GEAR FAILURE ANALYSIS AND HEALTH MONITORING PLAN ON THE MECHANICAL COMPONENT OF AN AMUSEMENT PARK EQUIPMENT

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DECLARATION

I declare that this project report entitled " Gear Failure Analysis and Health Monitoring Plan of Mechanical Component of an Amusement Park Equipment" is the result of my own work except cited in the references.

Signature:

Name :

Date :

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature :

Supervisor's Name:

Date :

DEDICATION

To my beloved father and mother

ABSTRACT

Gears are one of the most important mechanical component in machinery applications. An unexpected gear failure in mechanical equipment can cause a higher downtime. Research has shown that the failure and breakage of the gear is influenced by different type of initiator such as poor maintenance. The aimed for this study is to investigate the failure mode and develop the monitoring plan of the gear. The gear failure is analysed using Finite Element Analysis (FEA). The stress distribution of the gear during contact has been analysed under three different test conditions which is load, pitch circular (teeth size) and pitch diameter. The load values are 500 kg, 700 kg and 1100 kg and pitch circular with different size of teeth; Set 1(2 mm×6.5 mm and 2 mm×7 mm) Set 2(4 mm× 8.5 mm and 4 mm×9 mm) and Set 3 (1 mm×4.5 mm and 1 mm× 5 mm). For the pitch diameter, the load are tested with different diameter of pinion and driven gear which are; Diameter 60 mm and diameter 90 mm;, Diameter 65 mm and diameter 110 mm; and Diameter 100 mm and diameter 150 mm. From the FEA results, it is found that the higher the load given, the higher the stress concentration on the contact surface. The stress increases varies with load due to low percentage of lubricant use thus increase the surface contact of the gear. The rotational gear increases force distribute along the gear mechanism thus increases the stress to the contact surface of gear. Therefore it is recommended that the amusement park gives a proper maintenance of the gear. This mechanical component needs to be checked regularly every 6 months and major check-up can be carried out every 3 years. A correct lubrication type for gear and track need to be used based on the original equipment manufacturer specification.

ABSTRAK

Gear adalah salah satu komponen mekanikal yang paling penting dalam aplikasi jentera. Kegagalan gear yang tidak dijangka pada peralatan mekanikal boleh menyebabkan downtime yang lebih tinggi. Penyelidikan telah menunjukkan bahawa kegagalan dan kerosakan gear dipengaruhi oleh pelbagai jenis pemula seperti penyelenggaraan yang tidak baik. Tujuan kajian ini adalah untuk menyiasat mod kegagalan dan mengembangkan rancangan pemantauan roda gigi. Kerosakan gear dianalisis menggunakan Analisis Elemen Terhingga (FEA). Taburan tekanan gear semasa bersentuhan telah dianalisis di bawah tiga keadaan ujian yang berbeza iaitu beban, lingkaran bulat (ukuran gigi) dan diameter nada. Nilai beban adalah 500 kg, 700 kg dan 1100 kg dan pekeliling nada dengan ukuran gigi yang berbeza; Set 1 (2 mm × 6,5 mm dan 2 mm × 7 mm) Set 2 (4 mm × 8,5 mm dan 4 mm × 9 mm) dan Set 3 (1 mm × 4,5 mm dan 1 mm × 5 mm). Untuk diameter nada, beban diuji dengan diameter pinion dan gear yang berbeza; Diameter 60 mm dan diameter 90 mm ;, Diameter 65 mm dan diameter 110 mm; dan Diameter 100mm dan diameter 150mm. Dari hasil FEA, didapati bahawa semakin tinggi beban yang diberikan, semakin tinggi kepekatan tegasan pada permukaan kontak. Tekanan meningkat berbeza dengan beban kerana peratusan penggunaan pelincir yang rendah sehingga meningkatkan permukaan permukaan gear. Gear putaran meningkatkan daya mengedarkan di sepanjang mekanisme gear sehingga meningkatkan tekanan ke permukaan sentuhan gear. Oleh itu, disyorkan bahawa taman hiburan memberikan pemeliharaan gear yang betul. Komponen mekanikal ini perlu diperiksa secara berkala setiap 6 bulan dan pemeriksaan besar dapat dilakukan setiap 3 tahun. Jenis pelinciran yang betul untuk gear dan trek perlu digunakan berdasarkan spesifikasi pengeluar peralatan asal.

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TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVATIONS

RUL	Remaining Useful Life
CBM	Conditioned-Based Maintenance
OEM	Original Equipment Manufacturers
SHM	Structural Health Monitoring
FMEA	Failure Mode and Effect Analysis
UGW	Ultrasonic Guide Wave
ROT	Effective Remaining Operating Time
MTBF	Mean Time Before Failure
MTTR	Mean time To Repair
RPN	Risk Priority Number
EQN	Equation
O	Frequency of Occurrence
S	Detection Rating
D	Severity

CHAPTER 1

INTRODUCTION

1.1 Background

Amusement Park is a park features various attractions such as rides and games. As for the equipment maintenance is a continuous cost which draw the intention of the production management to plan the maintenance as it can increase the reliability of the Amusement Park equipment mentioned in journal (Mourtzis et al., 2016). Maintenance is an activity which affect the lifecycle which affect the total cost to do maintenance based on journal (Dhilon BS, 2006). Maintenance in machinery involving the Amusement Park usually lies on the way to prevent the equipment from failure thus reducing maintenance time and cost (Li et al., 2019).

It is common for original equipment manufacturers (OEMs) of high value product to provide maintenance or services packages to customers to ensure that their product are maintained to a longer lifetime as shared in journal (Ng et al., 2017). The data from the product monitoring are commonly generated thus transmitted back to OEMs to be diagnostic and prognostic analysis to be carried out. The conditioned-based maintenance (CBM) approach is used to encounter the mechanical equipment problems at Amusement Park. The CBM requires constant monitoring of the real time product working. The machine condition can be monitored using normal condition signals by applying methods which involved mechanical condition monitoring and fault diagnosis (Jiang et al., 2012). The CBM is also use to reduce the downtime and the cost of maintenance to a target of zero failure during working hours in the amusement park by monitoring the working condition of the mechanical equipment thus predicting the mean time to failure of the equipment (Li et al., 2019).

Monitoring plan works as an advanced monitoring system which uses certain technique to be able to detect equipment condition before the equipment fail (Takata S et al. 2004)

1.2 Problem Statement

The Ferris wheel has undergone a major breakdown due to the failure system of gear mechanism. Severe damage had occur to one of the pinion gear which causes gear failure which can occur due to excessive wear, fatigue crack, overload breakage or random fracture which can be cause by poor maintenance to the gear mechanism of the Ferris wheel. The poor maintenance may lead to excessive wear and causing a fatigue crack to the gear due to improper maintenance to the Ferris wheel in term of lubrication and maintenance frequency. Poor lubrication are due to incorrect consistency, mixing, incorrect lubrication used or degraded grease or oil. The overload breakage may lead failure to the gear because of the excessive stress load between the contact gear surfaces on the teeth of gears thus high stress produce can cause defect to the gear teeth. The gear failure can occur due to improper design and wrong material selection which are not adequate for the conditions of gear mechanism. Furthermore, due to improper maintenance, the shutdown of the Ferris wheel lead to a longer maintenance period. This problem rise due to unidentified causes which lead to unspecified alternative to overcome the problem. To encounter the problems face at the amusement park, the failure mode of the gear of the Ferris wheel is tested with different test analysis parameter and health monitoring plan is scheduled for proper maintenance to the Ferris wheel at the amusement park.

1.3 Objectives of study

i. To develop the health monitoring plan of the fail mechanical component.

ii. To investigate the failure mode of the mechanical component of amusement park.

1.4 Scope of Study

i. Gear failure analyse of Ferris wheel.

ii. Simulation of the working condition of until a specific gear is broken.

iii. Proposing a Monitoring Plan and optimum working condition.

CHAPTER 2

LITERATURE REVIEW

2.1 FMEA

Failure Mode and Effect Analysis (FMEA) is one of the most commonly used to analysis in term of complexity and time consuming as stated by (Cândea et al., 2014). The FMEA is also based on case-based reasoning to reduce the time and effort of doing the analysis as written by (Cândea et al., 2014). As stated in (Renu et al., 2016), FMEA can be divided into two groups of monitoring which is design FMEA and process FMEA. (Renu et al., 2016) stated that the design FMEA focus on the analyst of the equipment design and function ability whereas process FMEA is investigating the manufacturing, assembly of equipment thus identify and analyse to obtain the places where potential failure could occur in an equipment.

Furthermore, FMEA is known as the powerful method to define, identify and eliminate the known or unknown potentials of occurring failures, problems or error from the design of the equipment, the system flow of the equipment or mechanical component stated in (Renu et al., 2016) and lastly, written by (Cândea et al., 2014) FMEA has the main objective to allow analysis of the current equipment thus avoiding and prevent the known or potential failure before the occurrence thus the action can reduce the failure rate which started with the highest-priority to be handled.

FMEA which is known as the to help with the potential failure modes and their causes and effects which can be used as corrective action and the priority of failure mode can be determined by calculating the risk priority number (RPN) which is defined as product of occurrence (O), Severity (S) and detection (D) as shown in Figure 1.

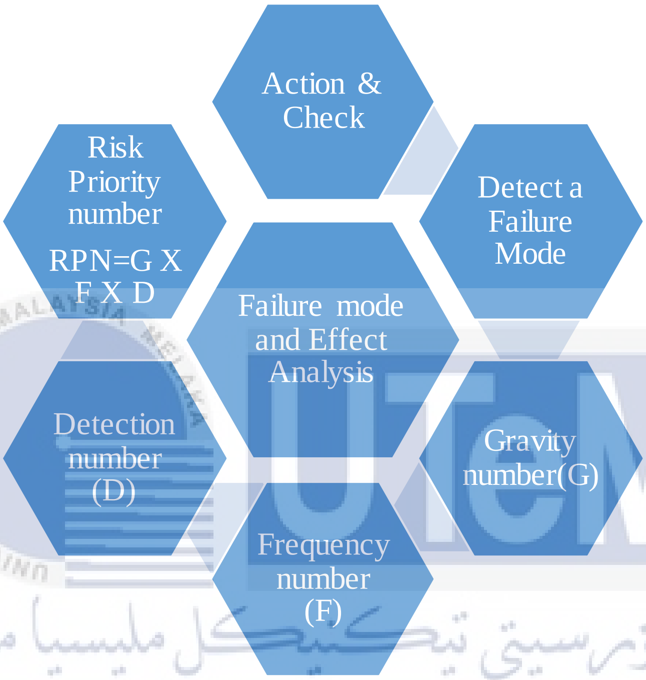


Figure 1:Main steps of FMEA (Cândea et al., 2014)

FMEA-driven software can be used as a preventing way process. It is used in both design and manufacturing thus the process are based on the worksheet which contain information gathered as stated in (Cândea et al., 2014).

$$RPN = O \times S \times D \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eqn.1)}$$

Where RPN= Risk Priority Number

O= Frequency of occurrence

S= Detection rating

D= Severity

When the three factors of frequency, severity and detection is calculated, the field of scope to do the inspection are shorten because the most prioritise is to ensure that the corrective action is done to the highest RPN value. The case data which contain any information is stated in the worksheet as shown in Figure 2 and Figure 3 below stated by (Cândea et al., 2014).

Item no.	Process Stepp/Input	Potential failure mode (deficiency)	Potential Failure Effects	G	Characteristic type C	Potential Causes	F	Verification measures to prevent	Verification measures to detect	D	C (GxFxD)
1	2	3	4	5	6	7	8	9	10	11	12
9	Conformity from the reference components (CAR EU-0000158397)	Mixed components (mix pipe with pipe from 790065-0005)	Scraps	7	C	Components mixed by supplier	2	Component validation at the reception	visually	6	84
				7	C	Components mixed on insert line.	2	Component validation at the reception	visually	6	84
				7	C	Components have not been identified during insert process.	2	Component validation at the reception	visually	6	84

Figure 2: Example of FMEA case representation-problem sheet (Cândea et al., 2014).

Action plan		The result of actions				
Suggested remedies as required	Responsible; Term	Data verification / measures taken	G	F	D	C
13	14	15	16	17	18	19
Send 8D report to the supplier in order to identify potential causes for mix components.	10.12.10		7	1	6	42
Update the process audit with checkings regarding change of production.	10.12.10		7	1	6	42
Update the Control Plan with reference correspondence between pipe and the reference in working during the change of production.	10.12.10		7	1	6	42

Figure 3: Example of FMEA case representation –solution sheets (Cândea et al., 2014).

2.2 Structural Health Monitoring

Structural Health Monitoring (SHM) is defines as process of implementing a damage detection strategy for civil, mechanical and aerospace (Sohn et al., 2001). Usage monitoring (UM) is one of the method used to measure inputs and responses of a crack damage structure. The usage monitoring is taken by using regression analysis to be performed thus the analysis done can be used to detect and predict the damage of the structural condition.

SHM involves in observation and monitoring of structure using sensors. The measurement of dynamic characteristics of structure was done thus the data obtain with the use of post processing and damage evaluation models which will give result in the structural integrity of the structure. Permanently mounted sensors in detecting local damage at single or specific point which can be combined with other SHM technique. The current SHM technique are either visual or localized methods such as acoustic or ultrasonic methods, eddy-current methods, radiography methods or magnetic fields methods (Sohn et al., 2001).

SHM is differ from NDT technique due to the use of sensors which are permanently mounted on the object and reports continuously obtain as if it is online monitoring system. Condition monitoring (CM) is an implementation of measurement system for machinery during operation which also shows that CM has similarities with SHM.

In this study, the knowledge about monitoring is important. The failure modes and monitoring techniques need to be established. SHM main objective is to reduce cost as the monitoring is to identify the critical failure modes as example is monitoring the mechanical component of certain structure. For example, if fatigue cracks are important to be tested, thus the location of the crack is investigated and analyse.

In Figure 2, SHM method shows the break down to a certain element which have mainly four different phases. This can be seen as iterative process whereby the steps are depending to each other. The planning phase is where the scope of SHM is defined. The major things to be checked is when, why, how and what do we need to monitor? (Sohn et al., 2001).

Data collection phase is the phase where the actual monitoring process is applied, the measurement technique and sensors to detect failure or cracks need to be done. The mechanical component is analyse. Data processing phase in SHM process involve selecting the number, type and location of where the sensors are used (Sohn et al., 2001). Data [processing involves the use of collected data or result which is transform into possible to understand and evaluate. Several transformation of data used based on certain method to identify the damage indicator which is sensitive to damage from certain defects such as vibration or crack. Lastly, the evaluation of processed data via feature extraction and data compression to measure the state of the mechanical structure by comparing data collected from the visual inspection and examination of the compartment parts. This method for damage identification can be classified into several levels whereby level 1 is to determine damage present in the mechanical component or structure. Next, level 2 which is to determine the specific location of the damage on the mechanical component while level 3 is to measure the severity of damage on the component or structure and lastly level 4 is to predict the remaining service life of the mechanical component or structure. Due to SHM method the technique to identify the damage on the mechanical equipment is shown in Figure 4.

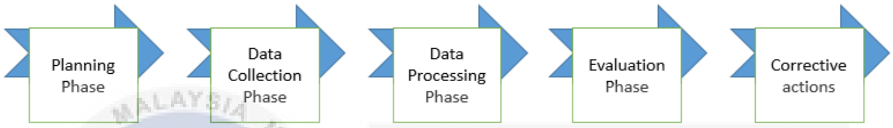


Figure 4: SHM flow method (Sohn et al., 2001)

2.3 Type of Mechanical Component

The mechanical component can be divide into few parts such as frame members, bearings, gears, splines, springs, seals, fasteners and covers. The basic structure and component which are in the amusement park that need to be inspect and monitor constantly such as tracks, rails, bolts, gear and other parts.

The mechanical component selected for the monitoring plan is gear of the amusement park component of Ferris wheel. A gear is basically a rotating machine part which have certain diameter of teeth that need to be mesh with another tooth part in order to transmit the torque. Gear are almost unavoidable component of every machine. The gear design ranges from simple to sophisticated gear pairs which is known to their complexity which is vulnerable to failure (Vukelic et al., 2019).

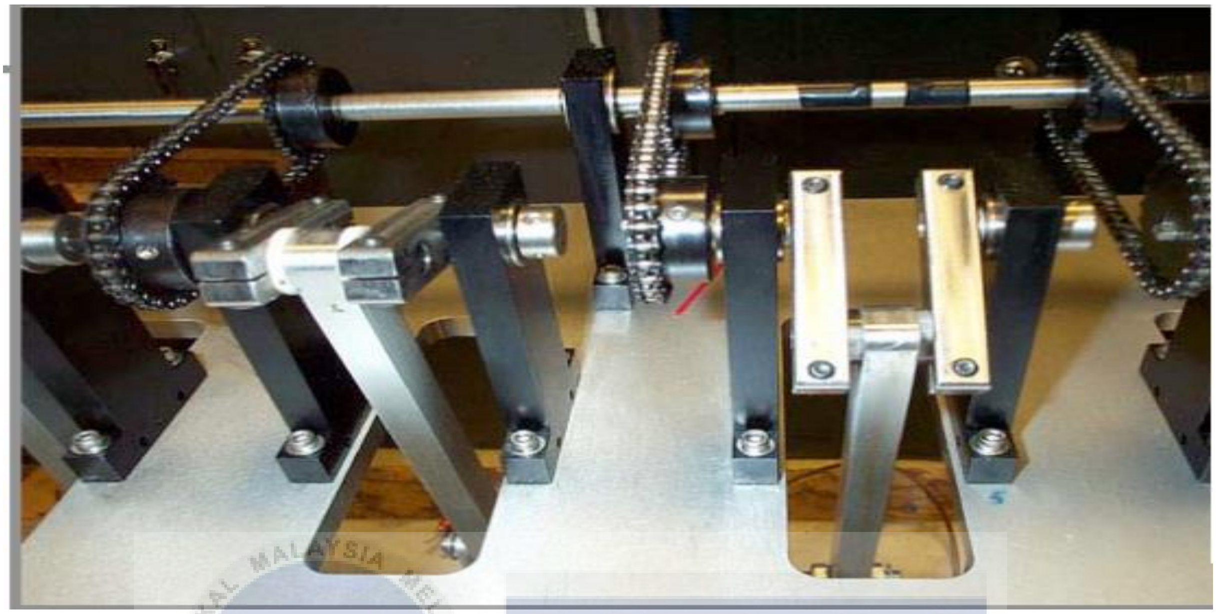


Figure 5 : Linkages gear (Opencourseware, 2009)

The gear component can be in the form of linkages as stated in (Opencourseware, 2009). The linkage is like a system which connect joint with a rotary or a linear type bearing thus allowing motion of occur as shown in Figure 5.

Gears are divided into several types which are worm gear, helical gear and spur gears. The gear are called pinion where the smaller gear drives another gear on the output shaft. Gears are generally used for a few reason which is to reverse the direction of rotation, to increase or decrease the speed of rotation, to move rotational motion to a different axis and also to keep the rotation of the two axes synchronized. The teeth of the gear is to prevent slippage between the gears, thus the axles connected to the gears must be always synchronized.

Figure 6: Bevel Gear(Watson, 1970)

Bevel gear as shown in Figure 6 stated by (Opencourseware, 2009) which have teeth cut on a cone instead of a cylinder black thus this gear type are used in pair in order to transmit the rotary motion and torque whereby the bevel gear shaft must be 90 degree to each other. The example shown in Figure 6 is shared by (Kohara Gear Industry CO., 2006).

Figure 7: Worm Gear (Watson, 1970)

The other form of gear is worm gear as shown in Figure 7. This worm gear has a screw thread combine with the helical gear. The worm gear drives the worm wheel while the worm wheel transmit the torque and the rotary motion. The advantages of worm gear is the mechanism has a quite running progress.

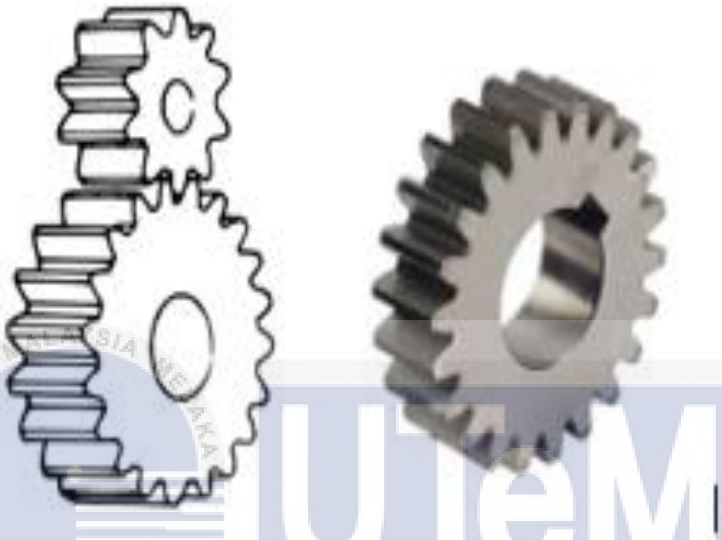


Figure 8: Spur Gear (Watson, 1970)

Beside a rack and pinion mechanism can be used to change the rotational motion of the gear into linear as shown in Figure 8. The function of spur gears is to transmit motion between the parallel teeth to the axis. When two spur gears with different mesh are locate together, the larger gear is called a wheel while smaller gear is called as pinion as stated by (Jayakiran Reddy & Pandu Rangadu, 2018). The input motion and force is applied to the driver gear and the output can be achieved by the transmission by the driven gear. It is obvious that the tooth encounters the maximum stress which will be resulting tooth failure.

There are three categories of gears accordance with the orientation of axes which is cited from (Kohara Gear Industry CO., 2006) as shown in Table 1 below.

Table 1: Categories of gears

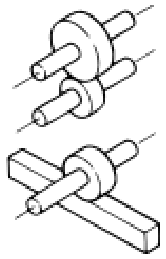
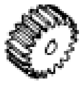
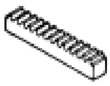
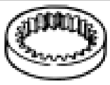
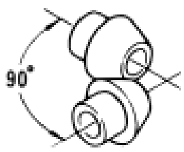
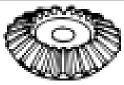
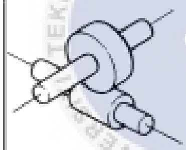
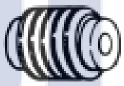
1) Parallel Axes 	Spur Gear		MSGA(B),SSG(S),SS,SSA,SSY,SSAY, LS,SUS,SUSA,SUSL,DSL,NSU,PU, PS,PSA,DS,BSS,SSCPG(S),SSCP, SUSCP,SSR,KTSCP
	Helical Gear		KHG,SH
	Rack		KRG(F),KRGD,SRGF,KRF,SR(F), SRFD,SUR(F),SURFD,BSR,DR, PR(F),SRO,SROS,SURO,KRHG(F), SRH,KRG(F)(D),SRCP(F)(D),KRCPF, SURCPF(D),SRCP,FRCP
	Internal Gear		SI,SIR
2) Intersecting Axes 	Miter Gear		MMSG,SMSG,MMSA(B), MMS,SMS,SMA(B)(C),MM,LM, SM,SAM,SUM,PM,DM
	Straight Bevel Gear		SB,CB,SBY,SUB,PB,DB
	Spiral Bevel Gear		MBSG,SBSG,MBSA(B),SBS,KSP
3) Nonparallel, Nonintersecting Axes 	Screw Gear		AN,SN,PN,SUN
	Worm		KWGDL(S),KWG,SWG,SW,SUW
	Worm Wheel		AGDL,AGF,AG,PG,CG,BG

Figure 9: Helical gear

Furthermore, as shown in the Figure 9 share by (Watson, 1970) the teeth are bent toward the axis of rotation. The transmission rotation between parallel shafts in the same way as spur gears, but it has less noticeable than spur gears related to the more gradual engagement of the teeth during meshing and therefore more suitable for transmitting movement at higher speeds.

2.4 Types of damage to the mechanical component

The incidents occur involving the amusement rides are huge based on the classified reports. 182 accidents were reported from over 38 countries which involved fatality from the mechanical rides and roller coasters. The amusement park or theme park such as mobile rides and waterparks also involved in the similar cases (Woodcock, 2019). Understanding the causes of gear damage and failures are important as a contributor to prevent a major damage to the gear.

2.4.1 Gear damages

There are a few type of severity damage. Severity damage can be due to heavy damage to the equipment or component. This includes the broken of certain parts such as broken axles, bending of frames or fracture of component. . There are a few failures which can occur to a gear such as polishing, moderate or excessive wear, abrasive or corrosive wear, fatigue crack, overload breakage and random fracture.

There are also two common localized gear tooth defect such as tooth filler crack and tooth surface spalling. The filler crack usually occurs at the tooth fillet region whereby the caused is due to damages to the gear tooth resulting stress concentration point act as the root cause damage (Vukelic et al., 2019). The fillet crack also developed near the pitch circle of the tooth surface which affecting a higher mesh force. Furthermore, as for tooth gear spalling occurs when a damage initiators such as extreme localized contact stress is pressured on the gear. The inspection services of amusement park are mostly subjected to weather or stress-related defects which includes corrosion, cracks and splits, debris build up, misalignment, structural fatigue, and vibration.

The most common damage can occur to the mechanical component is fatigue failure or misalignment due to vibration. The fatigue failure will starts with crack initiation, crack growth under cyclic loading and final failure. Based on Figure 10, the crack on gear teeth occurs due to deficiencies in the gear tooth which result stress concentration point on the gear to allow the damage to occur. The gear damage can occur due to the lack of lubricant used and also lack of maintenance done to the property.

Figure 10: Fatigue crack on gear teeth (Eugene E.Shipley (1967).)

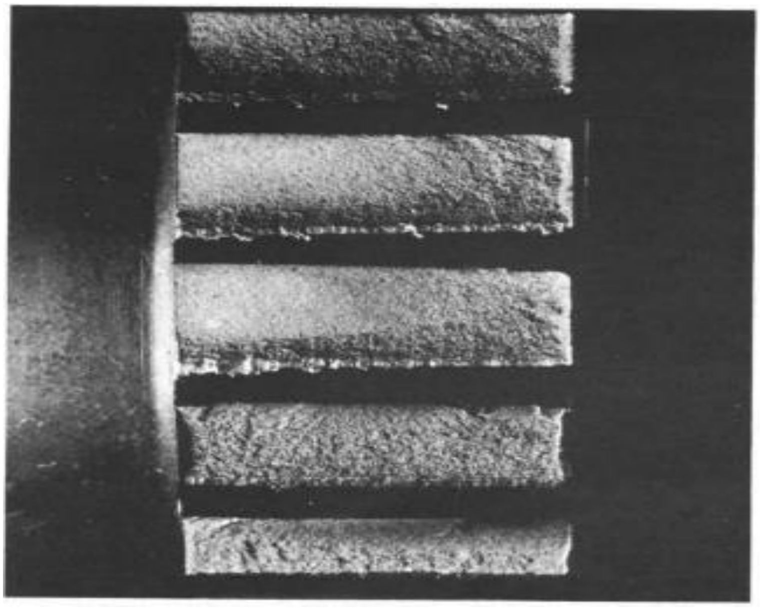


Figure 11: Overload Crack (Eugene E.Shipley (1967).

The overload fracture can be seen if the fibrous break showing the effect like being pulled or torn apart. The causes to the tooth breakage is caused by an overloaded which exceed the tensile strength of the gear material thus resulting a failure. This kind of failure shown in Figure 11 where is occur due to some unpredictable occurrence such as misalignment or vibration or pressure defects.

2.5 Damage detection technique

There are several technique that can be used to identify the damage on the mechanical component or equipment which can be tested during the monitoring of the amusement park mechanical equipment.

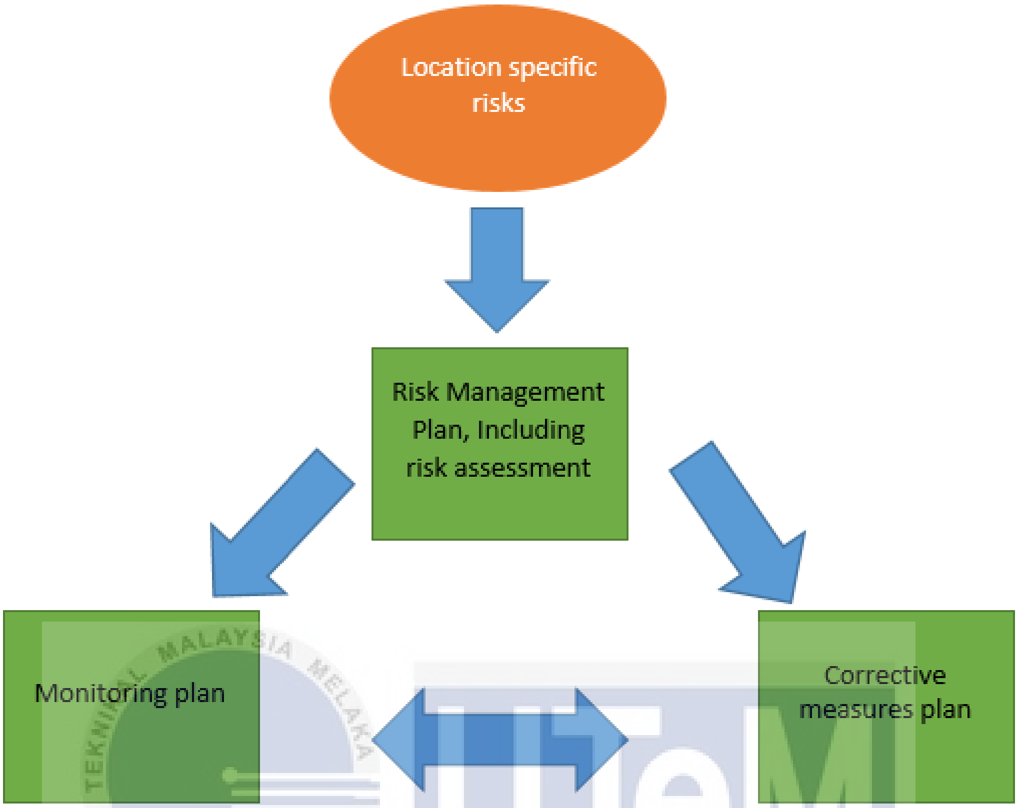


Figure 12: Consistency between risk management monitoring and corrective measure plan during damage crack detection (Steeghs et al., 2014)

Figure 12 illustrates the links for the consistency between plans of technique states in (Steeghs et al., 2014). The damage detection risk need to be evaluate before maintenance can be done to the mechanical component. The risk management step is to identify the risk then analyse the current condition of the risk to the current equipment. Next is to start monitoring plan which can be in term of temperature monitoring, pressure monitoring or visual monitoring which can be monitored to allow corrective plan. Corrective plan is based on the risk assessment. If monitoring plan triggered from potential leakage or defects to the mechanical component, the corrective measures will become operative if the event of leakage or irregularly occurring.

2.5.1 NDT technique

Structural damage found by the typical Non-destructive technique (NDT) like visual, acoustic, magnetic field or strain measurement are categorized under local damage technique. Local damage technique are restricted to detect damage at certain point which the sensor is installed. Based on the component which are examined, NDT inspection method are in the large portfolio of technique and capabilities to be applied. There are a few methods of NDT which are visual technique (VT), ultrasonic technique (UT) and ultrasonic guide wave (UGW) technique.

The NDT inspection or method is possible to be used to assess the condition of the amusement equipment of Ferris wheel and jumping star without disassembly or structural interference.

2.5.1.1 Visual Technique (VT)

Visual inspection is done to the defected mechanical component to determine the fracture and crack location as stated by (Vukelic et al., 2019). There can be such defects on surface but due to complicated 3D curves shapes, it is limited to do inspection except manually as stated by (Bračun & Lekše, 2019).

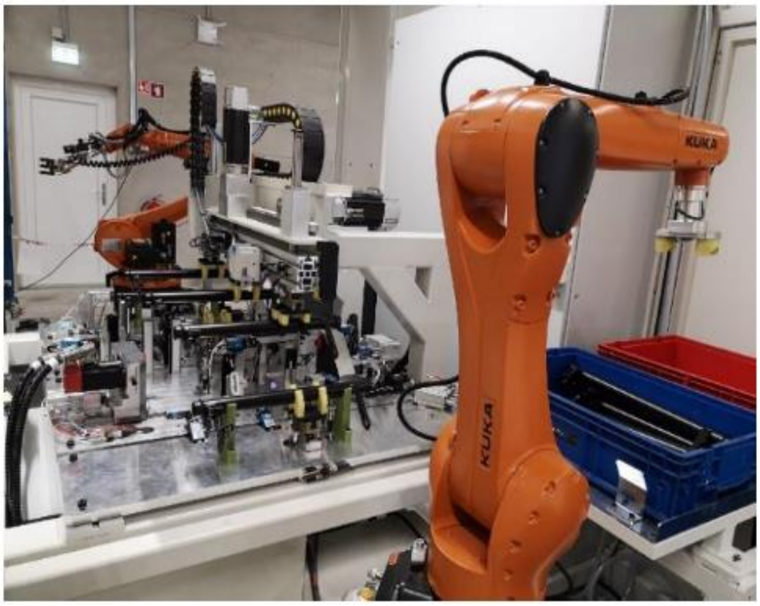


Figure 13: Automated visual inspection system (Bračun & Lekše, 2019)

The visual inspection can be in form of checking the coating or surface defects and (Bračun & Lekše, 2019) also states that the several specific defects location can be detected also by using automatic visual inspection as shown in Figure 13.

2.5.1.2 Ultrasonic Guide Wave (UGW)

The ultrasonic guide wave (UGW) is one of the most commonly used technologies for non-destructive testing and structural health monitoring (SHM) of structural component. The superior long range diagnostic capability, this recent method is effective in detecting cracks, fatigue based defects and the material loss (Abbas & Shafiee, 2018).

The structural degradation processes may occur in different form of fatigue crack, corrosion, erosion and also the strength reduction (Animah & Shafiee, 2018). The guided ultrasonic wave offering a high potential to an alternative solution to conventional approach toward NDT and SHM. The guided wave also has potential to be used in curved structure, therefore the guide wave are suitable to be inspection method for various type of shapes of component and can be used for a longer distance component (Abbas & Shafiee, 2018). The UGW has high sensitivity towards surface. The UGW is possible to identify the larger defects distance with a low distinct frequencies. The UGW method are commonly used to detect corrosion under insulation in pipelines and metallic or non-metallic surface (Abbas & Shafiee, 2018).

2.6 Life prediction and extension of equipment

The operational lifetime are subjected to certain type or several of degradation mechanisms such as corrosion, erosion, creep, fatigue crack and lastly wear and tear. The extending life span of the asset such as mechanical component beyond the original design life are crucial thus making life extension (LE) is important for the lifespan of the mechanical component in an equipment or amusement park (Animah & Shafiee, 2018). This could led to increase of the initiatives to aim for a better extending of the service lifespan of existing installed equipment in the amusement park (Animah & Shafiee, 2018). The life prediction theory which is based on the condition monitoring is an important research as continuous monitoring and testing can be done to the equipment (Wang et al., 2018).

The maintenance procedures must be followed as stated by the original equipment manufacturer (OEM) (Animah & Shafiee, 2018). The Life extension of certain equipment can be based on three main access which is condition assessment , remaining useful life (RUL) prediction and lastly life extending decision making (Animah & Shafiee, 2018). The operational lives of assets or component not only depending to the environmental loading conditions but can be in terms of component condition itself (Animah & Shafiee, 2018).

The proportional hazards model (PHM) analyses censored data, which establishes the failure or certain failure model based on the equipment condition monitoring and the history of the life data of the equipment (Wang et al., 2018). The other method to predict remaining life prediction of equipment is by using state-space Switching Kalman Filter (SKF) which is based on the degradation model (Wang et al., 2018).

In real life application of the theory of prediction, the trend of the prediction is a key to a certain component to have the remaining life time prediction thus by increasing the accuracy of the trend prediction will increase the equipment remaining life time (Wang et al., 2018). The current prediction method include curve-fitting methods, the time-series method, neural network method, support vector machine method and lastly the grey model methods.

The curve-fitting method is the easiest or simplest but the accuracy of prediction is low. The standard time-series prediction methods are based on certain autoregressive model and the prediction is low but it is suitable for short-term prediction. The neural network methods are method which support only vector machine which required trained data and disadvantages because this method cannot be used for trend prediction with little data set. Lastly , the grey system theory is some evaluation law of things that is based on the analysis of lacking systematic characteristics such as operating and mechanism (Wang et al., 2018).

The prediction of remaining useful life (RUL) for equipment or component is prescribed as an effective way to maximise the duration of time that the equipment could operate which is over their original design life. The RUL estimation and life extension (LE) can be proposed into three module which is condition assessment module which aim for the current health status of critical subsystem or component, RUL prediction module which is used to determine the maximum length of operation of each component and lastly LE decision making module to proposed a suitable LE management list or program stated by (Animah & Shafiee, 2018)

2.7 Effective Remaining Operating Time (ROT)

Designing cost-effective inspection and maintenance programmes for the mechanical component in the amusement park can slightly have high uncertainty due to the different assets and their failure modes, unpredictable spare parts demand, insufficient space or low access for repair and maintenance.

The extent and severity of these mechanism such as applied static loads and operating conditions. The inspection and maintenance of mechanical structures were performed mainly within the preventive (time-based) approach. The significance of structural health monitoring (SHM) technique has totally enhanced the health assessment of the mechanical component. The remaining useful life (RUL) prediction and condition-based maintenance (CBM).

The faults caused by vibration accounted was 70% of all mechanical faults (Wang et al., 2018). The CBM uses modern sensing technologies to provide the maintenance decision before the equipment becomes faulty totally. The CBM is more effective when determining equipment maintenance based on the vibration data, rather than the old traditional ways of maintenance thus the effectives maintenance strategies reduces the maintenance downtime and cost of the amusement park (Wang et al., 2018).The time left before a system fail to operate at acceptable level is referred to as remaining useful life (RUL) as the purpose for RUL is to predict the time of certain operation of equipment (Animah & Shafiee, 2018).

The expected result as the monitoring or maintenance approach is to be able to identify the potential failures of the machine tools and cutting tools. Therefore, the maintenance department will be able to perform quick and efficient maintenance to the machine. The machine tools of maintaining Machine Time Before Failure (MTBF) is basically based on the specifications from the experience and knowledge (Mourtzis et al., 2016). The remaining operating time (ROT) is the subtraction of the actual machine time from the MTBF of the measure tools (Eqn.2)

$$ROT = MTBF - AMT \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eqn.2)}$$

Where:

ROT= Remaining Operating Time of each mechanical component

MTBF= Mean time between Failure of each mechanical component

AMT= Actual Machining Time of each mechanical component

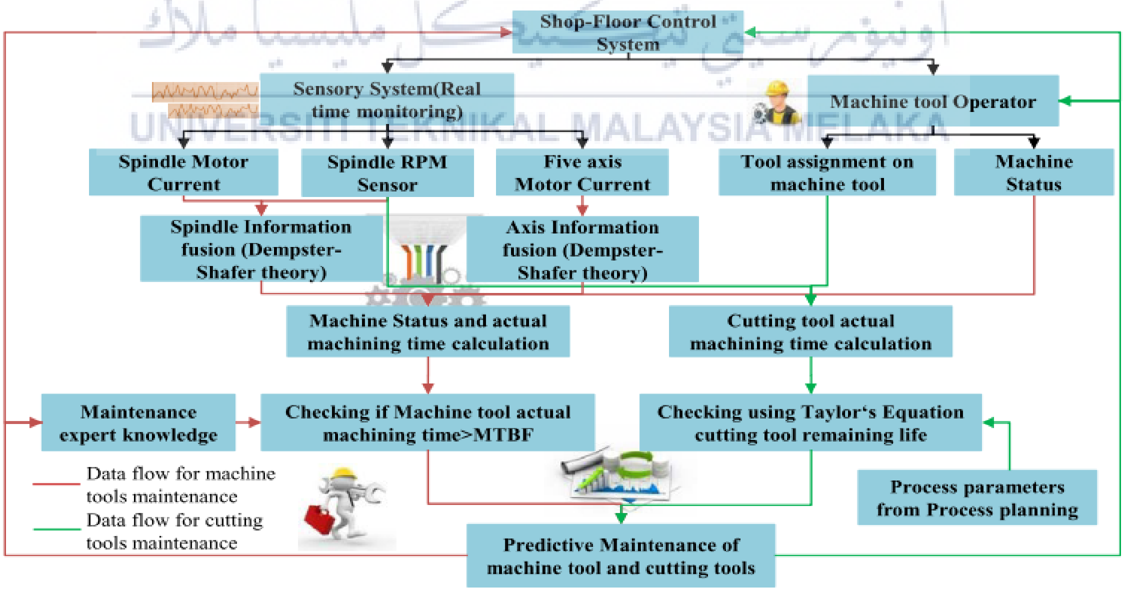


Figure 14: Detailed workflow target

The proposed calculation ROT according to (Eqn.2) is to inform the current condition of machine tools and the flow is shown in Figure 14 (Mourtzis et al., 2016). The method can be used to measure the gear ROT of Ferris wheel in the amusement park equipment. The visual inspection and method of crack gear detection thus FMEA method can be applied to allow advanced preparation of the equipment failure. Thus SHM monitoring must be applied to the mechanical equipment for certain range of time to collect data of the equipment.

2.8 Correction action

During maintenance, the time speed to restore a failed device acts as control variable thus this average time helps to get the availability and reliability of the equipment or component. The possibility to calculate the availability of the mechanical equipment.

$$MTBF = \frac{Total\ uptime}{number\ of\ breakdowns}(HRS) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (Eqn.3)$$

$$MTTR = \frac{Total\ downtime}{number\ of\ breakdowns}(HRS) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (Eqn.4)$$

Preventive maintenance is one of the basic of the maintenance can be done to certain problem such if the equipment caused a really high downtime maintenance. Predictive maintenance aims at the possibility of machine failure, a time dependent by increasing the time default should be considered continuously (Foerster et al., 2019). This will lead to a continuous existence of maintenance based on the current degree of wear of the machine.

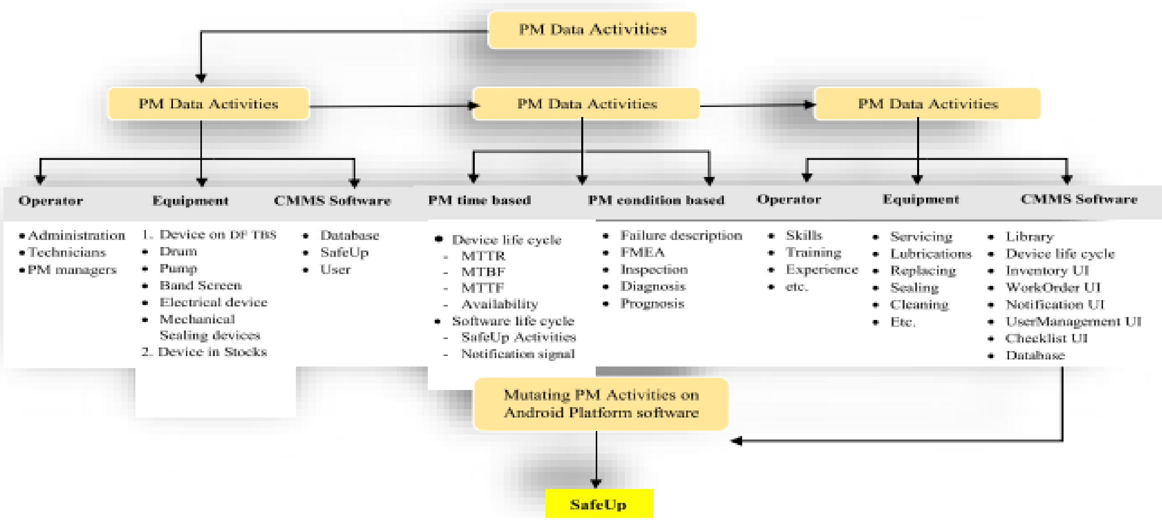


Figure 15: Preventive maintenance element algorithm (Munyensanga et al., 2018)

A case study is done to follow the instruction of redrawing the Ferris wheel and were tested with the mechanism of the mechanical component. This is to allow the use of preventive maintenance which would not allow further failure circumstances after the amusement park equipment is fixed shown in Figure 15.

2.9 The Effect on gears in Finite element analysis (FEA)

In modern mechanical engineering, gears are the most common means of transmitting power. The four major modes of failure in gears are tooth bending fatigue, contact fatigue, surface wear and score. In Finite Element Analysis (FEA) Involute spur gears are the most common form of gears used for the movement between parallel shafts. With the 3-D modelling tools nowadays it is easy to generate the involute spur gear with accurate involvement.

Discretization is the manner in which continuous models are transformed to discrete pieces. The goal is to select and locate finite element nodes and types of elements so that the associated analysis is accurate enough based on the journal (Bommisetty, 2012).

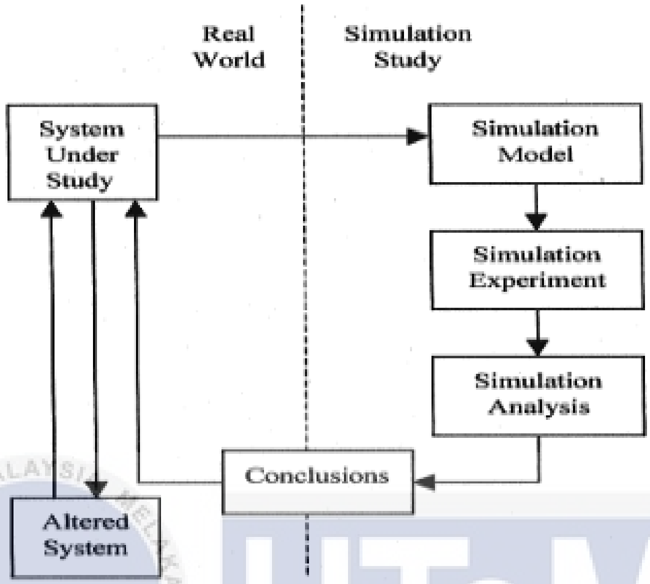


Figure 16: Study simulation schematic (Rufus et al., 2016)

The steps involved in developing a simulation model, designing a simulation experiment, and performing simulation analysis are as illustrates in Figure 16. The first step is to identify the problem and formulate the problem. Next is to collect and process the real system data. Besides, the next steps is to develop and validate the model and document the model for future use. In addition the next step is to select appropriate experimental design and establish the experiment. Lastly is to perform simulations and interpret the results.

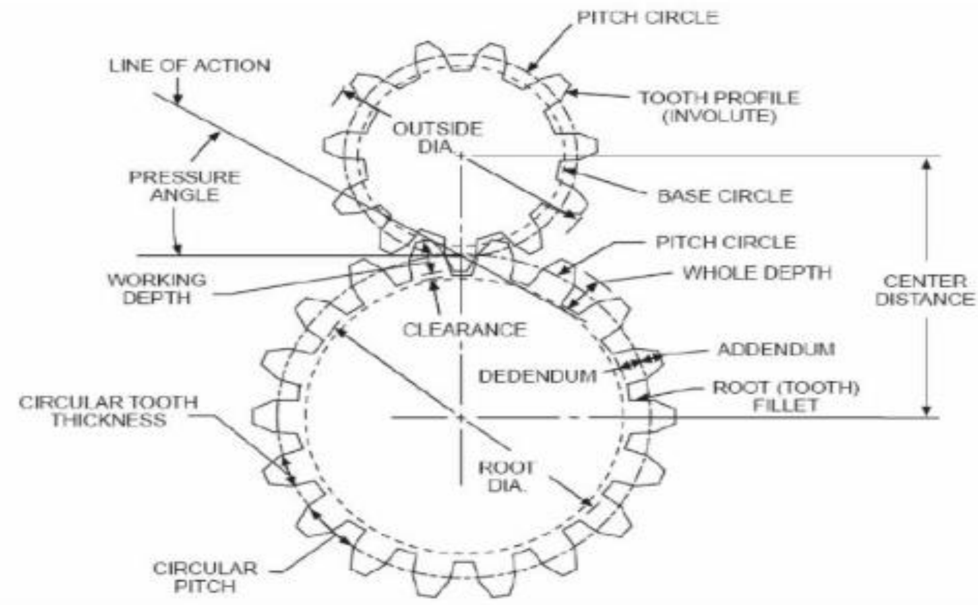


Figure 17: Gear dimensions fundamentals (Bhatia, n.d.)

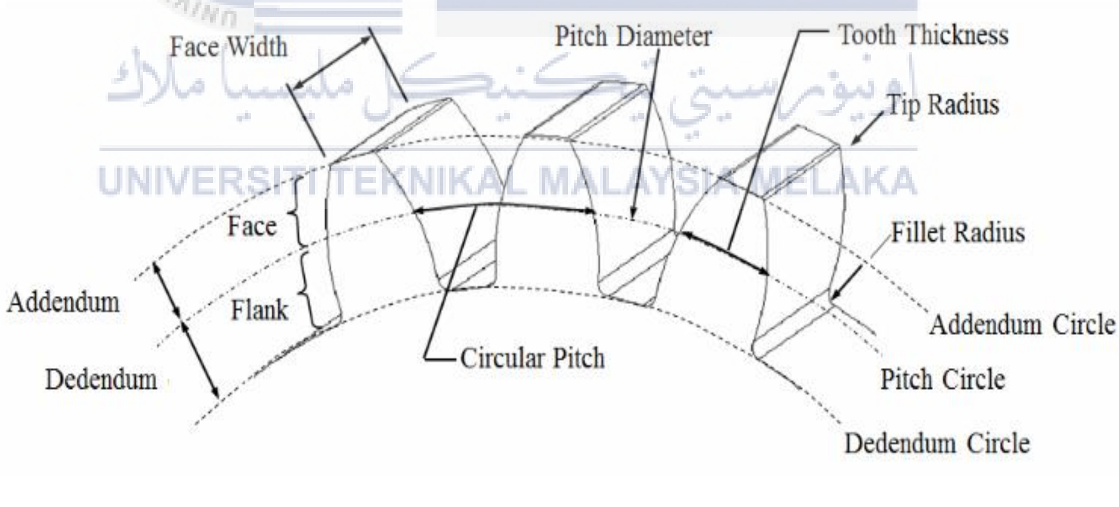


Figure 18: Basic fundamentals of gear (Bhatia, n.d.)

The basic fundamentals of gear when describing the dimensions of gear is as shown in Figure 17 and 18. A gear is known as toothed wheel that are in contact with another toothed mechanism to change the speed or the direction of the transmitted motion. Furthermore, gears with different value of tooth size based on the addendum size, pitch diameter, circular pitch and others value are affective in order to increase or decrease the speed rotation of gear. Next is the values can determined the change amount of force or torque produce during the rotation and also affect the rotational motion to different axis in term of linear, parallel or right angles.

Whereby:

- Addendum : Distance to pitch circle from top of a tooth.
- Dedendum : The distance from the pitch circle (root circle) to the bottom of the tooth space. It is equivalent to addendum + work clearance
- Outside Diameter : External gear diameter
- Base Circle Diameter: Diameter dependent on the involute teeth profile
- Addendum circle : A circle in the right segment of the gear bounding the ends of the teeth
- Dedendum circle : The circle in the right section of the gear bounding the gaps between the teeth

2.9.1 Weightage/Load

Solution Element includes an Analysis type declaration, force position and component fixation. Static structural form is used for the present analysis with no significant deflection. The gear is fixed by the fixed support tool at the bottom. Forces can be applied to the gear by selecting the edge from the graphics window, and forces in the component type are described as shown in Figure 19.

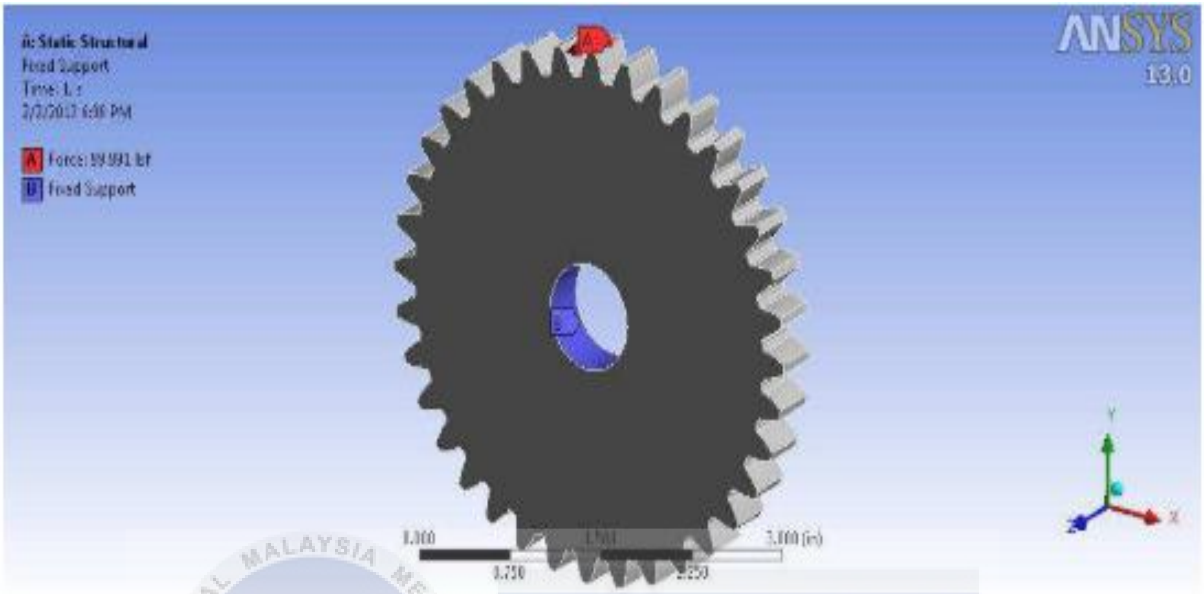


Figure 19: Location of force applied and fixed support in ansys software (Bommisetty, 2012)

A thorough analysis of the flash temperature gives insight into the mechanism of heat dissipation, which also defines the nominal increase in temperature. An increased temperature at the gear contact interface will lead to accelerated wear and even melting when the load is excessive. For gear systems, the temperature increase is considered to be the current consequence of heat generated by frictional processes. At the contact interface, frictional heat generated depends on three main parameters: sliding speed, contact pressure and friction coefficient (COF) (Černe et al., 2019).

Mechanical analysis of the system cycle using analysis of finite elements to evaluate the flash temperature increase of the spur gear pair during the meshing cycle, The first is to estimate the heat flux entering the tooth flanks due to friction, which depends entirely on the conditions present at the contact interface (i.e. contact pressure, sliding speed and

COF).(Černe et al., 2019) proposed that the effect depend on the gear type and geometry in term of material and running condition during Finite Element Analysis(FEA) as example is torque and rotational speed. In the journal also stated that the contact movement pattern of the gear and contact pressure can vary the theoretical predictions shown in Table 2.

Table 2: Gear Geometry parameters (Černe et al., 2019)

Parameter	Symbol (unit)	Value
Module	m[mm]	1
Number of Teeth	Z[/]	Unknown
Pressure angle	A[*]	Unknown
Gear/face Width	B[mm]	Unknown
Diameter	D[mm]	Unknown
Materials(Ali et al., 2018)	N/A	AISI 1040, AISI 3215

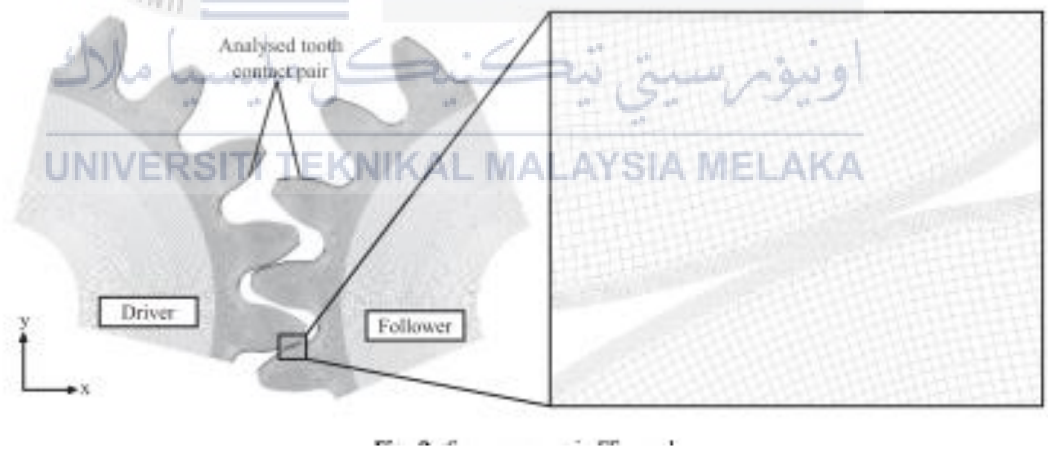


Figure 20: Spur Gear FE mesh (Černe et al., 2019)

The output of the FEA analysis is based on the table 3 shown below.

Table 3: Mechanical parameters of considered materials based on technical database (Černe et al., 2019)

Parameter	Symbol	Driver	Driven 1
Density	$\boldsymbol{\rho}\ [\boldsymbol{kg/m3}]$	Unknown	Unknown
Elastic modulus	E [MPa]	Unknown	Unknown
Young's modulus	Pa	$E = 2.068 \times 10^{11} Pa$	$E = 2.068 \times 10^{11} Pa$
Tensile yield strength	Rm [MPa]	Unknown	Unknown
Poisson ratio	m [/]	V=0.3	V=0.3
COF	l [/]	Unknown	Unknown
Safety Factor	Unknown	Unknown	Unknown

Check gear material properties such as Density, Young Modulus, Ratio of yield strength and Poisson for the simulation analysis as shown in Table 3 above. The frictional heat flux produced at the contact interface also depends on the speed of the slide. A gear pair's touch movements are in fact a relatively complex combination of sliding and rolling. Based on the Table 4 below, for lower loads a noticeable decrease in the flash temperature is observed.

Table 4 : Load case considering the temperature evaluation (Černe et al., 2019)

Load case	Torque(Nm)	Running Speed (min^{-1})
Load case 1	0.4	1458
Load case 2	0.7	1428
Load case 3	1	1392

2.9.2 Pitch Diameter

A gear can be defined in term of pitch, pressure angle and number of teeth. As for pitch circle diameter (d).

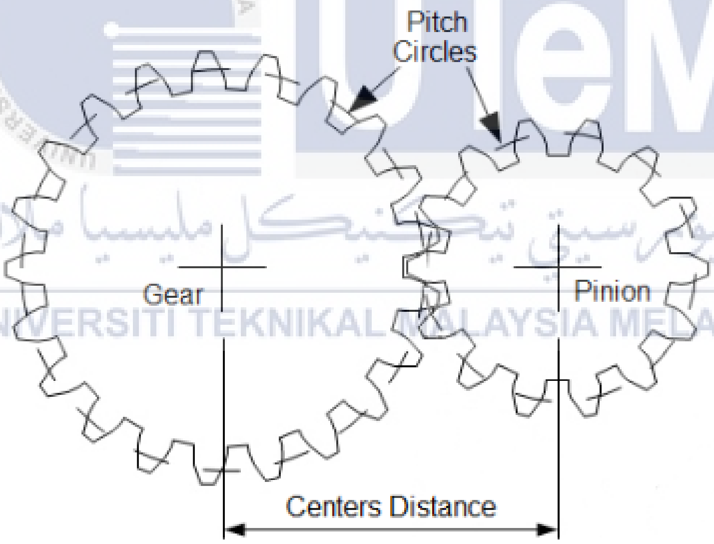


Figure 21: The gear basic terms (Watson, 1970)

This is the diameter of a circle built or constructed to geometry of the gear tooth illustrate in Figure 21. The pitch circle is the imaginary circle that was located at the point where the two gear teeth mesh. The pitch ring diameter is called the pitch diameter.

Whereby

Root- The root is the exterior of a gear wheel

Pitch- Pitch is a calculation of the spacing of a tooth around the pitch circle. It is the gap between any point on one tooth and the next tooth at the same point.

The pitch can be said to be in tern of diametric pitch (Pd) is the number of teeth per inch of the pitch diameter and it is given as:

$$P_d = \frac{Z}{d} \text{ .... (Eqn.5)}$$

Where:

Pd= diametral pitch

Z=Number of teeth

d=Pitch circle diameter in metre/inches

Module (m) is the metric equivalent if diametral pitch as example pitch diameter (in mm) divided by number of teeth, meshing gear must have equivalent module. The formula for module is:

$$m = \frac{1}{P_d} = \frac{d}{Z} \text{ .... (Eqn.6)}$$

$$\frac{\boldsymbol{\omega_1}}{\boldsymbol{\omega_2}} = \frac{\boldsymbol{r_1}}{\boldsymbol{r_2}} = \frac{\boldsymbol{d_2}}{\boldsymbol{d_1}} \text{ .... (Eqn.7)}$$

Specification	Pinion	Gear
Radius	$\boldsymbol{r_1}$	r_2
Diameter(inches/mm)	d_1	d_2
Speed (rad/s)	ω_1	ω_2

As for the contact ratio, the contact ratio of 1 and 2 means two pairs of teeth are in contact part of the time, and one pair is in contact during the remaining time. A ratio of 2 to 3 means 2 or 3 pairs of teeth frequently come into contact. The higher the contact ratio the greater the distribution of the load between the teeth. Having a touch ratio of 1.3 to 1.8 is good practice. The ratio will under no circumstances go below 1.1.

2.9.3 Fatigue condition

The tooth surface failure occurs due to excessive stress condition. This can cause the contact between tooth surface to be damage or deformed plastically, resulting in various gear defects such as tooth root crack, tooth breakage, chipping , spelling etc. stated by(Demet & Ersoyoğlu, 2018).

Fatigue life of certain equipment can be positively affected by the increase in the tooth strength gear as stated in (Demet & Ersoyoğlu, 2018). Due to less stress the fatigue life of gear increases. The fatigue damage on the asymmetric gear tooth which caused by cyclic loads and effect the material hardness on the fatigue life of gear tooth.

The tested gear were chosen to be made of material AISI 4140 material. Based on the article(Demet & Ersoyoğlu, 2018), the fatigue test are used to specify the torque value to the tooth which have different hardness and gradually reduce as the tooth is damaged.

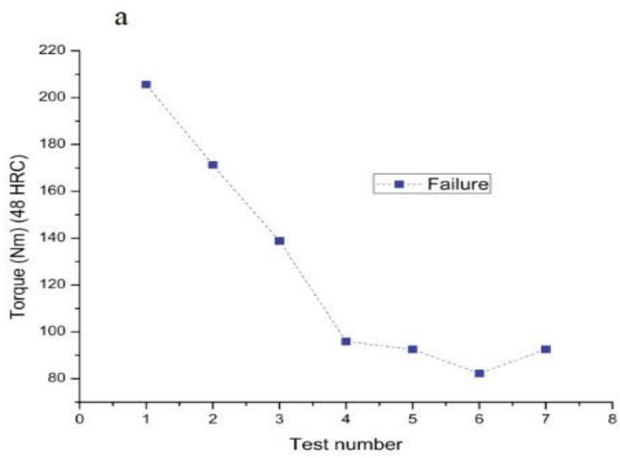


Figure 22: Staircase method assumption result of failure (Demet & Ersoyoğlu, 2018)

2.9.4 Analysis in CATIA V5

There are steps that are used to demonstrate the analysing Spur Gear using CATIA. The first step is to click start column on top left of the CATIA and select mechanical design. Then go to option and select assembly design. Next to insert the parts of the gear analysis, Select insert and choose existing component and choose file gear drawn earlier and click open. To align both pinion and driven spur gear, find Manipulation task bar and change the offside constraint and input value and click update bar. Next is to align the surface contact which is by searching the Control constraint bar thus select two phase of contact between both of the spur gear and click update. Lastly at top task bar select file and go to save management and save the file.

Secondly, to select the material to be used for both of spur gear during analysis is by select the start task bar and click analysis and simulation and scroll to generative structural analysis. Next, press Link manager and click open thus choose the two type of gear with the parameters decided to test and select the type of material which is commonly used for gear is steel. To select which gear to be pinion and driven is by choosing virtual part and select support and rename the moment and fixation gear which the moment is the pinion and the fixation is the driven gear. To fix a point is by select surface slides and search for pivot and click the properties bar at left side and select the moment gear and this step is repeated for fix gear point. Next is to select the amount of force use is by select distributed force and choose and the moment gear thus enter the amount of force wanted to be tested.

The third step of analysis is to do meshing test is by selecting the OCTRE G2 & G3 from the left list bar and choose mesh value. Next is select slider connection property and choose fastened connection properties contact surface and last step is to open Finite Element Method and open the nodal which represent the meshing and choose mesh visualization and select OK.

Last step is to test von misses stress testing is by choosing static case and choose static case solution and compute. Repeat the step and test for von misses stress test. The colour code for von misses value is changed to four in total with all the test to obtain a clear and accurate data. Lastly, select amplification magnitude and drag the factor to reorganize the force given then the animation can be made by pressing the animate button and result is obtained.

Safety factor is the ratio of the material's ultimate resistance to the approved stress. The concept was developed for the determination of appropriate stress. The ultimate strength of a given material divided by an arbitrary safety factor, totally reliant on the material and the use it is to be put on, gives the allowable stress. One explanation for this is that the safety factor is misleading, because it assumes a greater degree of safety than it really does exist. As stated in journal (Rufus.O et al., 2016), A safety factor of 4, for example, does not mean that a component can bear a load four times that it was built for.

The basic geometry set to be set up are shown in table 5:

Table 5: Geometry of gear set

Description	Symbol	Formulae	Values
Number of teeth on pinion	Zp	N/A	N/A
Module	m	N/A	N/A
Number of Teeth	N/A	N/A	N/A
Pressure angle	α_n	N/A	N/A
Gear/face Width	F	F=10 × m	N/A
Addendum height (mm)	h_a	ha = m	N/A
Dedendum height (mm)	h_d	hd = 1.25m	N/A
Addendum circle (mm)	d_a	da = dp + (2 ×m)	N/A
Dedendum circle (mm)	d_d	db = dp × cos α_n	N/A

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the methodology used in this project to propose a new set of working condition based on structural health monitoring (SHM) plan. The flow chart of the project is shown in Figure 23. The project starts by visiting the site of amusement park and study about the mechanism of the Ferris wheel. After the visual inspection of the Amusement Park equipment, the causes of amusement park equipment failure is detected. Thus the design specification of Ferris wheel is taken to redesign in the CATIA. The significant mechanism is tested until the causes of failure obtained. If the mechanism obtain specifies with the visual inspection, a solution is proposed to resolve the problem. The solution are in the form of proposing a new set of working condition

3.2 Flow chart

A flowchart is a type of diagram which represent the workflow of a certain project or status plan. A flowchart can also be defines as the diagrammatic representation of an algorithm which is an approach to solve a task which are given. The Flowchart in Figure 23 shows the status of the project during the monitoring plan of the Amusement Park mechanical equipment.

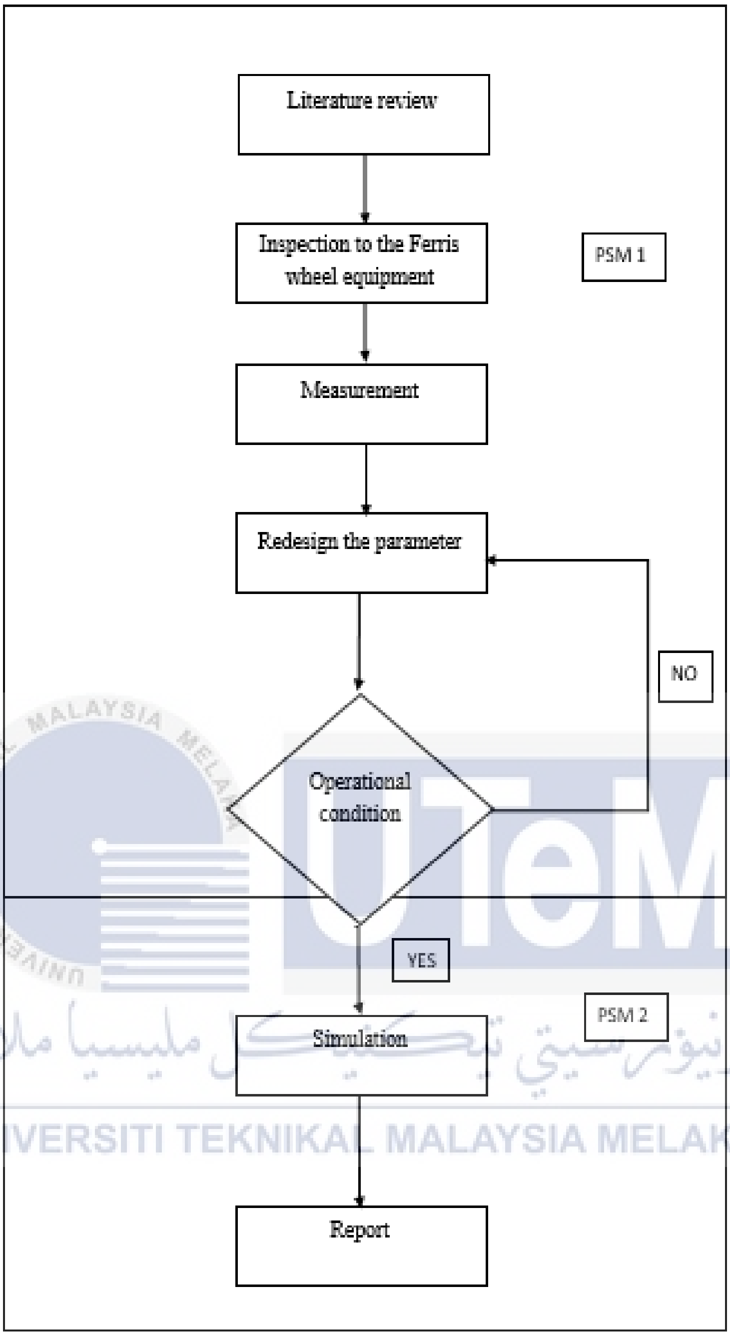


Figure 23: Flow of project

3.3 Structural Description-material

The mechanical component is a crucial parts for every component of machine. There are several type of gear in the Ferris wheel component which is Sprocket and Spur gears. The gear selection of the spur gears need are made based on the pitch, face width, material, pressure angle and number of teeth.

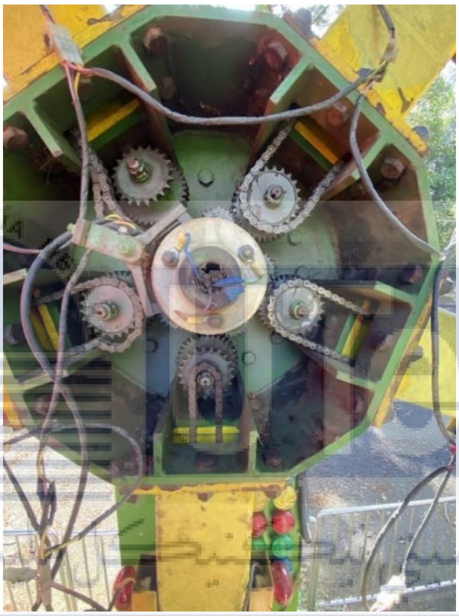


Figure 24: Gear mechanism in Ferris wheel

Furthermore, the spur gears characteristic is known as the simplest and most effective type of appliances to produce. Properties such as wear resistance, good fatigue strength as well as a low friction coefficient are desirable when specifying gear materials. In manufacturing of gears, alloy steels are most commonly used which it offer wide range of heat treatment properties and high strength. Limitation of spur gears where it is not suitable for switching direction between two shafts. Thus it can produce noise because the touch occurs instantaneously over the entire face width of the matting teeth as stated by (Bhatia, n.d.).

Next, usually steel gears are heat treated to properly mix toughness and hardness of the tooth. It is not essential to get the same material for both pinion and wheel gears because the smaller gear tend to rotate more turns compared to larger gear thus wear and tear are far more likely. Furthermore, the simplified version of selecting the gear material is the strength, endurance, durability and cost.

Figure 25: Damage Gear

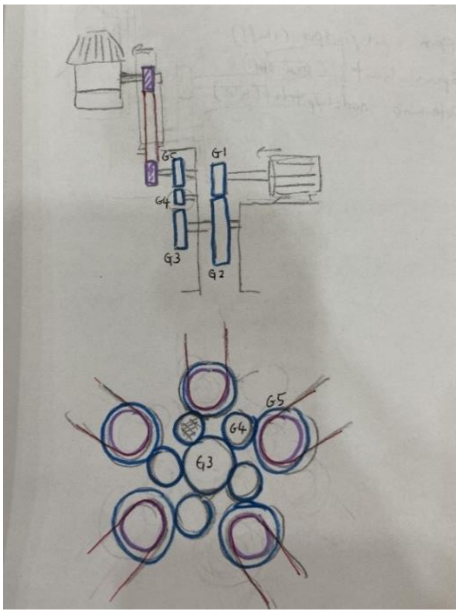


Figure 26: Gear mechanism redrawn

Based on the Figure 27 and Figure 29 shown below, the set of gear the Ferris wheel gear is measured and redrawn to know the total number of pitch and the sizes of the gears to work the Ferris wheel mechanism. For the properties of gear to have endurance strength is the material of the gear should have a good surface finish, where there will be less stress concentrations and also reduces the coefficient of friction. Next, a good gear material should have high fatigue and tensile strength to withstand the loads of the amusement equipment.

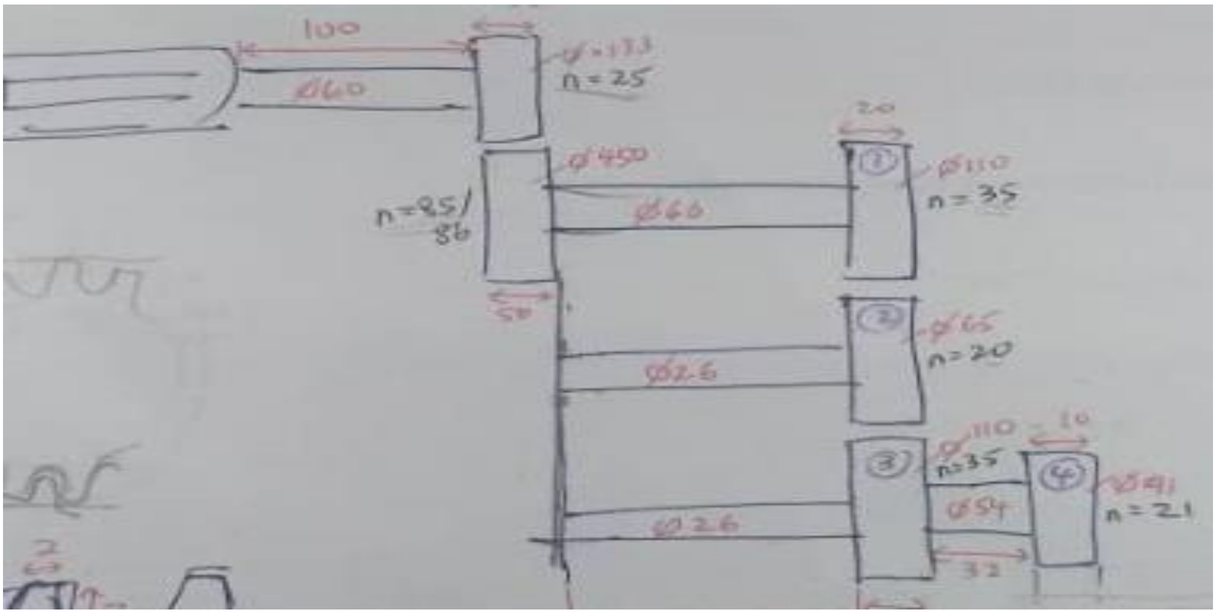


Figure 27: Gear dimension as per drawing

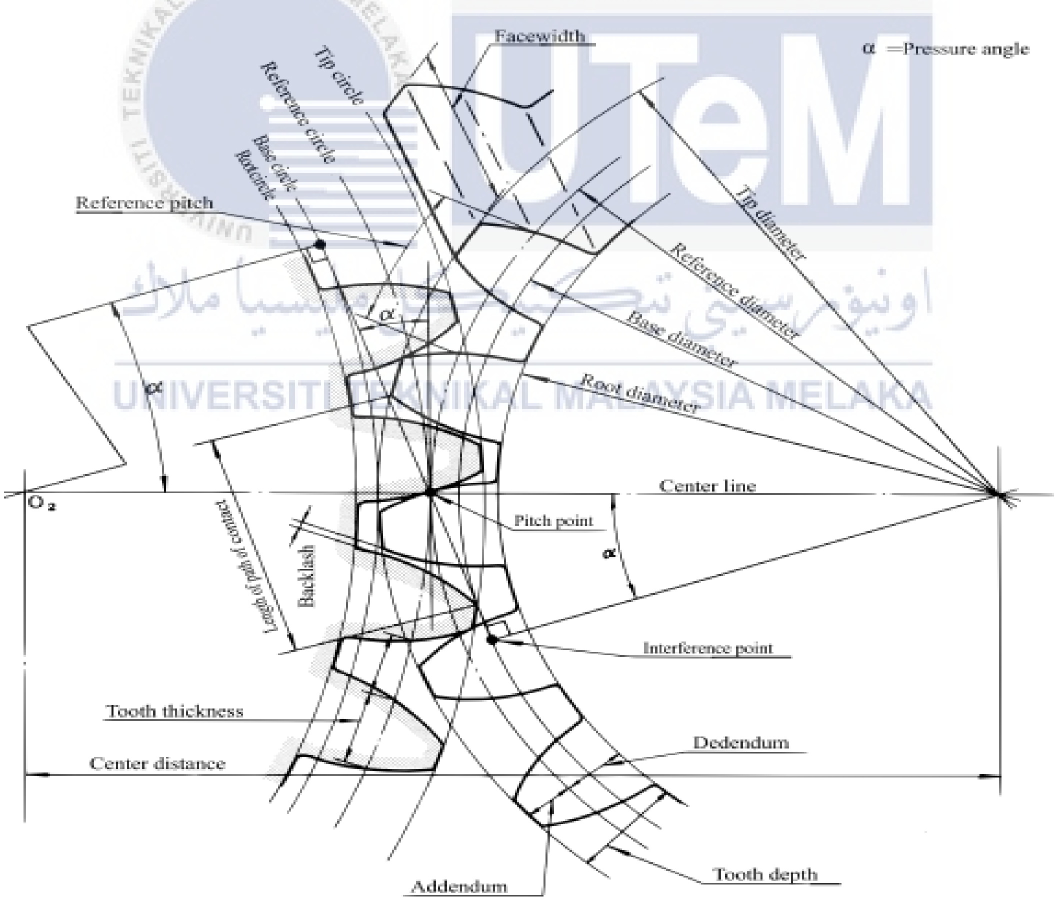


Figure 28: The terminology of gear (Kohara Gear Industry CO., 2006)

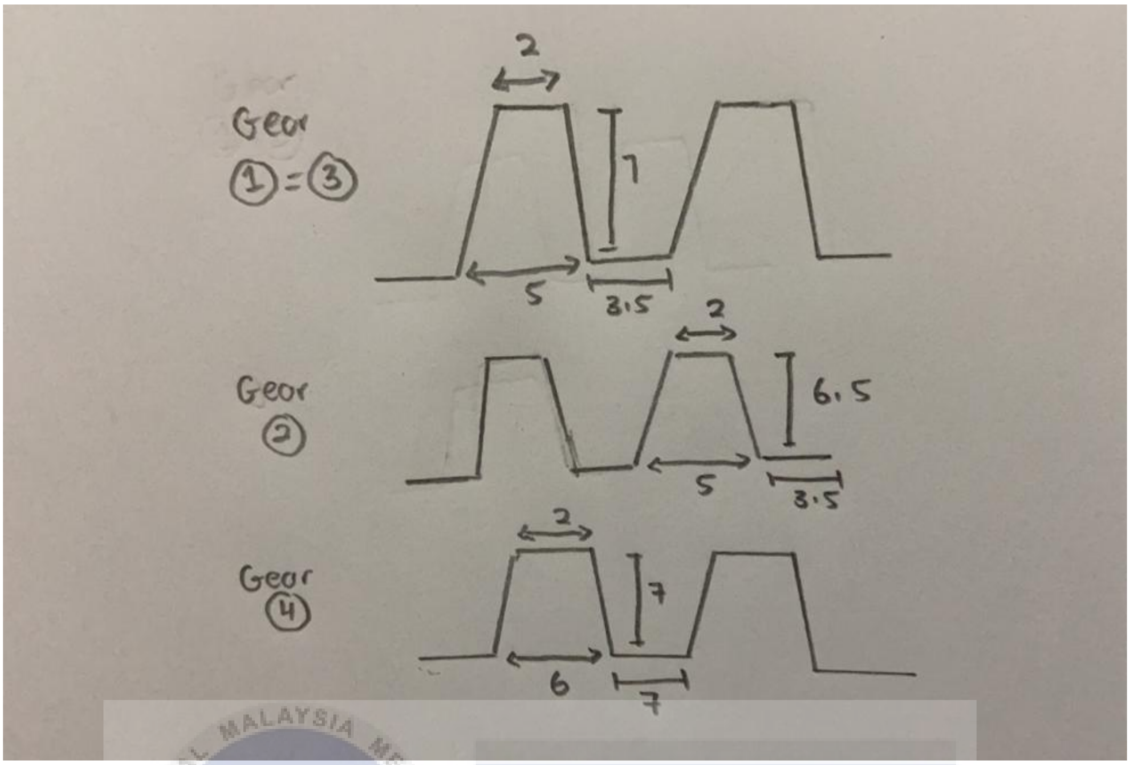


Figure 29: the pitch size of the Ferris wheel gear

Figure 28 illustrates the terminology of the spur gear stated in (Kohara Gear Industry CO., 2006) The size of the damage gear is measured with sizing of the gear tooth is shown in Figure 27 and Figure 29 whereby the pitch of the broken gear is gear number two in Figure 27 drawings.

3.4 Operational Condition

Operational condition is a technical performance when the equipment is properly perform based on its required function. A device is considered in the operational condition when the principle of the manual technical parameter specification is followed to avoid any circumstances. Based on Table 6 below shows the manual operational condition of the Ferris wheel based on the manual from the supplier.

Table 6: Operational Manual

Operational Condition	Manual value specification
Capacity	10 person (2 person/cabin) ×5 cabins
Max load Capacity	700 KG (70kg/person)
Area	4×4
Height	5 meters
Power	2.2 KW AC220V (motor)+ 0.8 KW(lighting)
Total weight	2300 KG
Rotational Speed	1.56 rpm
Speed	(0.2 m/s)
Cycle Per rotation	2 min per cycle
1st date operation	1st June 2015

The examination of performance of the mechanical equipment as to monitor the machine or mechanical component continuously as stated by (Wan, Gao, Li, Tong, & He, 2015) to obtain the statistic of the machine or mechanical component health and the requirement for the maintenance. When the result is obtain from the health monitoring from the mechanical equipment, the plan to maintain the machine. Based on Figure 30 shows the current Ferris wheel condition at the Amusement Park. As for Figure 31 shows that the control room which control the movement of the Ferris wheel which consist of power button, current and voltage control to measure the speed.

Figure 30: Ferris wheel at the amusement park

Figure 31: Ferris wheel Controller

Figure 32: Bearing of Ferris wheel

Figure 33: motor

The other main parts of the Ferris wheel is the bearing which is connected to the motor as shown in Figure 32 and Figure 33.

Figure 34: failure gear

Figure 35: Defect gear

During the inspection, the mechanical component of the Ferris wheel had damaged due to unknown circumstances. Based on Figure 34 and Figure 35, the gear of the main parts of the Ferris wheel mechanism has broken down due to fatigue crack which initially causing the other parts of the gear mechanism to have other related problem such as bend shaft and also damaging other gears. The inspection is done to analyse the possibility of the gear failure. The gearing position is as shown in Figure 27.

3.5 Failure analysis by using computer simulation

There gears are extensively used in machine parts to transmit power to others parts depending on the speed or direction. Stated by (Jayakiran Reddy & Pandu Rangadu, 2018) if a higher and better efficient power transmission is completely based of the effective of the gear system. The gear modelling using CAD not only helps in drawing the complex but the design will help the manufacturer to manufacture the gear based on the parameter drawn in the CAD stated by (Jayakiran Reddy & Pandu Rangadu, 2018).

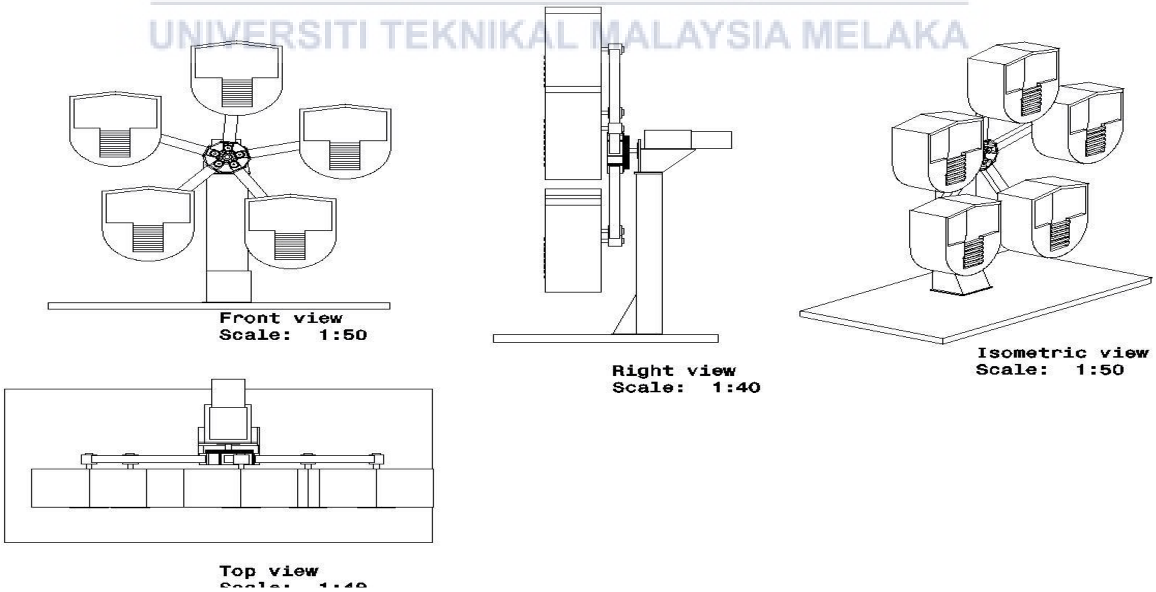


Figure 36: Design in CATIA

To gain a better understanding of failure analysis, a 3D model of Ferris wheel and the presentation of gear mechanism is designed using CATIA software. Based on the design shown are shown in Figure 36.

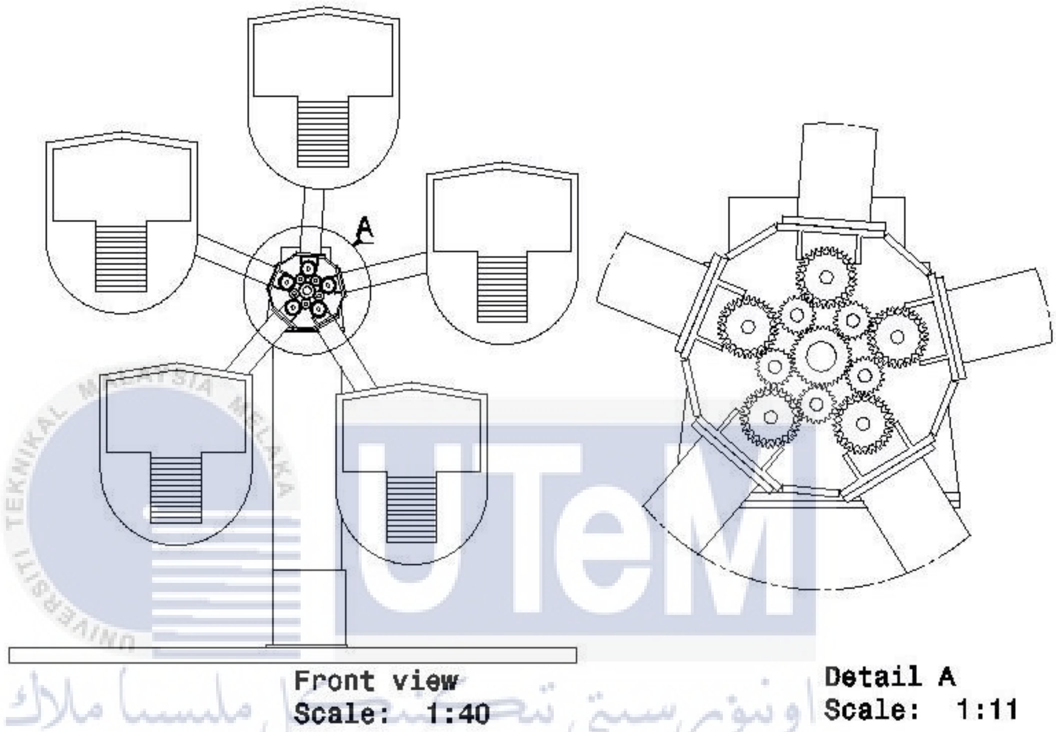


Figure 37: The gear mechanism designed in CATIA

The simulation of the mechanism will be done by using CATIA thus the gear mechanism is the most crucial parts to be tested as the design of mechanism in CATIA is illustrates in Figure 37.

The working condition must be evaluated thus making the right decision will help the smoothness of the motion of the amusement equipment. This working condition is changed based on the normal operational condition and by comparing with new operational condition as example is the speed or rotation, the load as stated in Table 6 above.

Comparing the shaft orientation, when using spur and helical gears, the shaft need to be verified as parallel in order to avoid the gear to break. Next, the operating environment of the amusement equipment. When the unit works in dusty situations or when water is splashed around the unit, contact seals should be used on input and output shafts. Two contact seals may be needed on each shaft in atmospheres laden with abrasive dust or in areas hung with water under pressure. An enclosure with oil lubrication around the gears is usually the preferable design, but grease-lubricated open can be used in clean environment. Besides, meeting the particular gear ration by splitting the full-load motor speed into the powered machinery revolutions per minute (RPM). Theoretically, there is no limit to the speed ratio that can be planned as a single reduction gearbox, but for each type of gear above, there is an estimated ratio where the materials are not efficiently used. These are the ratios are shown in Table 7 cited from (Bhatia, n.d.).

Table 7: Ratio range of gear (Bhatia, n.d.)

Type	Normal Ratio Range
Spur	1:1 to 6:1
Straight Bevel	3:2 to 5:1
Spiral Bevel	3:2 to 4:1
Worm	5:1 to 75:1
Hypoid	10:1 to 200:1
Helical	3:2 to 10:1
Cycloid	10:1 to 100:1

In term of loading and speed, constant torque change when the demand of load varies to the speed of rotation thus higher horsepower is needed to obtain a new constant speed with new load. Thus, different mass of load that will added give a higher gravity to the Ferris wheel thus need more torque to move.

Furthermore, by using CATIA , the simulation of the Ferris wheel is generated with different operational condition as stated above is tested to obtain the measurement of parameter which causing the gear to fail. So as for simulation done, the expected result would be measuring the causes which causes the gear mechanism of the Ferris wheel to break and become not functional. The simulation will be done to approve and proposed a new operational condition to the Ferris wheel amusement park in order to avoid more damage to the equipment.

3.6 FMEA ANALYSIS

The flow chart of the FMEA analysis shown below written by (Balaraju et al., 2019). The FMEA is used to identify the possible failure modes, their causes and the effects of the failure to the mechanical equipment. If the FMEA method is used, the possibility to identify the failures may safe the product or equipment before breakdown or disintegrate. The FMEA basically helps to define and control the failure modes by minimizing the area of failure regarding how the equipment works.

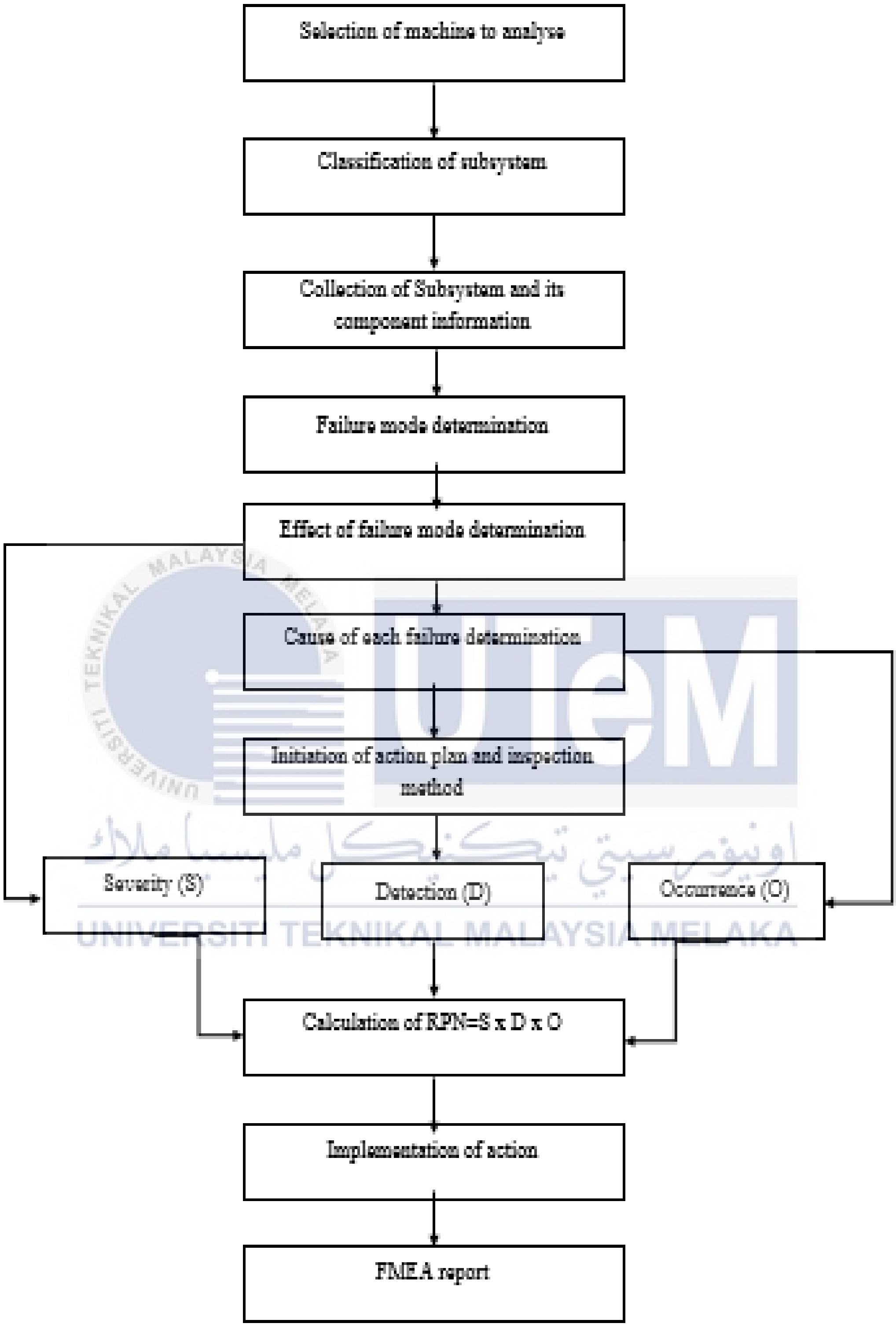


Figure 38: Flow chart for the FMEA analysis sequent

By using the FMEA analysis, the RPN value is to be calculated by measuring the severity (S), Occurrence (O) and Detection (D). The value of each parameter is shown in Table 8. The benefit of FMEA is to ensure the final product are safe as per defined.

Table 8: Severity Rankings

Severity Rankings			
Ranking	**Effect**	**Design FMEA Severity**	**Process FMEA Severity**
10	Hazardous-no warning	affects safe operation without warning	may endanger machine or operator without warning
9	Hazardous- w/ warning	affects safe operation with warning	may endanger machine or operator with warning
8	Very High	makes product inoperable	major disruption in operations (100% scrap)
7	High	makes product operable at reduced performance (customer dissatisfaction)	minor disruption in operations (may require sorting and some scrap)
6	Moderate	results in customer discomfort	minor disruption in operations (no sorting but some scrap)
5	Low	results in comfort and convenience at a reduced level	minor disruption in operations (portion may require rework)
4	Very Low	results in dissatisfication by most customers.	minor disruption in operations (some sorting and portion may require rework)
3	Minor	results in dissatisfication by average customer.	minor disruption (some rework but little affect on production rate)
2	Very Minor	results in dissatisfication by few customers.	minor disruption (minimal affect on production rate)
1	None	No effect	No effect

Table 9: Occurrence Rankings

Occurrence Rankings				
Ranking	**Effect**	**Failure Rates**	**Percent Defective**	**Cpk**
10	Extremely High	> 1 in 2	50%	Cpk < 0.33
9	Very High	1 in 3	33%	Cpk ~ 0.5
8	Very High	1 in 8	10-15%	Cpk ~ 0.75
7	High	1 in 20	5%	
6	Marginal	1 in 100	1%	
5	Marginal	1 in 400	0.25%	Cpk ~ 1
4	Unlikely	1 in 2000	0.05%	
3	Low	1 in 15,000	0.007%	Cpk > 1.33
2	Very Low	1 in 150,000	0.0007%	Cpk > 1.5
1	Remote	< 1 in 1,500,000	0.000007%	Cpk > 1.67

Table 10: Detection rankings

Detection Rankings			
Ranking	**Effect**	**Design FMEA Detection**	**Process FMEA Detection**
10	Absolute uncertainty	No chance that design control will detect cause mechanism and subsequent failure.	No known process control to detect cause mechanism and subsequent failure.
9	Very remote	Very remote chance that design control will detect cause mechanism and subsequent failure.	
8	Remote	Remote chance that design control will detect cause mechanism and subsequent failure.	Remote chance that process control to detect cause mechanism and subsequent failure.
7	Very Low	Very low chance that design control will detect cause mechanism and subsequent failure.	
6	Low	Low chance that design control will detect cause mechanism and subsequent failure.	Low chance that process control to detect cause mechanism and subsequent failure.
5	Moderate	Moderate chance that design control will detect cause mechanism and subsequent failure.	
4	Moderately High	Moderately high chance that design control will detect cause mechanism and subsequent failure.	
3	High	very remote chance that design control will detect cause mechanism and subsequent failure.	High chance that process control to detect cause mechanism and subsequent failure.
2	Very High	Very high chance that design control will detect cause mechanism and subsequent failure.	
1	Almost Certain	Design control will almost certainly detect cause mechanism and subsequent failure.	Current control almost certain to detect cause mechanism and failure mode.

Based on Table 11 shown below, the calculated RPN for the Ferris wheel gear is 400. The result shows higher RPN value at the gear showing the focus of the maintenance must be based on the gear as compared to the other mechanical equipment.

Table 11: The FMEA Analysis of the ferris wheel gear

System	Design Failure Analysis	Potential	FMEA Number	Project 1
Subsystem	Ferris Wheel	Failure Mode and Effects Analysis	Prepared By	Muhammad Hilmi Bin Mansor
Component	Gear Mechanism	(Design FMEA)	FMEA Date	12/12/2019
Design Lead	Muhammad Hilmi Bin Mansor	Key Date 12/12/2019	Revision Date	
Core Team	UTeM		Page	1 of 6

Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Occur	Current Design Controls	Det	RPN	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	New Sev	New Occ	New Det	New RPN
Owner sends in a quote request for maintenance	System, Software overlooked by owner	Customer needs not fully met by delivered system.	7	Human error	1	Design maintenance	3	21	Do preventive maintenance						0
Requirement entered and verified the problem	Gear failure	Ferris wheel break down	10	Human error or equipment error	8	Condition based maintenance	5	400	Maintenance such as oil lubrication to the gear						0
Designing the problem amusement park equipment	Operational condition unsatisfy	Failure of amusement park equipment	7	Requirements Overlooked.	3	inspection and simulation of gear mechanism	3	63	Test the operational condition in the Ansys to proposed new operational condition						0

CHAPTER 4 RESULT AND DISCUSSION

4.1 Weightage

The analysis of the contact of the gear are done between Pinion gear and Driven gear. As for general reason, when meshing pair of gears the smaller gear are called pinion gear while the driven are the larger gear.

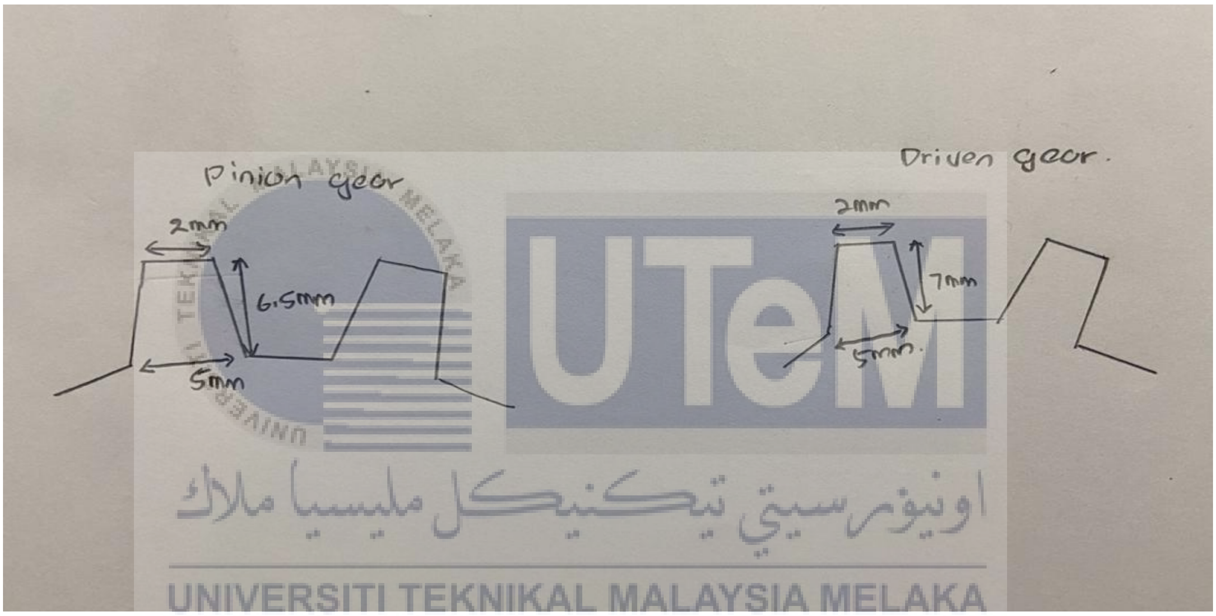


Figure 39**:** The characterization of size of driver and driven

Based on Figure 39, the gear is based on the measured gear at the site of amusement park Ferris wheel which shows that the measured data is the given size by the manufacturers which they uses measurement which are qualified by the Original Equipment Manufacturer (OEM).

As for material chosen with specification of all three test which are tested at 500 kg (4905 N), 700 kg (6867 N) and 1100 kg (10791 N) with a constant parameter gear as shown in table 12 below:

Table 12: The constant Parameter of gear

Parameter	Pinion(small gear)	Driven
Material	Steel	
Young's Modulus	$2{\times}e^{+11}\ {}^{N}\!/\!{}_{m^2}$	
Poisson's Ratio	0.266	
Yield Strength	$2.5 \times e^{+08}\ {}^{N}\!/\!{}_{m^2}$	
Pitch Diameter	65mm	110mm
Base Diameter	39mm	84mm
Number of Teeth	20	35
Module	0.0032	0.0031

Furthermore, from equation (Eqn 5) measurement of diametral pitch (pd) is used to measure the module (Eqn.6) of the test gear analysis for all load of 500 kg, 700 kg and 1100 kg.

The module calculated for pinion gear:

$$P_d = \frac{Z}{d}$$

$$P_d = \frac{20}{0.065m}$$

$$= 307.69$$

$$m = \frac{1}{P_d} = \frac{d}{Z}$$

$$= \frac{0.065m}{20}$$

$$= 0.00325$$

The module calculated for driven gear

$$P_d = {}^{35}/_{0.11m}$$

$$= 318.18$$

$$m = {}^{0.11m}/_{35}$$

$$= 0.0031$$

Where pd =diametral pitrch

Z=No. of teeth

M=module for meshing

The value of module is used calculated above is to analyse the meshing of the gear analysis using CATIA v5 analysis.

4.1.1 Testing mechanism at 500 KG (4.905 ×10^3 Nm)

This test uses same parameter as shown in Table 12 above which is tested with different load of 500 kg. For Meshing the value cover during the analysis are as shown below:

Entity	**Size**
Nodes	86224
Elements	389913

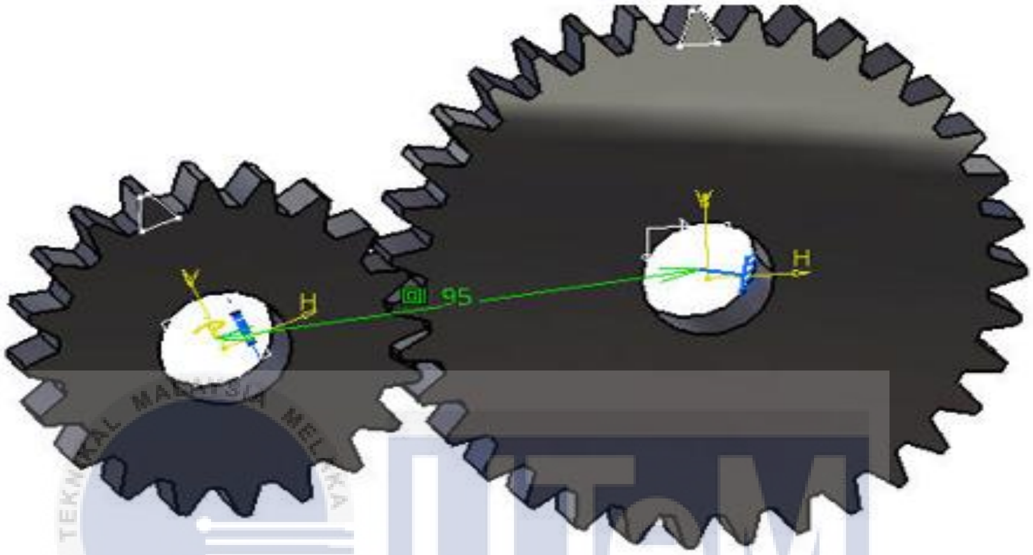


Figure 40: Assembly of pinion gear and driven gear for 500KG

Based on the Figure 40, the assembly is done critically to align the pinion gear and driven gear as the pitch circle are compatible to each gear to make contact. This is to avoid any unexpected failure during the test analysis. The alignment have a 95 mm difference between each centre point of the each pinion and driven gear.

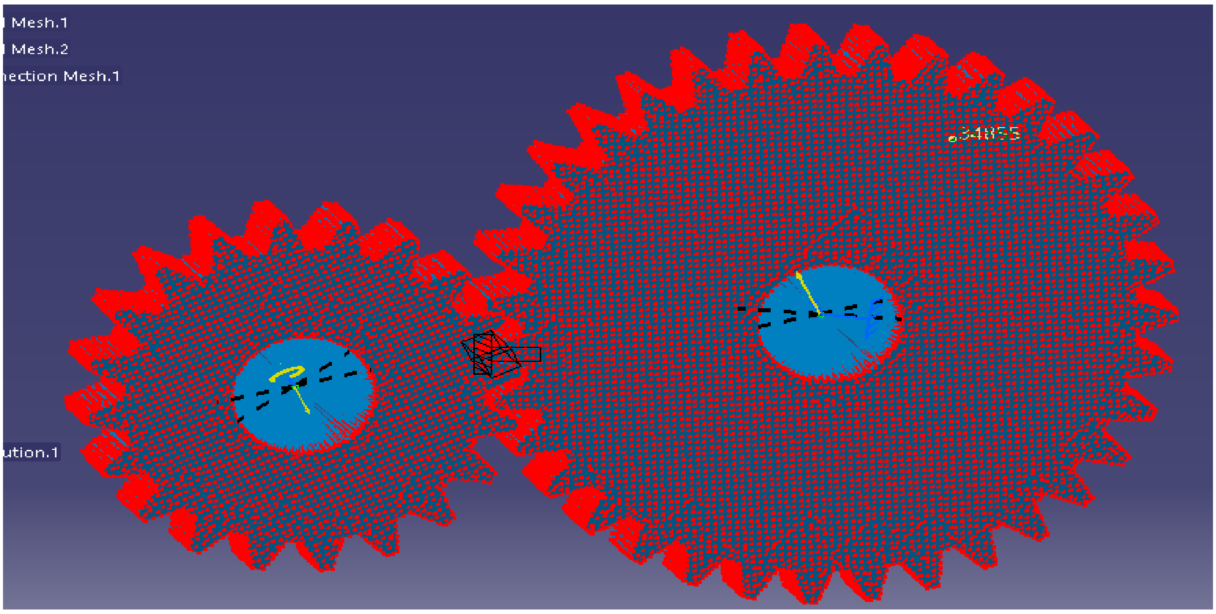


Figure 41: Deformed Mesh for 500 kg

Figure 42: Vons misses stress nodal for 500 kg analysis

Based on the Figure 41, shows the deformed mesh obtain by the test analysis while Figure 42 shows the maximum stress applied which is 3.47×10^9 (N/m^2). As for the result from the test for 500 kg shows that there is a low change of having a higher rate of failure which shows low percentage of red present in the analysis.

4.1.2 Testing mechanism at 700 kg (6.876 ×10^3 Nm)

This test analysis uses the same parameter for pinion and driven gear with different load which is 700 kg.

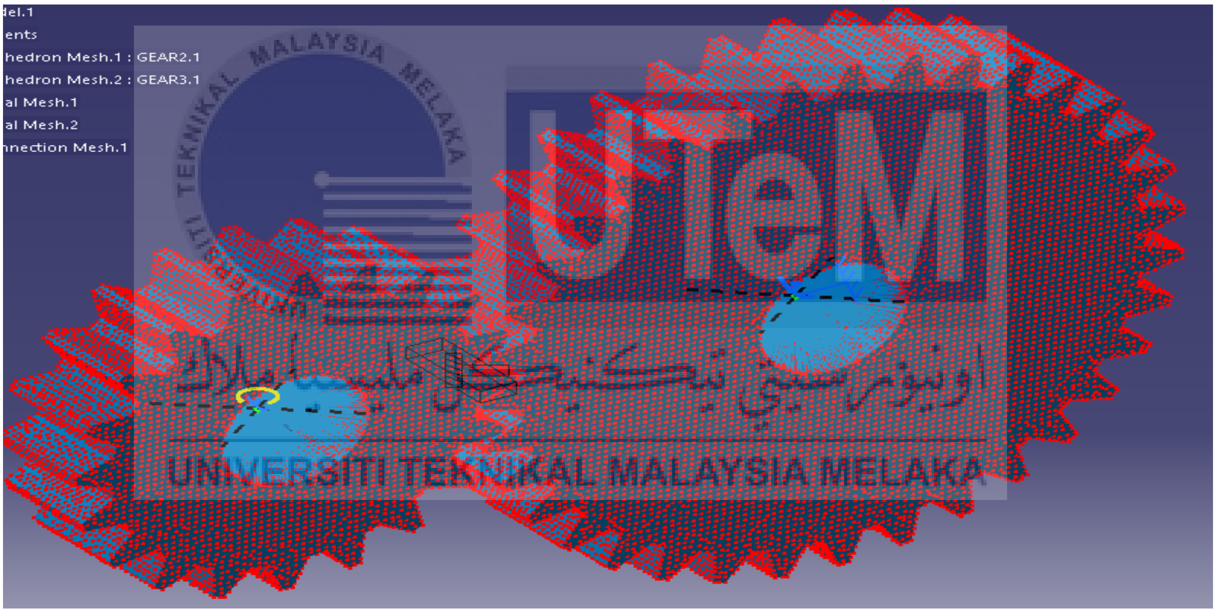


Figure 43: Mesh formed during 700 KG Analysis

Figure 43 shows the mesh analysis result while in figure shows the maximum stress for the test analysis for 700 kg (6867N) is 4.95×10^9 (N/m^2). This also shows that based on the weight given by the manufacturer is allowable based on the size of teeth and number of teeth of the pinion gear and driven gear.

Mesh:

Entity	Size
Nodes	86224
Elements	389909

Figure 44: Von misses stress for 700 KG test analysis

4.1.3 Testing mechanism at 1100 kg (10.791×10^3 Nm)

The test analysis is followed by using the same parameter in Table 12 stated above and tested with a larger load of 1100 kg (10791N)

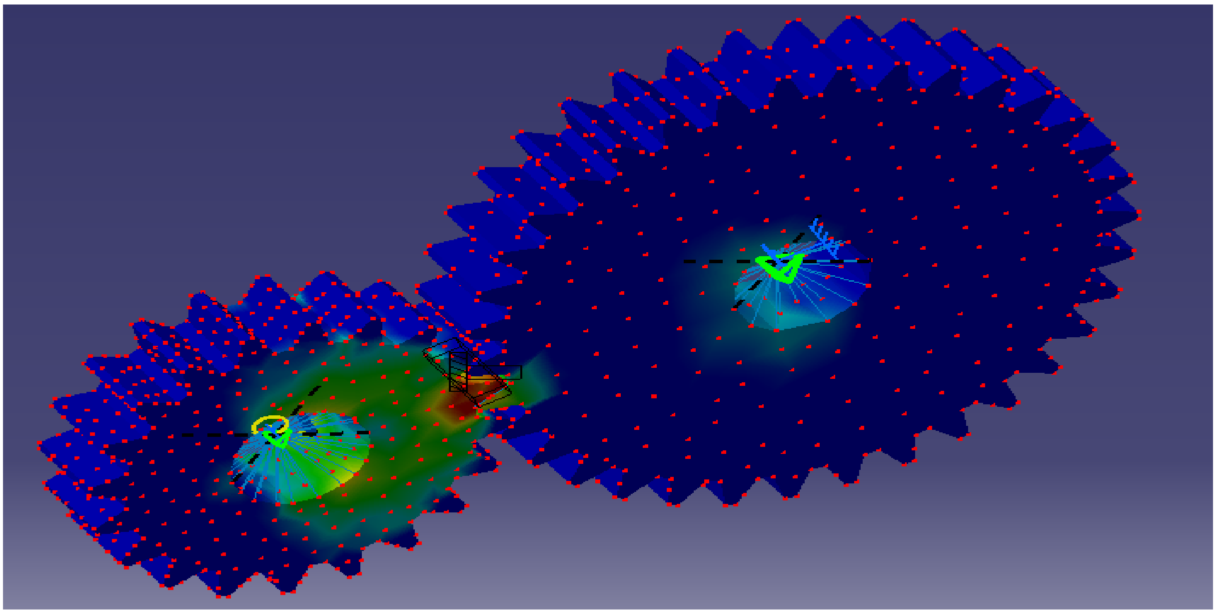


Figure 45: Mesh with nodes elements

Figure 46: The von misses test result for 1100 kg (10791 N)

Figure 45 shows the mesh element with and without nodes elements which shows different type of nodes that are widen. Based on Figure 46 shows the maximum stress during the 1100 kg test with the same constant gear size which is around 5.29×10^9 (N/m^2). This is proved due to the red measurement particle shown during the test analysis which shows the test has reached the possible maximum capacity during analysis test.

4.2 Pitch Circular

Pitch circular is known as the distance between the corresponding points of both consecutive gear teeth measured along the pitch circle. Based on the information mentioned in chapter 2.9 shows the location of the pitch circular pattern which allow the test to be analyse based on different type of Pitch Circular.

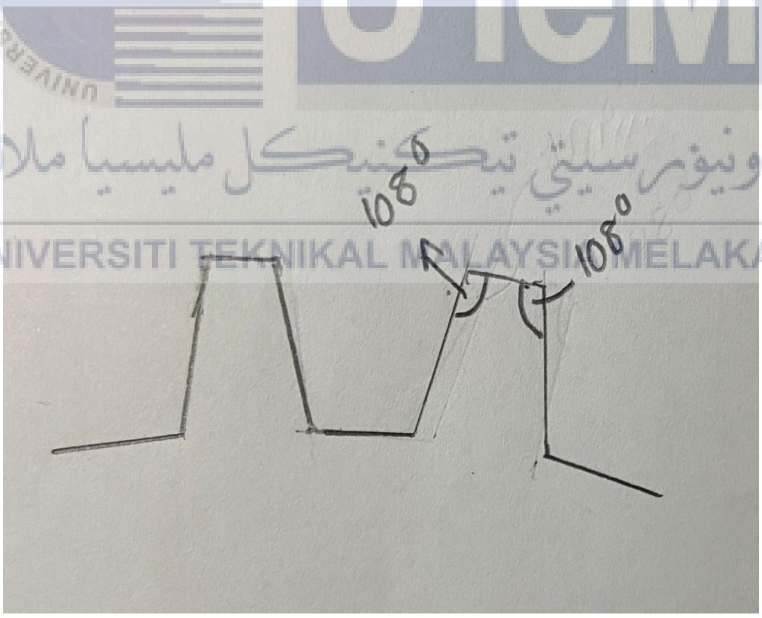


Figure 47: The constant angles for the test analysis

The circular pitch is measured by using a constant degree of angles which is 108 degree as shown in Figure 47. The next constant measurement that is taking ensure of is the amount of moment or force value used in all the test analysis for the Pitch Circular that is 700 kg (4905 N) which is kept as constant variables.

4.2.1 Set 2 of Pitch Circular

The test is using the same parameter as shown in Table 12 but tested with different size of teeth of each spur gear.

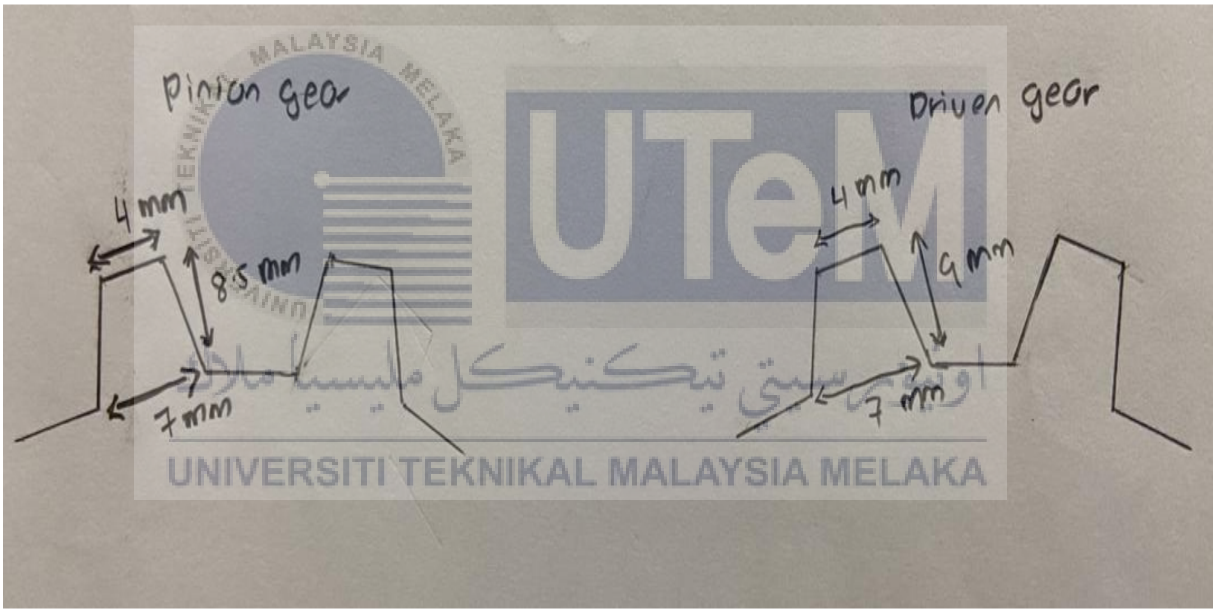


Figure 48: The size of teeth circular of pinion and driven gear

The first test of pitch circular measurement as shown in Figure 48. The ratio of the spur gear which used as the definition based on Table 7 is to design based on ratio 1:1 with pinion gear teeth number of 20, diameter of 65 mm and driven gear has teeth number of 35, diameter of 110mm. The number of teeth and diameter of gear are keep constant whereas the size of tooth and pitch circular is tested with different value.

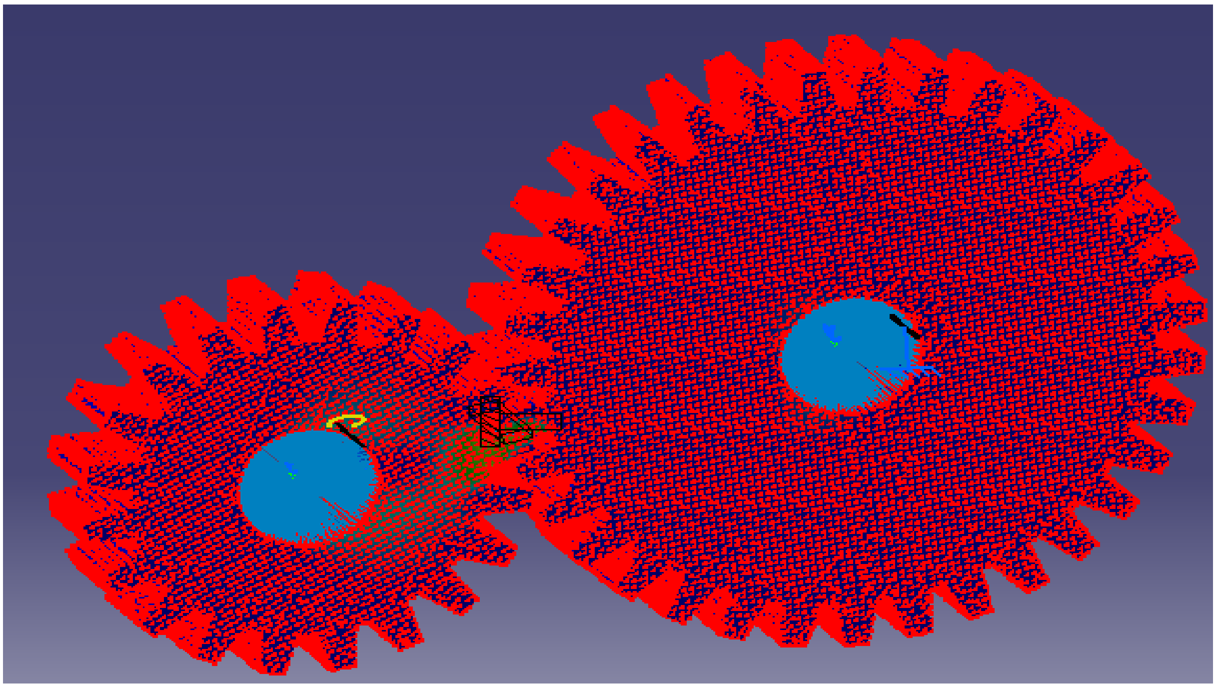


Figure 49: Deformed mesh analysis

Based on Figure 49, the Mesh deformed with nodes number of 96551 while the total elements number is 434179. The deformed mesh with nodes element is shown as a point of network where two or more circuit element are connected.

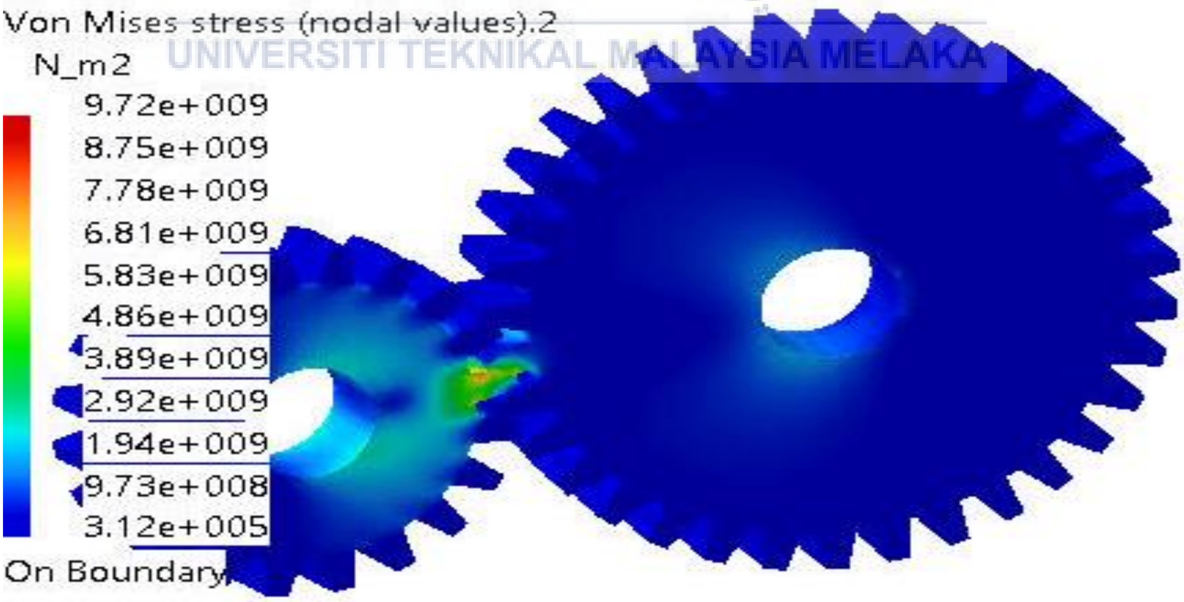


Figure 50: Von misses analysis result

The von misses analysis show a range value of 5.83×10^9 (N/m^2) which is considered in between since there are no red dot occur during the test analysis. The distribution of force in the Figure 50 which shows that the pinion gear receive extra force to sustain the gear rotation.

4.2.2 Set 3 of Pitch Circular

Next, the analysis is uses a smaller size of teeth but still uses the same parameter stated in Table 12 for both pinion and driven gear.

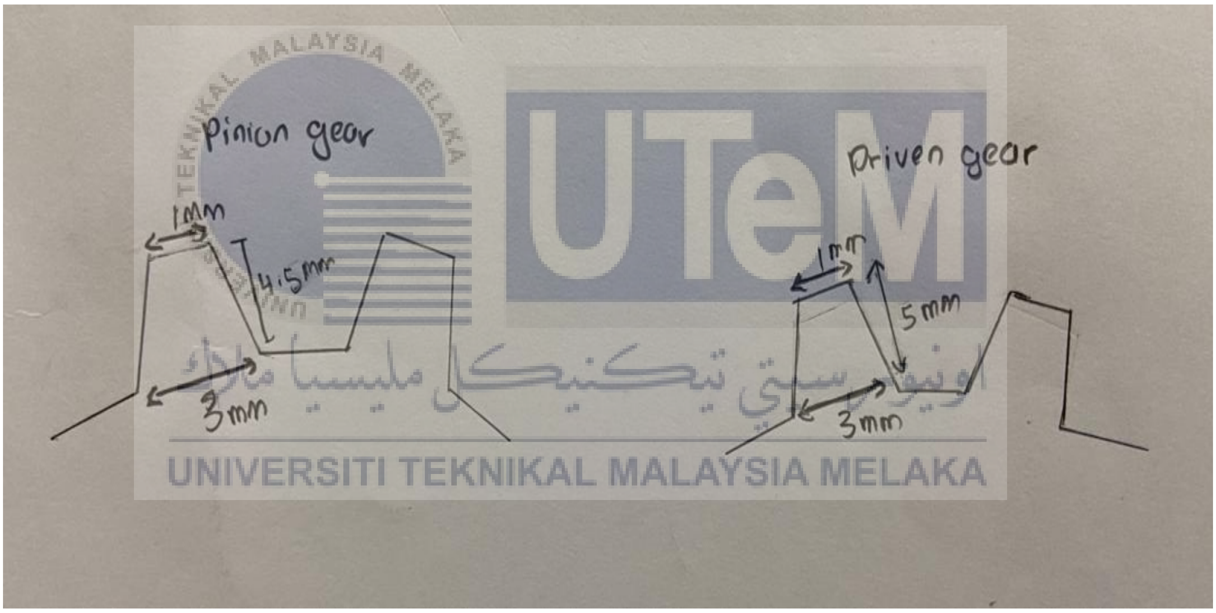


Figure 51: The teeth measurement of the test with 700 Kg (4905N)

The next test is to test at measurement shown in Figure 51. Based on Table 7, the ratio used are also 1:1 with a constant number of teeth for pinion and driven gear which is 20 and 35 while the diameter are also kept constant for both gear which is 65 mm for pinion and 110 mm for driven.

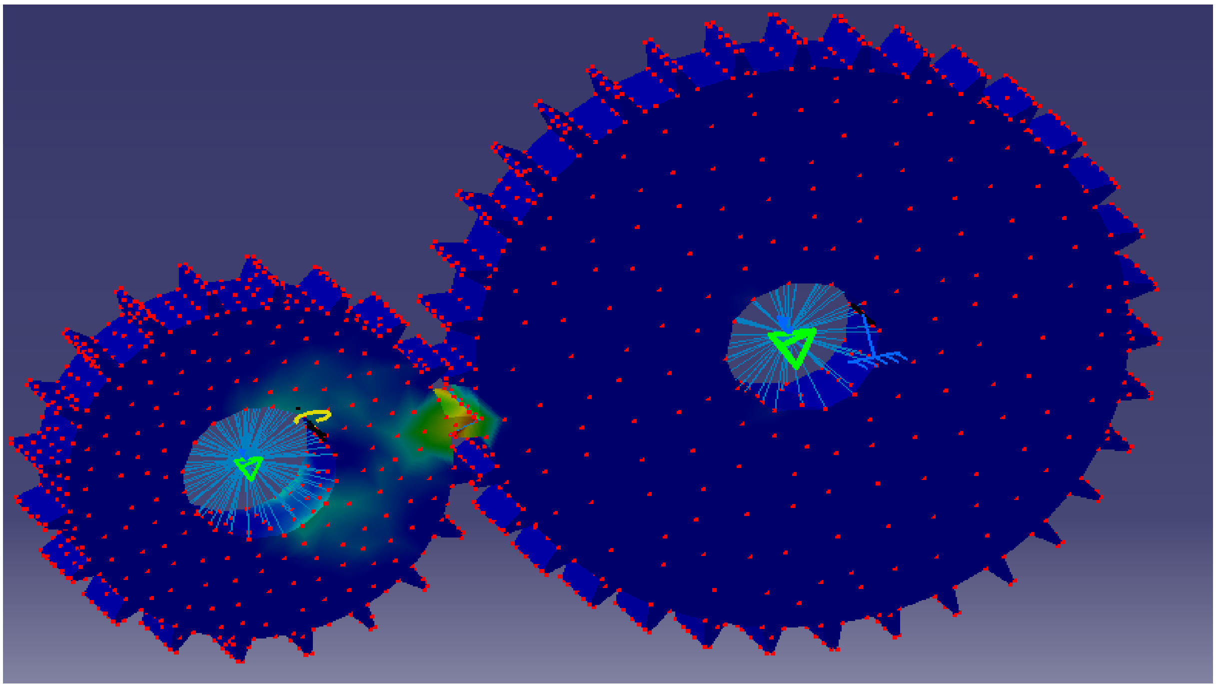


Figure 52: Deformed nodal mesh on test analysis

Nodal Mesh from the testing analysis is as shown in Figure 52 which shows the point of mesh. The nodal is connected to form meshing analysis.

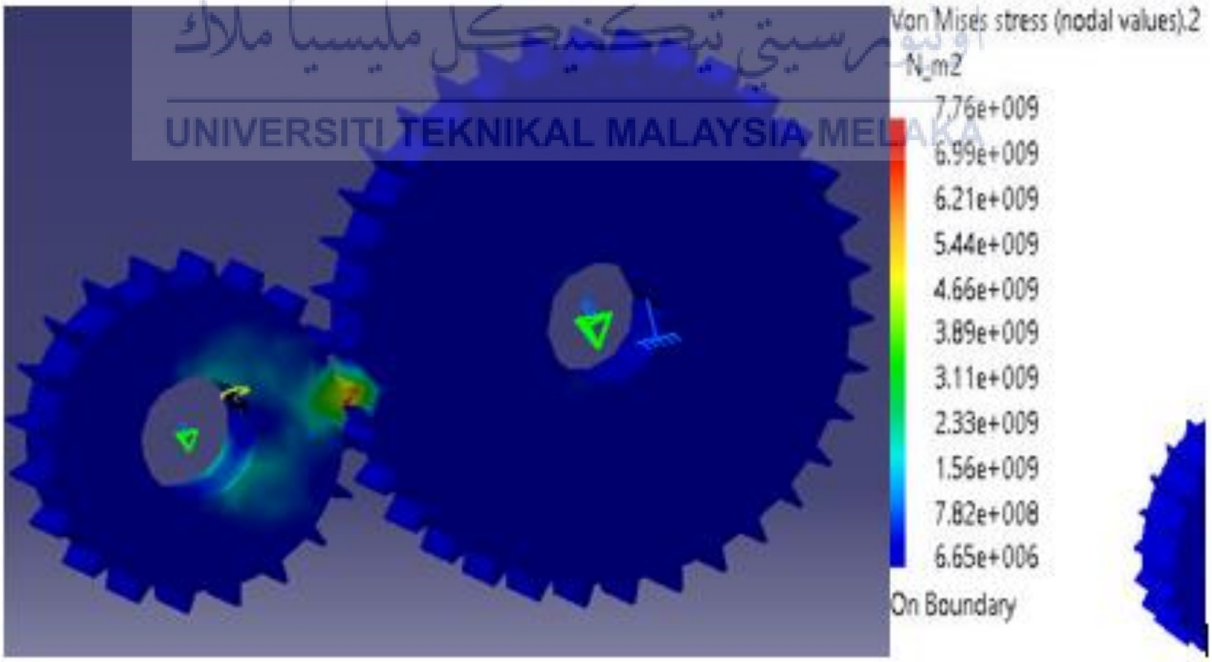


Figure 53: Von misses stress analysis result

Based on the analysis with the circular size and the teeth size of the gear, the result of the stresses are shown in Figure 53. The maximum stress based on the graphic visualization and testing is 6.21×10^9 (N/m^2). The analysis also shows that the deformation occur at the pinion gear which shows when the analysis is done, the gear are not align anymore which can be occur due to crack or forces defined at the teeth of the gear. The force distribution also occur at the pinion gear which shows that the pinion gear restrain a lot more to allow the rotating of the gear in the Ferris wheel.

4.3 Pitch Diameter of gears

Pitch diameter (D) for spur gears is the diameter of the pitch circle as shown in Figure 54 below. If there is a parallel gears, the pitch diameters can be determined by measuring the center distance to the teeth measurement.

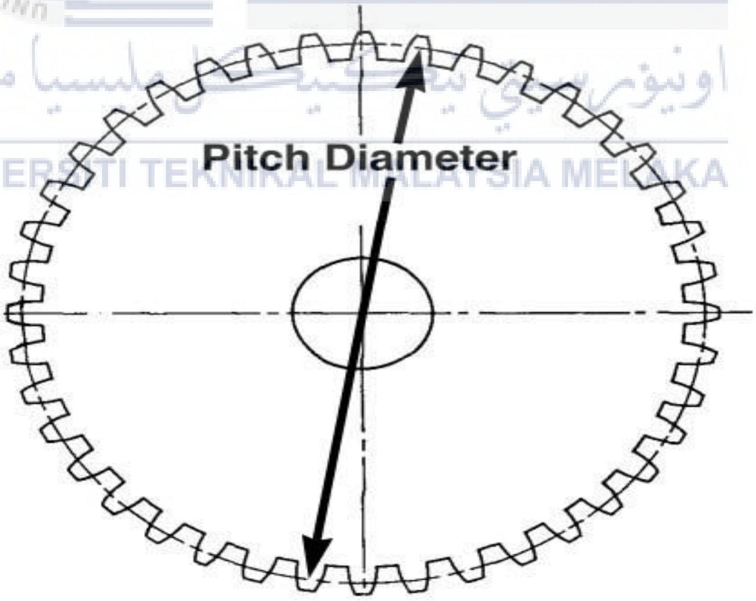


Figure 54: Pitch diameter example of gears

As for the number of teeth and the size are following the manufacturers measurements with different diameters. The constant size of teeth size for pinion and driven are shown below in Figure 55.

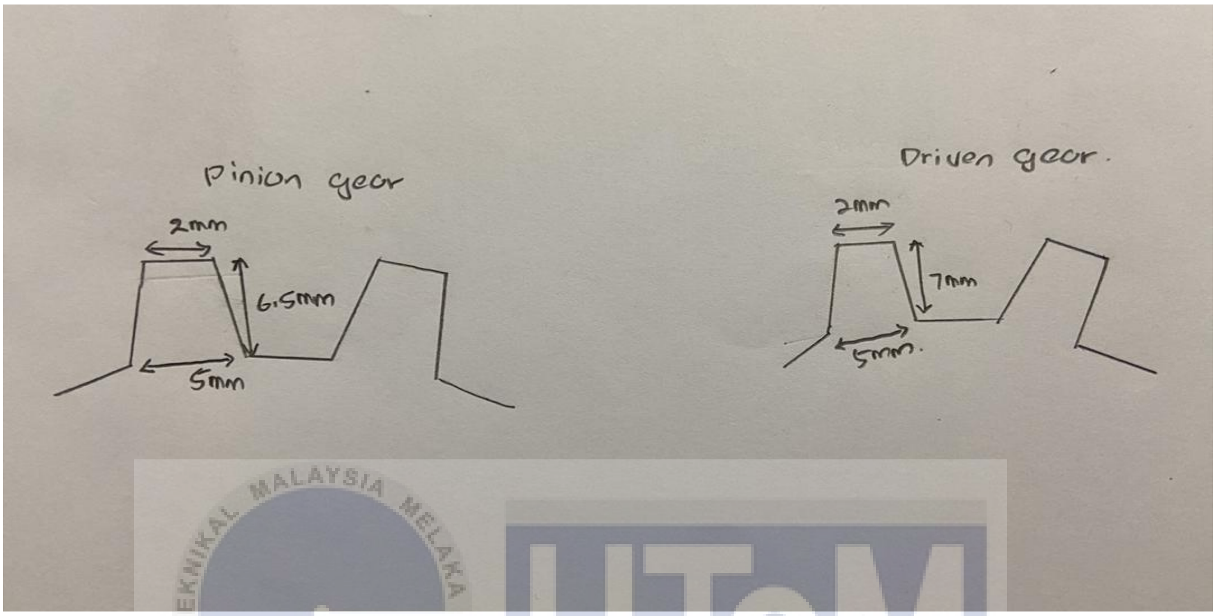


Figure 55: The teeth size following the original from OEM

4.3.1 Testing analysis at Diameter 60 mm pinion and Diameter 90 mm driven

Different type of enclosure is taken to the analysis with using different size of pinion and driven gear but sequence of parameter uses are based on Table 14 above regarding the value of mesh, material selection, Poisson ratio and others parameter.

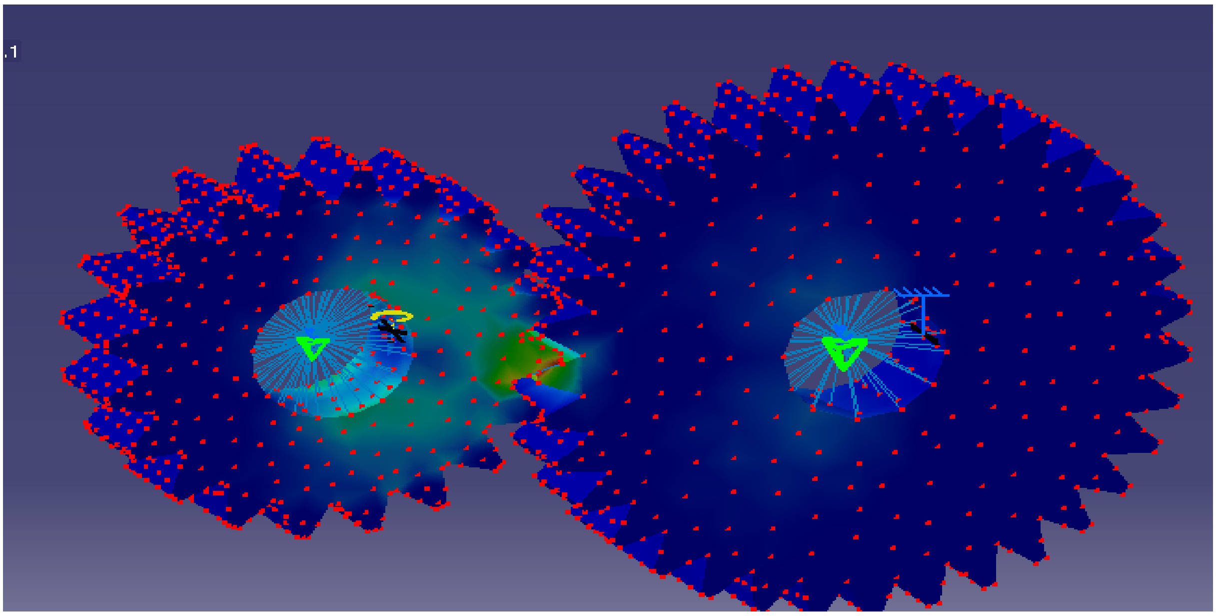


Figure 56: Mesh analysis of test result

The mesh analysis result for the test analysis is shown in Figure 56 which shows that the nodes points are wider in range.

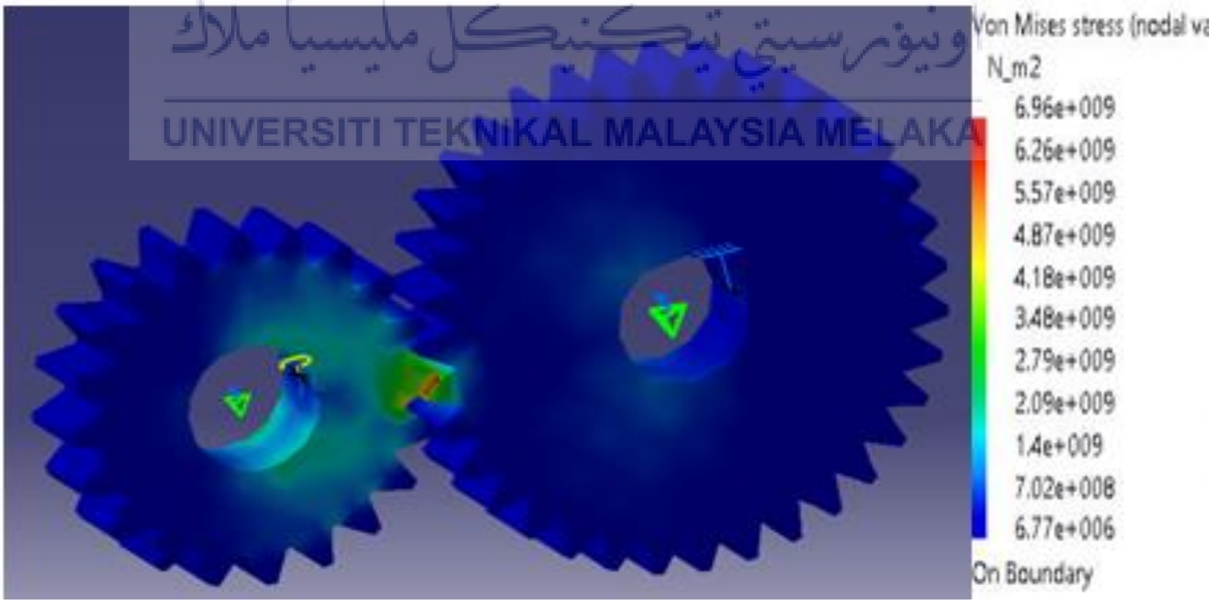


Figure 57: Von misses result

Figure 57 illustrates the forces used is 700 kg which is 6867 N which the moment used at the pinion gear causes the pinion gear to receive a spread amount of force as shown. The force spread shown at the pinion gear also shows that the pinion can have a large stress of 6.26×10^9 (N/m^2).

4.3.2 Testing analysis at Diameter 100 mm and Diameter 150 mm

The analysis is done with pinion diameter of 100 mm while the driven diameter is 150 mm. The number of teeth for both are kept constant which is 20 for pinion and 25 for driven gear. The amount of force also kept constant following the manufacturer which is 700 kg (6867 N).

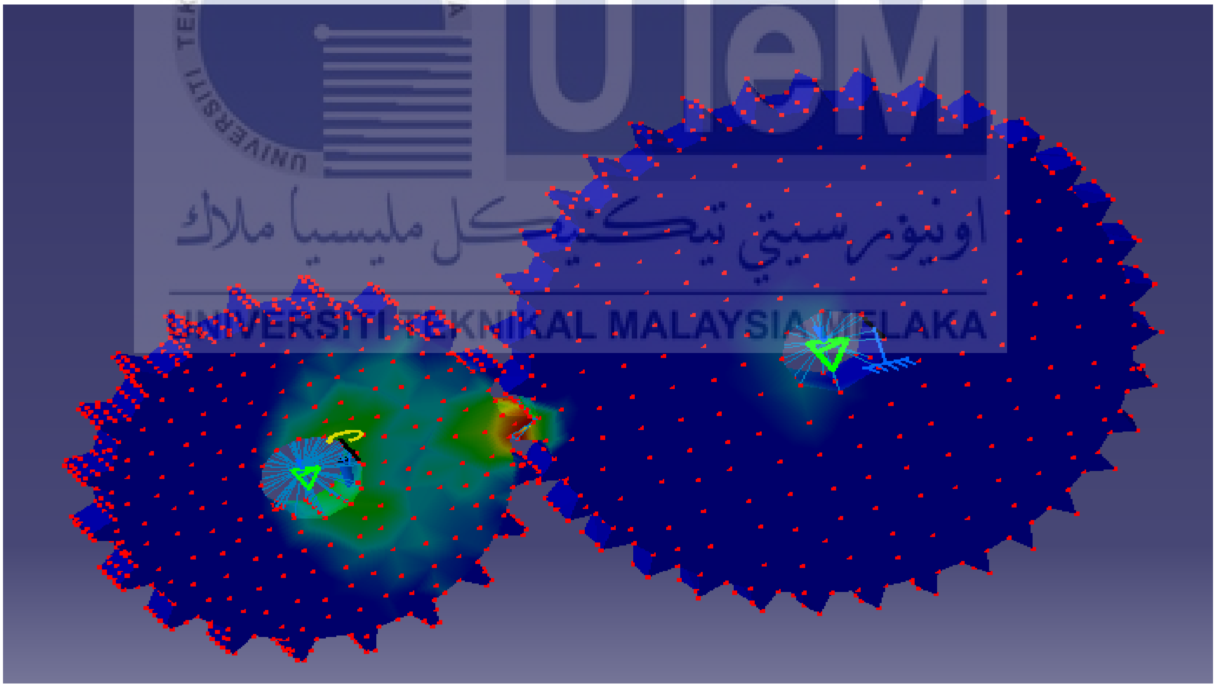


Figure 58: Mesh analysis result with deformed and nodes

The result of meshing is shown in Figure 58 shows that the point nodal of both pinion gear and driven gear are far apart.

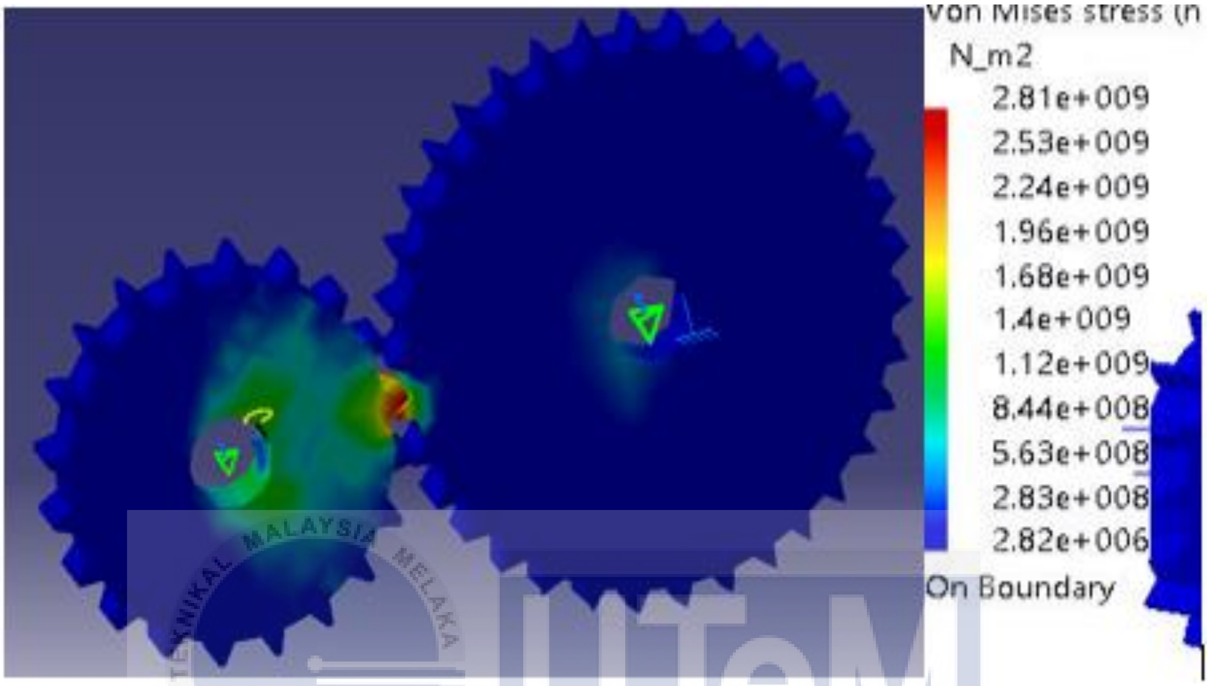


Figure 59: Von misses stress result analysis

The result for the stress analysis is shown in Figure 59 with the cut off of 2.81×10^9 (N/m^2). The highest point of stress measured before there is no reading due to higher risk of failure due to fatigue crack or non-acceptable sizing of the gear which are not compatible with the teeth size showing how the crack can occurs due to different size or weight tested due to high concentrated red colour on the result of analysis.

4.4 Analysis Result on the FEA Test

Based on the journal written by (Verma, Kumar, & Kankar, 2018) the gear tooth failure occurs due to plastic deformation on the tooth surfaces or based on the presence of fatigue crack. Proper shutdown of the system can be prepared by the early detection of a crack in the spur gear thus preventing catastrophic failure to occur. Thus this will also allow safer operation and high cost savings.

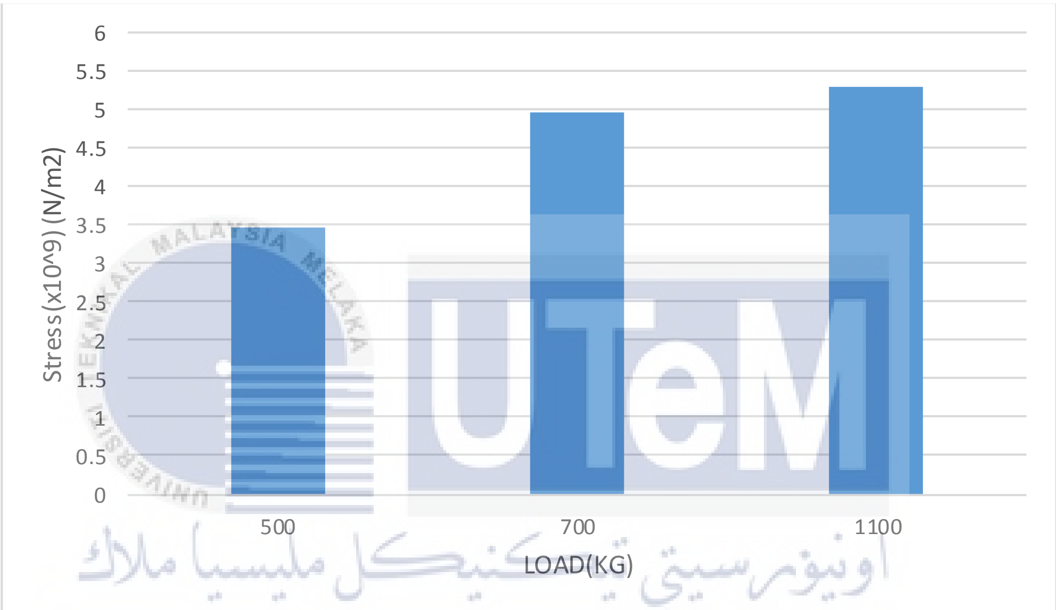


Figure 60: Test analysis for three consecutive weight load with stress

Based on the graph drawn shows that the difference between the mass and the stress value during the analysis. As shown in Figure 60, as the mass increases the stress value also increases. This is due to weightage and friction between the mechanisms which increases the stress.

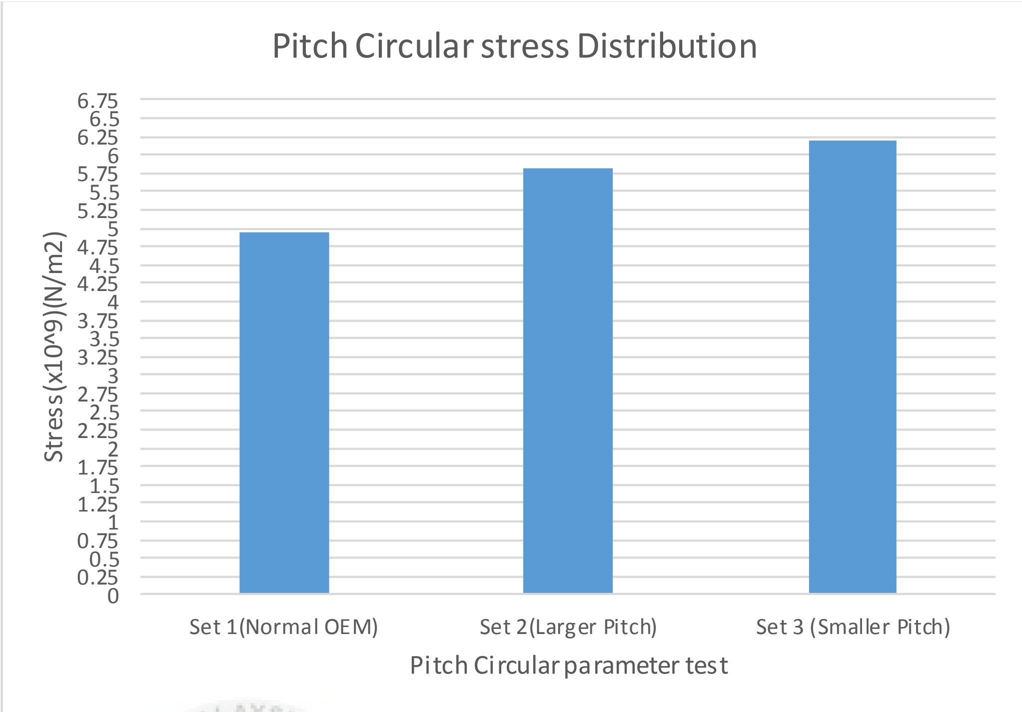


Figure 61: Values of Pitch Circular Analysis

Based on Figure 61, for Set 3, the circular measurement are smaller compared to the other both test analysis. The analysis uses the same load which is 700 kg (4905 N). From the analysis the smaller the size of teeth the higher the stress compute which is not suitable to be used as the mechanism for the amusement park.

Furthermore, by comparing the parameter suggested by the manufacturer (set 1) which gives the value of only 4.95 Giga newton while for set 2 pitch circular mentioned in 4.2.1 gives 5.83 Giga newton amount of stress. This means the safety are ensured to be safer to use the normal size suggested by the manufacturers

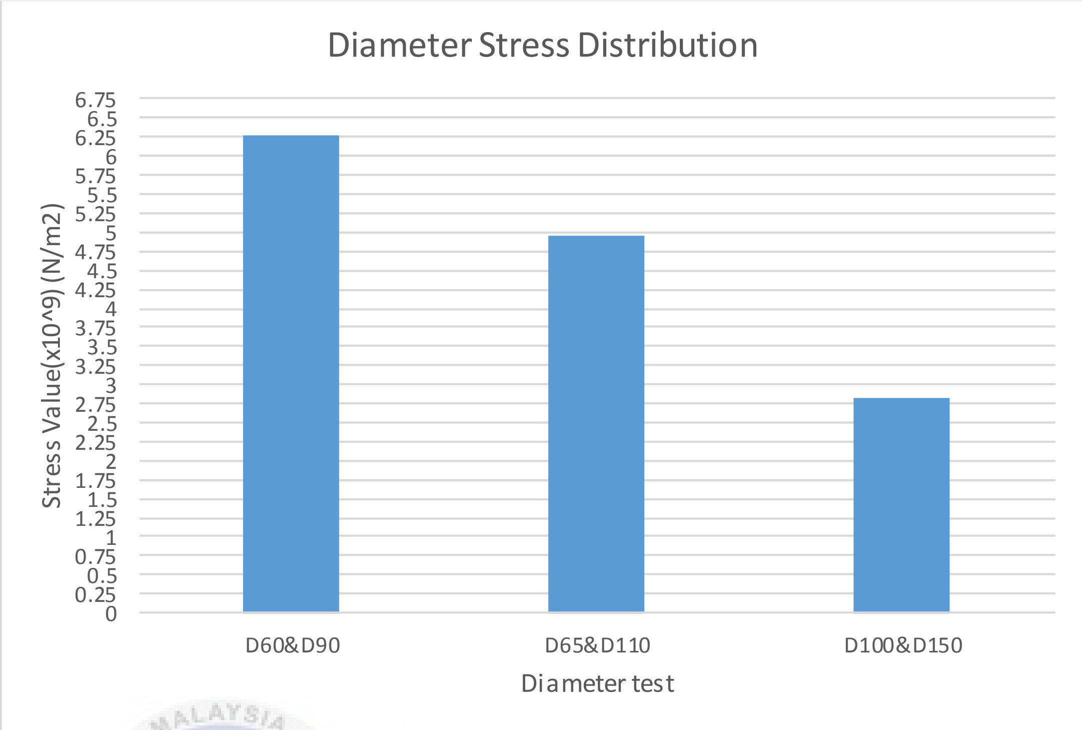


Figure 62: Stress of Pitch diameter analysis

Figure 62 illustrates, for the pitch diameter analysis shows that the stress decrease as the size of the diameter of both pinion and driven are larger. This is because the a larger surface can withstand a stress distributed from the pinion gear to the driver gear but based on the analysis the teeth of the diameter of pinion 100 mm and driver diameter of 150 mm are not compatible with the manufacturer parameters. In order to obtain the best result in the force or stress distribution, the size of teeth for the pinion and driver with diameter 100 mm and 150 mm need to changed so that the teeth and size of gear are compatible.

4.5 Discussion On CATIA Analysis

The result analysis of all the load test is compiled as shown below:

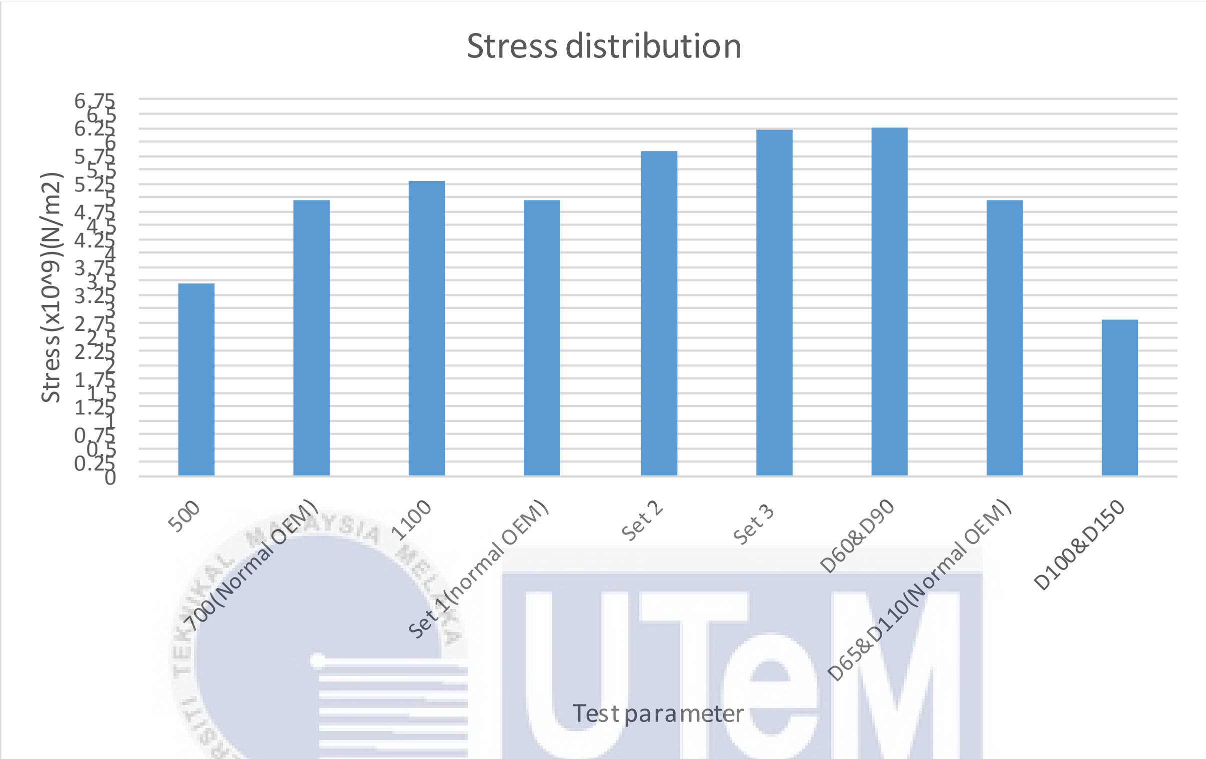


Figure 63: Test statistic for all analysis

Based on the Figure 63 the constant value is the normal OEM value of gear analysis which give the third lowest value which is at 4.95×10^9 (N/m^2) . The lowest value is tested for load 500 kg (4905 N) and tested at diameter D100 mm & D150 mm . But as for D100 mm & D150 mm tested are the lowest because the stress at it highest peak which only 2.81×10^9 N/m^2 before failure occur. The difference for load test shows that the safe load is tested at 500 kg (4905 N) which have the lowest stress value of 3.47×10^9 (N/m^2) shows the safe is load with 700 kg and below.

Based on the Figure 63 illustrated above, shows that there are decreasing trend of maximum stress for the difference of pitch diameter or the gear analyse. The bigger the diameter range with normal size of teeth are not compatible with the system. The larger diameter which is driver (d= 100 mm) and driven gear (d=150 mm) are tested with the load 700 kg (6867 N) tend to break at highest range value of stress 2.81×10^9 N/m^2 which shows that the safety to use larger diameter with smaller teeth size are avoidable.

There are slightly difference in maximum stress if there is change in size of teeth but same diameter based on OEM. The analysis proved that the gear can be broken due to a few main factors which is overload loading mass or poor maintenance. From the graph , we can conclude that the higher the load , the higher the stress and can inrease the change of wear and tear of gear. Significant changes in tooth stiffness can result in fatigue crack in tooth root.

4.6 Analytical calculation

Based on the equation (Eqn.3) the Ferris wheel in the amusement park first date of operation is on 1st June 2015 and the first breakdown occurs during 25th July 2016 which means 420 days with 8 hours max of running time.

$$MTBF=\frac{TOTAL\ UPTIME(HR)}{NUMBER\ OF\ BREAKDOWN}$$

$$=\frac{420\times 24\ hours}{1}$$

=10080 hours

Besides, based on the maintenance activity at the amusement park 19 June 2019 the Ferris wheel start to back up online after certain maintenance was done to it. Due to long time maintenance range, the mechanism can be affected by other factors which can be in term of lubrication or due to old condition wear of gear. From the latest maintenance the total days are 1059 days before next full maintenance done.

$$\text{MTTR}=\frac{1059\ x\ 24\ hrs}{2}$$

$$=12708\ \text{hours.}$$

Based on equation (Eqn.2), the remaining operating time formula given is

ROT = MTTF – AMT

=10080 – actual machine time of component

=10080 – (420×8 hours)

=10080—3360

=6720 hours

Based on the calculation above, it shows that the mean time to fail (MTTF) is around 10,080 hours which mean that the total hours of running should be maximum capacity at 10,080 hours per remaining operation time per year. The remaining operation time (ROT) is calculated to be 6720 hours which mean the lifetime of usage of the equipment are not maximise. The mean time to repair (MTTR) is calculated to have 12,708 hours since the maintenance takes longer downtime due to insufficient maintenance done which causes the failure of the gear and equipment.

In addition, based on the CATIA result shows that the possible rate of return of the lifetime extension can be based on the stress formed and the result shows that the best is to use lower range of load and do a proper maintenance to the equipment to increase the lifetime of the equipment.

RPN =S X 0 X D…………………………………………………………………… (Eqn.1)

=10 X 8 X 5 =400

Based on the Eqn. (1) and Table 11 discussed in chapter 3 shows that the value of the Risk Priority Number (RPN) shows higher value in term of gear. Thus the maintenance of the equipment must be implemented more to gear compare to other mechanism which is to avoid mechanical failure and reduce the probability of surface fatigue on gear mechanism.

4.7 Action Monitoring plan

Based on the analysis done to the spur gear, the suggestion of plan monitoring is suggested as shown in Table 13 below.

Table 13: Monitoring Plan

Suggestion	Explanation	Advantages	Disadvantages
Preventive maintenance	• Do maintenance regularly in 3 month range if the usage are frequently used • To prevent poor maintenance, the preventive maintenance need to be done to allow maximum safety and increase the life extension of equipment.	• Avoid unexpected broken or damage to equipment • Avoid sludge of oil contamination in the gear mechanism	• High cost
Lubrication	• Use oil lubrication in order to smoothen the movement of the gear mechanism	• Reduce friction thus reduce the risk of failure or fatigue to occur	• Finding a compatible viscosity to the gear mechanism

Load	• Monitor the total load allowable in term of human load or stagnant water during or working or static ferris wheel which can increase the force exerted over time on the gear mechanism	• Increase the lifetime of the amusement park equipment • Reduce cost of maintenance	• Hard to avoid mother nature disaster • Need more workers to handle the amusement park equipment

Table 13 illustrates the possible strategy or method to reduce the possibility of rate of fatigue failure to the mechanical component such as gears. Based on the analysis done within the specification of the possibility of gear failure. It can be proved that the fatigue crack of the gear can be due to overloading or due to external problem such as improper maintenance or environmental effects.

As the suggestion, the maintenance of the Ferris wheel need to be done regularly and the machine need to be working in order to avoid sludge of lubrication oil thus causing damage to the gear mechanism which is shown as the analysis shows that the related problem can be in term of maximum load or improper maintenance. The next suggestion is to use a lower mass of load in order to sustain the force and stress that can be exerted to the gear thus allowing the life extension to the mechanism itself. Since the cause of the incident can be due to more load during static or during working time can make the stress on the gear mechanism is higher thus increasing the effect to cause damage and broken a gear.

4.7.1 Proper Maintenance Schedule

The proper maintenance can be used to overcome the failure due to improper maintenance. The fault detection system should be introduced based on condition based maintenance to reduce the defect before fatigue crack occur to the system which is gear. Besides, based on the journal (Kumar, Goyal, Dang, Dhami, & Pabla, 2018) is shows that the periodic maintenance check by using predictive maintenance can reduce the possibility of crack or fatigue.

Preventive maintenance tend to reduces unpredictable failure breakdown. A few segment do tend to wear or fatigue at a predictable rate which can be predict using the mean time to failure. The higher the mean time to failure the better the outcomes from the preventive maintenance. The goal of the maintenance is to keep the equipment in the best working condition.

The preventive maintenance of the Spur gear mechanism of the Ferris wheel are to be carried often for every 6 month of duration of working, normally within a day such as quick survey on the mechanical component and major check-up needs to be done every 3 years.

The maintenance can be in term of oil sampling, particle counting to observe the current condition of the equipment lubricant. If the result of the sampling shows higher. In addition, impending failure knowledge can reduce the cost for maintenance thus helping the maintenance team to plan easier regarding the maintenance plan based on the condition of the. In journal (Nejad, Gao, & Moan, 2014) discussed about the higher the fatigue damage, the higher the probability of equipment failure.

4.7.2 Wear debris monitoring using Lubrication

Lubrication oil comes in direct contact with rotating parts such as gears. The segmentation destroy slowly and wear particles are diverted by the lubricating oil. The purpose of lubricating gears are to promote sliding between teeth of gears to reduce the friction coefficient. Furthermore, lubricant is used to limit the temperature that caused by the sliding or friction between the pinion and driven gear. Based on the FEA analysis shows that the higher the force, the higher the stress value. Therefore, to avoid difficulties such as tooth wear, fatigue crack to the gear, the most reliable lubricant are chosen

Gear lubrication can be in three methods which is grease lubrication, splash lubrication and forced oil circulation lubrication. For a low speed rotational parts, grease lubrication is a good choice while for medium and high speed rotation application the splash and forced oil lubrication is used.

Based on Table 6, the value of speed rotation stated by the OEM is v=0.2 m/s therefore based on the suggested lubricant, the grease lubricant are suitable to use to reduce the stress and friction on the teeth of the gear during contact.

CHAPTER 5 CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter includes the conclusion and the recommendation for the project.

5.2 CONCLUSION

As the conclusion, the maintenance should be done to the equipment in order to maintain the reliability and thus ensuring the equipment can be operated. This study intend to propose a new conditional operational plan based on the maintenance done to the gear by using simulation. Beside, determining the structural component, function and the material of the mechanical component of gear system of the amusement park thus determine the potential of a case study regarding mechanical gear failure of the amusement park equipment. The methodology of studying the crucial component of the amusement park by using Failure Mode and Effect Analysis (FMEA) and the operational condition is tested in the simulation according to the manual to test the failure mode of the gear mechanism thus proposing a new operational condition. Simulation tools allow us to be innovative and to rapidly test new ideas that would be much harder, more time-consuming and more costly to test in the laboratory.

The initial crack can be formed for different reasons. The most common reasons for this are short-term overload, material defects, mechanical or thermal treatment defects and material fatigue based on the article, (*Finite Element Analysis And Fatigue Analysis Of Spur Gear Under Random*, 2014) which shows that based on the FEA analysis tested, the higher the load the higher the stress produce. To propose to obtain a higher lifetime of equipment, a proper maintenance need to be followed gradually and the load must not be maximise to avoid gear failure as discussed in Table 13 above which to prepare a preventive maintenance in order to obtain reading or enclosure of the gear condition in real time thus can investigate the failure mode if there is defect to the gear and prepare for the monitoring plan to overcome the circumstances before failure occur to the equipment. For any mechanism especially gear need to use lubricant is order to allow the better performance and reduce the friction in contact thus reducing the wear and tear defect to the gear. Last but not least, the loading need to be use at range compatible with the equipment to avoid unintentionally sudden breakdown.

5.3 RECOMMENDATION

After conducting the analysis, there are a few recommendations to enhance the real data result of this experimental and monitoring project. Based on the current situation, the data analysis of precisely measuring the amount of hours and days of the Ferris wheel operates are not eligible thus making the suggestion of the monitoring plan is difficult. For new situation to obtain the real data, the analysis need to be access from virtual inspection to compare the analysis done with Finite Element Analysis (FEA) and real time data and defects.

This is because, comparison cannot be assumed due to the original data obtain from working Ferris wheel are limited due to early defective mechanism of gear avoiding to obtain real data and situation uphold.

In addition, it is recommended to assign a specific gear with specific size of gear teeth and the parameter is tested in the field which is the Ferris wheel and tested with FEA. This method can allow us to compare data of the defective gears due to certain circumstances. Besides, the design analysis based on the gear mechanism helps to determine the best maintenance plan and possible way to reduce the probability of fatigue failure of the gears.

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APPENDIX

APPENDIX A: GANT CHART FOR PROJEK SARJANA MUDA 1

No.	Task	Week															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Preparation of Progress Report																
2	Article and Journal Searching and Reading																
3	Progress on Literature Review																
4	Progress on Methodology																
5	Submission of Progress Report																
6	Progress on Full Report																
7	Preparation Slide Presentation																
8	Submission Of Draft final PSM 1 Report																
9	Presentation PSM 1																

APPENDIX B: GANT CHART PROJECT SARJANA MUDA 2

No.	Task	Week															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Literature Review																
2	Report Writing																
3	Experiment and simulation testing																
4	Analysis and discussion																
5	Seminar 2																
6	Report Submission																