Powertrain Component Modeling

Computational Design Laboratory
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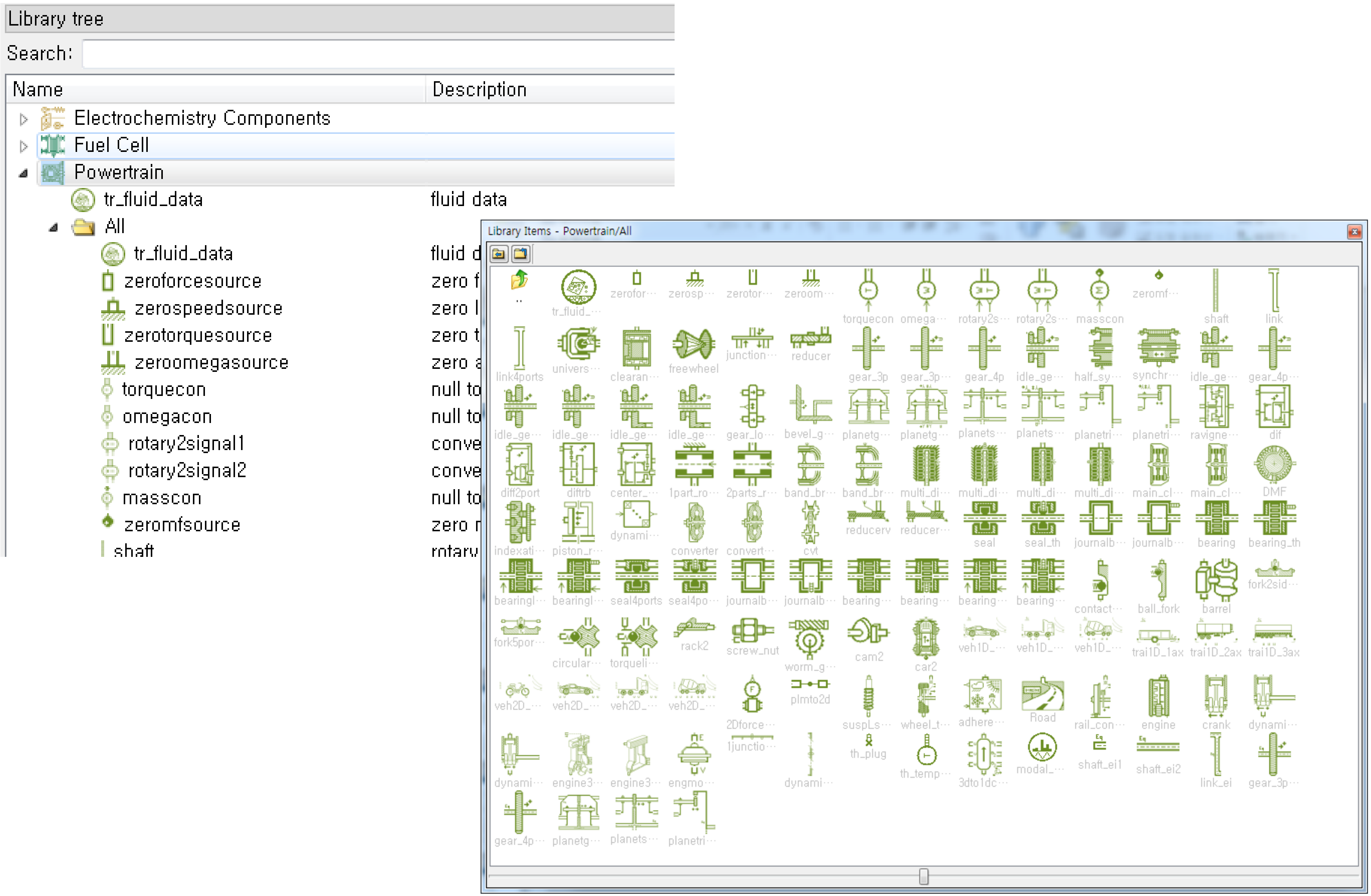
Hanyang University, Seoul, Korea

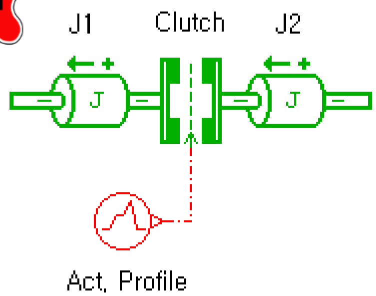
CONTENTS

POWERTRAIN LIBRARY

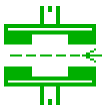


CLUTCH

1. 클러치 모델 구성
2. J1, J2 parameter 입력
3. clutch, act. profile parameter 입력
4. Run 및 J1, J2 속도 확인 (Run Parameters에서 Print interval 0.001로 setting)



$$F_{fric} = F_{dyn} \times \tanh\left(2 \times \frac{\omega_{rel}}{d\omega}\right)$$



Parameters of 2parts_rot_friction_new [FR2R000-1]

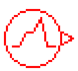
Title	Value	Unit
signal input: 1 fraction (0,1) of max, 2 normal force N 3 friction torque···	1	
invalid signal input: 1 use extreme value 2 stop simulation	1	
option 1: maximum Coulomb (dynamic) friction torque	**100**	Nm
option 2: Coulomb (dynamic) friction coefficient	0.1	null
option 2: diameter on which friction acts	100	mm
rotary stick velocity threshold	1	rev/min

J1 = 1 kgm^2
w1 = 0 RPM

J2 = 2 kgm^2
w2 = 100 RPM

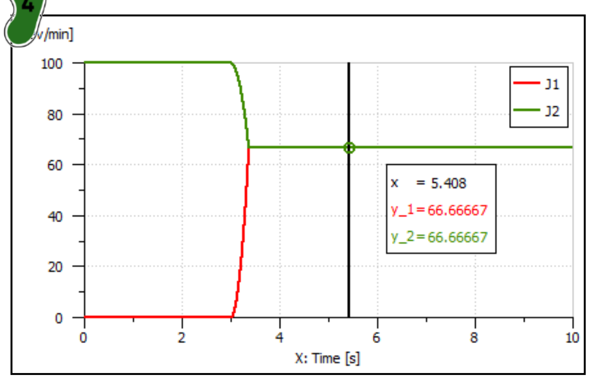
Parameters of rotaryload2_1 [RL02-2]

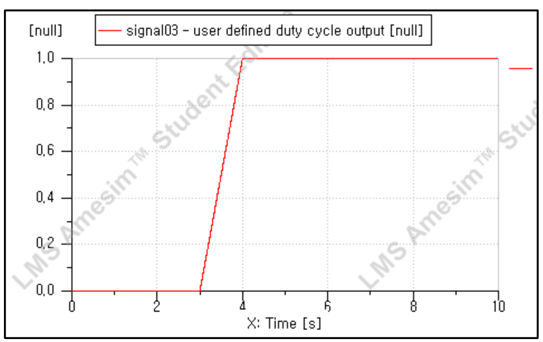
Title	Value	Unit
shaft speed port 2	**100**	rev/min
moment of inertia	**2**	kgm**2



Parameters of signal03 [UD00-1]

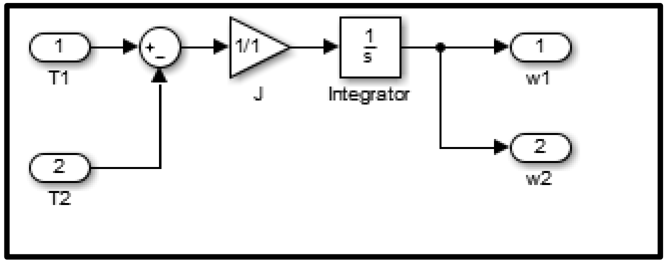
Title	Value	Unit
number of stages	3	
cyclic	no	
time at which duty cycle starts	0	s
output at start of stage 1	0	null
output at end of stage 1	0	null
duration of stage 1	**3**	s
output at start of stage 2	0	null
output at end of stage 2	**1**	null
duration of stage 2	**1**	s
output at start of stage 3	**1**	null
output at end of stage 3	**1**	null
duration of stage 3	1e+06	s



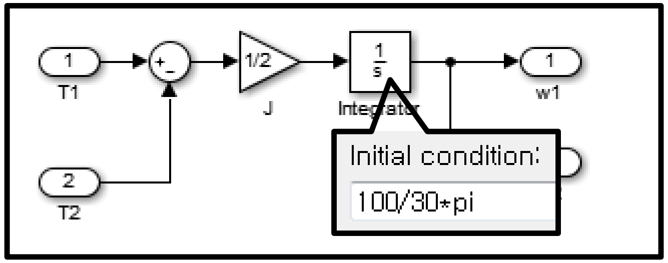


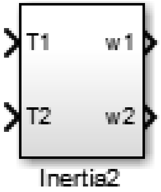
CLUTCH

J1



J2





1. J1 inertia 모델 구성
2. J2 inertia 모델 구성 및 초기 속도 입력 (100 RPM)
3. inertia subsystem 구성

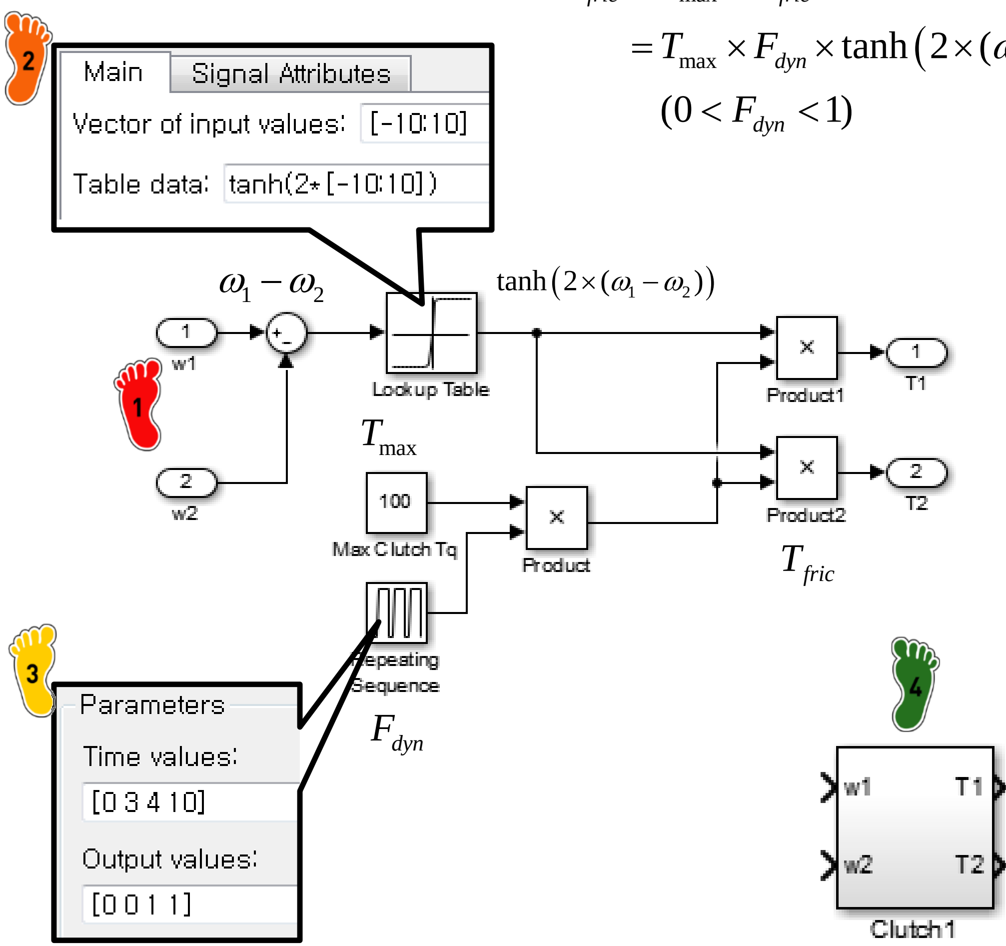
CLUTCH

$$F_{fric} = F_{dyn} \times \tanh\left(2 \times \frac{\omega_{rel}}{d\omega}\right) \Rightarrow F_{fric} = F_{dyn} \times \tanh\left(2 \times (\omega_1 - \omega_2)\right)$$

$$T_{fric} = T_{\max} \times F_{fric}$$

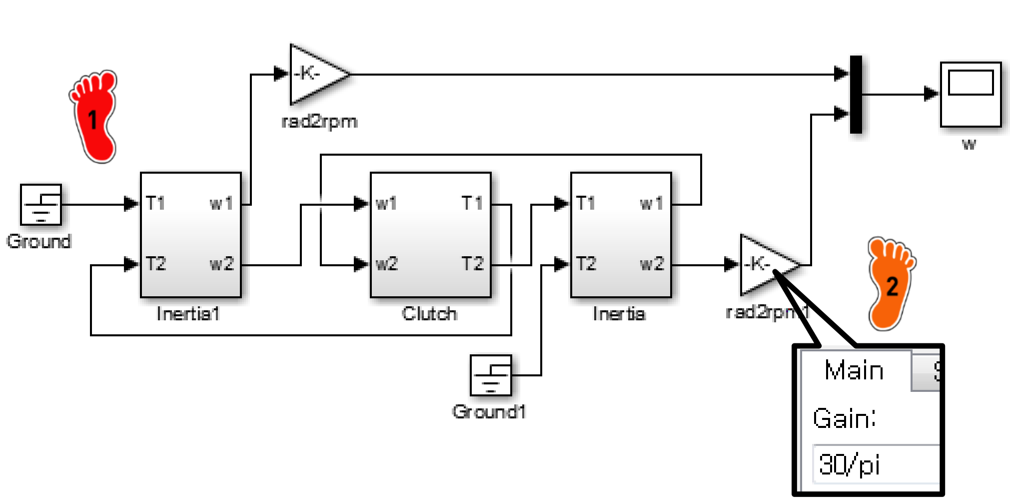
$$= T_{\max} \times F_{dyn} \times \tanh\left(2 \times (\omega_1 - \omega_2)\right)$$

$$(0 < F_{dyn} < 1)$$



1. 클러치 모델 구성
2. tanh func. table 입력 (또는 f(u) 사용 가능)
3. act. profile parameter 입력
4. clutch subsystem 구성

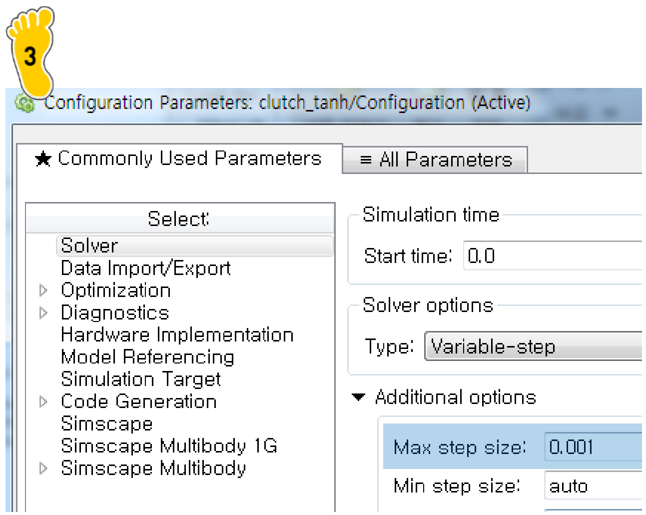
CLUTCH

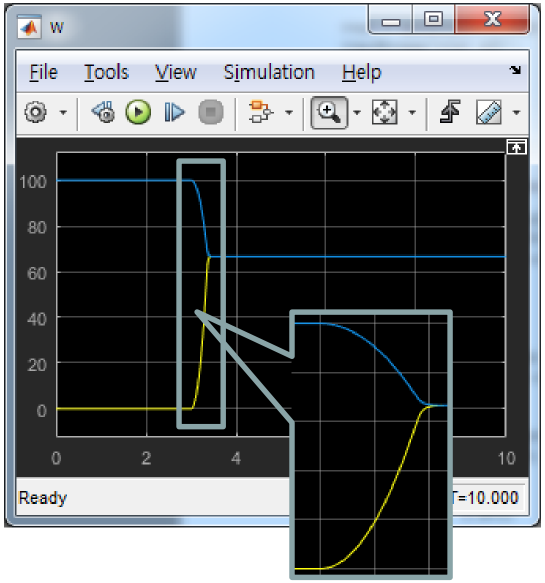


1 전체 system 구성

2 rad/s → RPM 변경 parameter 입력

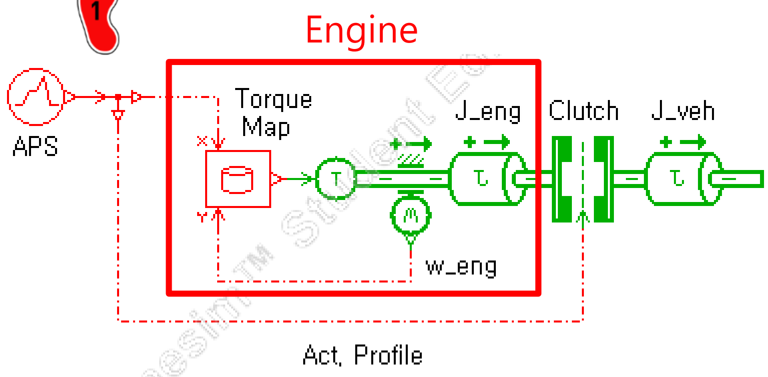
3 Run 및 J1, J2 속도 확인 (Solver Parameters에서 Max step size 0.001로 변경)

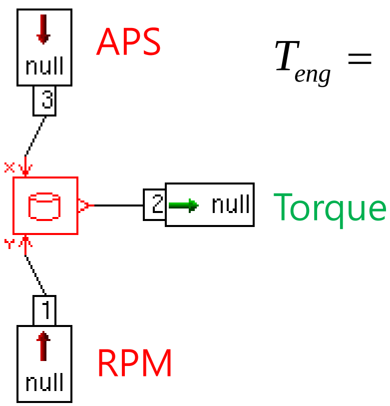




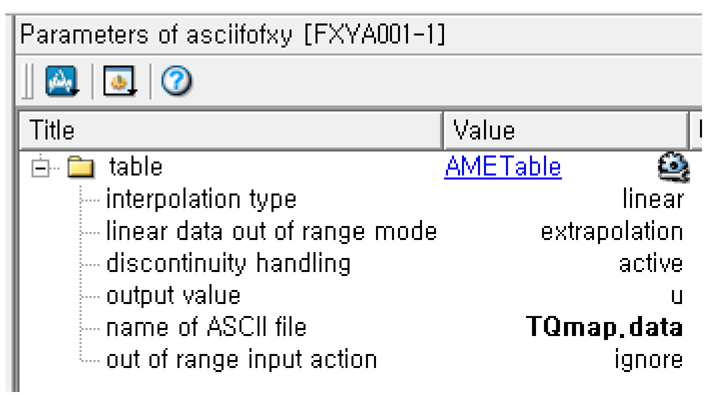
ENGINE

1. 엔진/클러치 모델 구성
2. Torque Map block 설명(function of two inputs)
3. block 파라미터 소개





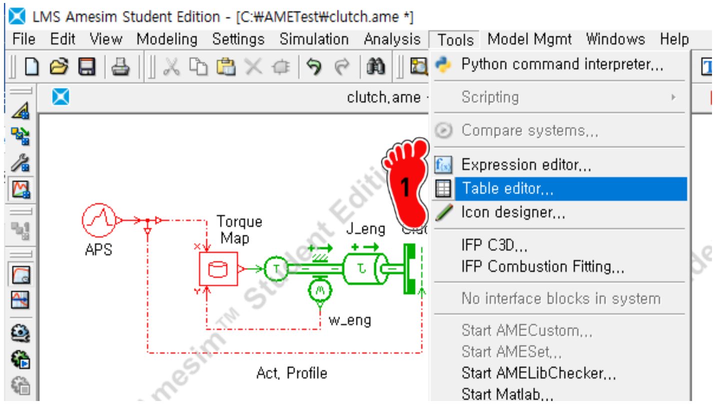
$$T_{eng} = f(APS, RPM)$$

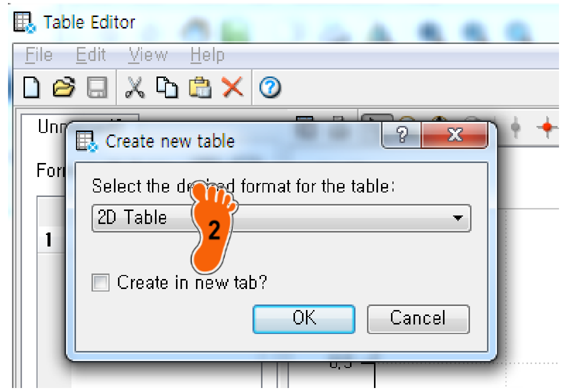


Parameters of asciifofxy [FXYA001-1]

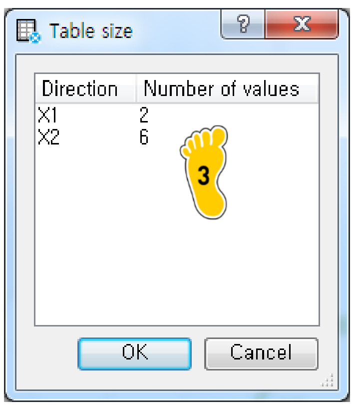
Title	Value
table	AMETable
interpolation type	linear
linear data out of range mode	extrapolation
discontinuity handling	active
output value	u
name of ASCII file	**TQmap.data**
out of range input action	ignore

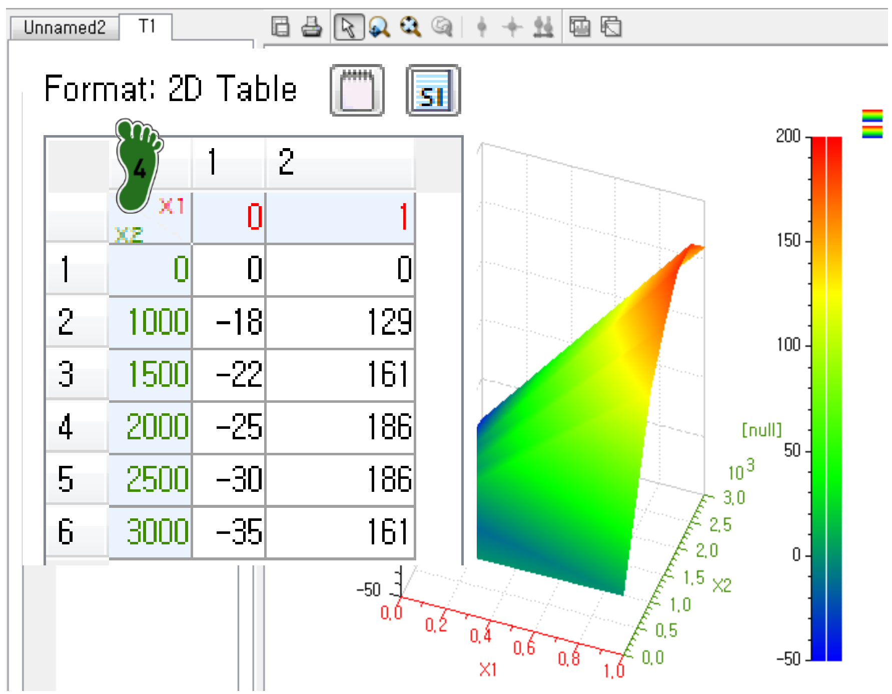
ENGINE





1. Tools → Table editor 클릭
2. File → New 클릭, 2D Table 선택 후 OK
3. X1 : 2, X2 : 6 입력 후 OK

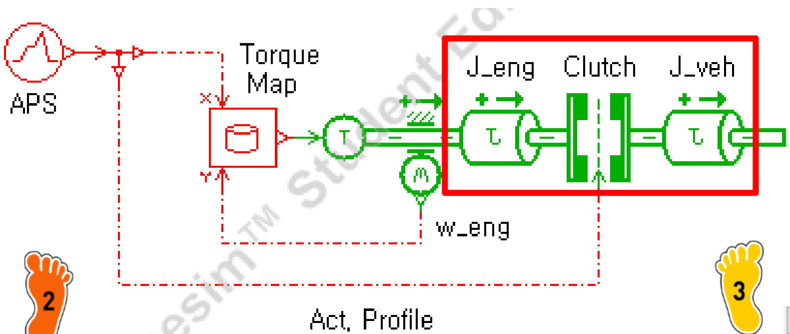




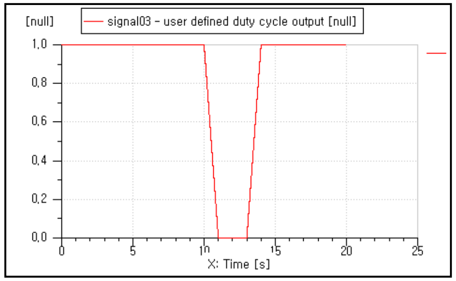
4. 생성된 table에 APS와 RPM에 따른 torque 값 입력 후 파일 저장
(파일명 및 저장위치 확인)

ENGINE

Title	Value
table	AMETable
interpolation type	linear
linear data out of range mode	extrapolation
discontinuity handling	active
output value	0
name of ASCII file	./TQmap.data ...
out of range input action	ignore



① J_eng = 0.1 kgm^2, w_eng = 0 RPM
② J_veh = 50 kgm^2, w_veh = 500 RPM
③ clutch friction torque = 200 Nm



Parameters of signal03 [UD00-1]

Title	Value	Unit
number of stages	5	
cyclic	no	
time at which duty cycle starts	0	s
output at start of stage 1	1	null
output at end of stage 1	1	null
duration of stage 1	10	s
output at start of stage 2	1	null
output at end of stage 2	0	null
duration of stage 2	1	s
output at start of stage 3	0	null
output at end of stage 3	0	null
duration of stage 3	2	s
output at start of stage 4	0	null
output at end of stage 4	1	null
duration of stage 4	1	s
output at start of stage 5	1	null
output at end of stage 5	1	null
duration of stage 5	1e+06	s

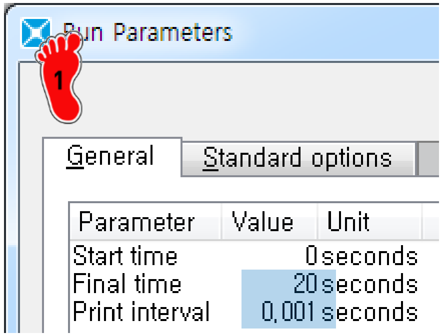
Parameters of signal03 [UD00-1] | Watch parameters

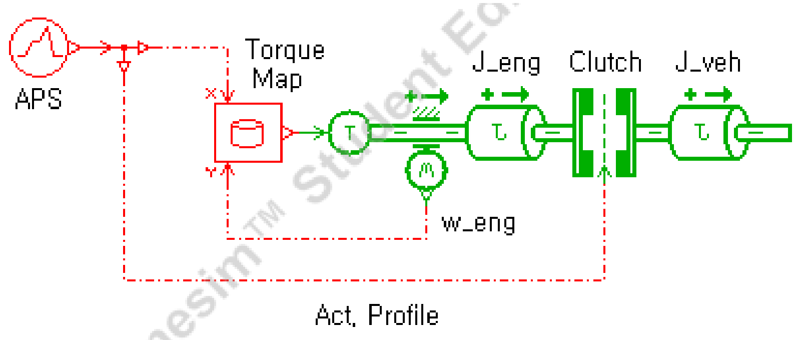
1 토크맵 block에서 ASCII file 입력부분 더블클릭, "…" 눌러서 앞에서 만든 파일선택

2 J_eng, J_veh, clutch parameter 값 입력

3 APS에 해당 parameter 값 입력

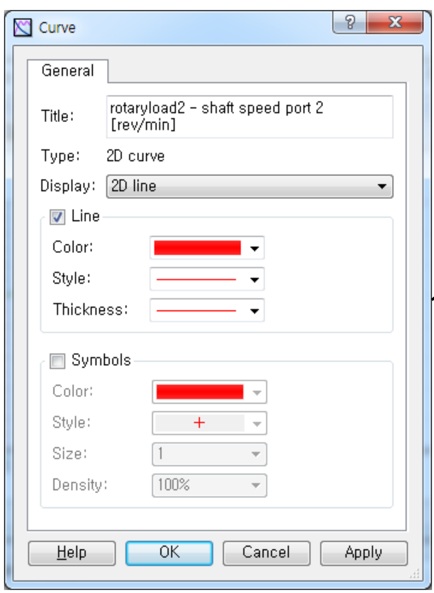
ENGINE

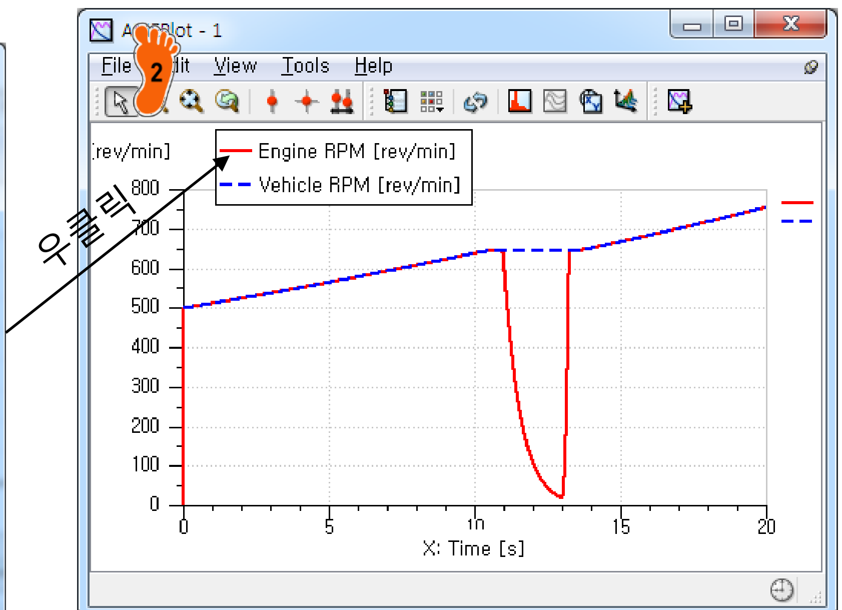




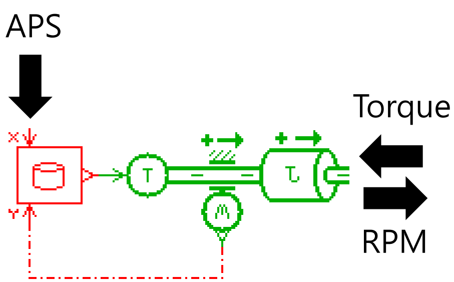
1 Run Parameters에서 Final time, Print interval setting

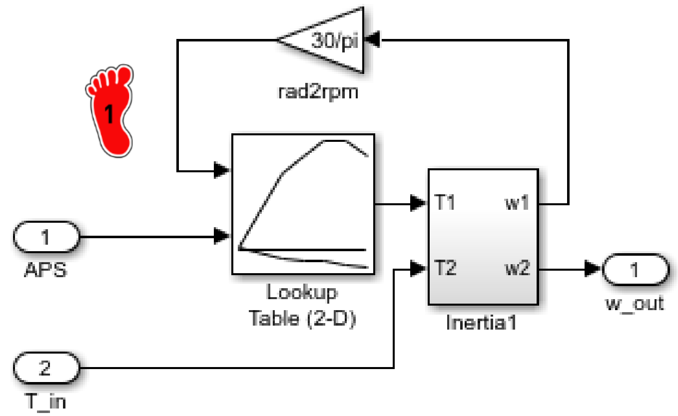
2 Run 및 Engine, Vehicle RPM 확인

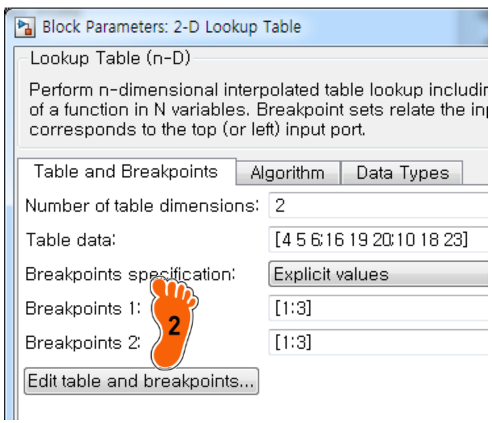


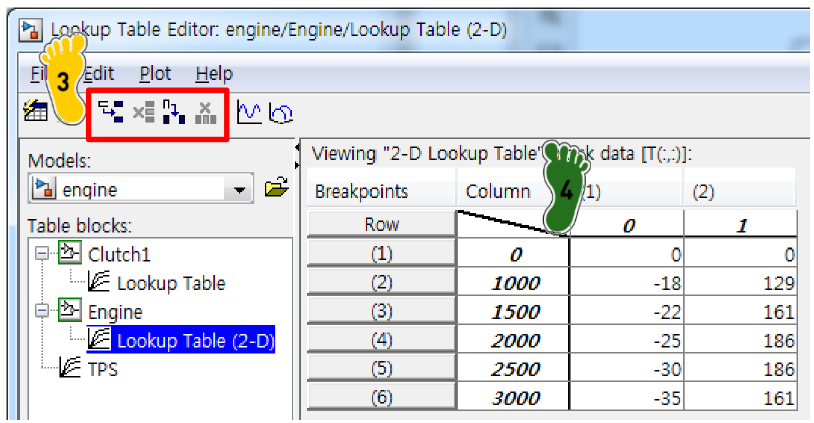


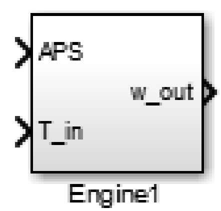
ENGINE











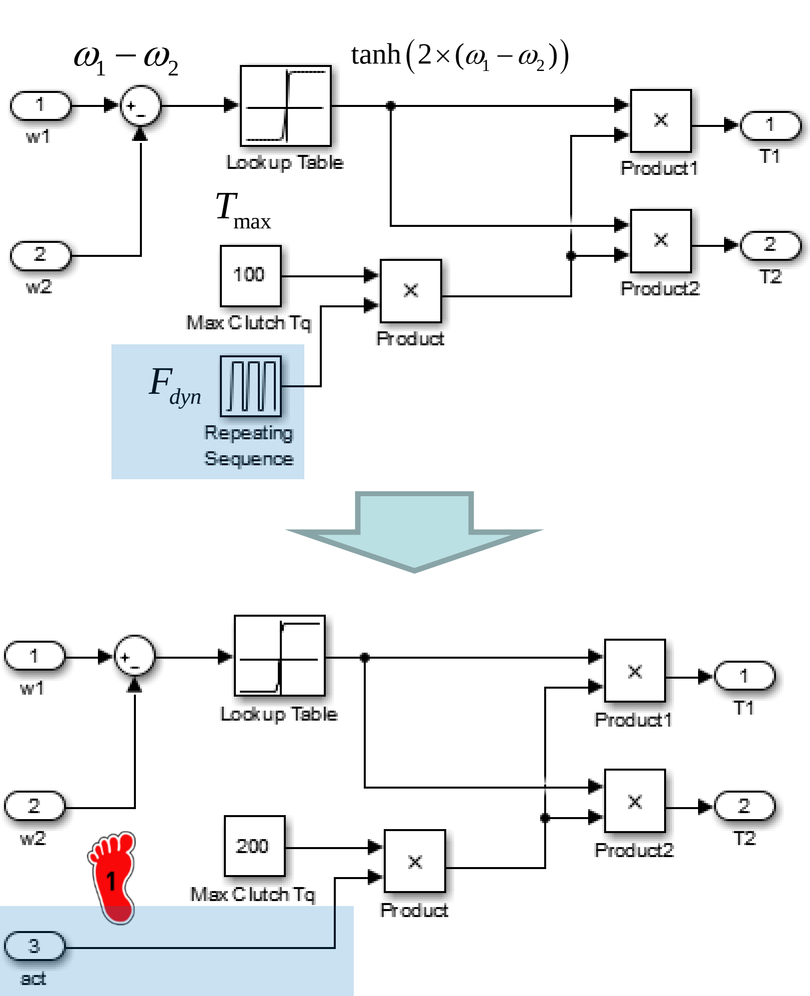
1 2-D lookup table과 이전에 구성한 inertia subsystem을 이용하여 구성

2 2-D lookup table 클릭 후 Edit table 클릭

3 toolbox의 add/remove row/column을 이용하여 6X2 table 생성

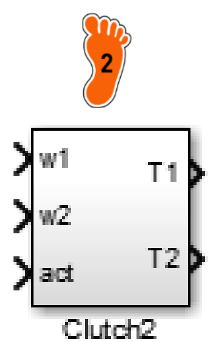
4 APS와 RPM 및 torque값 입력, 완료 후 engine subsystem 생성

ENGINE

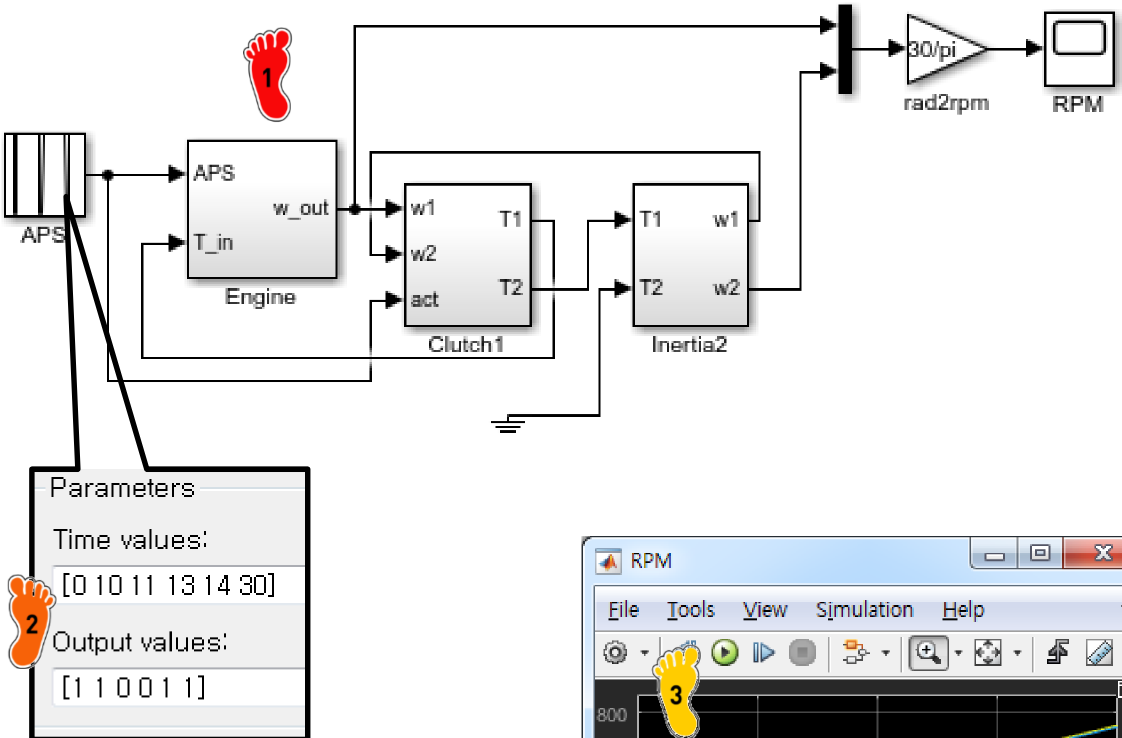


1 이전에 구성한 clutch model에서 Act. profile 부분 변경 (입력으로 받도록..)

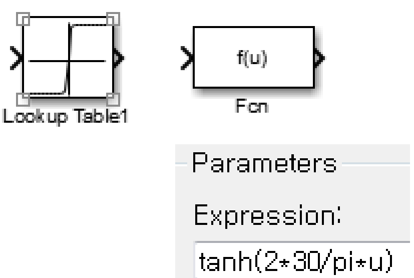
2 clutch subsystem 생성

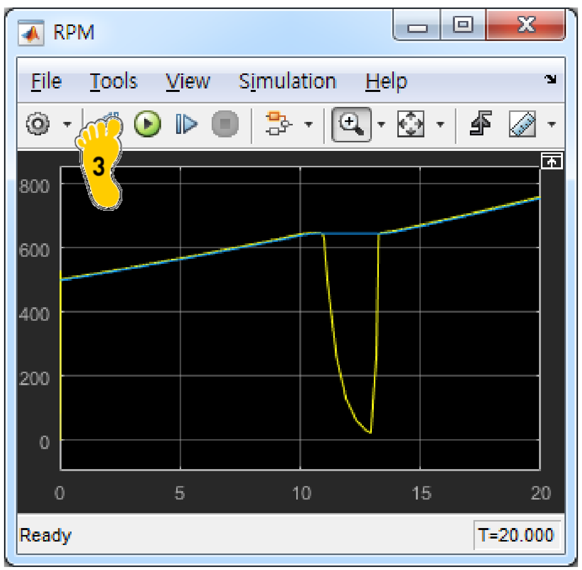


ENGINE



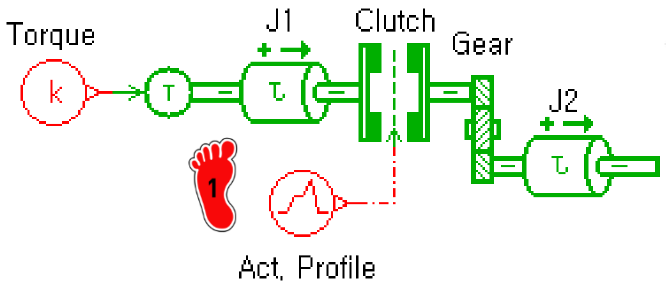
※ Clutch Slip Model





1. 전체 block diagram 구성
2. TPS값 입력, clutch profile 은 동일
3. Run 및 결과 확인 (20 s)

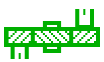
GEAR



① J1 = 1 kgm^2
② J2 = 1 kgm^2
③ Torque = 1 Nm
④ Clutch = 1000 Nm
⑤ Gear Ratio = 2
⑥ Act. Profile

Parameters of signal03 [UD00-1]

Title	Value	Unit
number of stages	3	
cyclic	no	
time at which duty cycle starts	0	s
output at start of stage 1	0	null
output at end of stage 1	0	null
duration of stage 1	3	s
output at start of stage 2	0	null
output at end of stage 2	1	null
duration of stage 2	1	s
output at start of stage 3	1	null
output at end of stage 3	1	null
duration of stage 3	1e+06	s



2. Output torque & speed

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

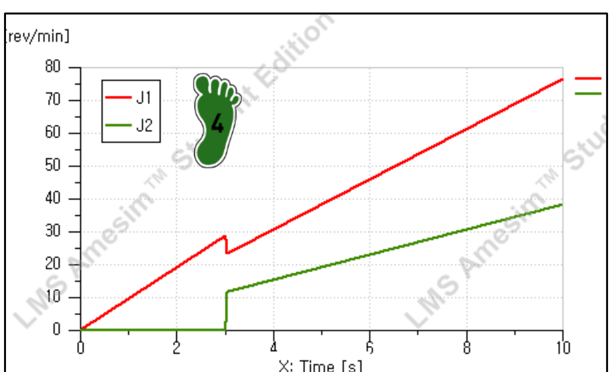
$$\omega_{out} = \frac{\omega_{in}}{GR}$$

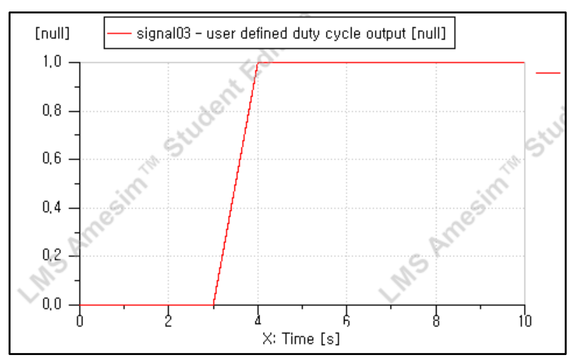
$w2 = alpha \times w1$

w1=w2/alpha

Parameters of reducer [RN000-1]

Title	Value	Unit	Tags	Name
gear ratio	2	null		alpha





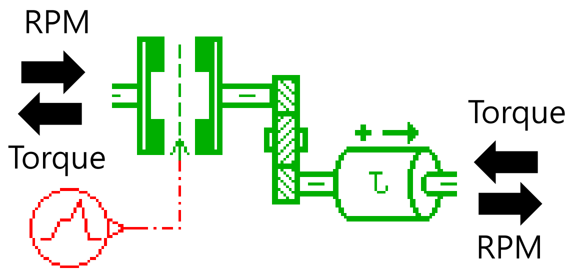
Gear 모델 구성

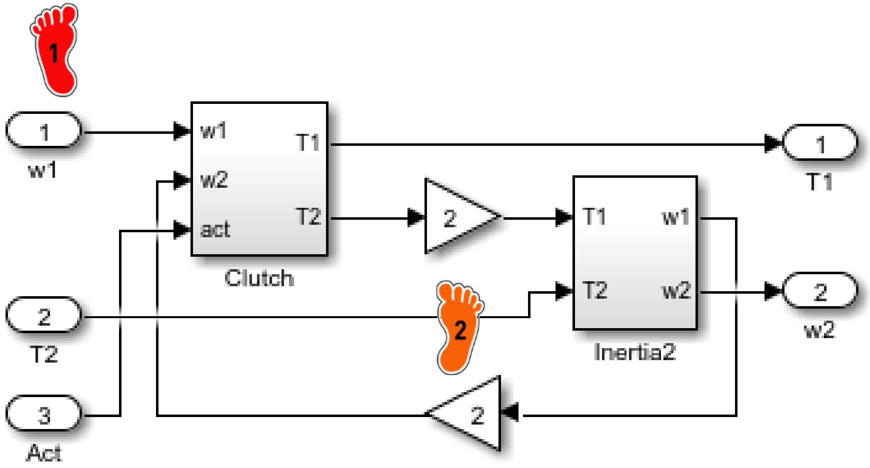
J1, J2, Torque, Clutch Parameter, Act. Profile 입력

기어비 입력 (GR)

Run 및 RPM 결과 확인 (10 s)

GEAR

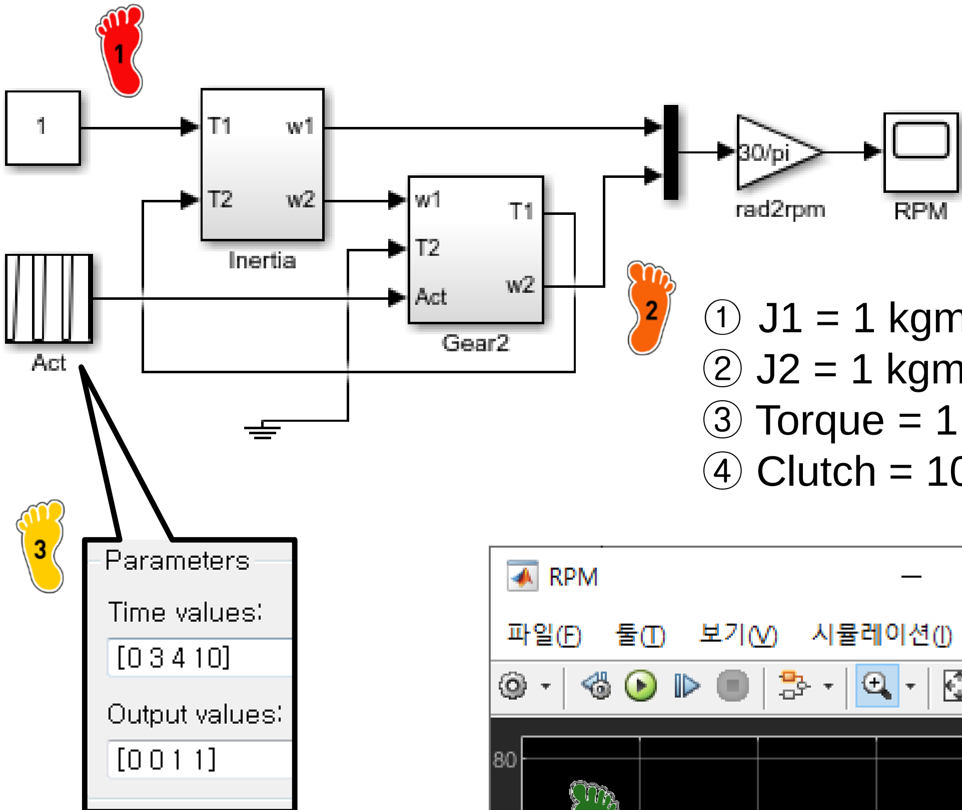




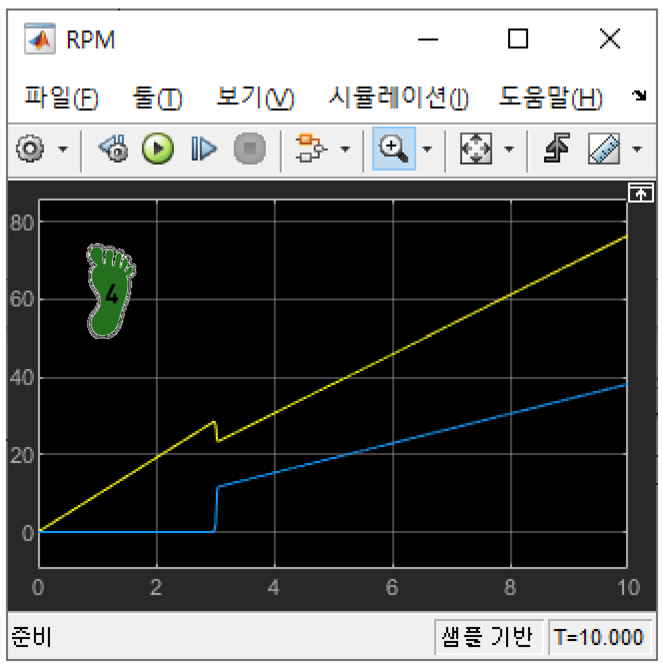
1 Gear 모델 구성

2 Gear ratio 입력 (out/in)

GEAR



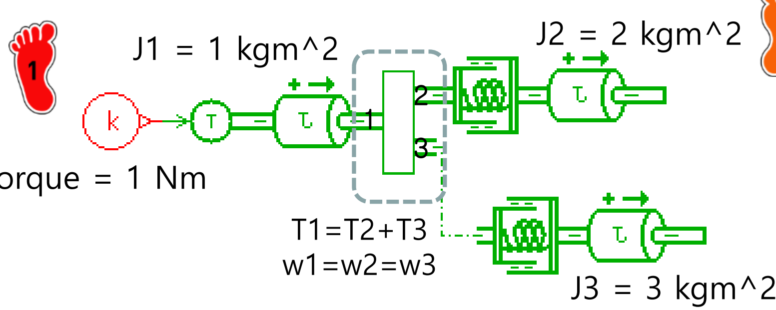
① J1 = 1 kgm^2
② J2 = 1 kgm^2
③ Torque = 1 Nm
④ Clutch = 1000 Nm

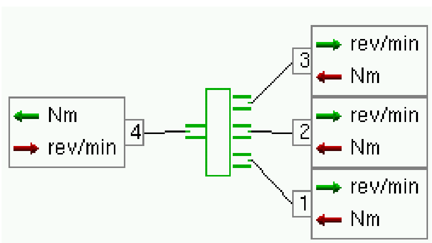


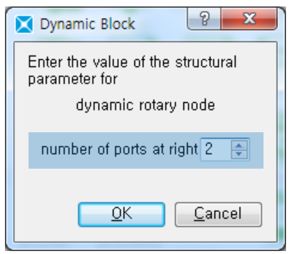
1. 전체 block diagram 구성
2. 각 모델 parameter값 입력
3. Clutch Act. Profile 입력
4. Run 및 RPM 결과 확인 (10 s)

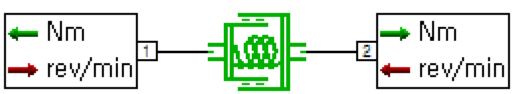
TRANSMISSION

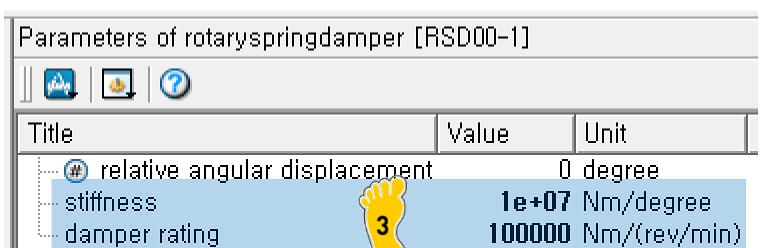
Rotary Mechanical Node





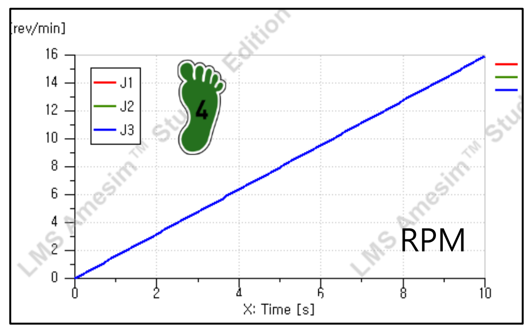


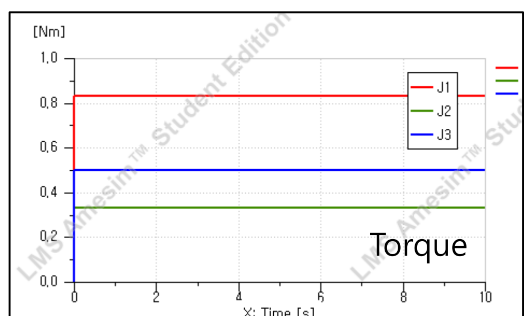



Parameters of rotaryspringdamper [RSD00-1]

Title	Value	Unit
relative angular displacement	0	degree
stiffness	1e+07	Nm/degree
damper rating	100000	Nm/(rev/min)

k=1e7, c=1e5

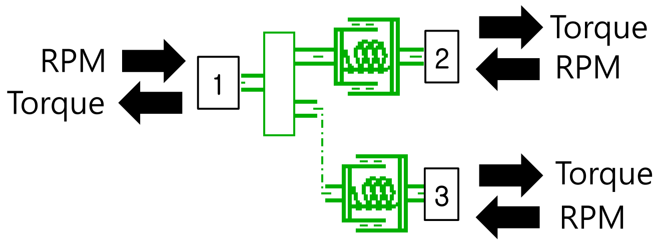


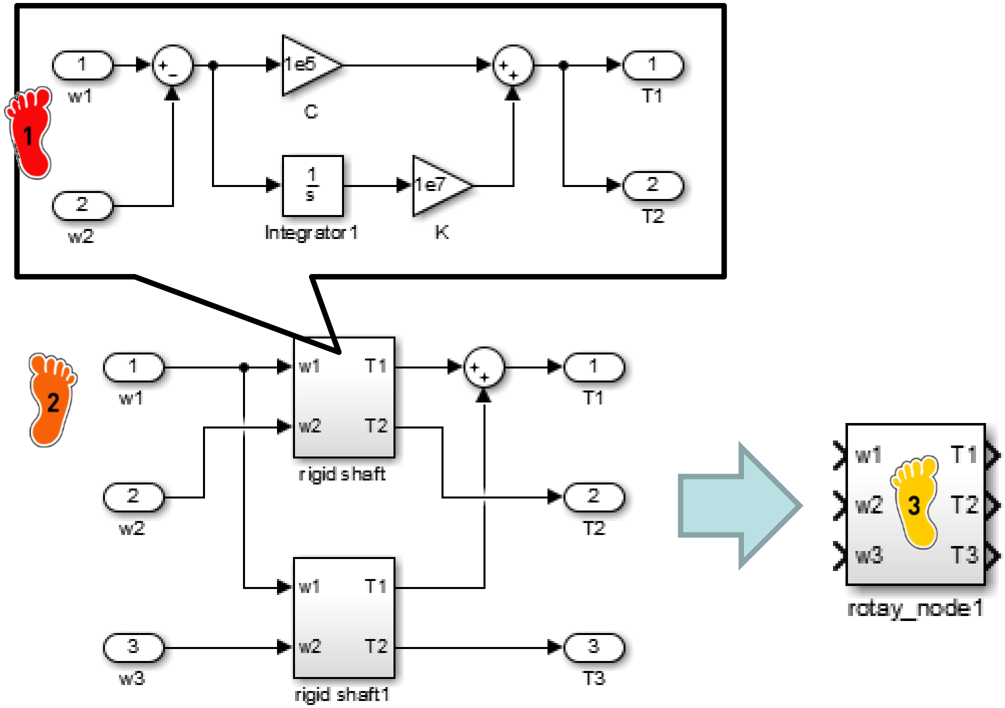


1. 전체 모델 구성 (Rotary Node는 2 port로…)
2. 그림과 같이 Inertia, Torque Parameter 입력
3. Shaft Parameter에 stiffness와 damping값 입력 (rigid shaft를 모사하기 위해 큰 값 입력)
4. Run 및 RPM & Torque 결과 확인 (10 s)

TRANSMISSION

Rotary Mechanical Node





T1=T2+T3
w1=w2=w3

1. rigid shaft 모델 구성 (기존 spring&damper 모델 이용)
2. 전체 모델 구성 (수식 참조)
3. subsystem 생성

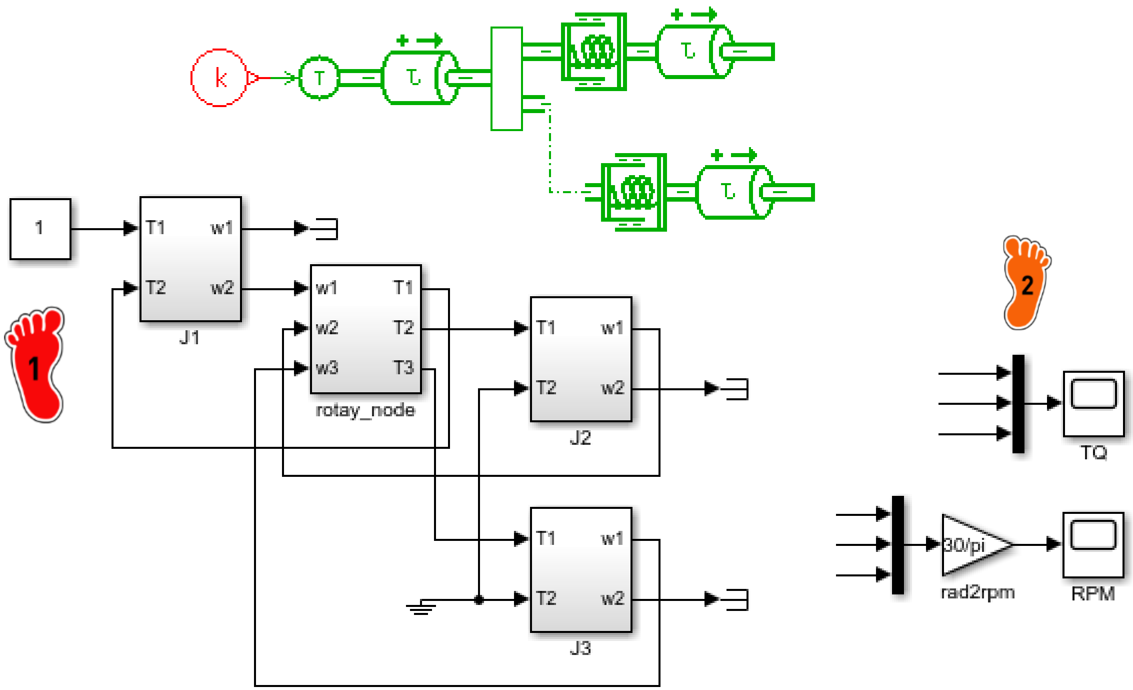
TRANSMISSION

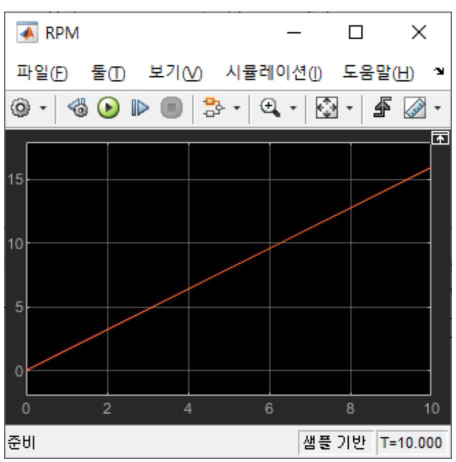
Rotary Mechanical Node

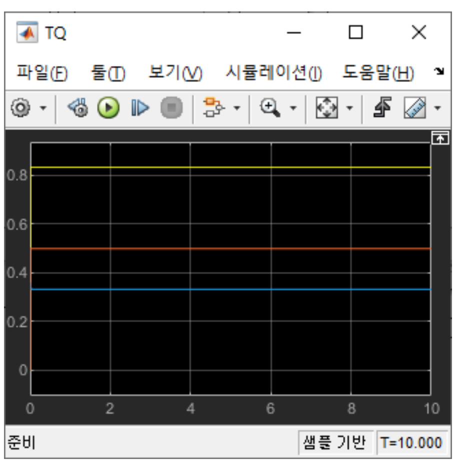
1 전체 모델 구성

2 Rotary node의 RPM과 Torque에 scope 생성

3 Run 및 결과 확인

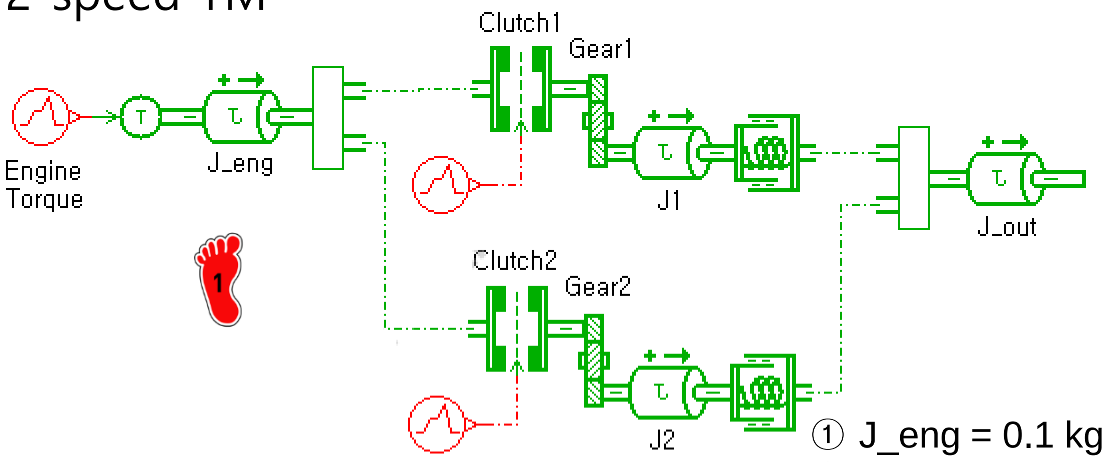






TRANSMISSION

2-speed TM



1 전체 모델 구성

2 각 모델 Parameter 입력 (shaft는 rigid 값 적용)

3 Engine Torque, Clutch Act. profile 입력

① J_eng = 0.1 kgm^2
② J_1/2 = 0.01 kgm^2
③ J_out = 50 kgm^2
④ Clutch1/2: 1000 Nm
⑤ Gear Ratio: 1st (4), 2nd (2)

Engine Torque

Parameters of signal03_2 [UD00-1]

Title	Value	Unit
number of stages	2	
cyclic	no	
time at which duty cycle st···	0	s
output at start of stage 1	0	null
output at end of stage 1	250	null
duration of stage 1	2	s
output at start of stage 2	250	null
output at end of stage 2	250	null
duration of stage 2	1e+06	s

Clutch1

Parameters of signal03 [UD00-1]

Title	Value	Unit
number of stages	4	
cyclic	no	
time at which duty cycle starts	0	s
output at start of stage 1	0	null
output at end of stage 1	1	null
duration of stage 1	0.2	s
output at start of stage 2	1	null
output at end of stage 2	1	null
duration of stage 2	4.8	s
output at start of stage 3	1	null
output at end of stage 3	0	null
duration of stage 3	0.2	s
output at start of stage 4	0	null
output at end of stage 4	0	null
duration of stage 4	1e+06	s

Clutch2

Parameters of signal03_2 [UD00-3]

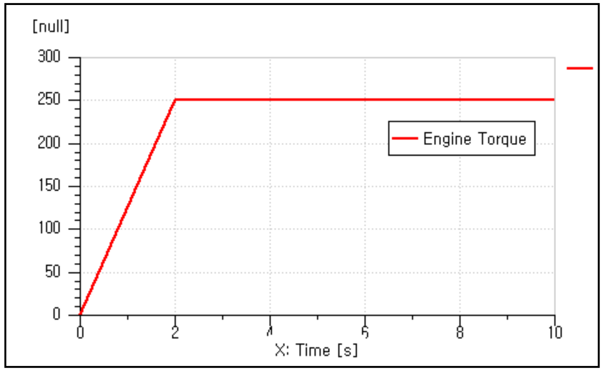
Title	Value	Unit
number of stages	4	
cyclic	no	
time at which duty cycle starts	5	s
output at start of stage 1	0	null
output at end of stage 1	1	null
duration of stage 1	0.2	s
output at start of stage 2	1	null
output at end of stage 2	1	null
duration of stage 2	4.8	s
output at start of stage 3	1	null
output at end of stage 3	0	null
duration of stage 3	0.2	s
output at start of stage 4	0	null
output at end of stage 4	0	null
duration of stage 4	1e+06	s

TRANSMISSION

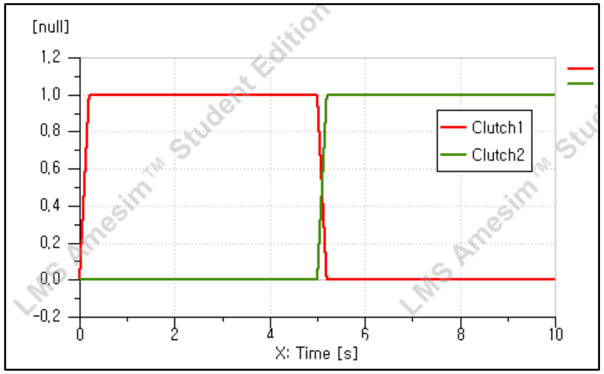
1 결과 확인

2-speed TM

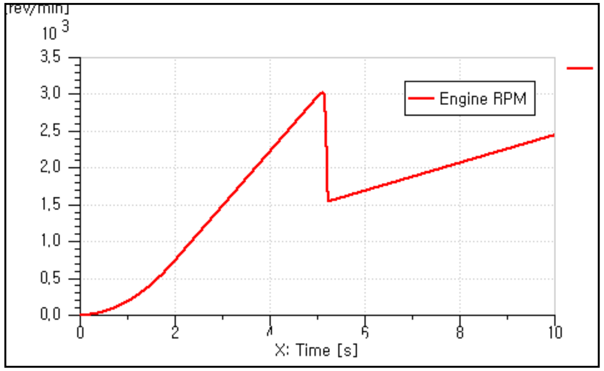
Engine Tq.



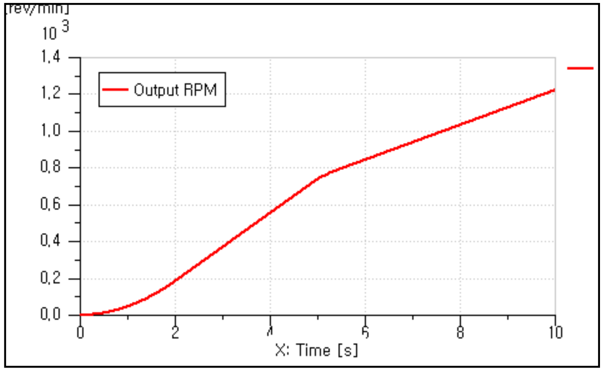
Clutch 1/2



Engine RPM

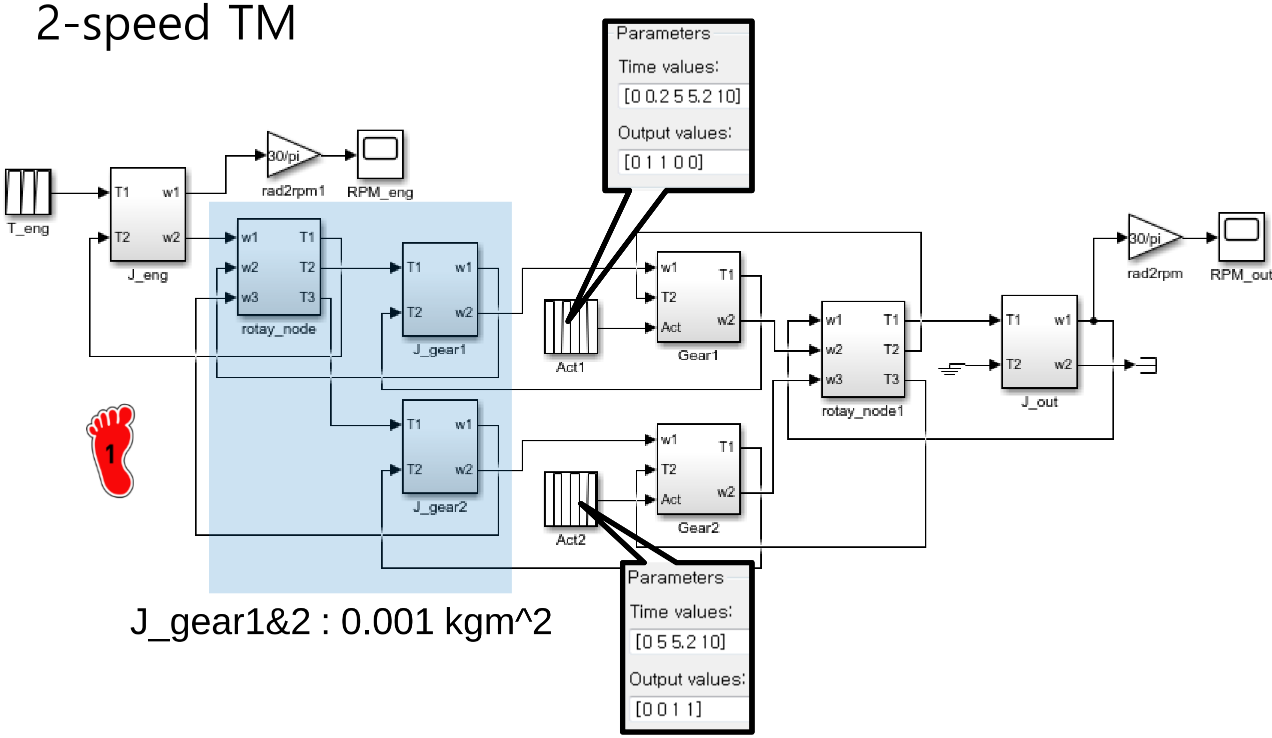


Output RPM



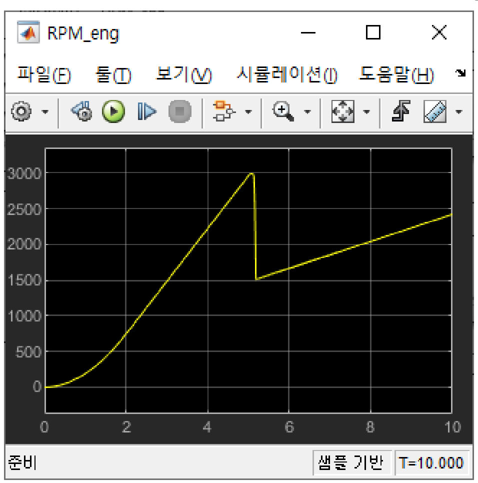
TRANSMISSION

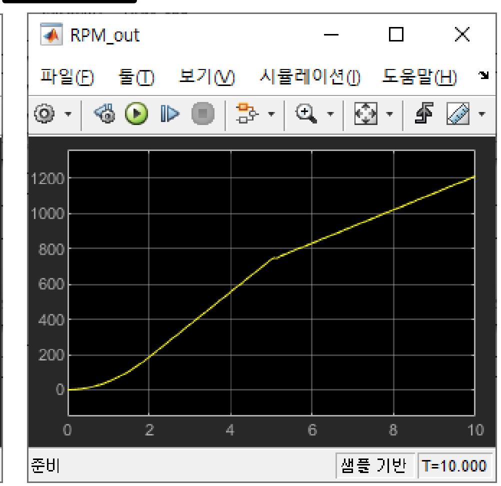
2-speed TM



J_gear1&2 : 0.001 kgm^2

- 전체 시스템 구성 (AMESim과 다르게 음영부분에 inertia 추가, why?)
- 결과 확인





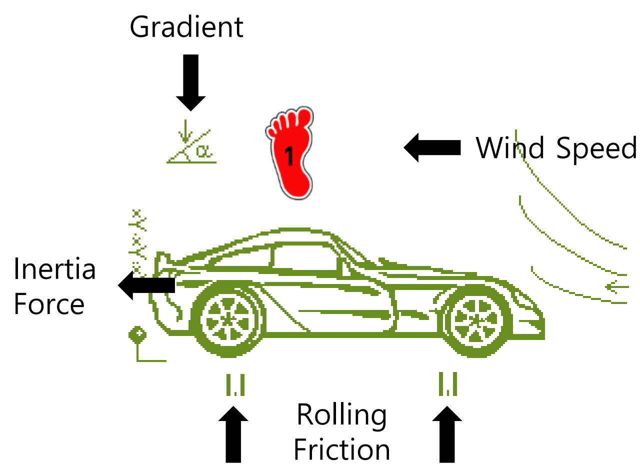
DRAG FORCE

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

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

$$F_c = m_{body} g \sin \theta_{grad}$$

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



1 powertrain library 내 vehicle model 제공

2 longitudinal외 vertical, pitch현상 같이 표현 (입력변수 많음, 생략)

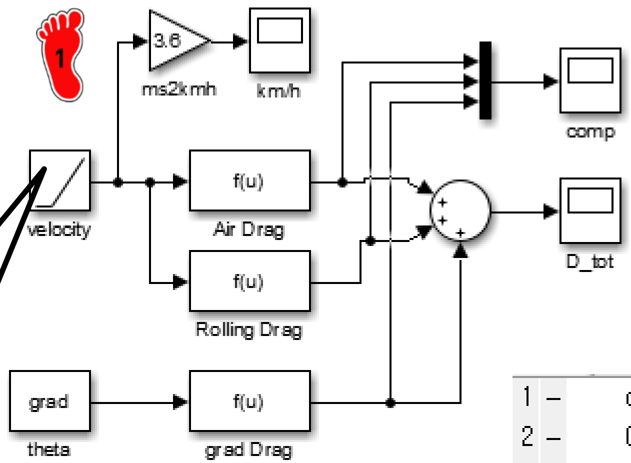
Real parameters

2

	Title	Variable name	Unit	Default value
1	carbody mass (including engine block)	mvehi	kg	1500
2	carbody pitch inertia (including engine block)	J	kgm**2	800
3	total unsprung mass at front	smassF	kg	40
4	total unsprung mass at rear	smassR	kg	40
5	X-position of carbody COG (Grid Frame, including engine block)	xcgp	mm	1000
6	Z-position of carbody COG (Grid Frame, including engine block)	zcgp	mm	250
7	X-position of rear wheel axis (Grid Frame)	xe	mm	2400
8	Z-position of rear wheel axis (Grid Frame)	ze	mm	0
9	Cx - drag coefficient in longitudinal direction	Cx	null	0.3
10	Cz - drag coefficient in vertical direction	Cz	null	0
11	Cm - drag coefficient for pitch	Cm	null	0
12	Sx - frontal area	Sx	m**2	1
13	air density	rhoair	kg/m**3	1.226
14	X-position of engine COG (Grid Frame)	Xeng	mm	1000
15	Z-position of engine COG (Grid Frame)	Zeng	mm	250
16	pitch inertia of engine at engine COG	Jeng	kgm**2	50
17	engine mass	Meng	kg	120
18	X-position of the COR (Grid Frame)	Xrefg	mm	0
19	Z-position of the COR (Grid Frame)	Zrefg	mm	0
20	Z-position of front wheels centers (Road Frame)	Zo	m	0.3
21	windage coefficient in longitudinal direction	rwvehx	N/(m/s)**2	0.6
22	windage coefficient in vertical direction	rwvehz	N/(m/s)**2	0
23	windage coefficient for pitch	rwvehy	N/(m/s)**2	0

DRAG FORCE

1. 전체 모델 구성
2. 속도 parameter와 drag 계산식 입력
3. 작업공간에 parameter 값 정의



Parameters

Slope:

2

Start time:

1

Initial output:

0

```
clear all; close all;
Cd=0.25; A=2; mu_roll=0.01;
grad=0.5*pi/180; M_body=1500;
```

작업 공간

이름	값
A	2
Cd	0.2500
grad	0.0087
M_body	1500
mu_roll	0.0100

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

Parameters

Expression:

0.5*Cd*A*1.226*u^2

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

Parameters

Expression:

mu_roll*M_body*9.81*tanh(u)

why?

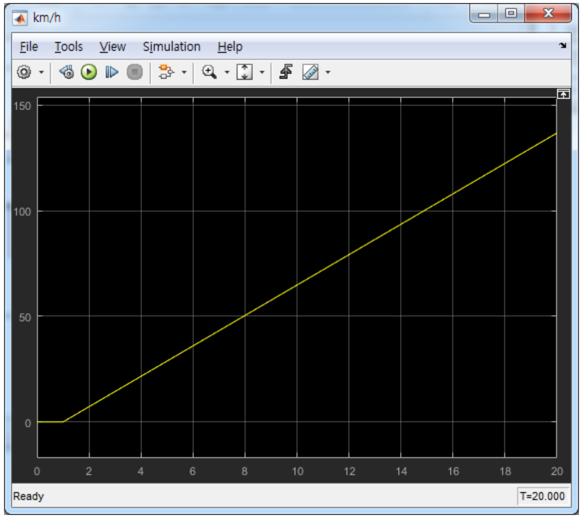
$$F_c = mg \sin \theta_{grad}$$

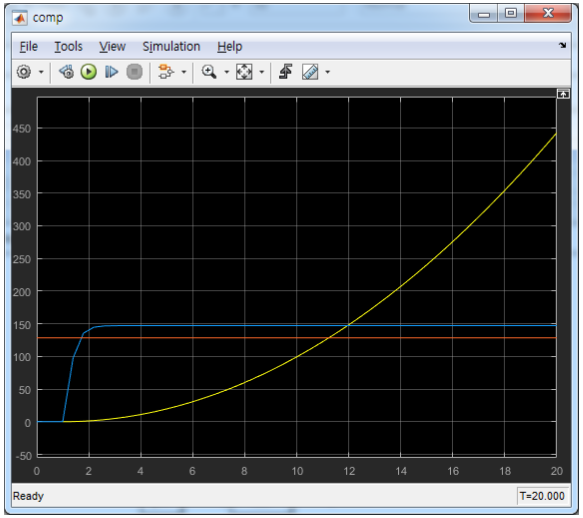
Parameters

Expression:

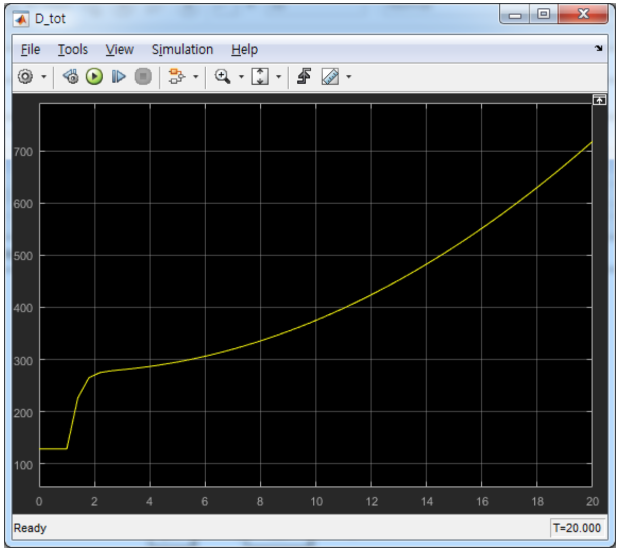
M_body*9.81*sin(u)

DRAG FORCE





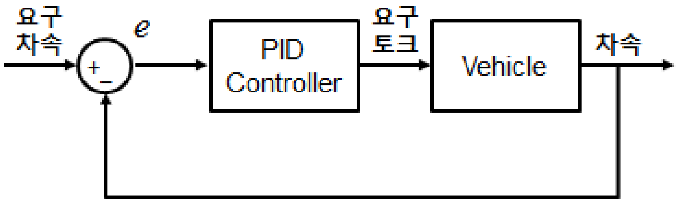
1 Run 및 결과 확인(20 s)



DRIVER CONTROLLER

1 제어 모델 구성

2 요구 속도, 요구 힘, 질량 값 입력



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

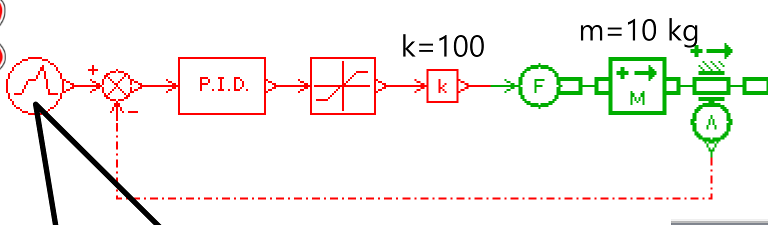
$$(e(t) = V_{req.} - V_{real})$$

K_p : proportional gain

K_i : integral gain

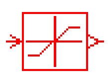
K_d : differential gain

1

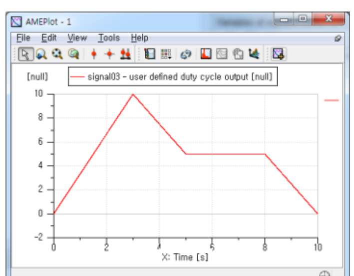


Title	Value	Unit
number of stages	5	
cyclic	no	
time at which duty cycle starts	0	s
output at start of stage 1	0	null
output at end of stage 1	10	null
duration of stage 1	3	s
output at start of stage 2	10	null
output at end of stage 2	5	null
duration of stage 2	2	s
output at start of stage 3	5	null
output at end of stage 3	5	null
duration of stage 3	3	s
output at start of stage 4	5	null
output at end of stage 4	0	null
duration of stage 4	2	s
output at start of stage 5	0	null
output at end of stage 5	0	null
duration of stage 5	1e+06	s

2

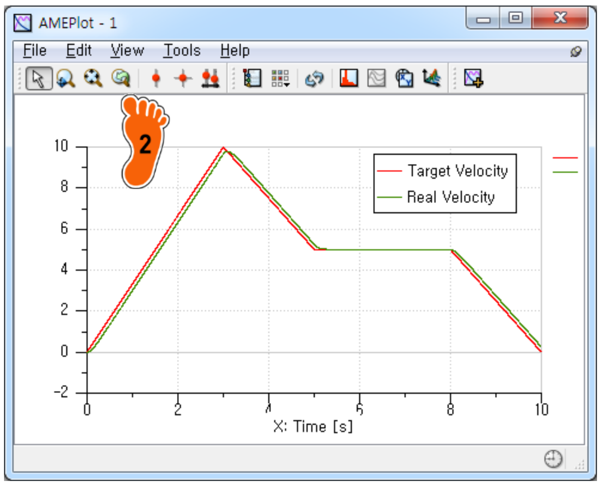


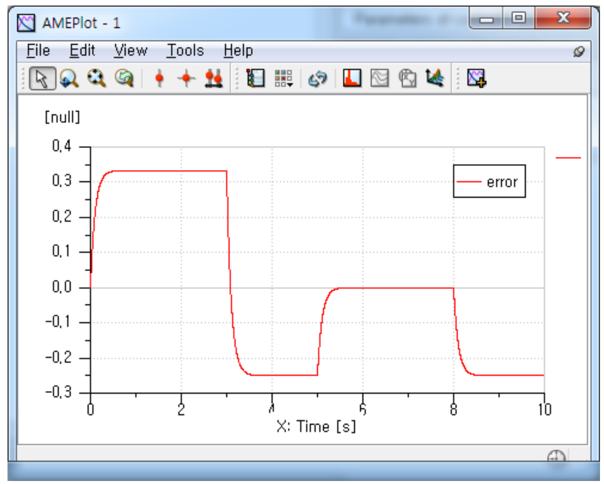
Title	Value	Unit
minimum permitted value	-1	null
maximum permitted value	1	null



DRIVER CONTROLLER

Title	Value	Unit
dummy state variable for estimati···	0	1/s
integral part	0	null
controller type	PID	
limit output	no	
proportional gain	1	null
integral gain	0	null
derivative gain	0	null
time constant for first order lag used t···	0.001	null

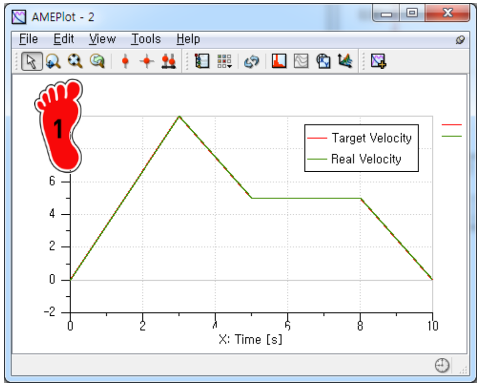


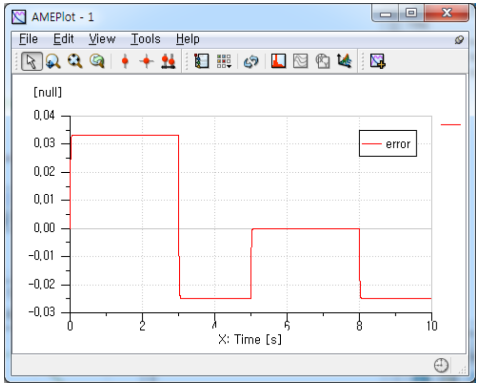


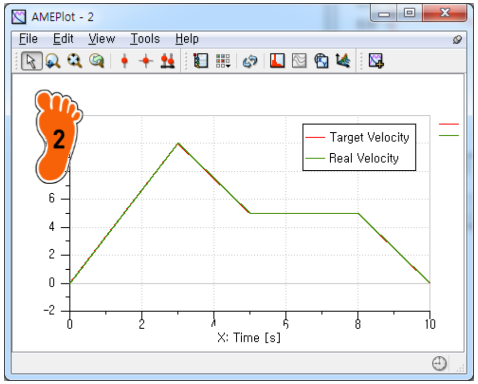
1 Kp=1, Ki=0, Kd=0

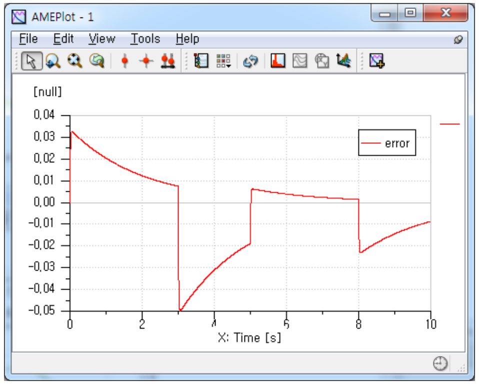
2 요구 속도, 실제 속도 확인
error값 확인

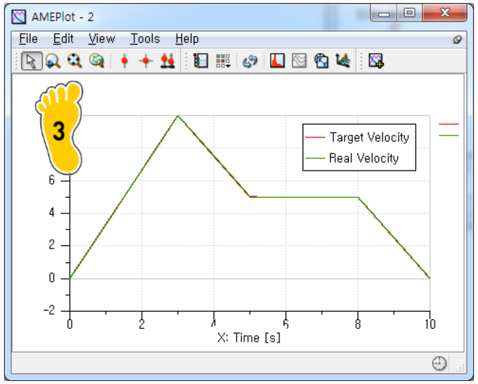
DRIVER CONTROLLER

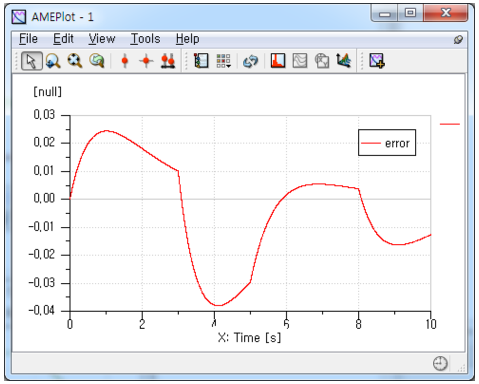










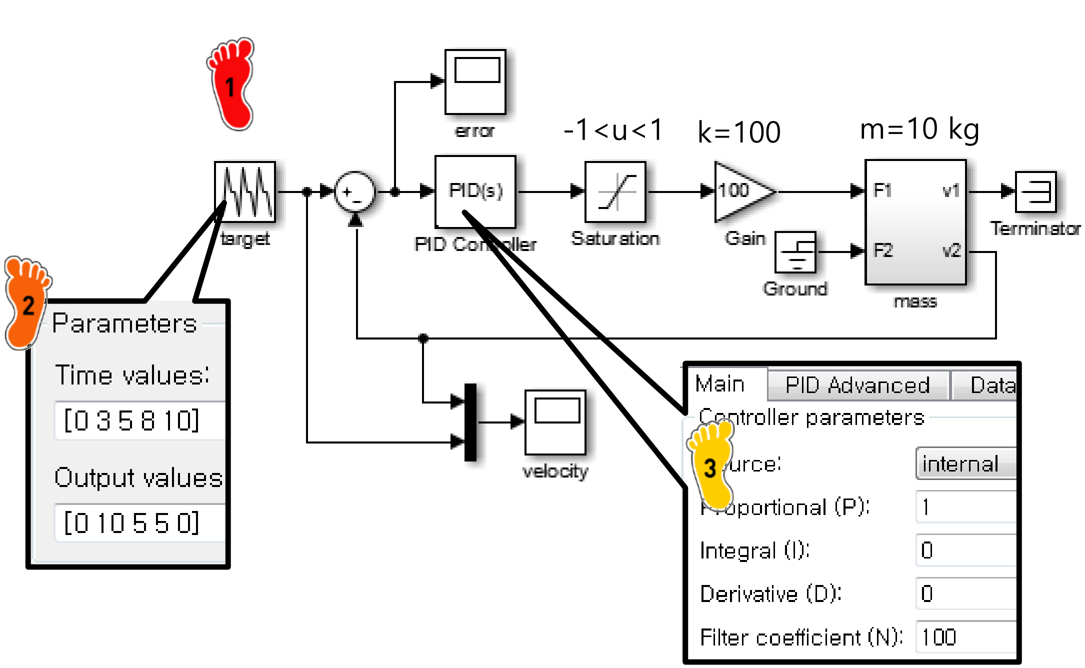


1 Kp=10, Ki=0, Kd=0

2 Kp=10, Ki=5, Kd=0

3 Kp=10, Ki=5, Kd=5

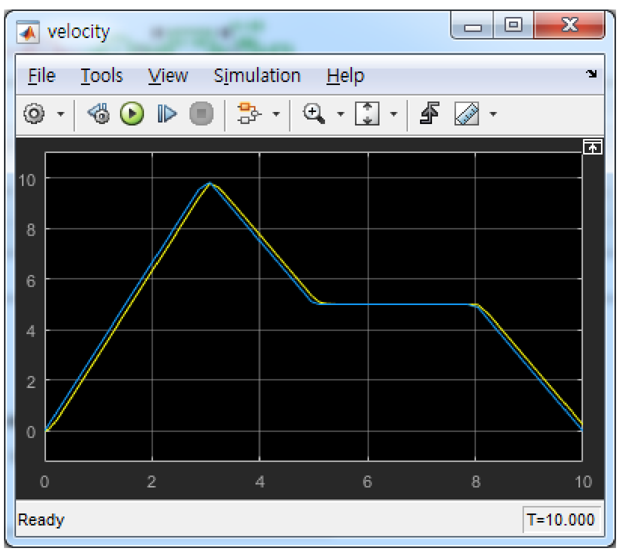
DRIVER CONTROLLER

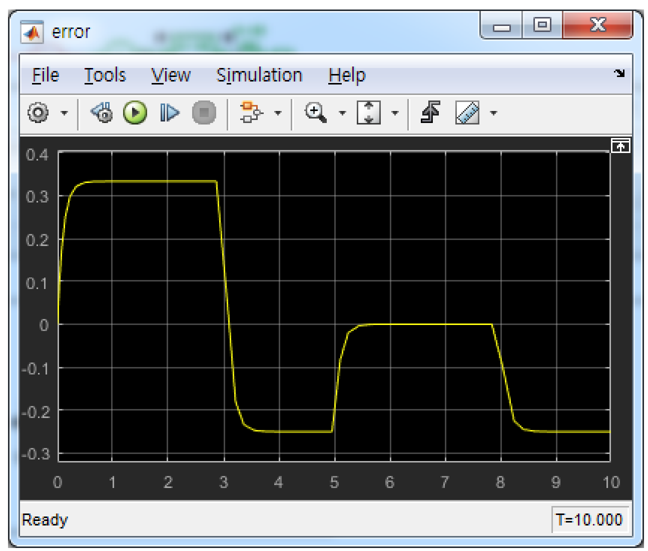


1 제어 모델 구성

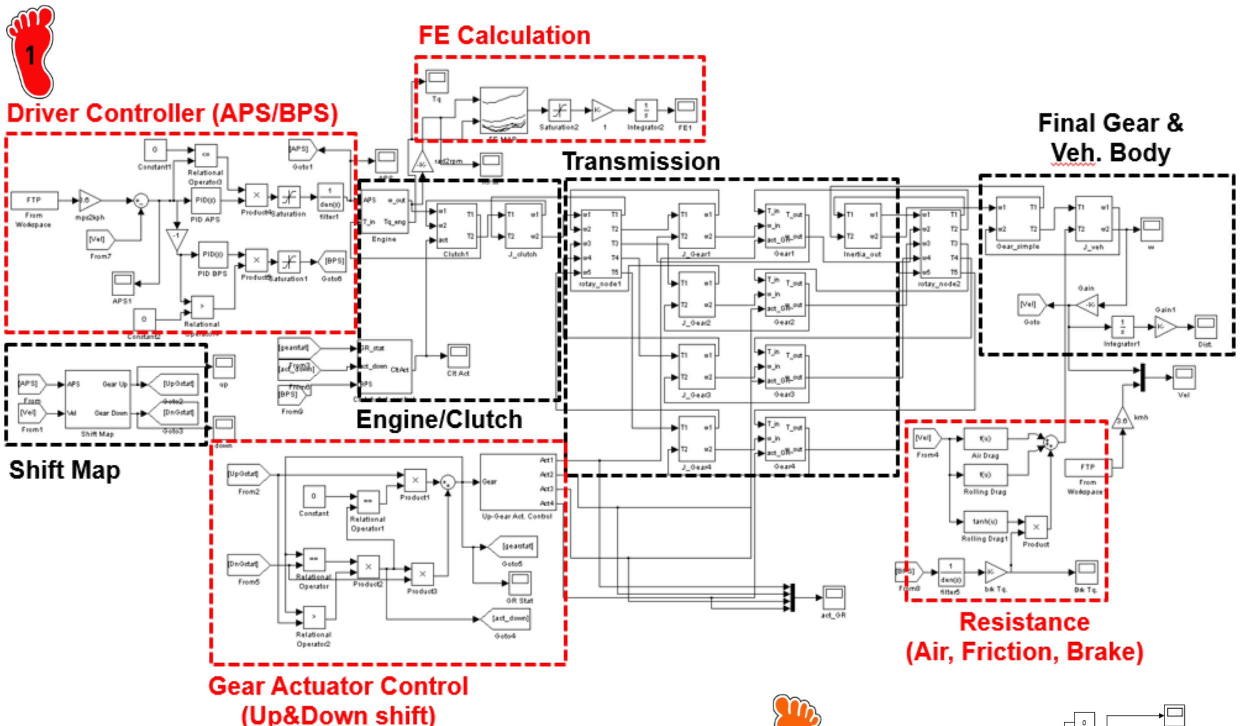
2 요구 속도, 요구 힘, 질량 값 입력

3 Kp, Ki, Kd값의 변화에 의한 결과 확인



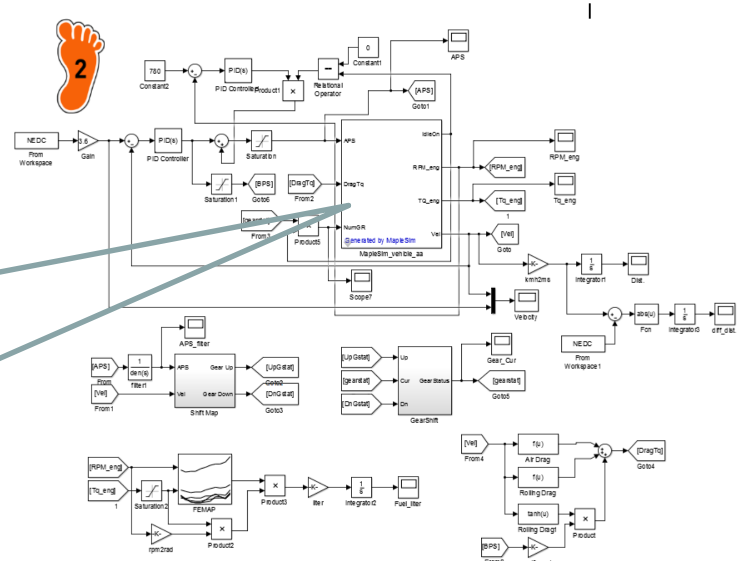


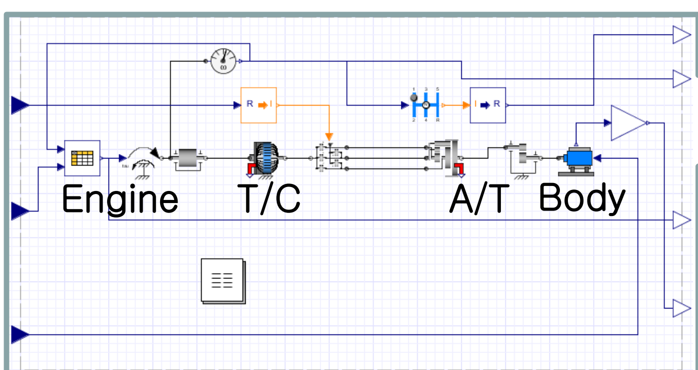
FULL VEHICLE MODEL



1 연비해석을 위한 4-speed 엔진구동 차량 모델

2 상용 툴을 이용한 동일 차량 모델

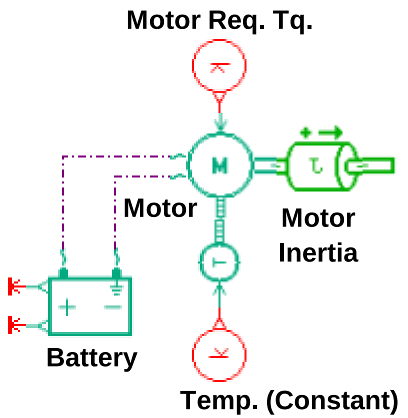


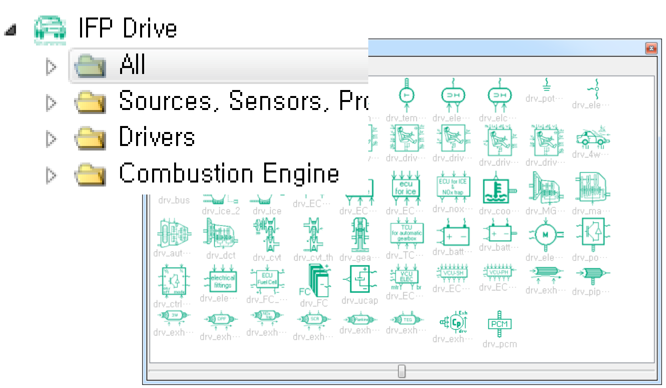


ASSIGNMENT

Electric Power System Modeling : Battery & Simple Motor (by Simulink)

1. Reference Model (AMESim)





① T_motor = 100 Nm

② J_motor = 100 kgm^2

Battery

Parameters of drv_battery_2 [DRVBAT03-1]

Title	Value	Unit
potential at port 2	122	V
state of charge at port 4	50	%
number of cells in series per battery bank	1	
number of battery banks in parallel	1	
number of battery banks in series	1	
discontinuity handling	active	
tables dependencies	state of charge (SOC)	
rated capacity of the battery	108.3	Ah
voltage time constant	0.5	s
filename for open circuit voltage (for one cell) [···	CAE/ocv.data	
filename for internal resistance (for one cell) [···	CAE/resistance.data	

OCV

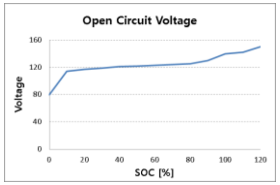
Format: 1D Table

	X1	Y
1	0	80
2	10	114
3	20	117
4	30	119
5	40	121
6	50	122
7	60	123
8	70	124
9	80	125
10	90	130
11	100	140

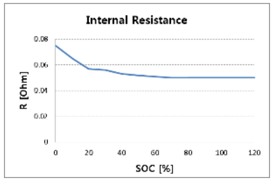
Resistance

Format: 1D Table

	X1	Y
1	0	0.075
2	10	0.065
3	20	0.057
4	30	0.056
5	40	0.053
6	50	0.052
7	60	0.051
8	70	0.05
9	80	0.05
10	90	0.05
11	100	0.05



$V_{OCV}(SOC)$



$R_{in}(SOC)$

Motor

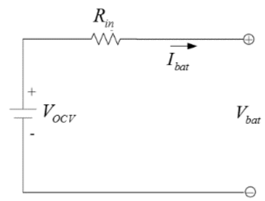
Parameters of drv_electricmotortherm [DRVELMT0A-1]

Title	Value	Unit
motor torque at port 2	0	Nm
data type for electric motor modeling	constant values	
time constant to determine the torque	0.1	s
maximum power	15000	W
maximum torque	150	Nm
mean efficiency	1	null
maximum rotary velocity	8000	rev/min

ASSIGNMENT

2. SOC calculation

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



V_{bat} : battery volatage [V]
V_{OCV} : open circuit voltage [V]
R_{in} : equivalent internal resistance [Ω]
I_{bat} : battery current [A]

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

SOC : state of charge [%]
C_{nom} : rated capacity [As]

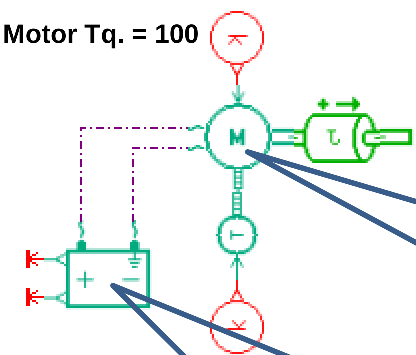
$$SOC = SOC_{ini} - \frac{100}{C_{nom}} \int I_{bat}\, dt$$

$$W_{motor} = T\omega = VI \text{ (without losses)}$$

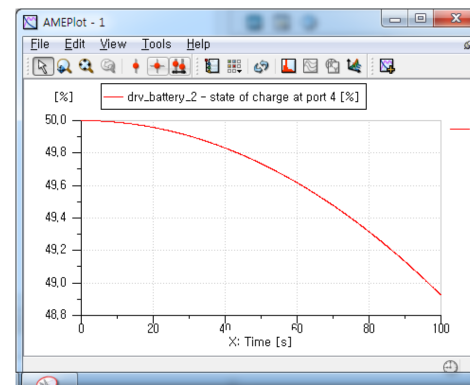
Mechanical Energy : $W = T\omega$
Electrical Energy : $W = VI$

※ Result (Simulation Time : 100 s)

Motor Tq. = 100



Title	Value	Unit
input voltage	117.486	V
input current	85.0314	A
rotor relative rotary velocity	99.9	rad/s



Title	Value	Unit
potential at port 1	0	V
current at port 1	85.0314	A
potential at port 2	117.486	V
current at port 2	-85.0314	A
open circuit voltage at port 3	121.892	V
state of charge at port 4	48.9248	%
depth of discharge	51.0752	%
charge used by the load	1.16448	Ah

Mechanical Energy : $W_{mec} = Tw = 100 \times 99.9 = 9990\ W$

Electrical Energy : $W_{elec} = VI = 117.49 \times 85.03 = 9990\ W$

SOC : $SOC = SOC_{initial} - \int I\, dt \bullet \frac{100}{C_{nom}} [\%]$

$$= 50 - 4192.02 \frac{100}{108.3 \times 3600} = 48.925\ \%$$