FACTOR ANALYSIS ON SPUR GEAR FAILURE USING COMPUTATIONAL SIMULATION

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FACULTY OF ENGINEERING
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RESEARCH REPORT SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF MECHANICAL ENGINEERING

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ABSTRACT

Spur gears are purported to be the most well-known and simplest gear as compared to other type of gears. Spur gears are also said to be regularly used in series to avoid from using massive size gear. The utilisation of spur gears is basically to shift movement from one shaft (tube) to another shaft that are similar or parallel. Due to deemed as the simplest gears of all gears, spur gears hence are widely applied in most of daily utilised devices and machine such as clocks, washing machines, blenders, kitchen mixers and even music equipment i.e. musical box. To ensure that the musical box can operate and emit a melodious and soothing sound, spur gears are one of the main components in it. Nevertheless, the musical box is criticised to be easily damaged, and the damage is often caused by the destruction of the spur gears encompass the device. In lieu of that, this study will involve the study of spur gears in the musical box that is intended to fill the literature gap. It is hoped that the findings and results from this study can contribute new knowledge in the field of mechanical, specifically on the mechanism of the spur gear. Apart from that, it is also hoped that the result from this study will be able to draw the baseline information on the effect of stress on spur gears towards the performance of the musical box.

***Keywords*:** Gears; Musical Box; Spur Gears; Stress.

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ABSTRAK

"Spur gears" dikenali sebagai gear yang paling terkenal dan paling ringkas ika dibandingkan dengan jenis-jenis gear yang lain. Selain itu, *"Spur gears"* juga seringkali dilaporkan untuk kegunaan secara bersiri untuk menghindari penggunaan gear yang ukuran besar. Penggunaan *"spur gears"* pada dasarnya adalah untuk mengalihkan pergerakan dari satu tiub *("shaft")* ke satu tiub yang lain yang serupa atau selari. Oleh kerana *"spur gears"* dianggap sebagai roda gigi yang paling ringkas ika dibandingkan dengan gear-gear yang lain, *"spur gears"* telah digunakan secara meluas di kebanyakan alat dan mesin yang digunakan setiap hari seperti jam, mesin basuh, pengisar, pengadun dapur dan juga peralatan muzik seperti kotak muzik. Untuk memastikan kotak muzik dapat beroperasi dan mengeluarkan alunan muzik yang merdu dan menenangkan, *"spur gears"* adalah salah satu komponen utama di dalamnya. Walaupun begitu, kotak muzik telah dikritik kerana mudah mengalami kerosakkan, dan kerosakan yang dilaporkan seringkali disebabkan oleh kerosakkan "spur gears" di dalam kotak muzik tersebut. Oleh yang demikian, kajian ini telah dilakukan dengan melibatkan kajian "spur gears" yang terkandung di dalam kotak muzik bagi tujuan mengisi jurang literatur. Hasil kajian dan penemuan daripada kajian ini diharapkan dapat menyumbang kepada pengetahuan baru dalam bidang mekanikal, khususnya mengenai mekanisme "spur gears". Selain itu, diharapkan juga hasil kajian ini dapat memnyumbang maklumat asas mengenai pengaruh tekanan yang secara spesifiknya berkaitan dengan "spur gears" di dalam kotak muzik.

Kata kunci: "*Gears"; "Musical Box"; "Spur Gears"; "Stress".*

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LIST OF SYMBOLS AND ABBREVIATIONS

3D	:	Three Dimensional
ANSYS	:	Analysis System
FEA	:	Finite Element Analysis
mm	:	millimetre
MPa	:	Mega Pascal
kg/m^3	:	Kilogram per meter cube
ABS	:	Acrylonitrile Butadiene Styrene
Nm	:	Newton Metre

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

1.1 Background

Spur gears are reported to be the most well-known and simplest gear as compared to other type of gears (Gonzalez, 2015). Spur gears are also said to be commonly used in series to avoid from using large size gear (Gonzalez, 2015). The utilisation of spur gears is basically to shift movement from one shaft (tube) to another shaft that are similar or parallel. The teeth are designed or being cut straight up and down (almost zig-zag patterned) that is corresponds and align to the rotation axis (Collins, 2017). Due to deemed as the simplest gears of all gears, spur gears hence are widely applied in most of daily utilised devices and machine such as clocks, washing machines, blenders, kitchen mixers and even music equipment i.e. musical box (Duckering, 2015; Heintz, 2002; Isiaka, 1997; Nakamori, 1995).

A musical box is a type of musical instrument that emits a soothing musical sound. The use of musical boxes was reported since in year 1700's ("Music Box," 2016). To ensure that the musical box can operate and emit a melodious and soothing sound, spur gears are one of the main components in it (Heintz, 2002). Since music is purported as pivotal part in human life, to this day, a musical box remains relevant and still believed to have its own value in developing human experience and meaning of life (Duckering, 2015).

However, the musical box is said to be easily damaged. Reported damage is often caused by the damage to the gears encompass the device and this is not limited to the damage of the spur gears (Duckering, 2015; Heintz, 2002; "Music Box," 2016). Based on the reported damages, therefore, there is a requirement on the importance and necessities for engineers, researchers or musical box specialist to conduct specific research that is pertaining to musical box durability

(Duckering, 2015; "Music Box," 2016). This is especially research in regard to the musical box's spur gears that are said to be one of the ordinary causes leading to musical box damage.

1.2 Problem Statement

Gears are purported to be the main parts for equipment or machines. Despite of gears as important components which allow movement for machine and equipment to function, gears are criticised as component that easily broken-down caused by several factors (Alban, 2002; Manny, 2016). Due to these criticisms, this study that is pertaining to spur gears will be conducted to confirm the claim apart from identifying the cause of the damage to the spur gears, specifically in the musical box.

This study will involve the study of spur gears in the musical box that is intended to fill the literature gap. This is because, there are several previous researchers have suggested the necessity for studies on spur gears, as components in machines and equipment, to be done that involved equipment or machines other than food packaging machine (Panwar & Mogal, 2015), hand tractor (Husaini et al., 2019), or automotive equipment (Ahmad Sabri et al., 2017). Since there are sparse studies done on musical box spur gears (Duckering, 2015), the researcher has decided to niche this study focusing merely on the mechanism of spur gears in musical box.

In addition, there are also recommendations to continue the study on the factors contributing to the failure of the spur gears despite of its overwhelming studies in the past (Maifi, Bourenane, & Khelif, 2018; Sivakumar & Joe Michael, 2018; Vembathu, 2019).

Furthermore, previous studies have mostly involved studies on spur gears in general (Ali, 2016). Therefore, this study is considered significant and hopefully can contribute new findings as well as is an added value to the body of knowledge in the field of mechanical engineering.

1.3 Research Objectives

Aligned with the highlighted managerial problem and the problem statements, hence, the prime objectives of this research are to obtain research objectives as below:

1. To identify the cause of musical box spur gears failure.
2. To analyse the type of stress that cause to the failure of music box spur gear.

1.4 Scope of Study

As cited by many previous researchers i.e. (Ahmad Sabri et al., 2017); (Gawande & Kokare, 2017); (Radil & Berkebile, 2020); (Vembathu, 2019), in a machine system, the gear plays a vital role and function. To date, it is reported that the spur gears are the simplest and the most common type of gear that is widely applied in the machines and devices that are used in our daily lives like washing machine, blender, watch, clock and many more. Spur gears are also deemed as one of the key components to ensure these machines and devices can function and run smoothly (Maifi et al., 2018).

Further to that, this study is going to be conducted that is focusing on the spur gears. Nevertheless, this study is more focused on spur gears applied in the musical box. The main reason of limiting the scope is because the previous studies on spur gears are mostly generic (Ali, 2016). Moreover, the study of spur gears applied in the music box is reported to be very limited (Duckering, 2015). Besides, according to Sekaran and Bougie (2016), a focused research is important as it will helps the researcher to be more specific in the explanation and elaboration of the study findings. This eventually will add significant contribution to the body of knowledge.

1.5 Significant of the Study

The purpose of this study is to identify the cause of musical box spur gear failure. On top of that, this research is also intended to analyse the type of stress that cause to the failure of a musical box.

1.6 Theoretical Contribution

Despite of the overwhelming interest in conducting research pertaining to stress as the common reason to gear failure, there are still recommendation for future studies to further and expand the study of spur gear failure (Husaini, Dawud, Putra, & Ali, 2019; Maifi et al., 2018; Salawu, Okokpujie, Ajayi, & Agarana, 2018). Due to the recommendation, this research has niched its focus on the cause of spur gear failure in musical box. According to Sivakumar and Joe Michael (2018); Vembathu (2019), the common cause of gear failures is stress. Hence, to confirm this assertion, this research will be focusing on the stress type that might occur in the operation of musical box, thus contribute to its failure.

It is hoped that the findings and results from this study can contribute new knowledge in the field of mechanical, specifically on the mechanism of the spur gear. Furthermore, earlier studies have mostly conducted studies on spur gear in general, hence making this study more significant to the mechanical engineering body of knowledge as this study merely focuses on the musical box's spur gears.

Apart from that, the researcher also hopes that the result from this study will be able to draw the baseline information on the effect of stress on spur gears towards the performance of the musical box. Lastly, other researchers may find the findings from this research to be useful to help them in preparing and conducting their future research.

1.7 Practical Contribution

In term of practical contribution, it will be beneficial to the lecturers and students in the related course i.e., mechanical engineering. The findings from this research can be adapted or utilised as an example for the mechanical engineering lecturers when explaining or providing example to students about spur gears. The result of this research, supported with the information from the earlier study, will broaden their knowledge and ideas on the operations of the spur gears, specifically in the musical box.

In addition, the results of this study that is related to the types of stress that can damage the spur gears in the musical box, it is also expected to help the musical box designer or inventor in producing a better quality and durable musical box. This is by ensuring that the spur gears used are resistant to the stress types that has been identified from this study.

Apart from that, it is also hoped that the findings from this study will be able to provide important information to musical box collectors about the way and measures of care of their musical boxes for durability enhancement. This is especially the care of the spur gears, that is deemed as one of the main components causing to musical box damage, as repeatedly reported (Duckering, 2015; Heintz, 2002; "Music Box," 2016).

1.8 Organisation of Proposal

This research comprises of five (5) chapters namely Introduction, Literature Review, Research Methodology, Data Analyses and Results, and finally Conclusions. Background of the study, problem statement, research objectives and scope of the study used are explained in chapter 1. Chapter 2 presents review of related past studies involving the spur gear, common causes of spur gear failure, type of stress occurred in regard to the operations of the spur gear as well as the spur gear usage in musical box. Chapter 3, on the other hand covers the methodology used in this study including tool for data analysis and pertinent techniques. Chapter 4 will present the empirical results and key findings. Chapter 5 which is the last chapter offers detailed discussion on findings, research implications, limitations and recommendation for future research and a conclusion.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter comprises of some of the relevant literature gathered on gears, especially the spur gears. Surface failure of gears were also addressed in general from different point of views.

2.2 Spur Gears

Spur gears are a sort of cylindrical material, with shafts that are purported to be parallel and coplanar (Hassan, 2009) with the teeth that are straight and arranged parallel to the shafts (Husaini et al., 2019). The teeth of a spur gear are reported to have an involute (rolled) profile and interlock (mesh) each tooth in turn or at a time. The involute structure implies that spur gears just produce radial forces hence no axial forces (Collins, 2017). Nevertheless, the approach of tooth interlocking affects high weight on the gear teeth and produce high noise. Along these lines, spur gears are regularly utilised for lower speed applications, despite the fact that they can be utilised at practically any speed (Collins, 2017).

As cited by Sivakumar and Joe Michael (2018), these gears can possibly interlock (mesh) accurately on the off chance that they are fitted to the corresponding axles. The proportions of the force are deemed can be controlled by considering the power that a tooth of one gear applies on a tooth of the other gear.

Spur gears are made of metals, for example, steel or brass. Besides metal, some spur gears are made of plastics, for example, nylon or polycarbonate (Hassan, 2009). Spur gears that are made of plastic is reported to have produced less noise.

Despite of the less noise, the disadvantage of plastic spur gears is often related to its strength and loading ability (Hassan, 2009).

As reported in Singh and Karma (2019), the spur gears are commonly seen as the best for applications that simultaneously need speed decrease and force increase. This is for example, ball mills or crushing equipment. The also added that, besides of spur gears are widely used for equipment that need decreasing speed while increasing force, equipment that require high-speed application also applies spur gears despite of their high noise levels. This is for example clothes washers, blenders airplane motors trains as well as bicycles.

Differ from other gear types, it is posited that spur gears do not possess any shortfall that is due to slippage. In lieu of this, spur gears are allegedly to be simple to make and appropriate for a wide scope of utilisations (Hassan, 2009).

2.3 The Common Cause of Spur Gears Failure

Equipment or machinery breakdowns are frequently the consequence of gear failure. The reason for gear failure can be due to numerous issues, yet the most reported is because of wear. Any part inside the machine will wear out from consistent use. If it happens with gears, it can detrimentally affect the operations of the equipment (Manny, 2016).

According to Panwar and Mogal (2015), gear failures because of wear may happen for various reasons i.e. moderate wear, excessive wear, abrasive wear, corrosive wear, frosting, spalling, pitting, breakage and stress.

2.3.1 Moderate Wear

This kind of wear is purported happened due to insufficient oil or could be because of pollution in the grease too. This type of wear normally leaves contacts patterns that show the metal has been affected in the addendum and the dedendum area (Manny, 2016).

2.3.2 Excessive Wear

Excessive wear is the type of wear that shows significant measure of material has been affected on the surfaces. The pitting on a surface level with extreme wear, usually caused by not realising it in the earliest wear early enough, thus it continues to progress (Manny, 2016).

2.3.3 Abrasive Wear

Abrasive wear might show up as radial scratch prints or some other identifier that would show contact is a problem. The most well-known causes to explain the how abrasive wear happens is because of unfamiliar bodies in the grease. This problem involves metallic trash either from the gear system or the bearing and not limited to rust, sand, or weld scatter (Manny, 2016).

2.3.4 Corrosive Wear

Actions from chemical substances weaken the surface of the gear, for example, through acids, added substances or dampness in the lubrication oil. As the oil separates, the chemical substances that exist in the lubricant attack the surfaces. Eventually, it will generally result in uniform, fine pitting on the two surfaces (Panwar & Mogal, 2015).

2.3.5 Frosting

Frosting problem that happen to gear usually shows up in the dedendum area of the driving gear. The wear pattern gives a frosted look with micro pits on the surface. Frosting is stated to be a corny problem when the heat breaks down the lubrication film (Sivakumar & Joe Michael, 2018). Figure 2-1 below depicts the gears with frosting issue.

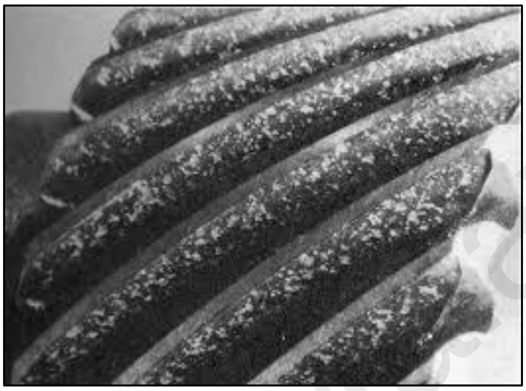


Figure 2-1 : Gear with frosting issue

2.3.6 Pitting

A problem with pitting can be considered as initial where the surface of the gear is experiencing small pits to damaging. Initial pitting could be a problem with the gears that are not matching or fitting together properly (*Failure Analysis*, 1978). Figure 2-2 below depicts the gears with pitting issue

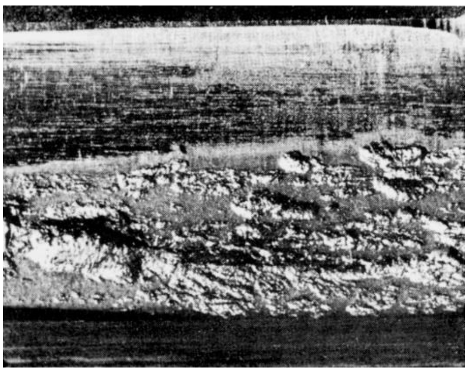


Figure 2-2 : Gear with pitting issue

2.3.7 Spalling

Spalling on the other hand is a severe pitting. The pits are described to be shallow and larger in diameter. Moreover, the area that is showing spalling does not tend to be uniform and spalling is a common problem due to the existence of excessive stress (Sivakumar & Joe Michael, 2018). Figure 2-3 below depicts the gears with spalling issue as well as the difference between spalling and pitting.

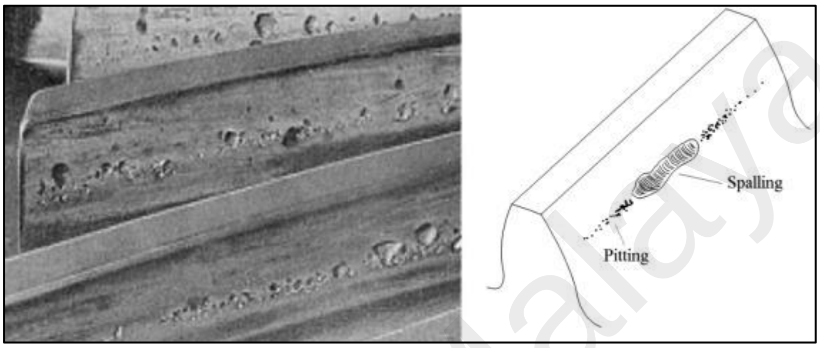


Figure 2-3: Spalling issue

2.3.8 Breakage

Sivakumar and Joe Michael (2018) opined that it is feasible for the whole tooth or a bit of the tooth to split away. It often leaves proof of the focal point of the fatigue that led to the break that is also due to high stress or excessive tooth loads. Figure 2-4 below depicts the gears with breakage issue.

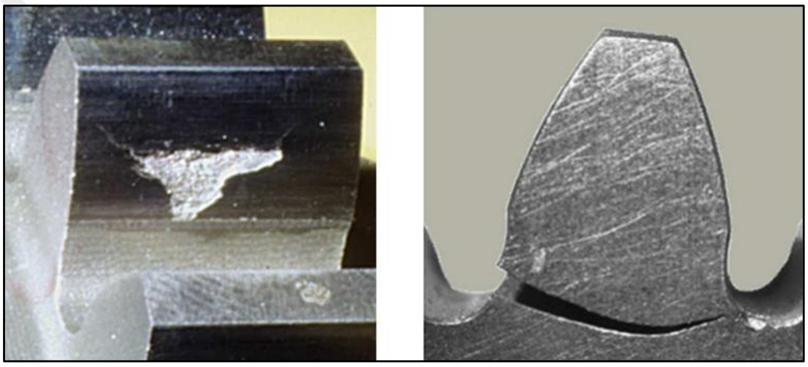


Figure 2-4: Breakage issue

Due to various reasons that contribute to gear damage, this study is going to study or identify the causes of spur gear damage contained in the musical box. This is because, according to on Duckering (2015), spur gear is one of the main components to ensure that the musical box works properly. This has eventually become the main motivator for this research to be conducted.

2.4 Stress Analysis of Spur Gears

Spur gears are generally utilised in the power diffusion mechanism of a few machines. Because of the transferred torque, spur gears normally experience high-level of stresses which could cause failure to its gear tooth from surface pitting or root crack (Maper et al., 2019).

2.4.1 Surface Failure of Gear Teeth

The transfer of energy or power between gears is purported to have taken place when there is a contact between the acting teeth (Hassan, 2009). Figure 2-5 below depicts a model of the gears with two parallel cylinders in contact. The contact between the acting teeth is asserted to not just produce the energy or power but also stress. The resulting stress can eventually cause damage to the spur gears.

Figure 2-5: Gear with two parallel cylinders

Therefore, it is important to know the maximum level of pressure that these spur gears can withstand before severe damage occurs. To find out the maximum level of this stress, according to Hassan (2009), it can be calculated by means of the Hertz theory. Through the mathematical calculation using the Hertz theory, the researcher will be able to obtain numerical expressions of stresses and distortions of curved bodies in contact.

Since this research is to identify the cause of musical box spur gears failure as well as to analyse the type or level of stress that can lead to the failure of music box spur gears, the application of the Hertz theory will be further analyse in Chapter 4.

2.4.2 Surface Contact Fatigue Failures in Gears

The well-known type of gear failure happened practically is because of the surface contact fatigue. This type of gear failure causes to break (crack) initiation at or close to the contact surface and may eventually prompt damage (Ali, 2016). The metal eliminated from the surface in such cases enters the machine system, and can, thusly, root rough or abrasive wear and failure to other components too. Besides, the pits that occurred on the damage surface indirectly become the factor contributing to the higher level of stress and serve as initiation sites for other type of failure to the gear (Ali, 2016).

2.4.3 Mechanism of Contact Fatigue

At the point when two bodies are not precisely interlocking (joined touch) each other without getting inflexibly connected, it is said that they are in contact. Contact stresses happened due to the pressure of one strong body on another over restricted areas of contact (Ali, 2016). It has been reported that in some cases, the contact stresses happened when two surfaces are squeezed together by the external loads (Ali, 2016; Sivakumar & Joe Michael, 2018). Contact stresses might be viewed as the significant reason for failure of one part body or both bodies in contact. The contact area transfers the forces from one body to the other body by the method of compressive and tangential or shear stresses (if erosion does exist). Hence again, the common failures due to this contact stresses are deemed to be breaks, pits or chipping on the outside part of the material (Ali, 2016; Sivakumar & Joe Michael, 2018).

In the situation when there are two curved surfaces are in contact under load, the contact appears along a line or point, or reliant on the elastic constants of the materials concerned, along a very minor circular or elliptical area (Ali, 2016; Maper et al., 2019). In lieu of the small contact areas, the shear stresses that were developed at and near the surface are subsequently very high. When the contacting stresses are recurring, the cyclic compressive stresses generated cause differing elastic and plastic behaviour in the near surface material. Depending on the microstructure and grain orientation of the material in this area, internal stress concentrations are developed which in the long run led to crack initiation (Maper et al., 2019).

Based on previous studies, most gears damage occurs due to pressure or stress on the spur gears when these gears are in contact. This has been the main motivation for this study to be implemented focusing on stress studies that cause damage to the spur gears inside the music box, which is believed to be lacking despite of the overwhelming studies done on spur gears failure.

2.5 Musical Box

Musical boxes were reported to have already existed since the 18th century. Some were said to be in the size of a bread loaf, and some could be as big as a cupboard ("Music Box," 2016). In those day, musical boxes are purported to be utilised to enjoy and appreciate some decent parlour music, which is dissimilar to the small whirling ballerina box ("Music Box," 2016).

In the 19th century, Swiss craftsman watchmakers were asserted to have constantly refined the musical box design. Thus, the musical boxes existed today is the aftereffect of many long periods of intervening with its gears, bells, pins, and steel combs (Duckering, 2015; "Music Box," 2016).

A musical box is said to operate by pivoting its metal cylinder with jutting pins that pluck the individual tines of a steel comb. The sounds that reverberate from the vibrating tines are the notes that were heard by the audiences (Heintz, 2002). The lower notes are from the longer tines meanwhile, the higher notes are from more shorter ones. For some other complex musical boxes have been asserted to even comprised of a little drum or little bells (Heintz, 2002).

2.5.1 Spur Gears in Musical Box

As cited by Isiaka (1997) and Nakamori (1995), a musical box encompasses a drive shaft that is basically to wind a spring, a drum which turns with transmitted spin or rotation of the drive shaft every time a spring is being released. Every time when the spring unwinds, the axle in the musical box will be turning in the opposite direction, where the tooth of the gear will be catching the pawls, that rotates the larger gear attached to it. The rotation is said to drives the musical box (Duckering, 2015).

Furthermore, as the spring unwinds, it will simultaneously rotate the first bevel gear, which engages a second bevel gear that is affixed to the drum (Duckering, 2015) as depicted in Figure 2-6

Figure 2-6: Bevel gears

The drum is also said to be fixed to a larger gear as shown in Figure 7.0. The larger gear on this piece engages to the first musical box spur gear and then affixed to the smaller end of the second musical box spur gears (Duckering, 2015) as depicted in Figure 2-7.

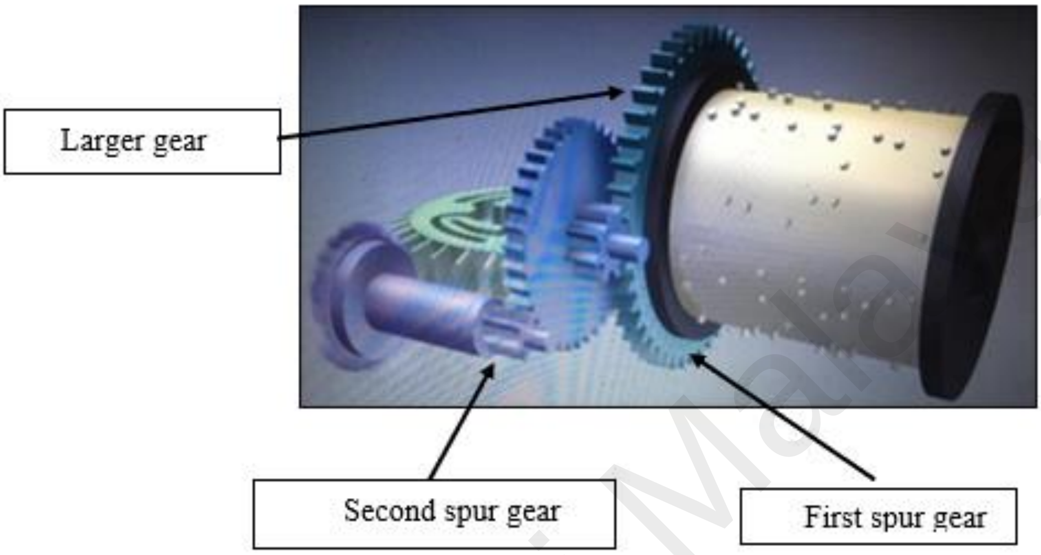


Figure 2-7: Spur Gear

Lastly, the second spur gear engages a worm screw on the shaft of the musical box governor (Duckering, 2015) as shown in Figure 2-8.

Figure 2-8: Governor and gear

It is the chain between the gears inside the musical box that allows a musical box to emit melodious music (Duckering, 2015; Heintz, 2002). In addition, based on the mechanism of movement and the chain of the gears, it is proven that spur gears are indeed the main components in the musical box. Hence, damage to the spur gears will interfere and disrupt the performance of the musical box (Duckering, 2015; Heintz, 2002). Therefore, this has become the reason and motivator for this study to be conducted.

CHAPTER 3: METHODOLOGY

3.1 Research Methodology

Towards at the end of the project, an evaluation between each failure will be recognized. This is to compare and can be compared the properties of failure modes to the maximum contact stress of the gear.

Finite element design and result methods are required for the exact calculation of three-dimensional spur gear contact stresses and will be determined for this project. The results will be then compared to calculations methods, Hertz theory with ANSYS contact stresses calculation. The aim of this research is to identify the cause of the damage to the spur gears by predict and do analyses of contact stresses of the spur gear in mesh using ANSYS software based on numerical method. Solidworks software used to create 3D model and ANSYS software to simulate the model.

The research will start by modelling of a spur gear for validation purpose. For the stress analysis, the procedure was taken from previous study (U. Kumar and J. Sushil Kumar Tiwari, 2012).

Hertz Equation was conducted to compare with Finite Element Analysis in Kumar and Tiwari studies. So many researcher analyse the contact stress between spur gear teeth using a plane model and validate Hertz stress with finite element contact stress.(Chacon et al., 2010) and concluded that FEA is able to simulate contact stress in a pair of mating gear.

The stress on the surface of gear teeth is usually determined by formula derived from the work of Hertz frequently these stresses are called Hertz stress. Hertz determined the width of the contact band and the stress pattern when various geometric shapes were loaded against each other.

Hertz equation given below (Hassan, 2009): -

$$\sigma_o = \sqrt{\frac{W(1 + r_{p1} / r_{p2})}{r_{p1} F\pi[(1-\nu_1^2)/E_1 + (1-\nu_2^2)/E_2]\sin\phi}} \quad (1)$$

W=Load

E_1 and E_2=Modulus of Elasticity of pinion and gear

V_1 and V_2=Poisson Ratios of pinion and gear

F=Face width of pinion

R_1 and R_2=Respective radii of the involute curve at contact point

Ø=Pressure angle

The results of the analysis for contact stress by using Hertz equation and Finite Element Analysis (U. Kumar and J. Sushil Kumar Tiwari, 2012) are shown in below Table 3-1.

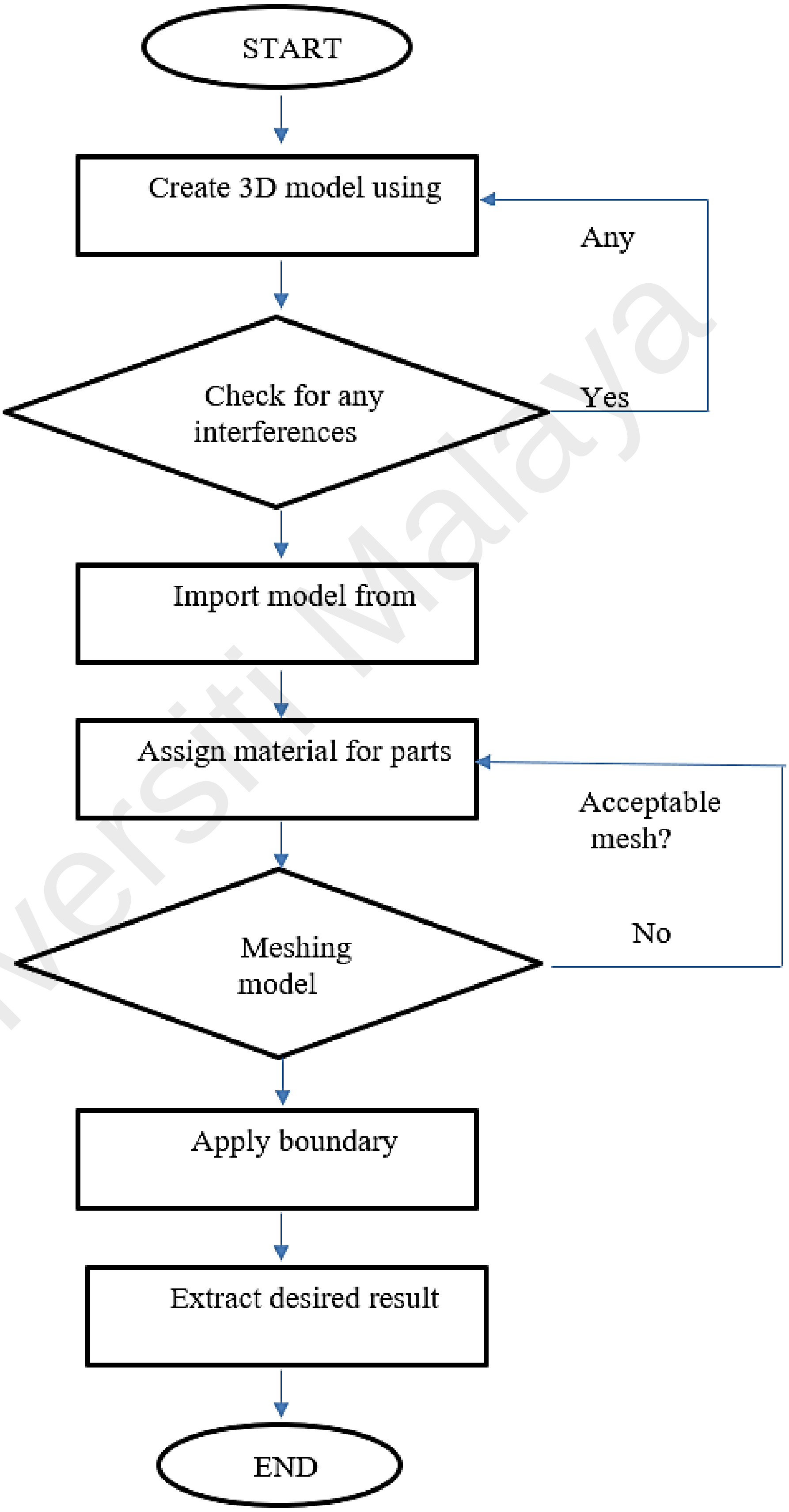
Table 3-1: Analysis Results (U. Kumar and J. Sushil Kumar Tiwari, 2012)

Method	Contact Stress (MPa)
Hertz Equation	-562.27
Finite Element Analysis	567.75

The main drive of using past study as a justification is to ensure the methodology used to analyse the gear is right

3.2 Project Flow Chart

Flow in conducting research project as below: -



3.3 Modelling and Simulation

Modelling of spur gear was done using the SolidWorks software. Figure 3-2 and Figure 3-3, guidance for selecting parameters to model a spur gear. For this research, may refer to Figure 3-1 in modelling music box 1:1 gear ratio is used. After each pinion and gear was design, an assembly was created in SolidWorks as shown in Figure 3-4. Spur gear design will follow the measurement and requirement as shown in Table 3-2: Gear Specifications:

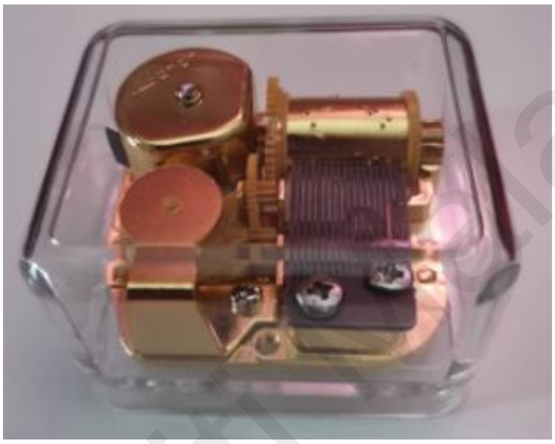


Figure 3-1 Musical Box

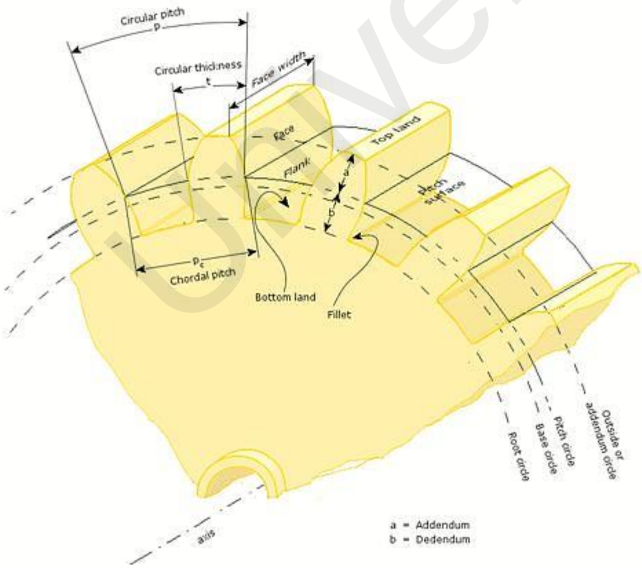


Figure 3-2: Standard system of Gear Teeth

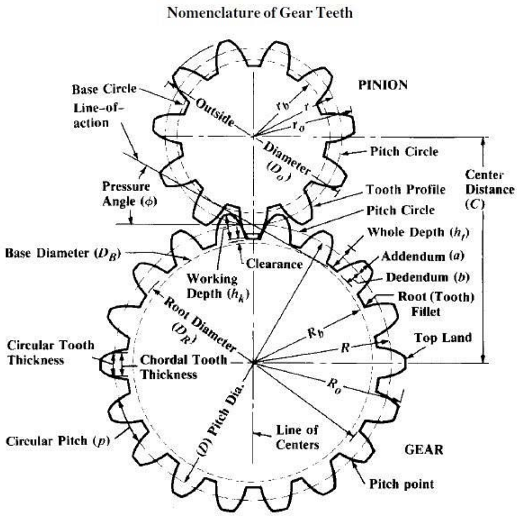


Figure 3-3: Nomenclature of Gear Teeth

Table 3-2: Gear Specifications

PARAMETER PINION GEAR	PARAMETER PINION GEAR 1	PARAMETER PINION GEAR 2
Number of Teeth	46	38
Material Grade	Acrylonitrile Butadiene styrene (ABS)	Acrylonitrile Butadiene styrene (ABS)
Pitch Radii Gear 1 (mm)	0.5	0.6
Pitch Radii Gear 1 (mm)	0.957	1.148
Face Width (mm)	1.016	1.016
Young's Modulus (MPa)	2390	2390
Poisson's Ratio	0.399	0.399
Density kg/m^3	1040	1040
Tensile Yield Strength (Mpa)	41.4	41.4
Shear Modulus (Mpa)	854.18	854.18

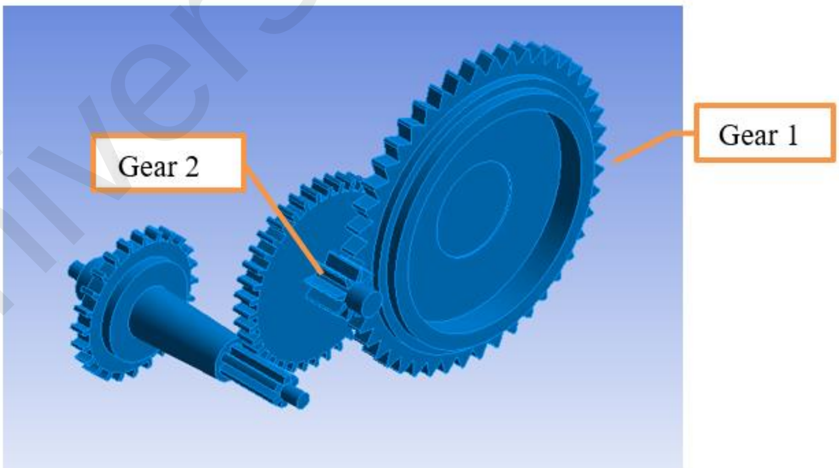


Figure 3-4: Assembly of Spur gear in Solid Works

3.4 Assign material of properties

Upon completing 3D model, need to assign material. The material selection for this music box spur gear is Acrylonitrile butadiene styrene (ABS) plastic. Engineering data in ANSYS as per below Figure 3-5 and Figure 3-6: -

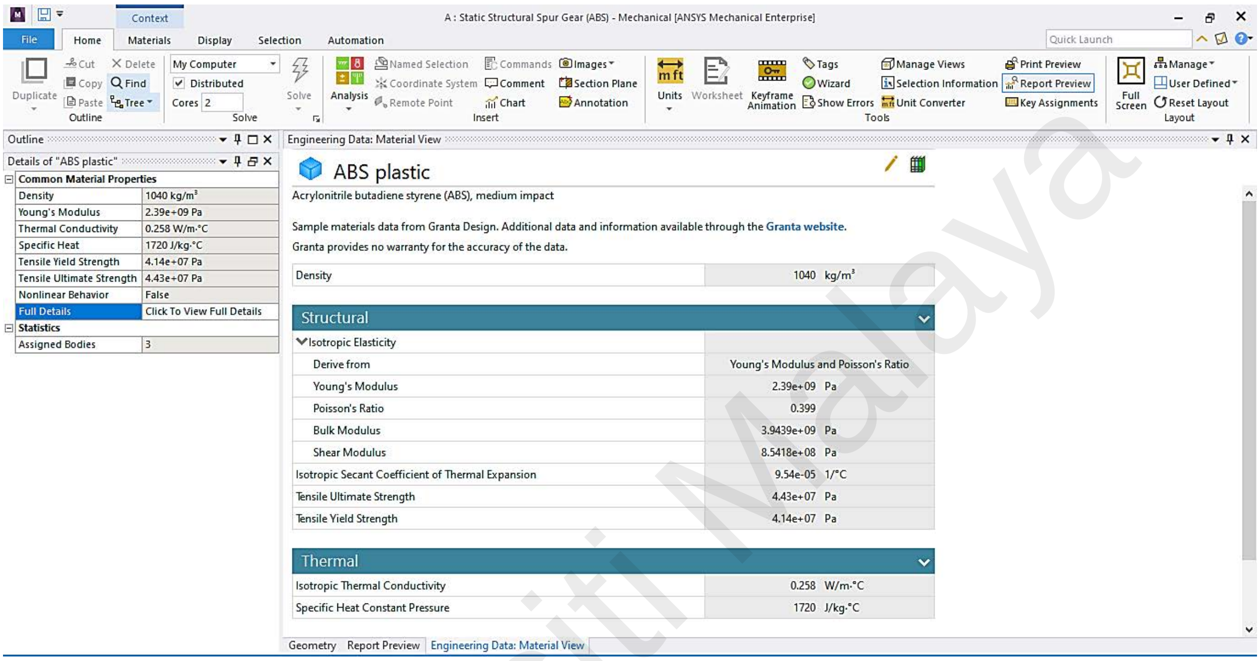


Figure 3-5: Spur Gear Material Properties

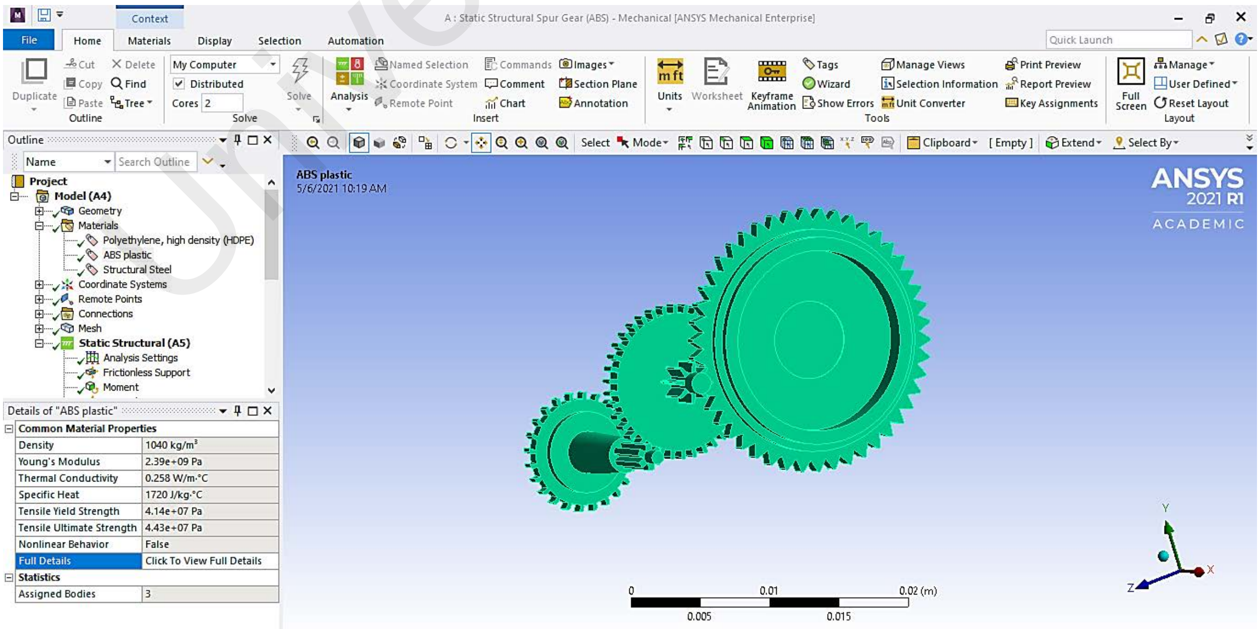


Figure 3-6: Materials assigned at spur gear

3.5 Pinball Region

Assigning pinball region between bodies from spur gear one (1) to target bodies spur gear two (2) as per shown in Figure 3-8 and Figure 3-7 for contact detection point purposes. Set radius of the pinball to 0.3mm radius and set default option, Program Controlled. There will be no sliding or separation between faces or edges by assigning pinball region.

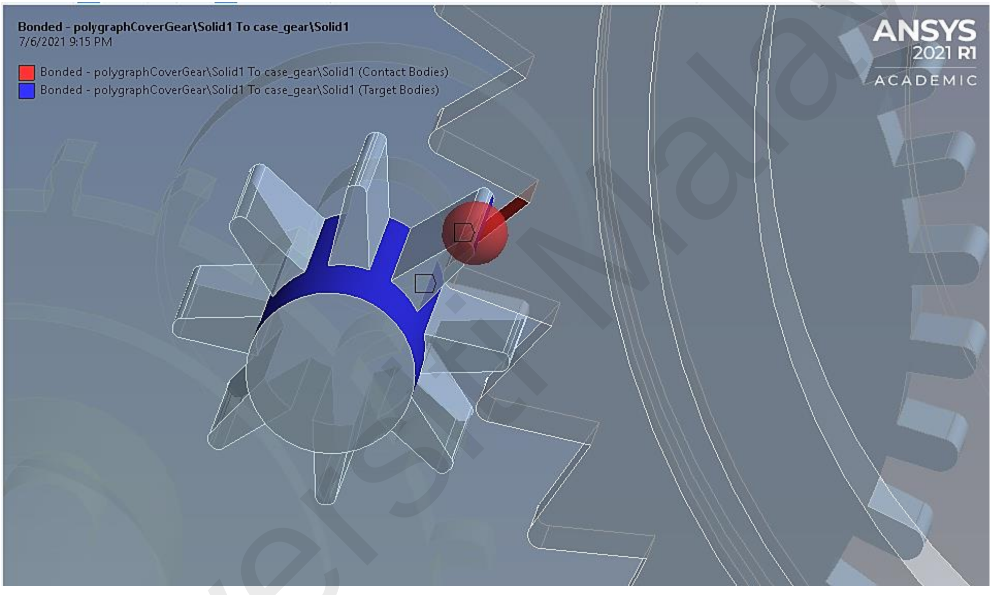


Figure 3-8: Pinball Region between face spur gear one and two

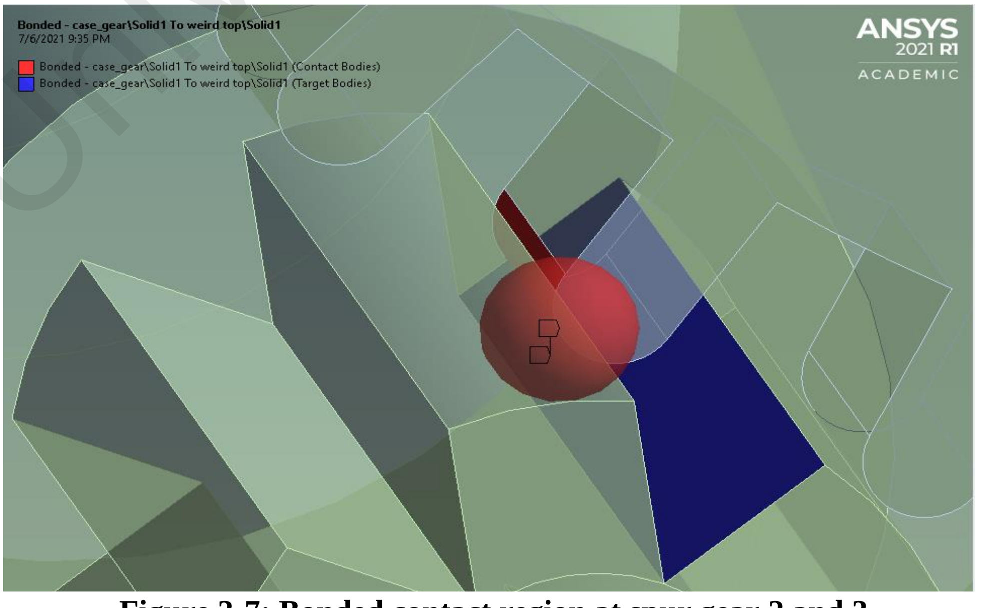


Figure 3-7: Bonded contact region at spur gear 2 and 3

3.6 Contact Region

Contact region is only made up of faces only. This contact allows linear solution since the contact length/area will not change during the application of the load. May refer to gear faces in Figure 3-9 and Figure 3-10

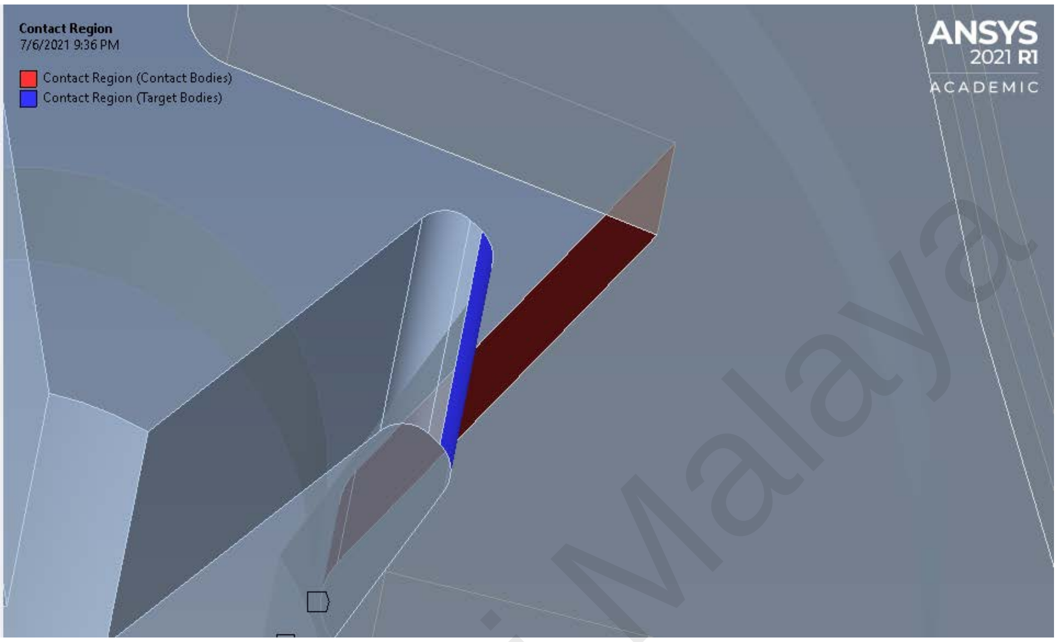


Figure 3-9: Contact faces for spur gear 1 and 2

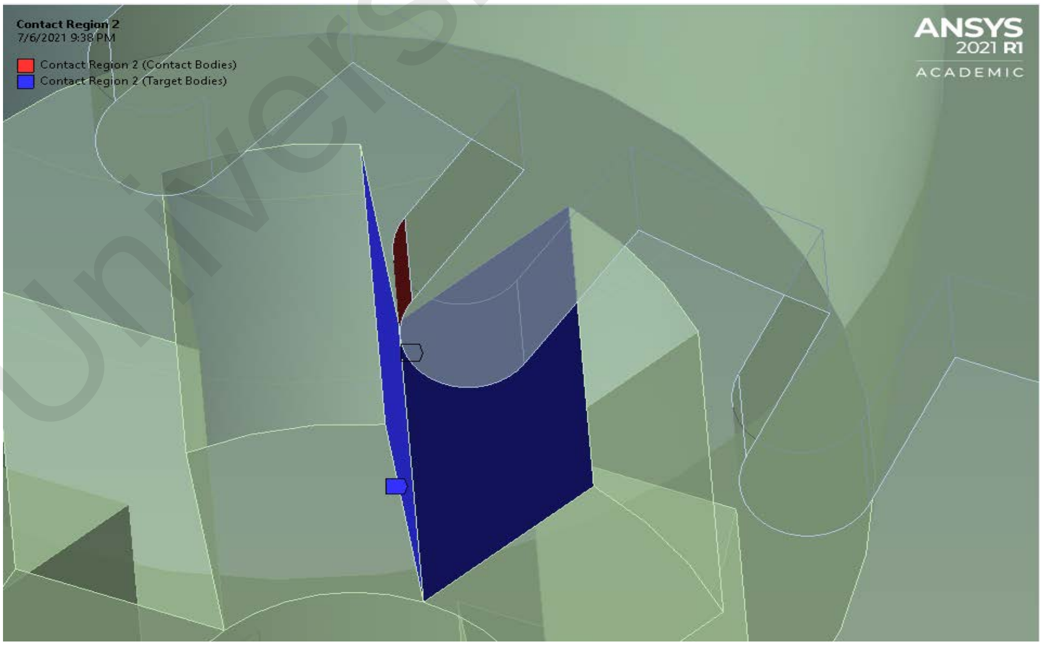


Figure 3-10: Contact faces for spur gear 2 and 3

3.7 Meshing

Mesh shown in Figure 3-11 has been created with element size, sizing resolution, and overall statistics of mesh as shown in Table 3-3.

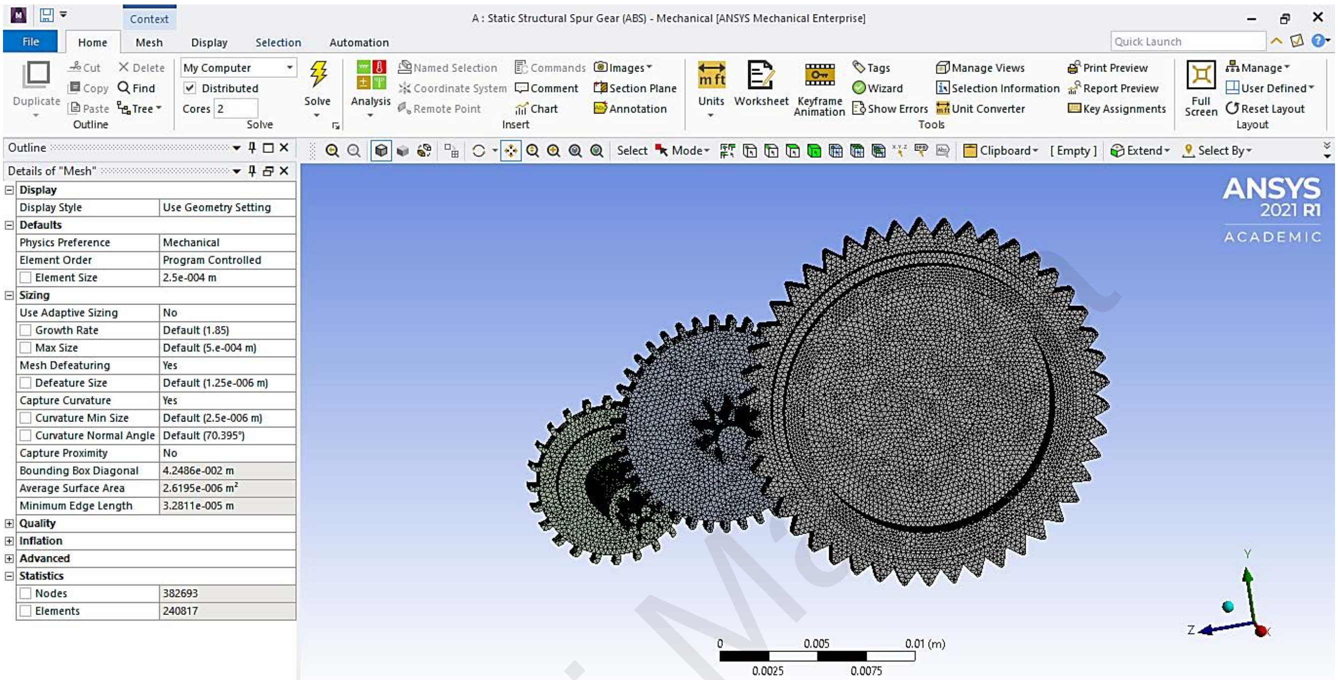


Figure 3-11: Spur gear mesh configuration

Table 3-3 Meshing Statistics

MESHING STATISTICS	
Nodes	382693
Elements	240817

3.8 Apply Boundary Conditions

Boundaries for moment, frictionless support and fixed support has been selected for simulation boundary conditions as per below Figure 3-12 and Figure 3-13. Frictionless support is to avoid one or more even or rounded faces from moving or deforming in the normal direction. The normal direction is relative to the selected geometry face. No part of the surface body can move, rotate, or distort normal to the face. For fixed support is to prevents a selected geometric or mesh entity from moving or deforming. The model will be simulated in static structural analysis. From this analysis, maximum contact stress can be obtained.

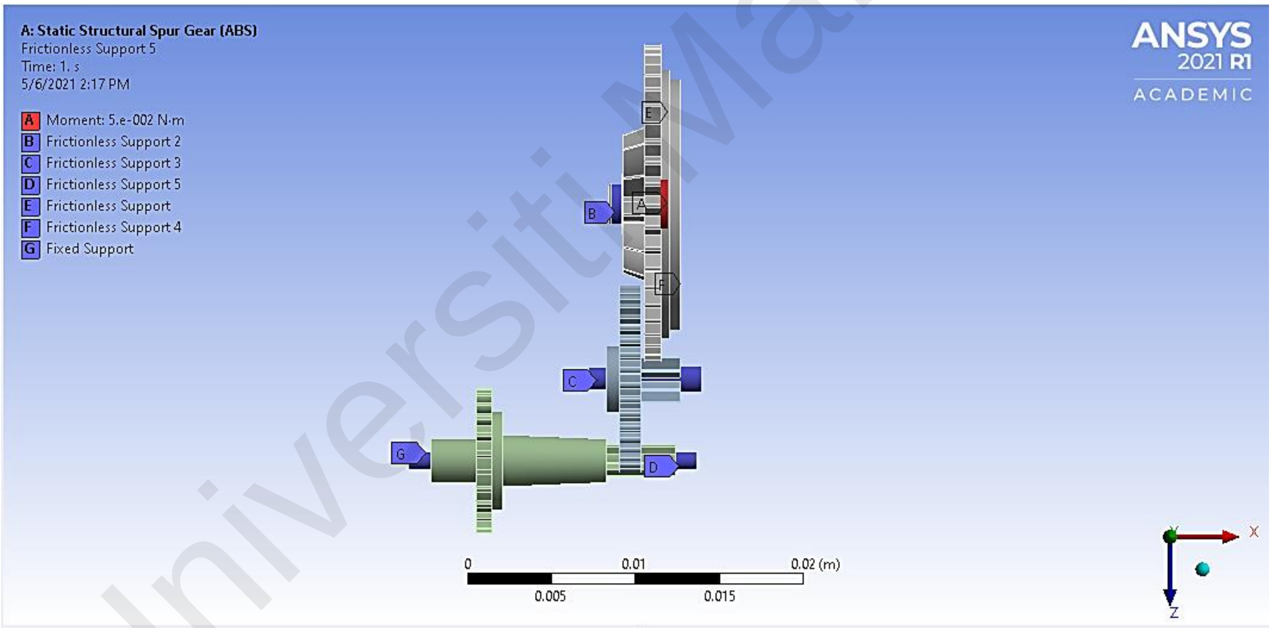


Figure 3-12: Boundary Condition for spur gear

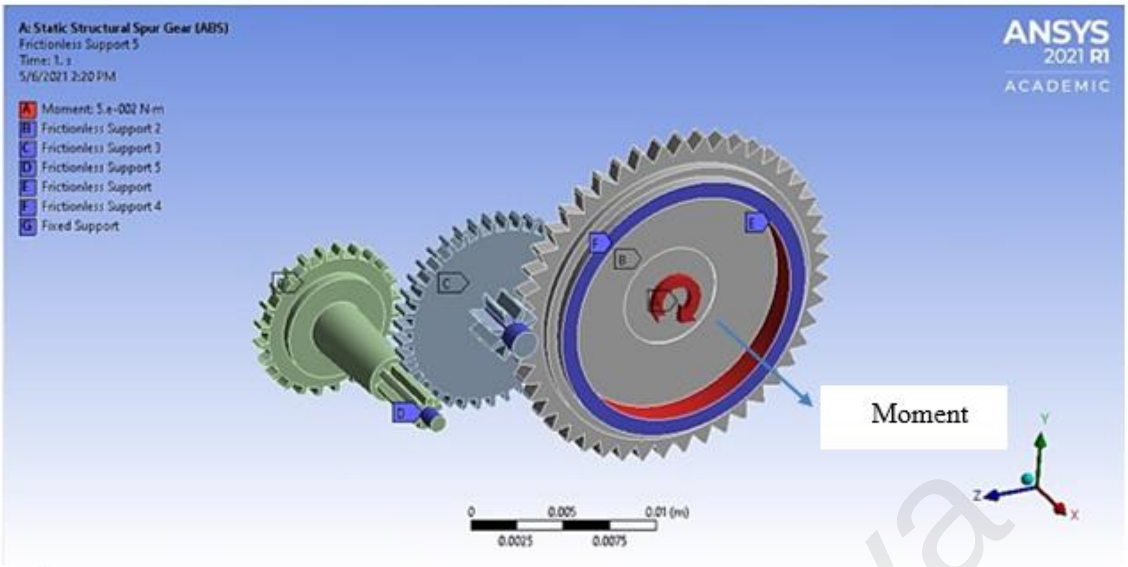


Figure 3-13 : Moment at spur gear

The driver will be applied a moment of 50 Nm and the driven gear will rotate accordingly. Apply frictionless support at point D and C since it connected to shaft. X, Y, Z displacement will be fixed for both gears since there is no translational drive involved (one degree of freedom). Significant the contact region is the main stage in simulating the gear using FEA. Once the geometry is attached with static structural analysis tab, we must express the contact between the two involutes teeth.

ANSYS has fundamental selection, which will read the attached geometry automatically for any predefined contacts or other boundary definitions as shown in Figure 3-14.

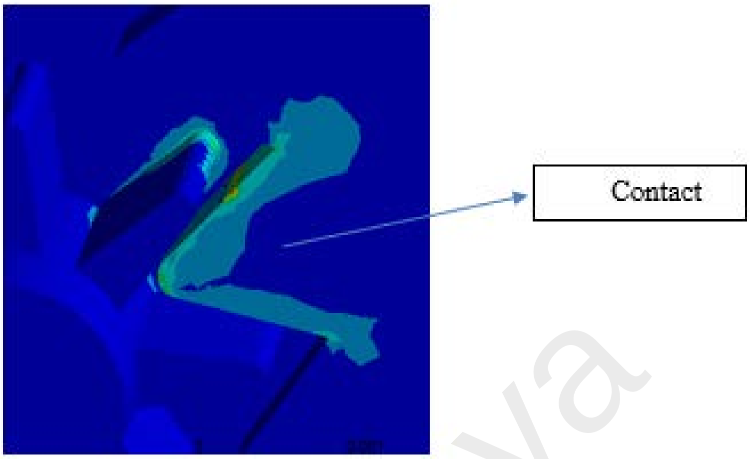


Figure 3-14: Contact region between two gears

3.9 Data Collection and Analysis

After running the simulation at the specified setup settings, result will be plotted into flow contours for load and time for analyses and comparison. It is a crucial and important process to diagnose the maximum stress logged for each case. The analysis was carried out to determine the defect that gives higher contact stress. From the outcome and analysis, we can presume which type of failure is affect the performance of the gear.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Results and Discussion

4.1.1 Simulation using Acrylonitrile butadiene styrene (ABS) as material

4.1.1.1 Equivalent Stress (overall process)

Result from FEA simulation, maximum contact stress was measured in order to find out the type of failure of spur gear. Material selection is Acrylonitrile butadiene styrene (ABS). From Figure 4-1 it shows that overall maximum equivalent (von-Mises) stress happens at the involute teeth. From the FEA simulation, the maximum equivalent stress obtained from spur gear simulation is 87.86Mpa and the minimum stress is 2.498Mpa. May refer to Figure 4-2 and Figure 4-3.

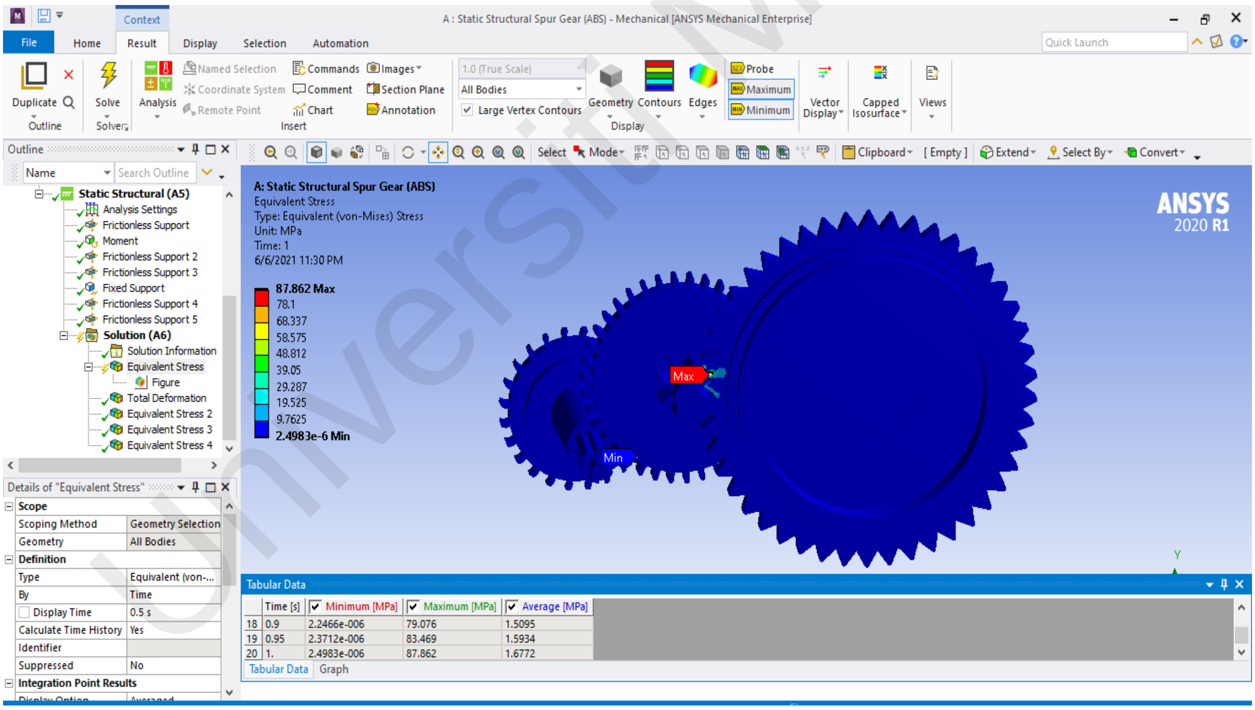


Figure 4-1: Minimum and maximum equivalent stress

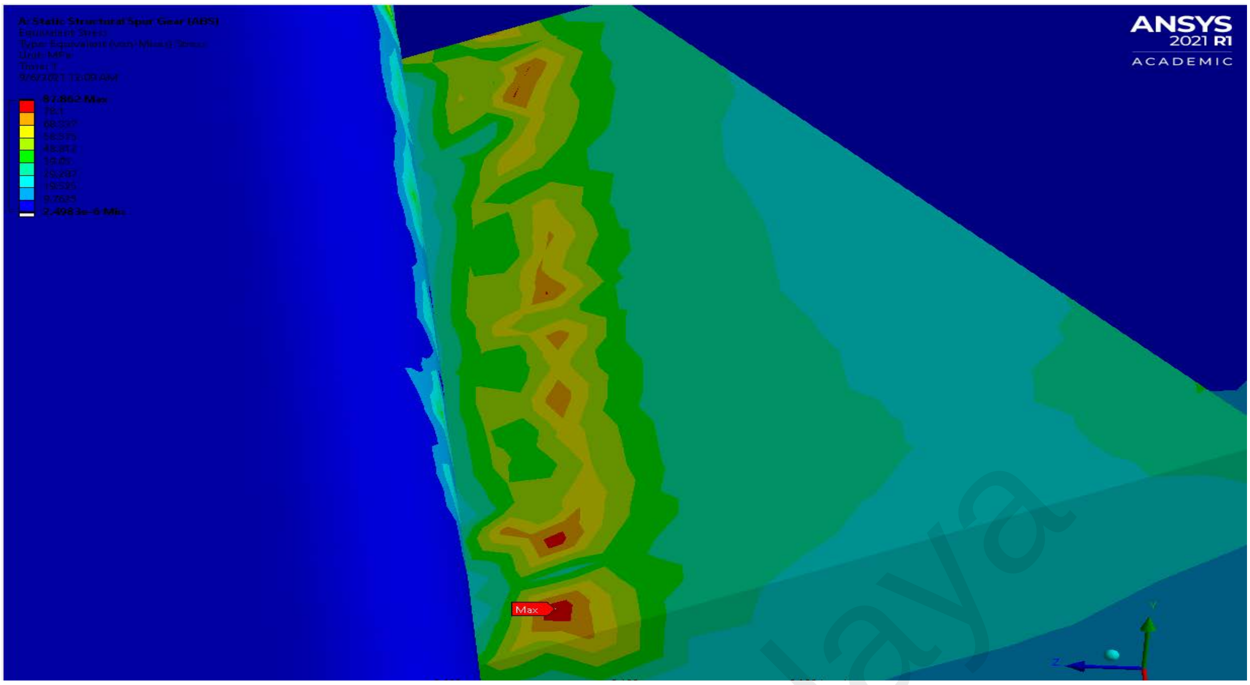


Figure 4-2: Close up maximum stress area (1)

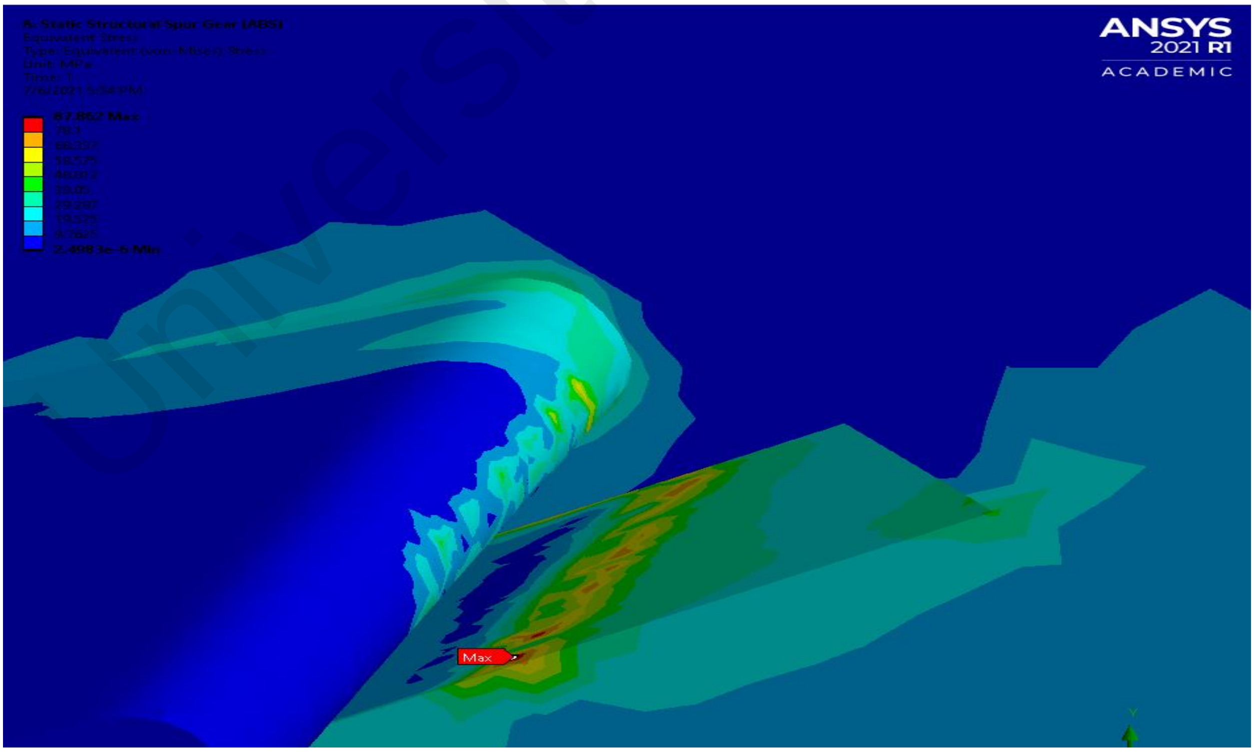


Figure 4-3: Close up maximum stress area (2)

Simulation of Finite Element Analysis capture for overall gears, minimum and maximum equivalent (von-Mises) stress and data as per shown in below Table 4-1. This outcome dependent on the same tractable pressure known as von Mises hypothesis where this hypothesis expresses that the disappointment at a specific area happens when the energy of distortion reaches the same energy for failure in tension. For this situation, yielding happens when the equivalent stress arrives at the yield strength of the material in basic strain. By applying the force data before in 1 seconds, the result of the stress was shown in Table 4-1 below. From the result, the graph Figure 4-4: Graph Maximum Stress vs Time, for equivalent von-Mises stress versus time was constructed. Starting from 0 second until 1 second, the stress was increase based on the load applied on it. The stress increase because of the loading applied is increase. This is the relationship between the load applied and stress occurs.

The least values of this stress means that the load applied still do not accomplish the extreme load applied. When time is increase, the stress also increases straight proportional to the time until reach the extreme stress before the axle housing failure. After 1 second, the stress reaches the maximum stress where the stress obtained from this analysis is 87.86MPa. This means after 87.86MPa the failure is start and these maximum stresses happen on the predictable failure region where the failure began.

Table 4-1: Tabular Data Minimum and maximum equivalent stress for overall spur gear

Tabular Data

	Time [s]	Minimum [MPa]	Maximum [MPa]	Average [MPa]
1	5.e-002	6.9759e-006	4.3931	9.431e-002
2	0.1	1.3952e-005	8.7862	0.18862
3	0.15	2.0928e-005	13.179	0.28293
4	0.2	2.7904e-005	17.572	0.37724
5	0.25	3.4879e-005	21.966	0.47155
6	0.3	4.1856e-005	26.359	0.56586
7	0.35	4.8831e-005	30.752	0.66017
8	0.4	5.5807e-005	35.145	0.75448
9	0.45	6.2784e-005	39.538	0.84879
10	0.5	6.9759e-005	43.931	0.9431
11	0.55	7.6736e-005	48.324	1.0374
12	0.6	8.3711e-005	52.717	1.1317
13	0.65	9.0688e-005	57.11	1.226
14	0.7	9.7663e-005	61.504	1.3203
15	0.75	1.0464e-004	65.897	1.4146
16	0.8	1.1161e-004	70.29	1.509
17	0.85	1.1859e-004	74.683	1.6033
18	0.9	1.2557e-004	79.076	1.6976
19	0.95	1.3254e-004	83.469	1.7919
20	1.	1.3952e-004	87.862	1.8862

Based on above Table 4-1, ANSYS software run the simulation for 1sec and capture various of data. In the above tabular data, the software detects the minimum, maximum and average contact stress. Based on the material engineering data, the tensile yield strength for the Acrylonitrile butadiene styrene (ABS) is 41.4MPa. By applying 50Nm load for simulation, the results show that the maximum contact stress detected at the red area at the spur gear teeth and the value is 87.86Mpa. This is due to that area is receiving amount of stress.

Based on the graph shown in Figure 4-4, the result exposed that the maximum equivalent von-Mises stress is 87.862 MPa when time taken reaches 1 second.

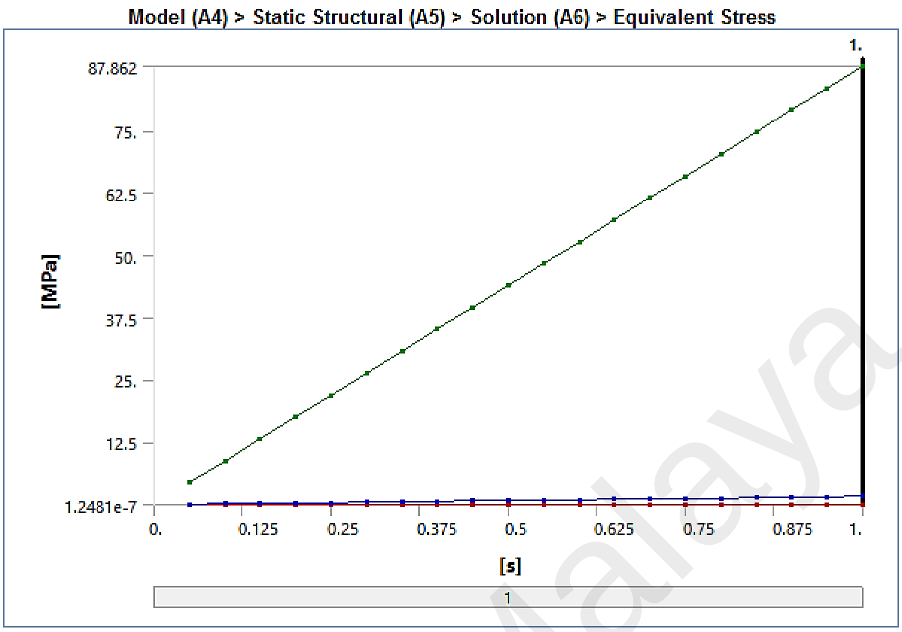


Figure 4-4: Graph Maximum Stress vs Time

Table 4-2: Details of Equivalent Stress

Details of "Equivalent Stress"	
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Equivalent (von-Mises) Stress
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Suppressed	No
Integration Point Results	
Display Option	Averaged
Average Across Bodies	No
Results	
Minimum	2.4983e-006 MPa
Maximum	87.862 MPa
Average	1.6772 MPa
Minimum Occurs On	weird top\Solid1
Maximum Occurs On	polygraphCoverGear\Solid1
Minimum Value Over Time	
Minimum	1.2481e-007 MPa
Maximum	2.4983e-006 MPa
Maximum Value Over Time	
Minimum	4.3931 MPa
Maximum	87.862 MPa
Information	

4.1.1.2 Contact Stress Calculations using Hertz Equation

To calculate contact stresses, Hertz equation (Hassan, 2009) will be implemented. Hertz theory assumes an elliptic stress distribution as parallel cylinders in contact.

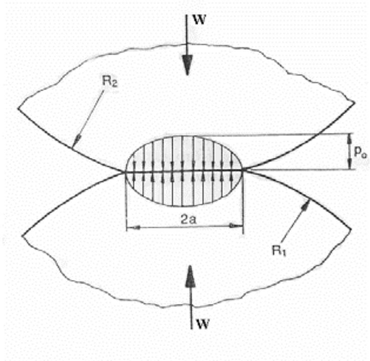


Figure 4-5: Parallel cylinders in contact

Derive the equation as below: -

$$\sigma_o = \sqrt{\frac{W(1/R_1 + 1/R_2)}{F\pi[(1-\nu_1^{\,2})/E_1 + (1-\nu_2^{\,2})/E_2]}} \qquad (1)$$

By presume contact happen at point 1, respective radii are equivalent to: -

$$R_1 = r_{p1} \sin\phi \qquad (2)$$
$$R_2 = r_{p2} \sin\phi$$

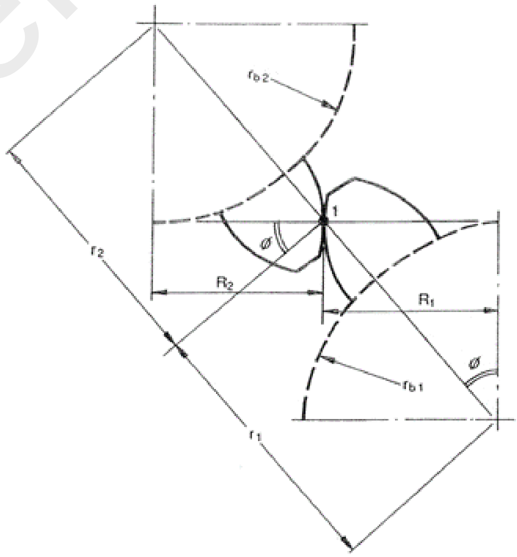


Figure 4-6: Two involute teeth in contact

Hertz equation for contact stresses as follows: -

$$\sigma_o = \sqrt{\frac{W(1 + r_{p1}/r_{p2})}{r_{p1}F\pi[(1-\nu_1^2)/E_1 + (1-\nu_2^2)/E_2]\sin\phi}} \quad (3)$$

Where: -

W = Load

E_1 and E_2 = Modulus of Elasticity of pinion and gear

v_1 and v_2 = Poisson Ratios of pinion and gear

F = Face width of pinion

R_1 and R_2 = Respective radii of the involute curve at contact point

∅ = Pressure angle

r_{p1} and r_{p2} = pitch radii of the pinion and gear

By substitute values in Table 4-3 into Hertz equations (3), results may refer to Table 4-4

Table 4-3: Dimension and Specification spur gear

Descriptions	Symbols	Value	Units
Load	W	5.246589717	N
Radius Gear 1	R_1	0.5	mm
Radius Gear 2	R_2	0.6	mm
Pitch Radii Gear 1	r_{p1}	0.957213068	mm
Pitch Radii Gear 2	r_{p2}	1.148655681	mm
Modulus of Elasticity Gear 1	E_1	2390	Mpa
Modulus of Elasticity Gear 2	E_2	2390	Mpa
Poisson's Ratio Gear 1	v_1	0.399	
Poisson's Ratio Gear 2	v_2	0.399	
Face width	F	1.016	mm
Pressure Angle	∅	31.49	deg
		0.549604181	rad

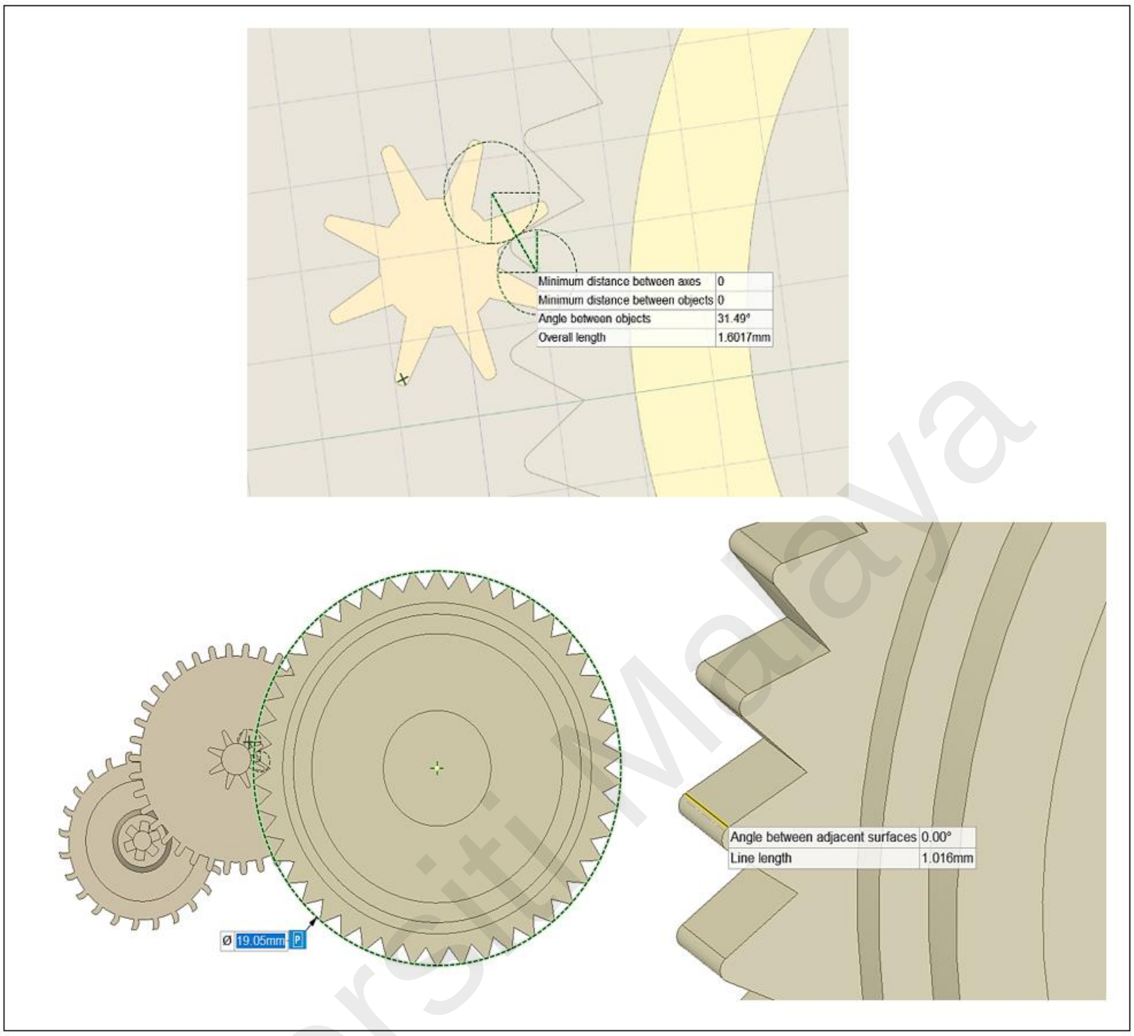


Figure 4-7: Spur Gear tooth dimensions

The results obtain from ANSYS and Hertz Equation calculations for maximum contact stress are tabulated as per below Table 4-4. This is shows that the value from ANSYS simulation is comparable to theoretical Hertz Equation calculations with some different by 5%.

Table 4-4: Contact stress results comparison

Material	Contact Stress (Mpa)		
	ANSYS	Hertz Equation Values	Error %
Acrylonitrile Butadiene Styrene (ABS)	87.86	92.55	5%

4.1.1.3 Equivalent Stress (Gear 1)

Below figure shown for equivalent stress maximum at spur gear 1. The simulation has been done by ANSYS software and analyse the maximum stress is 87.86 Mpa while the minimum stress is 1.39Mpa. May refer to Figure 4-8 and Figure 4-9 where the maximum stress appears at the spur gear teeth. ANSYS software collected few data in term of minimum, maximum and average stress. Tabular data shown in Table 4-5 and graph plotted in Figure 4-10.

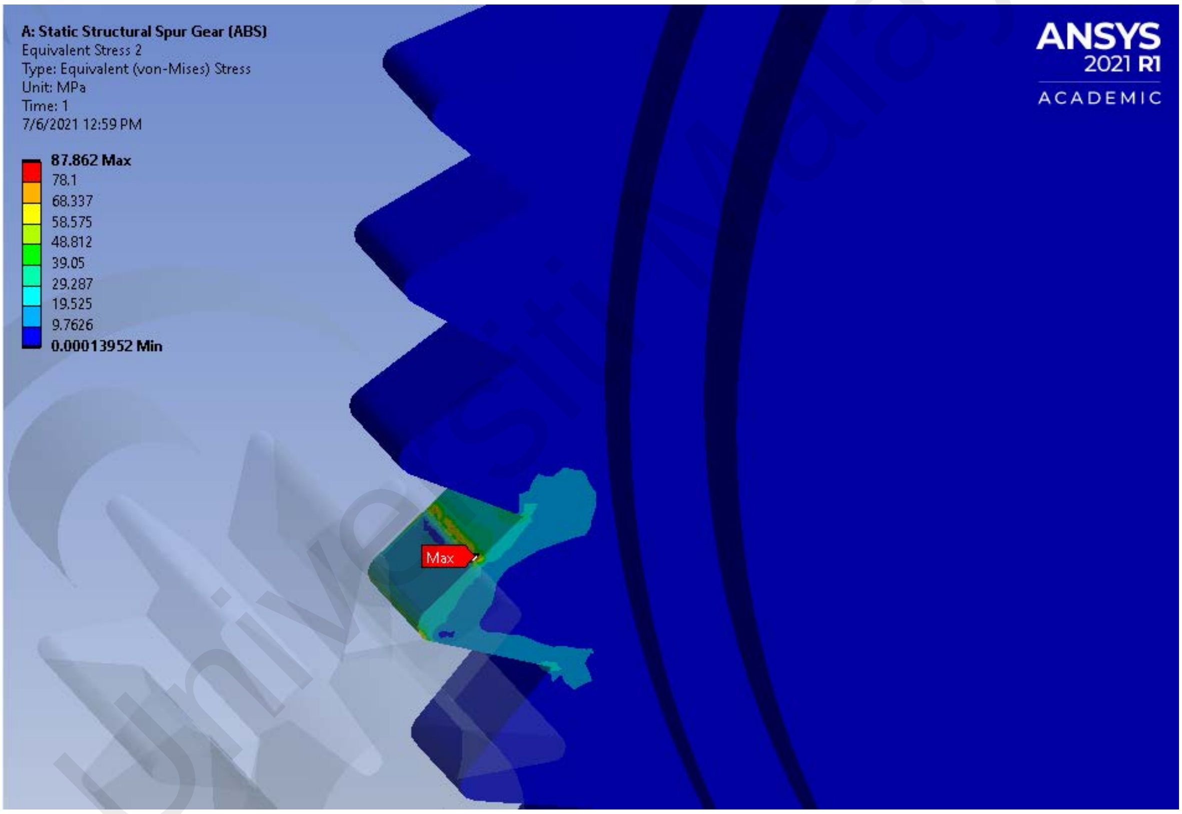


Figure 4-8: Maximum Stress Occur at Gear 2

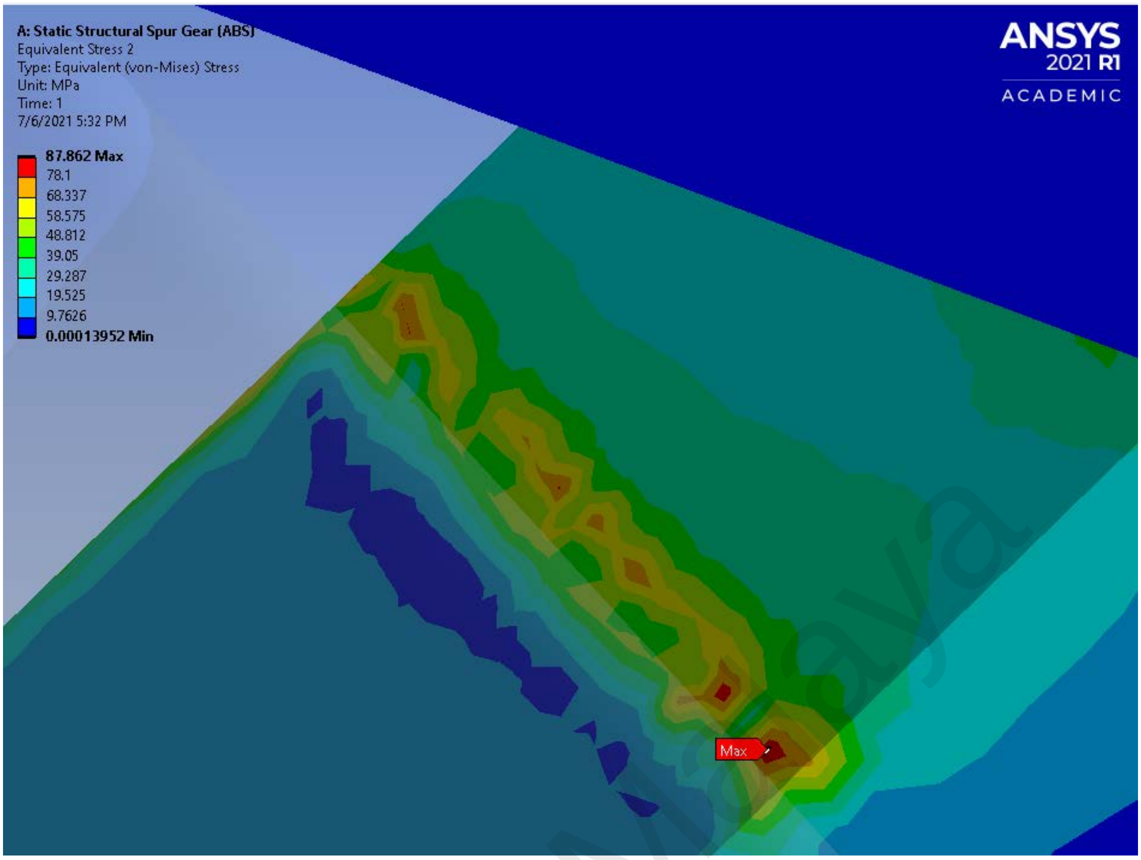


Figure 4-9: Stress Area

Table 4-5: Stress Tabular Data for Gear 1

Tabular Data

	Time [s]	Minimum [MPa]	Maximum [MPa]	Average [MPa]
1	5.e-002	6.9759e-006	4.3931	9.431e-002
2	0.1	1.3952e-005	8.7862	0.18862
3	0.15	2.0928e-005	13.179	0.28293
4	0.2	2.7904e-005	17.572	0.37724
5	0.25	3.4879e-005	21.966	0.47155
6	0.3	4.1856e-005	26.359	0.56586
7	0.35	4.8831e-005	30.752	0.66017
8	0.4	5.5807e-005	35.145	0.75448
9	0.45	6.2784e-005	39.538	0.84879
10	0.5	6.9759e-005	43.931	0.9431
11	0.55	7.6736e-005	48.324	1.0374
12	0.6	8.3711e-005	52.717	1.1317
13	0.65	9.0688e-005	57.11	1.226
14	0.7	9.7663e-005	61.504	1.3203
15	0.75	1.0464e-004	65.897	1.4146
16	0.8	1.1161e-004	70.29	1.509
17	0.85	1.1859e-004	74.683	1.6033
18	0.9	1.2557e-004	79.076	1.6976
19	0.95	1.3254e-004	83.469	1.7919
20	1.	1.3952e-004	87.862	1.8862

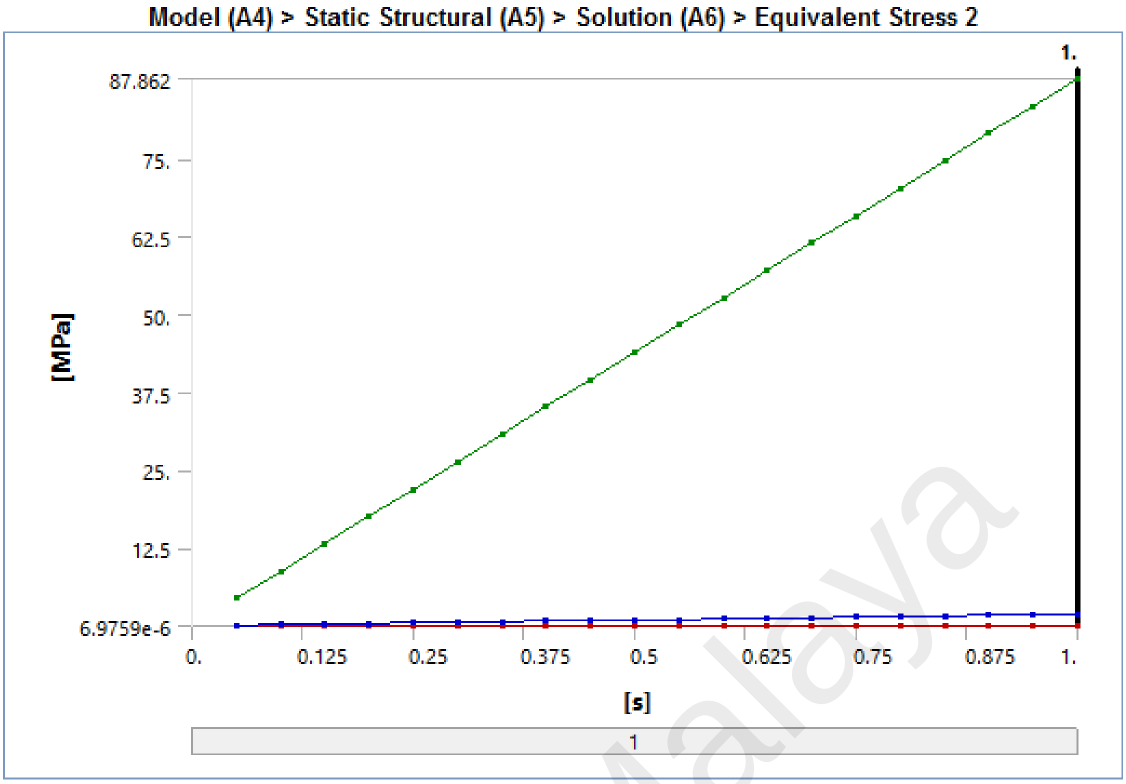


Figure 4-10: Graph Equivalent Stress vs Time for Gear 1

4.1.1.4 Equivalent Stress (Gear 2)

Below figure shown for equivalent stress maximum at spur gear 2. The simulation has been done by ANSYS software and analyse the maximum stress is 66.67 Mpa while the minimum stress is 3.46Mpa. May refer to Figure 4-11 and Figure 4-12 where the maximum stress appears at the spur gear teeth. ANSYS software collected few data in term of minimum, maximum and average stress. Tabular data shown in Table 3-1and graph plotted in Figure 4-13.

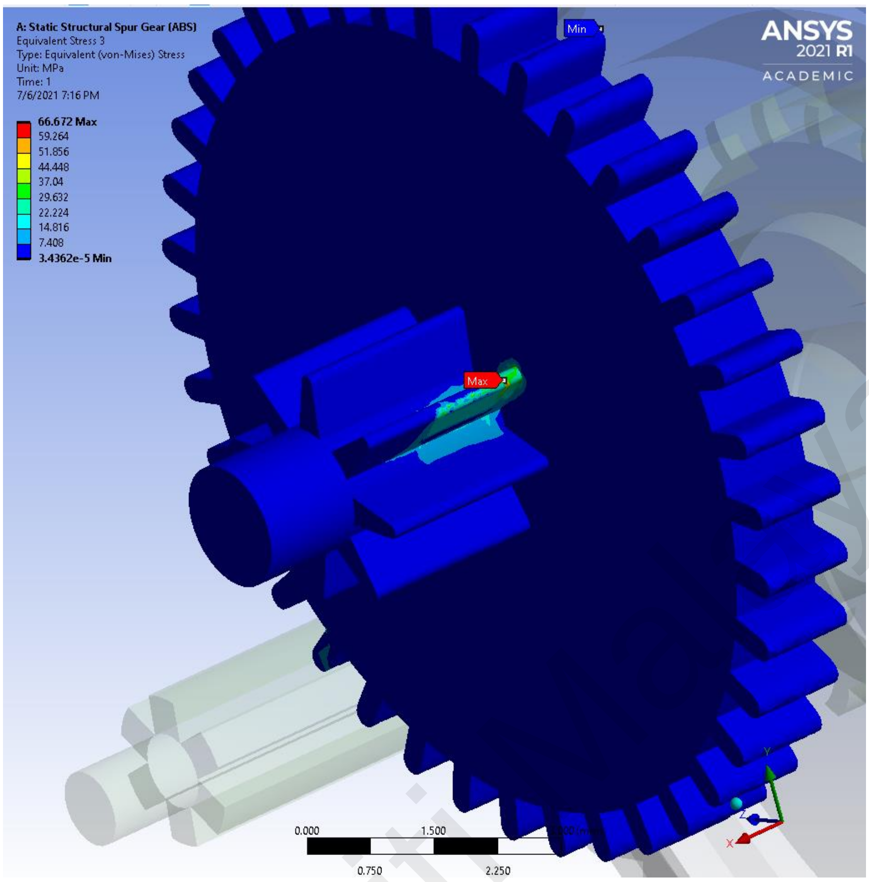


Figure 4-11: Maximum Stress Occur at Gear 2

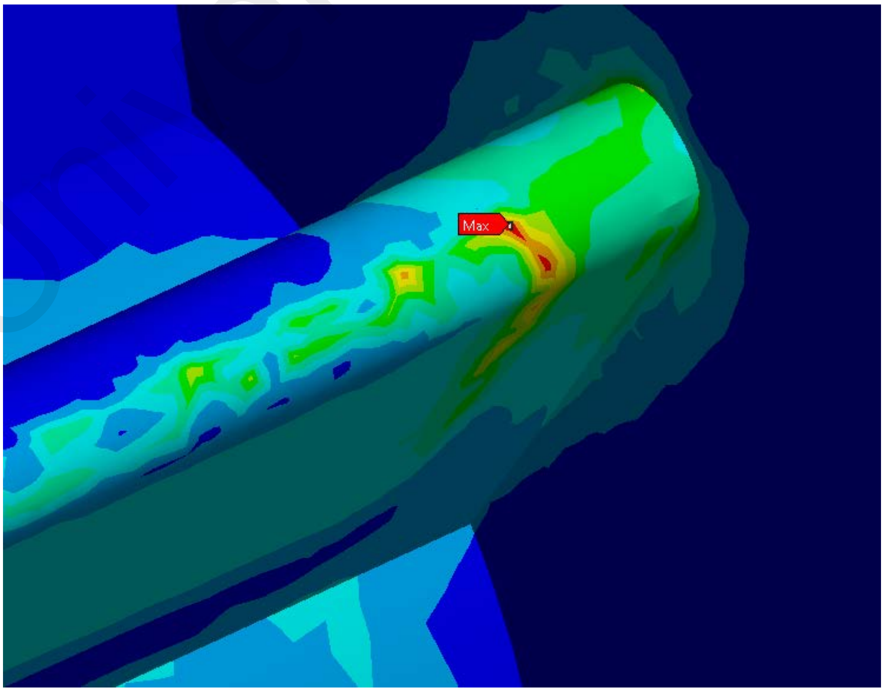


Figure 4-12: Close Up Stress Area Gear 2

Table 4-6: Stress Tabular Data for Gear 2

	Time [s]	Minimum [MPa]	Maximum [MPa]	Average [MPa]
1	5.e-002	1.7181e-006	3.3336	0.10469
2	0.1	3.4362e-006	6.6672	0.20937
3	0.15	5.1544e-006	10.001	0.31406
4	0.2	6.8725e-006	13.334	0.41874
5	0.25	8.5905e-006	16.668	0.52343
6	0.3	1.0309e-005	20.002	0.62811
7	0.35	1.2027e-005	23.335	0.7328
8	0.4	1.3745e-005	26.669	0.83748
9	0.45	1.5463e-005	30.002	0.94217
10	0.5	1.7181e-005	33.336	1.0469
11	0.55	1.8899e-005	36.67	1.1515
12	0.6	2.0617e-005	40.003	1.2562
13	0.65	2.2335e-005	43.337	1.3609
14	0.7	2.4054e-005	46.67	1.4656
15	0.75	2.5772e-005	50.004	1.5703
16	0.8	2.749e-005	53.338	1.675
17	0.85	2.9208e-005	56.671	1.7796
18	0.9	3.0926e-005	60.005	1.8843
19	0.95	3.2644e-005	63.338	1.989
20	1.	3.4362e-005	66.672	2.0937

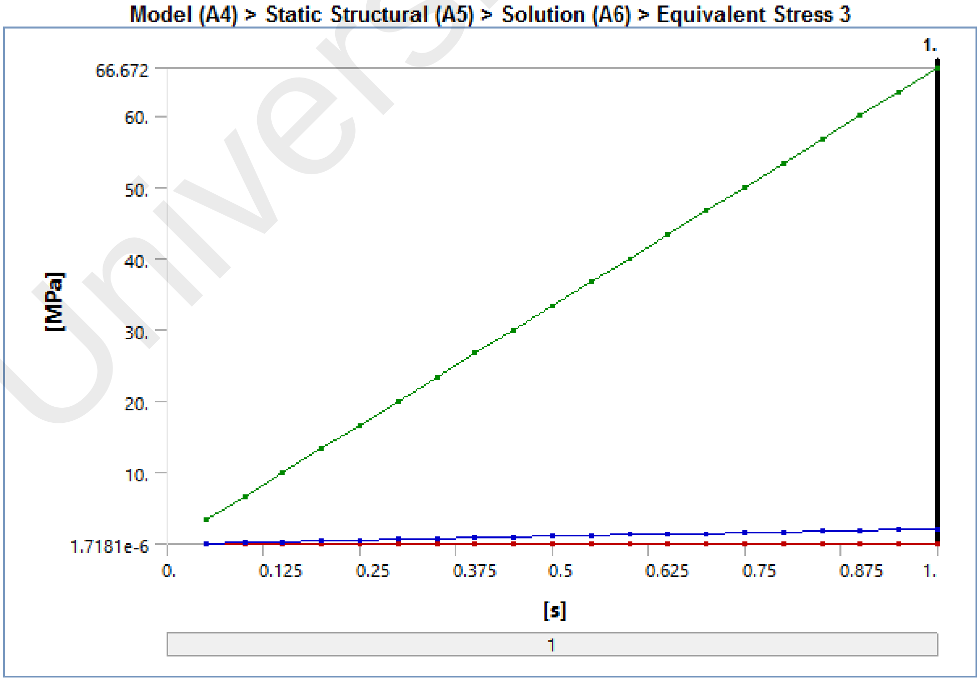


Figure 4-13: Graph Equivalent Stress vs Time for Gear 2

4.1.1.5 Equivalent Stress (Gear 3)

Below figure shown for equivalent stress maximum at spur gear 3. The simulation has been done by ANSYS software and analyse the maximum stress is 6.55 Mpa while the minimum stress is 2.49Mpa. May refer to Figure 4-14 and Figure 4-15where the maximum stress appears at the spur gear teeth. ANSYS software collected few data in term of minimum, maximum and average stress. Tabular data shown in Table 4-7 and graph plotted in Figure 4-16.

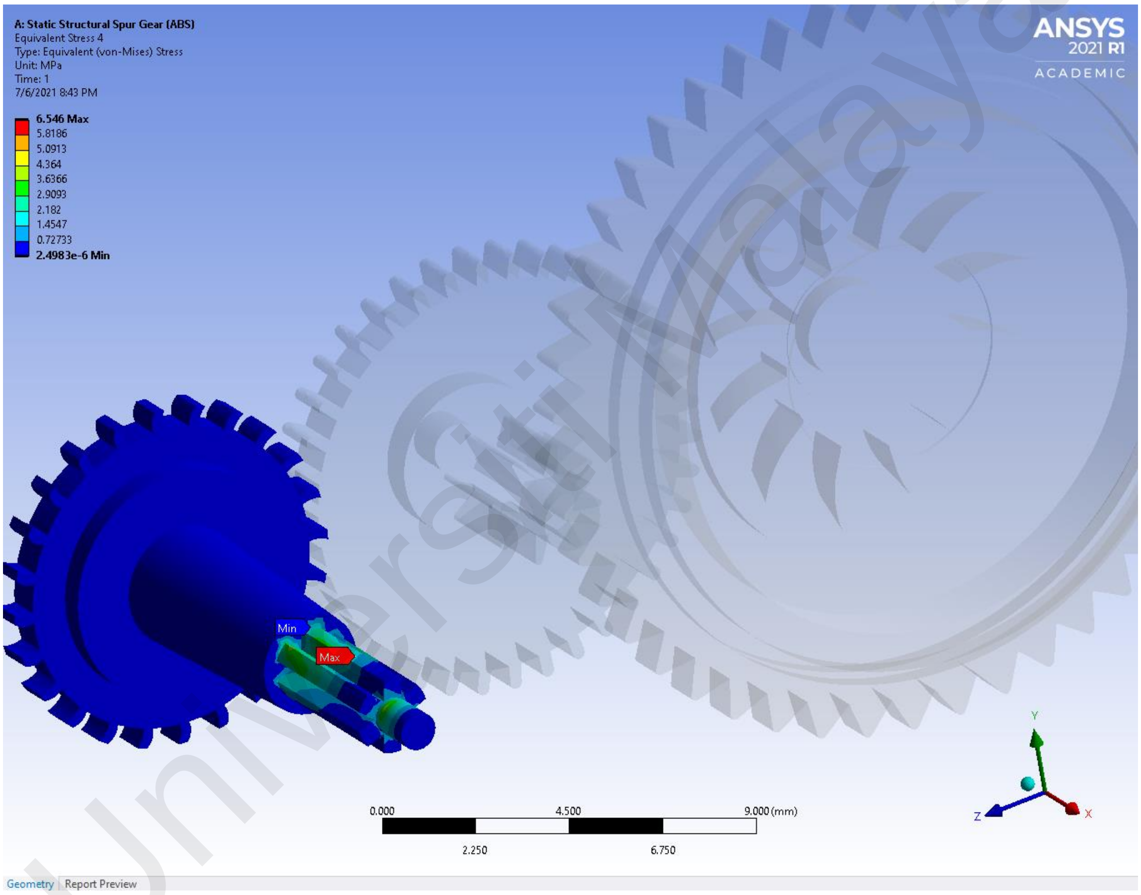


Figure 4-14: Maximum Stress Occur at Gear 3

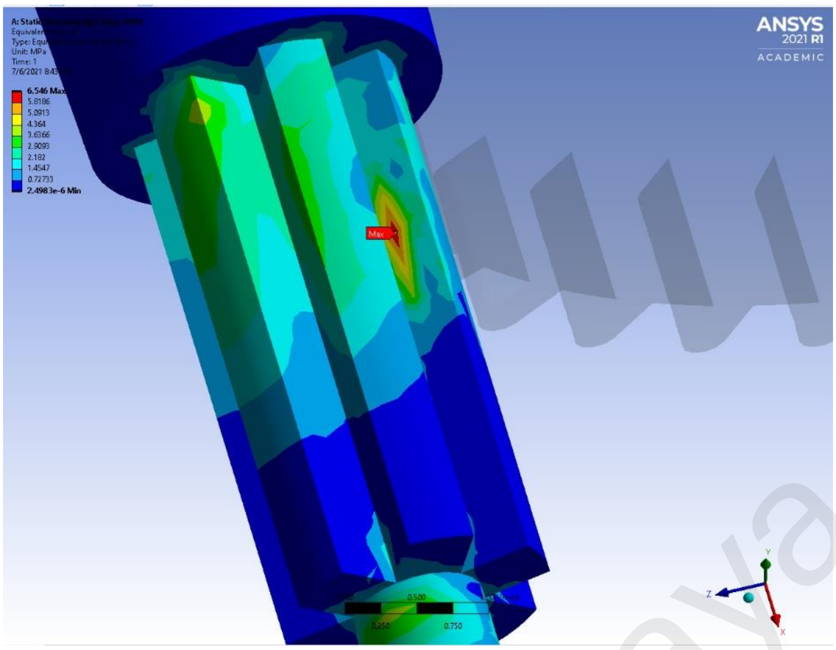


Figure 4-15: Close Up Stress Area Gear 3

Table 4-7: Stress Tabular Data for Gear 3

Tabular Data

	Time [s]	Minimum [MPa]	Maximum [MPa]	Average [MPa]
1	5.e-002	1.2481e-007	0.3273	1.3292e-002
2	0.1	2.4961e-007	0.6546	2.6584e-002
3	0.15	3.7443e-007	0.98189	3.9875e-002
4	0.2	4.9923e-007	1.3092	5.3167e-002
5	0.25	6.2458e-007	1.6365	6.6459e-002
6	0.3	7.4879e-007	1.9638	7.9751e-002
7	0.35	8.7372e-007	2.2911	9.3043e-002
8	0.4	9.9846e-007	2.6184	0.10633
9	0.45	1.1232e-006	2.9457	0.11963
10	0.5	1.2492e-006	3.273	0.13292
11	0.55	1.3728e-006	3.6003	0.14621
12	0.6	1.4976e-006	3.9276	0.1595
13	0.65	1.6225e-006	4.2549	0.17279
14	0.7	1.7474e-006	4.5822	0.18609
15	0.75	1.872e-006	4.9095	0.19938
16	0.8	1.9968e-006	5.2368	0.21267
17	0.85	2.1216e-006	5.5641	0.22596
18	0.9	2.2466e-006	5.8914	0.23925
19	0.95	2.3712e-006	6.2187	0.25254
20	1.	2.4983e-006	6.546	0.26584

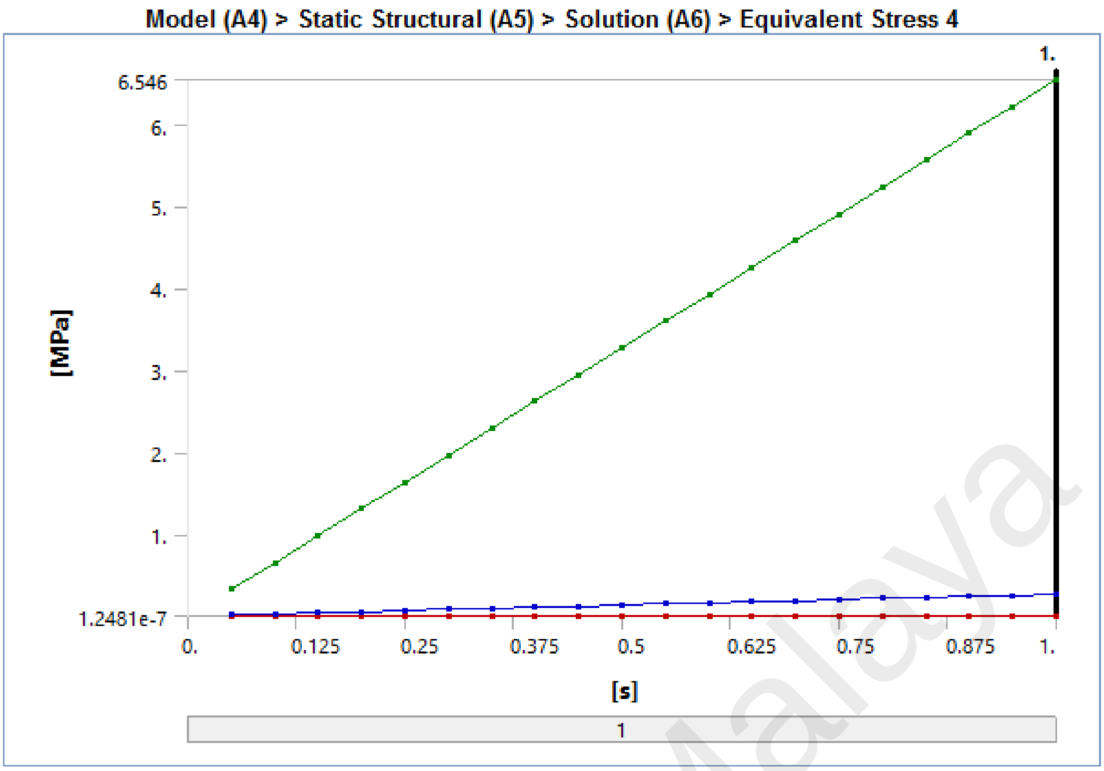


Figure 4-16: Graph Equivalent Stress vs Time for Gear 3

4.1.1.6 Total Deformation

The deformation is observed when 50 Nm load applies to the spur gear. The range of deformation on spur gear is from 0m to 0.0363m. The deformation is highest at the spur gear as can be seen in Figure 4-17.

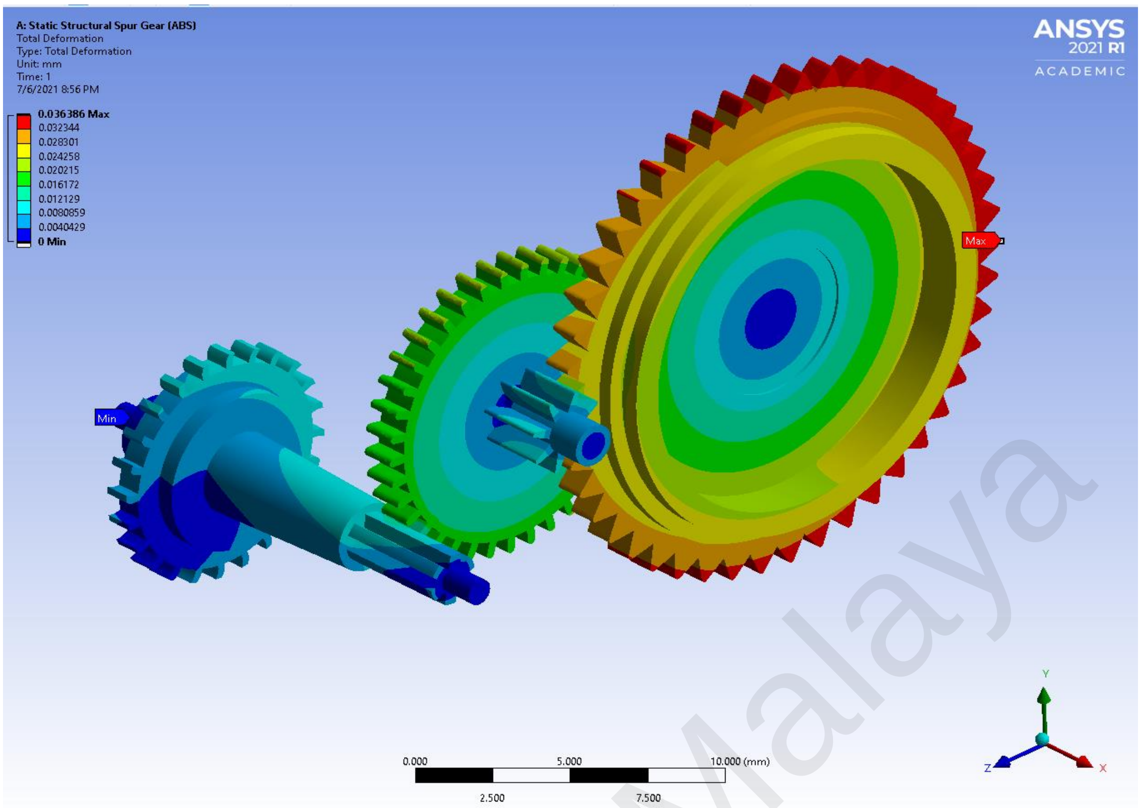


Figure 4-17: Total Deformation on Spur Gears

Table 4-8: Tabular Data for Total Deformation

Tabular Data

	Time [s]	Minimum [mm]	Maximum [mm]	Average [mm]
1	5.e-002	0.	1.8193e-003	8.4042e-004
2	0.1	0.	3.6386e-003	1.6808e-003
3	0.15	0.	5.458e-003	2.5213e-003
4	0.2	0.	7.2773e-003	3.3617e-003
5	0.25	0.	9.0966e-003	4.2021e-003
6	0.3	0.	1.0916e-002	5.0425e-003
7	0.35	0.	1.2735e-002	5.8829e-003
8	0.4	0.	1.4555e-002	6.7233e-003
9	0.45	0.	1.6374e-002	7.5638e-003
10	0.5	0.	1.8193e-002	8.4042e-003
11	0.55	0.	2.0013e-002	9.2446e-003
12	0.6	0.	2.1832e-002	1.0085e-002
13	0.65	0.	2.3651e-002	1.0925e-002
14	0.7	0.	2.5471e-002	1.1766e-002
15	0.75	0.	2.729e-002	1.2606e-002
16	0.8	0.	2.9109e-002	1.3447e-002
17	0.85	0.	3.0929e-002	1.4287e-002
18	0.9	0.	3.2748e-002	1.5128e-002
19	0.95	0.	3.4567e-002	1.5968e-002
20	1.	0.	3.6386e-002	1.6808e-002

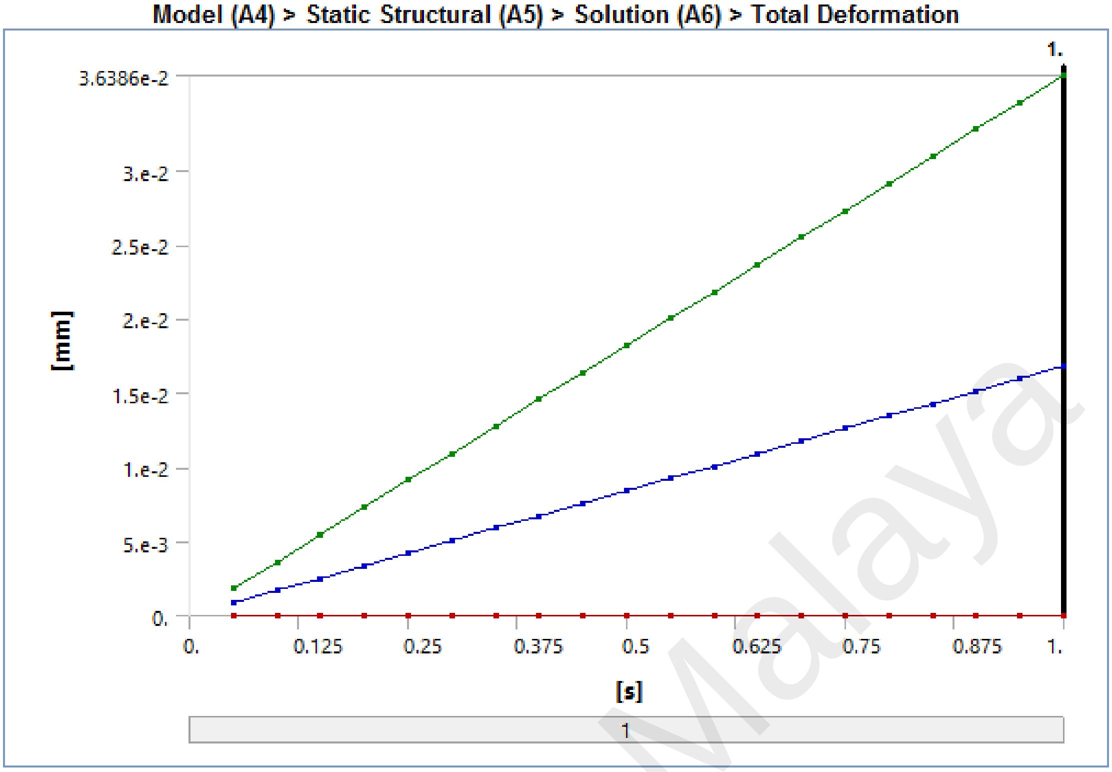


Figure 4-18: Graph Total Deformation vs Time

4.2 Overall Result

The results of FEA for each maximum contact stress location of spur gears are summarized in Table 4-9. Theoretically result obtained by Hertz equation and results are comparable with FEA of spur gear.

Table 4-9: Equivalent Stress for Gears

Material / Gear	Maximum Value of Equivalent (von-Mises) Stress (Mpa)
ABS / Gear One (1)	87.86
ABS / Gear Two (2)	66.67
ABS / Gear Three (3)	6.546

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Research Outcomes

This research project focused on the factor analysis on spur gear failure using computational simulation using ANSYS software. Theoretical knowledge with regards to contact stresses of spur gears revisited, summarized and recorded. Numerous FEA simulations have been successfully conducted in this project, Nonetheless, this research shows that by running the FEA simulation, factor failure and deformation of spur gear can be detected. This research project improves the CFD simulation skills and experiences for other stress analysis purposes in the future.

5.2 Conclusion

This research project has successfully implemented and the research objectives have

been achieved to meet the aim as a whole which can be conclude that maximum contact stress occurs at spur gears which affect the performance of gears. This research project concluded that the FEA simulation is an important tool for static structural studies, whereby a complex numerical calculation on a small-scale simulation can be done in a reasonable time to obtain accurate numerical method result, to make instant decision, particularly changes on design, setting condition, etc., without spending unnecessary time to redo the design and resources to make prototyping or physical hydraulic modelling for this case.

5.3 Future Works

Future works beyond this research project should further demonstrate the extensibility of the simulation by implementing additional variants of design failure to detect factor of failure of spur gear in music box. Suggestion for the continuing of this research will do the correlation between actual test and experiment of factor of failure of spur gear. Also add various of materials or design optimization.

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