Analysis of a gear train using finite element modelling

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Abstract

Here the theoretical maximum contact stress is calculated by Hertz equation. Also the finite element analysis of spur gear is done to determine the maximum contact stress by ANSYS 14.5. It was found that the results from both Hertz equation and Finite Element Analysis are comparable. From the deformation pattern of steel and grey cast iron, it could be concluded that difference between the maximum values of steel and grey CI gear deformation is very less. The simulation results have good agreement with the theoretical results, which implies that the model is correct. This study provides a sound foundation for future studies on contact stresses. The model is applied onto commercial FEA software ANSYS. Simulation results were compared and confirmed by the theoretical calculation data. According to these results, we can draw the conclusion; it was found out that the numerically obtained values of stress distributions were in good agreement with the theoretical results.

Keywords
Gear train, ansys, finite element analysis, simulation, modelling

1.0: INTRODUCTION
Gearing is a standout amongst the most discriminating segments in a mechanical force transmission framework, and in most modern rotating machinery. It is conceivable that gears will prevail as the best method for transmitting power in future machines because of their high level of reliability and compactness. Also, the quick move in the industry from overwhelming commercial enterprises, for example, shipbuilding to businesses, for example, automobile assembling and office mechanization instruments will require a refined application of gear technology. A gear train is framed by mounting gears so that gears engage. Gear teeth are designed to guarantee the pitch circles of connecting gears move on one another without slipping, this gives a smooth transmission of revolution from one gear to the next.

Some important features of gears ad gear trains are:

- The proportion of the pitch circles of mating gears characterizes the velocity ratio and the mechanical advantage of preference of the gear set
- A planetary gear train gives high gear rigging decrease in a compact package
- It is conceivable to design gear teeth for apparatuses that are noncircular, yet still transmit torque easily
- The speed ratio of chain and belt drives are registered in the same route as gear ratios

A portal axle is a rough terrain technology where the hub tube is over the focal point of the wheel center. It is a gear train framed by mounting gears on a frame so that the teeth of the gears engage... Figure 1 shows the comparison between the normal and the portal axle.

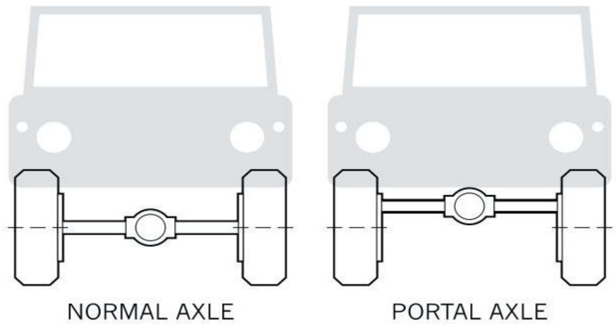


Figure 1: Comparison between a normal and a portal axle.

Compared to normal layout, portal axles enable the vehicle to gain a higher ground clearance, as both the axle tube and differential casing are tucked up higher under the vehicle. Due to the gear reduction at the wheel which lessens the torque on all the other drive train components, the size of the differential casing can be reduced to gain even more ground clearance. Additionally, all drive train elements, in particular the transfer gearbox and drive shafts, can be built lighter. This can be of use in lowering the center of gravity for a given ground clearance. As it requires a heavier and more complex hub assembly, however these systems can result in an increased unsprang weight and require robust axle-control elements to give predictable handling. In addition, at higher speeds the hub assembly can overheat.

1.1 BACKGROUND

The increasing demand for quiet power transmission in machines, vehicles, elevators and generators, has created a growing demand for a more precise analysis of the characteristics of gear systems (Umezawa, 1988). In the automobile industry, the largest manufacturer of gears, higher reliability and lighter weight gears are necessary as lighter automobiles continue to be in demand. In addition, the success in engine noise reduction promotes the production of quieter gear pairs for further noise reduction. Noise reduction in gear pairs is especially critical in the rapidly growing field of office-automation equipment as the office environment is adversely affected by noise, and machines are playing an ever widening role in that environment. Ultimately, the only effective way to achieve gear noise reduction is to reduce the vibration associated with them. The reduction of noise through vibration control can only be achieved through research efforts by specialists in the field. The source of vibration and noise in a gear train is the transmission error between meshing gears. It has been perceived as a principle for mesh frequency energized noise and vibration. If the pinion and gear have ideal involute profiles running with no loading torque they should theoretically run with zero transmission error. Nonetheless, when these same gears transmit torque, the consolidated torsional mesh stiffness of every gear changes all through the mesh cycle as the teeth redirect, bringing on variations in angular rotation of the gear body. Despite the fact that the transmission error is moderately little, these slight varieties can bring about noise at a recurrence which coordinates a resonance of the shafts or the gear housing, bringing on the noise to be upgraded.

The finite element method is frequently used to analyse the stress state of an elastic body with convoluted geometry, for example, a gearing. In this research, initially, the finite element models and arrangement systems required for the exact computation of two dimensional spur gear contact stresses and gear bending stresses were resolved. At that point, the contact and bending stresses calculated new FEM were compared to the results obtained from existing methods. The goal of this research is to develop a model to study and predict the transmission error model including the contact stresses, and the torsional mesh stiffness of gears in mesh using the SOLIDWORKS and ANSYS software packages based on numerical method. The aim is to reduce the transmission error in the gears, and thereby reducing the amount of noise generated.

1.2 PROBLEM STATEMENT

Gear noise and vibration due to transmission error are the greatest challenges in power transmission applications and is more significant in applications with higher operating speeds.

1.3 AIM

To perform a static and thermal analysis of a gear train using finite element analysis.

1.4 OBJECTIVES

- To develop and to determine appropriate models of contact elements, to calculate contact stresses using SOLID WORKS and ANSYS.
- To generate the profile of gear teeth and to predict the effect of gear bending using a three dimensional model and two dimensional model.
- To determine the static and thermal transmission errors of whole gear bodies in mesh.

1.5 SCOPE

This paper will only be limited to the portal axle as the gear train to be analysed. The scope will extend to cover both the static and thermal analysis of the portal axle.

2.0: LITERATURE REVIEW

There has been a great of research on gear analysis, and a large body of literature on gear modelling has been published. The gear stress analysis, the transmission errors, and the prediction of gear dynamic loads, gear noise, and the optimal design for gear sets are always major concerns in gear design. Errichello (1979) and Ozguven and Houser (1988) surveyed literature on the development of a variety of simulation models for both static and dynamic analysis of different types of gears. The first study of transmission error was done by Harris (1958). He showed that the performance of spur gears at low speeds can be summarized in a set of static transmission error curves. In later years, Mark (1978) analysed the vibratory excitation of gear systems theoretically. He derived an expression for static transmission error and used it to predict the various components of the static transmission error spectrum from a set of measurements made on a mating pair of spur gears.

2.1 GEAR BENDING STRESS ANALYSIS

In the middle of the 20th century, most gear designs were based upon Lewis original bending equation (Lewis, 1893; Dolan and Broghamer, 1942). Lewis (1893) based his analysis on a cantilever beam and assumed that failure will occur at the weakest point of this beam.

However, failure due to flexural stresses on bodies with changing or asymmetrical cross-sections was proved inaccurate by Dolan and Broghamer (1942). Their approach used photoelastic experiments to visualize the stress concentrations due to the fillets at the base of spur gears. By these visualization techniques they were able to predict more accurately at what stress levels gears will fail due to high bending stresses. Much earlier work was done using photoelastic experiments to design spur gears based on the stresses observed at the most critical points (Black 1936). The use of photoelastic experiment is rare due to the high cost of the equipment and it requires experience and skills to determine the gear stresses. Although this method is useful in determining static stresses in spur gears, the photoelastic trend has become more popular toward its usage in gear dynamic analysis (Shimamura and Noguchi 1965).

On the other hand, the bending stress for a standardized gear design can be estimated from numerous gear standards such as the AGMA standards and the ISO standards for gear. The AGMA standards were established in 1982 and are still widely used in gear design today. The bending stress equations found in these standards are based on the Lewis's original equation with several gear factors (Arikan 2002). The gear geometry factors found in the equations are critical in determining accurately the bending stresses for a wide variety of gears (Chong et al., 2002). These geometry factors accounted for the changing shape of the gear tooth, the point where the load is applied, as well as the fillet radius at the tip and base of the tooth. In general, the AGMA standard is only valid for standard gear design in which the gear must have 20º of pressure angle and the gear tooth profile must be symmetrical (Kawalec et al., 2006). Thus, these gear standards are not suitable for calculating the gear stresses for gear design with customized parameters.

The current trend of gear design is focused in designing different shaped gears to transmit higher loads without failure. The purpose of investigating the effect of the shaped gears is to precisely engineer these gears so that the maximum efficiency can be achieved and overdesign or under design of the gear can be avoided. By changing the shape of the gear tooth to an asymmetrical design the authors have proven a decrease in both bending stress and contact pressure (Cavdar et al. 2005). In the past, most 3D gear models developed was often a simplified model with many assumptions considered and some models are limited to analyzing the bending stress for a single involute spur gear. When the gears are operating, the gear teeth are often meshed with one or more gear teeth depending on the gear contact ratio (Wang and Howard 2005). The analysis of single gear tooth does not provide a full understanding of the actual gear meshing mechanism. Instead, a full gear bodies should be developed for a more comprehensive understanding of the gear stress analysis.

2.1.1 Lewis equation

Bending stress evaluation in modern gear design is generally based on the Lewis equation. This equation, applied with the stress concentration factor K_f, defines the bending stress geometry factor J for traditionally designed standard or close-to standard gears (Kapalevich and Shekhtman (2002). For determination of bending stress at gear root, Equations (1), (2) and (3) were used. In Equation (1) the gear root were investigated as a cantilevered beam (Budynas and Nisbett (2008).

$$\sigma = \frac{W^t P}{FY} \quad \text{………………..........} \; \textbf{(1)}$$

$$Y = \frac{2XP}{3} \quad \text{……………………….} \; \textbf{(2)}$$

$$l = \frac{t^2}{4X} \quad \text{……….……………….} \; \textbf{(3)}$$

Where: σ is bending stress, Mpa; *Wt* is tangential force, N; *P* is diametrical pitch, 1/mm; *F* is face width, mm; *Y* is Lewis form factor, dimensionless; *l* is tooth height, mm; *X;* t is thickness of tooth, mm.

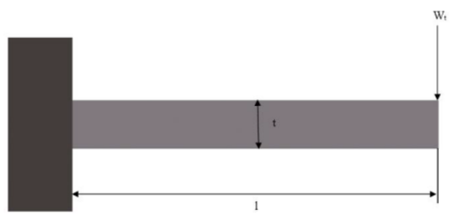


Figure 2: Loads and length dimensions used in cantilevered beam by Lewis

Hence, considering worst load condition in this work, the Y Lewis factor for a planet gear with 12 teeth, full depth profile, and 25 degree pressure angle is 0.245. Figure 3 shows the tooth gear with applied load approximately near to the pitch diameter of the tooth surface and their dimensions used in determining bending tooth stress.

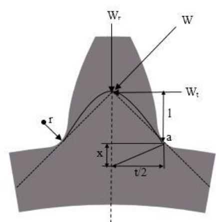


Figure 3: Loads and length dimensions used in determining tooth bending stress

3.0: Methodology

This briefly outlines the research techniques employed in carrying out the research of this project. The researcher used SOLIDWORKS and ANSYS soft wares to analyse the gear train in a portal axle. The chapter includes the modelling, simulation and all steps that were followed to achieve the objective of this study.

3.1 Analytical process

The major stages followed in analysing the gear train from problem identification to implementation is shown in the schematic diagram, Fig 4 below.

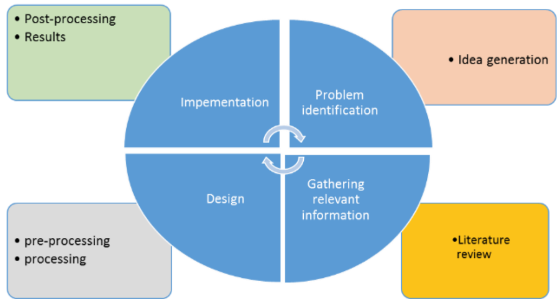


Figure 4: Analytic process

In this study, maximum contact stress is determined, during the transmission of torque of 15000 lb-in or 1694.7725 Nm (Huei-Huang Lee 2012) by steel and grey cast iron spur gears, using finite element analysis. The spur gear is sketched and modelled in the ANSYS Design Modeler. The dimensions of the gears are given in Table 1.

Table 1: Dimensions of Spur Gear

Dimension	Unit	Symbol	Value (For both gears in assembly)
Number of Teeth	-	Z	20
Pitch Circle Diameter	Mm	D	127
Pressure Angle	0	ϕ	20
Addendum Radius	Mm	R_A	69.85
Dedendum Radius	Mm	R_D	55.88
Face Width	Mm	B	25.4
Shaft Radius	Mm	R_s	31.75

4.0: RESULTS AND ANALYSIS

This presents the results that were got from the simulation done through SOLIDWORKS and ANSYS softwares. The types of analysis done is the static analysis and the thermal analysis.

4.1 STATIC ANALYSIS RESULTS

4.1.1 Assumptions

- Analysis is specifically for a 90 degree spur gear.
- Force is uniformly distributed at the end of the tooth. (serving as a maxima)
- Neglect surface wear and fatigue life.
- Neglect cyclic and impact effects from applied loading.
- Load application only on one tooth at any given time. (minimum req. for continuous contact, serving as a maxima).

Total Nodes	17245
Total Elements	10378
Maximum Aspect Ratio	6.1141
% of elements with Aspect Ratio < 3	94.7
% of elements with Aspect Ratio > 10	0
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:17
Computer name:	

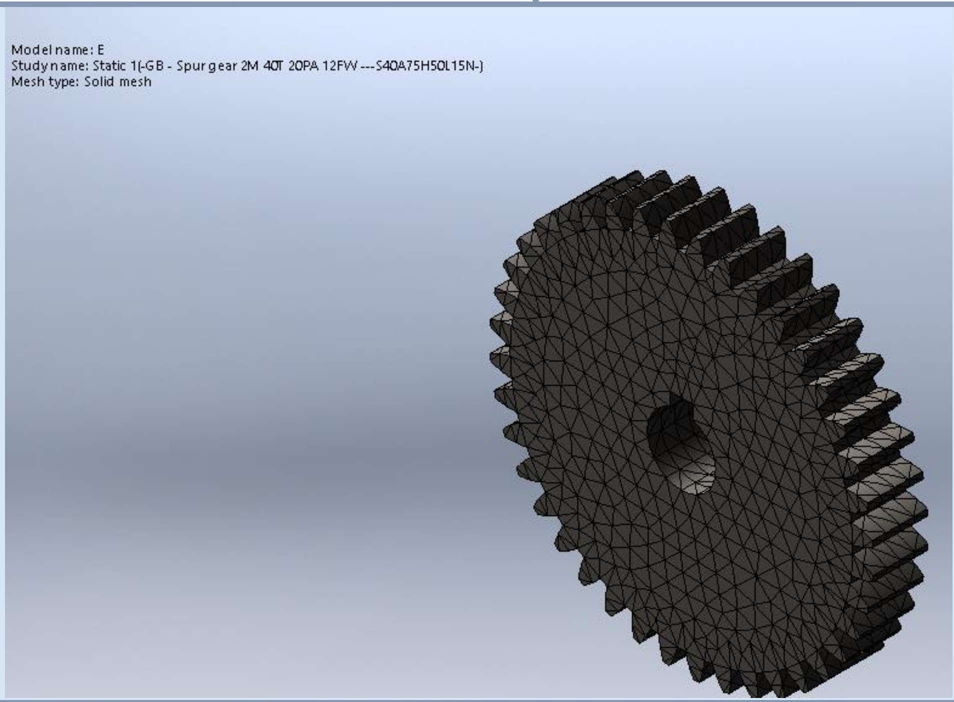


Figure 5: Gear mesh using Ansys

The following resultant forces were obtained as in table below

Table 2: Reaction forces

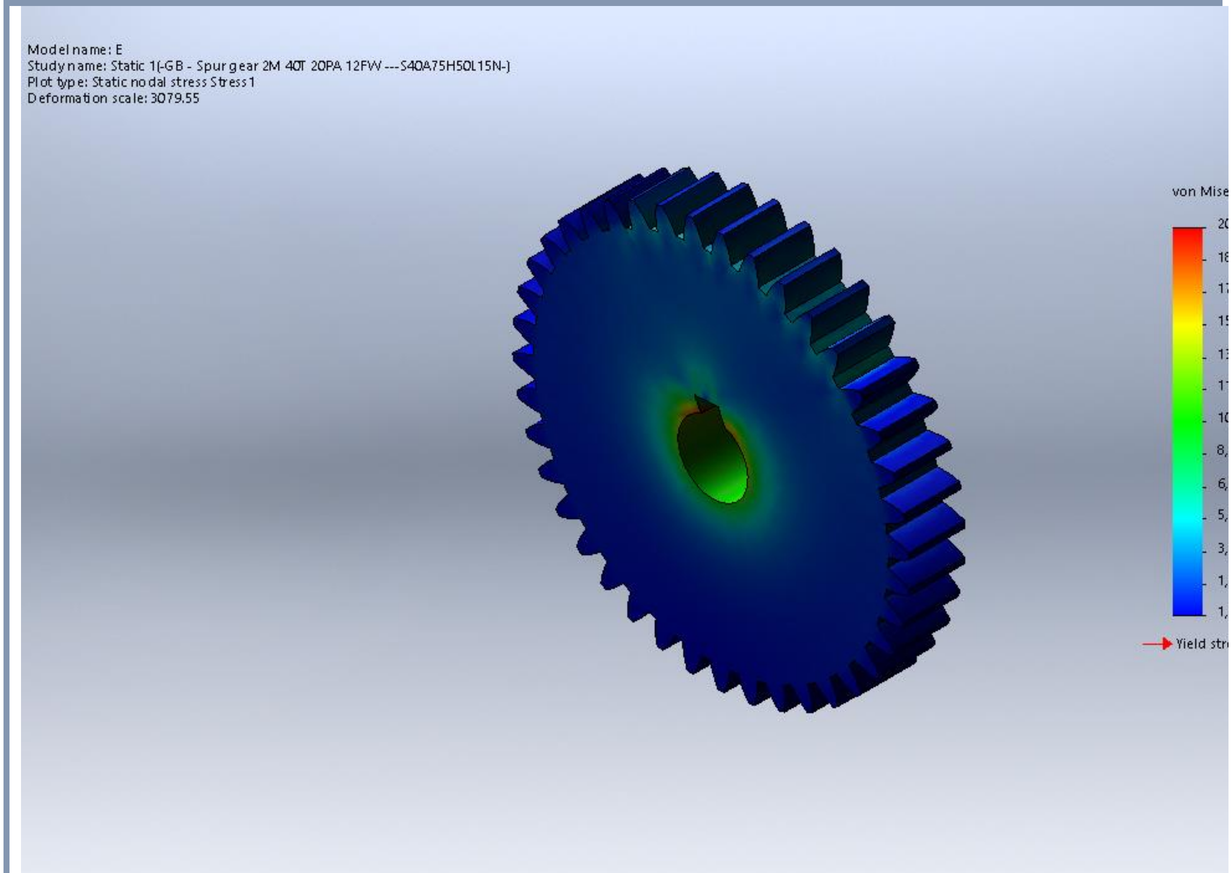
4.3.1 Reaction Forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-0.0201788	-7.20868	-746.089	746.124

4.3.5 Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

Name	Type	Min	Max
Stress1	VON: von Mises Stress	1280.25 N/m^2 Node: 684	2.04705e+007 N/m^2 Node: 1



E-Static 1-Stress-Stress1

Figure 6: Von Mises stresses obtained in gears

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 1	0.00274522 mm Node: 10338

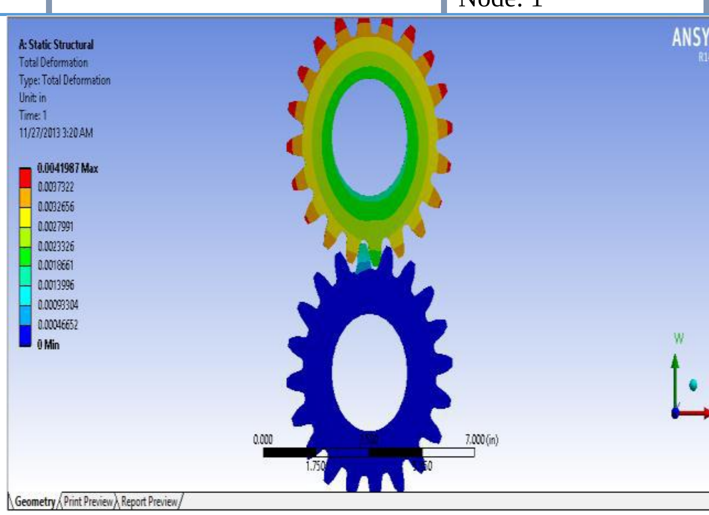


Figure 7: Deformation pattern of steel gear

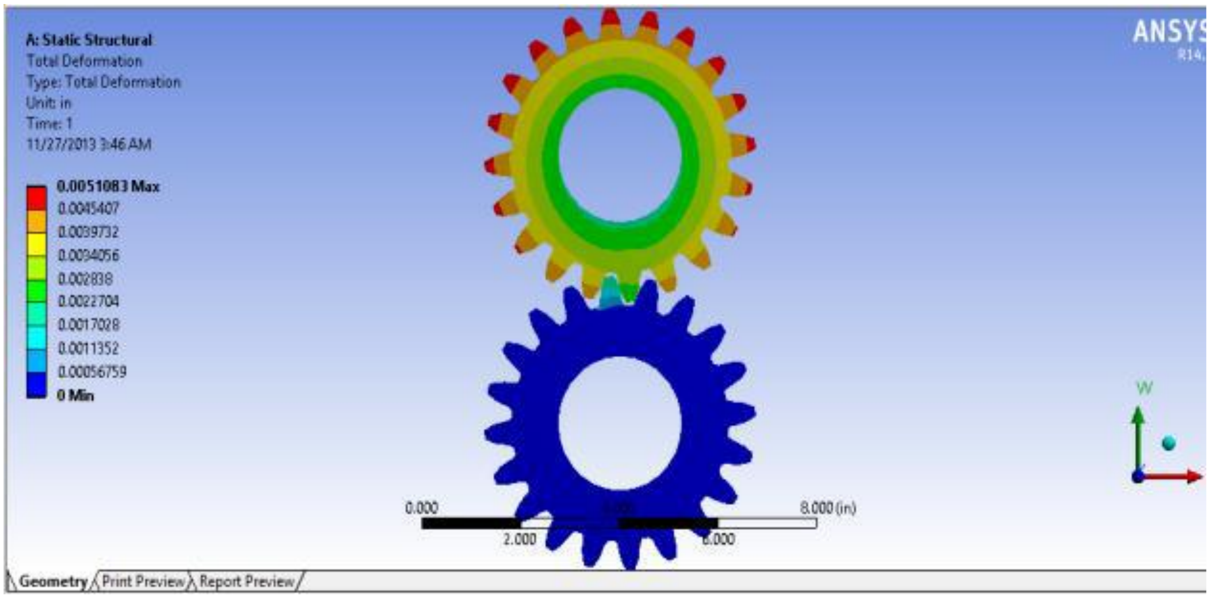


Figure 8: Deformation pattern of grey cast iron gear

5.0: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

The comparison of maximum contact stresses, for both steel and grey cast iron, obtained from Hertz equation and ANSYS 14.5 is given in Table below.

Table 3: Comparison of maximum contact stress obtained from Hertz equation and ANSYS 14.5

Gear	Stress through Hertzian formula (MPa)	Stress through ANSYS (MPa)	Difference (%)
Steel	2254.9821	2261.2052	0.28
Grey cast iron	2334.6414	2365.1782	1.29

The parametric model is capable of creating spur gears with different modules and number of teeth by modifying the parameters and regenerating the model. Sets of gears having the same module and pressure angle can be created and assembled together. It is possible to carry out finite element analysis such as root bending stress and contact stresses between gear teeth pair and effect of root fillet radius on the root stresses. In this paper, a 3D deformable-body (model) of spur gears is developed. The result is checked with theoretical calculation data. The simulation results have good agreement with the theoretical results, which implies that the deformable-body (model) is correct. This study provides a sound foundation for future studies on contact stresses. The model is applied onto commercial FEA software ANSYS. Simulation results were compared and confirmed by the theoretical calculation data. According to these results, we can draw the conclusion; it was found out that the numerically obtained values of stress distributions were in good agreement with the theoretical results.

Mesh stiffness variation as the number of teeth in contact changes is a primary cause of excitation of gear vibration and noise. This excitation exists even when the gears are perfectly machined and assembled. It is then vital to choose the best material for gears in an application. For the portal axle, we recommend steel.

5.2 Recommendations

After a comprehensive study in the area of finite element analysis of a gear train, the researchers recommend the following:

- A dynamic analysis using Software to find out how the gears operate when opposed with dynamic forces.
- The transmission error for all types of gears for example: helical, spiral bevel and other gear tooth form,
- Three-dimensionally meshed simulations for both spur and helical gears,

- Simulation of an oil film in contact zone.

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Biography

Tawanda Mushiri received the B.Sc. (Hons) in Mechanical Engineering and M.Sc. Manufacturing Systems and Operations Management degrees from University of Zimbabwe in 2008 and 2012, respectively. During 2008 – 2010, he went on to do a Graduate Trainee Learner ship from Oil Company under the Ministry of Energy and Power Development in Zimbabwe. He also worked as a Graduate Teaching Assistant at Chinhoyi University of Technology from 2011 to early 2013 teaching machine intelligence and advanced control and robotics. He is now a lecturer at the

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Charles Mbohwa's research activities and interests are in logistics, supply chain management, life cycle assessment and sustainability, operations management, project management and engineering/manufacturing systems management. His current Google Scholar h-index is 6 and Scopus h-index is 5. Currently is the Vice Dean of Research at University of Johannesburg and a full professor.