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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

ANALYSIS OF HATCHBACK CAR BETWEEN MANUAL AND CVT TRANSMISSION SYSTEMS

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ANALYSIS OF HATCHBACK CAR BETWEEN MANUAL AND CVT TRANSMISSION SYSTEMS

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A thesis submitted in fulfillment of the requirements for the degree of Master of Mechanical Engineering (Automotive)

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2019

DECLARATION

I declare that this thesis entitled "Analysis of Hatchback Car between Manual and CVT transmission systems" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

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Date : 15/7/2019

APPROVAL

I hereby declare that I have read this dissertation/report and in my opinion this dissertation/report is sufficient in terms of scope and quality as a partial fulfillment of Master of Mechanical Engineering (Automotive).

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Supervisor Name	: DR. SHAMSUL ANUAR BIN SHAMSUDIN
Date	: 15 JULY 2019

DEDICATION

To my beloved mother and father

ABSTRACT

Nowadays, many of the research studies in automotive fields conducted by most well-known universities around the world cover a wide range of key areas such as engine, transmission, control system and safety system so as to carry out a new design and innovation. Furthermore, in Malaysia most of the car owners have a high interest in exploring the vehicle performance of their own vehicles. Thus, several types of modifications have been performed with intention to enhance the vehicle performance optimally. However, in order to reduce the cost and time, the new design, innovation and modification should be initially executed with simulation software by modeling the complete vehicle before experimented with the actual prototype. Therefore, as to fulfil the purpose, a vehicle longitudinal dynamic model is developed in this study by using simulation software with mathematical equation based method. The main model is divided into two models due to the two different types of transmission systems; 5-Speed manual transmission (MT) and Continuously Variable Transmission (CVT). The main system for each model consisted of several subsystems namely engine dynamics, gearbox controller, speed converter, traction force, rolling force, aerodynamic drag force, vehicle longitudinal motion and traction torque. The car that is used as a testing vehicle is Proton Suprima Hatchback. It is equipped with 1.6 cc turbocharger spark ignition four-stroke internal combustion engine with electronic fuel injection system as the main power source. The complete vehicle is studied under dynamic conditions and it is simulated in longitudinal direction. Commonly, a moving vehicle in longitudinal direction will be encountered with various driving resistances such as aerodynamic drag resistance, rolling resistance, climbing resistance and acceleration resistance which can reduce its overall performance. For the aim of investigating the performances, its result is measured in the aspects of vehicle velocity, traction torque and vehicle power. Hence, the results between these two models are compared due to determine the optimum performances. MATLAB Simulink software is used for modeling the vehicle longitudinal dynamic and the vehicle parameter from the car manufacturer is used as the input and output values in the simulation software. The analysed result indicated that at the starting point of vehicle movement, CVT model can produce more speed than the MT model until certain range of time where the MT model is exceeded the velocity of CVT model. Besides, at the traction torque point of view, it showed that the CVT model had higher efficiency on the variator shift up transition, while MT model had a higher traction torque at the end of acceleration point. More or less than the result of velocity and traction torque, the vehicle power of CVT and MT model have produced a similar value at the start-off point. Although the CVT model has showed the superiority over MT model at middle range of vehicle power, at the end of the acceleration the MT model has produced more power than the CVT model.

ABSTRAK

Pada masa kini, banyak kajian penyelidikan yang dijalankan oleh kebanyakan universiti-universiti yang terkenal di seluruh dunia dalam bidang kejuruteraan automotif meliputi kajian meluas dalam sistem-sistem utama seperti enjin, transmisi, sistem kawalan dan sistem keselamatan untuk menghasilkan rekabentuk baru dan inovasi. Selain daripada itu, di Malaysia kebanyakan pemilik kenderaan mempunyai minat yang tinggi untuk mengetahui dengan lebih mendalam tentang prestasi kenderaan masing-masing. Oleh itu, pelbagai jenis modifikasi telah dilakukan semata-mata untuk meningkatkan prestasi kenderaan ke tahap yang paling baik. Walaubagaimanapun, untuk pengurangan kos dan tempoh masa, ciptaan baru, innovasi dan modifikasi kenderaan sepatutnya dilaksanakan bermula dengan perisian simulasi dengan memodelkan sebuah kenderaan yang lengkap sebelum dieksperimenkan menggunakan prototaip sebenar. Oleh itu, bagi memenuhi tujuan tersebut, satu model dinamik kenderaan membujur telah dibangunkan dalam kajian ini dengan menggunakan perisian simulasi yang menggunakan kaedah pengiraan matematik. Model utama ini telah dibahagikan kepada dua model berasingan yang berdasarkan kepada penggunaan dua jenis sistem penghantaran yang berbeza; 5-Kelajuan transmisi manual (MT) dan Transmisi Pembolehubah Berterusan (CVT). Sistem utama untuk setiap model terdiri daripada beberapa sistem tambahan seperti dinamik enjin, kawalan kotak gear, penukar jenis halaju, tork daya tarikan, daya gulungan, daya seret aerodinamik, pergerakan membujur kenderaan dan tork tarikan.Kereta yang digunakan sebagai kenderaan latihan ialah Proton Suprima Hatchback. Ia dilengkapi dengan enjin pembakaran dalaman 1.6 cc turbocharger yang menggunakan sistem enjin pembakaran dalaman empat stroke dengan sistem suntikan bahan api elektronik sebagai sumber tenaga utama. Kenderaan lengkap yang digunakan dalam kajian ini adalah berdasarkan keadaan dinamik dan ia disimulasikan dalam arah membujur. Kebiasannya, kenderaan bergerak dalam arah membujur akan berhadapan dengan pelbagai rintangan dalam pergerakannya seperti rintangan udara atau rintangan seret aerodinamik, rintangan bergulir, rintangan pendakian dan rintangan pecutan yang boleh mengurangkan prestasi keseluruhannya. Untuk tujuan memeriksa prestasinya, keputusan akan diukur berdasarkan tiga aspek-aspek berikut iaitu halaju kenderaan, tork daya tarikan dan kuasa kenderaan. Oleh itu, keputusan yang diperolehi telah dibandingkan di antara model-model tersebut yang menentukan prestasi kenderaan yang paling optimum. Perisian Matlab Simulink telah digunakan untuk memodelkan dinamik kenderaan membujur dan parameter kenderaan yang diperolehi daripada syarikat kenderaan akan dijadikan nilai input dan output kepada perisian tersebut. Hasil keputusan yang telah dianalisis menunjukkan ketika permulaan pergerakan kenderaan, model CVT

boleh menghasilkan halaju yang tinggi jika dibandingkan dengan model MT sehingga tempoh masa yang tertentu dimana model MT akan mengatasi nilai halaju model CVT. Selain itu, berdasarkan kepada keputusan tork tarikan, ia telah menunjukkan yang model CVT mempunyai kecekapan yang tinggi dalam transisi peralihan gear tinggi, namum model MT mempunyai tork tarikan yang tinggi pada titik akhir pecutan kenderaan. Lebih kurang sama dengan keputusan halaju dan tork tarikan, model CVT dan MT telah menghasilkan kuasa kenderaan yang lebih kurang sama pada titik permulaan pergerakan. Walaupun begitu, pada julat pertengahan model CVT menunjukkan yang ia mempunyai kelebihan mengatasi model MT, tetapi pada akhir pecutan, model MT telah menghasilkan nilai yang lebih tinggi daripada model CVT.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF SYMBOLS

ρ	-	Air density
C_d	-	Air drag coefficient
A	-	Vehicle frontal area
m_d	-	Driver mass
CG	-	Center of gravity
m_{cv}	-	Curb vehicle mass
WD	-	Weight distribution
h_a	-	Front vehicle height
h	-	Center vehicle height
b	-	Distance front axle to center of gravity
c	-	Distance rear axle to center of gravity
L	-	Distance from front axle to rear axle
D_A	-	Aerodynamic drag force
F_g	-	Road slope force of gravity
R_{xf}	-	Front tire rolling force
R_{xr}	-	Rear tire rolling force
F_{xf}	-	Front tire traction force
F_{xr}	-	Rear tire traction force
m_v	-	Total vehicle mass
a_x	-	Vehicle acceleration
β	-	Road gradient
v	-	Velocity

f_m	-	Mass factor
m_d	-	Driver mass
T_e	-	Engine torque
i_x	-	Transmission gear ratio
i_o	-	Final drive ratio
η_d	-	Driveline efficiency
r_{wd}	-	Wheel dynamic radius
I_{eff}	-	Effective moment of inertia
I_e	-	Engine moment of inertia
I_c	-	Clutch moment of inertia
I_{it}	-	MT input moment of inertia
I_{ot}	-	MT output moment of inertia
I_d	-	Driveshaft moment of inertia
I_w	-	Wheel moment of inertia
I_{icvt}	-	CVT input moment of inertia
I_{ocvt}	-	CVT output moment of inertia
AR	-	Aspect ratio
H	-	Tire sidewall height
W_t	-	Tire width
D_w	-	Wheel diameter
D_r	-	Rim diameter
r_{ws}	-	Wheel static radius
M_r	-	Rear moment
N_f	-	Front normal force
N_r	-	Rear normal force
f_r	-	Coefficient of friction
T_{emax}	-	Maximum engine torque
RPM	-	Revolution per minute
P_{hp}	-	Vehicle power
T_t	-	Traction torque

CHAPTER 1

INTRODUCTION

1.1 Background

In the automotive industry especially in Malaysia, many car owners have a high interest in exploring the vehicle performance of their own vehicles. There are several types of modifications have been conducted such as engine mechanical parts, transmission parts, vehicle body parts, powertrain control system and other systems with intention to enhance the vehicle performance optimally. The desire to improve the vehicle performance is essential in the automotive, in which the works are commonly performed by the design engineers, academic researchers or vehicle owners. However, all the improvements on the application should be implemented based on the validated automotive engineering technical documents and references. The vehicle performance can be considered as one of the important aspects in vehicle dynamic studies. Hence, the inventions of vehicle and the research and development in vehicle dynamics have always been a continuing study for decades. Engineers and researchers have been struggling to completely comprehend the vehicular dynamic behaviour as the machines operate in various driving conditions (Di Martino, 2005). According to Janarthanan et al. (2012), accurate off-line models can be used in vehicle development design and modification. More and more designers are gradually changing to modelling with computer packages in order to examine their proposed designs as an effort to forecast and optimise vehicle parameters as the situation changes. In spite of that, computer analysis could only be useful should the system be able to accurately predict the behaviour of the real vehicles (Ahmad et al., 2014). The advantages of the simulation model over practical test are cost and time reduction, which have made it popular among automotive manufacturers especially in Asian countries. It is preferable to perform simulations for a new design or modification model before conducting experimental works.

In this study, a hatchback vehicle is modelled using MATLAB Simulink and developed with mathematical equation-based method. This design modelling will include vehicle dynamic models for longitudinal dynamic motion, which initially powered by the powertrain system and transmitted to the driving wheels as a traction force. The created force can produce traction torque, vehicle power and vehicle speed that are categorised as a vehicle performance. Thus, in this simulation, the vehicle performance will be measured based on these three outputs as final results. However, if the speed, torque and power are not transmitted accordingly, the best performance could not be achieved although the engine efficiency is high. By the same token, researchers may focus on the transmission as the main key to deliver the optimum performance output is the transmission. For that reason, the vehicle dynamic model will be developed with two different types of transmission; a 5-speed Manual Transmission (MT) and a Continuously Variable Transmission (CVT), in order to analyse and compare the difference of overall performance results.

On the other part, in dynamics theory, when a vehicle is moving, it encounters various driving resistances namely air resistance or aerodynamic drag resistance, rolling resistance, climbing resistance and acceleration resistance. The greater these resistances get, the lower the longitudinal dynamic performances of a vehicle. The air resistance is the product of the vehicle frontal surface area and its air drag coefficient. This small value indicates how much more aerodynamically efficient a vehicle body is when compared with a box having vertical front face. It increases with air density row and with the square of the driving speed; in other words, when the vehicle speed doubles, the air resistance will quadruple. Consequently, it plays a particularly important role in vehicle high speed condition. The rolling resistance is dependent on the tyre design, air tyre pressure and the overall weight of the vehicle. At high speeds, the coefficient of rolling resistance increases because of its quicker flexing action. As stated in Shakouri et al. (2010), sometimes in developing the dynamic models of a vehicle, the tyre model is excluded for simplification, although it is the main source to propel the car forward during acceleration and to stop the vehicle when the brake is pressed. Conversely, the torque produced by the tyres through the powertrain is directly taken into account as a source of forcing the vehicle forward and then a brake torque to lower the speed of the vehicle. On top of that, the climbing resistance is found by the mass of the vehicle and on the angle of slope. Generally, an uphill drive is normally followed by a corresponding downhill one. Thus, the potential energy that is gained previously will be released when the vehicle is rolling down the hill. Additionally, the down slope force overcomes the other driving resistances either partially or fully. If the downslope force prevails, then in a conventional driven vehicle, the released energy is converted into heat in the brakes system. Despite that, for acceleration resistance, it depends totally on the vehicle mass because the mass inertia opposes the acceleration. When accelerating, the vehicle will gain kinetic energy and yet, it is released again when the vehicle slows down. Thus, it clearly shows that all the driving resistances dictate how much torque from the powertrain can be delivered to the wheels, so that the vehicle can maintain the desired speed and power. Furthermore, the vehicle design should not only have an adequate dynamic design but also need to contrive with the precise control system to enable the optimum performances. According to El Majdoub et al. (2012), most prior designs on axial control were based on simple models that ignored essential nonlinearities of the vehicle that include rolling resistance, aerodynamics effects, and road load. Moreover, little formal analysis has been attributed to the controller performances (Ren et al., 2008). In Yamakawa et al. (2007), longitudinal vehicle control was investigated chiefly in torque management for independent wheel drive. It is reported that in some previous studies on longitudinal vehicle dynamic motion, the control design has been based on simple models and only a few of them have been conducted on the analysis of differences performance on various transmissions.

The design of the longitudinal vehicle dynamic model that produces speed, traction torque and power from the front wheel propelled vehicle should be emphasised on modelling the powertrain system in order to generate an optimum rotational force for the acceleration drive mode. According to Hwang et al. (2000), a powertrain system is the system that transmits power from the engine to the wheels of a vehicle by synchronizing engine torque and speed as required by the operator of the machine. The system model includes a few subsystems such as the engine, the gearing or speed altering transmission, as well as the shaft and joints in the driveline. The engine generates the propulsion power while the mechanical speed transmission delivers the power within some speed range for effective gear shifting to ensure ride comfort for the passengers. Next after the transmission, the driveline works to deliver the power to the vehicle through the rotating wheels. Furthermore, as reported in Hayat et al. (2003), driveability of the powertrain system also has become the most important requirement for the customers nowadays. Driveability voices a global demand to separate the driver from out-of-vehicle distraction while supplying vital information for the person to steer the vehicle safely.

In this study, it aims to develop a vehicle dynamic model with two different types of transmission systems. The main model will be divided into two models, and the main system for each model will consist of several subsystems namely engine dynamics, gearbox controller, speed converter, traction force, rolling force, aerodynamic drag force, vehicle longitudinal motion and traction torque. Comparative study on performance analysis in the aspects of vehicle speed, traction torque and vehicle power is carried out using the proposed vehicle dynamic model. As shown in **Figure 1.1**, the Proton *Suprima* made by Proton automotive manufacturer in Malaysia has been selected to be a car model in the present work due to its specification that has complied with the requirement of this study.

Figure 1.1: Proton *Suprima* (courtesy of Proton Sdn. Bhd)

1.2 Statement of the Purpose

The purpose of this study is to provide an accurate result on investigation of performance of vehicle dynamic model using MATLAB Simulink to the automotive manufacturers, research communities and car owners for designing, modification and innovation purposes. The presented vehicle dynamic model can be experimented with selected parameters provided by the car manufacturer that will determine the potential improvements needed to meet the future demand. In fact, some of the cars owners in Malaysia are excessively interested in augment their car performance on speed and power. Furthermore, in order to satisfy their desires, several modifications on the physical and control system of the car were made. However, the modifications have caused many technical problems afterward and also complication with the authorities for the purpose of vehicle verification. Consequently, vehicle dynamic model with two different types of transmission systems that has been designed in this project is possible to be utilised as simulation-based model which can function as an initial testing tool on performance analysis of the cars. In this way, the objectives of automotive technology development on every community will be significantly satisfied to meet the national automotive policy.

1.3 Problem Statement

Nowadays, the automotive industry is known to be very competitive, to the extent of its design, material and performance. The automotive industry was chosen because of its confronting higher customer demand in business pressure to produce excellent product more rapidly at lower cost. The most important issues in the automotive industry recently have been tended to the researcher and automotive manufacturer to enhance its vehicle design either to reduce fuel consumption and emission products or increase the efficiency of output performance.

The automotive industry designers are dealing with a major challenge in deciding the most ideal choice of vehicle dynamic designs including the way of transmitted power from propulsion source to rotational tyres and structured the vehicle body during development of a vehicle. Therefore, some sorts of modifications that have been made to the vehicle's part or system must be tested in an appropriate way and should be complied with engineering specification requirements of Road Transport Act 1987 for comfort and safety purposes. Based on the desired outcome and available information, vehicle design, innovation and modification that driven by automotive manufacturer and invested by research