Acknowledgement

We express immensely our deep sense of gratitude to Ph.D Trần Đăng Long, Faculty of Transport Engineering, for his valuable guidance and encouragement at every stage of work for the successful fulfilment of students. We are very thankful to all lecturers of the Transportation Engineering and Technology Department, for their valuable suggestions, for all of the courses, subjects, instructions and experiences you provided us with and also spending even more time outside of a class period to help us evaluate our graduated dissertation. Last but not the least, we like to convey our thanks to all who have contributed directly or indirectly for the completion of our work.

Abstract

A “ **Energy Balance Analysis In Vehicle Longitudinal Motion Using Matlab/Simscape** ” topic focuses to model the vehicle in Matlab/Simulink, and simulate it to determine the energy during the acceleration/deceleration and drive cycle. After that, basing on many collected data, I will analyze and determine the result of each energy component during these process. This process is very helpful for the simulation of generating braking in electric vehicle (EV) or hybrid electric vehicle (HEV)

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Chapter 1 Introduction

1.1. Reason for choosing the topic

Longitudinal motions is one of the motions of the vehicle, which significantly affect to the real – time motion of the vehicle such as safety driving, fuel consumption, controlling system,… This study focuses on the understanding, modeling, and simulating the longitudinal motion to analyze the energy of the real vehicle motion on the processes.

1.2. Type of Study

Numerical Simulation

1.3. Objectives

Determining the energy of the real vehicle during the acceleration/deceleration and drive cycle in Matlab/Simulink.

1.4. Requirement

Build a chosen vehicle model with real specification on Matlab/Simulink then simulating this vehicle according to acceleration/deceleration and drive cycle. Plotting diagram for each energy component during these processes.

1.5.Working Condition

Using an actual specification of Mitsubishi Xpander 2020.

The acceleration and deceleration meet all the regulation of Vietnamese Road Adminstration.

1.6. Method of Study

Modelling the vehicle in Matlab/Simulink and comparing the results with the theoretical basis which was specified before to check the link between the simulating model and theoretical basis. Then modelling the vehicle base on the drive cycle to obtain the energy components.

1.7. Content Limitation

The model just focus about the result of longitudinal motion and eliminating the transversal and vertical motion of the vehicle.

In addition, the grading force of longitudinal motion is negligible.

1.8. The introduction about Mitsubishi Xpander 2020

1.8.1. Mitsubishi Motors

Mitsubishi Motors is a Japanese multinational automobile manufacturer, established in 1970 as a spin-off from the automotive division of Mitsubishi Heavy Industries. The company is renowned for its durable vehicles, particularly its all-wheel-drive (AWD) systems, and has a strong heritage in rally racing with the legendary Lancer Evolution. Mitsubishi was also one of the pioneers in electric vehicles. Currently, the company is part of the Renault-Nissan-Mitsubishi Alliance, focusing on developing electric vehicles and strengthening its global presence, including the Vietnamese market with popular models like the Xpander and Xforce.

1.8.2. Mitsubishi Xpander 2020

The Mitsubishi Xpander 2020 is a 7-seater MPV notable for its distinctive Mitsubishi Dynamic Shield exterior design, which gives it a strong and modern appearance. The car has overall dimensions of 4,475 mm (length) x 1,750 mm (width) x 1,700 mm (height), with a wheelbase of 2,775 mm and a ground clearance of 205 mm, providing urban maneuverability.

In terms of performance, the Xpander 2020 utilizes a 1.5L MIVEC (4A91) inline 4-cylinder, 16-valve DOHC gasoline engine, producing a maximum power output of 104 horsepower at 6,000 rpm and a peak torque of 141 Nm at 4,000 rpm. The vehicle offers a choice of a 5-speed manual or a 4-speed automatic transmission and features front-wheel drive (FWD).

The specification of Mitsubishi Xpander 2020

	Specification	Value
	Overall (mm)	4475 x 1750 x 1730
L_0	Wheelbase (mm)	2775
m_{xe}	Kerb weight (kg)	1275
m_{xef}	Gross weight (kg)	1780
a/b	the horizontal distance between the centre of the vehicle and front and rear axle, respectively (mm)	1280/1495
h_g	The height from the center of vehicle to road (mm)	570
r_{bx}	The tire radius (m)	0.3
	Front/rear track (mm)	1520/1510
	Front brake	disc
A_{disc}	Area of disc brake (mm)	334.59 mm^2 .
	Rear brake	drum
A_{drum}	Area of drum brake (mm)	2565.21 mm^2
Engine		
	Displacement (cc)	1.499
	Max.Output (PS/rpm)	105/6000
	Max.Torque (Nm/rpm)	141/4000
	Max.RPM (RPM)	6500

Table 1: Specification of Mitsubishi Xpander 2020

1.9. The introduction of Matlab Simulink/Simscape

1.9.1. The introduction of Matlab

Think of MATLAB as your digital workbench for working with numbers, visualizing data, and building computational tools. It's a powerful and user-friendly software environment that's widely used across various scientific and engineering disciplines.

Here's a breakdown of what makes MATLAB stand out:

- A Language for Numbers: At its heart, MATLAB has its own programming language. This language is specifically designed to handle mathematical operations efficiently, especially those involving matrices and vectors (hence the name "Matrix Laboratory"). This makes it super convenient for tasks like solving equations, performing statistical analysis, and implementing algorithms.
- An Interactive Workspace: When you open MATLAB, you get an interactive environment. This means you can type commands directly and see the results immediately. It's like having a powerful calculator on steroids where you can define variables, perform calculations, and even create simple programs on the fly.
- Tools for Visualization: MATLAB makes it incredibly easy to create all sorts of plots and graphs. Whether you need to visualize data trends, compare results, or present your findings, MATLAB has built-in functions to generate high-quality 2D and 3D visualizations with just a few lines of code.
- Libraries of Expertise (Toolboxes): One of MATLAB's biggest strengths is its extensive collection of "toolboxes." These are like add-on packs that provide specialized functions and tools for specific areas. For example, there are toolboxes for signal processing, image processing, control systems, optimization, machine learning, and many more. These toolboxes save you a lot of time and effort by providing pre-built, well-tested solutions to common problems.

- A Platform for Development: Beyond just calculations and visualization, MATLAB allows you to develop your own applications and scripts. You can write programs to automate tasks, build custom tools, and even create graphical user interfaces (GUIs) for your applications.
- Integration with Simulink**:** For those working with dynamic systems and simulations, MATLAB seamlessly integrates with Simulink. Simulink provides a graphical environment for modeling, simulating, and analyzing systems over time.

In general, MATLAB is a comprehensive software package that provides a powerful language, an interactive environment, and a rich set of tools for numerical computation, data analysis, visualization, and algorithm development. It's a go-to tool for anyone who works with data and mathematical models in fields like engineering, science, and finance.

1.9.2. The introduction of Simulink/Simscape

Simulink: Modeling and Simulating Dynamic Systems

Think of Simulink as a graphical environment built on top of MATLAB that allows you to model, simulate, and analyze dynamic systems. Instead of writing lines of code, you build your system by connecting blocks that represent different components or operations.

Simscape: Modeling Physical Systems

Simscape, on the other hand, is a specialized toolbox within the MATLAB and Simulink environment focused on physical modeling. Instead of representing systems as signal flows, Simscape allows you to build models using blocks that represent physical components and their interconnections through physical ports.

The Relationship Between Simulink and Simscape:

- Simscape is built on top of Simulink**.** It leverages the Simulink simulation engine and environment.

- They are often used together. You might use Simscape to model the physical plant of a system and Simulink to design and implement the control system that interacts with it.
- Simulink is more general-purpose for dynamic system modeling, while Simscape is specifically tailored for modeling physical systems based on their physical connections and underlying physical principles.

Think of it this way: if you're modeling the behavior of a control algorithm or processing a signal over time, Simulink is your primary tool. If you're modeling the actual physical components and their interactions within a system (like an electric circuit or a mechanical assembly), Simscape is the way to go. Often, the most powerful solutions involve combining the strengths of both within a single model.

Chapter 2 Theoretical Basis

The maximum achievable acceleration of a vehicle is limited by two factors: maximum torque at driving wheels, and maximum traction force at tireprints. The first one depends on engine and transmission performance, and the second one depends on tire-road friction. In this chapter, we examine engine and transmission performance.

2.1. Engine Dynamics

The maximum attainable power P_e of an internal combustion engine is a function of the engine angular velocity ω_e. This function must be determined experimentally, however, the function $P_e = P_e\ (\omega_e)$, which is called the power performance function, can be estimated by a third-order polynomial.**[1]**

$$P_e = \sum_{i=1}^{3} P_i \omega_e^i \tag{1}$$

$$= P_1\omega_e + P_2\omega_e^2 + P_3\omega_e^3 \tag{2}$$

If we use ω_M to indicate the angular velocity, measured in $[rad/\ s]$, at which the engine power reaches the maximum value P_M, measured in $[W =\ N\ m/\ s]$, then for spark ignition engines we use

$$P_1 = \frac{P_M}{\omega_M} \tag{3}$$

$$P_2 = \frac{P_M}{\omega_M^2} \tag{4}$$

$$P_3 = -\frac{P_M}{\omega_M^3} \tag{5}$$

The driving torque of the engine T_e is the torque that provides P_e

$$T_e = \frac{P_e}{\omega_e} \tag{6}$$

$$T_e = P_1 + P_2\omega_e + P_3\omega_e^2 \tag{7}$$

Converting the revolution from RPM to rad/s

We need converting the frequency from RPM to RPS :

$$f(RPS) = \frac{RPM}{60} \tag{8}$$

Then, we calculate the period:

$$T = \frac{1}{f} \tag{9}$$

Finally, we transmit the revolution (RPM) to the revolution (Rad/s) $= \frac{2\pi}{T}$

We need convert the revolution (RPM) of Xpander 2020 to the revolution (Rad/s)

$$4000\ RPM = 418.7\frac{rad}{s}$$

$$5000\ RPM = 523.6\frac{rad}{s}$$

$$6000\ RPM = 628\frac{rad}{s}$$

$$6500\ RPM = 680.33\frac{rad}{s}$$

Converting Horsepower (HP) to Power (W):

$$1\ HP = 745.7\ W \tag{10}$$

⇨ $Power\ (W) = 105 * 745.7 = 78298.5\ (W)$

According to (1) and basing on the engine specification of Xpander 2020, we can calculate the torque at high power

$$P_1 = \frac{P_M}{\omega_M} = \frac{78298.5}{628} = 124.68\frac{w}{s}$$

$$P_2 = \frac{P_M}{\omega_M^2} = \frac{78298.5}{628^2} = 0.1985\frac{w}{s^2}$$

$$P_3 = -\frac{P_M}{\omega_M^3} = -\frac{78298.5}{628^3} = -3.161 * 10^{-4}\frac{w}{s^3}$$

$$=> T_e = 124.68 + 0.1985\omega_M - 3.161 * 10^{-4}\omega_M^2 \tag{11}$$

From (2) we can calculate the Torque at each speed engine:

$$T_{max} = 141\ Nm$$

$$T(6000) = 124.67\ Nm$$

$$T(6500) = 100.43\ Nm$$

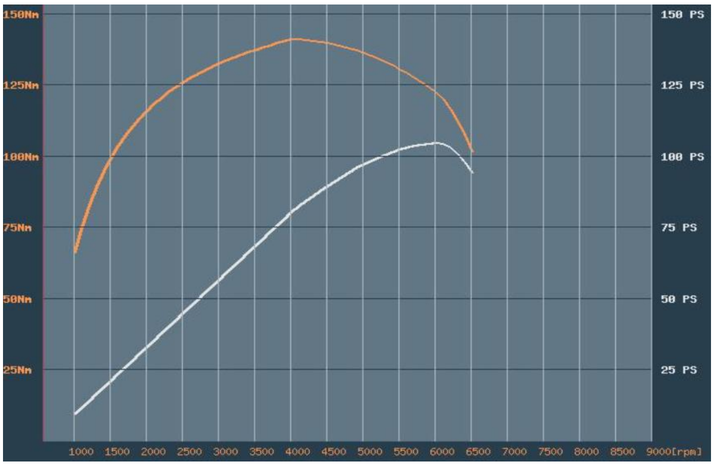

Figure 1: The performance of Mitsubishi Xpander 2020

Basing on QCVN 09:2015/BGTVT **[2]** (National technical regualtion on safety and environmental protecticon for automobiles) of Vietnamese Ministry of Transport:

- When tested under full load conditions on dry and flat roads, the vehicle must meet the following requirements:
- The acceleration time from the departure to the end of the 200m distance meets the following conditions:

$$t \leq 20 + 0.4G \tag{12}$$

$$=> t \leq 20.712 \tag{13}$$

Where:

t — Acceleration time is calculated from the moment of departure to the end of the 200 m distance (in seconds)

G — Maximum total design mass of the vehicle (in tons)

- The maximum velocity is not less than 60 km/h
- The acceleration time need to meet the standard of QCVN on the dry and flat roads. After that, we can use these parameters to simulate on the other type of roads.

2.2. The distribution of engine in vehicle

The distribution of an engine in a vehicle refers to its placement and orientation within the chassis. This significantly impacts the vehicle's handling, weight distribution, interior space, and even its aesthetic design. Here's a general overview of the common engine distribution methods:

Based on Engine Location:

- Front – engine: Front — Wheel Drive (FWD), Rear – Wheel Drive (RWD), All – Wheel Drive (AWD) / Four – Wheel Drive (4WD).
- Mid – engine: Rear – Wheel Drive (MR), All – Wheel Drive (M4).
- Rear – engine: Rear – Wheel Drive (RR).

Based on Engine Orientation:

- Longitudinal: It generally provides better weight distribution for RWD setups.
- Transverse: This is the dominant layout in modern FWD vehicles as it's more space-efficient, packaging the engine and transmission together more compactly.

The layout of Mitsubishi Xpander 2020 is FWD. Front-Wheel Drive (FWD) in a vehicle is a drivetrain configuration where the engine's power is transmitted solely to the front wheels. This means the front wheels are responsible for both pulling the vehicle forward and steering it. The rear wheels, in this setup, simply follow along and do not receive any power from the engine. This layout is space-efficient and generally offers good traction on slippery surfaces.

2.3. Driveline and Efficiency

We use the word driveline, equivalent to transmission, to call the systems and devices that transfer torque and power from the engine to the drive wheels of a vehicle. Most vehicles use one of two common transmission types: manual gear transmission, and automatic transmission with torque convertor. A driveline includes the engine, Torque converter, transaxle, final drive and driving wheel. The engine is the power source in the driveline. The output from the engine is an engine torque T_e, at an associated engine speed ω_e.

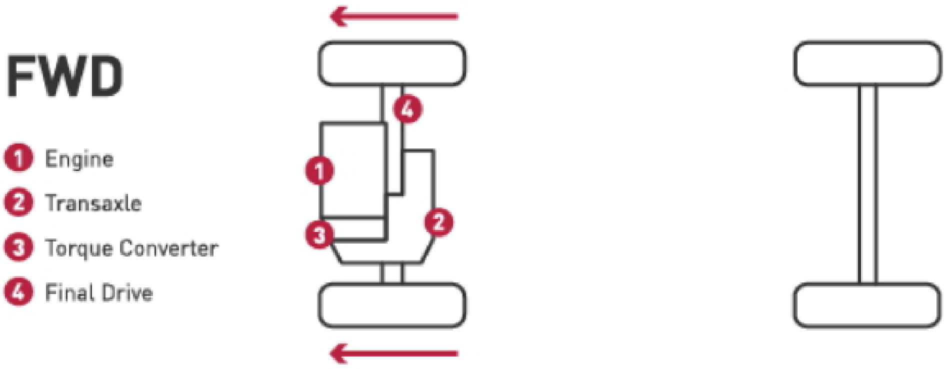

Figure 2: The structure of FWD vehicle

- Torque Converter: The primary function of a torque converter in a vehicle equipped with an automatic transmission is to act as a fluid coupling that transmits power from the engine to the transmission. It essentially performs the same role as a clutch in a manual transmission, allowing the engine to run independently of the wheels when the vehicle is stopped or moving at very low speeds

Figure 3: Torque Converter

- Transaxle: The main function of a transaxle is to integrate the transmission and the differential into a single unit to efficiently manage and deliver power to the driven wheels located on the same axle as the engine.

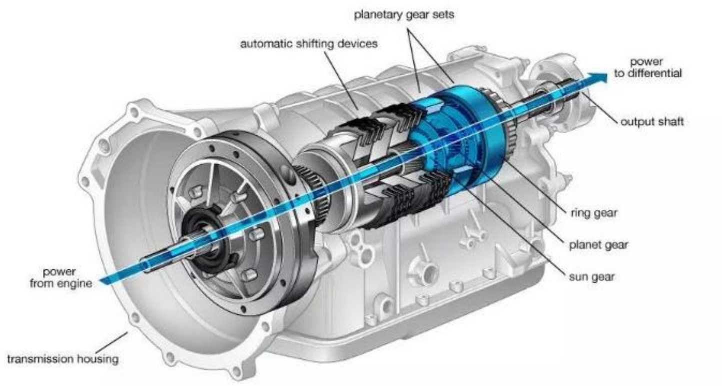

Figure 4: Transaxle

- Axle: The main function of an axle in a vehicle is to transmit rotational power from the drivetrain to the wheels and to support the weight of the vehicle.
- Drive Axles: These axles are connected to the drivetrain and deliver power to the wheels
- Non-Drive Axles (Dead Axles): These axles do not receive power from the drivetrain and simply support the weight of the vehicle and allow the wheels to rotate freely

Figure 5: Drive axles

The drive wheels transform the engine torque to a traction force on the road.

The available power at the drive wheels is

$$P_w = \eta P_e \tag{14}$$

where $\eta < 1$ indicates the overall efficiency between the engine and the drive wheels

$$\eta = \eta_c \eta_t \tag{15}$$

$\eta_c < 1$ is the convertor efficiency and $\eta_t < 1$ is the transmission efficiency.

The relationship between the angular velocity of the engine and the velocity of the vehicle is

$$v_x = \frac{r_w \omega_e}{n_g n_d} \tag{16}$$

where n_g is the transmission ratio of the gearbox, n_d is the transmission ratio of the differential, ω_e is the engine angular velocity, and r_w is the effective tire radius.

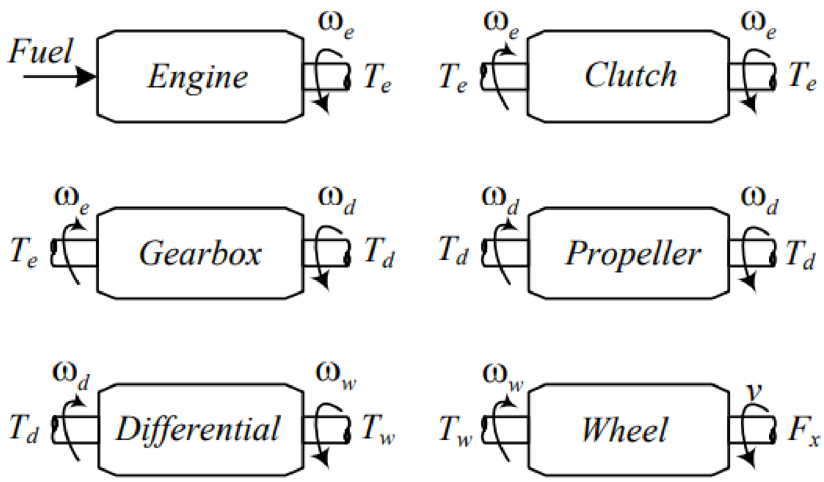

Figure 6: Driveline

2.4.Braking system

2.4.1. The definition of braking system

A brake constitutes a mechanical device engineered to impede motion by absorbing energy from a moving system, typically utilising friction. It serves the purpose of decelerating or halting the motion of vehicles. While complex in its components, the braking system may seem deceptively simple in its operation, triggered by pressing a single pedal that activates brakes on all four wheels. The process of deceleration is facilitated through hydraulic fluid, often requiring bleeding for optimal braking performance, with the exclusion of air to ensure effective component operation.

Traditionally, most brakes rely on friction between surfaces, where pressure converts the kinetic energy of a moving object into heat. Despite this, various energy conversion methods have been adopted. In modern automobiles, friction brakes harness and store braking heat within drum or disc brakes, gradually dissipating it into the air. Notably, the efficiency of a hydraulic braking system is often attributed to its ability to convert mechanical force into hydraulic pressure, effectively transmitting the braking force to the vehicle's brake components and ensuring responsive and controlled deceleration.

2.4.2. Working principle of Braking System

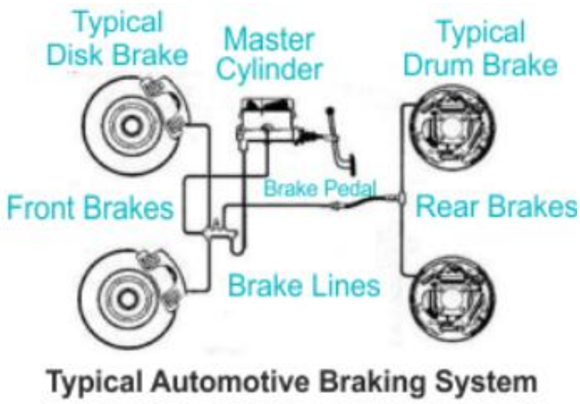

Figure 7: Brake mechanism

While the operation of a brake system may appear intricate, the elucidation of its components and types likely renders you acquainted with the relevant terminology. Brake systems come in two primary variants: disc brakes and drum brakes. Disc brakes find application on the front wheels of vehicles, while drum brakes are typically fitted to the rear wheels. However, some contemporary high-end vehicles incorporate disc brakes on all four wheels.

When the driver presses the brake pedal, a force is generated, subsequently amplified by the vacuum sourced from the engine. This enhancement ensures a quicker and more efficient response from the brakes. The force exerted by the vacuum booster propels the piston within the master cylinder against the spring, inducing the flow of brake fluid under pressure. This pressurised fluid traverses through the fluid lines to reach the brake calliper (in the case of disc brakes) or the brake cylinder (for drum brakes).

2.4.3. Functions of Braking system

The braking system in automotive engines performs the following functions:

- Halting the Vehicle: The brake system is responsible for bringing vehicles to a stop in the shortest distance feasible by converting the vehicle's kinetic energy into heat energy.
- Mechanical Control: Operating as a mechanical mechanism, the brake system intervenes in motion to swiftly and effectively halt a moving entity within a brief span of time.

2.4.4. Component of Braking System

Below are the components utilised in the automotive braking system:

- **Brake Pedal:** This component, located between the accelerator and clutch pedals inside the vehicle, is pressed by the foot to activate the brakes.
- **Fluid Reservoir:** The fluid reservoir houses the brake fluid or brake oil used in the braking system.
- **Fluid Lines:** Fluid lines consist of pipes through which brake fluid circulates within the vehicle.
- **Brake Pads:** Employed in disc brakes, brake pads are steel backing plates often composed of materials like ceramic, metal, or durable composites.
- **Brake Shoes:** Brake shoes are composed of two connected pieces of sheet steel that support the brake lining.
- **Brake Drum:** A rotating drum-shaped component integral to the drum brake system.
- **Rotor:** The rotor, often made of cast iron or reinforced materials like carbon-carbon or ceramics, serves as a brake disc connected to a wheel or axle.

- **Brake Lining:** Encased within the brake shoe, brake lining is a heat-resistant material with high friction properties, offering a balance of softness and toughness.

2.4.5. Calculating the brake force at brake system of vehicle

Using the available model: Mitsubishi Xpander 2020 First of all,Basing on QCVN 09:2015/BGTVT (National technical regualtion on safety and environmental protecticon for automobiles) of Vietnamese Ministry of Transport **[2]**:

Type	Passenger Car
$v\ (km/h)$	50
$s \leq (m)$	19
$d_m \geq (m/s^2)$	6.2

Table 2: The Standard of Deceleration for Part-load Vehicle

Type	Passenger Car
$v\ (km/h)$	50
$s \leq (m)$	20
$d_m \geq (m/s^2)$	5.9

Table 3: The Standard of Deceleration for Full-load Vehicle

The braking force at the front brake mechanism is determined to standard of braking test of full load vehicle:

$$F_{fbrake} = 2710N$$

The ideal distribution curve gives the maximum braking force which can make the front and rear wheels lock simultaneously for each friction coefficient. When the braking force is distributed to the front and rear wheels on the operating curve, safe braking is secured. It can be represented as:

$$F_{rbrake} = \frac{1}{2}\left[\frac{G}{h_g}\sqrt{b^2 + \frac{4h_g L_o}{G}F_{fbrake}} - \left(\frac{Gb}{h_g} + 2F_{fbrake}\right)\right] \tag{17}$$

$$F_{rbrake} = \frac{1}{2}\left[\frac{1780 * 9.81}{0.57}\sqrt{1.495^2 + \frac{4 * 0.57 * 2.775}{1780 * 9.81} * 2710} - \left(\frac{1780 * 1.495}{0.57} + 2 * 2710\right)\right]$$

$$F_{rbrake} = 1863.5\ (N)$$

We choose these braking force for all simulating situation of this report.

2.5.The definition of longitudinal vehicle dynamics model

A longitudinal vehicle dynamics model describes the motion and behavior of a vehicle along its longitudinal axis, which is the direction from rear to front. This model primarily focuses on the forces and motions that affect the vehicle's forward movement, including:

- Acceleration and Deceleration: The forces acting on the vehicle due to engine power (thrust) and braking forces.
- Longitudinal Forces: The forces generated by tire traction, friction, and aerodynamics that influence how the vehicle moves along a straight path.
- Vehicle Speed and Velocity: The relationship between the vehicle's speed and the forces acting on it, such as drag, rolling resistance, and tire forces.
- Traction and Tire Dynamics: How the tires interact with the road surface and how this affects acceleration, braking, and stability.

The model is typically used to analyze the vehicle's performance in terms of speed, acceleration, and fuel efficiency, and to simulate driving behavior under different conditions such as on flat roads, slopes, or during braking events. It's essential for vehicle design, control systems, and simulation in automotive engineering.

2.5.1. The equation of longitudinal vehicle dynamics

The longitudinal vehicle dynamics equation models the forces acting on a vehicle in the longitudinal direction (along the vehicle's length). A basic form of the equation is derived from Newton's second law of motion, which relates the net forces to the vehicle's acceleration.

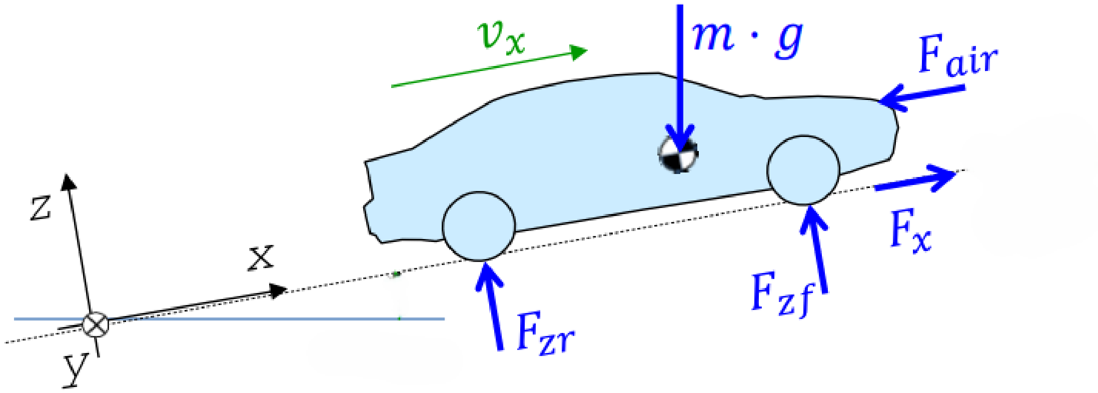

Figure 8: The Longitudinal Dynamics of Vehicle body

The general equation for longitudinal motion is

$$\sum F_x - F_{aero} = m\frac{dv}{dt} \tag{18}$$

Where:

m: the mass of the vehicle (kg)

$\frac{dv}{dt}$: the longitudinal acceleration/deceleration of the vehicle (m/s^2)

F_x: the longitudinal force (N)

F_{aero}: the aerodynamics drag force (N)

2.5.2. The tire dynamics model

Tires are an important part that connects the vehicle body and road. This is an important factor that determines the vehicle’s dynamics in three dimensions: vertical, longitudinal, and horizontal. In particular, in the vertical dimension, the tire has the effect of supporting the entire mass of the car and also directly affecting vibration properties of the car. In the longitudinal and horizontal dimensions, the tire – road surface connection has a decisive influence on the traction properties, braking properties and stability of the vehicle’s dimension of motion.

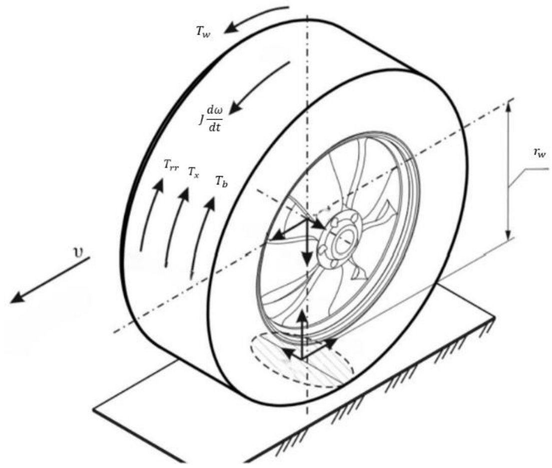

Figure 9: The longitudinal dynamics of tire

The equation of driven tire dynamics

$$T_w - (T_{rr} + T_x + T_b) = J\frac{d\omega}{dt} \tag{19}$$

$$\frac{T_w}{r_w} - \left(\frac{T_{rr}}{r_w} + \frac{T_x}{r_w} + \frac{T_b}{r_w}\right) = J\frac{d\omega}{dt}\frac{1}{r_w} \tag{20}$$

The equation of non — driven tire dynamics

$$-(T_{rr} + T_x + T_b) = J\frac{d\omega}{dt} \tag{21}$$

$$-\left(\frac{T_{rr}}{r_w} + \frac{T_x}{r_w} + \frac{T_b}{r_w}\right) = J\frac{d\omega}{dt}\frac{1}{r_w} \tag{22}$$

Where:

T_w: The traction torque from engine calculating at wheel (Nm)

T_{rr}: The torque was created by rolling resistance force (Nm)

T_x: The torque was created by the longitudinal reaction force from the ground (Nm)

T_b: The torque was created by the braking mechanism (Nm)

$J\frac{d\omega}{dt}$: The moment inertia of wheel

J: the inertia of wheel (kgm^2)

2.5.3. The general formula of longitudinal dynamics

From (20) and (22) we have:

$$(20) => \frac{T_w}{r_w} - \frac{T_{rr}}{r_w} - J\frac{d\omega}{dt}\frac{1}{r_w} - \frac{T_b}{r_w} = \frac{T_x}{r_w} = F_{xf} \quad (23)$$

$$(22) => -\frac{T_{rr}}{r_w} - J\frac{d\omega}{dt}\frac{1}{r_w} - \frac{T_b}{r_w} = \frac{T_x}{r_w} = F_{xr} \quad (24)$$

We change (23) and (24) to (18):

$$\left(2F_{xf} + 2F_{xr}\right) - F_{aero} = m\frac{dv}{dt} \quad (25)$$

$$=> 2\frac{T_w}{r_w} - \sum\frac{T_{rr}}{r_w} - \sum J\frac{d\omega}{dt}\frac{1}{r_w} - \sum\frac{T_b}{r_w} - F_{aero} = m\frac{dv}{dt} \quad (26)$$

2.5.4. Explain the force components

The traction torque: The torque from engine is transmitted to the wheel to propulsion

$$T_w = \eta T_e\ (Nm) \quad (27)$$

The rolling resistance torque: The torque was created by the rolling resistance force (F_{rr})

$$F_{rr} = c_{rr}F_z\ (Nm) \quad (28)$$

Where:

c_{rr}: the coefficient of rolling resistance

$F_z = 2F_{zf} + 2F_{zr}$: the normal force of vehicle

The inertia moment of wheel

$$J\frac{d\omega}{dt} \quad (29)$$

Where:

$J = m_w r_w^2$: The inertia of wheel (kgm^2)

m_w: The mass of wheel (kg)

r_w: The radius of wheel (m)

The torque of braking mechanism: the torque applied to the hub of the wheel, decreasing the speed of the wheel (T_b)

The force of aerodynamics: this force opposes the vehicle's motion due to air resistance. It is increases with the square of the vehicle's speed and is given by

$$F_{aero} = \frac{1}{2}C_d A\rho v^2 \quad (30)$$

Where:

C_d: drag coefficient

A: frontal area of the vehicle (m^2)

ρ: air density (kg/m^3)

v: velocity of the vehicle (m/s)

2.5.5. the tire dynamics model with slippage (Magic formula)

2.5.5.1 the coefficient of slip

Tire is affected by Forces include: ground reaction force F_z , longitudinal force F_x . The reaction force F_z depends on the weight distributed to the wheels and the dynamic force interacting between the wheels and the road surface. The reaction force component F_z affects the friction force so it determines the magnitude of the longitudinal force component F_x. The wheel rotates with an angular velocity ω and a linear velocity at the center of the wheel V_x compared to a fixed axle system mounted. If the tire is not deformed and does not slip, the vehicle will move at a long speed $V_x = r_w\,\omega$, while the tire tread longitudinal velocity is $V_T = r_w\omega + \dot{u}$ but in reality, when the vehicle moves, there is always slipping. Sliding speed Relatively calculated according to real work:

$$V_{sx} = V_x - V_T \tag{31}$$

The coefficient of slip:

$$s = -\frac{V_{sx}}{|V_x|} \tag{32}$$

In case the vehicle completely slip, $\omega = 0$, then $s = -1$; Ideal rolling case no case, $V_{sx} = 0$, then $s = 0$ **[3]**

Where:

r_w: the radius of the wheel (m)

ω: the wheel angular velocity (rad/s)

$\dot{u}$: tire deformation

2.5.5.2 Pacejka model – Magic formula

Traction force (F_x) is determined by Magic Formula:

$$F_x = f(s, F_z) = F_z.D.\sin\left(C.\tan^{-1}(Bs - E(Bs - \tan^{-1}(Bs)))\right)$$

Where:

F_x: The longitudinal Force (N)

F_z: The normal force of vehicle (N)

s: the coefficient of slip

B: the coefficient of the stiffness

C: the coefficient of the shape

D: the coefficient of the peak

E: the coefficient of the curvature

Note: the assumption of the model is that the wheel moves stably, with no rotational or horizontal vibrations caused by camber wheel angles or lateral forces

Surface	B	C	D	E
Dry Tarmac	10	1.9	1	0.97
Wet Tarmac	12	2.3	0.82	1
Snow	5	2	0.3	1
Ice	4	2	0.1	1

Table 4: Parameters of road type

2.5.6. The balancing power equation

2.5.6.1 The definition of longitudinal power

Output power (or useful power): This is the power that an engine generates to perform work (e.g., turning wheels, pumping water, generating electricity). This power is always a positive value, as the engine is 'working' and producing energy.

Consumed power: This is the electrical or fuel power that an engine consumes to operate. This power is always a positive value, as the engine is 'taking in' energy from an external source.

Power (in general) and braking power: When referring to power in a general sense within a mechanical system, it can be negative. This occurs when the engine is no longer producing work but is instead being pulled or braked by an external force. In this case, the engine functions as a generator (if it's an electric motor) or as a device that consumes mechanical energy (such as when a vehicle goes downhill and the engine creates resistance to slow it down).

When we talk about the power we need determine power of the engine to overcome the power of losses component and generating the actual power of the vehicle. In the contrast, when the vehicle is decelerating the actual mechanical power of vehicle maybe negative due to the power of losses components and the brake power is affected.

2.5.6.2 the balancing power equation

The principle of energy conservation in the longitudinal dynamics can be expressed as:

$$P_e = P_{actual} + P_{fricmech} + P_{rr} + P_{aero} + P_{brake} \quad (33)$$

The energy by the tractive force of the engine (P_e): This is the energy supplied by the engine (or electric motor).

$$P_e = T_e * \omega_e \tag{34}$$

Where:

T_e is the tractive torque of the engine. (Nm)

ω_e is the speed of the engine (rad/s)

2.5.6.2.1 Energy Output and Losses

The actual power (P_{actual}): This is the actual power of the vehicle. It means the power of the engine overcome the losses power to generate this power

In addition, the power of wheel inertia (P_j) is a part of the actual power

$$P_j = J \frac{d\omega}{dt} \frac{1}{r_w} * v \tag{35}$$

Where:

J is the wheel inertia (kgm^2)

r_w is the wheel radius (m)

The power against resistive forces: These forces oppose the motion of the vehicle and dissipate energy as heat or other forms

Aerodynamic drag (P_{aero}): The force of air resistance acting on the vehicle. The power against it depends on the drag force and the distance traveled.

$$P_{aero} = F_{aero} * v \tag{36}$$

Where:

F_{aero} is the aerodynamics force. (N)

Rolling resistance (P_{rr}): The friction between the tires and the road surface. The power against it depends on the rolling resistance force and the distance traveled.

$$P_{rr} = F_{rr} * v \tag{37}$$

Where:

F_{rr} is the rolling resistance force. (N)

Frictional Transmission ($P_{fricmec}$): The friction transmission of gearbox. The power is generated between mechanical part in driveline.

$$P_{fricmec} = P_{tractive(wheel)} - P_{engine} \tag{38}$$

Braking work (P_b): When brakes are applied, the actual power become negative

$$P_b = F_b * v \tag{39}$$

Where

F_b is the total braking force. (N)

2.5.7. The balancing energy equation

2.5.7.1 The definition of longitudinal energy

The net energy acting on the vehicle in the longitudinal direction must equal the rate of change of its kinetic energy plus any energy dissipated or stored. In simpler terms, the energy put into accelerating or decelerating the vehicle must account for the vehicle’s change in motion and any losses due to resistance.

2.5.7.2 The definition of longitudinal work

Work (or work done) is defined as the transfer of energy to or from an object by means of a force acting over a displacement.

2.5.7.3 The relation between work and energy

Work and energy are closely related through the **Work-Energy Theorem**: The change in an object’s kinetic energy is equal to the total work done by all forces acting on that object. This can be expressed as:

$$A = \Delta KE = KE_{final} - KE_{initial} \tag{40}$$

Where:

KE_{final} : Kinetic Energy at the final time (J)

$KE_{initial}$: Kinetic Energy at the initial time (J)

2.5.7.4 The energy balance equation

The principle of energy conservation in the longitudinal dynamics can be expressed as:

$$A_e = A_{vehicle\ inertia} + A_j + A_{aero} + A_{rr} + A_{fricmech} + A_b \quad (41)$$

The energy by the tactive force of the engine (A_e): This is the energy supplied by the engine (or electric motor).

$$A_e = \int P_e dt \quad (42)$$

Where

P_e is the tractive power of the engine. (W)

2.5.7.4.1 Energy Output and Losses

The vehicle inertia energy ($A_{vehicle\ inertia}$): This is the energy associated with the vehicle's motion. A change in speed directly corresponds to a change in kinetic energy.

$$A_{vehicle\ inertia} = \frac{1}{2}mv^2 \quad (43)$$

Where:

v_f is the final velocity (m/s)

v_i is the initial velocity. (m/s)

The energy of wheel inertia (A_j) is a wheel inertia component

$$A_j = \int P_j\, dt \quad (44)$$

Where:

P_j is the power of wheel inertia (W)

The energy against resistive forces: These forces oppose the motion of the vehicle and dissipate energy as heat or other forms

Aerodynamic drag (A_{aero}): The force of air resistance acting on the vehicle. The energy against it depends on the drag force and the distance traveled.

$$A_{aero} = \int P_{aero} dt \quad (45)$$

Where:

P_{aero} is the aerodynamics power. (W)

Rolling resistance (A_{rr}): The friction between the tires and the road surface. The energy against it depends on the rolling resistance force and the distance traveled.

$$A_{rr} = \int P_{rr}\, dt \tag{46}$$

Where:

P_{rr} is the rolling resistance power. (W)

Frictional Transmission ($A_{fricmec}$): The friction transmission of driveline. The energy is generated between mechanical part in driveline.

$$A_{fricmec} = \int P_{fricmec}\, dt \tag{47}$$

Braking work (A_b): When brakes are applied, they convert the kinetic energy of the vehicle into heat.

$$A_b = \int P_b\, dt \tag{48}$$

Where:

P_b is the total braking power. (W)

Chapter 3 Simulation Method

3.1. The Working Condition

The actual specification of Mitsubishi Xpander 2020, which was supplied by the manufacturer, is used to parameterize the model in application.

According to accelerating process, the vehicle must be meet the QCVN 09:2015/BGTVT **[2]**

3.1.1. Acceleration

When tested under full load conditions on dry and flat roads, moving in the longitudinal direction

Maximum velocity is not less than 60 km/h

The acceleration time from the departure to the end of the 200m distance meets the following conditions:

$$t \leq 20 + 0.4G \tag{49}$$

$$=> t \leq 20.712 \tag{50}$$

According to acceleration , the vehicle must be meet the QCVN 09:2015/BGTVT **[2]**

3.1.2. Deceleration

According to, the applied brake force which was calculated at **chapter 2**. The vehicle is must meet the standard of deceleration

No load with a driver

Type	Passenger Car
$v\ (km/h)$	50
$s \leq (m)$	19
$d_m \geq (m/s^2)$	6.2

Table 5: Reference Deceleration Standard for Part-load Vehicle

Full load

Type	Passenger Car
$v\ (km/h)$	50
$s \leq (m)$	20
$d_m \geq (m/s^2)$	5.9

Table 6: Reference Deceleration Standard for Full-load Vehicle

3.1.3. The hypothesis

The hypothesis for driveline consisting of:

The inertia of the components in driveline is negligible

The total efficiency from the engine to th driven wheel is 0.95

$$\eta_{total} = 0.95$$

The ratio of an engine is always 1.0

$$n_g = 1.1$$

The ratio of a differential is always 9.0

$$n_d = 9.0$$

3.2. The limitation of the mathematical model

Vehicle dynamics refers to the study of the forces and motions that act on a vehicle while it is in motion. It involves the analysis of how a vehicle behaves in response to various inputs such as steering, braking, acceleration, and road conditions. Vehicle dynamics examines the interaction between the vehicle's components (like tires, suspension, and chassis) and the environment, aiming to optimize vehicle performance, safety, and comfort. It means we assume a vehicle which is a rigid body with three primarily directions: longitudinal, lateral, and vertical direction. From three-axis, we can determine the individual components of the 3D vehicle force system: Longitudinal force, lateral force, normal force, roll moment, pitch moment, and yaw moment.

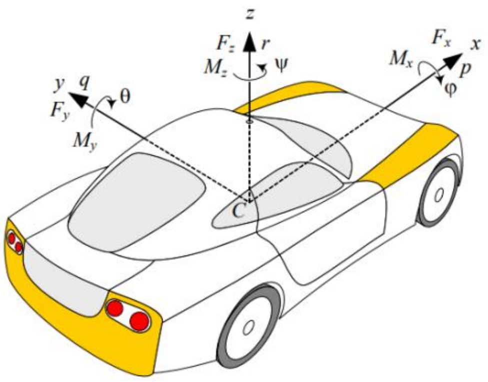

Figure 10: The origin of vehicle

Howevers, in this report, the chosen mathematical model just focus on the longitudinal and normal force (the suspension is ignore). The remains components in the vehicle dynamics is ignored. **[4]**

The longitudinal vehicle dynamic models consists of the force of rolling resistance, aerodynamic drag, brake system, grade, and towing. However, we assumed the vehicle is motion on the flat road and the towing force is negligible.

In addition, the backward motion of the vehicle do not refer in this report.

Finally, the gradign force of longitudinal motion is negligible.

3.3. Simulating Process

3.3.1. The acceleration

In this study, the vehicle model used for simulation is the Mitsubishi Xpander 2020. This vehicle utilizes transaxle consisting of an automatic transmission combined with a differential for front-wheel drive. This configuration results in a more structurally integrated and flexible powertrain. However, being equipped with mechanical components, the vehicle is inevitably subject to wear and tear and transmission losses during operation. Based on the hypothesis presented in **Chapter 3**, the overall transmission efficiency of the transaxle is 0.95, the gearbox is always operated at a gear ratio of 1.1, and the differential ratio at the front-driven axle is 9.0.

Therefore, the engine is the power source in the powertrain system. The torque T_e and engine speed ω_e are produced from the engine. Considering the gear ratio in the gearbox is 1.1 and the gear ratio in the front-wheel drive differential is $\eta_d = 9.0$ (being constant) , which allows the driven wheels to have different speeds. At the wheels, the task of converting torque T_w and angular speed ω_w into tractive force F_x and wheel speed v_w is performed.

The efficiency of the powertrain system:

Due to friction within the powertrain system, the power at the driving wheels is always less than the power at the engine output shaft. The ratio between the output power and the input power is a value known as efficiency:

$$\eta = \frac{P_{out}}{P_{in}} \tag{51}$$

The efficiency of the powertrain system depends on many parameters and the operating conditions of the vehicle, such as: load, speed, manufacturing quality of components, lubricant viscosity, etc. The efficiency of the powertrain system can be determined by the product of the efficiencies of the individual components within the powertrain. Here, according to the hypothesis, we choose the overall efficiency to be:

$$\eta = 0.95$$

The transmission ratio of driveline

The transmission ratio n represents the change in torque T with respect to angular velocity ω. When $n < 1$, the torque T will decrease by n times, and correspondingly, the angular velocity ω will increase by n times. Conversely, with a transmission ratio $n > 1$, the torque T will be amplified, and the angular velocity ω will decrease.

$$n = \frac{T_{out}}{T_{in}} = \frac{\omega_{in}}{\omega_{out}} \tag{52}$$

Considering the structural aspect of the vehicle, the transmission ratio of the powertrain system is nearly equal to the product of the transmission ratios of the individual components within the powertrain, consistent with the chosen model. However, based on the hypothesis in **Chapter 3**, we will select the transmission ratios for the differential and the gearbox.

$$n = n_d * n_g = 9.0 * 1.1 = 9.9$$

Where

n_d: the ratio of differential

n_g: the ratio of gearbox

Thus, each component of the powertrain system has characteristic parameters: a transmission ratio n and an efficiency η. These components serve to amplify or reduce the torque T and the angular velocity ω. Therefore, the torque T_w and angular velocity ω_w applied to the wheels will be calculated as follows:

$$T_w = \frac{T_e * n * \eta}{n_w} = \frac{T_e * n * \eta}{n_w} \tag{53}$$

Where

n_w: the number of driven wheel

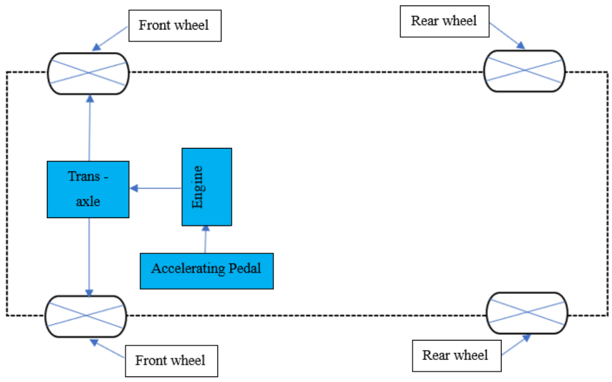

Figure 11: The driveline of FWD vehicle

From the general dynamics equation above, we need to determine the equation for the acceleration from the moment equation of the wheel to the equation of vehicle body. This is FWD vehicle so the moment equation of the driven and non – driven wheel is different.

	Driven wheel	Non – driven wheel
Accelerating	$T_w - (T_{rr} + T_x) = J\frac{d\omega}{dt}$ (54) $\frac{T_x}{r_w} = \frac{T_w}{r_w} - \frac{T_{rr}}{r_w} - J\frac{d\omega}{dt * r_w}$	$-(T_{rr} + T_x) = J\frac{d\omega}{dt}$ (55) $\frac{T_x}{r_w} = -\frac{T_{rr}}{r_w} - J\frac{d\omega}{dt * r_w}$

Table 7: Wheel Equation of Acceleration

These equation represent for each wheel so, if you need to calculate according to the vehicle body equation you need to total these equation.

The force equation of vehicle body:

$$\sum F_x - F_{aero} = m\frac{dv}{dt} \quad (56)$$

The general equation for acceleration according to the force equation of vehicle body is:

The process	The accelerating equation
Acceleration	$\sum\frac{T_w}{r_w} - \sum\frac{T_{rr}}{r_w} - \sum J\frac{d\omega}{dt * r_w} - F_{aero} = m\frac{dv}{dt}$ (57)

Table 8: General Equation of Acceleration

After that, you need to calculate the power of the engine to overcome the losses component to generarate the actual power of vehicle. However, the accelerating equation is determine from the equation of the vehicle, you need to calculate the power at engine. It means you need to calculate the power of frictional transmission to the balancing power equation.

The balancing power equation of acceleration.

$$P_e = P_{vehicle\ inertia} + P_j + P_{frictrans} + P_{rr} + P_{aero} \tag{58}$$

Finally, we determine the energy of vehicle in acceleration.

$$A_e = A_{vehicle\ inertia} + A_j + A_{aero} + A_{rr} + A_{frictrans} \tag{59}$$

Similarly the Power, the energy of wheel inertia is a part of the kinetic energy

3.3.2. The Deceleration

The braking system will play the primary role in decelerating the vehicle. When wanting to reduce speed, the driver has two options: reducing pressure on the accelerator pedal, whereby the inertia of the rotating components and friction within them will slow the vehicle down; the other option is to completely release the accelerator pedal and depress the brake pedal. At this point, the master cylinder will convert the pedal force into hydraulic pressure, which is transmitted to the brake force regulator valve and then to the wheel cylinders. This creates a force that presses the brake pads against the rotor, generating a negative torque that opposes the rotation of the wheels. Simultaneously, the inertia and friction of the powertrain system will also contribute to the deceleration of the vehicle. Therefore, we will consider the more general case of deceleration by releasing the accelerator pedal and applying the brake pedal.

To simplify the simulation model, we will consider the master cylinder, brake booster, and brake force regulator valve as a single brake actuator unit. When the driver applies force to the brake pedal, this unit will amplify the braking force and distribute it equally to the braking mechanisms of all four wheels. The brake mechanism assembly at each wheel, consisting of the wheel cylinder, brake pads, and rotor, will be treated as a single unit. This unit receives the braking force as input and converts it into a negative torque T_b applied to the wheel.

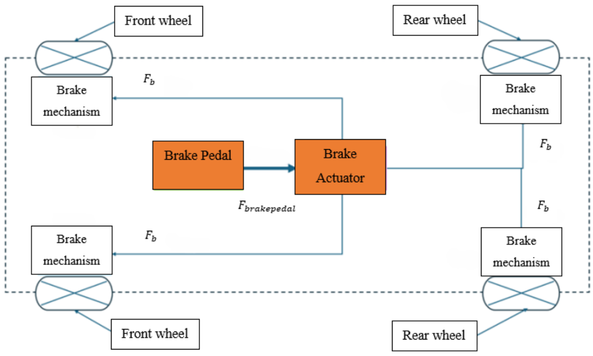

Figure 12: The structure of brake mechanism

Using Pascal's law, we can determine the force at the brake actuator mechanism

$$\frac{F_{brakepedal}}{A_{master\ cylinder}} = \frac{F_{brake\ actuator}}{A_{brake\ actuator}} \tag{60}$$

Where

$F_{brakepedal}$: the force at brake pedal (N)

$F_{brake\ actuator}$: the force is formed by force' brake pedal according to the principle of Pascal (N)

$A_{master\ cylinder}$: the area of master cylinder (mm^2)

$A_{brake\ actuator}$: the area of brake actuator cylinder (mm^2)

The braking force generated at each brake assembly has been determined in the equation above.

In this study, we will choose two disc brakes for the front wheels and two double — shoe brakes for the rear wheels, consistent with the actual configuration of the Mitsubishi Xpander 2020 model.

The disce brake [5]

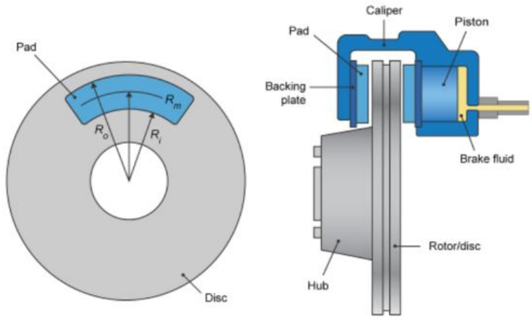

Figure 13: The disc brake

A disc brake converts brake cylinder pressure from the brake cylinder into force. The disc brake applies the force at the brake pad mean radius.

The equation that the block uses to calculate brake torque, depends on the wheel speed, ω

$$T_{bfront} = \frac{\mu_s P \pi D_b^2 R_m N}{4} \tag{61}$$

$$R_m = \frac{R_o + R_i}{2} \tag{62}$$

Where:

T_{bfront}: is the brake torque of front wheel.

P: the applied brake pressure.

ω: the wheel speed.

N: the number of brake pads in disc brake assembly.

μ_s: the disc pad-rotor coefficient of static friction.

D_b; the brake actuator bore diameter.

R_m: the mean radius of brake pad force application on brake rotor.

R_o: the outer radius of brake pad.

R_i: the inner radius of brake pad.

The double – shoe brake [6]

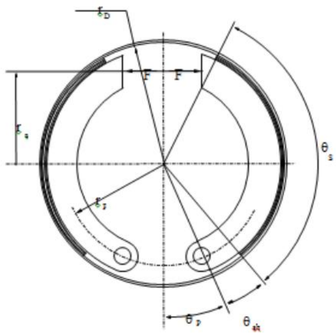

Figure 14: The double - shoe brake

a positive actuation force *F* brings the shoe and drum friction surfaces into contact. The result is a friction torque that causes deceleration of the rotating drum

The model uses the long-shoe approximation. The equations for the friction torque that the leading and trailing shoes develop are:

$$T_{LS} = \frac{c\mu p_a r_D^2 (cos\theta_{sb} - cos\theta_s)}{sin\theta_a} \tag{63}$$

$$T_{TS} = \frac{c\mu p_b r_D^2 (cos\theta_{sb} - cos\theta_s)}{sin\theta_a} \tag{64}$$

Where:

T_{LS}: the brake torque the leading shoe develops.

T_{TS}: the brake torque the trailing shoe develops.

μ: the effective contact friction coefficient.

p_a: the maximum linear pressure in the leading shoe-drum contact.

p_b: the maximum linear pressure in the trailing shoe-drum contact.

r_D: the drum radius.

θ_{sb}: the shoe beginning angle.

For $o \leq \theta_s \leq \frac{\pi}{2} \rightarrow \theta_a = \theta_s$

$\theta_s \geq \frac{\pi}{2} \rightarrow \theta_a = \frac{\pi}{2}$

θ_s: the shoe span angle.

θ_a: the angle from hinge pin to maximum pressure point.

c: the arm length of the cylinder force with respect to the hinge pin.

The net braking torque is

$$T = T_{LS} + T_{TS} + \mu_{visc} * \omega_{shaft} \quad (65)$$

Where:

μ_{visc}: the viscous friction coefficient.

From the general dynamics equation above, we need to determine the equation for the deceleration from the moment equation of the wheel to the equation of vehicle body. This is FWD vehicle so the moment equation of the driven and non – driven wheel is same in this situation.

	Driven wheel	Non – driven wheel
Decelerating	$-(T_b + T_{rr} + T_x) = J\frac{d\omega}{dt} \quad (66)$ $\frac{T_x}{r_w} = -\frac{T_b}{r_w} - \frac{T_{rr}}{r_w} - J\frac{d\omega}{dt * r_w}$	$-(T_b + T_{rr} + T_x) = J\frac{d\omega}{dt} \quad (67)$ $\frac{T_x}{r_w} = -\frac{T_b}{r_w} - \frac{T_{rr}}{r_w} - J\frac{d\omega}{dt * r_w}$

Table 9: Wheel Equation of Deceleration

These equation represent for each wheel so, if you need to calculate according to the vehicle body equation you need to total these equation.

The force equation of vehicle body

$$\sum F_x - F_{aero} = m\frac{dv}{dt} \quad (68)$$

The general equation for both situation accordign to the force equation of vehicle body is:

The process	The accelerating equation
Dccelerating	$\sum\frac{T_b}{r_w} - \sum\frac{T_{rr}}{r_w} - \sum J\frac{d\omega}{dt * r_w} - F_{aero} = m\frac{dv}{dt} \quad (69)$

Table 10: General Equation of Deceleration

After that, you need to calculate the actual power (consisting of the power of wheel inertia) However, the decelerating equation is determine from the equation of the vehicle, in this situation the power of the engine would be negative due to the power of brake, and the frictional transmission power in this situation is taken into account – the engien brake

The balancing power equation of deceleration.

$$P_{brake} = P_{vehicle\ inertia} + P_j + P_{rr} + P_{aero} + P_{frictrans} \quad (70)$$

Finally, we determine the energy of vehicle in deceleration.

$$A_{vehicle\ inertia} + A_j = A_{brake} + A_{rr} + A_{aero} + A_{frictrans} \quad (71)$$

3.3.3. The Drive Cycle

3.3.3.1 Definition

A drive cycle is a standardized sequence of vehicle speed and time used to assess the performance of vehicles under various driving conditions. It essentially represents a typical pattern of acceleration, deceleration, cruising, and idling that a vehicle might experience in real-world use.

3.3.3.2 Applications of Drive Cycles:

Powertrain Development and Calibration: Automotive engineers use drive cycles to simulate real-world loads on the engine, transmission, and other powertrain components during development and calibration.

Hybrid and Electric Vehicle Testing: Drive cycles are essential for evaluating the energy consumption, range, and regenerative braking capabilities of electric and hybrid vehicles.

Development of Driving Style Recognition Systems: Some research uses drive cycle data to develop systems that can identify different driving styles for applications in hybrid vehicle control and driver assistance

3.3.3.3 well-known drive cycles

NEDC (New European Driving Cycle): An older European cycle often used for emissions and fuel economy testing.

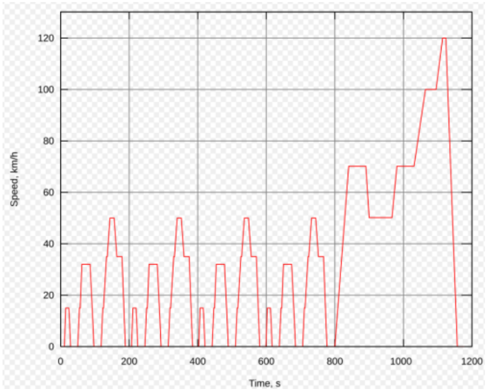

Figure 15: The NEDC drive cycle

FTP-75 (Federal Test Procedure 75): A US EPA cycle representing urban driving conditions. The entire FTP-75 cycle consists of the following segments:

1. Cold start transient phase (ambient temperature 20-30°C), 0-505 s,
2. Stabilized phase, 506-1372 s,
3. Hot soak (min 540 s, max 660 s),
4. Hot start transient phase, 0-505 s.

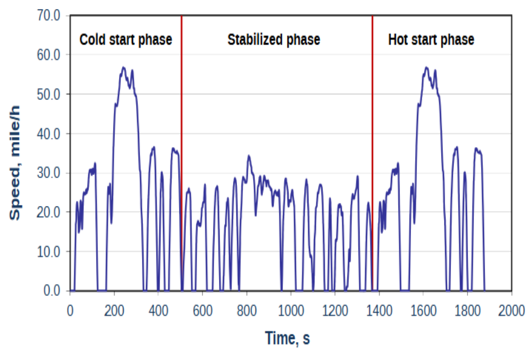

Figure 16: FTP-75 drive cycle

JP 1015 (Japanese 10-15 Mode): The 10-15 mode cycle had been used in Japan for emissions and fuel economy testing for light duty vehicles. Over the period of 2008-201. The 10-15 Mode test is derived from the 10-mode cycle by adding another 15-mode segment of a maximum speed of 70 km/h

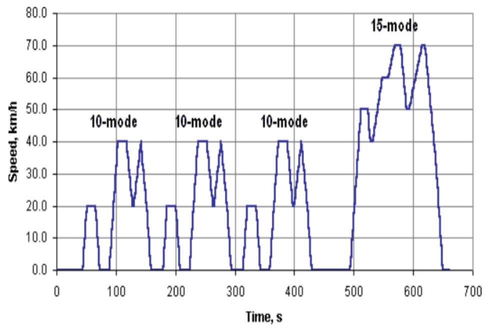

Figure 17: JP1015 drive cycle

In this Report, FTP – 75, NEDC, JP1015 is chosen for simulating to determine the losses energy during the process

3.4.Simulink Method

3.4.1. The purpose of simulation

The vehicle is modelled in Matlab/Simulink and I base on the feature of Simscape Block in Driveline library to determine some parameters over time such as acceleration/deceleration, velocity, power, energy, torque. Through these outcomes according to each working condition, I can determine the accuracy of model in Matlab/Simulink as well as the assessment of vehicle performance.

3.4.2. The theoritical basis of Matlab/Simulink (Simscape block)

To build a model, we start Matlab and initialize Simulink, open the Simulink library browser, and then select the appropriate groups. The Simulink library typically has 8 groups:

- Continuous and Discrete: contains basic blocks for processing continuous and discrete signals;
- Function & Tables: contains blocks for calling functions from Matlab, interpolation blocks, and transfer function blocks;
- Math Operations: contains blocks that implement mathematical functions;
- Nonlinear: contains nonlinear blocks;
- Signals & Systems: contains signal processing tool blocks;
- Sinks: contains blocks that perform output functions;
- Sources: contains signal generation blocks.

To copy a block from the library to the model window, select the block, click and drag the selected block, and then drop it into the model window. Within the model window, if you want to copy a block, press the Ctrl key and drag the block to the desired location for the copy; if you want to delete a block, select it and press the Delete key. To perform a simulation process, we proceed with the following steps: build the simulation model; set the values of the model parameters and initial conditions; choose the method for outputting the results; and control the execution of the simulation process.

3.4.3. The assumption and the definition of each Simscape block in Model

3.4.3.1 The assumption

According to the supplied Simscape block in Matlab/Simulink, I ignore the grading ability and the towing force of the vehicle, because these components do not support determine the purpose of the report

The inertia of the engine component is negligible.

The total efficiency of differential and gearbox is 0.95.

The gearbox ratio is 1.1.

The ratio of differential is 9.0.

The viscous friction in the engine component as well as brake mechanism is negligible.

The specify stiffness and damping of wheel is negligible.

3.4.3.2 The definition of Simscape Block in this model

We need clearly understand the characteristics of each Simscape block to build the accurate model and determine the desired parameters through the connection between many blocks.

In general, I considered the mechanical components that the engine creates. Therefore, the simulation model is only derived from the engine.

- Engine block: Choosing Ideal Torque Source block

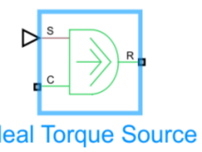

Figure 18: Ideal Torque Source

This block consist of 3-port:

- Port S: Physical signal input port, through which the control signal that drives the source is applied.
- Port R: Mechanical rotational conserving port associated with the source moving part (rod).

– Port C: Mechanical rotational conserving port associated with the source reference point (case).

  - Mechanical Rotational Reference to connect with this port.

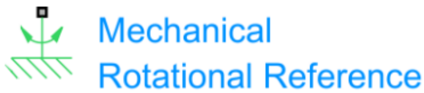

Figure 19: Mechanical Rotational Reference

  - Reduce block: Choosing Simple Gear block

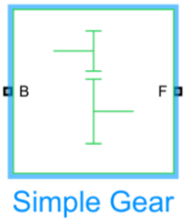

Figure 20: Simple Gear

This block has 2-port:

– B port: (Mechanical rotational conserving port associated with the base shaft) This port represents for the driving gear, connected to the S port of the Ideal Torque Source block and receiving the torque signal from this block.

– F port: (Mechanical rotational conserving port associated with the follower shaft) This port represents for the driven gear, the torque signal was calculated with the specified parameters of this block such as efficiency η_g and transmission ratio i_g.

  - Differential block: choosing differential block

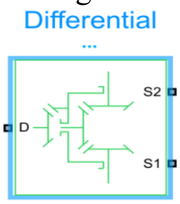

Figure 21: Differential

This figure has 3-port:

– D port (driveshaft): Rotational mechanical conserving port associated with the longitudinal driveshaft. This block represents for pinion gear, connected to the F port of the Simple gear block and receiving the torque signal of this block. The torque was calculated with the specified parameters of the differential such as efficiency η_d and the ratio transmission i_d then transmitted to 2-wheel through S1 and S2 port.

- S1 port (Sun gear 1): Rotational conserving port associated with sun gear 1.
- S2 port (Sun gear 2): Rotational conserving port associated with sun gear 2.
  - Tire blocks: choosing Tire (Magic Formula) block

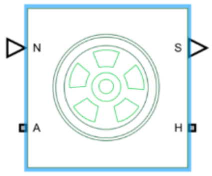

Figure 22: Tire (Magic Formula)

This block has 4-port:

- A port (Mechanical rotational port associated with the axle that the tire sits on): this block connects to the S1 and S2 ports of the differential blocks, and receiving the torque to be propulsive the vehicle forward.
- H port (Mechanical translational port associated with the wheel hub that transmits the thrust generated by the tire to the remainder of the vehicle): this block represents for axle, connected to the H port of the Vehicle Body block
- N port: Physical signal input port associated with the normal force acting on the tire, in N. The normal force is positive if it acts downward on the tire, pressing it against the pavement.
- S port: Physical signal output port associated with the relative slip, k, between the tire and road.

In addition, the wheel blocks also have an accompanying brake block, choosing the brake block as the

- Double-Shoe Brake Block for rear axle.

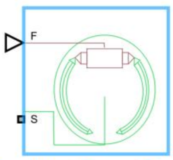

Figure 23: Double-Shoe Brake in Simulink

This block consists of 2-port:

– F port (Physical signal input port associated with the applied actuating force): this port receives physical signal to create negative torque which decelerated the motion of wheel through S port

– S port (Rotational conserving port associated with the rotating drum shaft): this port creates braking torque signal, connected to the A port of the Tire block to interfere with the amount of torque transmitted to the wheel and decelerate the vehicle’s speed.

Besides, the wheel blocks also have an accompanying brake block, choosing the brake block as

- The Disc Brake Block for front axle:

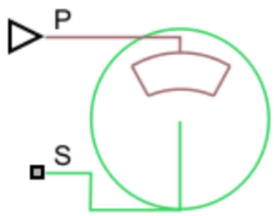

Figure 24: Disc Brake in Simulink

This block consists of 2-port:

– P port (Physical signal port associated with cylinder pressure, in bars): this port represent the cylinder pressure. Positive pressure creates friction torque that resists shaft rotation.

– S port (Rotational mechanical conserving port associated with the shaft): this port creates braking torque signal, connected to the A port of the Tire block to interfere with the amount of torque transmitted to the wheel and decelerate the vehicle’s speed.

- Ideal Sensor Torque:

represents a device that converts a variable passing through the sensor into a control signal proportional to the torque. The sensor is ideal because it does not account for inertia, friction, delays, energy consumption, and so on.

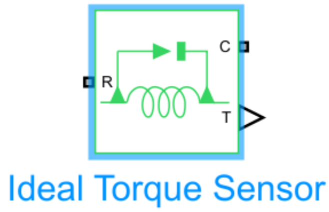

Figure 25: Ideal Torque Sensor

Connection T is a physical signal port that outputs the measurement result. The block positive direction is from port R to port C. This means that positive torque applied to port R (the sensor positive probe) generates a positive output signal.

This block consists of 3 – port:

- R port (Rotational mechanical conserving port associated with the sensor positive probe.
- C port (Mechanical rotational conserving port associated with the sensor negative (reference) probe.)
- R port (Nm): Physical signal output port for torque.
  - Ideal Rotational Motion Block:

This block measures angular velocity or angle in a mechanical rotational network. The sensor is ideal since it does not account for inertia, friction, delays, energy consumption, and so on.

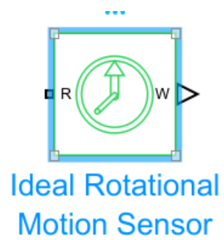

Figure 26: Ideal Rotational Motion Sensor

This block consist of 2 – port:

- R port (Mechanical rotational conserving port associated with the sensor positive probe.)
- W port (Angular velocity, rad/s): Physical signal output port for angular velocity.
  - Ideal Force Sensor:

The block represents an ideal force sensor, that is, a device that converts a variable passing through the sensor into a control signal proportional to the force with a specified coefficient of proportionality. The sensor is ideal since it does not account for inertia, friction, delays, energy consumption, and so on.

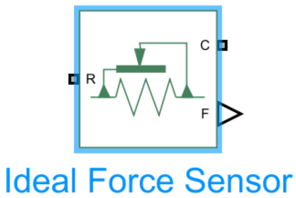

Figure 27: Ideal Force Sensor

This sensor is connected between H port of tire and vehicle body

This block consists of 3 – port:

- R port (Mechanical translational conserving port associated with the sensor positive probe.)
- C port (Mechanical translational conserving port associated with the sensor negative (reference) probe.)
- F port (Force, N): Physical signal output port for force.
    - Vehicle body block: choosing Vehicle Body Block

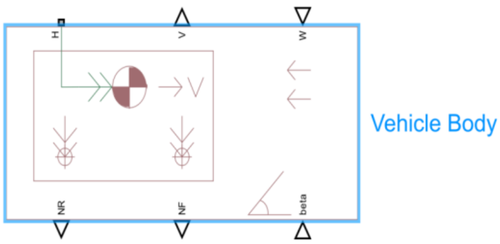

Figure 28: Vehicle Body

This block consists 6-port:

- H port: Conserving port associated with the horizontal motion of the vehicle body. Connect tire traction motion to this port. This port connect to the H port of the tire blocks
- V port (m/s – scalar): Physical signal output port for vehicle longitudinal velocity in the vehicle reference frame.

– NF and NR port (N – scalar): Physical signal output port for normal force on the front and rear axle, respectively. Wheel forces are considered positive if acting downwards.
– W port (m/s): Physical signal input port for headwind speed.
– Beta port (rad): Physical signal input port for road incline angle.

- Signal Editor block:

The Signal Editor block displays, creates, and edits interchangeable scenarios, which contain signals. This block creates the torque signal for Ideal Torque Source block.

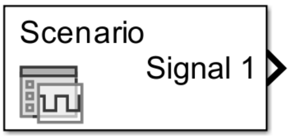

Figure 29: Signal Editor

- The Step block: this block creates braked torque signal for braking

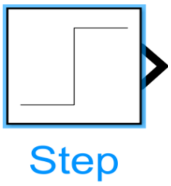

Figure 30: Step

- The Scope block: This block used to display simulation graphs over time.

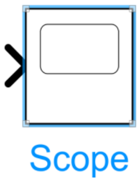

Figure 31: Scope

- Solver Configuration block: this block is used to calculate the model

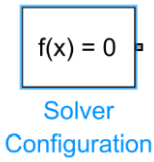

Figure 32: Solver Configuration

- Simulink – PS Converter block: this block converts the simulink signal to the physical signal.

Figure 33: Simulink - PS Converter

- PS – Simulink Converter block: this block converts the physical signal to the simulink signal

Figure 34: PS - Simulink Coverter

Besides, Matlab/Simulink supply for the user some calculating blocks. In this model, I used some available calculating blocks consisting of:

- The Derivative block:

Approximates the continuous derivative of the continuous input signal u with respect to the simulation time t. Use the Derivative block when you need to compute the derivative for a differentiable signal that has continuous sample time

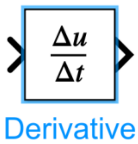

Figure 35: Derivative

- The Integrator block:

Integrates an input signal with respect to time and provides the result as an output signal.

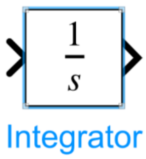

Figure 36: Integrator

- Longitudinal Driver Block:

The Longitudinal Driver block implements a longitudinal speed-tracking controller. Based on reference and feedback velocities, the block generates normalized acceleration and braking commands that can vary from 0 through 1. You can use the block to model the dynamic response of a driver or to generate the commands necessary to track a longitudinal drive cycle.

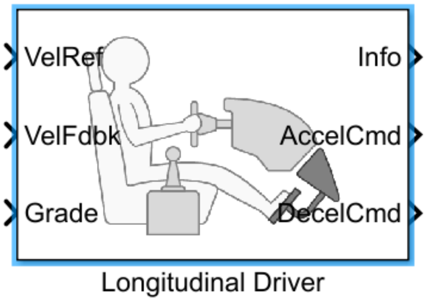

Figure 37: Longitudinal Driver

This block consists of 6 – port:

- Reference vehicle velocity port (m/s): reference velocity
- Longitudinal velocity feedback port (m/s): Longitudinal vehicle velocity, U, in the vehicle-fixed frame
- Road Grade Angle port $(\deg)$: Road grade angle, θ or γ.
- Info – bus signal port: Bus signal containing these block calculations.
- Commanded vehicle acceleration port: Commanded vehicle acceleration, y_{acc}, normalized from 0 through 1.
- Commanded vehicle deceleration port: Commanded vehicle deceleration, y_{dec}, normalized from 0 through 1.

The Longitudinal Driver block simulates the driver's ability to control the vehicle in situations such as: accelerating (pressing the accelerator) when the current speed is lower than the set speed, and braking (decelerating) when the current speed is higher than the set speed. The block consists of two main components:

- Controller: This component uses control algorithms (PID or linear control) to reduce the error between the current speed (VelFdbk) and the reference speed (VelRef).
- Output: This component generates the acceleration control signal (AccelCmd) and the deceleration control signal (DecelCmd).

There are 3 pre-built control algorithm types available within the block: PI, Scheduled PI, and Predictive.

The Proportional-Integral (PI) control type is commonly employed in control systems to enhance performance and stability. PI control comprises two primary components: the Integral Component, which addresses long-term errors by accumulating error over time, and the Proportional Component, which manages short-term errors based on the present error. Its advantages include simplicity and ease of implementation, effectiveness in systems exhibiting relatively stable responses, and the ability to eliminate steady-state error. However, PI control can induce oscillations if the proportional gain (Kp) is excessively high, exhibits a slow response to rapid system changes, and presents challenges in optimization across diverse operating conditions.

The Scheduled PI (Programmed PI Controller) control type is well-suited for complex systems with diverse operating conditions because it utilizes multiple PI controllers, each with different parameters, and switches between these controllers based on the system's operating conditions. Its advantages include optimized performance across varying operating conditions, improved stability and faster response compared to a single PI controller, and greater flexibility and adjustability for intricate systems. However, it is more complex and requires detailed configuration, necessitates the definition and tuning of switching points between controllers, can be time-consuming to implement, and demands a thorough understanding of the system to establish logical switching conditions.

Predictive Control utilizes a mathematical model of the system to forecast future states and make adjustments based on these predictions. Its advantages include high performance in systems with complex dynamics and precise control requirements, the ability to anticipate and proactively adjust to changes in operating conditions, and suitability for applications demanding accurate and rapid control, such as autonomous driving systems and obstacle avoidance. However, it is more complex and computationally intensive, requires accurate information about the system model and driving conditions to operate effectively, and can be costly in terms of computation and system resources. Given that it is the highest-performing control type, yielding accurate and rapid results, this research will select Predictive Control for the driver block.

3.4.4. Parameterizing the model

- **Vehicle Body**

According to the specification of Mitsubishi Xpander 2020, and other parameters collecting from many documents. We will parameterize for vehicle body in Matlab model

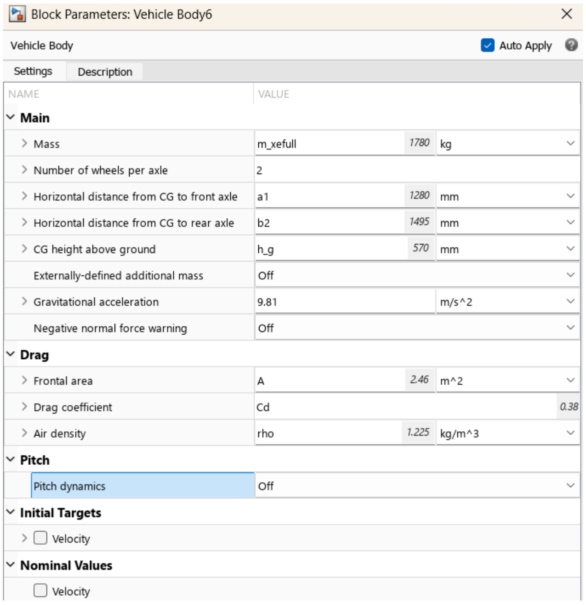

Figure 38: Parameterizing Vehicle Body

- **Driveline Components**

According to the hythesis and assumption above, we will parameterize for Simple Gear and Differential in Matlab model

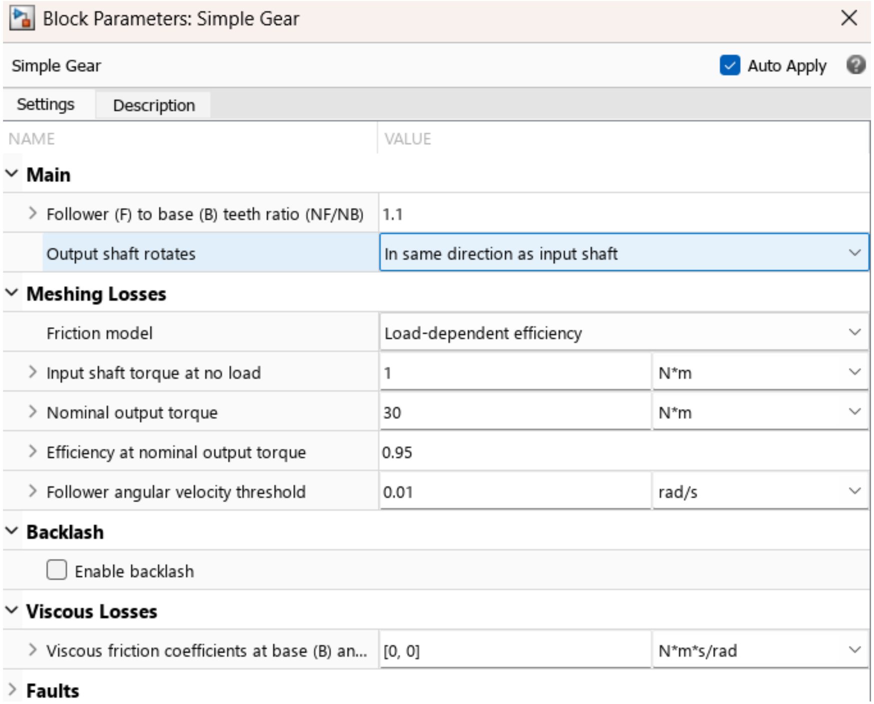

Figure 39: Parameterizing Simple Gear

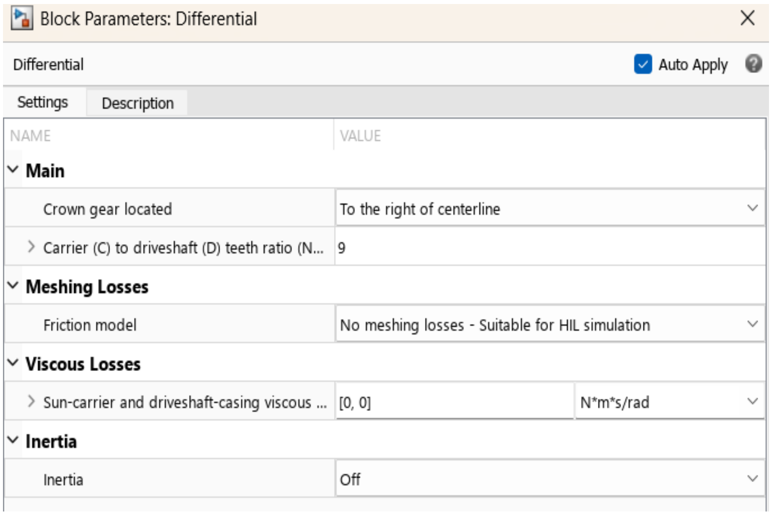

Figure 40: Parameterizing Differential

We just parameterize meshing losses for simple gear because we assume the simple gear and differential being a transaxle

- **Tire and Brake Mechanism**

– Tire: According to the specification, hythesis and assumption above, we will parameterize for Tire (Magic Formula) in Matlab model.

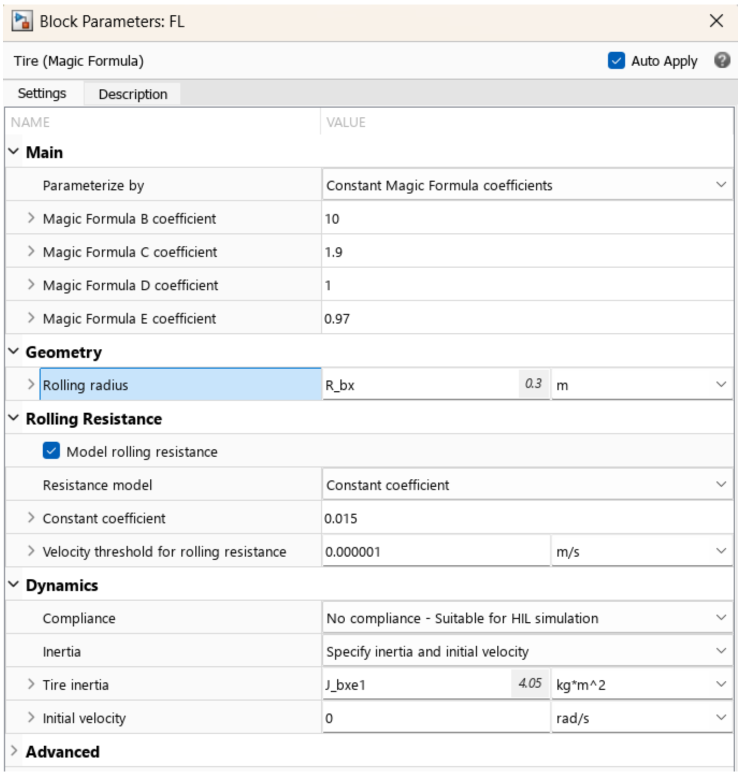

Figure 41: Parameterizing Tire (Magic Formula)

– Disc Brake: According to the specification, hythesis and assumption above, we will parameterize for Disc Brake in Matlab model.

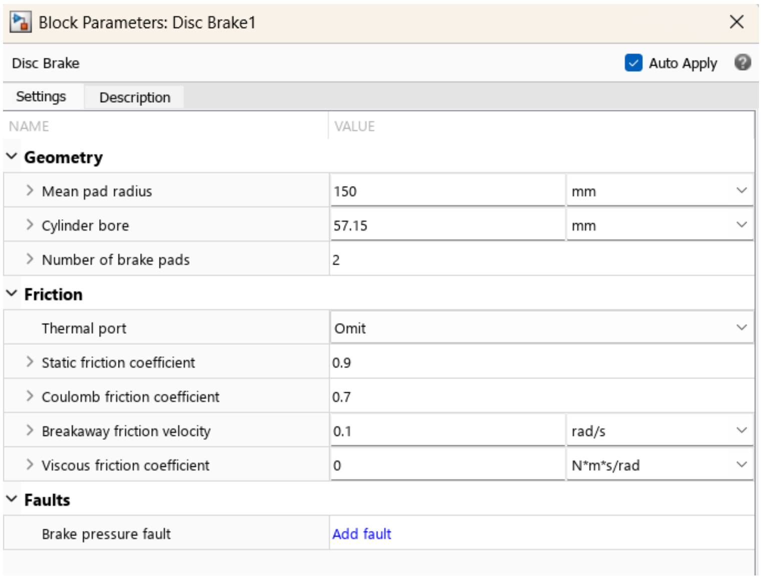

Figure 42: Parameterizing Disc Brake

– Double – shoe Brake: According to the specification, hythesis and assumption above, we will parameterize for Disc Brake in Matlab model.

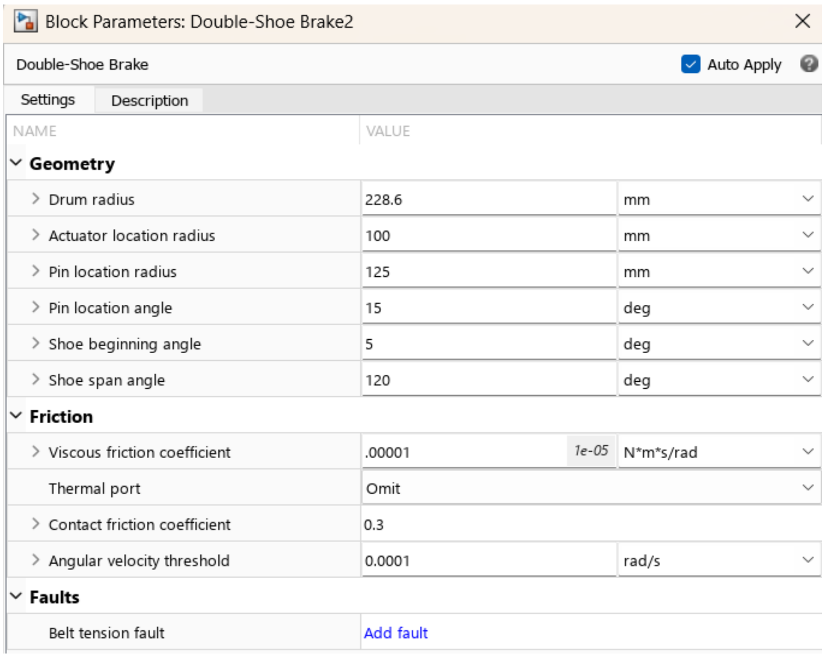

Figure 43: Parameterizing Double - Shoe Brake

3.5.Control Signal and Simulating Method

3.5.1. Control Signal

According to the specification and calculation above, we can create the control signal for the model

- **Torque Signal**

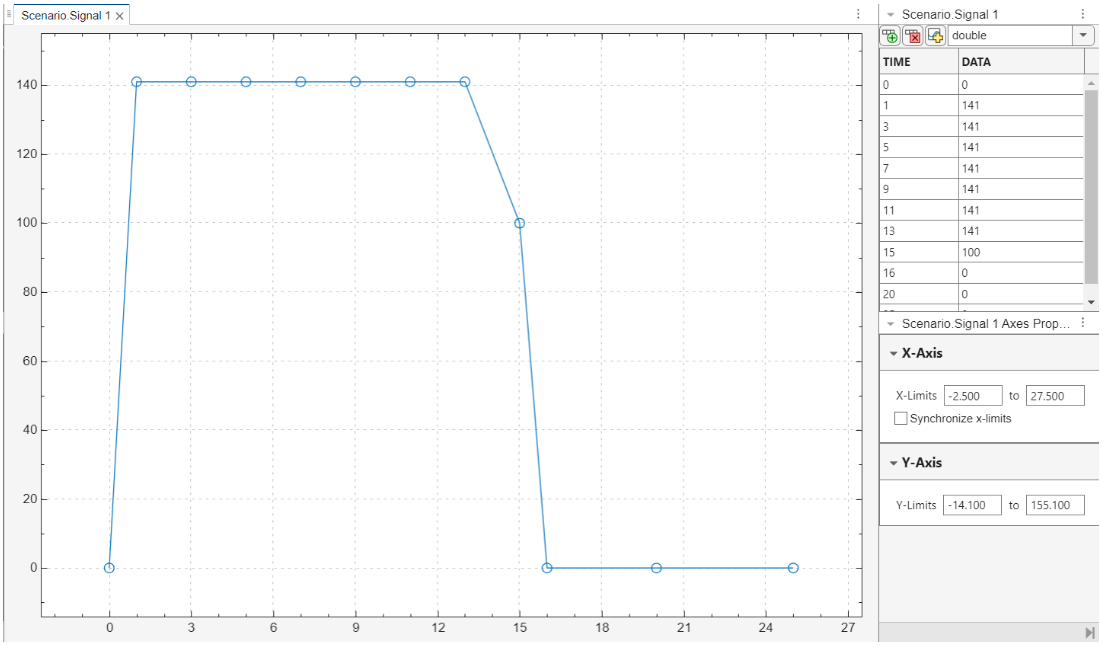

Figure 44: Torque Signal

In the figure above, I produce 141 Nm for the model from 1 second to 13 second then reducing to 100 Nm in 2 second. At 16st second, I stop produce Torque for the model and applying brake force for brake mechanism.

- **Brake Signal for Disc brake**

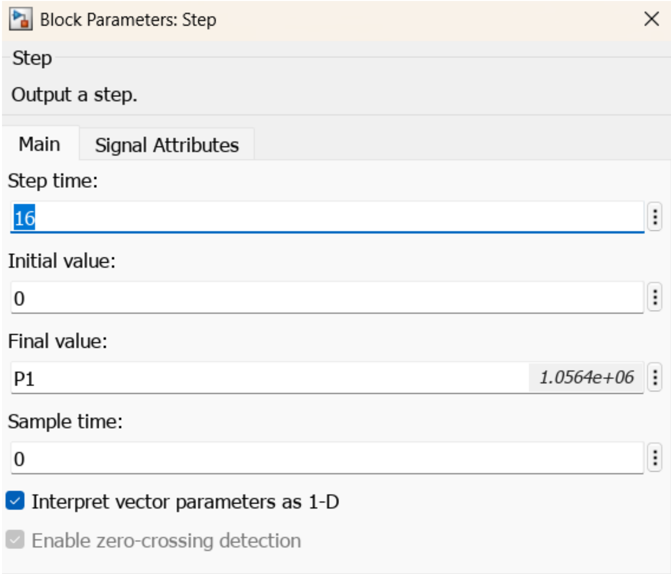

Figure 45: Brake Signal for Disc Brake

In the figure above, at 16st second, I produce the pressure which was calculated from brake force applied to brake mechanism. The brake force will be stop when the velocity of the vehicle will be equal zero.

- **Brake Signal for Double — shoe brake**

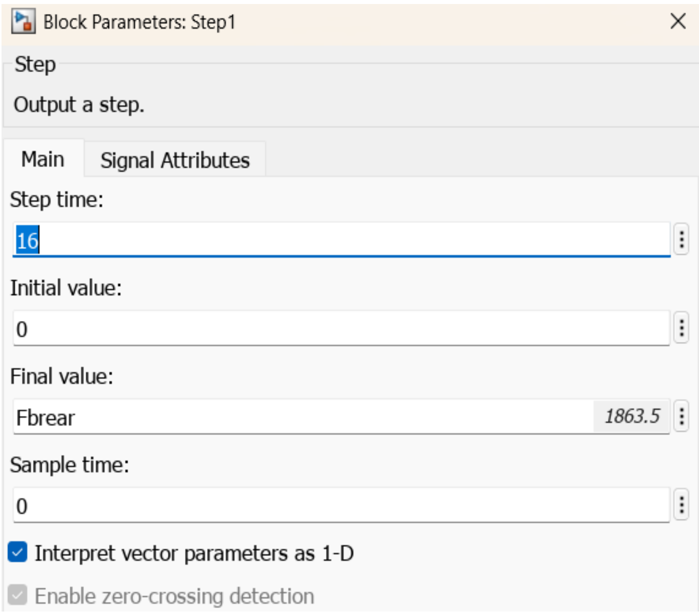

Figure 46: Brake Signal for Double-Shoe Brake

In the figure above, at 16st second, I produce the brake force applied to brake mechanism. The brake force will be stop when the velocity of the vehicle will be equal zero.

The signal when velocity equal zero the brake force will be stop produce to brake mechanism.

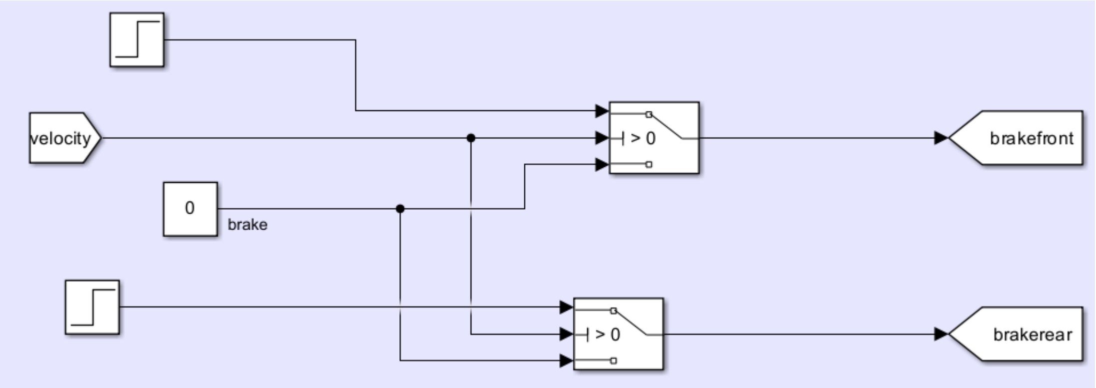

Figure 47: Signal for Brake Mechanism

Then, I will apply the knownledge when I study Automotive Computer – Controlled System Course to determine the control method which is suitable for the model.

- **There are two – type of control method:**

Open Loop Control: An open-loop control is a type of control system where the output of the system is not monitored or fed back to the controller to make adjustments. In simpler terms, the system operates based on a predetermined input, and it executes without knowing the actual result or if the desired outcome has been achieved.

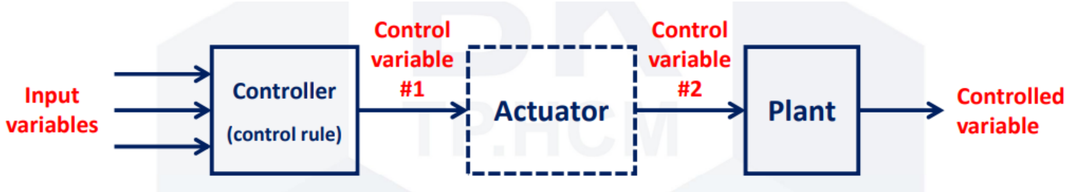

Figure 48: Open Loop Control [7]

A closed-loop control, also known as a feedback control system, is a type of control system where the output of the system is monitored and fed back to the controller to make necessary adjustments to the input. This feedback mechanism allows the system to automatically regulate itself and maintain the desired output, even in the presence of disturbances or changes in the system's characteristics.

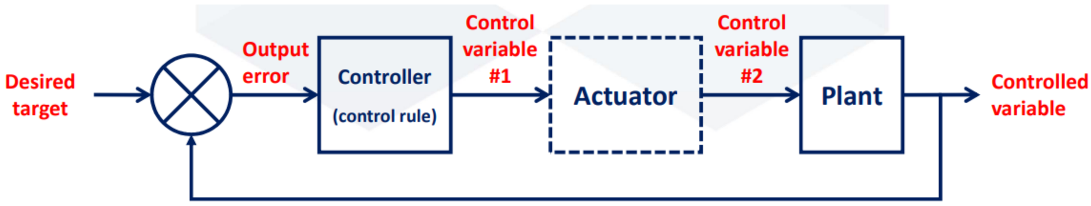

Figure 49: Close Loop Control ***[8]***

First of all, with these signals, the time to reach the 100 km/h, the standard for acceleration and deceleration when braking is determined in the previous project. After the test case, we will check the balancing about power and energy to check the operating mechanism of simulating model on Matlab/Simulink.

After determine the equation of vehicle dynamics we will simulate to determine the balance in the acclerating/decelerating process.

After checking the balancing of force, we will check the balance of for in both situation:

When Vehicle is accelerating:

$$P_{engine} = P_{rr} + P_{aero} + P_{wheel\ inertia(J)} + P_{vehicle\ inertia} + P_{frictrans} \quad (72)$$

$$A_{engine} = W_d + A_J + A_{rr} + A_{aero} + A_{frictrans} \quad (73)$$

When Vehicle is decelerating:

$$P_{wheel\ inertia(J)} + P_{vehicle\ inertia} = P_{brake} - P_{rr} - P_{aero} - P_{frictrans} \quad (74)$$

$$W_d + A_j = A_b + A_{rr} + A_{aero} + A_{frictrans} \quad (75)$$

In this case, we will change the configuration to fixed – step with auto solver and the fixed step size is 0.0001.

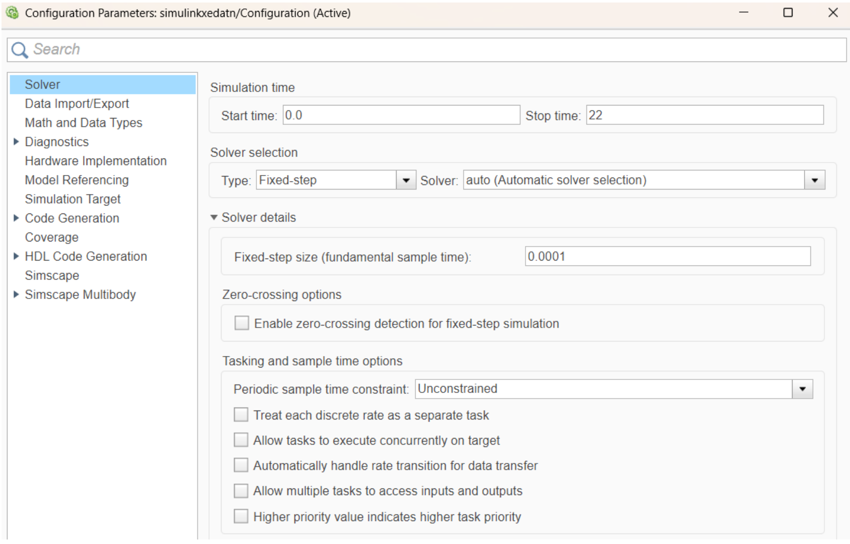

Figure 50: Configuration Parameters for acceleration/deceleration

When we ensure the energy of all component is balance, we move to next stage to check the energy of the vehicle running with respect to drive cycle.

Secondly, I will choose Close – loop control system combining with PI method to control the velocity of the simulating model. In addition, Using FTP – 75, NEDC, JP 1015 drive cycle is a input signal for the close – loop system. Then I will obtain the velocity according to this drive cycle.

The signal when velocity equal zero the brake force will be stop produce to brake mechanism.

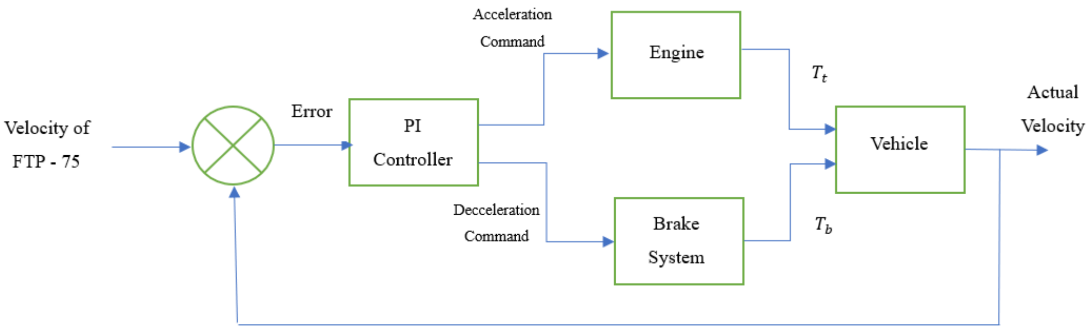

Figure 51: Control Path

After the model operating according to these drive cycle processes, we will determine each energy losses, engine energy, brake energy as well as each power components with respect to time. We will analyze the energy take account into the process.

In this case, we will change the configuration to fixed — step with auto solver and the fixed step size is 0.01. I choose the step size because the time to run drive cycle is very long and the computer cannot compile it if the step size is smaller than 0.01.

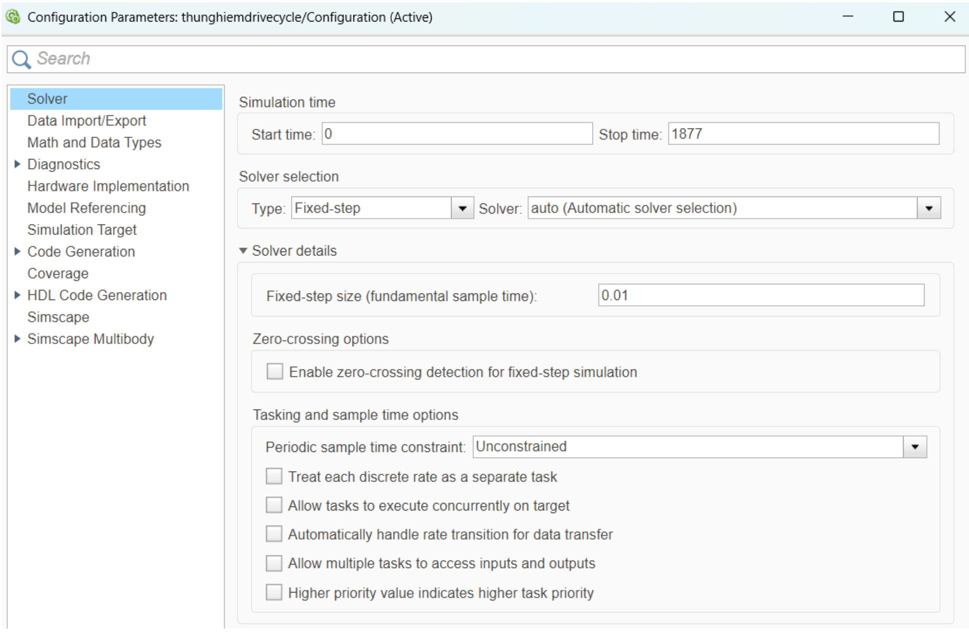

Figure 52: Configuration Parameters for Drive Cycle

3.6. Calculating Method and Data processing

3.6.1. Calculating Method

According to the object of the study, we need to analyze the longitudinal energy of the vehicle. In Matlab, we need to build the available tools to synthesize, compile, extract the information from many calculation.

To display the data which serve for this study, we use some available sensors in Matlab such as Ideal Torque Sensor, Ideal Force Sensor, Ideal Rotational Motion Sensor to measure the parameters during the simulating process. Then, Connecting it to Scope, throung PS – Simulink converter which is available in each unit. I used these sensors to serve to determine the energy which is produced to propel or the losses energy during the simulating process. In addition, each sensor has different connecting type. For example, if we need to measure the Torque or Force of driveline we need to connect Ideal Torque sensor and Ideal Force sensor in series; However, The Ideal Roational Motion sensor need to connect in parallel with driveline to measure the rotational motion. From these sensors, we can determine the Torque T, Force F, and rotational motion ω. From these data, we can determine the Power and then we integrating it with respect to time to determine the energy of each component

$$E = \int F * v \tag{76}$$

$$E = \int P * \omega \tag{77}$$

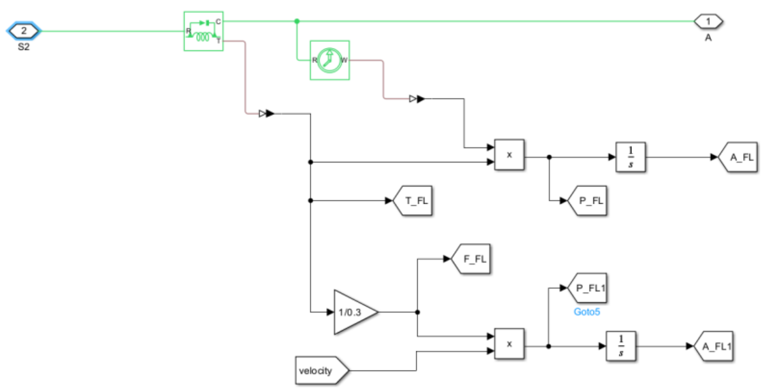

Figure 53: Processing Data

After set up these sensor in the driveline to measure the parameters, we use the available math operation in Matlab/Simulink to calculate the accelerating/decelerating, power, energy,… Besides, some parameters is supplied from the available block such as s $(slip\ ratio)$ from Tire (Magic Formula) Block, v $(velocity)$ and F_{zf} and F_{zr} $(Front\ and\ Rear\ Normal\ Force, respectively)$ from Vehicle Body Block

3.6.2. Processing and Anaylyzing Data

With all data we can determine from the available block in Matlab: Torque (T), Force (F), Rotational Motion (ω), Wheel Velocity (V_w), Vehicle Velocity (V), Slip ratio (s), Front and Rear Normal Force $(F_{zf}\ and\ F_{zr})$. This data is display respect to time. Howevers, The losses components like aerodynamics forces (F_{aero}), rolling resistance (F_{rr}),… we need to calculate these losses from formula and available data

- **Rolling resistance force**

The normal force of front and rear wheel (F_{zf} *and* F_{zr}) are determined from the NR and NF port of the vehicle. Due to, the rolling resistance is constant so we product each normal force with rolling resistance coefficience (C_{rr}). If you need to determine the normal force of the vehicle, you must double the F_{zf} *and* F_{zr}

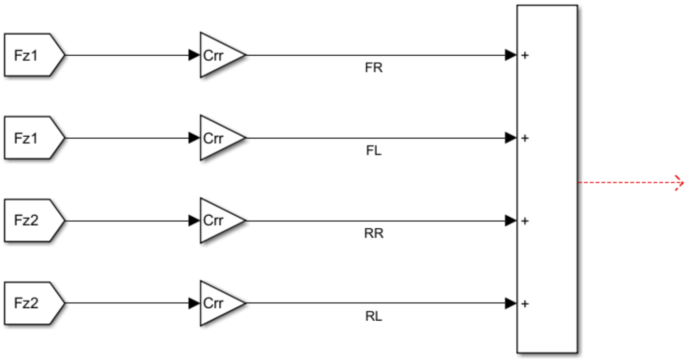

Figure 54: Rolling Resistance Force

After determining the Rolling Resistance Force of the vehicle, we need to product it with vehicle velocity (v) to determine a loss power and then integrating it with respect to time to determine a loss energy of Rolling Resistance

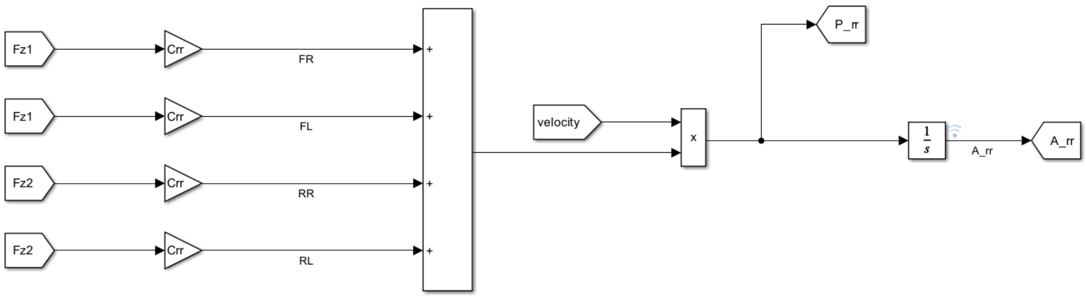

Figure 55: Rolling Resistance Energy

- **Aerodynamic Drag Force**

According to the formula of Aerodynamic Drag Force ($F_{aero} = \frac{1}{2} * C_d * \rho * A * v^2$), we will extract the velocity (v) from Vehicle Body Block and squaring it and gain it with available parameters to determing the Aerodynamic Drag Force (F_{aero})

After determining the Aerodynamic Drag Force of the vehicle, we need to product it with vehicle velocity (v) to determine a loss power and then integrating it with respect to time to determine a loss energy of Aerodynamics Drag

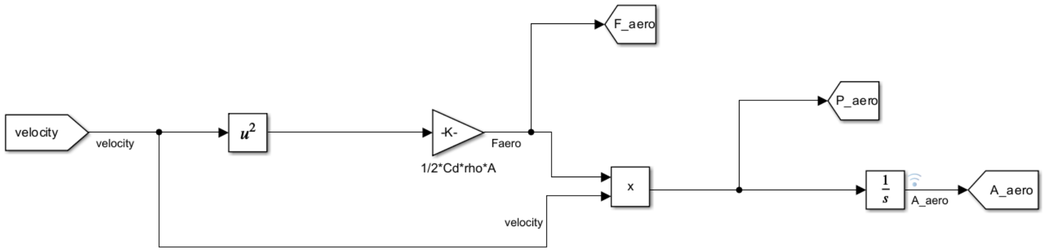

Figure 56: Aerodynamics Resistance Energy

- **The force of inertia wheel**

From the inertia moment of wheel is determine by: Firstly, we will measure the angular speed of the wheel by the Ideal Rotational Motion Sensor then we derivate it with respect to time to determine the angular acceleration.Secondly, We multiply it with the wheel inertia J_w. Finally, deviding it to the radius of wheel r_w to determine the Force of Wheel Inertia (F_J)

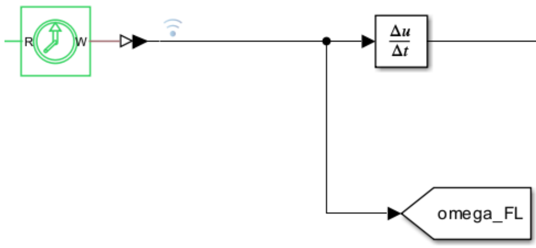

Figure 57: The Derivative of Angular Speed

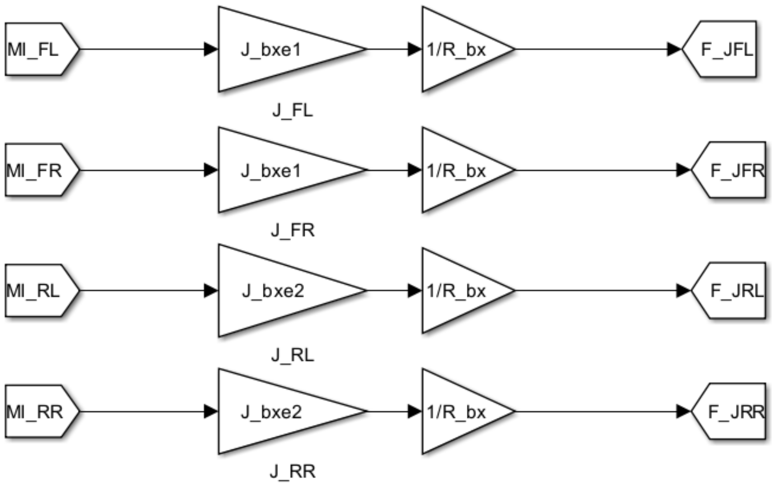

Figure 58: Wheel Inertia Force

After determining the Force of Wheel Inertia of the vehicle, we need to product it with vehicle velocity (v) to determine a power and then integrating it with respect to time to determine a energy of Wheel Inertia

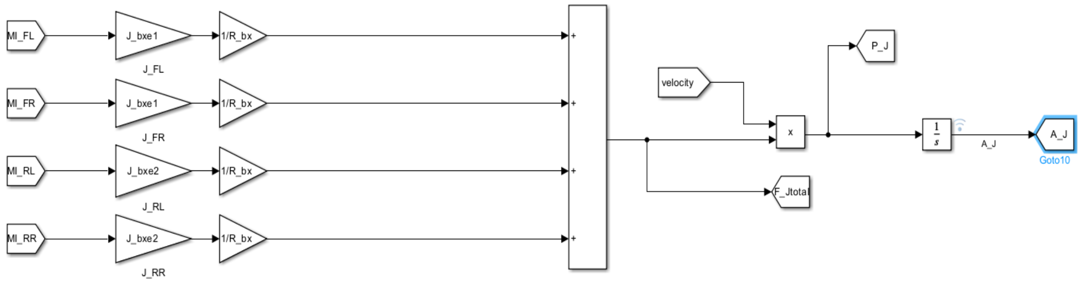

Figure 59: Wheel Inertia Energy

- **Brake Force**

We applied the force to the brake mechanism to produce the Brake Force, we measure the brake torque at the axle of the wheel by the Ideal Torque sensor. Then, dividing it with the radius of the wheel to determine the Brake Force

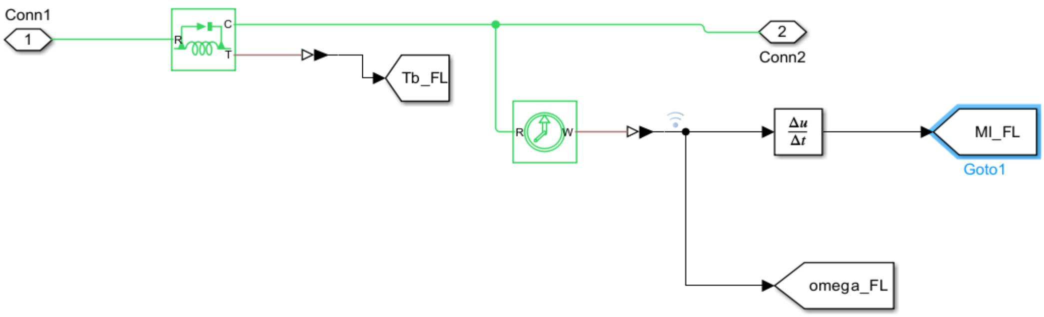

Figure 60: Brake Torque

After determining the Brake Force of the vehicle, we need to product it with vehicle velocity (v) to determine a loss power and then integrating it with respect to time to determine a energy of the Brake Force

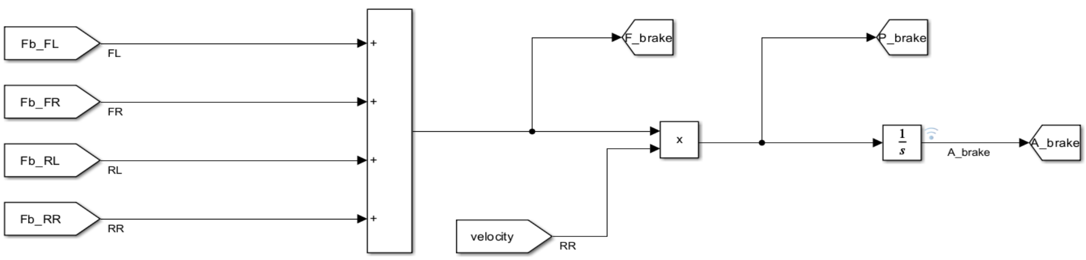

Figure 61: Braking Energy

- **Traction Force**

We measure the Tractive Torque at the axle of the wheel by the Ideal Torque sensor during the accelerating process. Then, dividing it with the radius of the wheel to determine the Tractive Force

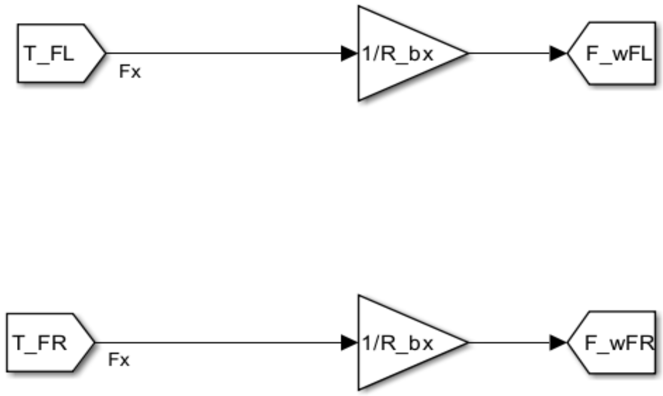

Figure 62: Tractive Force

After determining the Tractive Force of the vehicle, we need to product it with vehicle velocity (v) to determine a loss power and then integrating it with respect to time to determine a energy of the Tractive Force

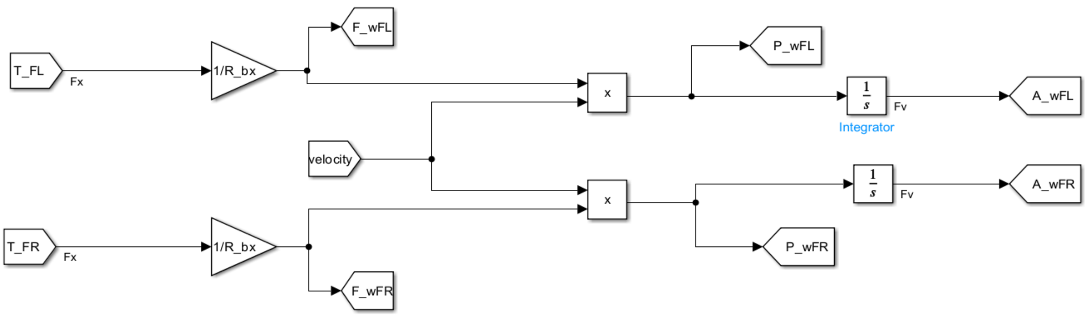

Figure 63: Tractive Energy

These components need to connect with scope to display the data with respect to time. You want to extrac these data to workspace,

3.6.3. Connecting these data to From Block.

In the connecting line, you need to choose Log Selected Signal.

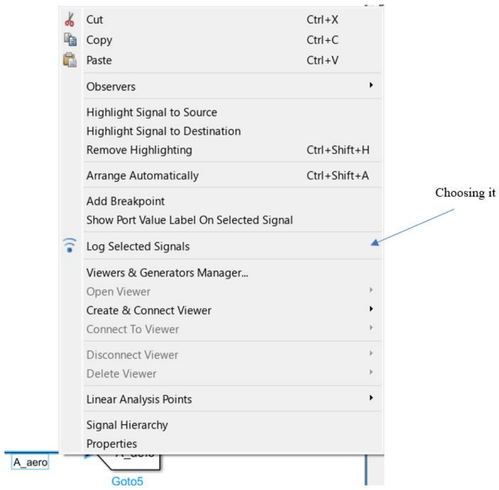

Figure 64: Extracting Signal

After the simulating process is done, the data which was Log Selected Signal, is saved to the file out at workspace.

We will call each component out and assign it to a variable as follows.

[variable name] = out.[variable name in file out]{the number of variable}.Values.Data;

Then use the plot function to draw the graph. Specifically, the code to draw the graphs used in this report will be presented in Appendix 1

3.7.Result and Determine

3.7.1. Simulating the model according to the simulation method.

3.7.1.1 Acceleration and Deceleration

3.7.1.1.1 The acceleration

In the first 16 second, the vehicle is in the accelerating process. We will see some essential data which will assist for next stage such as wheel speed, moment components, power components, energy components.

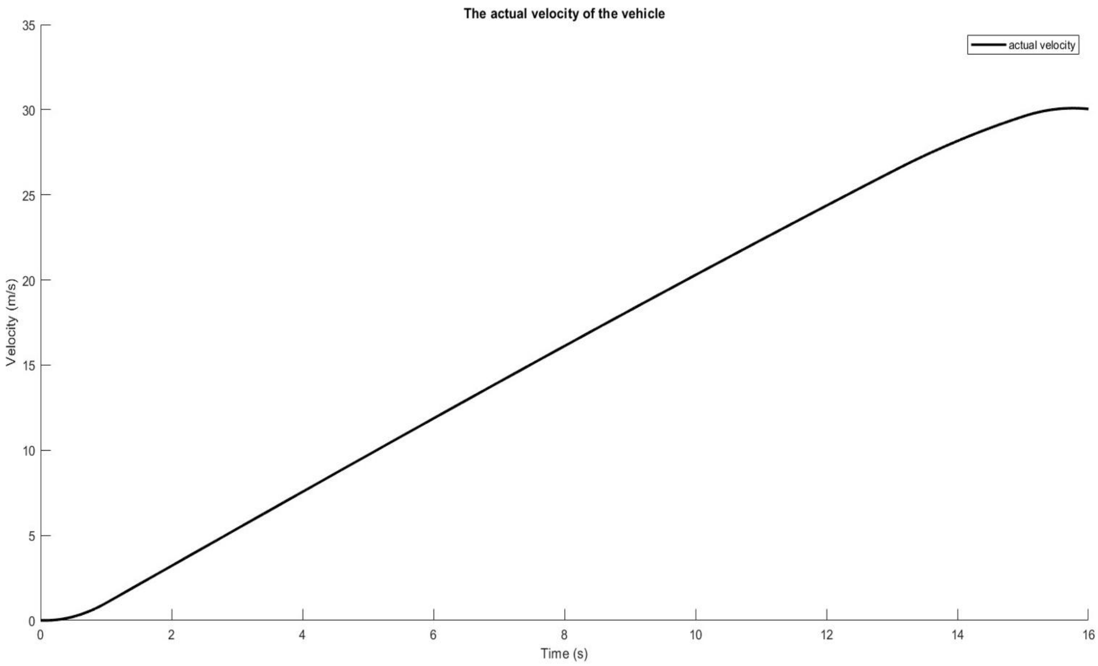

Figure 65: Velocity of Acceleration

The velocity of the vehicle reach the 100 km/h (27.78 m/s) in 15s and the velocity is met the QCVN 09:2015/Vietnamese Ministry Transport.

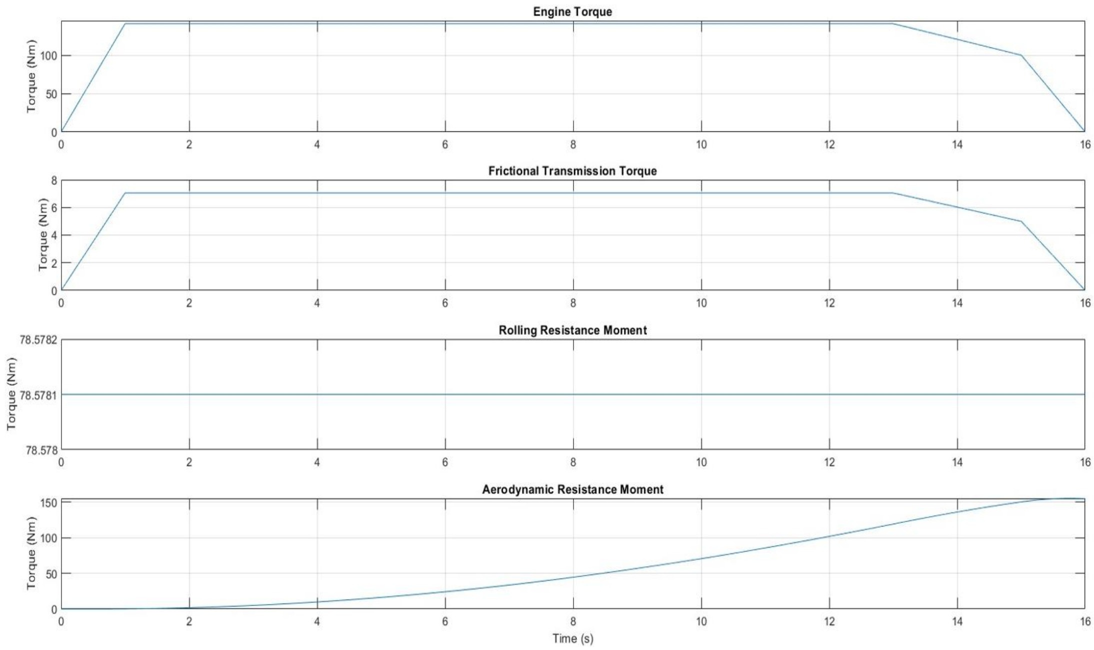

Figure 66: Torque of Acceleration

We can see these moment components during the acceleration. The rolling resistance moment unchange, because we choose the constant rolling resistance coefficient.

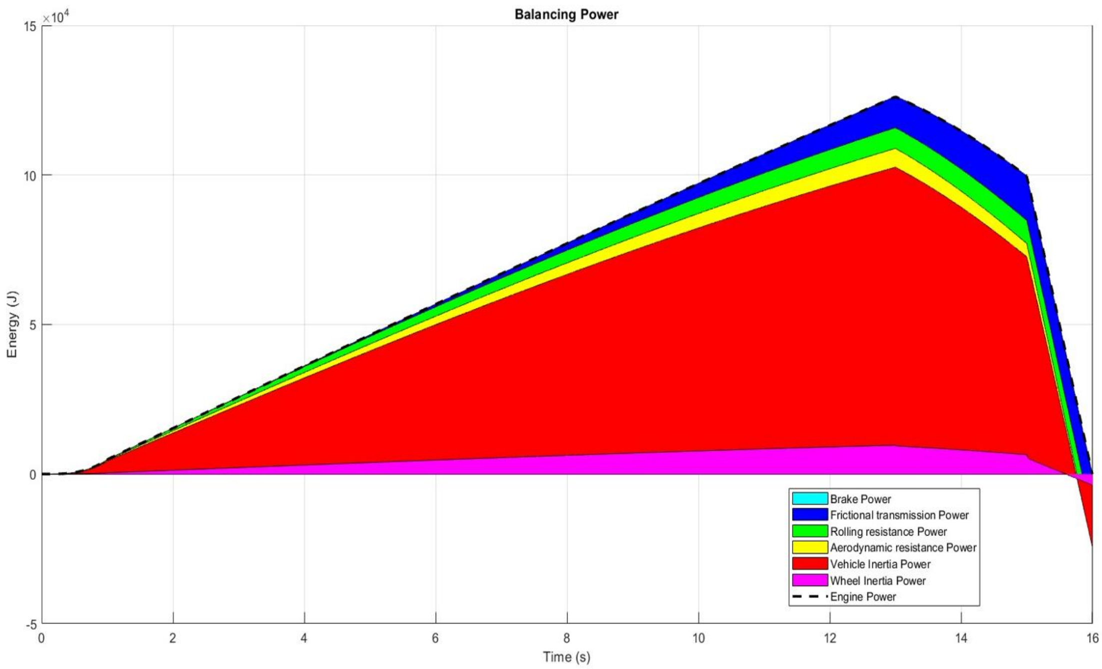

Figure 67: Power Components of Acceleration

Next, this is the power balance figure. This figure show the power of engine generating the actual power after overcoming the losses power.

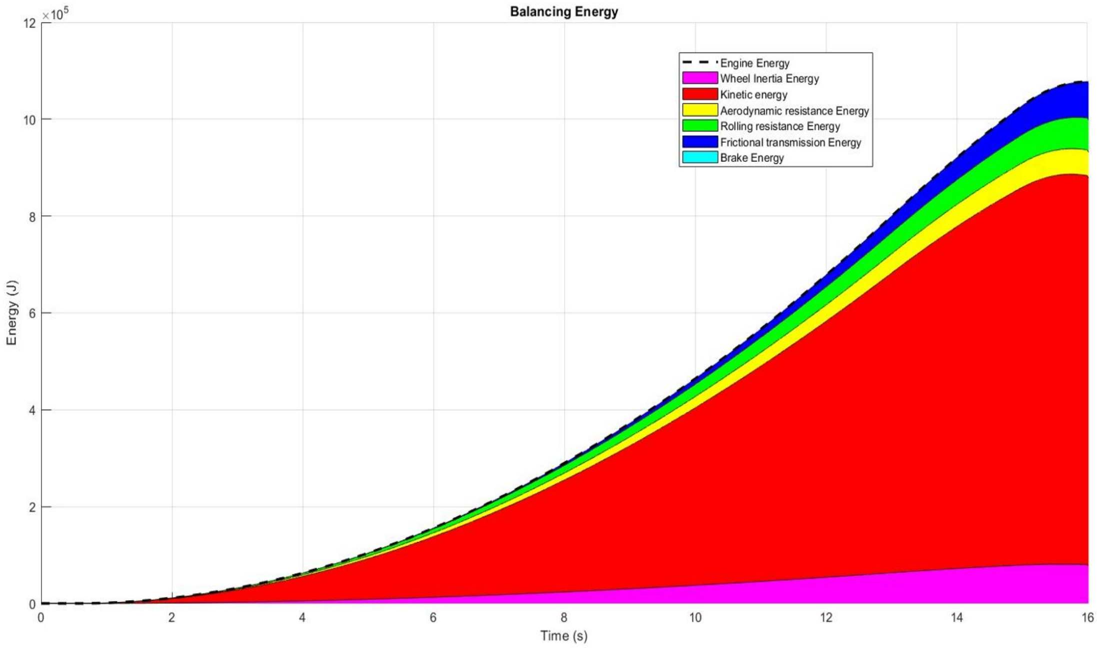

Figure 68: Energy Balance of Acceleration

we can see the balancing energy figure of acceleration. This figure is same the power balance figure. It means

$$A_{engine} = A_{vehicle\ inertia} + A_J + A_{rr} + A_{aero} + A_{frictrans} \tag{73}$$

Finally, the rate of losses energy components is illustare in pie chart.

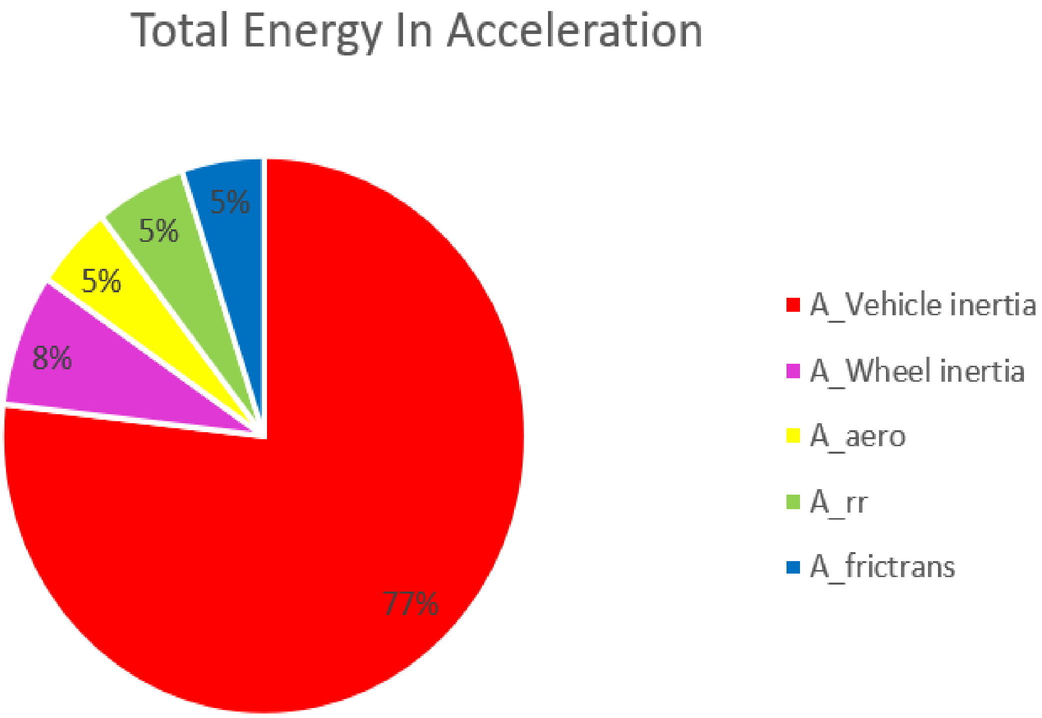

Figure 69: Energy Components of Acceleration

we can see this is the total energy of energy operate. It means the $A_{vehicle\ inertia}$ accounts for 77% and the energy of wheel inertia is 8%. This is a total kinetic energy which help the vehicle motion. Next, the following percentage of A_{rr}, $A_{fricrtrans}$ and A_{aero} is $5\%, 5\%, and\ 5\%$, respectively. This is the losses energy components which reduce the engine energy.

3.7.1.1.2 The Deceleration

In the last 6 second of the process (from $16s$ to $23s$), A vehicle does not produce torque and start brake, we will see some data to determine the deceleration

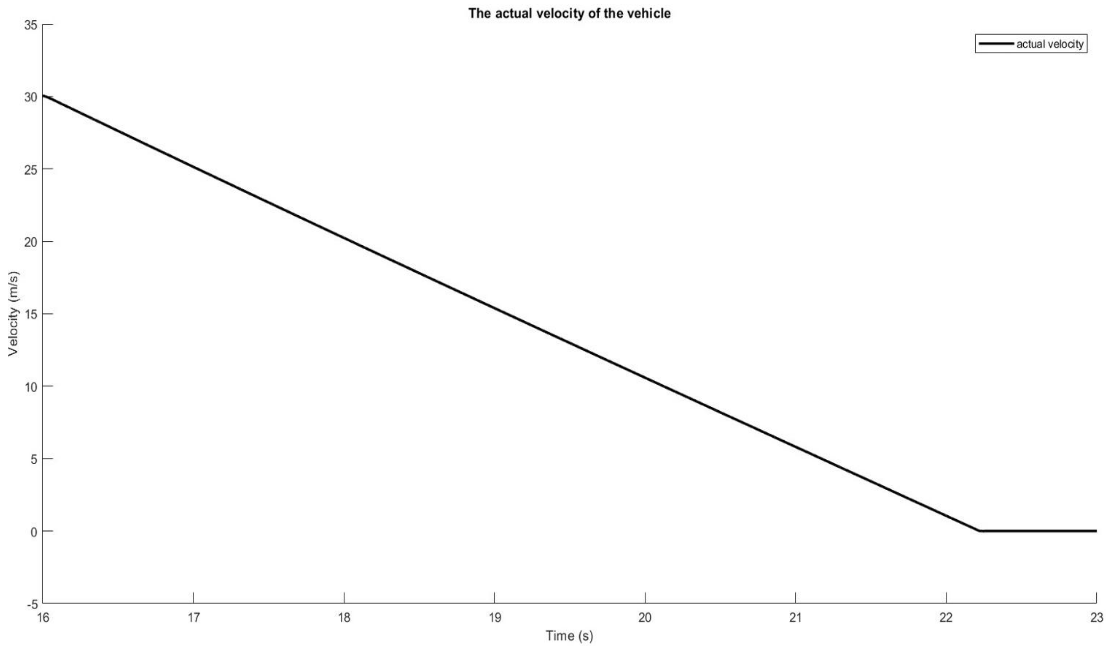

Figure 70: Velocity of Deceleration

When a vehicle brake, the brake period is about 6s from 30 m/s to zero. It result is proved in the previous project which is meet the standard of Vietnamese Ministry Transport.

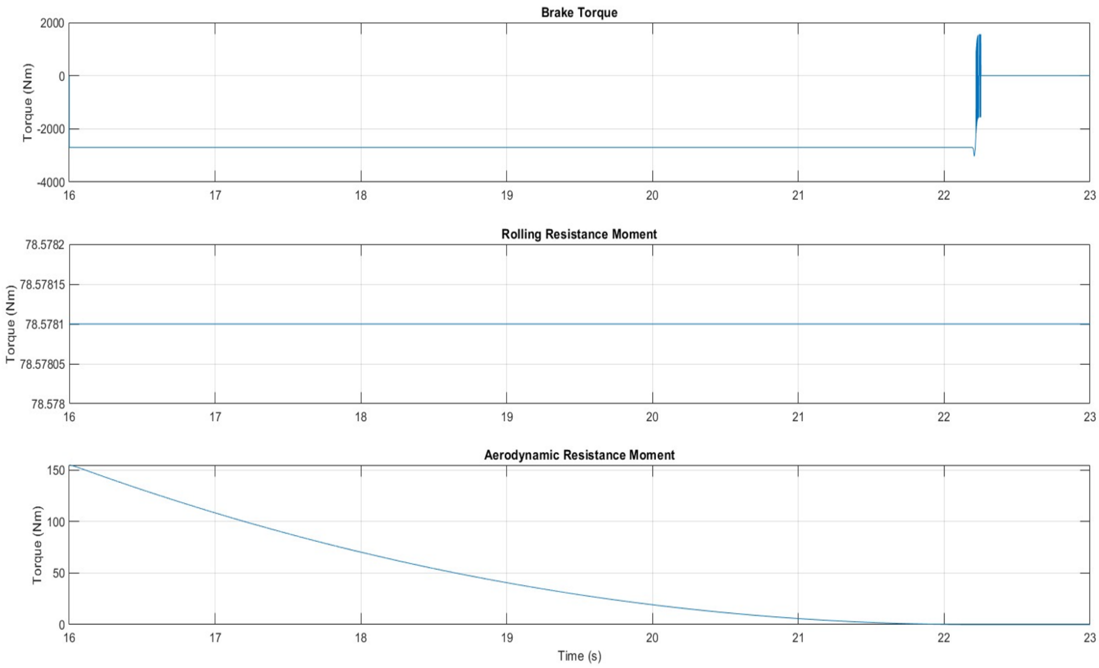

Figure 71: Torque of Deceleration

In this figure, these data are showed the moment components during deceleration. Specially, we can see the frictional Transmission Torque equal zero. We almost know the engine have a characteristic to brake. However, in this model, I was chosen the constant transmission ratio being 1.1. It means the internal engine resistance appear in the decelerating process but it very small and I will explain it with some reasons:

The engine speed and wheel speed is revolute with a small difference of speed -> The internal engine resistance is exist due to the speed difference between them, but it is very small.

The internal engine resistance is amplified but it is not too much due to the 1.1 transmission ratio.

After we clearly understand about the existance of the frictional transmission torque. We will analyze the power in this process.

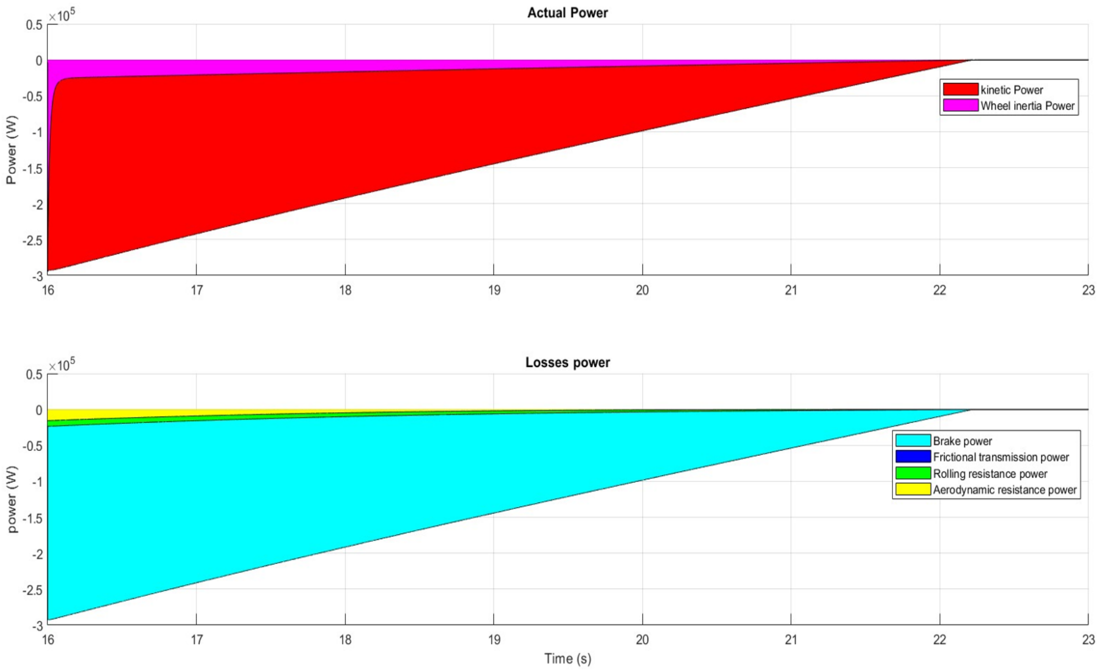

Figure 72: Power Components of Deceleration

We can see the actual power of vehicle is negative because this is a mechanical power. The power is generated the losses components. To understand this problem we will see the chart of energy to analyze the accuracy of model.

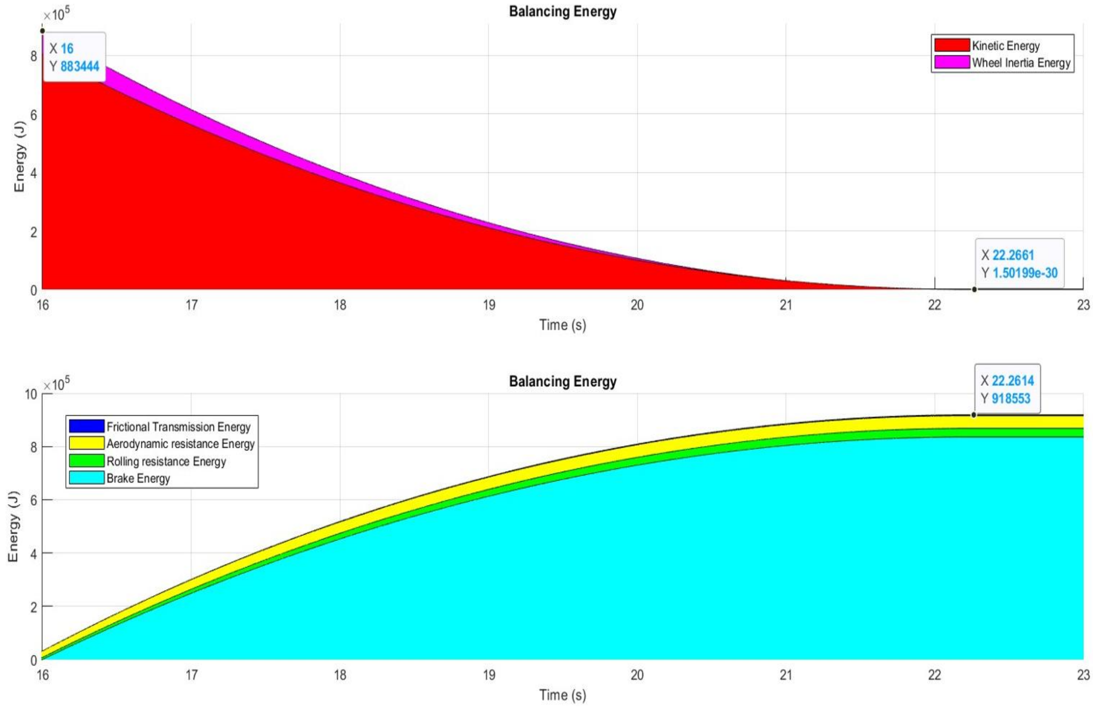

Figure 73: Energy Balance of Deceleration

In this figure, this is the result of energy balance. The total kinetic energy is losen throught the losses energy components.

$$A_{vehicle\ inertia} + A_j = A_b + A_{rr} + A_{aero} \quad (75)$$

The difference between the total kinetic energy and the losses energy components is 3.5% and this error is acceptable. In addition, the friction transmission energy (engine brake) is very small due to the ratio of the gearbox is 1.1, so the difference of speed between gearbox and wheel is very small.

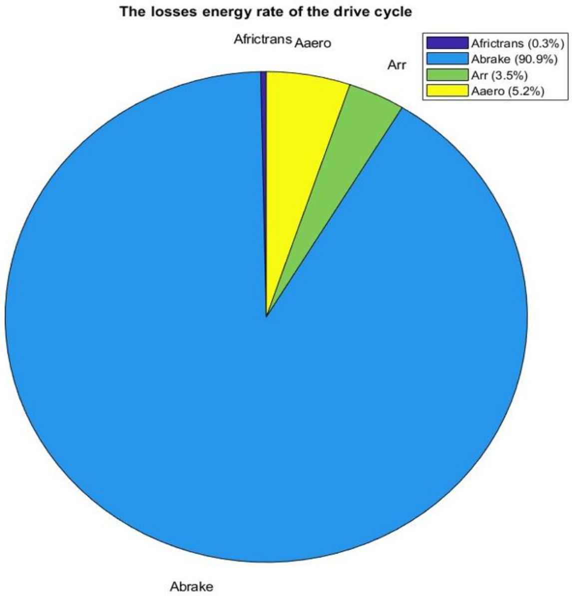

Figure 74: Energy Components of Deceleration

We can see in the pie chart, the brake energy is highest losses energy which caused the deceleration of vehicle. In addition, some effects such as the energy of rolling resistance, aerodynamics resistance and frictional transmission which assisted the brake mechanism to reduce the speed of vehicle

3.7.1.2 Simulating process according to the drive cycle

Basing on the description for the drive cycle process in Simulating method in **Chapter 6**. I will simulate the model run in some drive cycle processes such as FTP – 75, NEDC. JP1510 to determine some specific results consist of: velocity, the moment components, the power components, the energy components.

3.7.1.2.1 FTP – 75

First of all, basing on the specification of FTP – 75, the simulated model runs in drive cycle

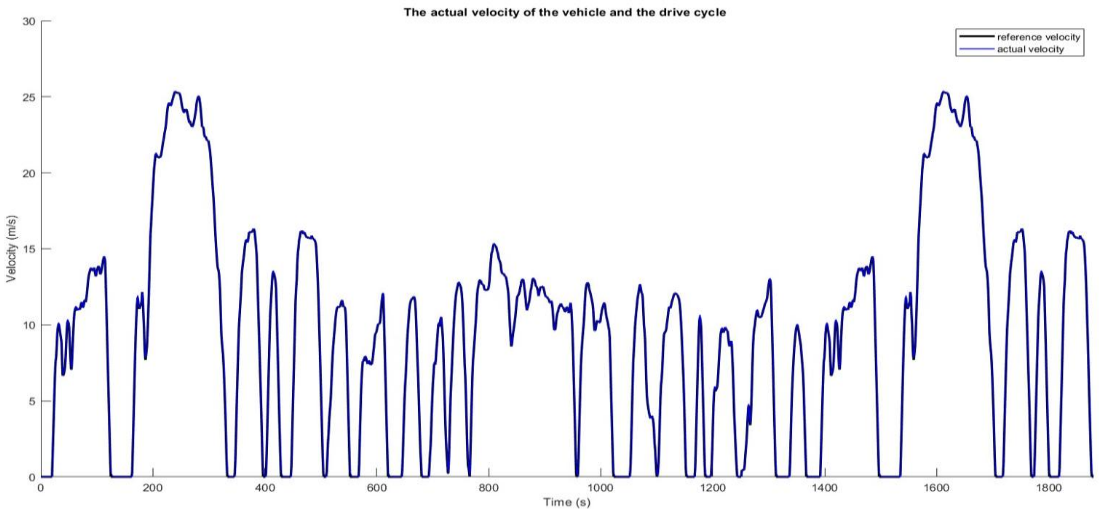

Figure 75: Velocity of Vehicle in FTP-75 Drive Cycle

According to my simulating method, the vehicle's velocity (blue line) closely follows the velocity of FTP-75 (black line).

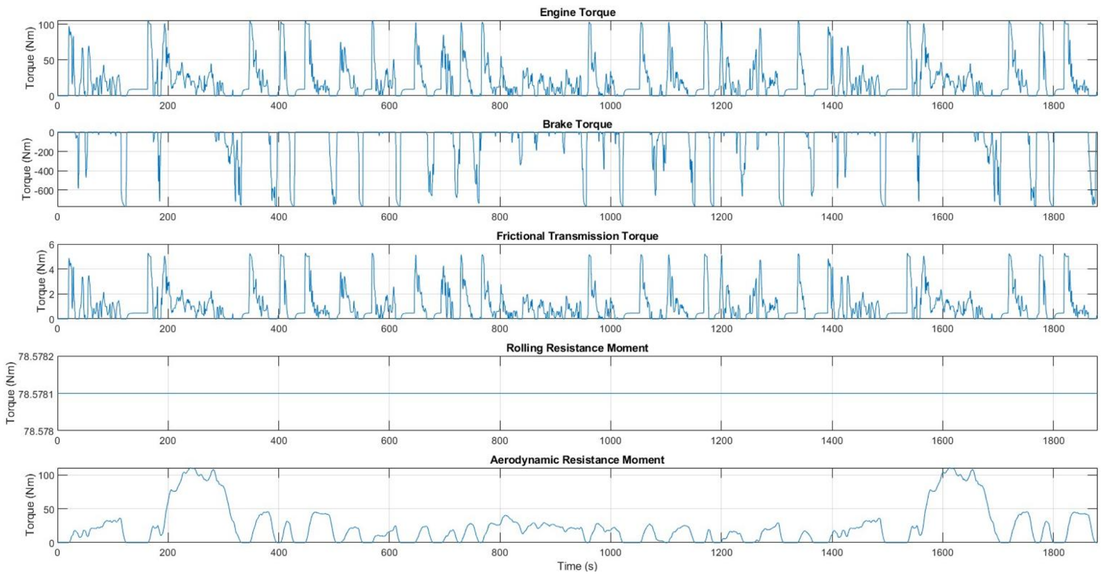

Figure 76: Torque of Vehicle in FTP-75 Drive Cycle

We can see the moment figure, the resistance moment is changed with respect to time excepting rolling resistance moment and the charateristic of the frictional transmission moment in decelerating process which I explain before.

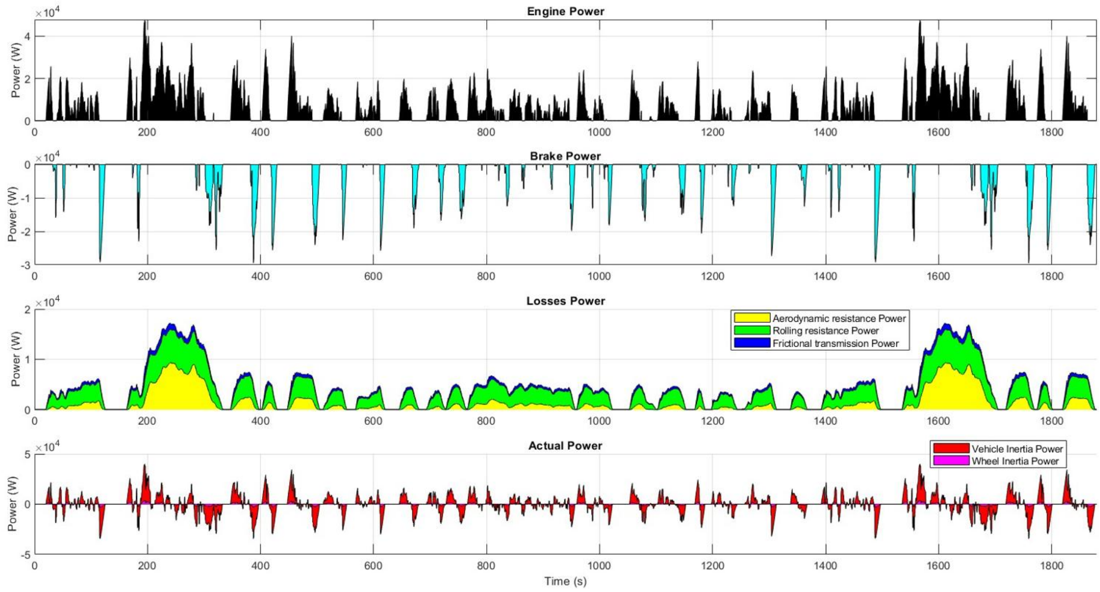

Figure 77: Power Components of Vehicle in FTP-75 Drive Cycle

We can see there are the result of each power component with respect to time. To deeply understand this problem we need to see the energy components chart to clearly analyze each component

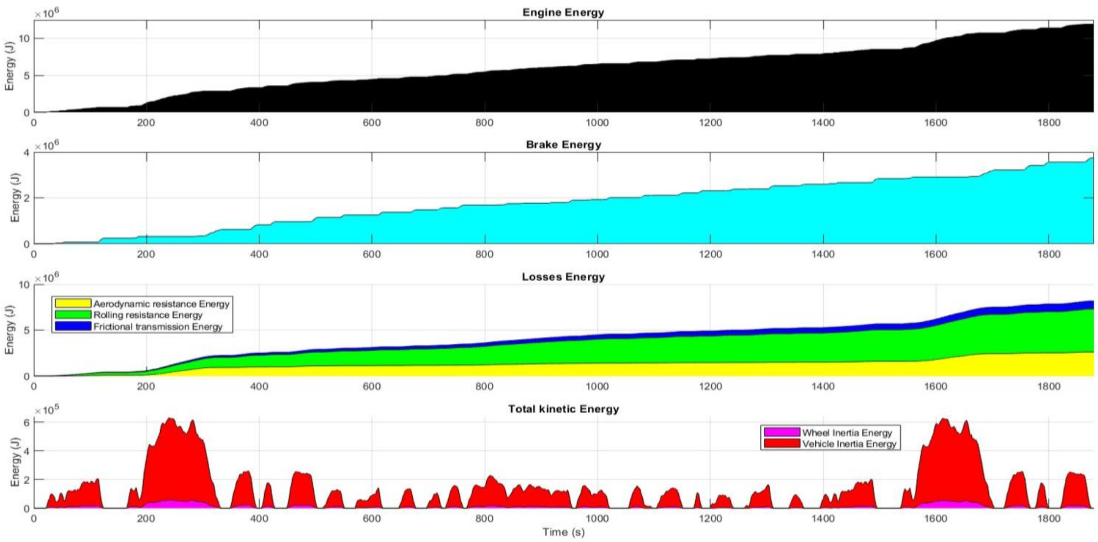

Figure 78: Energy Components of Vehicle in FTP-75 Drive Cycle

Next, you can see each energy components with respect to time. We will deeply understand about the operating of the figure. First of all, if the vehicle accelerate the engine energy increase and the brake energy is stable , while when the vehicle decelerate the engine energy is stable and the brake energy go up. The increase of both component is large or small basing on the accelerating and decelerating process.

After that, we will see the energy balance chart of the vehicle in drive cycle FTP-75.

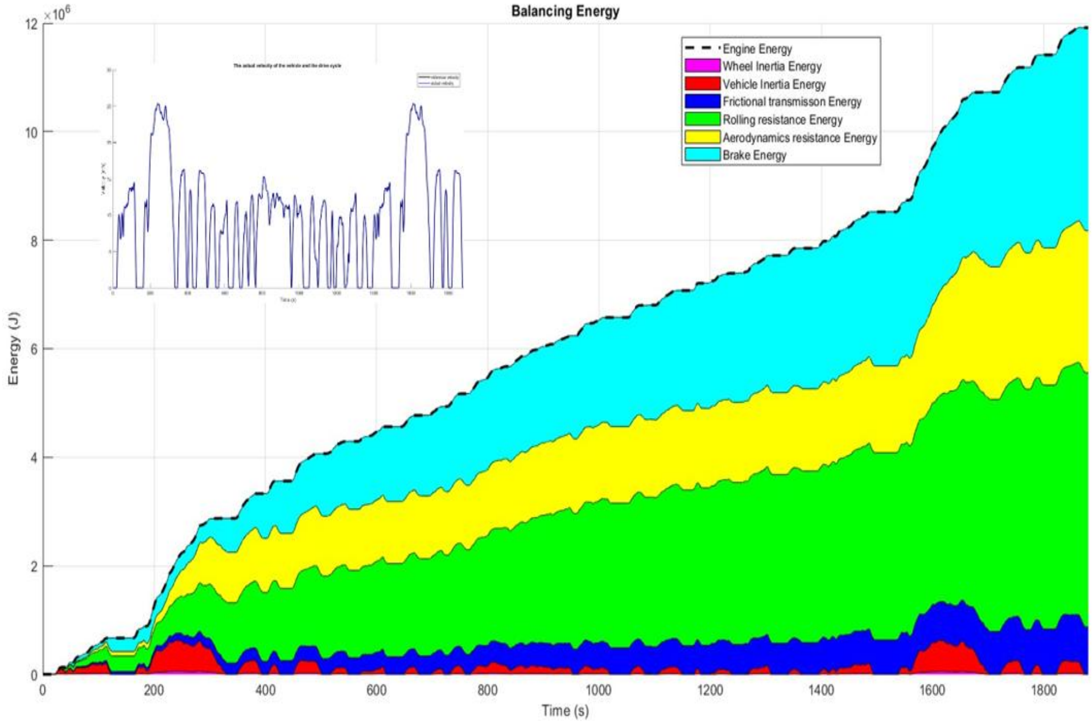

Figure 79: Energy Balance of Vehicle in FTP-75 Drive Cycle

This is the total energy during the drive cycle FTP-75. This is chart is show according to the available equation:

$$A_e = A_{vehicle\ inertia} + A_j + A_{aero} + A_{rr} + A_{fricmech} + A_b \tag{78}$$

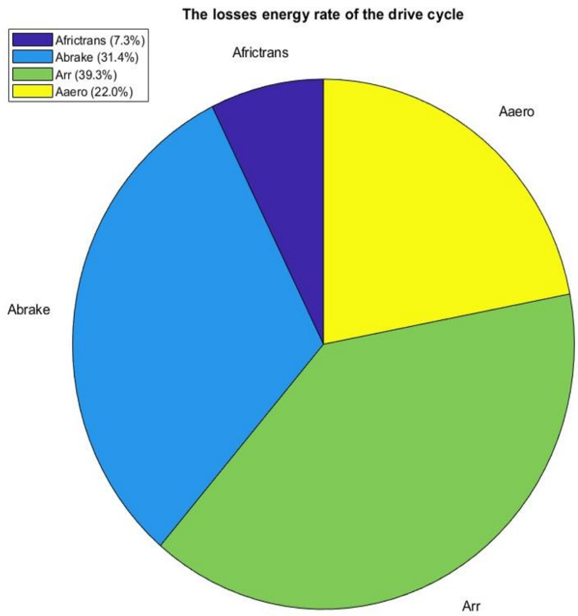

Figure 80: Losses Energy Components of Vehicle in FTP-75 Drive Cycle

In the pie chart, we can see during the drive cycle process the rolling resistance energy is the highest losses components due to the rolling resistance always exists during the drive cycle while brake energy components is at a second place of this cycle with 31.4 %. This is the total brake energy is generated when the vehicle decelerate. We can recover this energy if we apply the vehicle using electrical engine.

3.7.1.2.2 NEDC

First of all, basing on the parameters of NEDC, the simulated model runs in drive cycle

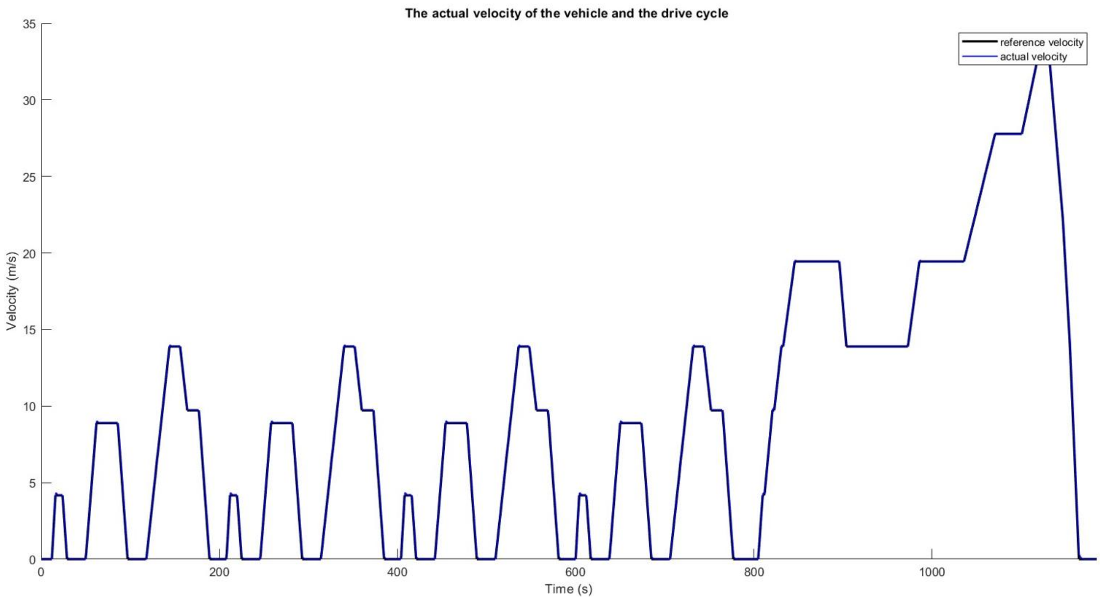

Figure 81: Velocity of Vehicle in NEDC Drive Cycle

Similarly FTP – 75, In this figure above, the velocity of the vehicle closely follows the reference velocity of NEDC. In this drive cycle, the highest speed reach 120 km/h (33.33 m/s) in the last phase which means the vehicle is run in sub – urban area or highway. Besides, in the first four – phase the maximum speed is 50 km/h (13.889 m/s). It means the vehicle is operated in urban area with low speed and continuously decelerated.

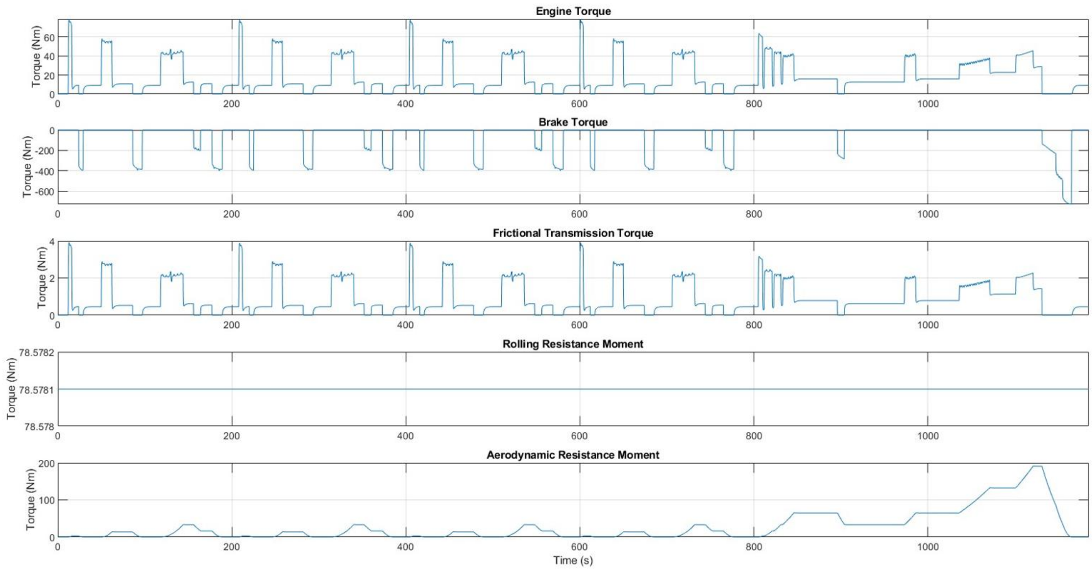

Figure 82: Torque of Vehicle in NEDC Drive Cycle

We can see the moment figure, the resistance moment is changed with respect to time excepting rolling resistance moment. In addition, due to the characteristic of NEDC velocity, the aerodynamics resistance significantly changed in the last phase.

Next, we will see the power components of a vehicle in the NEDC.

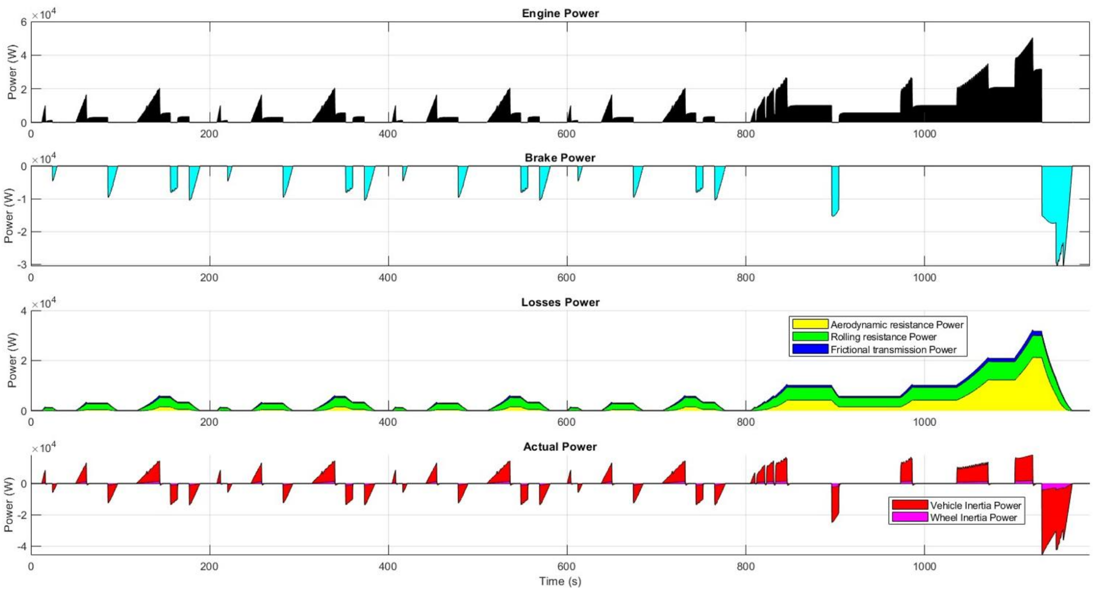

Figure 83: Power Components of Vehicle in NEDC Drive Cycle

We can see in this figure each component with respect to time. We can see the change of actual power in acceleration and deceleration which is generated from different energy components. It means if a vehicle accelerate, the power is positive which is generated from the engine power overcoming the losses power, or a vehicle decelerate, the actual power is negative which is generated from the total losses power of brake, rolling resistance, aerodynamics resistance and frictional transmission. In addition, the actual power consists of the inertia of vehicle body and wheel with red and purple area, respectively.

Next, we will see all total energy components existing in a vehicle when run in the NEDC drive cycle.

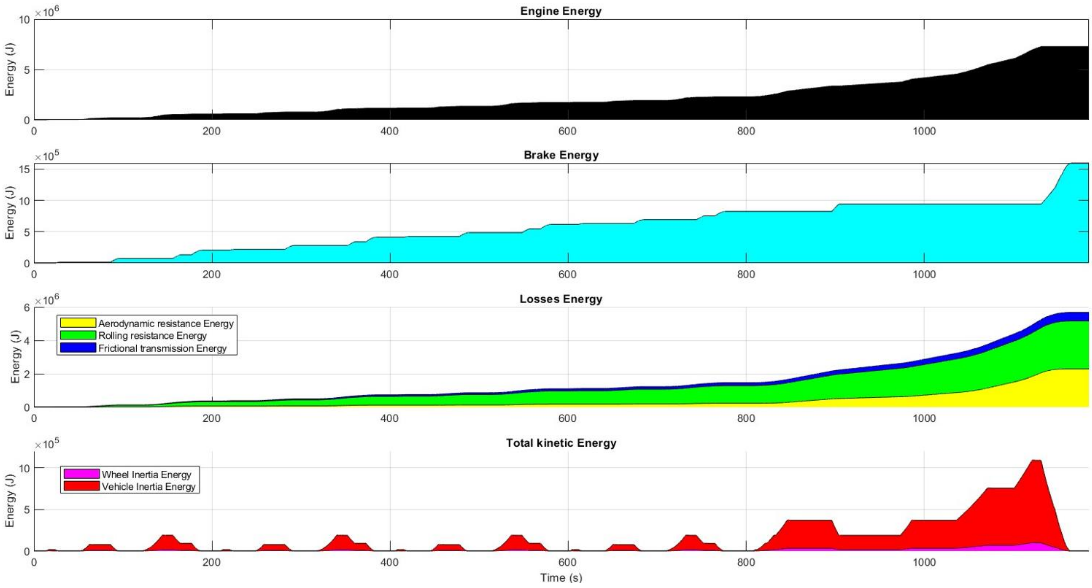

Figure 84: Energy Components of Vehicle in NEDC Drive Cycle

The figure above illustrates the clear change in the last phase (the vehicle accelerate to 120 km/h and decelerate to zero). It means the energy of engine go up when a vehicle accelerate and the energy of brake sharply increase when vehicle decelerated from 120 km/h to zero.

Finally, we will analyze the energy balance of NEDC

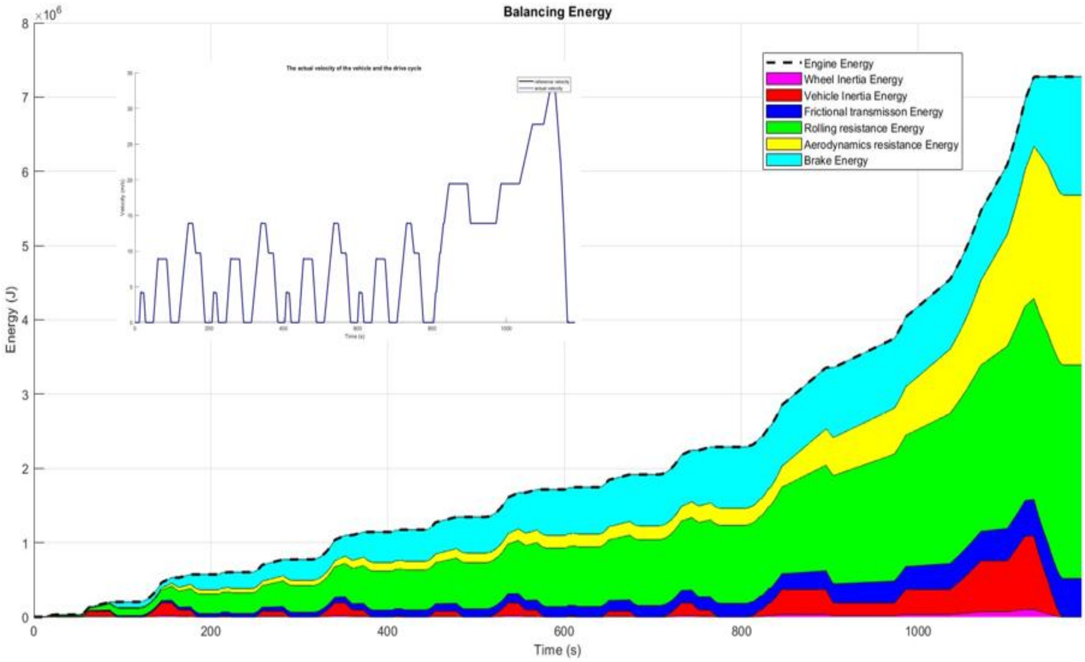

Figure 85: Energy Balance of Vehicle in NEDC Drive Cycle

According to the available equation:

$$A_e = A_{vehicle\ inertia} + A_{wheel\ inertia} + A_{aero} + A_{rr} + A_{fricmech} + A_b \qquad (78)$$

I drew the chart to balance the energy during the NEDC drive cycle. We can see the total of losses energy consisting of brake, aerodynamics resistance, rolling resistance, and frictional transmission, and the total of kinetic energy consisting of the inertia of vehicle body and wheel, being equal with the total energy of the engine generated.

The pie chart shows the rate of losses energy component when a vehicle run in NEDC

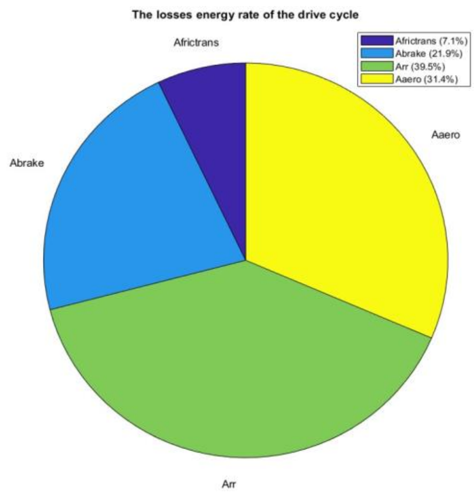

Figure 86: Losses Energy Components of Vehicle in NEDC Drive Cycle

We can see the rate of losses components in NEDC drive cycle having the difference compare with FTP-75. First of all, the rolling resistance is the highest losses energy components in the rate with 39.5%.Secondly, due to the maximum velocity of this drive cycle is 120 km/h (33.33 m/s) leading to the aerodynamic resistance significantly increase and occupy the second place with 31.4% during the drive cycle. In addtion, in this drive cycle, the brake energy is not too much, accounting for 21.9% of net losses energy component.

3.7.1.2.3 JP1015

First of all, basing on the specification of NEDC, the simulated model runs in drive cycle

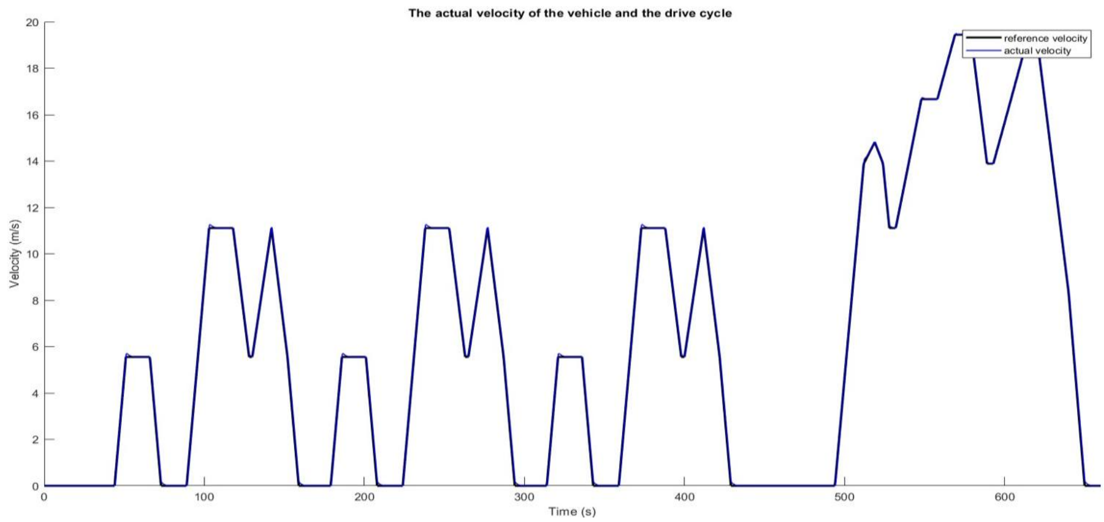

Figure 87: Velocity of Vehicle in JP1015 Drive Cycle

In the chart above, we can see the vehicle velocity closely follow the reference velocity of JP1015. The characteristics of JP1015 drive cycle have many similarities with the characteristics of transport system in Vietnam. It means, the drive cycle has 10-mode which represent for operating in urban area with a maximum speed being 50 km/h (13.889 m/s) while the 15-mode represents for operating in sub-urban area with a maximum speed being 70 km/h (19.44 m/s). The maximum speed in 15-mode is same as the valid average speed in many sub-urban road in Vietnam.

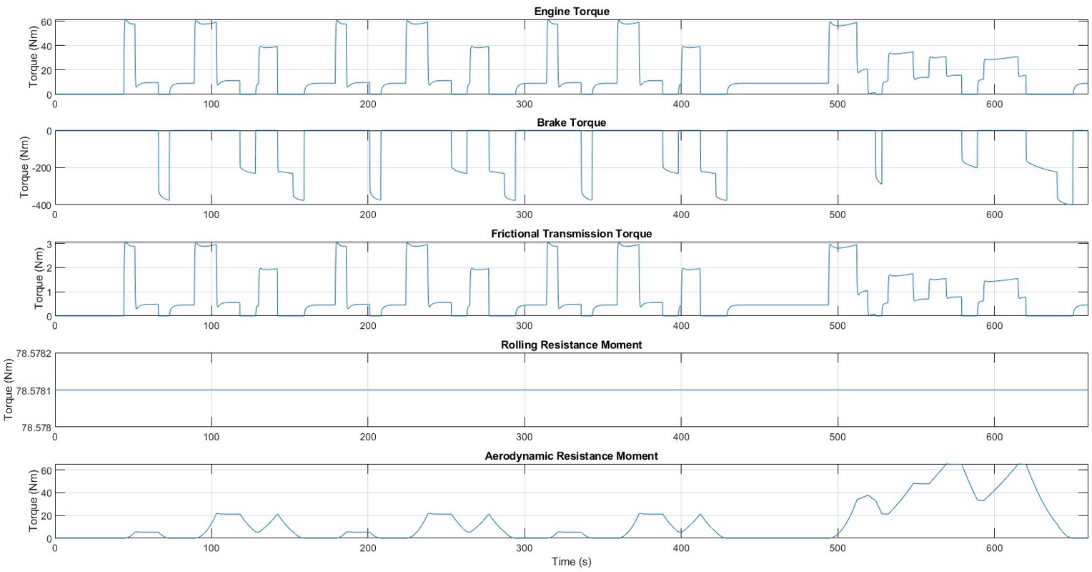

Figure 88: Torque of Vehicle in JP1015 Drive Cycle

We can see the moment figure, the resistance moment change with respect to time excepting rolling resistance moment.

Next, we will see the power components of a vehicle in the JP1015.

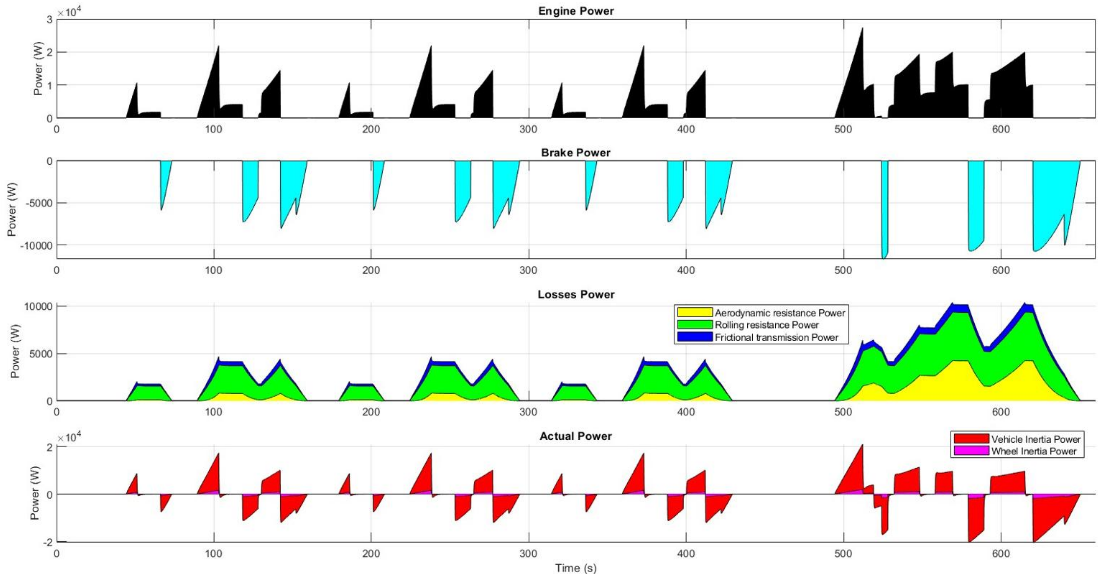

Figure 89: Power Components of Vehicle in JP1015 Drive Cycle

We can see in this figure each power component with respect to time. Due to the drive cycle have a short period and the maximum velocity is not too much, so on the actual power is relative small.

Next, we will see each energy components of a vehicle in JP1015 drive cycle

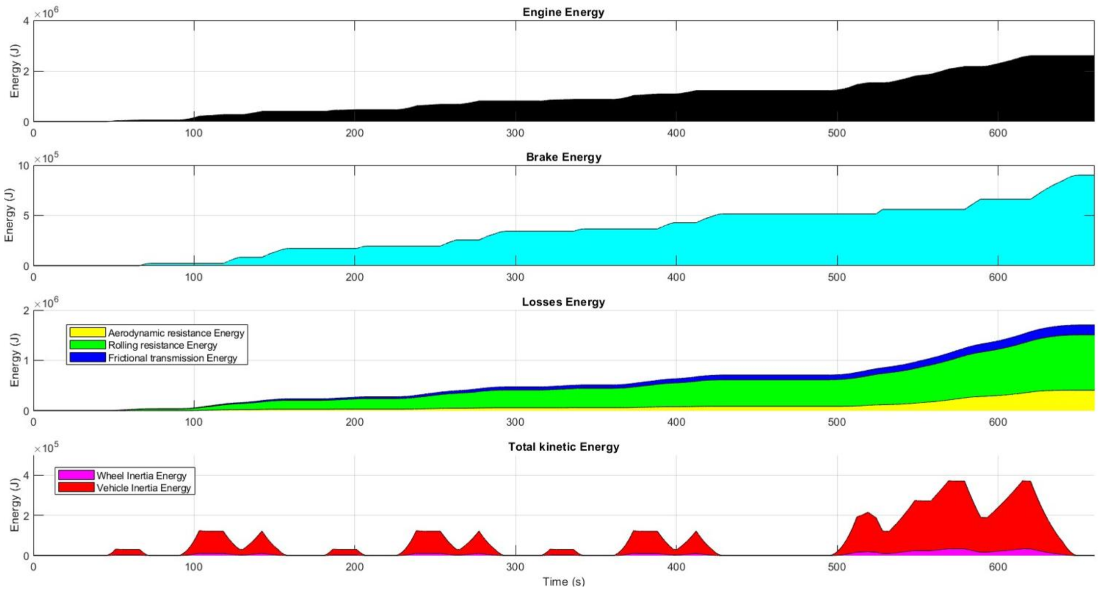

Figure 90: Energy Components of Vehicle in JP1015 Drive Cycle

You can see the magnitude of each energy components of vehicle in drive cycle is relative small, which is caused for some problem:

- The average speed of drive cycle is lower than other one.
- The time of rest is too much (the period from $400s$ to $500s$)

After that, we will see the results of energy balance in JP1015 drive cycle.

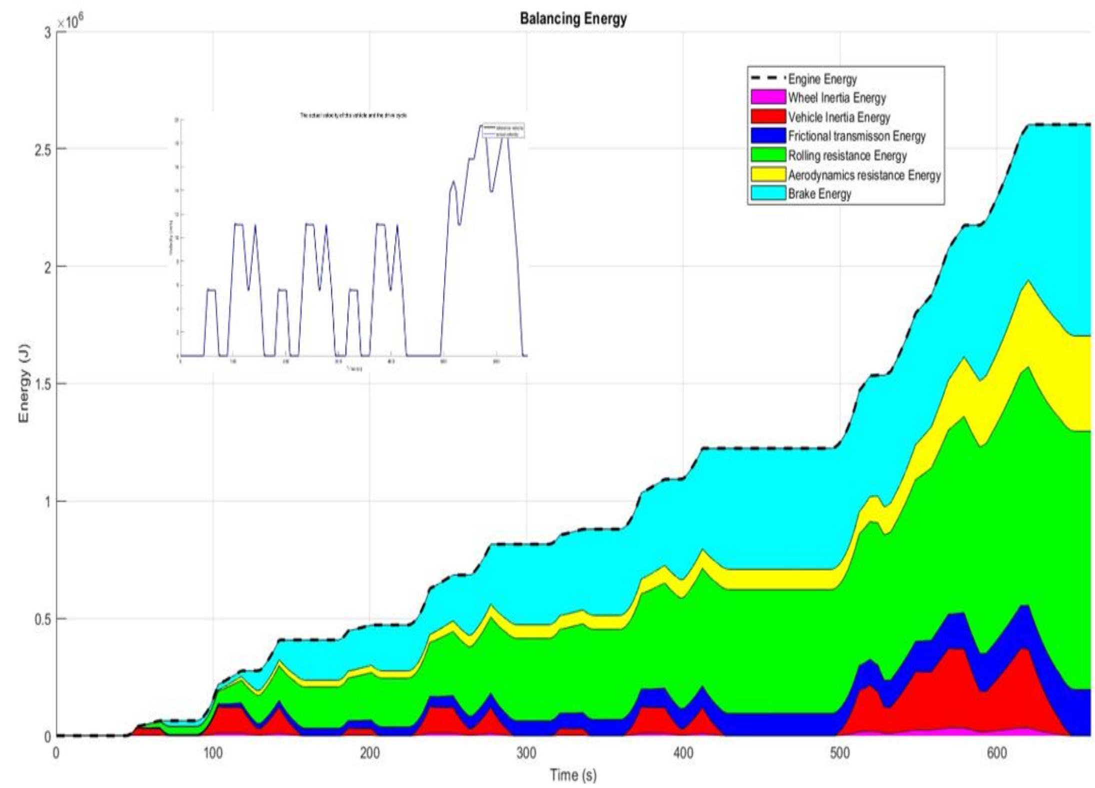

Figure 91: Energy Balance of Vehicle in JP1015 Drive Cycle

This is the total energy during the JP1015 drive cycle, consisting of actual energy, engine energy, brake energy, rolling resistance energy, aerodynamic resistance energy, and the frictional transmission energy. It is suitable with the available balancing energy equation before.

$$A_e = A_{vehicle\ inertia} + A_j + A_{aero} + A_{rr} + A_{fricmech} + A_b \tag{78}$$

The rate of losses energy component existed during the JP1015 drive cycle

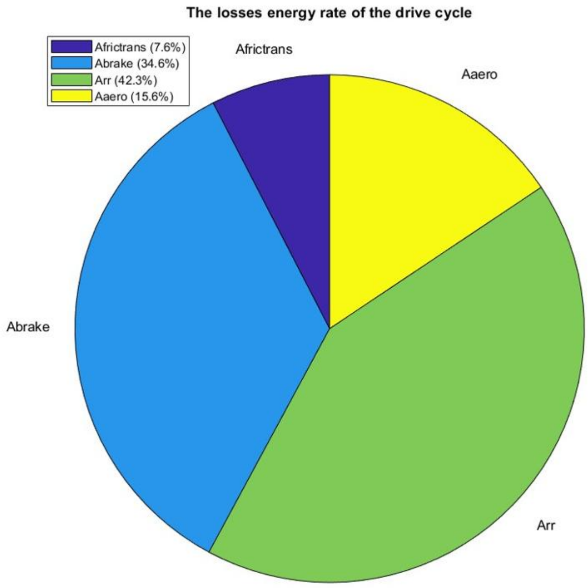

Figure 92: Losses Energy Components of Vehicle in JP1015 Drive Cycle

In the JP1015 drive cycle, the rolling resistance energy is the highest losses energy with 42.3% while the brake energy accounts for 34.6% which have a second place in this chart.

3.7.2. The conclusion determine for the result

Basing on the rate losses component analysis of each drive cycle before, we can give some assessment after obtaining the result:

- In three drive cycles, the JP1015 drive cycles has some characteristics similar to the transport system in Vietnam from the highest velocity to the average velocity in urban. Besides, the FTP-75 drive cycle have a continuous change during the cycle which show the formation of energy brake or the NEDC drive cycle illustrate a increase and stability in the energy in the last phase of them.
- The rolling resistance energy: is the highest losses energy during all the process. This energy always exists when the vehicle accelerate or decelerate with

a constant rolling resistance coefficient. If we can improve the characteristic of wheel material, the pressure which can reduce the contact patch between the wheel and road surface leading to the reduce of the rolling resistance energy during the operation.

- The aerodynamics resistance energy: This energy is depended a lots on the velocity of a vehicle. If we want to reduce the energy of aerodynamics resistance when a vehicle accelerate, we need to improve the frontal area and optimize the drag coefficient. From this we can economize the energy from the engine.
- The frictional transmission energy: This energy always exists when a vehicle operate, this energy depend a lots on the transmission ratio or efficiency. Howevers, the efficiency can optimize by current technology so this energy components cannot improve.
- The braking energy: exists when the vehicle braking and decelerating. This energy can use to become the regenerative energy for the battery if we use the electrical engine. The braking energy is affected by many factors such as the material in brake mechanism, the other external and internal losses energy, the efficiency of brake mechanism,…

Chapter 4 Future plan

In the future, the project can be development through many ways. For example:

- Wheel: The follower need to deeply study about the slip friction and add it to the model in Matlab/Simscape as well as a moment equation of wheel. In addition, the stiffness and damping of the wheel, the pressure is added to the model to determine the losses when the vehicle operate.
- Brake mechanism:
  - Studying the efficiency of regenerative energy, analyzing and optimizing the regenerative energy.
  - Intergrating some modernize technology of brake such as electric brake system (EBS), Anti – lock braking system (ABS), … to optimize the regenerative energy.
- Enhancing a vehicle simulation model:
  - Simulate Electric Vehicles (Evs): Integrate battery systems and power converters to accurately model regenerative braking performance.
  - Optimize Hybrid Systems: Study and optimize the interaction between the internal combustion engine and electric motor during braking and energy recovery.
  - Improve Realism: Incorporate the effects of electric motors/internal combustion.
- expanding the application of an existing core braking model:
  - Vehicle Diversity: Apply the model to a wider range of vehicles, including heavy-duty vehicles, trucks, and buses.
  - Autonomous Vehicle Integration: Incorporate the braking system into self-driving car models to improve their safety and precision.
  - Real-world Validation: Conduct field tests to validate the model's accuracy by comparing its simulations against actual performance in diverse road and environmental conditions.

Appendix I:

```
Parameters of vehicles
m_xe = 1275; % mass of vehicle (kg) — kerb weight
m_xefull = 1780; %gross weight (kg)
g = 9.81 ;% gravitional acceleration (m/s^2)
A = 2.46 ;% frontal area (m.^2)
Cd = 0.38; % drag coefficient
rho = 1.225; % air density (kg/m^3)
theta= pi/6; % road incline
R_bx = 0.3; % rolling radius (m)
Vo = 28 ; % initial velocity (m/s)
Crr = 0.015; % rolling resistance coefficient
Td = 500 ; %driving torque (N*m)
m_bxe = 45 ;%mass of wheel (kg)
© = 1; %transmission ratio
J_bxe1 = m_bxe * (R_bx)^2; %inertia of front wheel
J_bxe2 = m_bxe * (R_bx)^2; %inertia of rear wheel
M_flywheel = 10; %mass of flywheel (kg)
R_flywheel = 0.3; %radius of flywheel (m)
I_e = M_flywheel * (R_flywheel)^2 ; %inertia of flywheel
j_inertia = (1+(J_bxe1*m_xe)/(R_bx*R_bx)+(I_e*i*m_xe)/(R_bx*R_flywheel)); %the
coefficience of inertia
%the coefficience of rear wheel: +(I_bxe2*m_xe)/(R_bx*R_kbxe2)
a1 = 1280; %horizontal distance from CG to front axle (mm)
b2 = 1495; %horizontal distance from CG to rear axle (mm)
h_g = 570; %CG height above ground (mm)
L_0 = 2775; %wheelbase (mm)
%parameters of dry tarmac
B1=10; % B coefficient (magic formula)
C1=1.9; %C coefficient (magic formula)
D1=1; % D coefficient (magic formula)
E1=0.97; % E coefficient (magic formula)
%parameters of wet tarmac
B2=12;
C2=2.3;
D2=0.82;
E2=1;
%parameter of snow
B3=5;
C3=2;
D3=0.3;
E3=1;
%parameter of ice
B4=4;
C4=2;
D4=0.2;
E4=1;
%braking
Fbfront=2710; %front braking force full load (N)
```

```
Fbrear=1/2*(m_xefull*g/h_g*sqrt((b2)^2+(4*h_g*L_0*Fbfront)/(m_xefull*g))-
((m_xefull*g*b2)/h_g+2*Fbfront)); %rear braking force full load (N)
Adrum=334.59; %the area of drum (mm^2)
Adisc=2565.21;%the area of disc (mm^2)
P1=Fbfront/Adisc*10^6; %the pressure of front braking force full load (Pa)
```

Appendix II:

The plotting program for acceleration

```
%extract data from Simulink
%velocity + veloref + wheel velocity
t=out.logsout{1}.Values.Time;
vel = out.logsout{29}.Values.Data;
wheelFL = out.logsout{41}.Values.Data;
wheelRL = out.logsout{42}.Values.Data;
velref = out.logsout{11}.Values.Data;

%Moment
Tengine = out.logsout{30}.Values.Data;
Tbrake = out.logsout{37}.Values.Data;
Tfricmech =out.logsout{31}.Values.Data;
Trr = out.logsout{21}.Values.Data;
Taero = out.logsout{2}.Values.Data;

%Power
Pengine = out.logsout{35}.Values.Data;
Pactual = out.logsout{6}.Values.Data;
Pj = out.logsout{12}.Values.Data;
Prr = out.logsout{23}.Values.Data;
Pfricmec = out.logsout{34}.Values.Data;
Paero = out.logsout{4}.Values.Data;
Pbrake = out.logsout{40}.Values.Data;

%Energy
Aengine = out.logsout{33}.Values.Data;
Abrake = out.logsout{39}.Values.Data;
Arr = out.logsout{22}.Values.Data;
Aaero = out.logsout{3}.Values.Data;
Aj = out.logsout{15}.Values.Data;
Africmec = out.logsout{32}.Values.Data;
Wd = out.logsout{5}.Values.Data;

figure(1);
hold on
plot(t,vel,'k-','LineWidth', 2,'DisplayName','actual velocity');
legend;
title('The actual velocity of the vehicle');
ylabel('Velocity (m/s)');
xlabel('Time (s)');
xlim([0 16]);

figure(2)
hold on
subplot(4,1,1);
plot(t,Tengine);
title('Engine Torque');
ylabel('Torque (Nm)');
```

```
xlim([0 16]);
ylim([0 145]);
grid on

subplot(4,1,2);
plot(t,Tfricmech);
title('Frictional Transmission Torque');
ylabel('Torque (Nm)');
xlim([0 16]);
ylim([0 8]);
grid on

subplot(4,1,3);
plot(t,Trr);
title('Rolling Resistance Moment');
ylabel('Torque (Nm)');
xlim([0 16]);
ylim([78.5780 78.5782])
grid on

subplot(4,1,4);
plot(t,Taero);
title('Aerodynamic Resistance Moment');
xlabel('Time (s)');
ylabel('Torque (Nm)');
xlim([0 16]);
grid on
figure(3)
a = Pj;
g = a + Pactual;
b = g + Pfricmec;
c = b + Prr;
d = c + Paero;
e = d + abs(Pbrake);
f = Pengine;

hold on;
area(t,e,'facecolor','c','DisplayName','Brake Power');
area(t,d,'facecolor','b','DisplayName','Frictional transmission Power');
area(t,c,'facecolor','g','DisplayName','Rolling resistance Power');
area(t,b,'facecolor','y','DisplayName','Aerodynamic resistance Power');
area(t,g,'facecolor','r','DisplayName','Vehicle Inertia Power');
area(t,a,'facecolor','m','DisplayName','Wheel Inertia Power');
plot(t,f,'k—','LineWidth', 2,'DisplayName','Engine Power');
legend;
title('Balancing Power');
xlabel('Time (s)');
ylabel('Energy (J)');
xlim([0 16]);
ylim([-50000 150000]);
grid on

figure(4)
```

```
a = Aj;
g = a + Wd;
b = g + Africmec;
c = b + Arr;
d = c + Aaero;
e = d + abs(Abrake);
f = Aengine;

hold on;
area(t,e,'facecolor','c','DisplayName','Brake Energy');
area(t,d,'facecolor','b','DisplayName','Frictional transmission Energy');
area(t,c,'facecolor','g','DisplayName','Rolling resistance Energy');
area(t,b,'facecolor','y','DisplayName','Aerodynamic resistance Energy');
area(t,g,'facecolor','r','DisplayName','Kinetic energy');
area(t,a,'facecolor','m','DisplayName','Wheel Inertia Energy');
plot(t,f,'k—','LineWidth', 2,'DisplayName','Engine Energy');
legend;
title('Balancing Energy');
xlabel('Time (s)');
ylabel('Energy (J)');
xlim([0 16]);
grid on

figure(5);
new_Arr = out.Arollingresistance;
new_Africmec = out.Africmec;
new_Aaero = out.Aaerodynamic;

end_Arr = 58322;
end_Africmec = 52921;
end_Aaero = 50896;
end_AwJ = 80206; %wheel inertia energy
end_AvJ = 803237;%vehicle inertia energy

data = [end_AwJ,end_AvJ,end_Africmec, end_Arr, end_Aaero,];
labels = {'Aj','Avehicle inertia','Africtrans','Arr', 'Aaero'}; % label for each value
% sum data
total = sum(data);
% percentage label
percent_labels = cellfun(@(x) sprintf('%s (%.1f%%)', x, 100 * data(strcmp(labels, x)) /
total), labels, 'UniformOutput', false);
% pie figure;
% new figure
pie(data, labels); % plot pie chart
legend;
title('The losses energy rate of the drive cycle'); % diagram label
legend(percent_labels);
```

Appendix III:

The plotting program for deceleration

```
%extract data from Simulink
%velocity + veloref + wheel velocity
t=out.logsout{1}.Values.Time;
vel = out.logsout{29}.Values.Data;
wheelFL = out.logsout{41}.Values.Data;
wheelRL = out.logsout{42}.Values.Data;
velref = out.logsout{11}.Values.Data;

%Moment
Tengine = out.logsout{30}.Values.Data;
Tbrake = out.logsout{37}.Values.Data;
Tfricmech =out.logsout{31}.Values.Data;
Trr = out.logsout{21}.Values.Data;
Taero = out.logsout{2}.Values.Data;

%Power
Pengine = out.logsout{35}.Values.Data;
Pactual = out.logsout{6}.Values.Data;
Pj = out.logsout{12}.Values.Data;
Prr = out.logsout{23}.Values.Data;
Pfricmec = out.logsout{34}.Values.Data;
Paero = out.logsout{4}.Values.Data;
Pbrake = out.logsout{40}.Values.Data;


%Energy
Aengine = out.logsout{33}.Values.Data;
Abrake = out.logsout{39}.Values.Data;
Arr = out.logsout{22}.Values.Data;
Aaero = out.logsout{3}.Values.Data;
Aj = out.logsout{15}.Values.Data;
Africmec = out.logsout{32}.Values.Data;
Wd = out.logsout{5}.Values.Data;

figure(1);
hold on
plot(t,vel,'k-','LineWidth', 2,'DisplayName','actual velocity');
legend;
title('The actual velocity of the vehicle');
ylabel('Velocity (m/s)');
xlabel('Time (s)');
xlim([16 23]);

figure(2)
hold on

subplot(3,1,1);
plot(t,Tbrake);
```

```
title('Brake Torque');
ylabel('Torque (Nm)');
xlim([16 23]);
grid on

subplot(3,1,2);
plot(t,Trr);
title('Rolling Resistance Moment');
ylabel('Torque (Nm)');
xlim([16 23]);
ylim([78.5780 78.5782])
grid on

subplot(3,1,3);
plot(t,Taero);
title('Aerodynamic Resistance Moment');
xlabel('Time (s)');
ylabel('Torque (Nm)');
xlim([16 23]);
grid on
figure(3)
subplot(2,1,1);
a = Pj;
b = a + Pactual;
hold on;
area(t,b,'facecolor','r','DisplayName','kinetic Power');
area(t,a,'facecolor','m','DisplayName','Wheel inertia Power');
legend;
title('Actual Power');
ylabel('Power (W)');
xlim([16 23]);
grid on

subplot(2,1,2);
x = -Paero;
y = x — Prr;
z = y + Pfricmec;
v = z — abs(Pbrake);
hold on;
area(t,v,'facecolor','c','DisplayName','Brake power');
area(t,z,'facecolor','b','DisplayName','Frictional transmission power');
area(t,y,'facecolor','g','DisplayName','Rolling resistance power');
area(t,x,'facecolor','y','DisplayName','Aerodynamic resistance power');
legend;
title('Losses power');
ylabel('power (W)');
xlabel('Time (s)');
xlim([16 23]);
grid on

figure(4)
a = Wd;
b = a + Aj;
```

```
c = abs(Abrake);
d = c + Arr — 58322;
e = d + Aaero — 50896;
f = e + Africmec — 52921;

subplot(2,1,1);
hold on;
area(t,b,’facecolor’,’m’,’DisplayName’,’Wheel Inertia Energy’);
area(t,a,’facecolor’,’r’,’DisplayName’,’Kinetic Energy’);
legend;
title(‘Balancing Energy’);
xlabel(‘Time (s)’);
ylabel(‘Energy (J)’);
xlim([16 23]);
ylim([0 910000])
grid on

subplot(2,1,2);
hold on;
area(t,f,’facecolor’,’b’,’DisplayName’,’Frictional Transmission Energy’);
area(t,e,’facecolor’,’y’,’DisplayName’,’Aerodynamic resistance Energy’);
area(t,d,’facecolor’,’g’,’DisplayName’,’Rolling resistance Energy’);
area(t,c,’facecolor’,’c’,’DisplayName’,’Brake Energy’);
legend;
title(‘Balancing Energy’);
xlabel(‘Time (s)’);
ylabel(‘Energy (J)’);
xlim([16 23]);
grid on
figure(5);
new_Arr = out.Arollingresistance;
new_Abrake = out.Abrake;
new_Aaero = out.Aaerodynamic;
new_Africmec = out.Africmec;

end_Arr = new_Arr(220001,1) — 58322;
end_Abrake = abs(new_Abrake(220001,1));
end_Aaero = new_Aaero(220001,1) — 50896;
end_Africmec = new_Africmec(220001,1) — 52921;

data = [end_Africmec,end_Abrake, end_Arr, end_Aaero,];
labels = {‘Africtrans’,’Abrake’,’Arr’, ‘Aaero’}; % label for each value
% sum data
total = sum(data);
% percentage label
percent_labels = cellfun(@(x) sprintf(‘%s (%.1f%%)’, x, 100 * data(strcmp(labels, x)) /
total), labels, ‘UniformOutput’, false);
% pie figure;
% new figure
pie(data, labels); % plot pie chart
title(‘The losses energy rate of the drive cycle’); % diagram label
legend(percent_labels);
```

Appendix IV:

The plotting program for drive cycle

```
%extract data from Simulink
%velocity + veloref + wheel velocity
t=out.logsout{1}.Values.Time;
vel = out.logsout{29}.Values.Data;
wheelFL = out.logsout{41}.Values.Data;
wheelRL = out.logsout{42}.Values.Data;
velref = out.logsout{11}.Values.Data;

%Moment
Tengine = out.logsout{30}.Values.Data;
Tbrake = out.logsout{37}.Values.Data;
Tfricmech =out.logsout{31}.Values.Data;
Trr = out.logsout{21}.Values.Data;
Taero = out.logsout{2}.Values.Data;

%Power
Pengine = out.logsout{35}.Values.Data;
Pactual = out.logsout{6}.Values.Data;
Pj = out.logsout{12}.Values.Data;
Prr = out.logsout{23}.Values.Data;
Pfricmec = out.logsout{34}.Values.Data;
Paero = out.logsout{4}.Values.Data;
Pbrake = out.logsout{40}.Values.Data;

%Energy
Aengine = out.logsout{33}.Values.Data;
Abrake = out.logsout{39}.Values.Data;
Arr = out.logsout{22}.Values.Data;
Aaero = out.logsout{3}.Values.Data;
Aj = out.logsout{15}.Values.Data;
Africmec = out.logsout{32}.Values.Data;
Wd = out.logsout{5}.Values.Data;

figure(1);
hold on
plot(t,velref,’k-‘,’LineWidth’, 2,’DisplayName’,’reference velocity’);
plot(t,vel,’b-‘,’LineWidth’, 1,’DisplayName’,’actual velocity’);
legend;
title(‘The actual velocity of the vehicle and the drive cycle ‘);
ylabel(‘Velocity (m/s)’);
xlabel(‘Time (s)’);
xlim([0 660]);

figure(2);
hold on
subplot(5,1,1);
plot(t,Tengine);
title(‘Engine Torque’);
```

```
ylabel('Torque (Nm)');
xlim([0 660]);
grid on

subplot(5,1,2);
plot(t,Tbrake);
title('Brake Torque');
ylabel('Torque (Nm)');
xlim([0 660]);
grid on

subplot(5,1,3);
plot(t,Tfricmech);
title('Frictional Transmission Torque');
ylabel('Torque (Nm)');
xlim([0 660]);
grid on

subplot(5,1,4);
plot(t,Trr);
title('Rolling Resistance Moment');
ylabel('Torque (Nm)');
xlim([0 660]);
ylim([78.5780 78.5782])
grid on

subplot(5,1,5);
plot(t,Taero);
title('Aerodynamic Resistance Moment');
xlabel('Time (s)');
ylabel('Torque (Nm)');
xlim([0 660]);
grid on

figure(2)
a = Aj;
g = a + Wd;
c = Abrake;
d = Aengine;
x = Aaero;
y = x + Arr;
z = y + Africmec;

hold on;
subplot(4,1,1);
area(t,d,'facecolor','k');
title('Engine Energy');
ylabel('Energy (J)');
xlim([0 thefinaltimeofdrivecycle]);
ylim([0 upperylimit]);
grid on

subplot(4,1,2);
```

```
area(t,abs©,'facecolor','c');
title('Brake Energy');
ylabel('Energy (J)');
xlim([0 thefinaltimeofdrivecycle]);
grid on

subplot(4,1,3);
hold on;
area(t,z,'facecolor','b','DisplayName','Frictional transmission Energy');
area(t,y,'facecolor','g','DisplayName','Rolling resistance Energy');
area(t,x,'facecolor','y','DisplayName','Aerodynamic resistance Energy');
legend;
title('Losses Energy');
ylabel('Energy (J)');
xlim([0 thefinaltimeofdrivecycle]);
grid on

subplot(4,1,4);
hold on;
area(t,g,'facecolor','r','DisplayName','Vehicle Inertia Energy');
area(t,a,'facecolor','m','DisplayName','Wheel Inertia Energy');
legend;
title('Total kinetic Energy');
xlabel('Time (s)');
ylabel('Energy (J)');
xlim([0 thefinaltimeofdrivecycle]);
ylim([0 upperylimit]);
grid on

figure(3)
a = Pj;
b = a + Pactual;
c = Pbrake;
d = Pengine;
x = Paero;
y = x + Prr;
z = y + Pfricmec;

hold on;
subplot(4,1,1);
area(t,d,'facecolor','k');
title('Engine Power');
ylabel('Power (W)');
xlim([0 thefinaltimeofdrivecycle]);
grid on

subplot(4,1,2);
area(t,c,'facecolor','c');
title('Brake Power');
ylabel('Power (W)');
xlim([0 thefinaltimeofdrivecycle]);
grid on
```

```
subplot(4,1,3);
hold on;
area(t,z,'facecolor','b','DisplayName','Frictional transmission Power');
area(t,y,'facecolor','g','DisplayName','Rolling resistance Power');
area(t,x,'facecolor','y','DisplayName','Aerodynamic resistance Power');
legend;
title('Losses Power');
ylabel('Power (W)');
xlim([0 thefinaltimeofdrivecycle]);
grid on

subplot(4,1,4);
hold on;
area(t,b,'facecolor','r','DisplayName','Vehicle Inertia Power');
area(t,a,'facecolor','m','DisplayName','Wheel Inertia Power');
legend;
title('Actual Power');
xlabel('Time (s)');
ylabel('Power (W)');
xlim([0 thefinaltimeofdrivecycle]);
grid on
figure(4)
a = Aj;
g = a + Wd;
b = g + Africmec;
c = b + Arr;
d = c + Aaero;
e = d + abs(Abrake);
f = Aengine;

hold on;
area(t,e,'facecolor','c','DisplayName','Brake Energy');
area(t,d,'facecolor','y','DisplayName','Aerodynamics resistance Energy');
area(t,c,'facecolor','g','DisplayName','Rolling resistance Energy');
area(t,b,'facecolor','b','DisplayName','Frictional transmisson Energy');
area(t,g,'facecolor','r','DisplayName','Vehicle Inertia Energy');
area(t,a,'facecolor','m','DisplayName','Wheel Inertia Energy');
plot(t,f,'k—','LineWidth', 2,'DisplayName','Engine Energy');
legend;
title('Balancing Energy');
xlabel('Time (s)');
ylabel('Energy (J)');
xlim([0 thefinaltimeofdrivecycle]);
grid on
figure(5)
end_Arr = Arr(end);
end_Aaero = Aaero(end);
end_Africmec = Africmec(end);
end_Abrake = abs(Abrake(end));
data = [end_Africmec,end_Abrake, end_Arr, end_Aaero,];
total = sum(data);
labels = {'Africtrans','Abrake','Arr', 'Aaero'};
```

```
percent_labels = cellfun(@(x) sprintf('%s (%.1f%%)', x, 100 * data(strcmp(labels, x)) / total), labels, 'UniformOutput', false);
pie(data, labels); % plot pie chart
title('The losses energy rate of the drive cycle'); % diagram label
legend(percent_labels);
```

Reference

[1] R. N. Jazar, *Vehicle dynamics : theory and application*. Cham: Springer, 2018.

[2] The Vietnamese Transport Ministry (2015). QCVN 09:2015/BGTVT: National technical regulation on Safety and environmental protection for automobiles

[3] "VisibleBreadcrumbs," *Mathworks.com*, 2024. https://www.mathworks.com/help/sdl/ref/tiremagicformula.html

[4] R. N. Jazar, *Vehicle dynamics : theory and application*. Cham: Springer, 2018.

[5] "Frictional brake with pressure-applying cylinder and pads with faulting - MATLAB," *www.mathworks.com*. https://www.mathworks.com/help/sdl/ref/discbrake.html

[6] "Double-Shoe Brake - Frictional brake with two pivoted shoes diametrically positioned about a rotating drum with triggered faulting - MATLAB," *Mathworks.com*, 2024. http://mathworks.com/help/sdl/ref/doubleshoebrake.html (accessed Jun. 04, 2025).

[7] Dang Long Tran, *Automotive Computer-Controlled Systems*. 2021.

[8] Dang Long Tran, *Automotive Computer-Controlled Systems*. 2021.