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Times Three Dimensional Spur Gear Static Contact Investigations Using Finite Element Method

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Abstract

A gear is a critical component and can be found in many industrial applications. This investigation develops a three dimensional finite element spur gear model to calculate the contact stress on the gear tooth surfaces. Contact stress is one of the main factors that is used to decide the gears tooth surface strength. In addition there are other important factors such as frictional forces and micro-pits that influence the gear tooth surface. Different analytical techniques have been used to calculate the contact stress of the gear surfaces namely; Hertzian theory and AGMA standards. The analytical results have been compared to the numerical analysis to verify the spur gear finite element model.

Keywords: contact stress, spur gear, AGMA, finite element analysis

1. Introduction

The Now days, there are various kinds of gears being manufactured and used in different types of applications. The central categories of gears are: spur, helical, bevel and worm gears. In the spur gears the axis of rotation will be parallel to the gear teeth, and used to transmit the rotation shaft to another (Darle 1994 & Giin 2001). All the types of gears based on the spur gear as it consider the simplest shape. The simulation of gears is one of the most challenging nonlinear problems in mechanical design, as it includes all sources of nonlinearity. A gear structural geometry is complex, and made up of different materials. During operation, it will experience high impact loads, resulting in high stresses. Once these stresses exceed the material yield load or the critical limit, the structural components undergo large progressive elastic-plastic deformation. The entire process occurs within very short time durations. Hertzian theory and AGMA standard currently are used in gear design for strength standard (M. Ristivojević et al., 2013 & Budynas, 2006). However the assumptions used to evaluate the gear surface strength using these methods is uniform load along a line contact between the teeth.

(Rama Thirumurugan & G. Muthuveerappan, 2010) formulate a finite element spur gear model to explore the influence of different gear parameters such as module, pitch circle, teeth number and pressure angle on the gear. They used MATLAB to create the involute surface using mathematical relations, and they used ANSYS to find the stress and deformation of the gear tooth. Shuting in 2008 used finite element analysis and mathematical calculation to examine the consequence of changing the addendum on the basic performance of a spur gear tooth. (Bahattin 2007) proposed another finite element analysis on a spur gear to come across the stress and deflection on the mid line of the gear tooth. In 2013 Seok-Chul enlighten more investigation on the contact analysis for a spur and helical gear tooth. They used AGMA 2101-C95 standard to compare the contact stress with their finite element results. Miryam B. Sánchez et al. (2013), provide an advanced study on a non-standard spur and helical gears with load distribution along the tooth contact. The purpose was to determine of the critical tooth root stress and the load capacity of the tooth [9]. Using the same conditions in another effort, they calculated the contact stress of the non-standard spur and helical gears. The model was single tooth contact (Alqrimli et al., 2015, Olle 2007, Olle & Anders, 2007). In this investigation three dimensional finite element analyses have been carried out on a spur gear. The analysis is static and the achieved contact stress results compared with Hertzian theory and

AGMA standards. The load distribution along the gear tooth surface was a line contact.

2. Analytical Analysis

The Contact mechanics theories are created to observe the deformation of mechanisms that are in contact. The fundamental thought of these theories is to calculate the stress, pressures and adhesion of two connected surfaces, and find the stress between the surfaces. These theories will be discussed with more details in this section.

2.1 Hertzian Theory

Include The Hertz contact stress theory derivate his method based on elastic contact of two cylinders. This equivalence can be functional to a surface contact between a gear tooth and pinion. For the reason that the outline of spur gear tooth is characterized through an involute curve and the radius of the involute cylinder in each tooth is the same. Calculating the value of the contact stress is extremely important, when a prediction of surface failure on a gear tooth is required. As pitting is a common surface failure in gears tooth and it occurs due to the high contact stresses on the gear surface when the gear is operating. The maximum surface stress or pressure on the surface equation is:

$$p_{c\max} = \frac{2\times F}{\pi\times B\times L} \tag{1}$$

Where:

$$B = \sqrt{\frac{2\times F}{\pi\times l}\times\frac{\frac{1-\nu_1^{\ 2}}{E_1}+\frac{1-\nu_2^{\ 2}}{E_2}}{(\frac{1}{D_1}+\frac{1}{D_2})\frac{1}{\sin\alpha}}} \tag{2}$$

The Hertz equations discussed can be developed to calculate the contact stresses of spur gear tooth surfaces. Substitute variables in Equation (2) and Equation (3) in Equation (1), the maximum surface contact stress at the involute spur gear tooth surface will be established in Equation 4:

$$F = \frac{F_t}{\cos\alpha}, \quad L = b, \quad D_1 = D_p\times\sin\alpha \tag{3}$$

Where: F is the applied force, and are Poison's ratio, D1, D2 diameters and E1, E2 modules of elasticity. By assuming the value of =0.3 for steel. From Equation 4, the contact stress on the pitch point for a spur gear tooth can be found.

$$p_{c\max} = \frac{2\times F_t/\cos\alpha}{\pi\times B\times F} \tag{4}$$

And Equation (2) will be:

$$B = \sqrt{\frac{2\times F_t}{\pi\times F\times\cos\alpha}\times\frac{\frac{1-\nu_1^{\ 2}}{E_1}+\frac{1-\nu_2^{\ 2}}{E_2}}{(\frac{1}{D_1}+\frac{1}{D_2})\frac{1}{\sin\alpha}}} \tag{5}$$

2.2 AGMA Standard

The American standard association derived equations to determine the allowable contact stresses on a gear surface. ANSI-AGMA_2001-D04, Design Manual for spur gear teeth has published a design standard that illustrates all aspects of spur gear tooth design, starting from preliminary design standards and moving towards to complete the design and to be ready for analysis. The AGMA equation used to calculate the compressive stress in spur gear tooth is given by (Darle 1994 & Giin 2001):

$$\sigma_c = C_p\sqrt{W_t K_o K_v K_s \frac{K_m}{d_p F}\frac{C_f}{I}} \tag{6}$$

Where C_p is the elastic coefficient, W_t is the tangential tooth load, $K_\circ$ is the overload factor, K_v is the speed factor, K_s size factor, F is gear face width, d_p pitch diameter, K_m load distribution factor, and I is the geometry factor. C_f is the surface condition factor has not been evaluated and it's always equal to 1. The elastic coefficient can be calculated by using the equation below:

$$C_p = \left[\frac{1}{\pi(\frac{(1-v_g{}^2)}{E_g} + \frac{(1-v_p^2)}{E_p})} \right]^{\frac{1}{2}} \tag{7}$$

Where E and stands for the Young's modulus and Poisson's ratio of the material correspondingly. The values of the factors that have been used in this investigation are shown in Table 1.

Table 1. Values used in for the current spur gear

No	Name	Value
1	Elastic coefficient C_p	187 (MPa)
2	surface condition factor C_f	1
3	Overload factor $K_\circ$	1
4	Geometry factor for pitting resistance I	0.115
5	Dynamic factor K_v	1
6	Load distribution factor K_m	1
7	Face width F	120 (mm)
8	Size factor K_s	1
9	Pitch diameter (mm) d_p	88
10	Tangential tooth load W_t	9032 (N)

3. Numerical Analysis

In the preprocessing phase the spur gear 3D model has been defined of the physical problem and creates an ABAQUS input file. The model is usually created graphically by using ABAQUS/CAE or directly using a text editor, but in this study a 3D model was created in special CAD software (SolidWorks) then imported it to create ABAQUS input file for analysis. Table 2 displays the standard geometry of the spur gear tooth sector. The section is arranged in such a way to provide the reader with information and knowledge of the entire steps on creating three dimensional finite element spur gear model using ABAQUS.

Table 2. Spur Gear Geometry Data

NO.	Geometry Data	Value
1.	Pressure angle	20°
2.	Module	8
3.	Face width (mm)	120
4.	Pitch diameter (mm)	173
8.	Number of teeth	24

In this study the gear tooth have a curve surface and choosing elements that have edges adapt more intimately to curved surfaces comparing to linear elements. Quadratic elements have been used as its batter appropriate for solid modeling and most regular used elements for gear analysis. On the other hand, choosing quadratic elements will increase the computational time. Salinas steel 316L has been chosen as the material for the spur gear as it is one of the mainly and commercially use steel in the industrial purposes. The material properties of steel are shown in Table 3. After defining the mechanical properties of the material in the FE model, a solid homogenous section for each one of the gears and the parts used in the simulation were assigned and created.

Table 3. Spur Gear Material properties

Material Type	Steeliness steel
Density ρ (g/cm^3)	7.8
Young's Modulus E (MPa)	200000
Poisson Ratio ν	0.3
Tensile strength (MPa)	620

3.1 Boundary Conditions

For this research, ABAQUS standard has been selected to operate static method on the spur gear model. Torque was the only input load applied in the boundary condition. One pair of the gear is fully restricted in all degree of freedom, while the other gear has one rotational direction. Figure 1 shows the boundary conditions applied on the spur gear in ABAQUS static analysis. The magnitude of the applied torque is (1987 *N.m*), which is used in the present work.

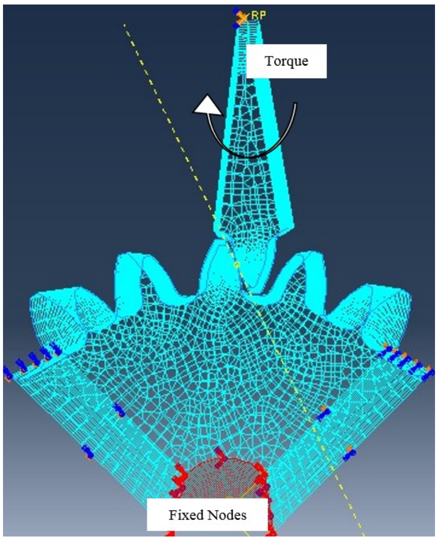

Figure 1. Spur Gear Boundary Conditions

3.2 Interaction Property

Considering the interaction property is significant in defining the interfacing surfaces between the contact teeth. The master surface and the slave surface of the gear have to be picked in order to complete the interaction properties. Until now there are various issues related to interaction flanked by two or more mechanism. The major motive of simulating the contact between gears is to spot the surface areas that are in contact and to analyze and determine the contact stress generated. According to ABAQUS manual diverse contact selections can be used in the simulation. Consequently, it is essential that the connected areas can be detected in the software. At any rate to do an accurate simulation, surfaces that will be in contact supposed to be formed. After creating the contact surfaces, the next step will be creating Surface to surface interaction between the gear teeth. The interaction property will simply be propagated to the other steps of the analysis, once it's completely defined.

4. Results and Data Validation

From the result in Figure 2 and Figure 3, the stress value at the tooth pitch circle and the contact segment showed higher results than the other spots after applying the torque. For that reason the gear tooth will have surface failure, and then micro pitting will start as well as pitting. The simulation showed a reliable distribution out comes comparing to actual situations which is a line contact. The analysis proven to have accurate values of the stress and Hertzian stress as shown in Table 4 and the values is less than the yield strength of the material used to make the model. By applying Equation 4 and Equation 6, the Hertzian contact stress and AGMA standers will be found. Table 4 demonstrates a comparison between the finite element model and the theory calculations. Table 5 gives an idea about the percentage of error between the finite element model and the other approaches.

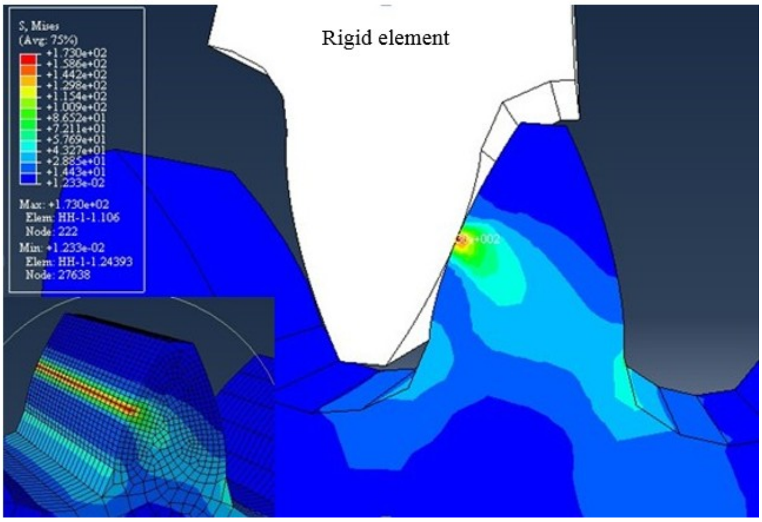

Figure 2. Shows the stress distribution along the spur gear tooth model

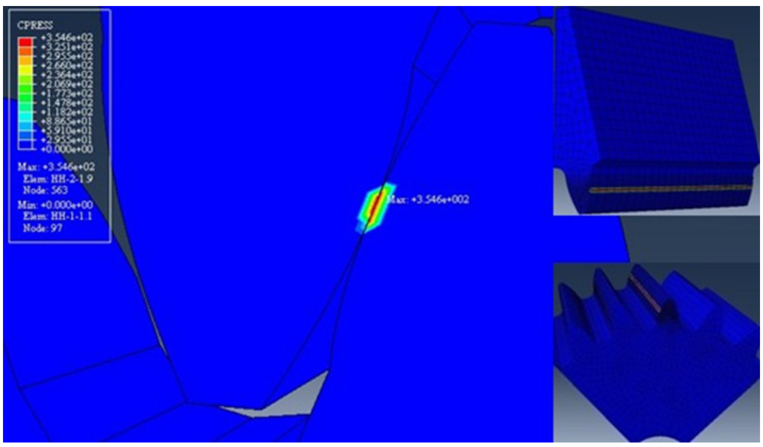

Figure 3. Shows the contact stress along the spur gear tooth model

The theory calculation used in this research to provide accurate results for the spur gear under practical load conditions. From the theory results, it can be seen that it match with the results of the finite element model. Based on the percentage of error in Table 5, it can be concluded that the FE model is correct.

Table 5. Percentage of Error in FEA model comparing to theoretical equations

Percentage of Error (%)	
FEA vs. Hertz	FEA vs. AGMA
12.71 %	1.66 %

5. Conclusion

A spur gear have been modeled and analyzed using finite elements method and simulated by ABAQUS under static conditions. A comparison between the finite element results and analytical equation (Hertz theory and AGMA Standard) has been done, to validate the spur gear model. After submitting the spur model for analysis, the report showed that the highest stress appears on the pitch circle of the gear tooth and the maximum value is 1.730 x 102 MPa. The stress distribution and the maximum value can be observed from Figure 2.

Acknowledgments Conclusion

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