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Development of Flywheel Regenerative Capture System to Improve Electric Vehicle Energy Captured System

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***Abstract*—Regenerative Braking System (RBS) converts kinetic energy into electrical energy by using a motor and functions as a generator when decelerations occur. Regenerative braking is an effective alternative to increase the driving range of a vehicle and can save around 8% - 25% of the total energy used by a vehicle. The purpose of this research is to produce a design of the FRCS Braking System (Flywheel Energy Regenerative Capture System) and its system topology. The design of this system is to optimize the download of vehicle kinetic energy based on the duration of energy transfer that occurs. This study focuses on the flywheel energy download system and is done by numerical simulation using Simulink. The method to be designed is to apply FRCS topologies.**

***Keywords*—RBS, FRCS,numeric simulation,topologies**

I. INTRODUCTION

Electric vehicle (EV) is an alternative step for reducing carbon dioxide pollution in ICE vehicles towards zero emissions climate. Technology electric vehicle has been growing rapidly with high costs in the development, production and use. Batteries are the main element that affects the high cost of these vehicles. Some of the electric vehicles that have been introduced to the consumer market and mass produced include Tesla Roadster, Nissan Leaf, Mini E and Mitsubishi iMiEV. Most electric vehicles use the same type of transmission as conventional vehicle, namely the clutch, drive shaft, gearbox and differential. Like conventional's, transmission affects the efficiency and mass of the vehicle. When viewed from its characteristics, the electric vehicle is different from conventional's. Electric vehicle provides maximum torque at low speeds, while conventional's provides maximum torque at certain speeds. Until now, the weakness of the electric vehicle is the limit of electrical energy that can be used while driving. This weakness can be anticipated by the existence of system regenerative braking. Regenerative braking is an important technology for improving energy efficiency and driving distance on Electic Vehicles [6]. The regenerative braking method has gained more popularity when used in Formula 1 (F1) vehicles. Electro-mechanical regenerative braking system (RBS) converts kinetic energy into electrical energy by using a motor and functions as a generator when decelerations occur. Regenerative braking is an effective alternative to increase the driving range of a vehicle and can save around 8% - 25% of the total energy used by a vehicle, depending on the driving cycle and driving method [10]. The results of the study show that up to 50% of total braking energy can be reused in urban driving cycles [8]. In a Regenerative braking design system, braking strategies and increased vehicle efficiency are very important. Almost all electric vehicles like the Prius, Leaf and S Model, are designed to be driven by axle motors, either regenerative brake or mechanical brake (conventional brake) designed to work serially or parallel [4, 12]. The motor will provide braking torque to the wheels and braking in this way compared to conventional braking causing several effects, namely the presence of wheel lock and slip and pounding on the vehicle [9]. Regenerative braking can work with existing ABS systems. Integrated RBS and ABS utilize as much as possible the transfer of energy through the wheels without locking the wheels of the vehicle. [12] designed and observed the performance of electro mechanical RBS integrated in electric buses. When the pedal position reaches 40%, the wheels start to lock, one by one. The ABS system then works to control air pressure, sends a signal that reduces regenerative braking gradually to zero, thus ensuring the stability of the vehicle by transferring the braking power control back to ABS. Various forms of Regenerative braking applications, one of which is Hybrid Powertrain. Hybrid powertrain is equipped with a secondary power source that can increase fuel economy on hybrid vehicles. Hybrid powertrain is also equipped with energy storage devices (ESD) including batteries, ultracapacitors and hydropneics in hybrid vehicles [9]. [5] shows the capture of Regenerative Braking energy with Downshift Transmission. The braking system uses a hydraulic braking system (HBS). Meanwhile, a thermoelectric generator converts heat from an engine system into electrical energy. [2]. Furthermore, one of the important components for downloading energy in the regenerative braking system is

Flywheel. According to [3, 7] the flywheel energy storage system produces greater energy efficiency compared to lithium-ion batteries and energy consumption (energy released) decreases by 22.7%. Based on the class of vehicle used, the energy delivered (delivered energy) by the flywheel is different. For light duty vehicles, the amount of energy delivered is 0.3 - 0.5 kWh (1.08 - 1.80 MJ). For heavy duty vehicles, the amount of energy delivered is 2 kWh (7.2 MJ) [2]. The purpose of this research is to produce a design of the FRCS Braking System (Flywheel Energy Regenerative Capture System) and its system topology. The design of this system is to optimize the download of vehicle kinetic energy based on the duration of energy transfer that occurs.

II. METHODS

A. Phenomenon of Research Objects

The phenomenon of FRCS research objects is based on driving patterns when acceleration, constant speed and deceleration occur. Here is a form of urban cycle driving patterns for vehicles shown by [11], [1].

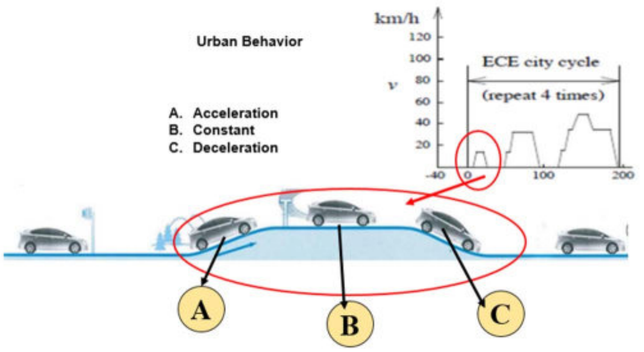


Figure 1 Driving pattern on the Urban Driving Cycle

To take the kinetic energy of a vehicle with a driving pattern of urban driving cycle, it is done by doing three (3) deceleration models namely deceleration without braking, deceleration with braking and gearshift-based decelerations. Energy that cannot be captured is caused by rolling resistance consumption, water resistance consumption, ramp consumption and heat consumption. Only components that rotate with large dimensions (motors / generators, tires / wheels and driveline) that contribute to analyzing energy that can be reused [5]. The following is a form of FRCS system design in the research conducted.

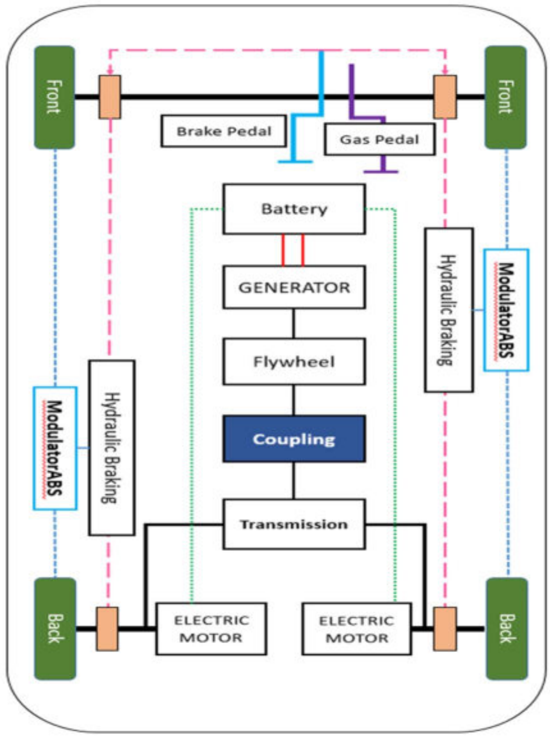
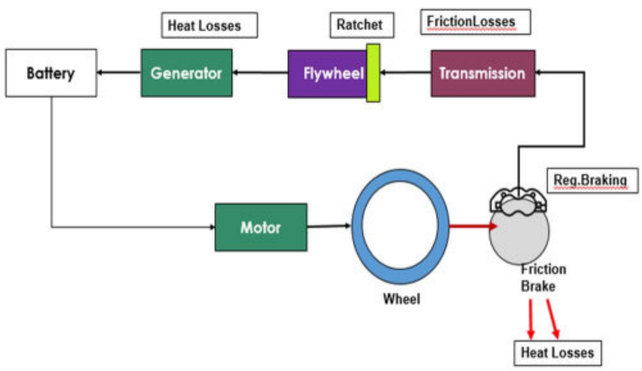


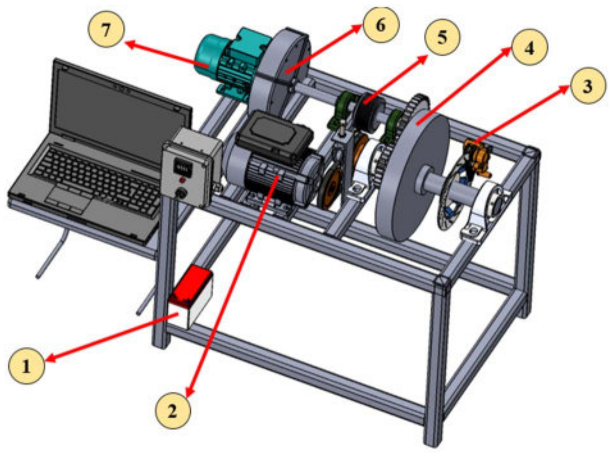
Figure 2. FRCS concept

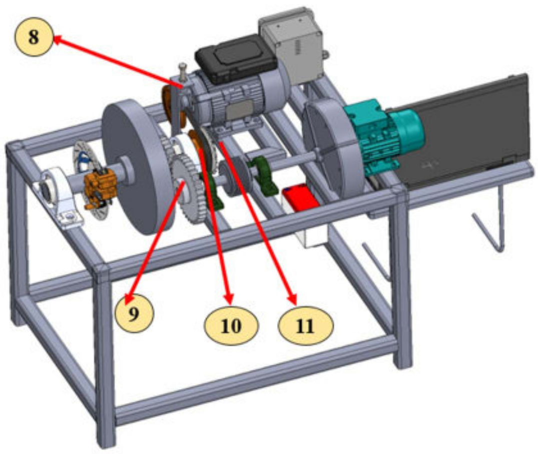
B. Flywheel Energy Regenerative Capture System (FRCS)

The flywheel energy storage system with mechanical transmission allows regenerative braking and power enlargement during acceleration when applied to vehicles. Flywheel is a passive device that requires an actively controlled transmission that is able to provide torque to the flywheel for the FRCS device charge and discharge process. The type of transmission used can be a type of mechanical transmission or electric transmission. The form of system topology design as shown in figure 3. This topology is representative of the vehicle layout in figure 2 above.



That is illustration of simple FRCS from figure 2 FRCS concept





The components consist of: 1) Battery, 2)Electric motor, 3) Brake, 4) *Flywheel (W)* as vehicle's wheel, 5) coupling, 6) *Flywheel (F)* as energy harvesting, 7)Generator, 8) *Tensioner*, 9) *Gear to gear connection*, 10) Belt Connection

FRCS 2D model :

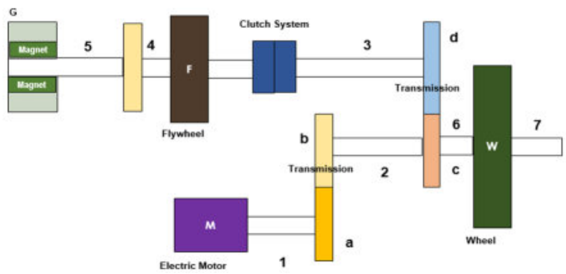
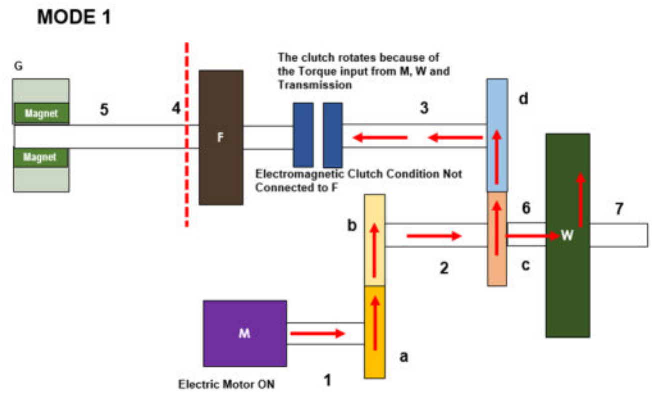


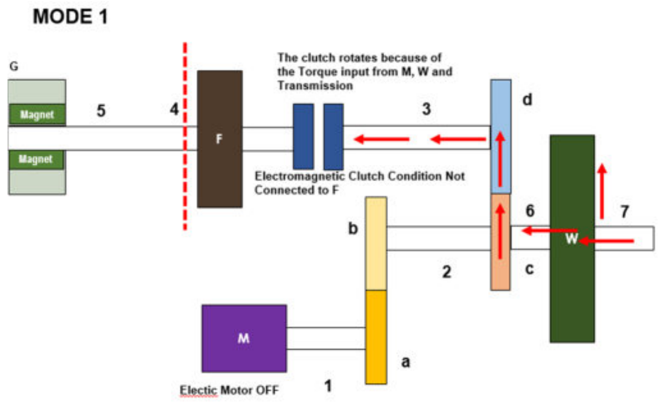
Figure 3. Topology FRCS without ratchet

From the picture above can be explained below, Flywheel Simulator - Wheels represent the wheels of a vehicle, an electric motor is a driving unit of the vehicle. Flywheel capture energy represents a mechanism for retrieving kinetic energy from wheel speed and vehicle speed. The generator is a kinetic energy storage unit into electrical energy which is a source of additional energy for vehicle propulsion. The way the FRCS system works is as follows:

MODE 1



Mode 1 (a) electric motor ON



Mode 1(b) electric motor OFF

Figure 4. Work mode 1 FRCS

In mode 1 there are two events that take place, namely:

a) When the vehicle starts running it will have a speed of Va1. In a certain period of time the vehicle speed will increase so that from the speed of Va1 to Va2 speed. This is illustrated in mode 1 - A, namely the Electric Motor ON in the Plant, moves the Flywheel (W) wheel with a clutch condition that is not connected to the Flywheel (F).

b) After having a constant speed, the Electric Motor is OFF at the plant. The system which initially received the initial torque input from the Electric Motor will be replaced by a Flywheel Torque (W; wheel) which becomes the torque input for the system

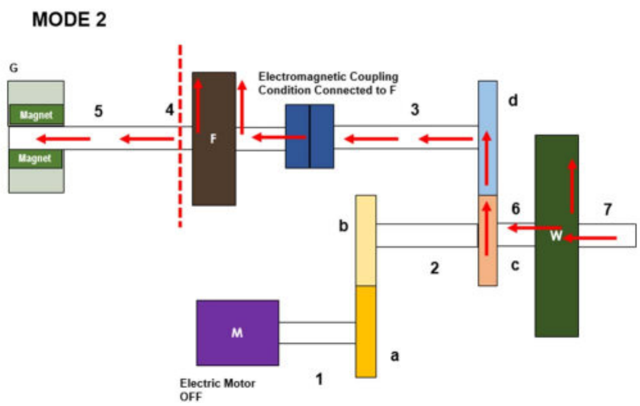


Figure 5. Work mode 2 FRCS

In mode 2 of this system, events that take place are:

a) When braking on a vehicle, the brake system will be active. The electromagnetic clutch will be connected to the Flywheel (F) Plant. In this condition the electric motor is OFF (the electric motor is a representative of the gas pedal, so when braking is done, the gas pedal is lifted).

b) During this braking process, there is a transfer of the Flywheel (W; wheel) torque speed to the flywheel (F). With this torque transfer speed, the energy download process at the flywheel (F) is faster. In the FRCS topology equipped with a ratchet, an anti-reverse flywheel (F) will occur. The ratchet system will capture the impulse that occurs when there is braking of the vehicle as a regenerative energy input.

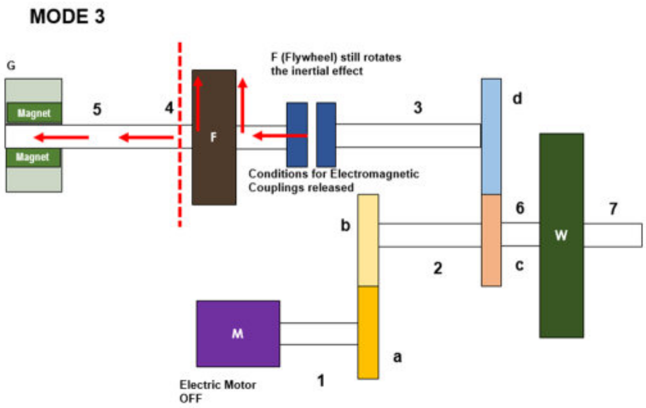


Figure 6. Work mode 3 FRCS

In this third mode, the process took place :

a) The electromagnetic clutch is removed, after braking. The Flywheel (F) keeps spinning because the inertial effect gets a torque transfer speed from the flywheel (W). From the braking process in the previous mode 2, the flywheel (F) has downloaded kinetic energy. So that it can be used again as a thrust vehicle.

III. Result and Discussion

The forms of FRCS modeling are as follows:

1. Modeling of Electric Motors - Transmission - Flywheel (W) (Wheel Simulator)

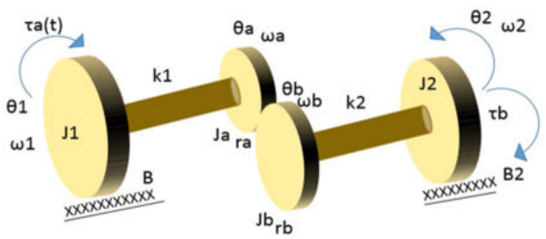
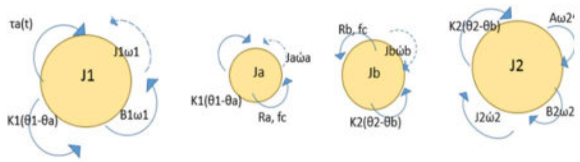


Figure 7. 4DOF Dynamic Modeling

Free Body Diagram (FBD) modeling is:



State Variabel :

$$\dot{\omega}1 = \frac{1}{J1}\big(-B1\omega1 - k1(\theta1 - \theta a) + \tau a(t)\big)$$

$$\dot{\omega}2 = \frac{1}{J2}(-B2\omega2 - A\omega^2 - k2(\theta2 - \theta b)$$

$$\dot{\omega}a = \left[\left(\frac{1}{Ja + \frac{Jb}{N^2}}\right] . \left[\left(\frac{k2}{N}(\theta2 - \theta b)\right]$$

$$\dot{\theta}1 - \dot{\theta}a = \omega1 - \omega a$$

$$\dot{\theta}2 - \dot{\theta}b = \omega2 - \frac{1}{N}\omega a$$

$$\dot{\omega}a = \left[\left(\frac{1}{Ja + \frac{Jb}{N^2}} . (k1(\theta1 - \theta a))\right] + \left[\frac{1}{Ja + \frac{Jb}{N^2}}\left(\frac{k2}{N}(\theta2 - \theta b)\right)\right]$$

2. Coupling modelling

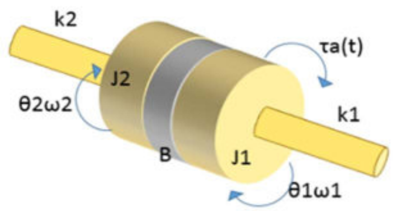
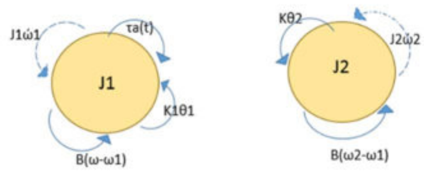


Figure 8. 2 DOF Dynamic Modeling

Free Body Diagram (FBD) modeling is:



State Varibel :

$$\dot{\theta}1 = \omega1$$

$$\dot{\omega}1 = \frac{1}{J1}\big(-k1\theta1 - B\omega1 + B\omega2 + \tau a(t)\big)$$

$$\dot{\theta}2 = \omega2$$

$$\dot{\omega}2 = \frac{1}{J2}(B\omega1 - k2\theta2 - B\omega2)$$

Where $\tau a = B(\omega2 - \omega1)$

3. Modeling of Flywheel (F) (Flywheel Capture) - Generator

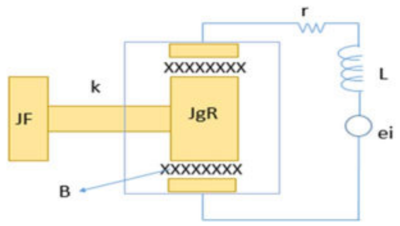
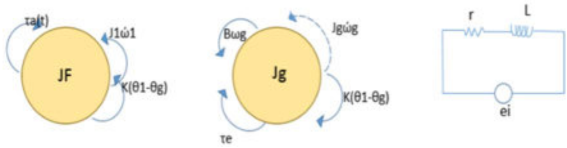


Figure 9. 3 DOF Dynamic Modeling

Free Body Diagram (FBD) modeling is :



State Variabel :

$$\dot{\omega}1 = \frac{1}{JF}(-k(\theta 1 - \theta g) + \tau a(t))$$

$$\dot{\omega}g = \frac{1}{Jg}(-B\omega g + k(\theta 1 - \theta g) + \tau e) \text{ where } \tau e\text{=di}$$

$$\frac{di}{dt} = \frac{1}{L}(-\propto v - ri + ei)$$

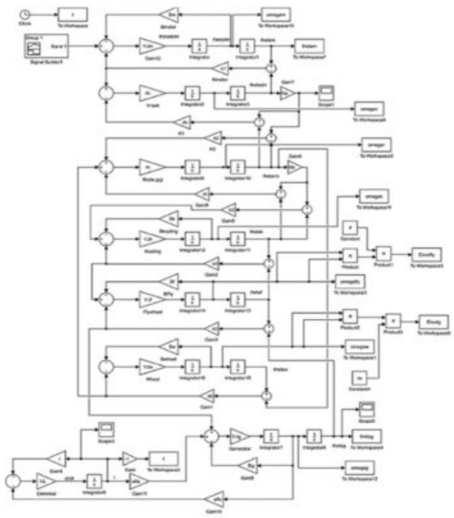


Figure 13. Block of FRCS Plant simulink diagram

The numerical simulation results based on the FRCS Simulink diagram modeling and block are as follows:

a. ABS Optimal V= 100 km/h

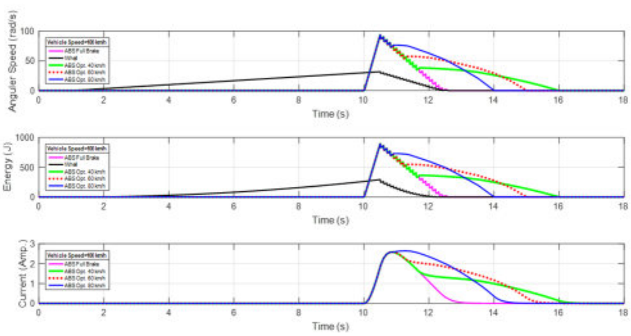


Figure 14. ABS Optimalwith V=100 km/h

b. ABS Optimal v=80 km/h

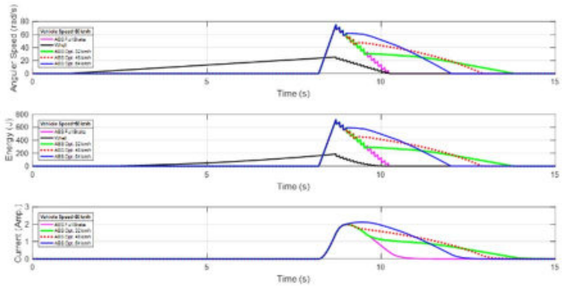


Figure 15. ABS Optimal with V=80 km/h

c. ABS Optimal v=60 km/h

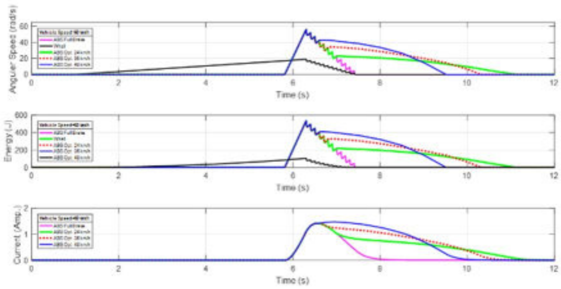


Figure16. ABS Optimal with V=60 km/h

d. ABS full brake

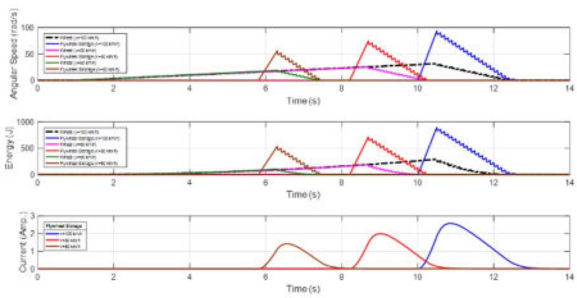


Figure 17. ABS Fullbrake

e. Omega for ABS Optimal

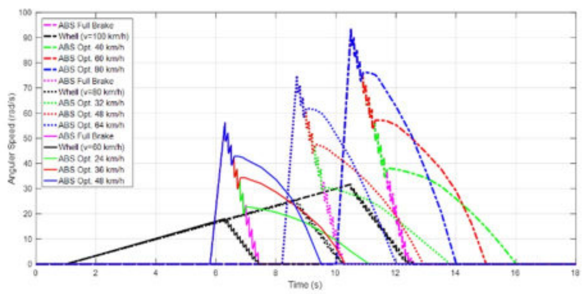


Figure 18. Omega for ABS Optimal

In the graph, it is a study of the development of the ABS brake system by optimizing the percentage in deciding on a flywheel at a certain speed. In analyzing the graph, researchers made 3 variations of speed to see their tendency. The variation of speed used is 100 km / h, 80 km / h, & 60 km / h and variations in speed will be made variations in terms of optimization of flywheel release with a percentage of 80%, 60%, 40%, and 0% (full brake)) The black line is a representation of the speed of the vehicle from stopping until then the brake and stop is carried out, where at vehicle speeds of 100 km / h, 80 km / h, and 60 km / h are obtained for each angular maximum speed on the wheel each of 32 rad / s, 25 rad / s, and 18 rad / s.

IV. CONCLUSION

It can be seen in the speed variation of 100 km / h obtained when full-brake without optimal release, the vehicle will stop at an interval of 2.2 seconds with an angular maximum speed of 94 rad / s. At an optimal variation of 80%, the vehicle speed at discharge is 80 km / h and the flywheel stops at an interval of 4 seconds. At an optimal 60% vehicle speed of 60 km / h when discharged with a time interval of stop of 5 seconds, while at optimal 40% the speed is 40 km / h with an interval of 6 seconds

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