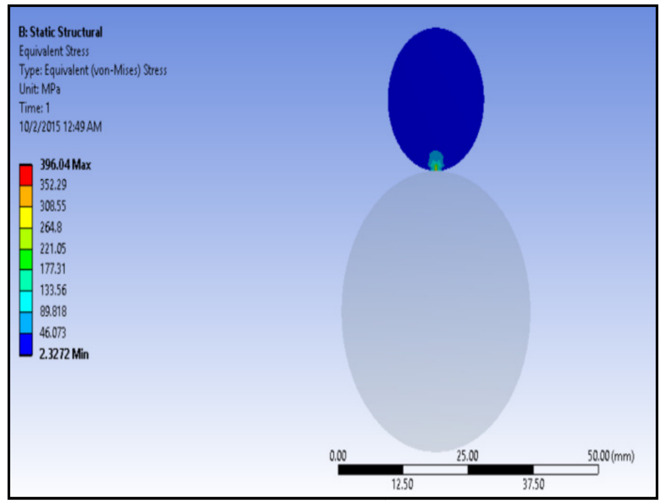

Fig. 3. Von-Mises Stress for Case 1

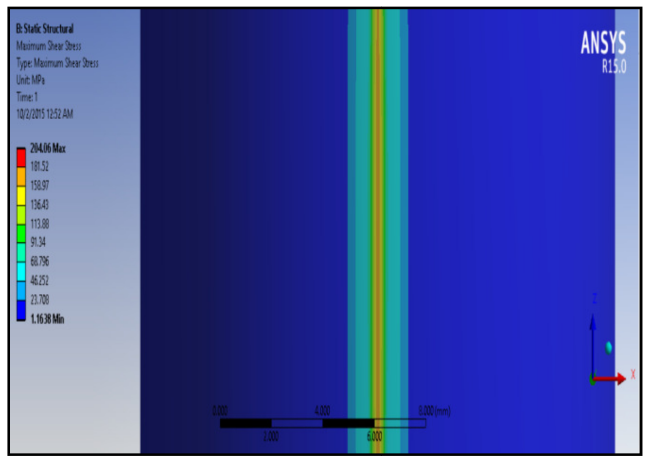

Fig. 4. Maximum shear stress for Case 1

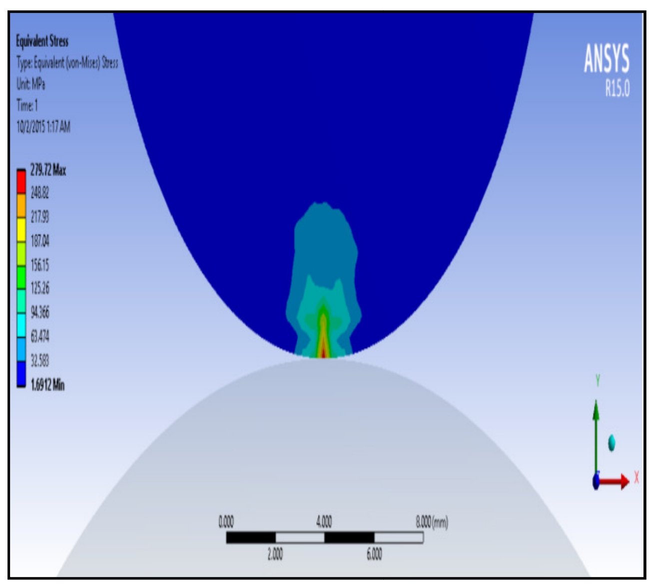

Fig. 5. Von-Mises Stress for Case 2

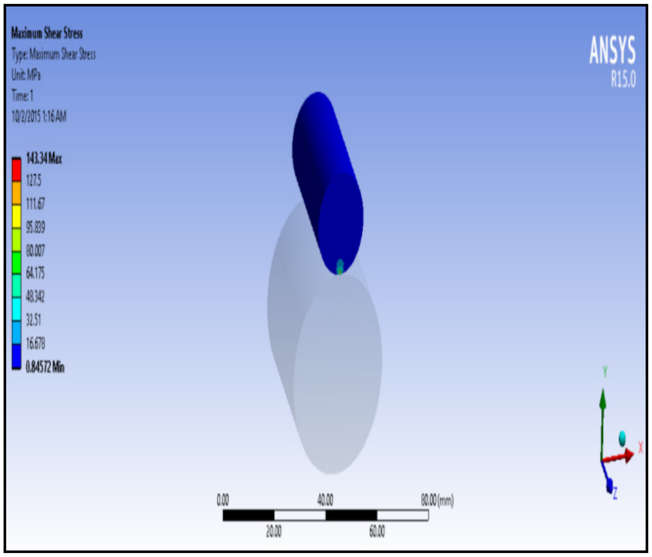

Fig. 6. Maximum shear stress for Case 2

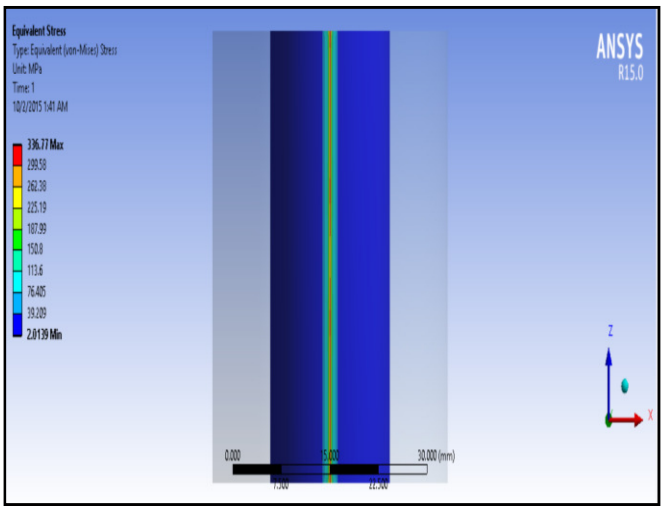

Fig. 7. Von-Mises Stress for Case 3

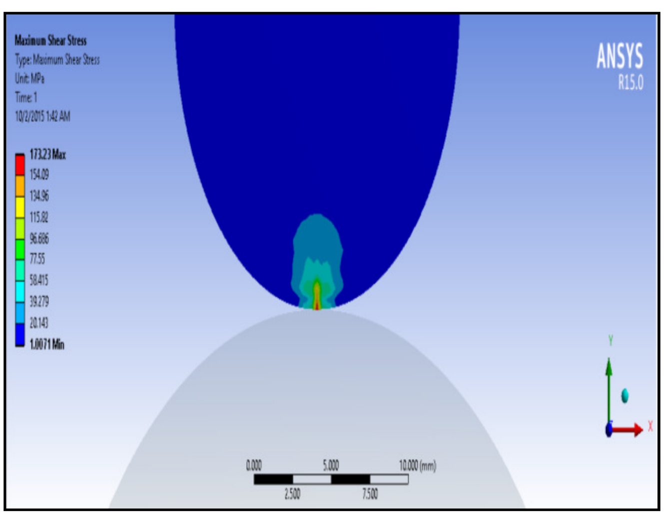

Fig. 8. Maximum shear stress for Case 3

TABLE 3: Comparison with ANSYS results

Case	von-Mises Stress (Theoretical)	von-Mises Stress (Analysis)	Percentage Error	Maximum Shear Stress (Theoretical)	Maximum Shear Stress (Analysis)	Percentage Error
1	385.8 MPa	396 MPa	2.64	207.7 MPa	204 MPa	-1.78
2	288.5 MPa	279.7 MPa	-3.08	153 MPa	143.3 MPa	-6.33
3	323.6 MPa	336.7 MPa	4.04	174.2 MPa	173.23 MPa	-0.55

The von-Mises stress for the Case 1 is 396 MPa with a percentage error of 2.6% compared to the theoretical values. In the second case, the von-Mises stress is 280 MPa with an error of -3% as compared to theoretical values. Thus, there is a reduction in the von-Mises stress by 30% when the disc material is changed from structural steel to grey cast iron. The value of maximum shear stress for Case 2 is less than that of Case 3 by nearly 35%. The stress value for Case 3 are higher than Case 2 but are significantly lower than Case 1, hence a gear combination defined by case 2 is a good choice due to lower stresses. Also, Grey Cast Iron has good damping characteristics and produces low noise during operation. The results found by Finite Element analysis are nearly equal to results obtained through theoretical calculations.

5. CONCLUSIONS

Based on the above research following conclusions can be drawn:

1. Twin-disc setup can be effectively used to evaluate the performance of different materials used for gear manufacturing with respect to tooth interior fatigue failure.

2. Gray cast iron is a better choice as a gear material owing to its less maximum shear stress and thus will perform better as far as tooth interior fatigue fracture crack initiation is concerned.

3. Overall, cast iron can be an economical solution for problems created by noise and vibration, especially in applications. The relative damping capacity of ductile iron is twice that of steel and thus is a good choice.

REFERENCES

[1] Sukumaran, J.; Ando, M.; De Baets, P.; Rodriguez, V.; Szabadi, L.; Kalacska, G.; Paepegem, V. Modelling gear contact with twin-disc setup, Tribology International, 2012, 49, 1–7

[2] Stanojevic, V.N.; Cvejic, I. The analysis of contact stress on meshed teeth's flanks along the path of

contact for a tooth pair. Facta Universitatis, Series: Mechanics, Automatic Control and Robotics 2003, 3, 1055–66.

[3] Hooke, C.J.; Kukureka, S.N.; Liao, P.; Rao, M. Chen YK. The friction and wear of polymers in non-conformal contacts. Wear. 1996, 200, 83–94.

[4] Ahlroos, T.; Ronkainen, H.; Helle, A.; Parikka, R.; Virta, J.; Varjus,S. Twin disc micropitting tests, Tribology International**,** 2009, 42, 10, 1460–1466.

[5] Kleemola, J.; Lehtovaara, A. Experimental simulation of gear contact along the line of action, Tribology International**,** 2009, 42 (10), 1453–1459.

[6] Mack Aldener, M.; Olsson, M. Analysis of crack propagation during tooth interior fatigue fracture, Engineering Fracture Mechanics**.** 2002, 69 (18), 2147–2162.

[7] Richard, G.; Budynas, J. Shigley, K. N. Mechanical Engineering Design, 6th edition, Tata McGraw Hill India, 2010.

[8] Norton, R.L.; Machine Design: An Integrated Approach, 5th Edition, Prentice Hall, 2013.