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TOPICS

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+ Electric Motors & Generators
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Hybrid Electric Vehicles

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Simulink Modeling for Hybrid Vehicle Dynamic Characteristics

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Abstract

The recent environmental interests and concerns have an effect on the entire vehicle industry. Since the regulations like limiting the emission of greenhouse gases take into effect, people are more interested in green vehicles such as hybrid vehicle, electric vehicle, and fuel cell vehicle for they emit less greenhouse gases than conventional vehicle. Especially, hybrid vehicle is the most commercialized vehicle among green cars. The maximum velocity and the acceleration characteristic of a vehicle are important factors to figure out the performance of the vehicle. Driving real vehicle adjusting parameters like mass, frontal area, etc. may be accurate. However, this method costs highly and readjusting parameters may take too much time. So using programs and simulating the vehicle model may save time and money. In this study, hybrid vehicle will be modeled using MATLAB Simulink and the dynamic characteristics of the vehicle will be figured out considering some conditions.

The type of hybrid vehicle model will be 6-wheel series hybrid combat vehicle using In-Wheel motor. The forces acting on the vehicle were calculated to figure out the dynamic characteristics of vehicle. Tractive force from each motor in each wheel can be calculated and resistive force such as drag resistance, rolling resistance, and slope resistance can also be calculated. After calculating net force on the vehicle, instantaneous acceleration and velocity can be obtained. The maximum velocity of the vehicle can be calculated when the resistance force and tractive force are equal during process of feedback of instantaneous velocity. If there are errors between characteristic of Simulink model and real model, discussions will be added.

Keywords: dynamic characteristic, hybrid vehicle, maximum velocity

1 Introduction

The growth of environmental interest resulted in many effects on entire vehicle industry. Regulations such as limiting the emission of greenhouse gases will be strengthen and there are efforts to reduce carbon dioxide emission with carbon footprint, carbon emission trading etc. This increasing demand for environmentally friendlier vehicles made automotive companies to focus on electric vehicles, hybrid electric vehicles, and other kinds of eco-friendly vehicles
[1]-[3].

Especially, hybrid electric vehicle (HEV) is the most commercialized vehicle among green cars, since other kinds of green cars have their own limit in driving range or efficiency. HEV is a vehicle using two or more energy sources; normally electric motor powered by battery and combustion engine using fossil fuels as an energy source [1]

It is important to figure out the performance of the hybrid vehicle with given parameters such as vehicle mass, frontal area, wheel radius etc. Driving a real vehicle may be an accurate method to find it, however, adjusting vehicle parameters on every experiment will take too much cost and time. So it is desirable to build a simulation with programs for this method can save time and money.

In this paper, dynamic equations will be discussed for describing dynamic characteristics of series In-Wheel driven HEV. Then using MATLAB Simulink model will be built with equations. Finally, dynamic characteristics of HEV will be figured out considering some conditions.

2 Dynamic Equations

To build a simulation, some dynamic equations are needed. Since resistance forces and traction force is the main forces that affects the vehicle acceleration, each of them will be discussed in this session [4]. Figure 1 describes the forces acting on a vehicle. M is mass of the vehicle, θ is grading angle, g stands for gravitational acceleration, F_T is tractive force acting on a vehicle, and F_r, F_D, F_G are resistance forces acting on a vehicle, each of which will be discussed later.

2.1 Resistance Forces

Resistance force acts as a load of the vehicle that prevents the vehicle from accelerating. Three kinds of forces will be discussed.

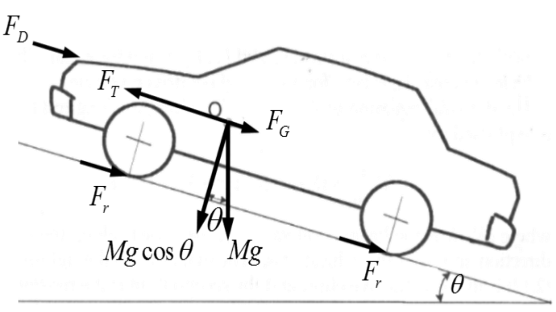


Figure 1: Forces acting on a vehicle

2.1.1 Grading Resistance

Grading Resistance acts when a vehicle is on the slope. Grading resistance force F_G can be written as (1)

$$F_G = Mg\sin\theta \quad \text{[N]} \tag{1}$$

2.1.2 Drag Resistance

Drag Resistance occurs while air flows over the vehicle. Defining ρ to be air density, A_f to be frontal area of the vehicle, C_D to be drag coefficient, V to be velocity of vehicle, and V_w to be wind velocity, drag resistance force F_D can be written as (2).

$$F_D = \frac{1}{2}\rho A_f C_D \left(V + V_w\right)^2 \quad \text{[N]} \tag{2}$$

The value of drag coefficient varies depending on the type of vehicle. Commonly, range of drag coefficient value of cars is 0.3 to 0.35, and 0.42 to 0.46 in case of pickup trucks [4].

2.1.3 Rolling Resistance

Rolling resistance is generated when tire deflects due to the ground condition. Rolling resistance force F_r can be defined as (3) when f_r is rolling resistance coefficient.

$$F_r = Mgf_r\cos\theta \quad \text{[N]} \tag{3}$$

The value of rolling resistance coefficient varies depending on the type of vehicle and the type of surface. The values are shown in Table 1 [4].

2.2 Traction Force

Traction force accelerates the vehicle to the front direction. In series HEV electric motor solely generates the force while the combustion engine charges the battery pack. The relationship between power of the motor and traction forces will be discussed [5].

Table 1: Values of rolling resistance coefficient

	Surface		
Vehicle Type	Hard Ball	Medium Hard	Sand
Passenger Cars	0.015	0.08	0.30
Heavy Trucks	0.012	0.06	0.25
Tractors	0.02	0.04	0.20

Table 2: Values of gear efficiency

Gear Type	Gear Efficiency
Direct Gear	90%
Other Gear	85%
Very high Reduction Gear	75-80%

Traction Force F_T can be written as (4) while r_d is wheel radius and T_w is wheel torque.

$$F_T = \frac{T_w}{r_d} \quad [\text{N}] \tag{4}$$

(5) shows the relationship between wheel torque and motor torque T_p

$$T_w = \lambda \eta_t T_p \quad [\text{Nm}] \tag{5}$$

λ is gear ratio and η_t is gear efficiency. Table 2 shows the values of gear efficiency depending on gear type [5].

Since the vehicle drives with In-wheel motor, direct gear is selected.

Vehicle velocity V can be expressed as (6) when N_p is rotating speed of motor and the relationship between motor torque and power of motor P can be written as (7)

$$V = \frac{\pi \cdot N_p \cdot r_d}{30\lambda} \quad [\text{m/s}] \tag{6}$$

$$T_p = \frac{60 \cdot P}{N_p \cdot 2\pi} \quad [\text{Nm}] \tag{7}$$

From equations (4)-(7), traction force acting on the vehicle is as follows

$$F_T = \frac{\lambda \cdot \eta_t \cdot P \cdot 60}{N_p \cdot 2\pi \cdot r_d} \quad [\text{N}] \tag{8}$$

With Newton's 2nd law equation and using equations (1)-(3), (8) acceleration of vehicle can be written as (9). [6]

$$a = \frac{F_T - (F_r + F_G + F_D)}{M} \tag{9}$$

3 Simulation and Results

With equations obtained Session 2, Simulation model can be built using MATLAB Simulink. In this paper, a combat series HEV model were chosen as an example model to examine the simulation and the dynamic characteristics of the vehicle are obtained. In this simulation, three kinds of inputs; vehicle properties, motor properties, and driving condition were put into the simulation model, the abstract of the model were depicted in Figure 2.

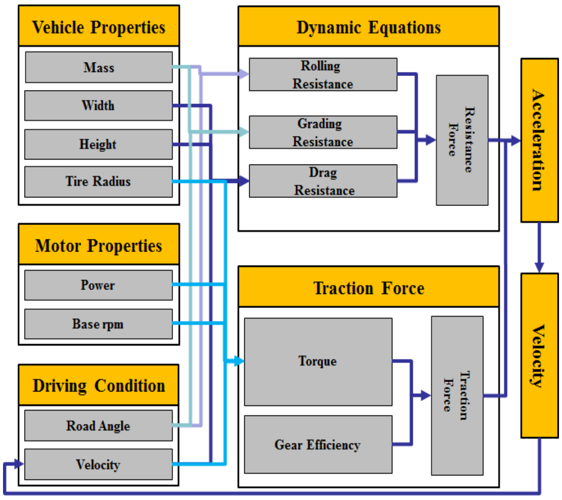


Figure 2: Abstract diagram of simulation model

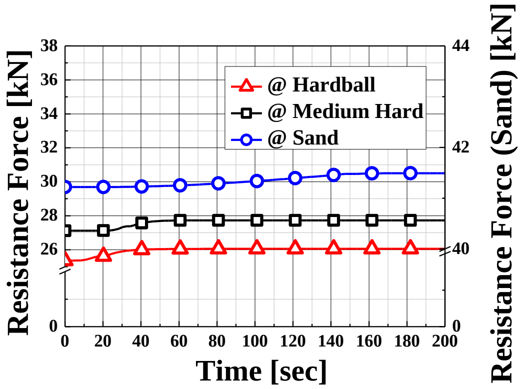
To obtain result of the simulation input parameters are needed. So in this paper, reference model of combat series HEV was adopted. Figure 3 shows the reference model and Table 3 shows the parameters of the vehicle [7].

The result obtained by the Simulink simulation contains traction force and resistance force acting on the vehicle, acceleration, and velocity. Figure 4 shows the result of the simulation. The road angle is 15°, initial velocity is 0 m/s, base rpm is 1900 rpm, and the power of the motor is 780 kW (130 kW each wheel).

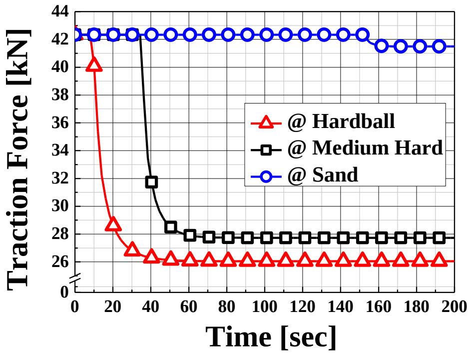
Figure 3: Autonomous Platform Demonstrator (APD)

Table 3: Values of parameters of APD

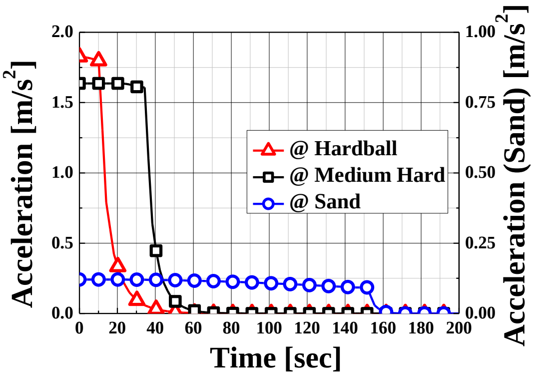
Parameters	Value
Acceleration (0-48.3km/h)	10.5 sec
Maximum velocity (Hardball)	80.5 km/h
Maximum velocity(Cross country)	45.1 km/h
Total Mass	9.30 ton
Height	2.20 m
Width	2.24 m
Wheel radius	0.50 m



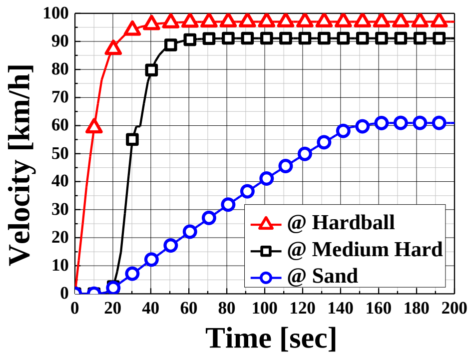
(a) Resistance force acting on a vehicle



(b) Traction force acting on a vehicle



(c) Acceleration of a vehicle



(d) Velocity of a vehicle

Figure 4: Dynamic characteristics of vehicle obtained from simulation

The simulation was done three times by changing the road condition (Hardball, Medium Hard, and Sand), which is related to rolling coefficient. This result tells us that it is harder to drive the vehicle in the sand than other road conditions.
Comparing characteristics between real vehicle model and simulation results at Hardball, some differences can be found. In case of the acceleration characteristic, in 10.5 seconds the vehicle speed rises up to 61.0 km/h while the real vehicle rises up to 48.3. Also, the maximum velocity of the result is 97.0 km/h while the maximum velocity of reference model is 80. This differences may occurred from parameters of motors that has not been informed in Table 3.

4 Conclusion

This paper explains the process of building simulations to obtain dynamic characteristics of series HEV with Simulink. Some dynamic equations were considered to build it. As a result, it is possible to simulate repeatedly change parameters of the vehicle on every trial without wasting cost and time.
The error of the result of the simulation has a possibility to decrease if the motor parameters are determined appropriately. Thus, further works that determining proper parameters of motor should be taken.

Acknowledgments

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