

Modelling and Simulation of Automatic Transmission

Eng. Naser Rashid Manea Rahian Al-Ajmi¹, Hadyan Ali Alajmi²

¹ Specialist Trainer (C) in Public Authority for Applied Education and Training, Arabic Republic of Egypt, Egypt.

² Specialist Trainer (G) in Public Authority for Applied Education and Training, University of Arab Academy for Science, Technology and Transport.

****Corresponding Contact**

Abstract:- Several factors affect the characteristics of vehicles, and among these factors is the modelling and simulation of vehicle control shift components and which occurs through the transmission of gears while determining the features of the shift. Characteristics that are affected in vehicles when modelling and simulation are used are the vehicle's fuel-burning efficiency, gearbox durability, operability of vehicle, and driving comfort. This thesis used MATLAB software to design a model and simulate simplified models for gear-shift methods, considering traffic conditions like road slope, calculus of vehicle speed, and other factors to assess the transmission system's behaviour. The findings revealed that since the throttle input was reduced, the torque of the engine was increased whereas the speed of the engine was reduced. Vehicle automation could be reliably achieved by optimizing the interaction between the speed of the engine and the torque of the engine.

Keywords;- MATLAB, Vehicle Control Shift, Modelling, Simulation, Vehicle Automation, Gear-Shift Methods, Traffic Conditions.

I. INTRODUCTION

Currently, there is a constant and significant growth and improvement in the good scope for vehicles with the automatic gearboxes when it comes to gearshift. Controlling and handling a gearbox switching components, such as freewheels and the clutches, has a significant impact on gearshift comfort. Electronic Control Unit (ECU) is implemented to do this controlling (Nezhadali and Eriksson, 2015).

There are many configurations used in automobiles, but the "Automatic Transmission (AT)" is one of the most widely used. These systems involve planetary gear sets that achieve multiple gear ratios by combining components from various planetary gear (Yi et al., 2017).

The main focus of this study is Matlab/Simulink for transmission integration. The changing state of the transmission output shaft and the crankshaft is obtained from the differential design and engine design. The output shaft value and the torque of the crankshaft are returned after it had been calculated. The procedure is illustrated in the following figure (Zhao, 2013).

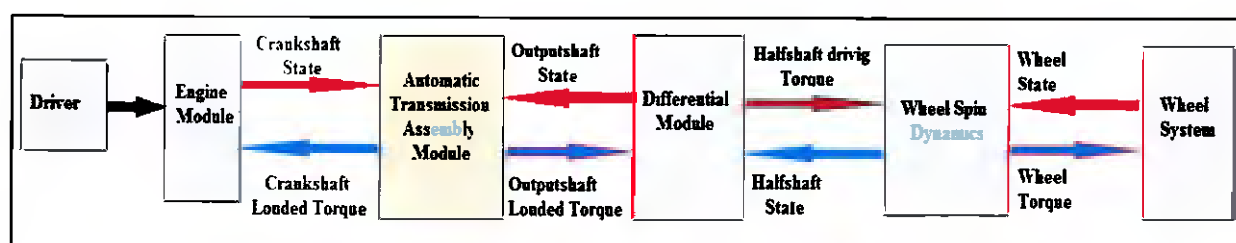


Figure 1: Structure of the model of the entire powertrain (Zhao, 2013).

II. AIMS AND OBJECTIVES

A huge increase noticed during the recent years within legal requirements and customer regarding automotive industry taken into account the emissions produced by the automotive industry.

Simulations were granted a vital and significant role in the growth of the automotive industry. The programming resources, in that their own items are included, are created by vehicle manufacturers to be used later for trails and

testing, as the computer's performance continues to improve, and novel modelling techniques become available.

Regardless of whether a prototype of a car is being designed or not, computer simulation is recognized as a key element to use in developing new products as well as different vehicles. These simulations can also be used to optimize different features and components of the drivetrain during pre-studies. The most important objectives from this paper are:

- To develop mathematical and physical model for a gearbox of an automatic type regarding the car of the passengers.
- To use the simplest design for the gearshift methods, considering the expected circumstances such as; vehicle speed calculus.
- To approximate the proposed and styled scheme under various failure modes, such as Gear hunting.
- To use Matlab/Simulink to simulate the suggested model.
- To carry out a systematic estimate for the suggested model in order to equate its reliability to that of other related recent new vehicles:

III. LITERATUR REVIEW

Overview

The automatic transmission is the preferred mode of transmission for the majority of drivers in today's society. As opposed to conventional three-pedal shifters, hassle-free moving, usability, and convenience have hit new heights. The automatic transmissions began as simplistic gear shifting mechanisms, and they were recognised for less than stellar fuel mechanisms. They are now well-known for their reliability and high performance (Transmission, 2019).

Types of automatic transmission

The six types of automatic transmission can be given as follows:

- **Traditional Automatic Transmission**

This type is also known as the torque automatic converter, it is implemented in nearly each car. They use hydraulic fluid and torque converter to do the function of varying gear in the place of the clutch. The control of engine unit is directly attached with this type of mechanism as well as allows the precise and the smooth engine control for the car.

- **Automated-Manual Transmission**

This type, which is manual transmission uses a regular gear in addition to clutch and makes use of the actuators, sensors, pneumatics, and processors to assist manual usage for the gears (Automatic Transmission, 2019).

- **Continuously Variable Transmission (CVT)**

This type allows the seamless gear shifting by using pulleys or even belts in the place of the traditional gears, which made of steel, along with the numerous ratios that are dependent on the RPM or on the engine speed, as seen in Figure 2.

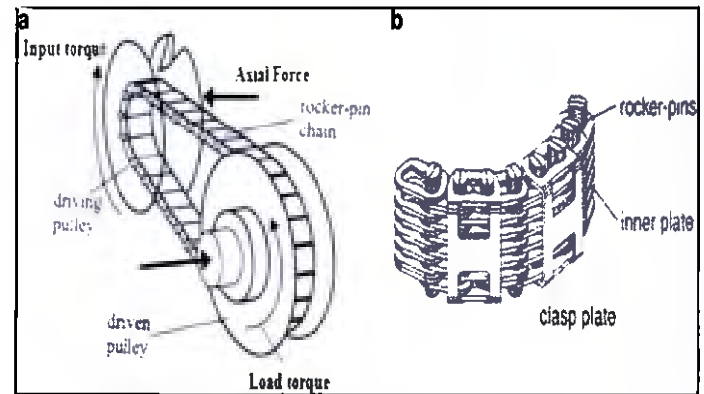


Figure 2: Configuration of continuously Variable Transmission

In addition, the CVT has one unique gear that functions as a parameter and can move smoothly across nonstop appropriate gear ratios and sizes. This also allows us to control the RPM or engine speed depending on the driver's behaviour when accelerating or decelerating.

- **Dual-Clutch Transmission (DCT)**

It is a manual/automatic transmission that lacks a torque converter. Aside from that, it has two shafts with clutches for shifting gears, one for the even number gears as well as the one for odd number ones.

Shifting between higher and lower gears is smooth, but they can move unevenly over time and become noisy. This type is known as dry transmission because it does not require a driver to change the gearbox oil. It finally loses its frictional performance and left the clutch (Auto Deal, 2019).

- **DSG (Direct Shift Gearbox)**

It has a similar configuration to a dual-clutch transmission in that it has two clutches which open interchangeably when changing gears. It provides smooth acceleration as well as fast shifting. New systems offer more reliable fuel systems than manual patterns. This process is known as wet transmission, as well as it is expected to last for decades in case of the fuel is replaced on a daily basis (Automatic Revolution, 2019).

- **Tiptronic Transmission**

This type is commonly used in performance-oriented cars or in sport and are called *manumatic*. It was founded during the late of '90s by Porsche. Its principle is same as the manual gearbox. Based on the previous information, the best type to choose is depends mainly on the design of the model.

Working Principle for Automatic transmission

Based on Mechanical Booster (2019), sliding mesh gearbox or synchromesh was implemented in the manual transmission, while the epicyclical gearbox was used in automatic transmission. These types of gearboxes used no gear or even sliding dogs to entice but the speeds of the distinctive gear are obtained by fixing the brake bands within the gear drum.

The guided shaft rotates and is linked to the earth gear. Following the removal of the gear system, it is able to shift as a function of a planet gear movement that is moved in the direction of the axis. Any planet gear has many units to get the numerous patterns (Mechanical Booster, 2019).

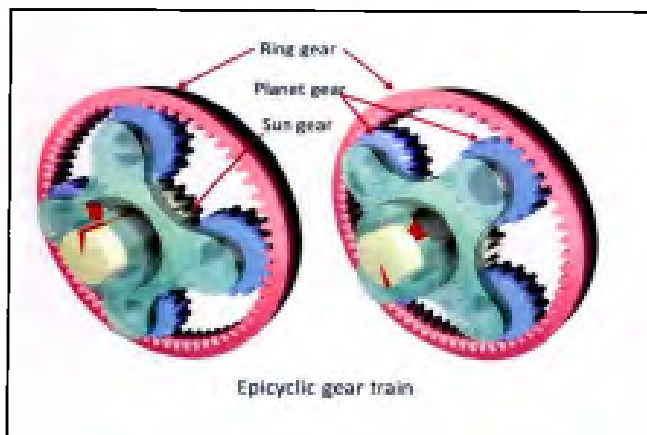


Figure 3: Epicycle gear train (Mech study, 2019)

The automatic transmission includes of different important components, its main component are oil plan, a converter housing, and the extension house. A converter housing assists in enfold torque converter as well as the case owns specific train gear. The overall unit of the transmission is linked with the engine block (Mech study, 2019).

The difference between working of manual transmission and the automatic transmission is that the control process for automatic transmission is made by arrangement of the brakes that are operated in hydraulically way (Alf cars, 2019).

Gearbox management system

A transmission box, which is also known as a gearbox, is the vehicle's secondary source of power. It is used to adjust the torque and speed of a vehicle in response to a range of load loads and road conditions. When climbing hills or when the car needs, the gearbox converts the engine's speed into torque. It is also used as a torque converter and transmission box (Alonso and Agusti, 2004). The shaft for the counter is hammered to a clutch in a gearbox control system with a couple of gear shifts.

In the gearbox control system, the teeth for the gear as well as other varying metal could not touch. (Lemmers et al., 2011). The following are the three primary stages of the gearbox control scheme.

1. Providing the required torque to move the automobile based on a difference in load situations. This can be made by changing the ratio for the gear which is between the engine crankshaft and the vehicle drive wheels.
2. Be shifted into reverse so that the vehicle can return smoothly.
3. Be transferred into the manual mode to start the engine.

The gear is the most simple to configure, use, and extend in any car management system. Since it is extremely effective, compact, and consolidates a variety of other management functions into a single location for users (Flamang et al., 2005)

Energy efficiency of automatic transmission

The basic feature of the automatic transmission, in conjunction with differential, is to reduce the relatively high degree of engine power to the vehicle's slower wheel speeds as well as to increase the torque for the wheels (Sudha et al., 2011).

Automatic transmissions allow smooth gear shifting by using rollers or belts instead of standard steel gears, as well as a variety of ratios that are based on RPM or speed control. Transmission design has an effect on automotive fuel consumption as well as energy quality (Gong, et al., 2014).

IV. METHODOLOGY

The running of combustion engines is carried out at high speeds, which are in fact imperfect and unsuitable for starting, stopping, or going slowly. The gearbox's aim is to manage the engine's speed and torque ratios and then providing the car with a wider range of driving.

This is known as overdrive since the torque can be reduced when the rpm is increased. The two equations that follow show the obtained speed ω_{eng} and torque T_{eng} upon gearbox, on the prop shaft about gear i with r_i ratio (Guiju et al. 2014).

$$T_{eng} \cdot r_i = T_{prop} \dots (1)$$

At the same power level, the relation between speed can be got, Power = Torque X speed

$$\frac{\omega_{eng}}{r_i} = \omega_{prop} \dots (2)$$

In the previous equations, ω_{eng} as well as T_{eng} denotes that the speed as well as the torque obtained by the engine. The source power P which is rotational is in turns that given by the necx equation:

$$P = \omega \cdot T \dots (3)$$

Planetary-Gear Sets

In many other cases, automatic gearboxes in commercial vehicles use a planetary-gear rail to switch between various ratios of the gear. It is made up of various planter-gear classes and, in some cases, standard gears. The planter-gear kit contains three major components: sun-gear, earth gears, and the internal gear, as well as a planet carrier. Every one of these elements may function as output, information, or remain constant. As seen in Figure 4, all components in a planetary gear set configuration share a common rotational axis (Wendelius, 2012).

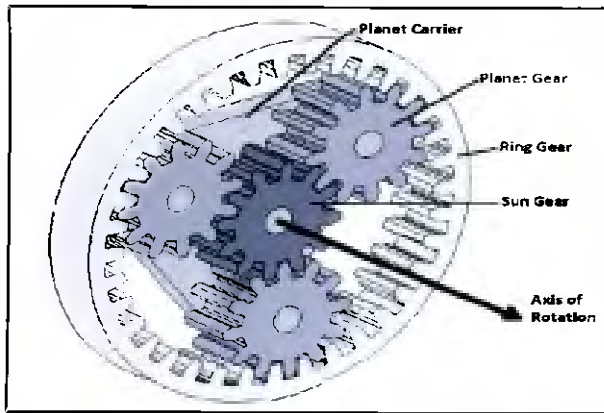


Figure 4: illustrates the components of planetary-gear set (Wendelius, 2012)

Clutches

Despite the fact that cars equipped with automatic gearboxes do not have a clutch pedal, it also does not imply that no clutches will be used inside the gearbox. In contrast, multiple clutches are used inside the gear train. The clutch, in particular, consists of two plates with friction plates as well as a technique which either moves or presses these apart. (Zhang et al. 2015).

Torque Converter

The torque converter is a form of hydraulic fluid coupling that connects the engine flywheel to the gearbox. Initially, when the engine is run at a low speed while traveling, a very limited amount of traveling torque is obtained by the converter, allowing the car to stop without the engine destroying. The torque converter, on the other hand, provides additional torque to the vehicle during the take-off phase. As a result, the car is more comfortable to ride (Wendelius, 2012).

Table 2: The relations for one planetary-gear set under diverse fixed, output and input components, Z_i signifies the number of cogs within i^{th} component (Wendelius, 2012).

Input	Output	Fixed	Ratio of conversion	Comments
Sun	Carrier	Ring	$1 + \frac{Z_{Ring}}{Z_{Sun}} > 1$	Torque is amplified
Ring	Carrier	Sun	$1 + \frac{Z_{Sun}}{Z_{Ring}} > 1$	Torque is amplified
Carrier	Sun	Ring	$\frac{1}{1 + \frac{Z_{Sun}}{Z_{Ring}}} < 1$	Overdrive
Carrier	Ring	Sun	$\frac{1}{1 + \frac{Z_{Ring}}{Z_{Sun}}} < 1$	Overdrive
Sun	Ring	Carrier	$-\frac{Z_{Ring}}{Z_{Sun}} < 0$	Reverse Gear
Ring	Sun	Carrier	$-\frac{Z_{Sun}}{Z_{Ring}} < 0$	Reverse Gear

By the driving point, the stator redirects the fluid as it is driven through the impeller and the decelerated through the turbine. Despite the major power losses, this ensures that the turbine's torque is higher than the engine's torque. However, the rise in torque within the conversion ratio is represented by measures and is measured as seen below in the following equation (Mathwork, 2019):

$$\mu = \frac{T_T}{T_P} \dots \dots (3)$$

The torque for the turbine is denoted by T_T in the previous mathematical representation, while the torque for the impeller is denoted by T_P . There are various observed details about the ration of converting, this has an amount greater or equal than 1 $\mu \geq 1$, the maximal value for the ration regarding the conversion is achieved when the car is stopped, so the rotor speed is equal to zero $\omega_T = 0$.

This is analogous to the situation where the driver presses the brake pedal, and the stopping torque is sufficient to keep the car at a standstill. In case like this, the proportional power loss between the turbine as well as the impeller is equal to 100%. The corresponding formula is used to calculate the power loss inside the torque converter (Mathwork, 2019)

$$P_{Loss} = \omega_P T_P - \omega_T T_T \dots \dots (4)$$

The following formula is used to calculate the reduction of relative power:

$$\eta_{rel} = \frac{P_{Loss}}{\omega_P T_P} \dots \dots (5)$$

While the driver releases the brakes, the turbine picks up the speed, increasing in ω_T .

Although the turbine's speed reaches the impeller's speed, $\omega_T \rightarrow \omega_P$, A decrease results in torque conversion and a reduction in power losses. This will continue until the speed relationship between the impeller's speed and the turbine's speed is provided by the given formulas (Nezhadali, and Eriksson, 2015):

$$v = \frac{\omega_T}{\omega_P} \dots \dots (6)$$

It indicates that while the conversion ratio is reduced to one, there is no rise in torque. In case like this and based on eq. (4), $P_{loss} = (1 - v_{coup}) \cdot \omega_P T_P$. The converter's function is accomplished in this situation, but more efficiency can be obtained if the turbine as well as impeller are locking comparatively so that within losses are completely removed (Nezhadali, and Eriksson, 2015).

As previously mentioned, the impeller and turbine flywheel are linked, which ensures they run at identical speeds $\omega_P = \omega_{eng}$. Whatever the case might be, the resulting impeller torque, which is hydrodynamic T_P , is not approximately identical to the engine torque. To calculate the impeller, torque the following formula will be used:

$$T_p = \sigma \rho_{fluid} D_p^5 \omega_p^2 \dots \dots (7)$$

In the preceding equation, σ denotes the performance index of the converter, ρ_{fluid} denotes the hydraulic fluid density, D represents the density of the impeller. The maximum amount of the torque conversion is obtained in case when the car is at the situation of stopping, so $\omega_T = 0 \Rightarrow v = 0$. As the turbine's speed increases, the conversion ratio decreases, and the speed ratio reaches 1. This decrease is usually linearly styled before the point of coupling, v_{coup} , is obtained, v_{coup} , in case like this $\mu(v_{coup}) = 1$. Hence, μ can be expressed as given below in the following equation:

$$\mu = \begin{cases} \mu_{max} - \frac{\mu_{max}-1}{v_{coup}}, & 0 \leq v \leq v_{coup} \\ 1, & v_{coup} < v \leq 1 \end{cases} \dots \dots (8)$$

Retarder

The proportion for the gear influences the retarder's brake torque. Since it is unsafe for any driver to push both

the accelerator and the brake pedals at the same time, it could be safe assuming that $T_{eng} = 0$ in case of an active retarder. Therefore, T_{prop} is established by the next formula:

$$T_{retarder} \cdot r_i = T_{prop} \dots \dots (9)$$

Which means that in case of low gears, $r_i > 1$, a magnification will result on the braking torque. Whatever, when $r_i < 1$ the torque will be reduced. As a result, main retarders are more appropriate and efficient for use in cars that travel at extremely low speeds, like city buses. Vehicles that move at very high speeds, on the other hand, typically use secondary types of retarders (Mathwork, 2019).

V. RESULTS AND DISCUSSION

Automatic Transmission Controller Analysis.

In this chapter, the controller system of automatic transmission was analysed depending on block diagram which is shown in Figure 5.

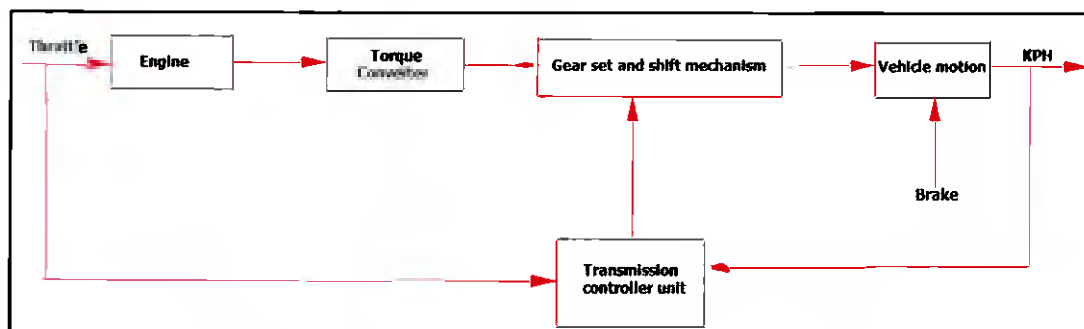


Figure 5: Automatic Transmission Block diagram controller

Figure 5 shows the block diagram for the ATC. The distribution for the flow of the power is presented. Differential equations can be used to model a car engine. These differential equations have some characteristics such as regular and nonlinear and were chosen to simplify modelling.

The previous block diagram shows each unit which are required for the modelling of the vehicle. For example, the block diagram which is responsible to make a decision and to apply the logics for the system is a transmission control.

Modelling of the Engine.

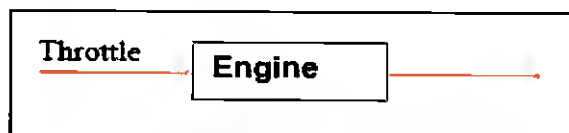


Figure 6: Modelling of the engine

As shown in Figure 6, the throttle provides feedback for the engine. The order is issued when the throttle is opened or closed. For simplification, the order from throttle would be dealt to be closed or open only.

There is a difference between the torques based on the motion of impeller as well as the motion of the engine because of the inertia for both of them. The following equation describes the difference in torque.

$$T_e - T_i = (I_i + I_e) N_e \quad (10)$$

Where,

N_e = engine speed

I_e = Moment of inertia of the engine

I_i = Moment of inertia of the impeller

T_e = Torque of the engine

T_i = Torque of the impeller

Since the moment of inertia for the impeller and engine own physical properties derived from manufacturing, the variance between the torques could be minimized or improved if and only if a changing in speed was made. The process of transmission is represented in Figure 7.

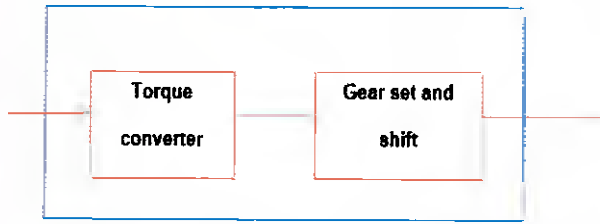


Figure 7: Transmission process in torque converter, gear set and shift

Modelling of the torque converter:

As seen in the following equation, the torque proportion is proportional to speed by the diameters for the driver or by number of teeth.

$$\frac{w_{pinion}}{w_{gear}} = \frac{d_{gear}}{d_{pinion}} = \frac{N_{gear}}{N_{pinion}} = \frac{T_{gear}}{T_{pinion}} \quad (11)$$

4.2.2 Mathematical equation of torque converter unit:

The engine speed is considered to become the most important parameter regarding torque. Taken into account the capacity factor K. The following figure shows a relationship between speed ratios and torque (Pohl, 2003).

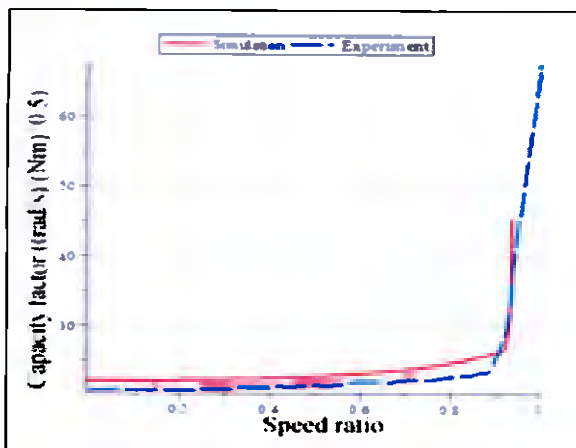


Figure 8: capacity factor VS speed ratio

Based on the following equation, the torque ratio and the K factor have an opposite relationship.

$$T_1 = \frac{N_e^2}{K^2} \quad (12)$$

Where,

$$K = f_2 \frac{N_{in}}{N_e} \quad (13)$$

The torque ratio is defined as the ration of output of torque converter to speed of vehicle engine.

$$R_{TQ} = \frac{T_{in}}{N_e} \quad (14)$$

And the ratio between speed ratios and is expressed as:

$$T_{in} = f_3 * N_{in} \quad (15)$$

After substituting in the torque ratio (R_{TQ}):

$$R_{TQ} = f_3 \frac{N_{in}}{N_e} \quad (16)$$

Gear set modelling:

The ratio of transmission is a ratio of output torque to input torque:

$$R_{TR} = \frac{T_{out}}{T_{in}} = \frac{N_{in}}{N_{out}} \quad (17)$$

$$\text{Thus, } N_{in} = R_{TR} N_{out}$$

$$T_{in}, T_{out}$$

= output and input torque in the transmission

$$N_{in}, N_{out}$$

= output and Input speed in the transmission

f_4 is a gear.

Vehicle motion modelling

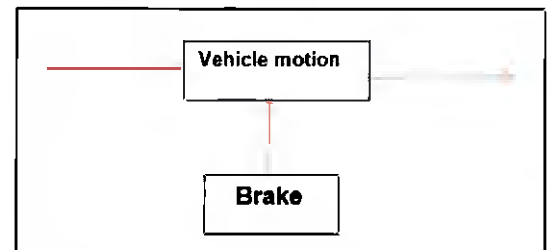


Figure 9: Motion modelling of vehicle

From the general conservation of momentum and energy equation:

- The torque of the load the output torque because of some losses. The formula which links the load torque, and the output torque is shown below:

$$I_v N_w = (T_{out} - T_{load}) \quad (18)$$

I_v = Moment of inertia of the vehicle

N_w = Speed of the vehicle wheels (RPM)

- This is a theoretical equation.

- The influence of final drive ratio has to be understood. because of the inversely proportional to torque, the modelling equation is:

$$I_v N_w = R_{fd} (T_{out} - T_{load}) \quad (19)$$

R_{fd} = The ratio for the final drive of the vehicle

The torque produced by load must be considered in vehicle motion modelling, the following equation shows that:

$$T_{load} = f_5(N_w) \quad (20)$$

The road load can be determined by calculating both the aerodynamics and the frictional damage.

$$T_{load} = \text{sgn}(Kph)(R_{load0} + R_{load2}kph^2 + T_{break})$$

Relevant shift points are chosen for automatic transmission programs based on the car velocity, as seen in Figure 10.

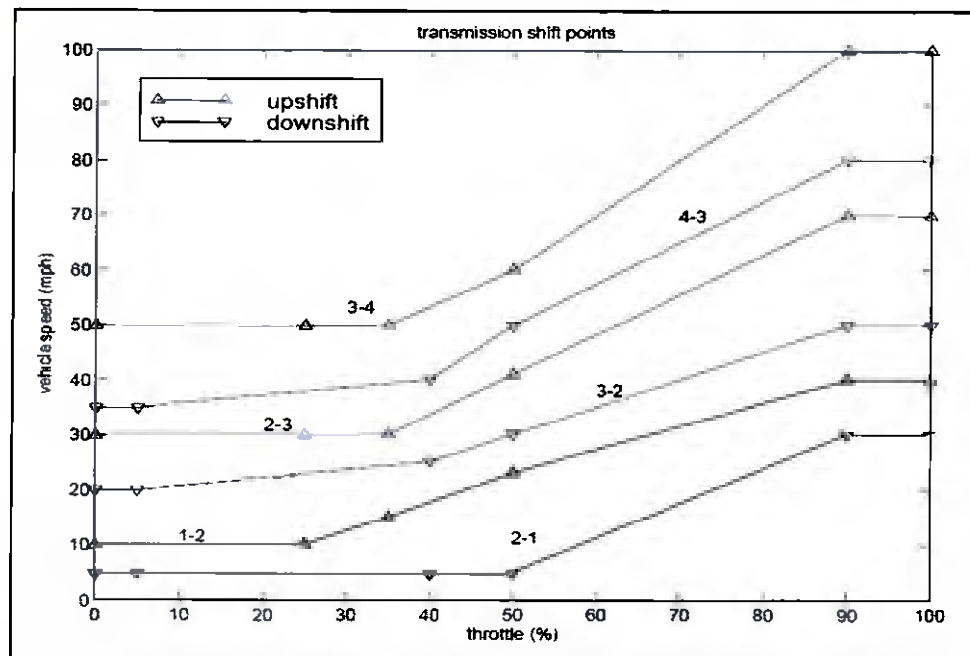


Figure 10: Transmission shift points as per the vehicle speed

Modelling of the Automatic Transmission for the vehicle.

MATLAB Simulink has been used to build a model for automatic transmission for a vehicle, as seen in Figure 11.

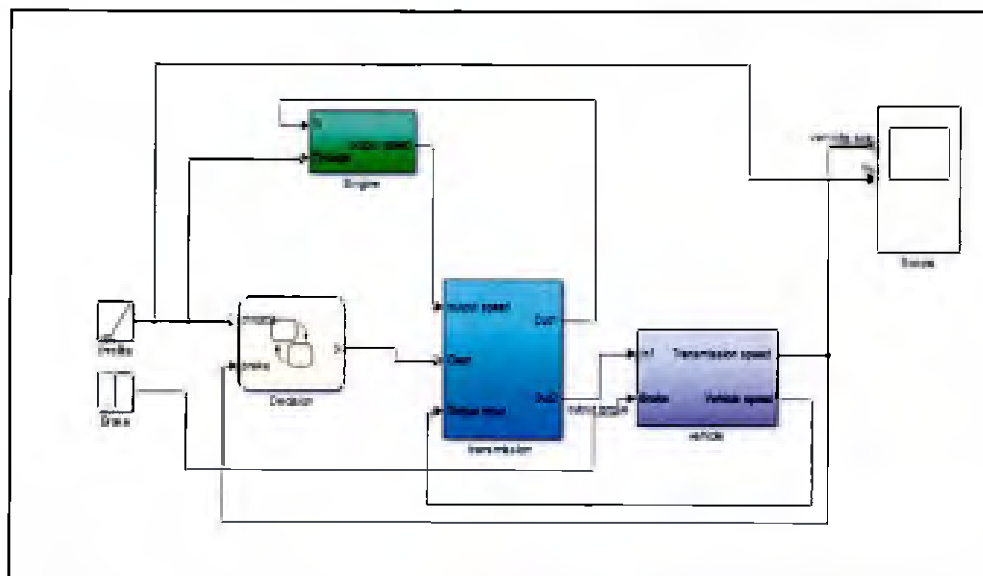


Figure 11: Matlab Simulink modelling for the Automatic Transmission for a vehicle

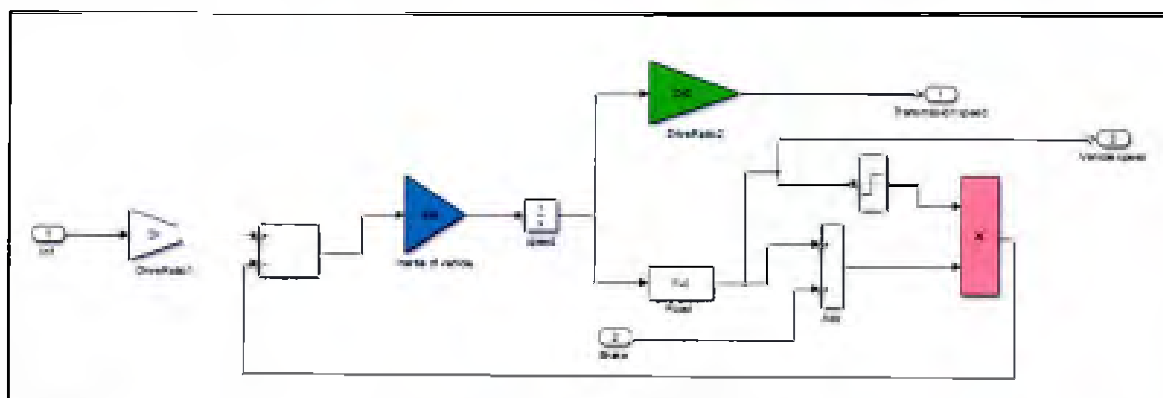


Figure 12: block diagram for the vehicle

Figures 11 and 12 show the Matlab Simulink model for an automatic transmission car. Each unit in this model operates independently, allowing for optimization of each necessary parameter.

- Engine MATLAB Simulink model

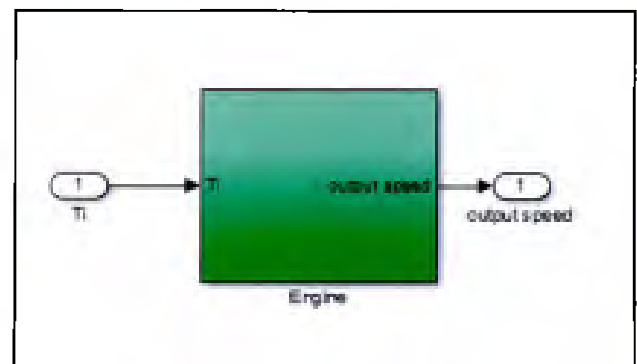


Figure 13: Engine subsystem

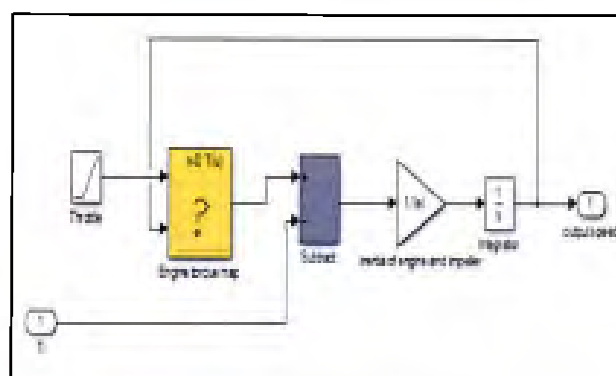


Figure 14: Engine Matlab Simulink Model

The Simulink model of vehicle engine is seen in Figures 13 and 14. Based on these block diagram, the three key variables used to model the vehicle's engine are throttle, engine speed, and engine torque.

Transmission system Matlab Simulink model

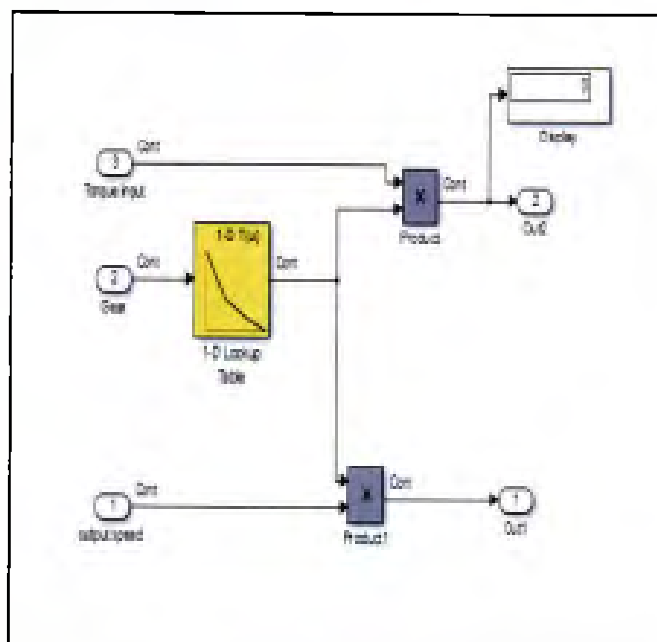


Figure 15: Transmission system Matlab Simulink model

Figure 15 shows the model of the vehicle's transmission system. According to these block diagram, the parameters which used in constructing this model are throttle input and vehicle motion dynamics.

- **Torque Converter Matlab Simulink model**

Using the Simulink, the torque converter has been constructed as illustrated in Figure 16.



Figure 16: torque converter subsystem

The full details regarding torque converter is shown in Figure 17.

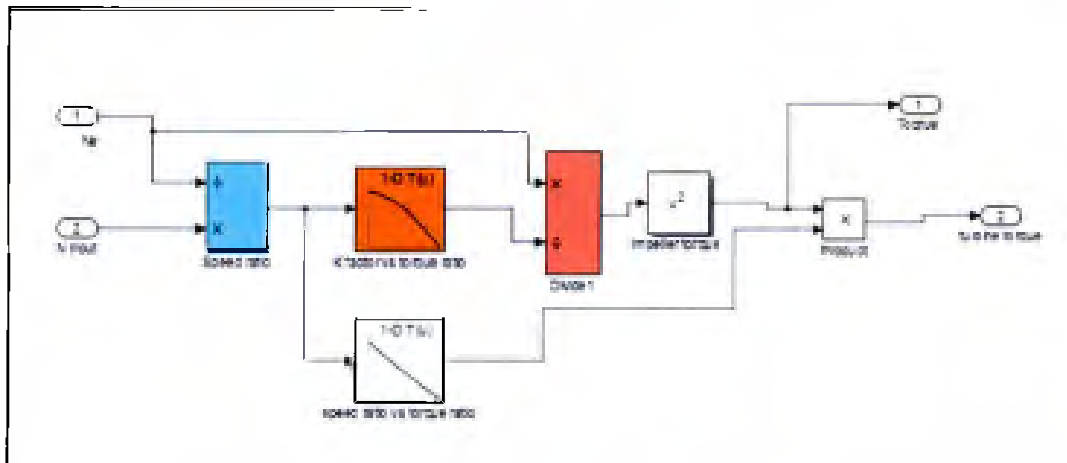
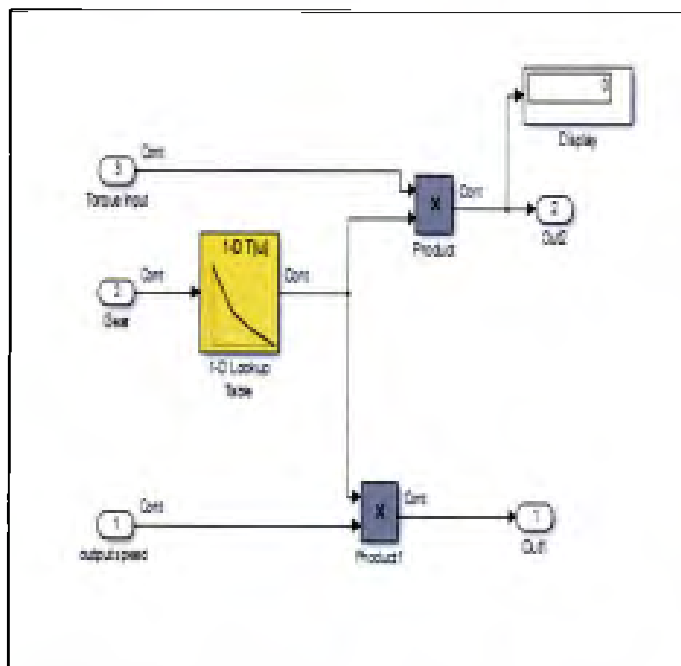


Figure 17: Torque Converter Matlab Simulink model

Figure 17 represents the model of the vehicle's torque converter. According to these block diagram, the parameters used in constructing a torque converter mechanism are gear ratio, impeller torque, engine speed, turbine speed, and torque ratio.

Transmission Gear Ratio Matlab Simulink model

Ratio of gear is a vital element in maintaining motor performance; if the gear ratio value is incorrect, the motor would not operate at the preferred speed, the amount of the energy expended will be relatively high, and the produced torque will be decent but not at the optimum degree.

Figure 18: Transmission Gear Ratio Matlab Simulink model
Obtained Results.

The engine speed as well as torque were investigated by engine torque and speed, and the outcomes were plotted. Map of engine torque and K factor are derived from the following sources:

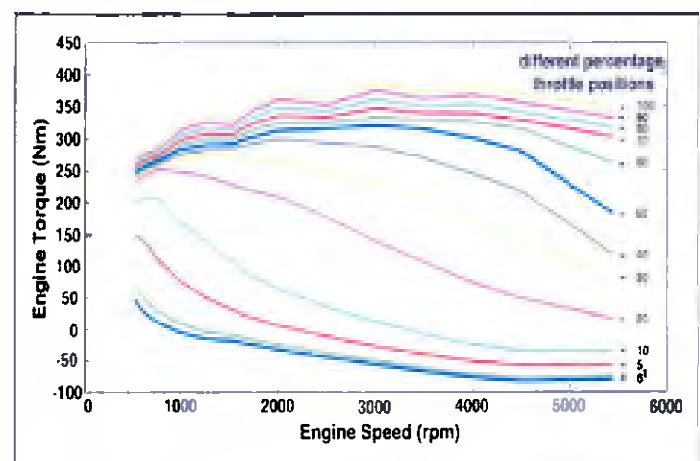


Figure 19: Engine Torque map data used in simulation

According to the graph in Figure 19, while the throttle input is low, the engine torque is high when the speed of the engine is low. According to the graph in Figure 19, while the throttle input is low, the engine torque is high when the speed of the engine is low. Vehicle automation could be efficiently achieved by maximizing the relation between the torque and the speed of engine.

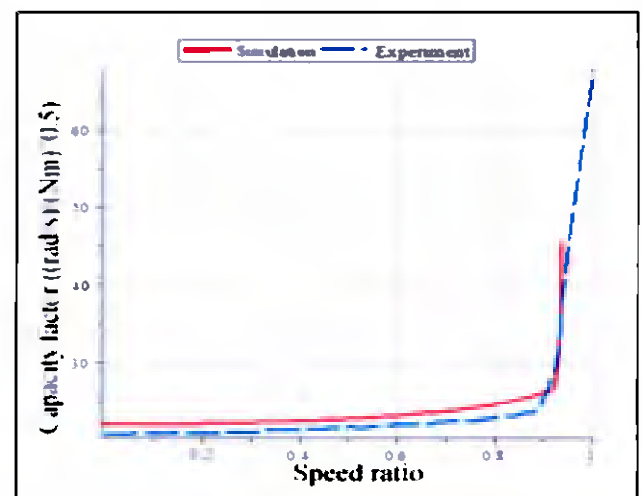


Figure 20: Capacity factor used in simulation at 2nd and 3rd gear ratio

A torque converter's characteristics are shown in the graph above in Figure 20. A red line indicates the torque characteristics in gear ratio 2, and a blue line indicates the torque characteristics at gear ratio 3.

Table 4: Opening percent of throttle and required time

Time (in second)	Input throttle %
0	60
15	40
150	0
250	0

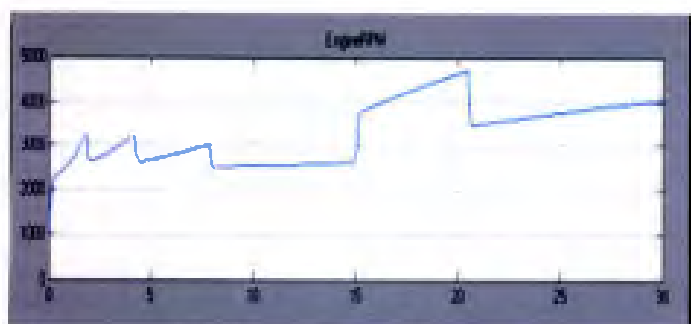


Figure 21: Automatic Transmission Simulink

Simulink's automatic transmission is used. The torque value set to zero. When the break torque is zero hence the vehicle is starting with 1000 RPM.

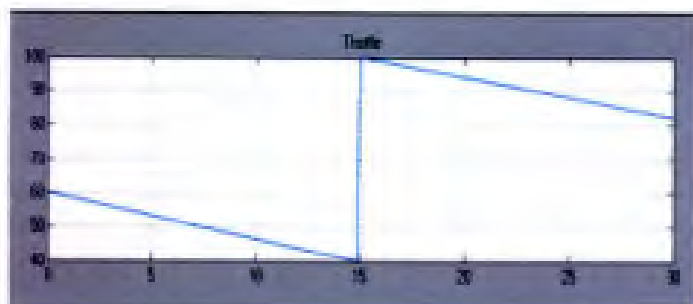


Figure 22: Vehicle input throttle graph

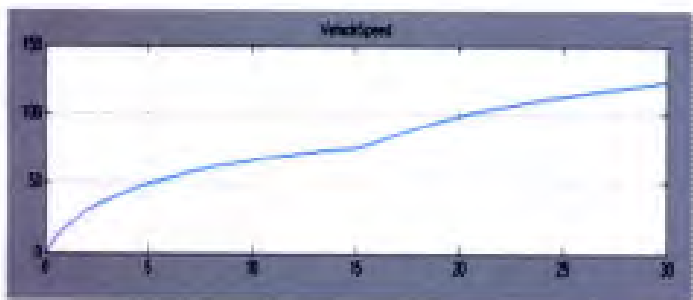


Figure 23: Vehicle speed

When $t=0$, 60% input throttle is given by the driver, the result is low ratio of speed for torque converter that lead to high ratio of torque as represented in Figure 19 and Figure 23.

The car and its engine obtained an increase in speed before time $t = 2s$. The vehicle engine's speed was greatly decreased, and it achieved its high acceleration value once more.

At 4 and 8 seconds, upshift points 2-3 as well as 3-4 occurred. At this time, the vehicle's speed remains constant. At $t=15$ seconds, an input throttle hit 100%, and the transmission switched to the third gear in the car, resulting in a significant increase in engine speed from 2600 RPM to 3700 RPM. As the throttle is depressed, the engine accelerates to 100 mph and then shifts to overdrive at $t = 21$ seconds. The car could shift into fourth gear.

V1. CONCLUSION

There are many configurations used in automobiles, but the Automatic Transmission (AT) is among the most commonly used schemes. These systems provide terrestrial sets of the gear that achieve a variety of gear ratios by connecting various planetary gear set components. At the time of gearshift, the coupling procedure is carried out by connecting brakes as well as oil-immersed clutches, also known as change parts. Using planetary gear set mixtures during the process of transmission allows for varying gear proportion to be obtained, while transmission's lightweight construction allows it to be used in all standard passenger cars.

In recent years, there has been a substantial and significant growth in consumer and regulatory standards pertaining to the automobile industry. Further, the new carbon dioxide emission standards, the EU and customers continue to emit NOxI and various particulates. Simulations have recently been given an important and significant role in the growth of the automotive industry.

After modelling all of the vehicle automation system's units, all of the parameters are varied and adjusted for the desired performance. The torque of the engine and the engine speed are then investigated, and a graph regarding the variable speed of the engine and the engine torque is formed. The findings revealed that when the throttle input is low, the torque of the engine is high as well as the engine speed is low. Vehicle automation can thus be efficiently achieved by maximizing the relation between engine torque and the engine speed.

Depending on the findings of this thesis and the improvements that have arisen in the systems of the transmission, the following recommendations should be considered in the future:

- It is easy to find clutch control functions which satisfy the criteria for the comfort of the gearshift in terms of force. Since the actuators of the Hydraulic clutch are used in most automatic gearboxes, they produce extra dynamics, making the functions of the clutch control more difficult to implement. In order to solve this issue, the hydraulic regulation of the gearbox clutches should also be modelled.
- The measurements in the vehicle are compared with the results obtained from the simulation using MATLAB Simulink, in order to obtain a comprehensive investigation of the validity of the models that were designed..

REFERENCES

- [1]. Alf cars. (2019). Automatic transmission principle of operation. *Overview of the automatic transmission*. Retrieved 25 July 2019, from
- [2]. Alonso, L. and Agusti, R. (2004). Automatic rate adaptation and energy-saving mechanisms based on cross-layer information for packet-switched data networks. *IEEE Communications Magazine*, 42(3), pp.S15-S20.
- [3]. Auto Deal. (2019). Here are the different types of Automatic Transmissions | Autodeal. Retrieved 25 July 2019, Available at <https://www.autodeal.com.ph/articles/car-features/here-are-different-types-automatic-transmissions>
- [4]. Automatic Revolution. 2019. Automatic Revolution: Comparing CVT, Dual-Clutch, and Automated-Manual Transmissions. Retrieved 25 July 2019, from <https://blog.consumerguide.com/automatic-revolution-comparing-cvt-dual-clutch-automated-manual-transmissions/>
- [5]. Automatic Transmission Types Explained. (2019). Automatic Transmission Types Explained: CVT, DSG, Tiptronic, Dual-Clutch, Automated-Manual Transmission – CAR FROM JAPAN. Retrieved 25 July 2019, from <https://carfromjapan.com/article/industry-knowledge/automatic-transmission-type-explained/>
- [6]. Flamang, P. and Smook, W., Hansen Transmissions International NV. (2005). *Dry sump lubrication system with removable oil reservoir for wind turbine gearbox*. U.S. Patent Application 10/491,668.
- [7]. Florencio, D.G., Assis, E.R. and Amendola, C.H.F. (2004). *The Manual Transmission Automated-Gearshift Quality Comparison to a Similar Manual System* (No. 2004-01-3363). SAE Technical Paper.
- [8]. Gong, J., Zhao, D.X., Chen, Y. and Chen, N. (2014). Study on shift schedule saving energy of automatic transmission of ground vehicles. *Journal of Zhejiang University-SCIENCE A*, 5(7), pp.878-883.
- [9]. Guiju, Zh. And Caiyuan, X. (2014). Application of Pro/E in Modeling of Tracked Vehicle Transmission System, Measuring Technology and Mechatronics Automation (ICMTMA).
- [10]. Gustafson, A., Schunnesson, H. and Kumar, U. (2015). Reliability analysis and comparison between automatic and manual load haul dump machines. *Quality and Reliability Engineering International*, 31(3), pp.523-531.
- [11]. Jiffy Lube. (2019). *What the transmission does and why it is important to maintain*. - Jiffy Lube California. Retrieved 25 July 2019, from <https://www.jiffylubeca.com/2012/12/11/what-the-transmission-does-and-why-it-is-important-to-maintain/>
- [12]. Lemmers, G.C. and Behling, D.S., Hamilton Sundstrand Corp, 2011. *High to low-pressure spool summing gearbox for accessory power extraction and electric start*. U.S. Patent 7,882,691.
- [13]. Mathwork. (2019). Modeling an Automatic Transmission Controller, [Online], Available at <https://www.mathworks.com/help/simulink/slref/modeling-an-automatic-transmission-controller.html>, Accessed at 8/Jul./2019.
- [14]. Mech study. 2019. *What is Automatic Transmission : Principle and Working* - mech4study. Retrieved 25 July 2019, from <https://www.mech4study.com/2015/09/automatic-car-transmission-principle-and-working.html>
- [15]. Mechanical Booster. (2019). *How Automatic Transmission Works?* - Best Explanation Ever - Mechanical Booster. Retrieved 25 July 2019, from <https://www.mechanicalbooster.com/2017/12/how-automatic-transmission-works.html>
- [16]. Nezhadali, V. and Eriksson, L. (2015). A framework for modelling and optimal control of automatic transmission system. *IFAC-Papers Online* 48-15 (2015) 285–291.
- [17]. Pohl, B. (2003), „Transient Torque Converter Performance, Testing, Simulation and Reverse Engineering“, SAE Paper, 2003-01-0249.
- [18]. Sudha, M.N., Valarmathi, M.L. and Babu, A.S. (2011). *Energy-efficient data transmission in an automatic irrigation system using wireless sensor networks*. *Computers and Electronics in Agriculture*, 78(2), pp.215-221.
- [19]. Taguchi, Y., Soga, Y., Mineno, A., Kuzuya, H., Horiuchi, I., Ueda, Y. and Miyazaki, T., (2003). *Development of an automated manual transmission system based on robust design* (No. 2003-01-0592). SAE Technical Paper.
- [20]. Tobola, J., Otter, M. and Bunte, T. (2017). Modelling of Vehicle Powertrains with the Modelica PowerTrain Library, The Modelica Association and Linköping University.
- [21]. Transmission. (2019). *What is a transmission and why it's important?*. Retrieved 25 July 2019, from <https://www.eagletransmission.com/what-is-a-transmission-and-why-it-s-important>
- [22]. Wendelius, L. (2012). Development of a Simulation Model of an Automatic Gearbox, Umeå University.
- [23]. Yi, J., Wang, X.-L., Hu, Y.-J., & Li, C.-G. (2017). Modelling and simulation of a fuzzy controller of automatic transmission of a tracked vehicle in complicated driving conditions. *Journal of Automobile Engineering*, 221(10): 1259–1272.
- [24]. Zackrisson, T. (2013). Modeling and simulation of a driveline with an automatic gearbox, Kluwer Academic Publishers.
- [25]. Zhang Y, Chen X, Zhang X, Jiang H, and Tobler W. (2015). Dynamic Modeling and Simulation of a Dual-Clutch Automated Lay-Shaft Transmission. *ASME. J. Mech. Des.*
- [26]. Zhao, S. (2013). Modeling and Simulation of the Automatic Transmission Assembly Using Matlab/Simulink, *Applied Mechanics and Materials*, Vols. 291-294, pp. 2287-2290

