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

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A report submitted

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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 :

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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 :

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DEDICATION

To my beloved father and mother

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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.

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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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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

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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

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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

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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.

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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.

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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.

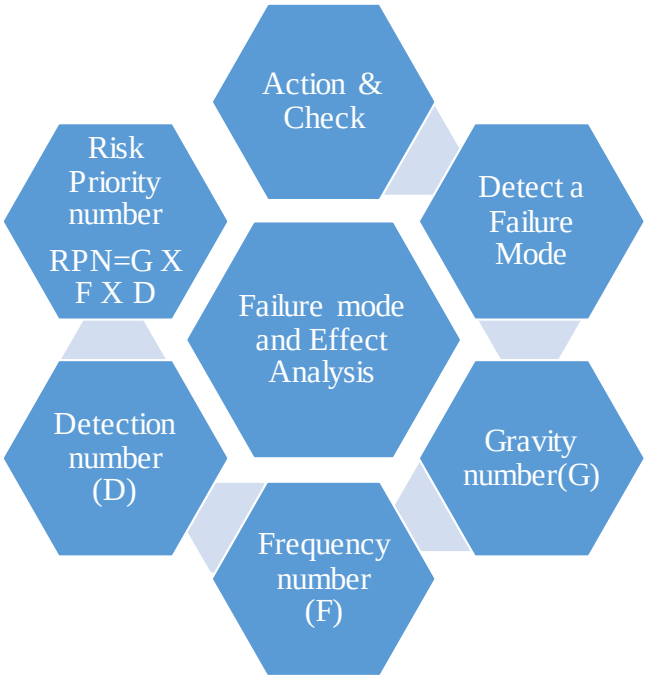

Figure 1:Main steps of FMEA (Cândea et al., 2014)

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).

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RPN =O x S x D…… (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	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).

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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).

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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

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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.

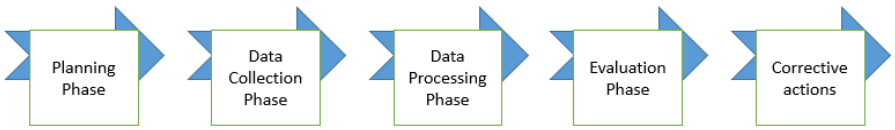

Figure 4: SHM flow method (Sohn et al., 2001)

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

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