DEVELOPMENT OF AUTONOMOUS ELECTROMAGNETIC TWO SPEED GEARBOX FOR ELECTRIC VEHICLE

BY

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A thesis submitted in fulfilment of the requirement for the degree of Master of Science (Automotive Engineering)

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ABSTRACT

The goal of the National Automotive Policy (NAP) 2020 is to develop advanced automotive technologies for the next generation vehicle (NxGVs) with improving energy efficiency and autonomous for the future mobility in Malaysia. Conventional transmissions such as automatic transmission (AT), manual transmission (MT), and / or continuously variable transmission (CVT) for NxGV will cause energy consumption due to their bulkiness and difficulty to install directly with the EV's motor-head. In addition, the single-speed gearbox (SS-GB) is lighter, but not suitable for generating enough torque at start-up or when going uphill. Therefore, the development of a compact and autonomous energy-efficient transmission is a key technological issue for NxGV. The aim of this study is to fabricate a prototype of a compact and lightweight autonomous electromagnetic two-speed gearbox (AEM2SGB) for EV in accordance with NAP-2020 and IR4.0. The first-gear is used for acceleration in uphill, which provide high torque, and the second-gear is used for higher speed. A compact and lightweight laboratory-scale AEM2SGB has been developed. Furthermore, an autonomous fuzzy controlled system has been developed with associating the wheel speed sensor and motor sensor to control the power flow to the electromagnetic actuator (EMA). A laboratory experiment is conducted using equivalent road-loads. It is observed that the AEM2SGB's shift times in first gear to be 1.5 seconds with a higher torque of 3000 Nm and 1.8 seconds in second gear for 110 km / h with supplying current in the range of 12-16A.

Keywords: Electromagnetic gearbox; Fuzzy logic controller; Energy efficient; Gear shifting time.

خلاصة البحث

الهدف من السياسة الوطنية للسيارات 2020 (NAP) هو تطوير تقنيات سيارات متقدمة لمركبة الجيل القادم (NxGVs) مع تحسين كفاءة الطاقة والاستقلالية للتنقل المستقبلي في ماليزيا. ناقلاتNxGV التقليدية مثل ناقل الحركة الأوتوماتيكي (AT) ، وناقل الحركة اليدوي (MT) ، و / أو ناقل الحركة المتغير المستمر (CVT) سوف تتسبب في استهلاك الطاقة نظرًا لضخامتها وصعوبة تثبيتها مباشرةً مع رأس محرك EV. بالإضافة إلى ذلك ، فإن علبة التروس أحادية السرعة (SS-GB) أخف وزنًا ، ولكنها غير مناسبة لتوليد عزم دوران كافٍ عند بدء التشغيل أو عند الصعود إلى المنحدرات. لذلك ، يعد تطوير ناقل حركة مدمج ومستقل وموفرًا للطاقة هو مفتاح الحل الرئيسي لـ NxGV الهدف من هذه الدراسة هو تصنيع نموذج أولي لعلبة تروس كهرومغناطيسية ثنائية السرعة وخفيفة الوزن ومستقلة (AEM2SGB) للمركبات الكهربائية وفقًا لـ NAP-2020 و IR4.0. يتم استخدام الترس الأول للتسريع في المنحدرات ، مما يوفر عزم دوران عالي ، ويستخدم الترس الثاني لسرعة أعلى. تم تطوير AEM2SGB صغير الحجم وخفيف الوزن في نطاق معملي. وايضا ، تم تطوير نظام تحكم ضبابي ذاتي مع ربط مستشعر سرعة العجلة ومستشعر المحرك للتحكم في تدفق الطاقة إلى المشغل الكهرومغناطيسي (EMA). تم إجراء تجربة معملية باستخدام أحمال الطريق المكافئة. كان ملاحظا أن أوقات تغيير سرعة AEM2SGB في الترس الأول تكون 1.5 ثانية مع عزم دوران أعلى يبلغ 3000 نيوتن متر و 1.8 ثانية في الترس الثاني مقابل 110 كم / ساعة مع إمداد تيار في نطاق 12-16 أمبير.

الكلمات المفتاحية: علبة التروس الكهرومغناطيسية. تحكم منطق ضبابي, كفاءة الطاقة؛ وقت تبديل التروس.

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APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science (Automotive Engineering)

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DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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LIST OF ABBREVIATIONS

NAP	National Automotive Policy
NxGV	Next-Generation Vehicle
EV	Electric Vehicle
CAV	Conditional Autonomous Vehicle
IR	Industrial Revolution
AT	Automatic Transmission
MT	Manual Transmission
AMT	Automatic Manual Transmission
CVT	Continuously Variable Transmission
DCT	Dual-Clutch Transmission
EMA	Electromagnetic Actuator
AEM2SGB	Autonomouse Electromagnetic Two Speed Gearbox
ICE	Internal Combustion Engine
RPM	Revoulation Per Minute
GHG	Greenhouse Gas
HEV	Hybrid Electric Vehicle
GM	General Motors
FLC	Fuzzy Logic Controller
DC	Direct Current
AC	Alternative Current
V	Voltage
OEM	Original Equipment Manufacturer
SAE	Society of Automotive Engineering
GSQ	Gear Shift Quality

GSQA	Gear Shift Quality Assessment
FLES	Fuzzy Logic Expert System
PID	Proportional Integral Derivative
EMF	Electromagnetic Force Force
LH	Left Hand
COG	Center of Gravity
COA	Center of Average
HPEVS	High Performance Electric Vehicle System
GR	Gear Ratio
FIS	Fuzzy Inference System

LIST OF SYMBOLS

T_w	Wheel Torque
T_m	Motor Torque
η_d	Drive Ratio
η_m	Mechanical Efficiency
r_w	Wheel Radius
F_t	The Force Acting on the Wheel
F_R	Acting on the Opposite of Traction Force
F_{rl}	Rolling Resistance
f_R	Rolling Resistance Coefficient
W	Mass of the Vehicle
θ	Angle of Inclination
F_a	Aerodynamic Force
A	Centre Distance
K_A	Centre Distance Factor
$T_{m(max)}$	Maximum Engine Torque
η_t	Efficiency of Automobile Transmission
b	Tooth Width
K_c	Coefficient of Tooth Width
m_n	Normal Modulus
d	Pitch Diameter
h_a	Addendum
h_f	Dedendum
d_a	Tip diameter
Z	The Number of Teeth

f_o	Addendum Coefficient
β	The Angle of Inclination of the Spiral
c	Radial Gap Coefficient
F_{ax}	Axial Force
α_c	The Cone Angle for Engagement
J	Inertia
$\Delta\omega$	The Angular Speed Differences of The Synchronizing Ring and Gear Cone
n_c	The Number of Cone
μ_c	The Friction Coefficient of the Cone
d_m	The Mean Cone Diameter
t	The Shifting Time
F_{emf}	Electromagnetic Force
l_w	The Total Length of the Solenoid Coil
B	Magnetic Flux Density
I	Current
μ	Magnetic Permeability
L_{sol}	The Solenoid Length
h_i	Inner Radius
h_o	Outer Radius
N	The Total Number of Turns in the Solenoid
r	The Radius of the Wire Segment from the Center of the Solenoid
φ_{total}	Total Magnetic Flux Linking
L_{ind}	Self-Inductance
E_d	Energy Density EMA For Single Coil
E_{act}	The Energy Actuation of the EMA System

R_{rad}	The Radiation Resistance
l_c	length of the core
d(r)	The Distance of the Radiation Measuring
R_c	Wire Resistance
ρ	Resistivity of Conductor
d_w	The Wire Diameter

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

In the automotive industry, an electric car is a vehicle powered by an electric motor rather than a gasoline engine. The electric motor is driven by the controller, which gives power like an accelerator pedal. Charging by home electricity and then stored in a battery which is rechargeable. An electric car acts as the opposite of a car with an internal combustion engine. For these reasons, car companies have begun to improve the performance of every component of their product. However, in the 1970s, people became concerned about preserving the environment and conserving non-renewable energy sources, which seems to a much greater focus on electric vehicles (C. C. Chan 2013).

The performance of an electric vehicle's power train plays an important role in determining efficiency. Electric motor and transmission are the main components of a power train. Transmission system performance is the deciding factor in vehicle performance. To improve the efficiency of the transmission, it is more beneficial to improve the efficiency of the transmission system than the efficiency of the the electric motor (R. Tahmasebi November 2014, 2015). The first demonstration electric vehicles were invented in the 1830s, and commercial electric vehicles became available in the late 19th century. Electric cars entering its third century as a commercially available product and has proved very successfully more than many other technical ideas come. However, electric vehicles are not as successful as vehicles with internal combustion engine (ICE), which usually have a longer distance and are very easy to refuel when needed. The concern about the environment, particularly noise and exhaust emissions coupled with new developments in battery technology and fuel cells which can change the balance in favour of EV today. Therefore, it is important that the principles underlying the design of electric vehicles technology and environmental issues related can be fully understood (Larmini, et.al, 2012).

Electric vehicles can be thought of as a combination of different subsystems. Each of these systems interacts with each other to make an electric vehicle work, and there are several technologies that can be used to control the subsystems. Figure 1.1 shows the key parts of these subsystems and their contribution to the overall system. Some of these parts need to work actively with some of the others, while some need to interact very less. Be that as it may, the electric car works thanks to the collaboration of all these systems (UN-Noor, et. Al, 2017).

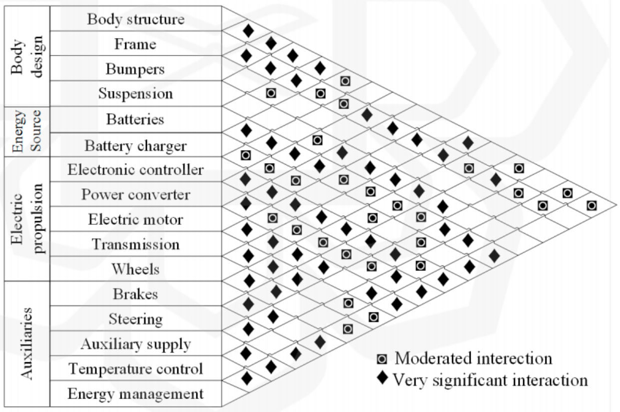

Figure 1.1: Major EV subsystems and their relations (UN-Noor, et. Al, 2017).

Internal Combustion Engines (ICEs) generate effective power in specific rpm ranges for fast acceleration or efficient cruising. Therefore, adequate power distribution is required by shifting gears in the correct RPM range. Typically, maximum torque is achieved in low gears when driving from a standstill. As the car picks up speed, the torque gradually decreases. For these reasons, gear ratios are carefully calculated and set by manufacturers to match engine power to maximize effective power in each gear. This is not the case with electric vehicles. An electric vehicle does not require a multi-speed transmission due to the electric motor. While internal combustion engines require multiple gears with different gear ratios for power output, electric motors produce constant torque at any given speed within a specific range. Electric motors deliver power instantly, which means the torque build-up process is not needed like in an internal combustion engine. Car manufacturer's use carefully calculated gear ratios to maximize electric motor efficiency without shift gear (KIA Motors, 2019). In addition, most electric motors can run at over 10,000 rpm with ease. Because electric motors are capable of delivering constant torque over such a wide rpm range compared to the 6,000 rpm of many internal combustion engines. Multi-speed transmissions for EV will only create inefficiencies such as added weight and additional manufacturing costs (KIA Motors, 2019)

The increase in the number of electric vehicles will lead to an increase in the demand for electricity. The growing share of renewables will make it more important to match battery charging with wind and solar power. Consequently, the structure of the energy sector must be adapted to the new consumer of electricity in order to achieve the goal of an overall reduction in greenhouse gas (GHG) emissions. In the European Union, additional electricity generation will be required to meet the additional energy demand generated by an 80% share of electric vehicles in 2050. The share of total electricity consumption in Europe from electric vehicles will increase from about 0.03% in 2014 to about 4–5% by 2030 and 9.5% by 2050 (Rahman et al,2018). The main concern of this study is to develop an electromagnetic autonomous transmission for 2-speed gearbox of electric vehicle.

1.2 PROBLEM STATEMENT

The first modern all-electric vehicles were developed by leading automakers using a two-wheel drive system with a centrally located electric motor that is connected to the wheels through a single-speed gearbox, differential and axle shafts. The basic single-speed drivetrain is an economical solution, but does not imply a performance limitation. Customer reports say the compact transmission can replace multi-speed transmissions and deliver less than 1/3 the size and weight of the transmission. It allows you to put the motor on in the transmission tunnel, improving weight distribution. A multi-speed drivetrain can improve the traction performance of an electric vehicle, but it also increases weight, cost, and efficiency.

A motor torque around 136 Nm@2000 rpm develops EV speed about 48 km/h by drawing battery current about 650 A and develops EV's speed about 48 km/h. If we added third gear it involves a far more complicated shifter, as it is no longer just backwards and forwards involves simply shifter sideways movement. A 2-speed compact gearbox is the best option for the EV/HEV, which can be located anywhere, maybe bolted directly to the motor, something like a 2 cog reduction box but with a second gear.

The French company Exagon Motor has developed the Exagon Furtiv e-GT gearshift mechanism. It is designed with two motors, each with its own two-speed gearbox. Both motors run in first gear when the car is in start mode. When the car accelerates, one motor shifts into second gear. While the other one remain with the 1st gear and it will be an idler. This approach is extreme, expensive and as complex as a manual transmission. The Volt, Ampera, Toyota Prius, Auris, Fusion and C-MAX operate in single motor mode epicycle transmission with 2 or 3 clutches and operating