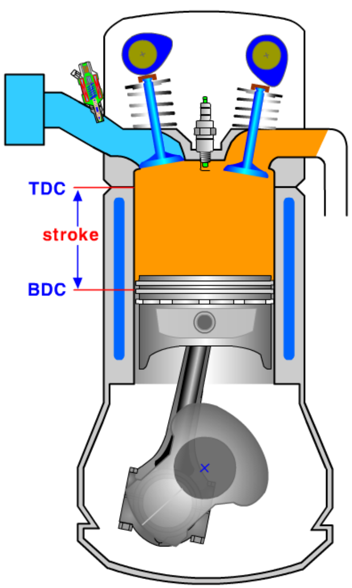
Contents

- Power Source : Engine/Motor
- Power Transfer : Clutch/Transmission
- Power Storage : Battery
- Driving Resistance
- Driver Controller
- HEV Model

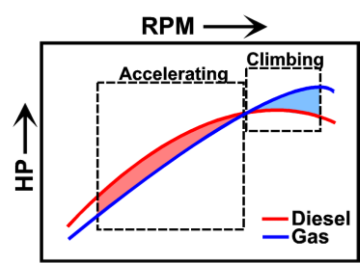
Engine

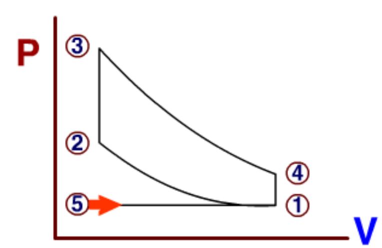
- Generation of the power to drive a vehicle
- Principle of operation
  - Force generation by fuel injection and ignition in the cylinder
  - Torque generation on a crank shaft from the force through the mechanical linkage

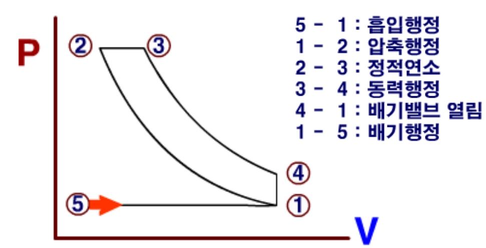


작동원리 Link

Specification	Gasoline Engine (Otto)	Diesel Engine
Ignition Type	Spark Ignition	Compression Ignition
Compression Ratio	Between 8:1 and 12:1	Between 16:1 and 22:1
Efficiency	25-30%	36-45%
Maximum Engine Speed	7000-8250 RPM	up to 5250 RPM
Exhaust Temperature (under full load)	700-1200 Degrees Celsius	300-900 Degree Celsius







Mean Value Model

- Input : fuel mass flow rate
- Output : engine torque

1. Engine dynamic equation

$$J_e \dot{\omega}_e = T_e = T_{ind} - T_{ext} - T_{loss}$$

J_e : engine equivalent inertia [kgm^2]

ω_e : engine angular velocity [rad/s]

T_e : engine output torque [Nm]

T_{ext} : external load torque [Nm]

T_{loss} : pumping and friction losses [Nm]

2. Indicated combustion torque

$$\dot{m}_f = \frac{\dot{m}_{ao}}{L_{th}} \qquad T_{ind} = \frac{H_u \eta_i \dot{m}_f}{\omega_e}$$

$\dot{m}_f$: air mass flow rate [kg/s]

$\dot{m}_{ao}$: fuel mass flow rate into cylinder [kg/s]

L_{th} : stoichiometric air/fuel mass ratio

T_{ind} : indicated combustion torque [Nm]

H_u : fuel energy constant [J/kg]

η_i : indicated efficiency

3. Pumping and friction losses

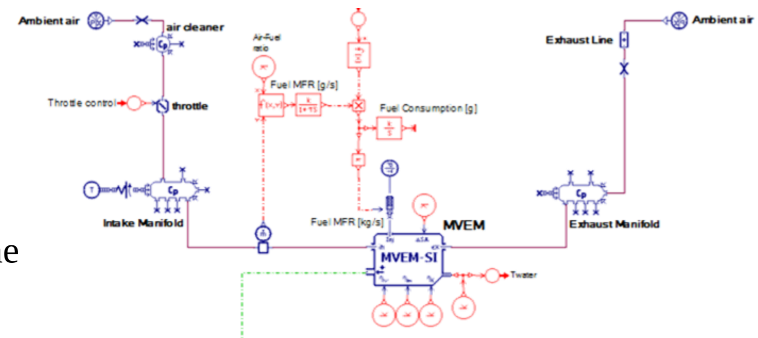
$$T_{loss} = F_{loss} + P_{loss}$$

$$F_{loss} = a_0 \omega_e^2 + a_1 \omega_e + a_2$$

$$P_{loss} = b_0 \omega_e p_{man} + b_1 p_{man}$$

a_0, a_1, a_2, b_0, b_1 : parameters dependent on specific engine

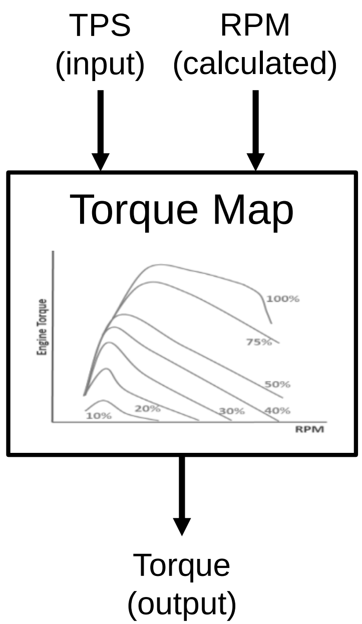
p_{man} : manifold air pressure [bar]

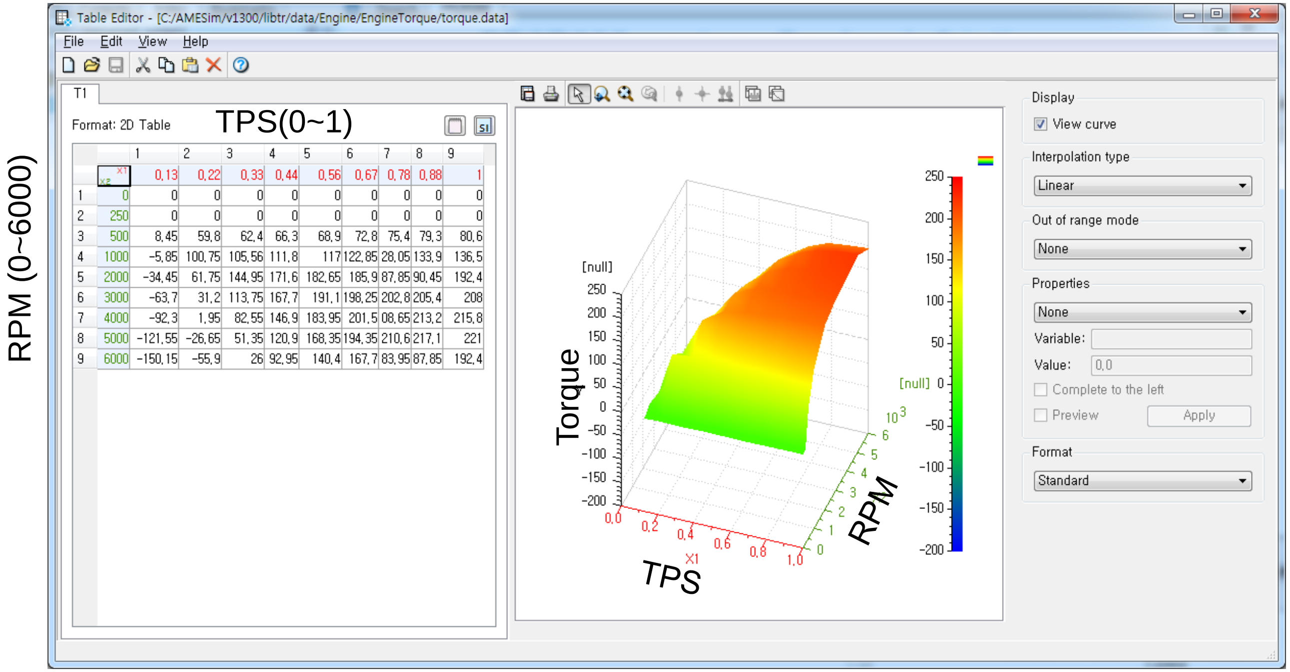


Torque Map Model

- Input : TPS(throttle position sensor)
- Output : engine torque
- Calculation of the engine torque from the experimental torque map

$$T_e = f(TPS, RPM)$$

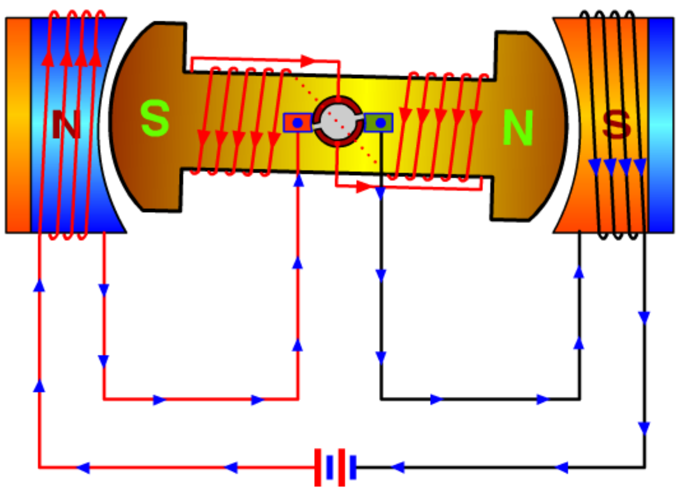




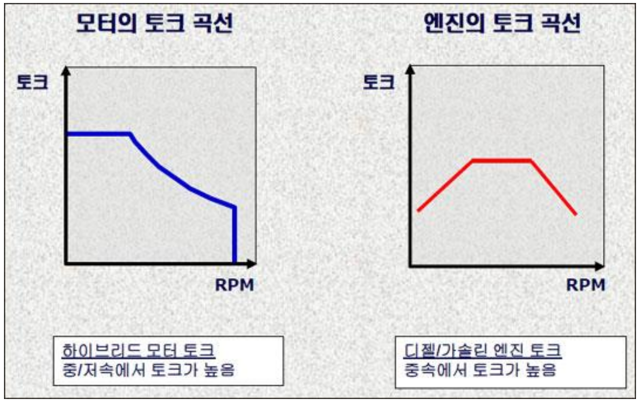
	X1 / X2	1	2	3	4	5	6	7	8	9
		0,13	0,22	0,33	0,44	0,56	0,67	0,78	0,88	1
1	0	0	0	0	0	0	0	0	0	0
2	250	0	0	0	0	0	0	0	0	0
3	500	8,45	59,8	62,4	66,3	68,9	72,8	75,4	79,3	80,6
4	1000	-5,85	100,75	105,56	111,8	117	122,85	28,05	133,9	136,5
5	2000	-34,45	61,75	144,95	171,6	182,65	185,9	87,85	90,45	192,4
6	3000	-63,7	31,2	113,75	167,7	191,1	198,25	202,8	205,4	208
7	4000	-92,3	1,95	82,55	146,9	183,95	201,5	08,65	213,2	215,8
8	5000	-121,55	-26,65	51,35	120,9	168,35	194,35	210,6	217,1	221
9	6000	-150,15	-55,9	26	92,95	140,4	167,7	83,95	87,85	192,4

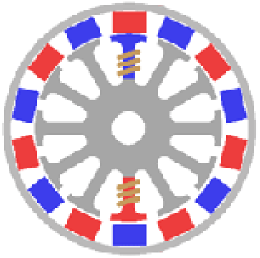
Motor

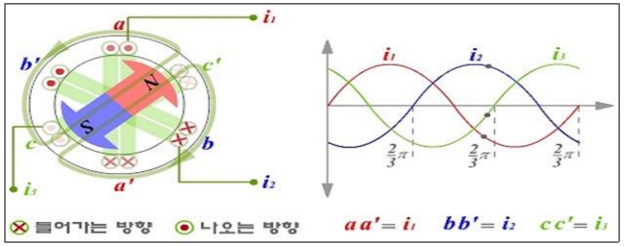
- Generation of the power to drive a vehicle
- Principle of operation
  - Generation of a rotating magnetic field from an electric current
  - Mechanical torque generation on a rotating shaft from the magnetic force



[작동원리 Link]

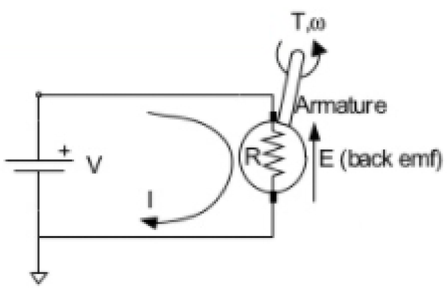






Electric Circuit Model

- Input : source voltage
- Output : motor torque



1. Circuit equation

$$V = IR + E_b$$

$$V \text{ :source voltage [V]}$$

I :electric current [A]

R :resistance [Ω]

E_b :back electro motive force [V]

2. Motor equations

$$E_b = K_e \omega_m$$

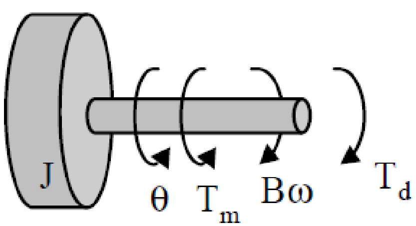
$$T_m = K_t I$$

K_e :back-EMF constant [Vs]

ω_m :motor shaft speed [rad/s]

$$T_m \text{ :motor torque [Nm]}$$

K_t :torque constant [Nm/A]



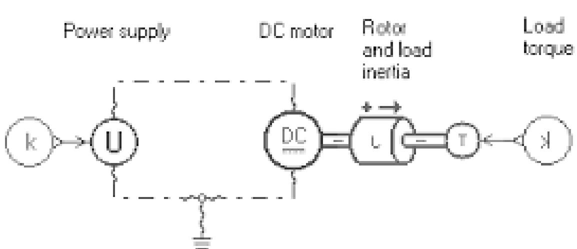
3. Motor dynamics

$$T_m - T_d = J\dot{\omega}_m + B\omega_m$$

T_d :drag torque [Nm]

J :motor inertia [kgm^2]

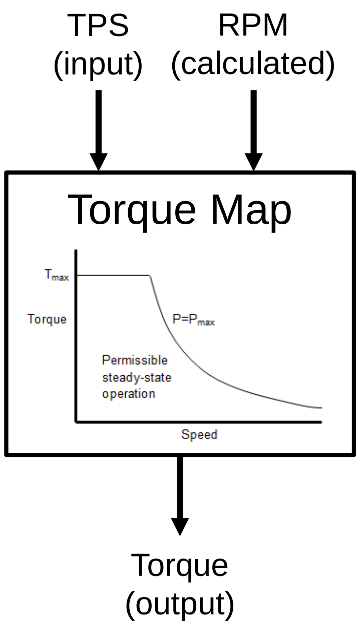
B :damping coefficient [Nms]

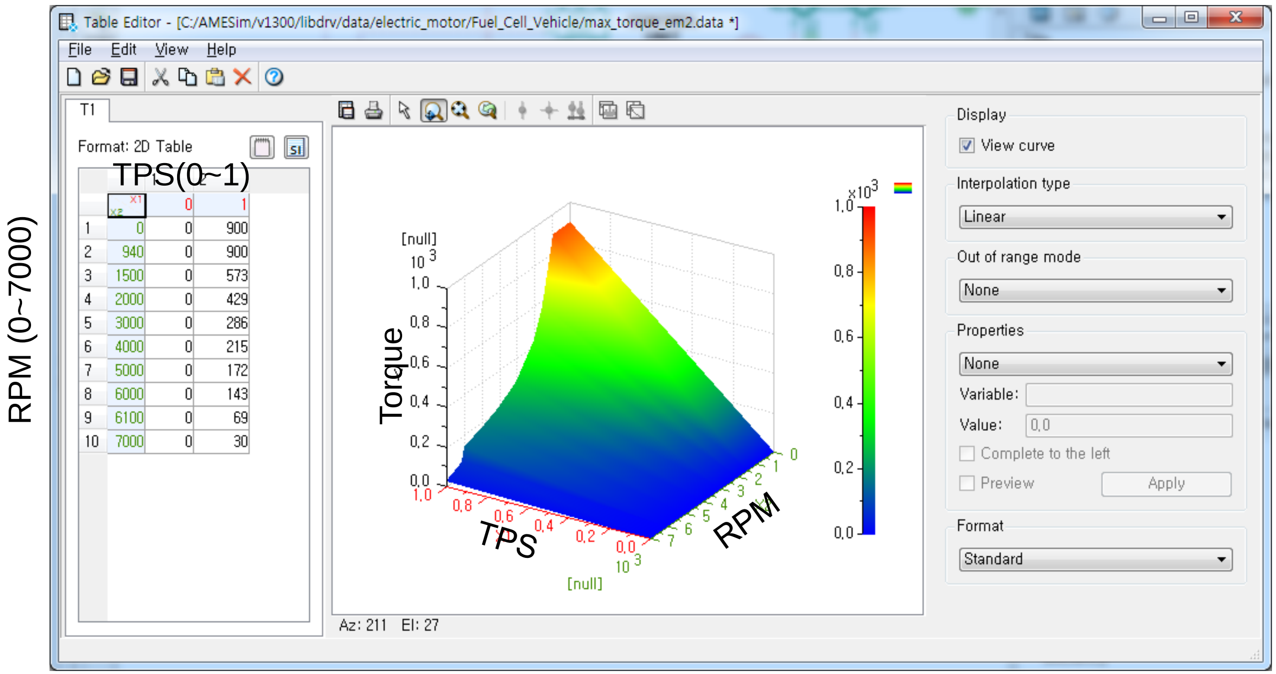


Torque Map Model

- Input : TPS(throttle position sensor)
- Output : motor torque
- Calculation of the motor torque from the experimental torque map

$$T_m = f(TPS, RPM)$$

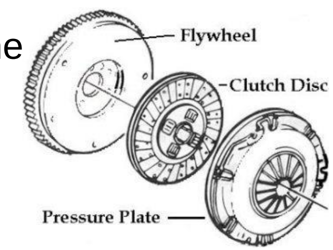




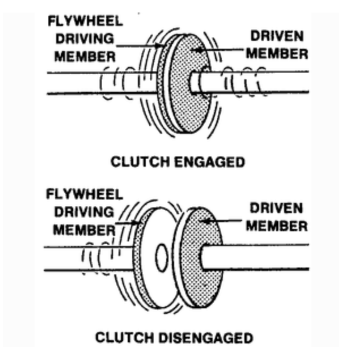
Clutch

- Torque transfer or cut-off between input and output shaft
- Principle of operation
  - Generation of the friction torque on a clutch disk by the clutch engaging or disengaging
  - Synchronization of both shaft speeds

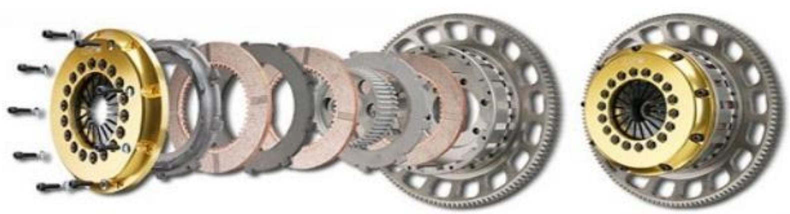
Engine side

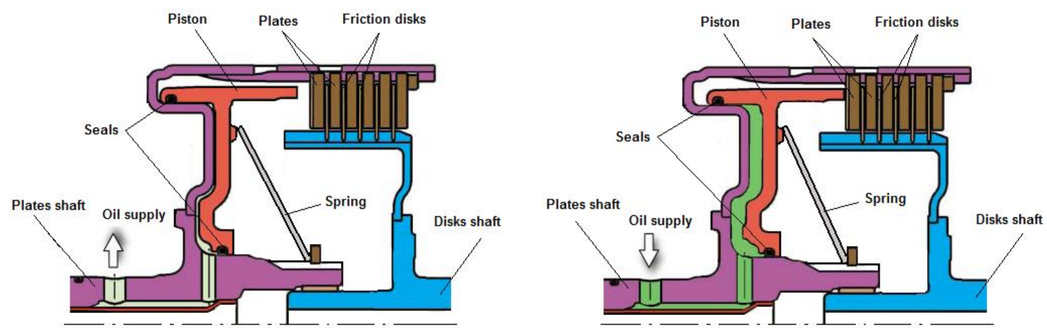


TM side



< Single Disk >





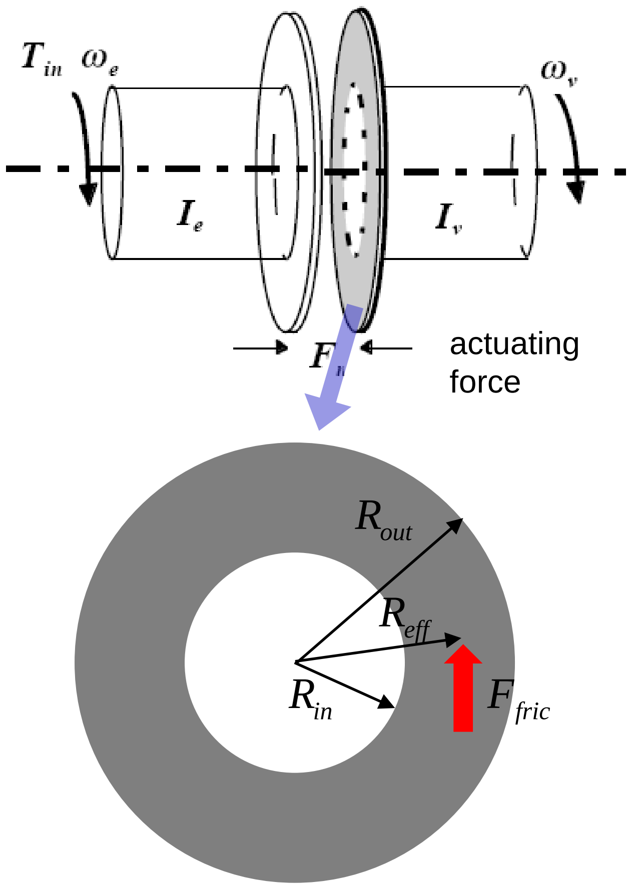
Disengaged

Engaged

< Multi Disk >

Friction Torque Model

- Input : clutch actuating force
- Output : output shaft torque



1. Output torque equation

$$T_{out} = \begin{cases} F_{fric} R_{eff} & (\omega_{rel} \neq 0) \\ T_{in} & (\omega_{rel} = 0) \end{cases}$$

F_{fric} :friction force [N]

R_{eff} :effective firction radius [m]

ω_{rel} :relative speed of shafts [rad/s]

2. Friction equation

$$F_{fric} = \mu_{disk} F_n$$

$$F_n = F_{act} \tanh\left(2 \frac{\omega_{rel}}{d\omega} \right)$$

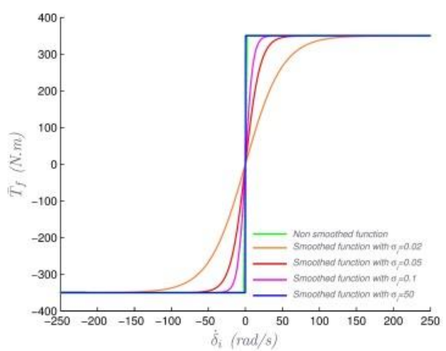
$$\omega_{rel} = \omega_e - \omega_v$$

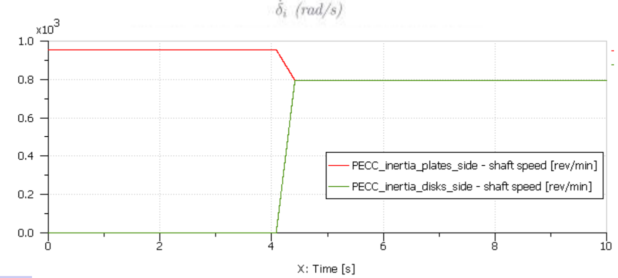
$$R_{eff} = \frac{2(r_{out}^3 - r_{in}^3)}{3(r_{out}^2 - r_{in}^2)}$$

μ_{disk} :friction coefficient

F_n :normal force on disk [N]

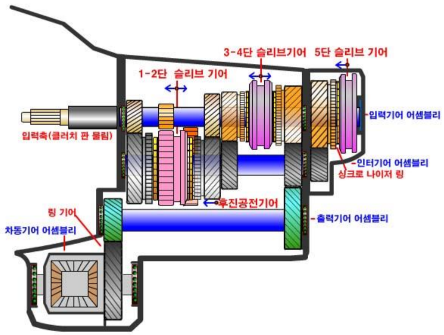
F_{act} :clutch actuating force [N]



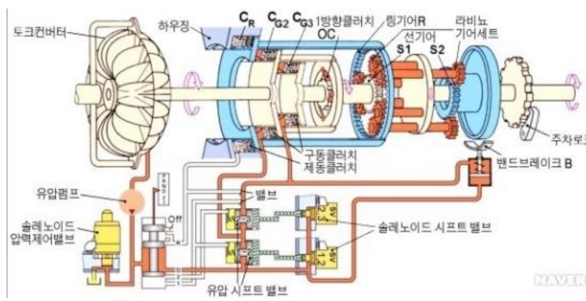


Transmission

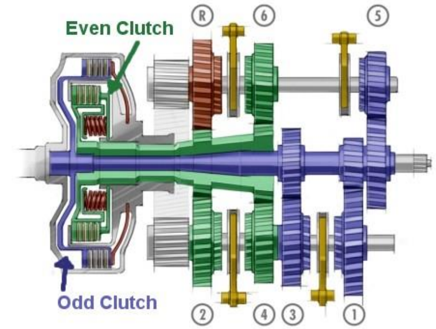
- Conversion of the torque and speed from input shaft to the proper torque and speed on output shaft
- Principle of operation
  - Selection of a proper gear by operating a clutch
  - Increasing or decreasing of the torque and speed from input shaft



< Manual Transmission(MT) >

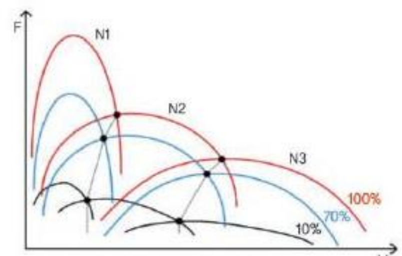


< Automatic Transmission(AT) >

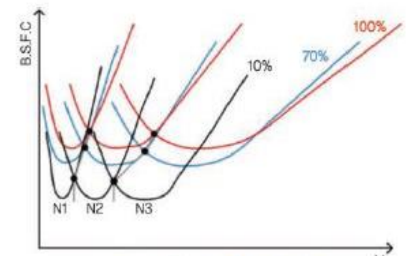


< Dual Clutch Transmission(DCT) >

	MT	AT	DCT
Efficiency	↑	↓	↑
Drivability	↓	↑	↑
Cost	↓	-	↑



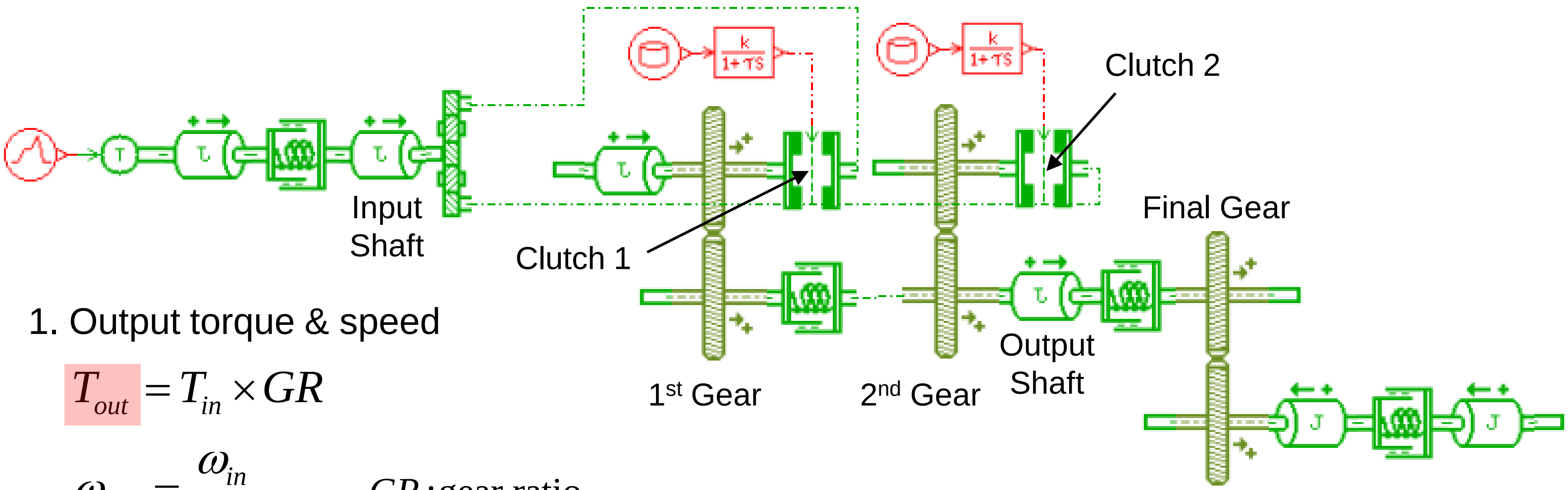
〈그림 6〉 파워 기준 변속시점



〈그림 7〉 연비 기준 변속시점

Spur Gear Model (MT)

- Input : clutch actuating force on speed gear
- Output : output shaft torque



1. Output torque & speed

$$T_{out} = T_{in} \times GR$$

$$\omega_{out} = \frac{\omega_{in}}{GR} \qquad GR: \text{gear ratio}$$

2. Example : $T_{in} = 100\ \text{Nm},\ \omega_{in} = 3000\ \text{RPM}$

1) $GR = 4\ (1st)$

$$T_{out} = 100 \times 4 = 400\ \text{Nm}$$

$$\omega_{out} = \frac{3000}{4} = 750\ \text{RPM}$$

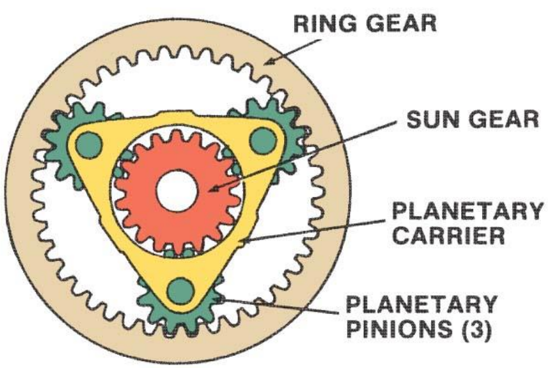
2) $GR = 2\ (2nd)$

$$T_{out} = 100 \times 2 = 200\ \text{Nm}$$

$$\omega_{out} = \frac{3000}{2} = 1500\ \text{RPM}$$

Planetary Gear Model (AT)

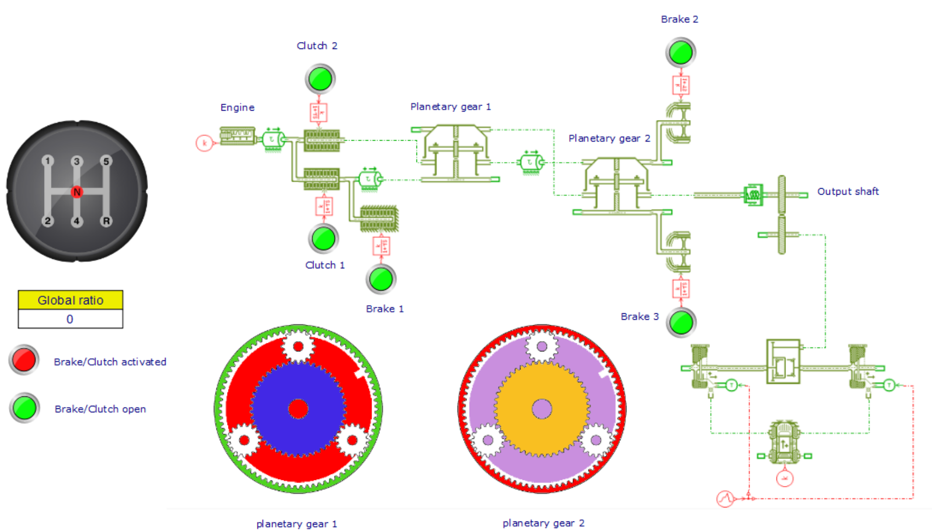
- Input : clutch or brake actuating force
- Output : output shaft torque



Ring	Carrier	Sun	Gear Ratio
driven	drive	fix	Zr/(Zs+Zr)
drive	driven	fix	(Zs+Zr)/Zr
fix	drive	driven	Zs/(Zs+Zr)
fix	driven	drive	(Zs+Zr)/Zs
driven	fix	drive	-Zr/Zs

Zr : # of ring gear teeth
Zs : # of sun gear teeth
Zs+Zr : # of carrier equivalent teeth

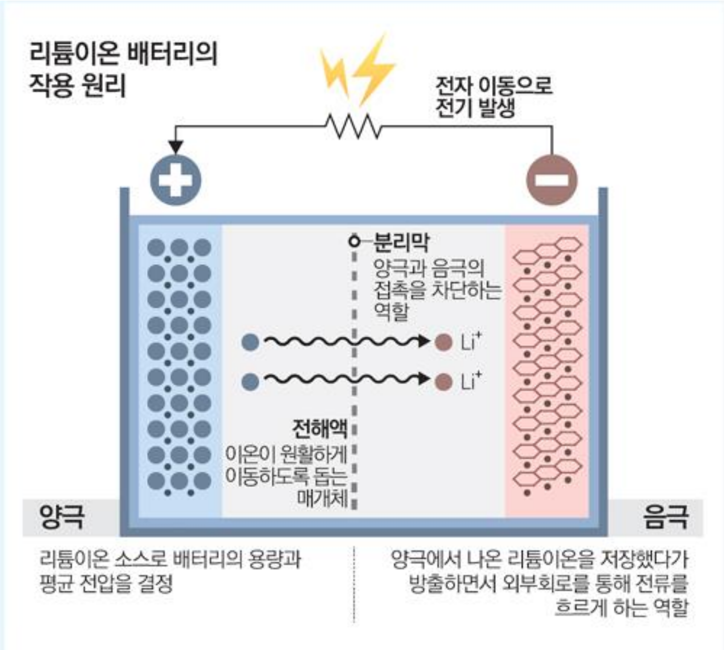
ex) Zr=80, Zs=40
ring fixed, carrier drive
gear ratio?
increasing speed?
decreasing speed?

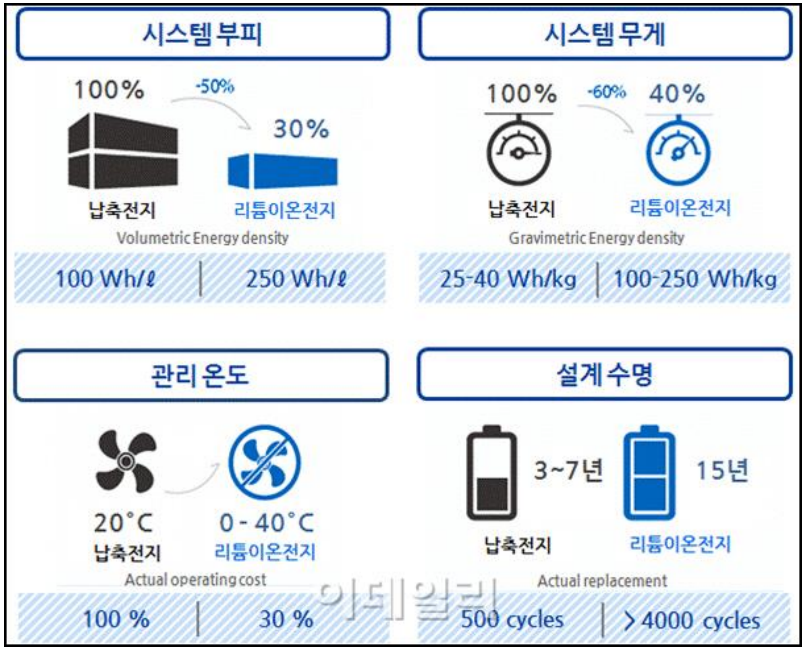


	Clutch 1	Clutch 2	Brake 1	Brake 2	Brake 3
Neutral					
Reverse	●			●	
1th Gear	●				●
2nd Gear		●			●
3rd Gear	●	●			
4th Gear		●	●		

Battery

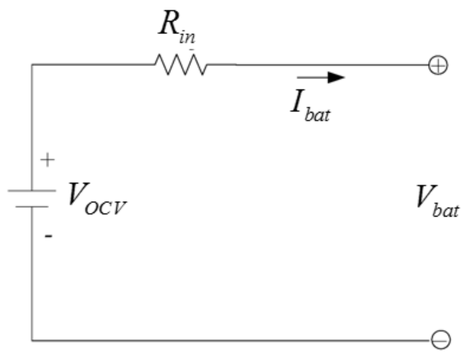
- Providing the current to generate the mechanical torque from a motor
- Principle of operation
  - Conversion of the electric energy in a capacitor to the current by the battery voltage and resistance





Equivalent Circuit Model

- Input : motor consuming power
- Output : state of charge(SOC)



1. Equivalent circuit equation

$$V_{bat} = V_{OCV} - R_{in} I_{bat}$$

V_{bat} : battery volatage [V]

V_{OCV} : open circuit voltage [V]

R_{in} : equivalent internal resistance [Ω]

I_{bat} : battery current [A]

2. SOC calculation

Mechanical Power = Electrical Power

$$T_{mot} w_{mot} = \eta V_{bat} I_{bat} \text{ (discharging)}$$

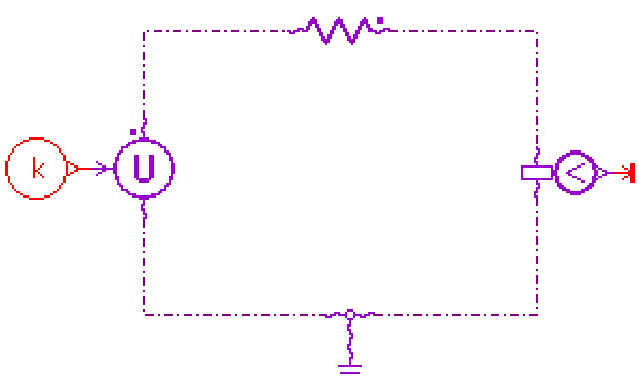
$$\eta T_{mot} w_{mot} = V_{bat} I_{bat} \text{ (charging)}$$

$$\frac{dSOC}{dt} = -I_{bat} \frac{100}{C_{nom}}$$

$$SOC = SOC_{ini} - \frac{100}{C_{nom}} \int I_{bat}\, dt$$

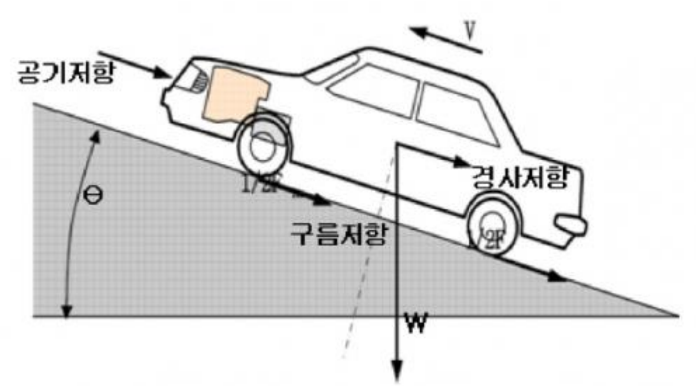
SOC_{ini} : initial state of charge [%]

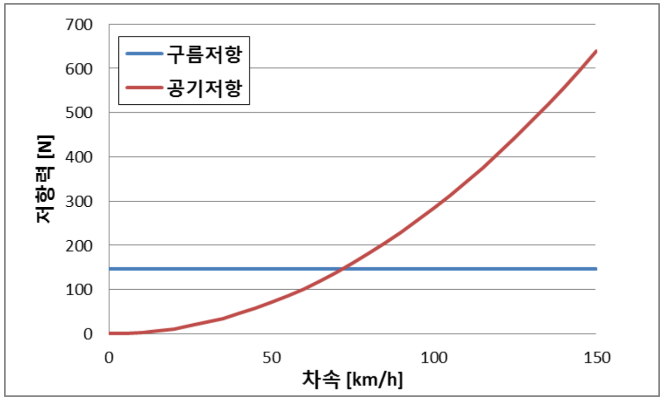
C_{nom} : rated capacity [As]



Driving resistances

- Drag forces during the driving from the various conditions
- Air, rolling, climbing, and acceleration resistance





< Air resistance >

< Rolling resistance >

< Climbing resistance >

Resistance Calculation Model

- Input : vehicle speed, gradient
- Output : drag force

1. Air resistance

$$F_{air} = \frac{1}{2} C_d A_{fr} \rho_{air} V_{veh}^2$$

C_d : air drag coefficient

A_{fr} : frontal area [m^2]

ρ_{air} : air density [kg/m^3]

V_{veh} : vehicle speed [m/s^2]

2. Rolling resistance

$$F_{roll} = \mu_r m_{body} g$$

μ_r : rolling friction coefficient

m_{body} : body mass[kg]

3. Climbing resistance

$$F_c = mg \sin \theta_{grad}$$

θ_{grad} : gradient [rad]

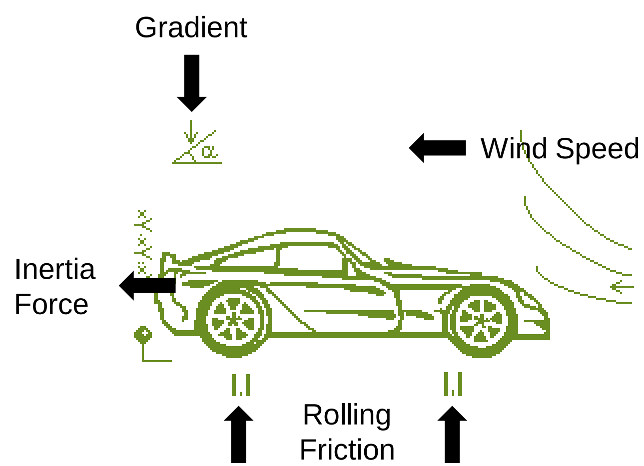
4. Acceleration resistance

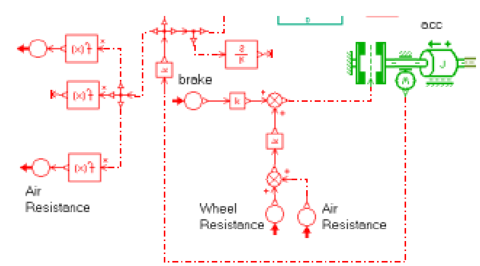
$$F_{acc} = ma = J_{eq} \alpha_{whl} R_{tire}$$

J_{eq} : vehicle equivalent inertia [kgm^2]

α_{whl} : wheel rotational acceleration [rad/s^2]

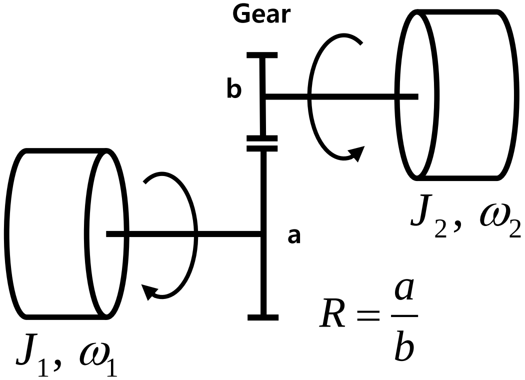
R_{tire} : effective tire radius [m]





Equivalent Inertia

- Calculation of an equivalent inertia from each inertias



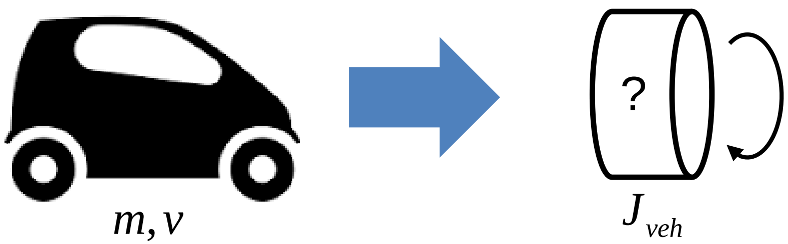
$$E_1 + E_2 = E_{eq} \quad \text{(energy conservation)}$$

$$\frac{1}{2}J_1\omega_1^2 + \frac{1}{2}J_2\omega_2^2 = \frac{1}{2}J_{eq,1}\omega_1^2$$

$$J_1\omega_1^2 + J_2R^2\omega_1^2 = J_{eq,1}\omega_1^2 \quad (\omega_2 = R\omega_1)$$

$$J_{eq,1} = J_1(1 + R^2)$$

Equivalent inertia w.r.t vehicle mass



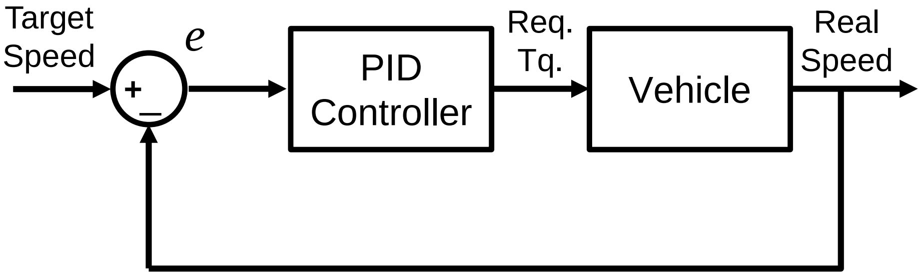
$$E_v = E_w$$

$$\frac{1}{2}mv^2 = \frac{1}{2}J_{veh}\omega^2 \quad (v = R_{tire}\omega)$$

$$J_{veh} = mR_{tire}^2$$

Driver Controller

- Torque control to match a target vehicle speed from the driver request
- Principle of operation
  - Reducing an error between the target speed and the real speed



$$T_{req} = K_p e(t) + K_i \int e(t)\,dt + K_d \frac{de(t)}{dt} \quad \begin{cases} e(t) \geq 0 : \text{accelation} \\ e(t) < 0 : \text{braking} \end{cases}$$

$$(e(t) = V_{target} - V_{real})$$

K_p : proportional gain

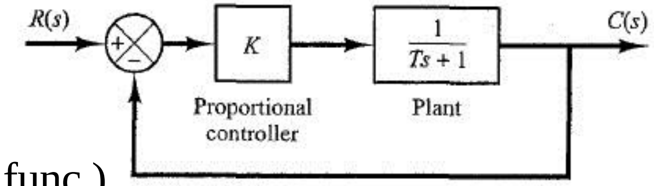
K_i : integral gain

K_d : differential gain

PI control

- Proportional control

$$G(s)=\frac{K}{Ts+1} \qquad \frac{E(s)}{R(s)}=\frac{R(s)-C(s)}{R(s)}=1-\frac{C(s)}{R(s)}=\frac{1}{1+G(s)}$$

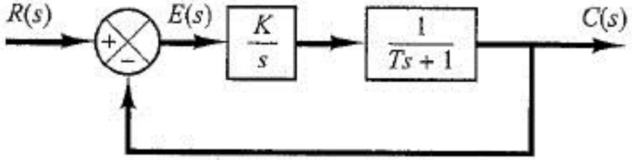


$$E(s)=\frac{1}{1+G(s)}R(s)=\frac{1}{1+\dfrac{K}{Ts+1}}R(s) \qquad R(s)=\frac{1}{s}\ \text{(unit-step func.)}$$

$$E(s)=\frac{Ts+1}{Ts+1+K}\frac{1}{s} \qquad e_{ss}=\lim_{t\to\infty}e(t)=\lim_{s\to 0}sE(s)=\lim_{s\to 0}\frac{Ts+1}{Ts+1+K}=\frac{1}{K+1}$$

- Integral control

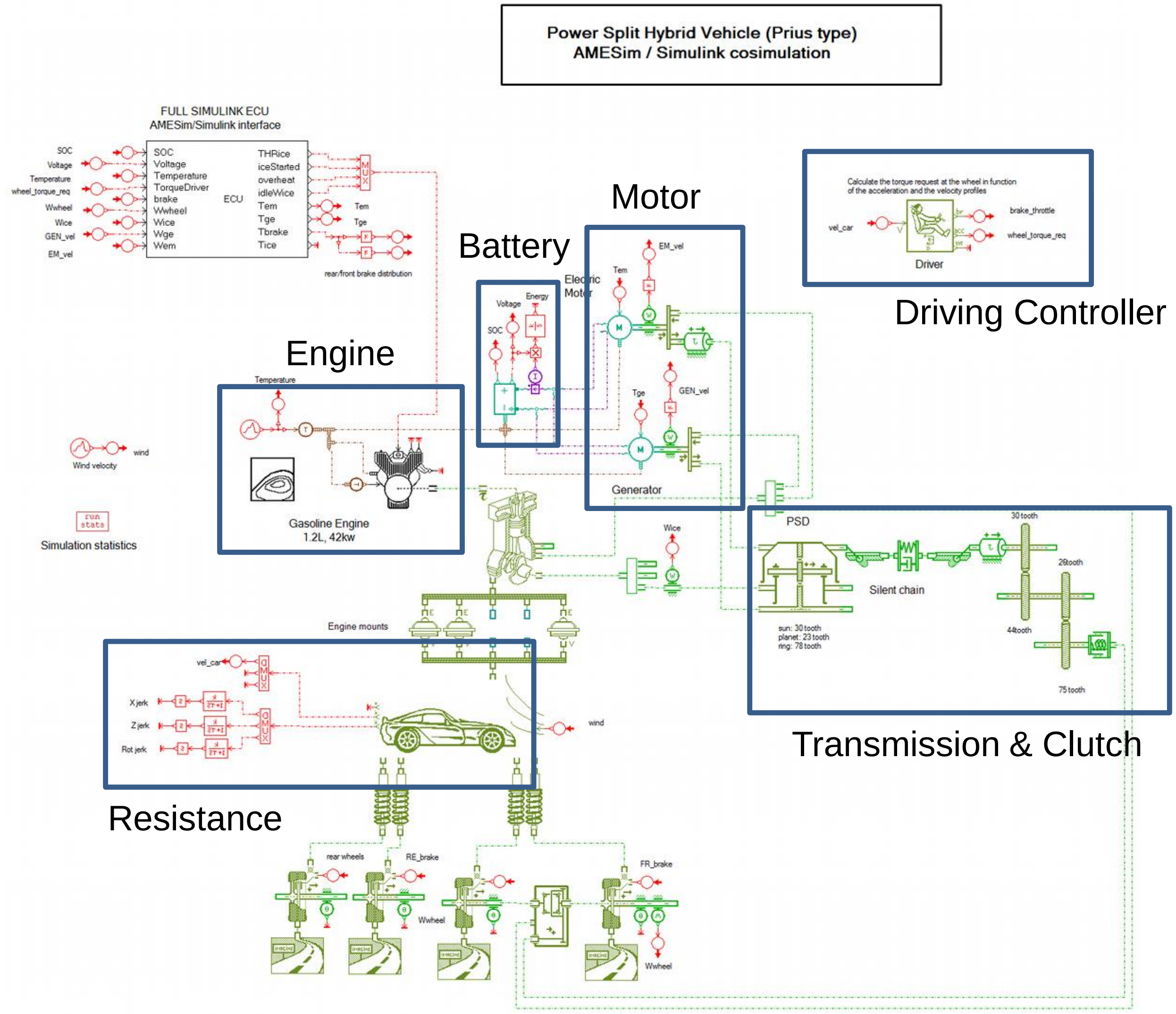
$$\frac{C(s)}{R(s)}=\frac{K}{s(Ts+1)+K} \qquad \frac{E(s)}{R(s)}=\frac{R(s)-C(s)}{R(s)}=\frac{s(Ts+1)}{s(Ts+1)+K}$$



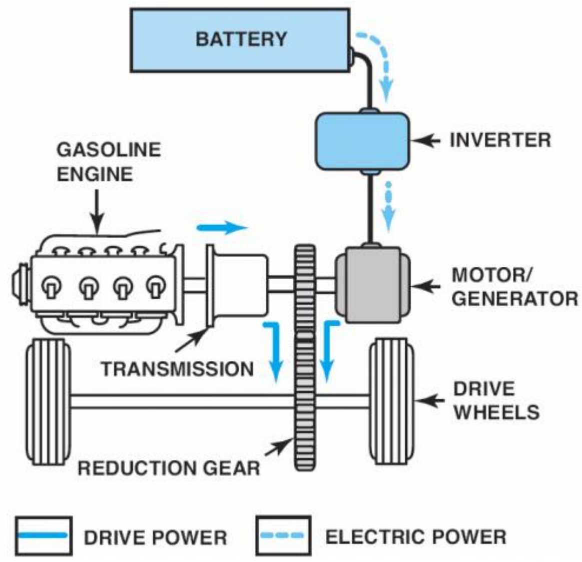
$$E(s)=\frac{s(Ts+1)}{s(Ts+1)+K}\frac{1}{s} \qquad R(s)=\frac{1}{s}\ \text{(unit-step func.)}$$

$$e_{ss}=\lim_{t\to\infty}e(t)=\lim_{s\to 0}sE(s)=\lim_{s\to 0}\frac{s^2(Ts+1)}{Ts^2+s+K}\frac{1}{s}=0$$

HEV Model


Power Split Hybrid Vehicle (Prius type)
AMESim / Simulink cosimulation
FULL SIMULINK ECU
AMESim/Simulink interface
Motor
Battery
Engine
Driving Controller
Driver
Gasoline Engine
1.2L, 42kw
Generator
PSD
Silent chain
Engine mounts
Simulation statistics
Wind velocity
Transmission & Clutch
Resistance

Assignment



Vehicle Parameters

$$J_{eng} = 0.2\,\text{kgm}^2,\ J_{motor} = 0.05\,\text{kgm}^2$$

$$GR_{TM} = 2,\ GR_F = 4$$

$$M_{veh} = 1500\,kg,\ R_{tire} = 0.3$$

$$T_{eng} = 80\,Nm,\ T_{mot} = 50\,Nm$$

Resistance Parameters

$$A = 2\,m^2,\ C_d = 0.3,\ \rho = 1.2\,\text{kg/m}^3,\ V = 15\ \text{m/s}$$

$$\mu_{roll} = 0.01,\ g = 9.81\text{m/s}^2$$

Problem

1. Equivalent inertia at wheel
2. Driving torque at wheel
3. Drag torque at wheel (air, rolling)
4. Vehicle acceleration speed

```
Eq. Inertia : 148.6 [kgm^2]
Driving Torque : 840 [Nm]
Drag Torque : 68.44 [Nm]
Vehicle Acc. : 1.558 [m/s^2]
```