DESIGN FOR REMANUFACTURING: A STUDY OF ELECTRIC VEHICLE TRANSMISSION

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This report is submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Hons.)

by

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UTeM

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DECLARATION

I hereby, declared this report entitled "Design For Remanufacturing: A Study Of Electric Vehicle Transmission" is the result of my own research except as cited in references.

Signature : ……………………………………

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Date : 27 JANUARY 2023

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Hons). The member of the supervisory committee is as follow:

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(DR. NURAZUA BINTI MOHD. YUSOP)

ABSTRAK

Industri pengangkutan mengeluarkan 25% daripada *Greenhouse Gases* (GHG) yang dihasilkan oleh industri berkaitan tenaga. Dengan peranan yang besar dalam sektor automotif, *Electric Vehicle* (EV) dijangka dapat mengurangkan kesan-kesan rumah hijau. Selaras dengan bilangan tambahan pengeluaran EV, penghujung hayat komponennya perlu dikaji dengan teliti untuk mengelakkan kesan negatif baharu terhadap alam sekitar. Pengilangan semula adalah salah satu kaedah yang boleh digunakan untuk mengurangkan kesan terhadap alam sekitar oleh komponen EV. Pengilangan semula ialah proses perindustrian untuk memulihkan produk lama kepada produk baharu dan diberi nilai tambah. Kajian ini memberi tumpuan kepada pengilangan semula transmisi EV atau *transmission*. Kajian ini juga akan melakukan penilaian kitaran hayat (LCA) yang dibina dengan menggunakan perisian openLCA untuk membandingkan antara kitaran hayat transmisi EV yang baharu dengan transmisi EV yang dikilangkan semula. Jenis LCA yang digunakan ialah *cradle to gate* yang lebih memfokuskan kepada bahan yang digunakan semasa proses pengilangan produk. Keputusan menunjukkan transmisi yang dikilangkan semula menghasilkan impak yang lebih rendah terhadap alam sekitar berbanding transmisi yang baharu. Dari segi *abiotic depletion,* ia menunjukkan bahawa pengilangan semula mampu meminimumkan 84% penggunaan bahan mentah berbanding transmisi yang baru dikeluarkan secara keseluruhan dan menyumbang 63% lebih rendah *Global Warming Potential* (GWP) berbanding transmisi yang baru dikeluarkan. Penyumbang utama terhadap keputusan tersebut adalah daripada jumlah penggunaan bahan dan pengunaan tenaga yang lebih sedikit oleh proses pengilangan semula transmisi berbanding transmisi yang baharu.

ABSTRACT

The transportation industry releases 25% of the Greenhouse gases (GHGs) produced by energy-related industries. With a substantial presence in the automotive sector, Electric Vehicles (EVs) are expected to lower the impact of the greenhouse effect. EVs have grown in popularity in recent years. Their participation is important in lowering GHG emissions into the atmosphere. Corresponding to the additional number of EVs production, the end of life of their components needs to be carefully studied to avoid new negative environmental impacts. Remanufacturing is one of the methods that can be used to reduce and eliminate the environmental impact of EV components. Remanufacturing is an industrial process to restore an old product to a new with value-added product. In addition, there is a minimal amount of study regarding the remanufacturing of EV transmissions. The study included the life cycle assessment constructed by using the openLCA software to compare between the life cycle of a new EV transmission with the remanufactured EV transmission. The type of LCA used is cradle to gate which is focused more on the injected material used to manufacture the product. The result shows that the remanufactured transmission performs significantly better than the newly manufactured component in terms of all environmental impact categories considered. In terms of abiotic depletion, it shows that remanufacturing able to minimise 84% the used of raw material compared to newly manufactured transmission in total and contributed 63% lesser of Global Warming Potential (GWP) compared to the newly manufactured transmission. The savings are chiefly due to lower power consumption and material requirements as a result of the reuse of components.

DEDICATION

The name of Allah, the Most Gracious and the Most Merciful

my beloved father, Azman Bin Musa

my appreciated mother, Norlaila Binti Ali

my cats

my siblings

my supervisor

my fellow friends

for giving me moral support, love, money, cooperation,

encouragement, and also understandings

Thank You So Much & Love You All Forever

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Aside from that, I'd like to thank my parents and family members for their unwavering financial, mental, and physical support in helping me achieve my goals. Finally, I'd want to express my gratitude to Akalil Ahmad, my best buddy, for always encouraging me and other friends who provided me with mental drive and cooperation in completing this report. Throughout my investigation, they had made significant suggestions and remarks. Thank you for your wonderful friendship.

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LIST OF ABBREVIATION

EV	-	Electric vehicle
GHG	-	Greenhouse gas
CO2	-	Carbon dioxide
SO2	-	Sulphur dioxide
EF	-	Environmental Footprint
EU	-	European Union
ICE	-	Internal combustion engine
ELV	-	End-of-life vehicle
LCA	-	Life cycle assessment
OEM	-	Original equipment manufacturer
EEE	-	Electrical and electronic equipment
EoL	-	End of Life
PHEV	-	Plug-in hybrid
NAP	-	National Automotive Policy
TNBES	-	Tenaga Nasional Berhad Energy Services
MGTC	-	Malaysian Green Technology Corp
RM	-	Ringgit Malaysia
HEV	-	Hybrid electric vehicle
BEV	-	Battery electric vehicle
FCEV	-	Fuel cell electric vehicle
EREV	-	Extended range electric vehicle
SEV	-	Solar electric vehicle
DC	-	Direct current
EVB	-	Electric vehicle battery
kW	-	Kilowatt
AC	-	Alternating current
RPM	-	Revolution per minute

SD	-	System dynamic
DES	-	Discrete event simulation
LCC	-	Life cycle cost
LCIA	-	Life Cycle Impact Assessment
LCR	-	Life cycle replacement
UNEP	-	United Nation Environment Programme
CLD	-	Causal loop diagram
SFD	-	Stock flow diagram
BOM	-	Bill of Material
GWP	-	Global Warming Potential
ADP	-	Abiotic Depletion Potential

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Electric vehicles (EVs) have grown in popularity in recent years, and there are a variety of reasons for this. Their participation is critical in lowering greenhouse gas (GHG) emissions into the atmosphere. Transportation was responsible for 25% of the GHGs created by energy-related industries. Climate change is caused by the greenhouse effect, which is a natural occurrence. Industrial revolutions, humans have consumed massive amounts of fossil fuels such as oil and gas. Huge volumes of carbon dioxide are released into the atmosphere by fossil fuels. The gases released into the atmosphere operate as an invisible "blanket," warming the earth and trapping heat from the sun. This effect is known as the "Greenhouse Effect."

With a substantial presence in the automotive sector, EVs are expected to lower the impact of the greenhouse effect. The automobile industry is undergoing rapid and widespread change. Automobiles cause numerous environmental and fuel-related issues. As a result, electric vehicles are becoming more mainstream and becoming increasingly important in the automobile industry. Various firms such as Tesla, Nissan, Hyundai, Honda, Ford, and Tata are optimistic about the EV market because of its environmental, fuel economy, and other benefits. The battery, motor, and transmission system are the several components of an EV, but the main focus of this study is only for the transmission system.

More than 1 million new EVs were registered for the first time, and 60% of them from China (MacDonald, 2016). According to Deloitte Insight, worldwide EV estimate global unit sales will expand at a rate of 29 percent per year over the next 10 years. Electric car sales will increase from 2.5 million in 2020 to 11.2 million in 2025, and 31.1 million in 2030. Electric cars would account for around 32% of new automobile sales, according to the report (Bryan Walton, 2022).

Corresponding to the additional number of EVs production, the end of life of its components needs to be carefully studied to avoid from new bad environmental impact. Remanufacturing is one of the methods that can be used to reduce and eliminate the environmental impact of electric vehicle (EV) components. Remanufacturing is the process of restoring a used product to its original state by regaining the component's added value when it was initially made (Dietz, 2015). In another research, remanufacturing also can be defined as the supplier taking their product back and restore them to like a new state of product or better in an industrial process (Lindkvist Haziri & Sundin, 2020). The author also said significant energy consumption and emissions to air and water, such as carbon dioxide (CO2) and sulphur dioxide (SO2), can be reduced by extending the lifespan of components. Comparing remanufacturing against new manufacturing and/or material recycling reveals that remanufacturing provides environmental benefits. This is due to reduced resource depletion, reduced global warming potential, and higher prospects of closing the loop for safer toxic material management (Lindkvist Haziri & Sundin, 2020).

In the production phase, the automobile industry is reliant on a variety of raw materials and rare metals, which limits the sector's future growth. The automobile sector consumes 12% of total world steel consumption, as per World Steel Association (Gabhane & Kaddoura, 2017). In addition, according to the US Geological Survey, it is also responsible for 60% of global lead use, with reserves expected to run out by 2030 (Otter, 2018). Remanufacturing is a strategy to minimize at the same time to reduce the dependency of automotive industry to the new raw material supply.

1.2 Problem Statement

Government all across the world are enacting policies and programmes to minimise the carbon emissions (Angius et al., 2016). The same article also stated that the United Kingdom aims to reduce carbon emissions by 45% by 2020. The European Union (EU) has established goals for 2021 and 2022 that will reduce air pollution emissions by 18 and 40 percent, respectively, compared to 2007 levels (Rauh, 2019). Not to left behind, Malaysian's 9th Prime Minister has announced the target for Malaysia to become a carbon neutral country by 2050 at the earliest (Fang, 2022). The annual carbon dioxide emissions from a typical passenger vehicle are approximately 4.6 metric tonnes (Greenhouse Gas Emissions from a Typical Passenger Vehicle, 2021). Thus, EVs is a good option to replace the internal combustion engine (ICE) vehicle to compliment the global goals towards minimizing the carbon emissions due to the zero-exhaust emission.

Figure 1.1 below depicts the rapid selling of electric vehicles in China, Europe, the United States, and other nations from 2010 to 2020. By 2020, around 3 million new electric vehicles will have been registered. For the first time, Europe has the largest number with 1.4 million new registrations. The second one, China with 1.2 million new electric vehicle registrations, and United States with 295 000 new EV registrations. This increasing trend in electric vehicle sales is extremely beneficial since it has the potential to minimize the world's indirect reliance on natural resources such as petroleum.

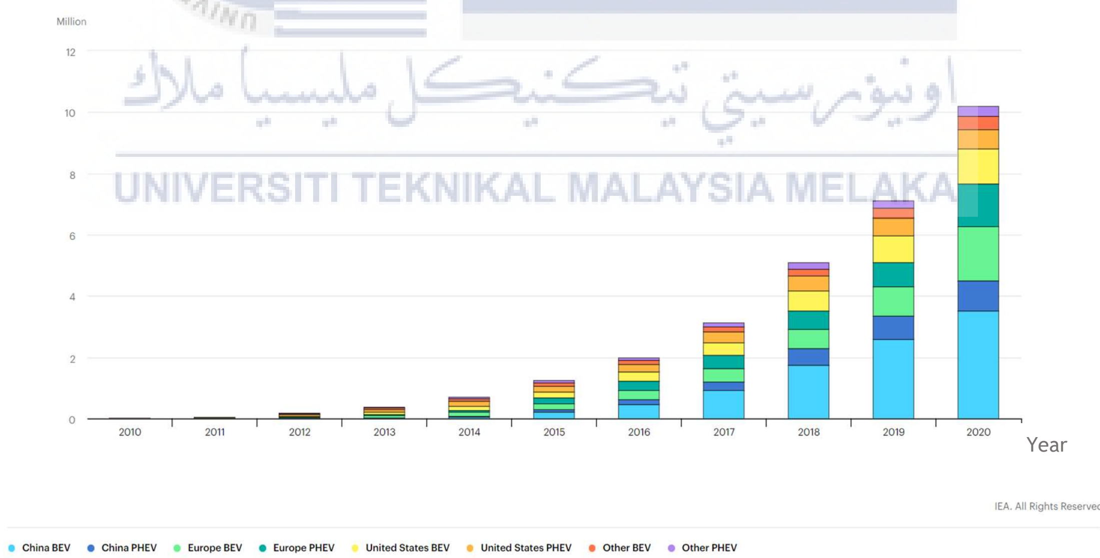

Figure 1.1: Global electric passenger car stock, 2010-2020 (Global electric passenger car stock for 2010-2020, 2020).

Unfortunately, those fact led to the second problem statement where EVs manufacturing industries still relying on the natural resources such as aluminium, steel, cast iron, stainless steel, and lithium to build the components for the EVs. This increasing demand on metals and the emissions associated with their production has resulted in increasing pricing and challenges ensuring the process's supply chain. To avoid this, remanufacturing of the components at the End-of-Life vehicles (ELVs) is one of the ways. Finally, there is minimal amount of study regarding the remanufacturing of EVs transmission. Most scholars are interested in EVs battery because it is the main components for EV such as a study by Fotouhi et al., 2016, Wang et al., 2020, and Xiong et al., 2020. That research only focusing on EV battery. There is several study regarding EV transmission, such as written by Sirohi et al., 2017, Joshi & Ugale, 2020, and Carlos Daniel Pires, 2018, only focusing on the design structure of EV transmission. Therefore, it is important to study about EVs transmission because it still relying to the raw material resources to manufacture the part.

1.3 Objectives

The objectives of this study are as follow:

i. To study the concept of electric vehicle transmission.
ii. To identify the main component for the remanufactured electric vehicle transmission.
iii. To propose the environmental impact performance analysis of newly manufactured and remanufactured electric vehicle transmission.

1.4 Scope

The scope of the thesis is to study the concept of EV remanufacturing in Malaysia particularly for transmission part. An interview will be conduct with automotive engine workshop to identify the main component of the EV transmission and the component that mostly need to be change for remanufactured transmission. Furthermore, the life cycle assessment will be proposed by using openLCA software to compare the environmental impact between the newly transmission versus the remanufactured transmission. The type of LCA use is cradle to gate which is focused more to the manufacturing flow.

1.3 Importance of Study

The primary goal of this research is to determine and quantify Malaysian acceptance toward EV and the remanufactured product. This study is important to create an awareness to Malaysian and Malaysian automotive industries regarding the EVs problem occur at the ELVs of the EVs especially for the transmission component. In general, present researchers have undertaken substantial research on the life cycle assessment of electric vehicle batteries and have established a preliminary research system. However, there is lack of study on electric vehicle transmission component. It is important to establish a basic study regarding the life cycle assessment (LCA) of EV transmission to cope with the massive wave of end-of-life of EV in the future.

1.6 Organization of the Thesis

The first part of this thesis is chapter 1, introduction. It starts with background of study which briefly explain the main idea of this study. The problem statement is presented in the second section of this chapter, followed by the objectives, scope, importance of the study, and summary. Next, chapter 2 is about literature review which will describe in more detail regarding the idea of this study. Next, on the Chapter 3: Methodology, will be identify the method approach that suitable with the aim of the thesis. Chapter 4 is for Result and Discussion and the final chapter will be conclusion.

1.7 Summary

The main focus of this thesis is to study the concept of transmission for EVs. Remanufacturing is an industrial process of restoring a used product to like a new condition by recovering the value added to the component like when it was first produced. This study is important in respond to the Malaysia's government target to be a carbon neutral country by 2050. The results will indicate if remanufacturing able to solve the problem of raw material exploitation to manufacture an EV. Findings will provide multidisciplinary viewpoints and important information for the preparation for the ‘greener’ option for automotive industries.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction of Literature Review

This chapter will summarize previous research on related articles, journals, websites, and books conducted by the researchers. The topic has been covered in this chapter is remanufacturing, remanufacturing in general, remanufacturing in the automotive industry, and remanufacturing in Electrical Vehicle (EV), electric vehicle, the history of EVs, the type of EV and their working principle, the main component of the EV, EV transmission, and the process flow of the remanufacturing of an EV transmission.

2.2 Remanufacturing

Consumers, businesses, governments, and the general public are becoming more aware of the importance of sustainability issues, prompting many industries to implement environmentally conscious policies in their product development, manufacturing, distribution, service, and end-of-life management. In recent years, the market for remanufactured items for secondary use has grown dramatically as a result of more excellent consumer and industry knowledge of the benefits from remanufacturing (Mitsutaka Matsumoto, Shanshan Yang, 2016).

Several formal definitions of remanufacturing have been proposed over the years, most of them describe remanufacturing as "an industrial technique for restoring value to old