

Mag.Lev.Up

2015012951 최호현

2015012897 조용식

2015012697 김찬

Object

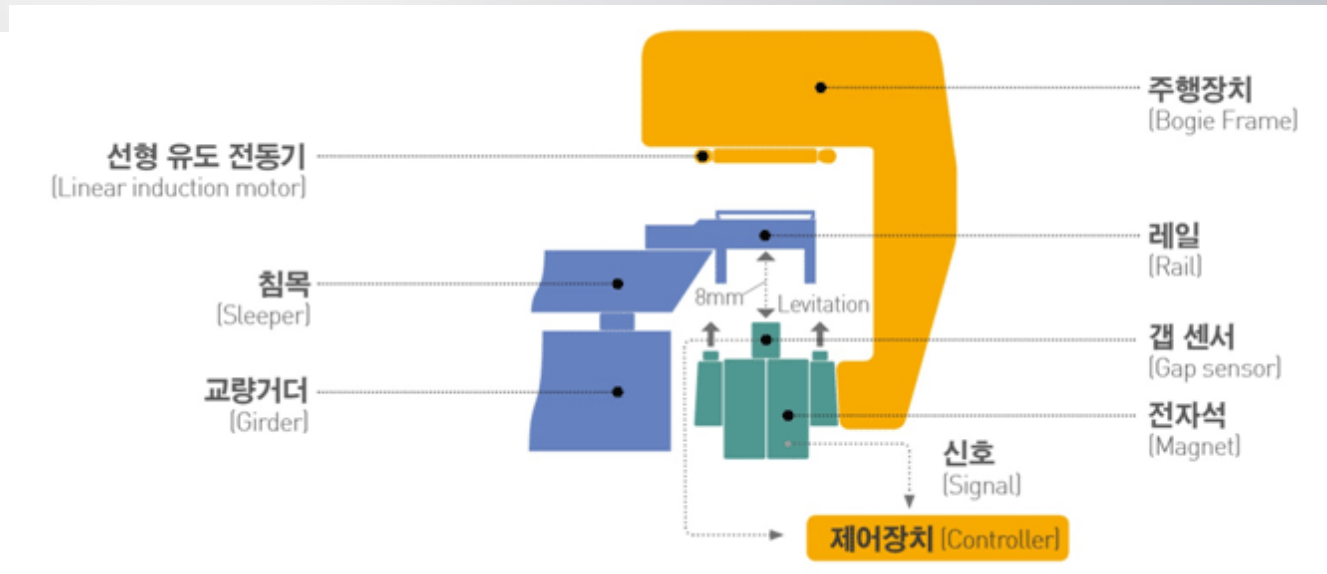
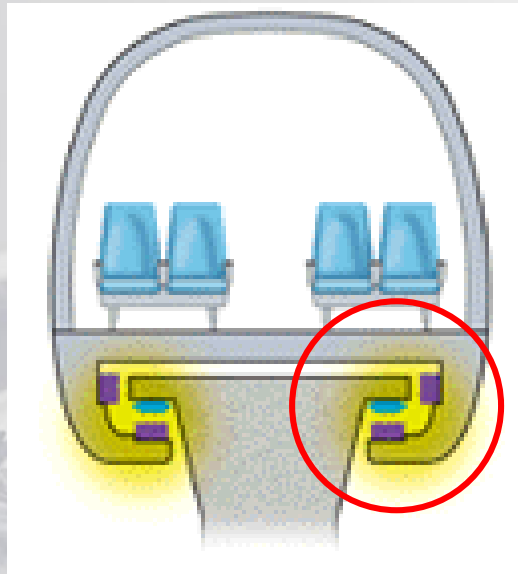
- 자기부상열차 : 고속, 저소음, 저진동 운행 가능
 - 단점? : 고도의 제어 기술 필요
- 미래의 대중교통수단이 될 것으로 생각
- 최적의 높이 및 각도 제어를 위한 PI 제어기 도출

Team Name 선정 배경

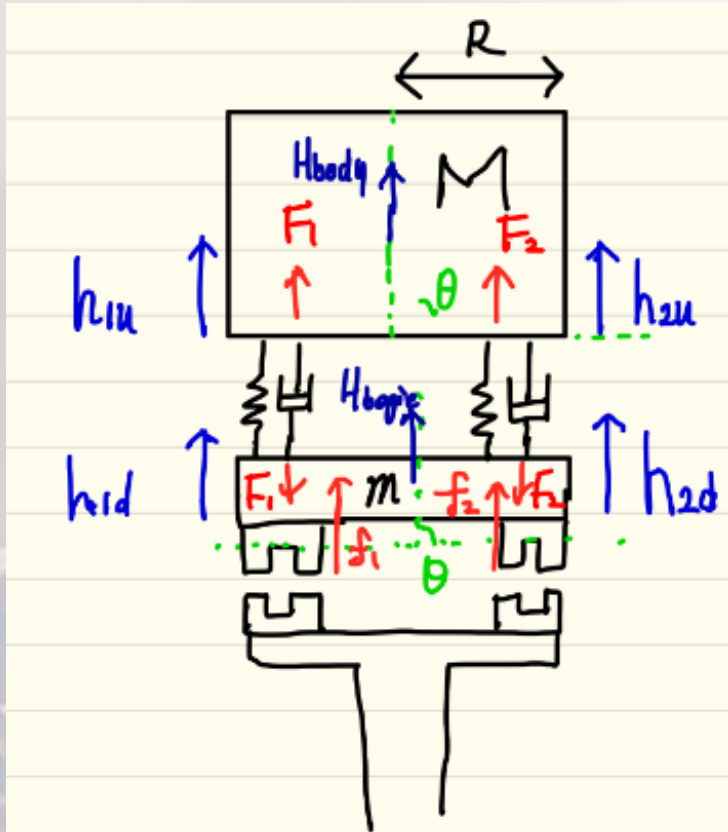
- 자기부상열차 : MAGLEV Train
- MAG.LEV.UP : 마구레벨업
- Maglev train 연구를 통해 자기부상열차와 우리의 실력을
마구 레벨업 시킬 것이다

How MAGLEV Works?

- 상전도 흡인식 자기부상열차



상태 방정식



$$J_{body} \ddot{\theta}_{body} = T = R(F_1 - F_2)$$

$$M\ddot{H} + F_1 + F_2 - Mg = 0$$

$$h_{1u} = H_{body} + R \sin(\theta_{body})$$

$$h_{2u} = H_{body} - R \sin(\theta_{body})$$

$$F_1 = K(h_{1d} - h_{1u}) + b(\dot{h}_{1d} - \dot{h}_{1u})$$

$$F_2 = K(h_{2d} - h_{2u}) + b(\dot{h}_{2d} - \dot{h}_{2u})$$

$$J_{bogie} \ddot{\theta}_{bogie} = T = R(f_1 - F_1 - f_2 + F_2)$$

$$mH_{bogie} + f_1 + f_2 - F_1 - F_2 - mg = 0$$

$$h_{1d} = H_{bogie} + R \sin(\theta_{bogie})$$

$$h_{2d} = H_{bogie} - R \sin(\theta_{bogie})$$

$$f_1 = f(h_{1d}) * \left(\frac{I_1}{I_{ref}} \right)^2, \quad f_2 = f(h_{2d}) * \left(\frac{2}{I_{ref}} \right)^2$$

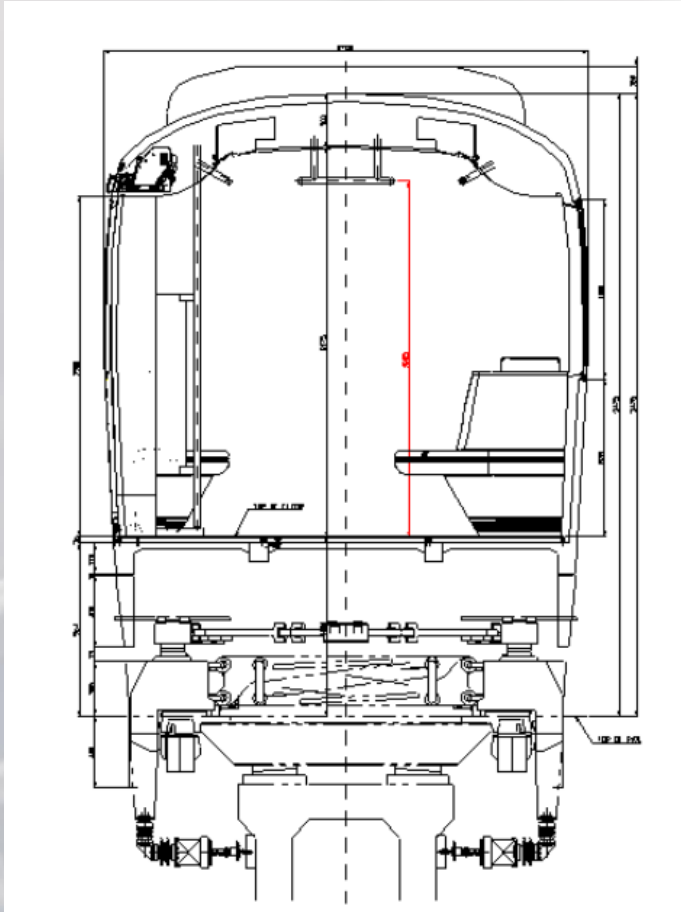
제원

수주년도	2011년
납품년도	2013년
시행청	인천국제공항공사
공급수량	8량
설계 최고 속도	110km/h
궤간	1,850mm
차량전원	1,500V DC
차량치수 (L X W X H)	12,000 X 2,700 X 3,475(mm)(길이 X 너비 X 높이)
차체 재질	알루미늄
중량(편성 중량)	38.2t
정원(편성 정원)	230명
신호 시스템	ATP / ATO(Posco Pattern belt)

정밀 System Model 구성

- 철도연구소 등의 입찰공고
- 현대로템 (차체 제작사)
- 철도공사
- Maglev 연구 논문
- 실제 물성치 조사

CATIA 활용한 회전관성 측정



A 3D model of a vehicle chassis, showing a side view with a red vertical line and a green horizontal line. The model is highlighted in blue. A dialog box titled 'Measure Inertia' is open, showing the following results:

Definition
Selection : Face...Scaling.2...Part1.1

Result
Calculation mode : Exact
Type : Surface

Characteristics		Center Of Gravity (G)	
Area	4.185m ²	Gx	20mm
Mass	4774.464kg	Gy	2012.297mm
Surfacic mass	1140.955kg_m ²	Gz	2749.294mm

Inertia / G | Inertia / O | Inertia / P | Inertia / Axis | Inertia / Axis System

Select Point
Px 20mm Py 2010.603mm Pz 1516.317mm

Inertia Matrix / P					
IoxP	18005.474kgxm ²	IoyP	14226.444kgxm ²	IozP	3779.03kgxm ²
IxyP	0kgxm ²	IxzP	0kgxm ²	IyzP	-20.439kgxm ²

Keep measure only main bodies Create geometry Export Customize...
OK Cancel

Real parameter 활용 상수 결정

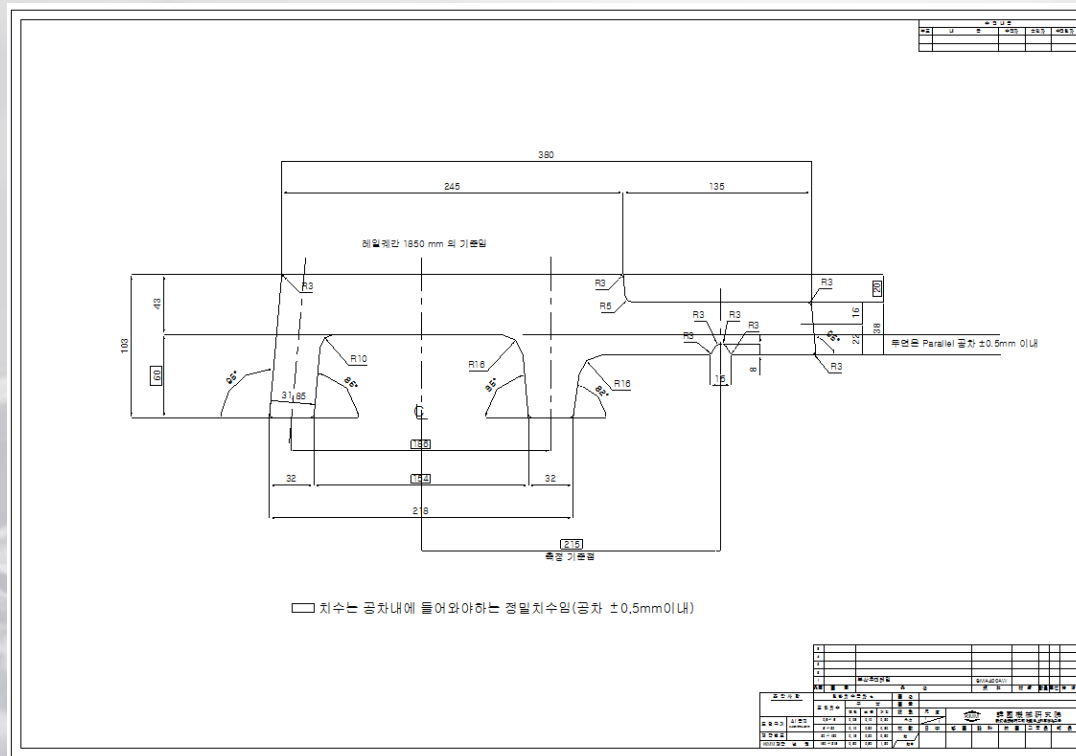
```
편집기 - C:\Users\Administrator\Desktop\constant+simulink_pwm\maglev_constant.m
maglev_constant.m
-   clc; clear all;
-
-   m=38200;
-   h1des=8;
-   h2des=8;
-   J=18005.474+1000000;
-   R=1850/2;
-   l_ref = 11695.2;
-   g = 9.81*1000;
-   kp = 1000;
-   ki = 50;
-   %V = 1500;
-   %res = 0.001;
-   K = 500000;
-   b = 1000;
-   m_bogie = 14000;
-   m_body = 20200;
-   J_bogie = 18005.474+1000000/34+14;
-   J_body = 18005.474+1000000/34+20;
-
-   filename= 'Force_Data.xlsx';
-   xlRange_h = 'B1:B151';
-   xlRange_F = 'D1:D151';
-   h_vari = xlsread(filename,1,xlRange_h);
-   F_vari = xlsread(filename,1,xlRange_F);
```

Assumption

- 차체의 회전 각도가 매우 작다
 - 팔 길이 : 1900mm, 높이 변화 8mm
 - $\theta \approx 0$, $\sin\theta \approx \theta$
 - 전자석은 틀어짐 없이 상하 운동만 있다
- 힘의 크기는 전류의 제곱에 비례한다 (선형)
 - COMSOL : 전류값 10배 → 힘의 크기 100배 확인
 - 비례관계를 알기 때문에 Table 대신 식 이용

Real Model 기반 COMSOL해석

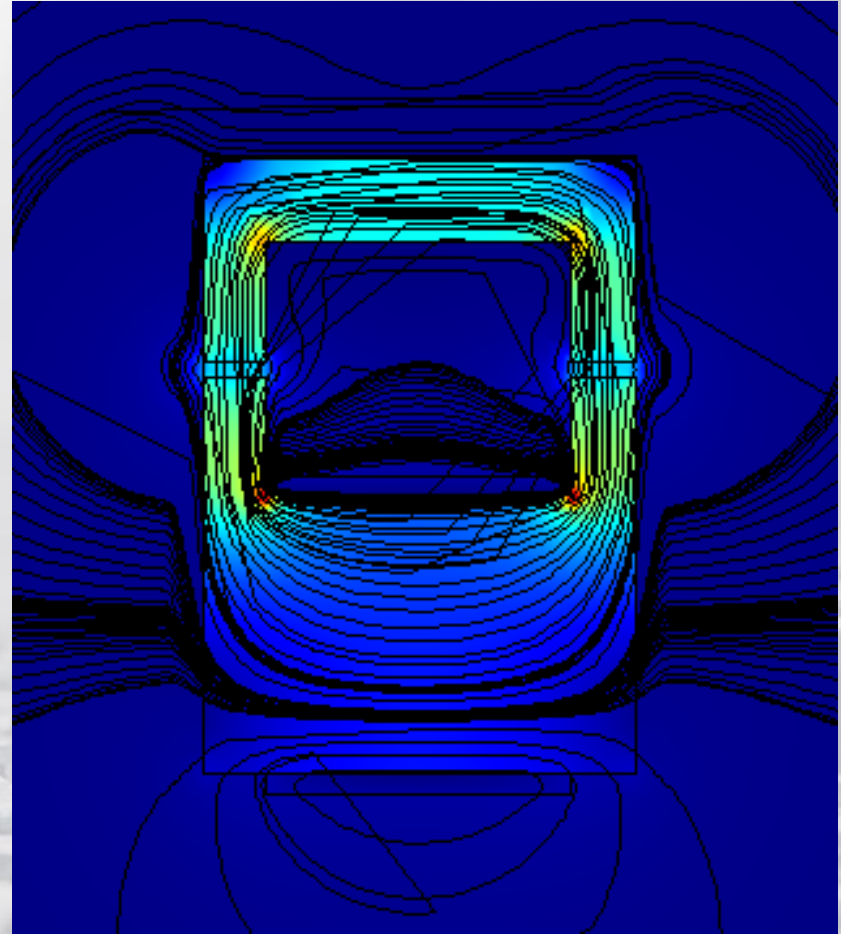
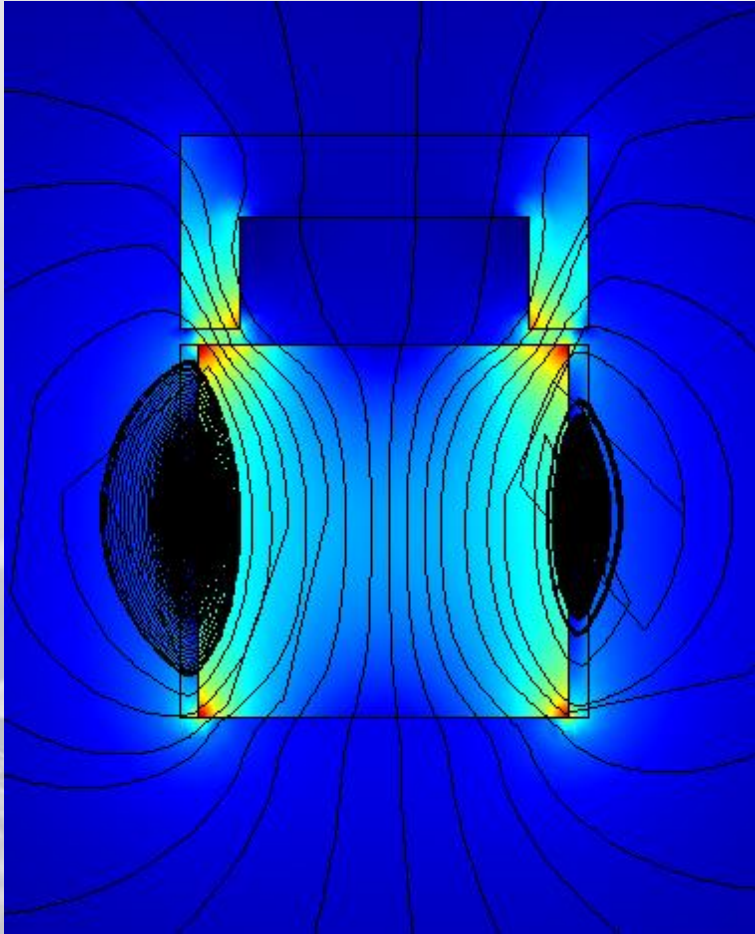
- 자기부상열차 레일 재질 : S20C



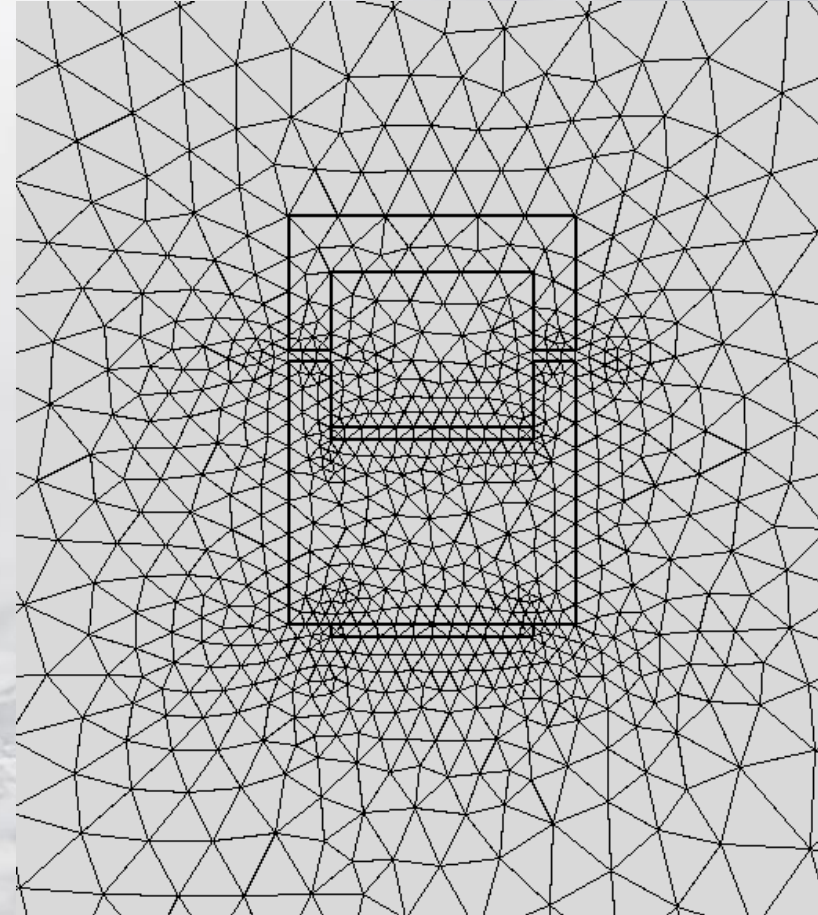
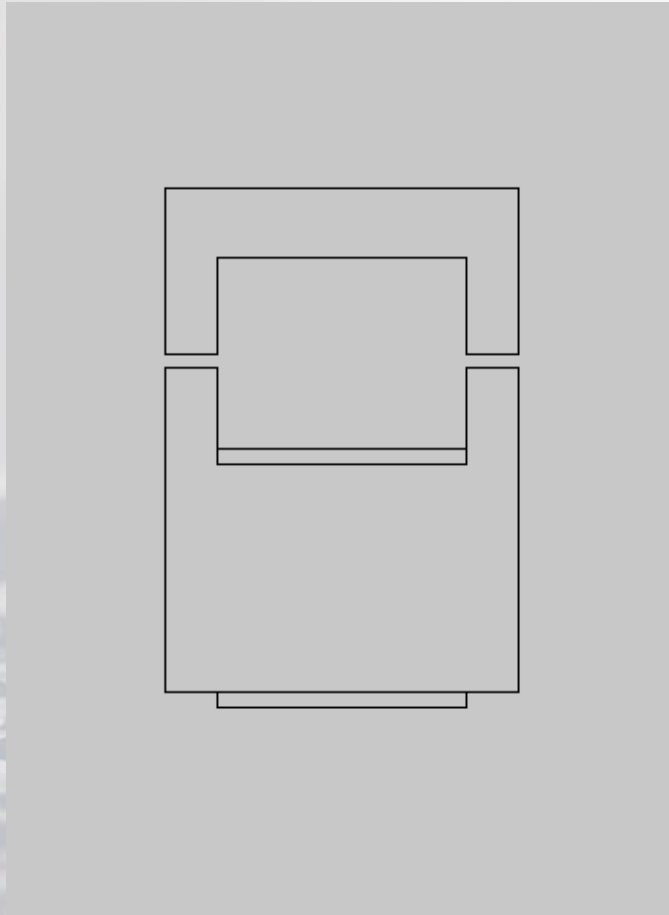
[표 1] 솔레노이드의 자기적 특성

component	Material	Relative permeability	Saturation Flux Density
Ferro-magnetic	S20C	2000	1.5Tesla

Simple Modeling



Modeling, Mesh



Finer mesh VS Dense data

- Force calculation : 개인 노트북 이용 해석
 - 150번의 해석 : Shorter time is better
 - System 유사성 측면 : Finer is better

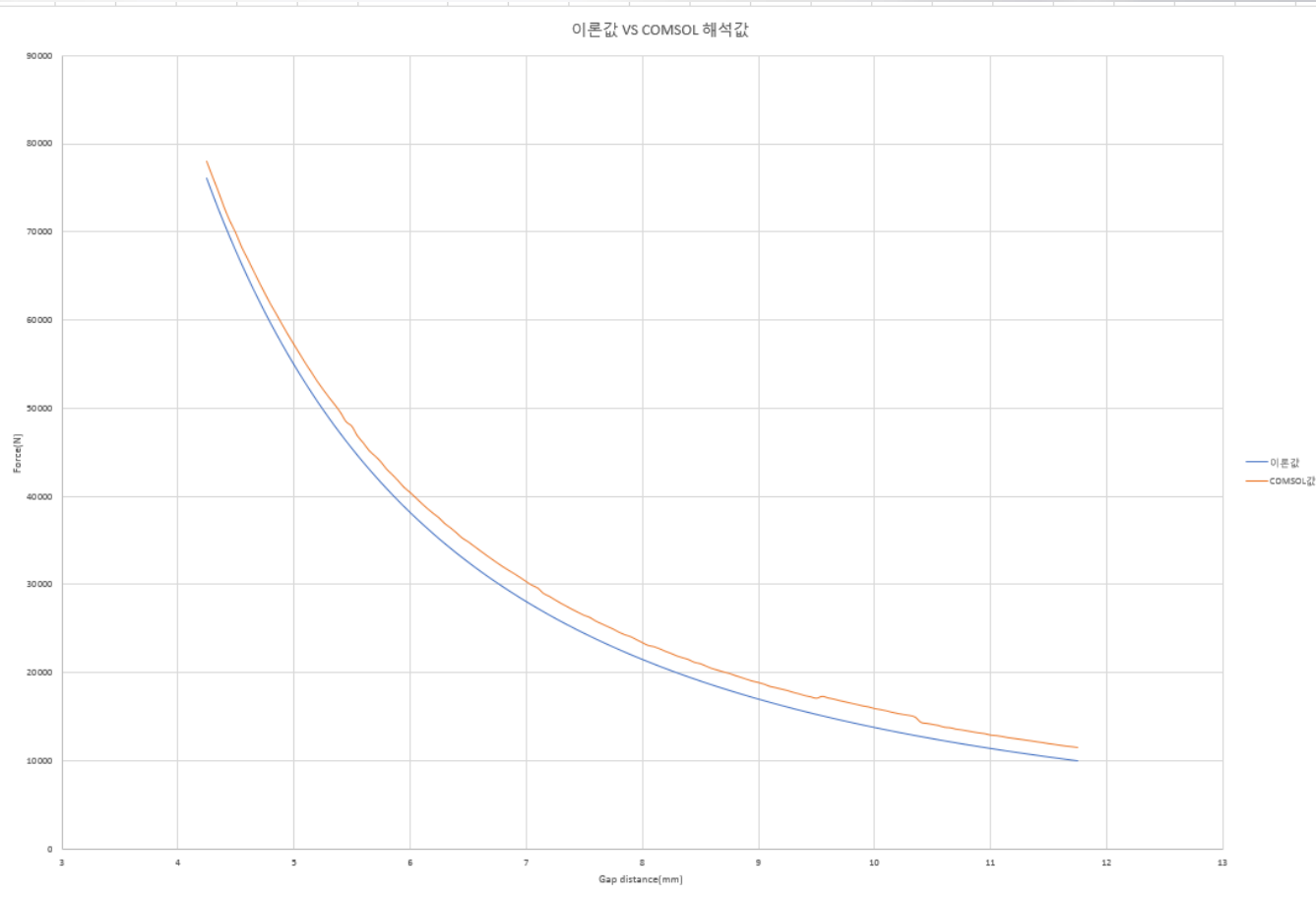
I = 11695.2 A , h = 8mm 기준

	Solution Time	DOF	Armature Force
Extremely Fine	4s	62101	-23386
Extra Fine	3s	18645	-23471
Normal	1s	5217	-23397

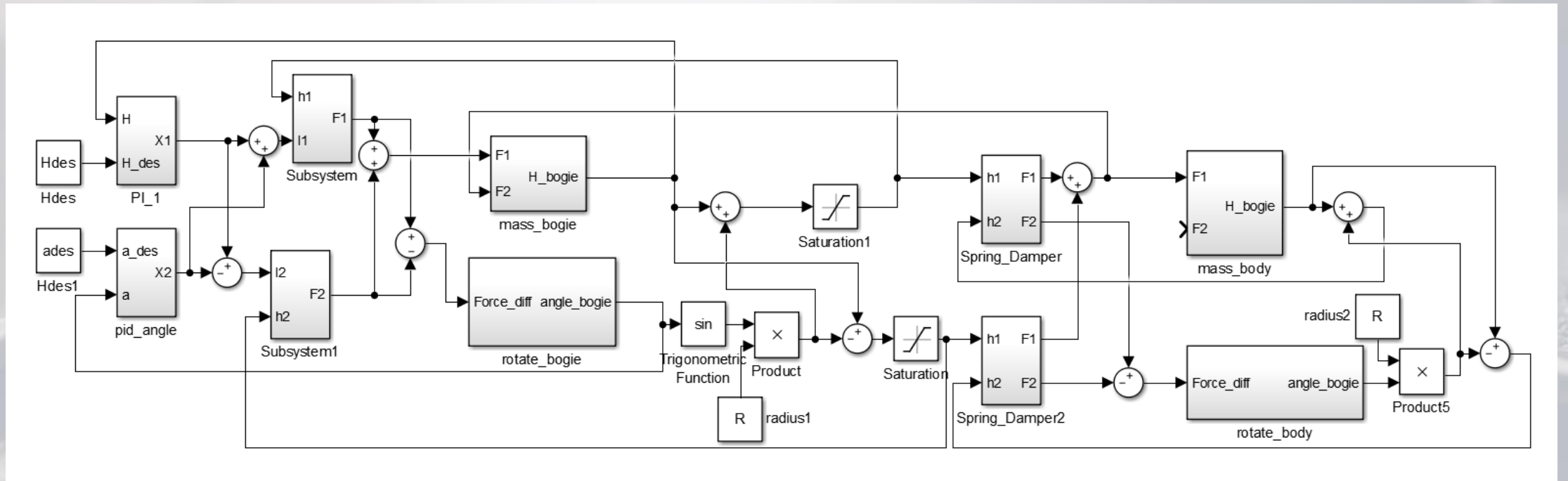
- 결론 : Shorter time, small difference

이론 데이터 VS COMSOL

103	1.35	9.35	-17577	17577	15728.664
104	1.4	9.4	-17381	17381	15561.783
105	1.45	9.45	-17241	17241	15397.544
106	1.5	9.5	-17072	17072	15235.891
107	1.55	9.55	-17292	17292	15076.77
108	1.6	9.6	-17115	17115	14920.13
109	1.65	9.65	-16978	16978	14765.918
110	1.7	9.7	-16806	16806	14614.084
111	1.75	9.75	-16662	16662	14464.58
112	1.8	9.8	-16512	16512	14317.359
113	1.85	9.85	-16367	16367	14172.374
114	1.9	9.9	-16210	16210	14029.58
115	1.95	9.95	-16094	16094	13888.934
116	2	10	-15913	15913	13750.392
117	2.05	10.05	-15796	15796	13613.912
118	2.1	10.1	-15664	15664	13479.455
119	2.15	10.15	-15492	15492	13346.979
120	2.2	10.2	-15352	15352	13216.447
121	2.25	10.25	-15233	15233	13087.821
122	2.3	10.3	-15131	15131	12961.063
123	2.35	10.35	-14947	14947	12836.138
124	2.4	10.4	-14348	14348	12713.01
125	2.45	10.45	-14226	14226	12591.645
126	2.5	10.5	-14111	14111	12472.011
127	2.55	10.55	-13991	13991	12354.073
128	2.6	10.6	-13793	13793	12237.8
129	2.65	10.65	-13740	13740	12123.16
130	2.7	10.7	-13584	13584	12010.125
131	2.75	10.75	-13491	13491	11898.662
132	2.8	10.8	-13372	13372	11788.745
133	2.85	10.85	-13255	13255	11680.343
134	2.9	10.9	-13147	13147	11573.43
135	2.95	10.95	-13062	13062	11467.977
136	3	11	-12905	12905	11363.96
137	3.05	11.05	-12843	12843	11261.351
138	3.1	11.1	-12737	12737	11160.126
139	3.15	11.15	-12614	12614	11060.26
140	3.2	11.2	-12524	12524	10961.728
141	3.25	11.25	-12429	12429	10864.507
142	3.3	11.3	-12338	12338	10768.574
143	3.35	11.35	-12239	12239	10673.905
144	3.4	11.4	-12138	12138	10580.48
145	3.45	11.45	-12043	12043	10488.276
146	3.5	11.5	-11932	11932	10397.272
147	3.55	11.55	-11843	11843	10307.447
148	3.6	11.6	-11747	11747	10218.781
149	3.65	11.65	-11647	11647	10131.254
150	3.7	11.7	-11582	11582	10044.847
151	3.75	11.75	-11491	11491	9959.5412
152		R		COMSOL	21484.987



2-DOF PID 제어

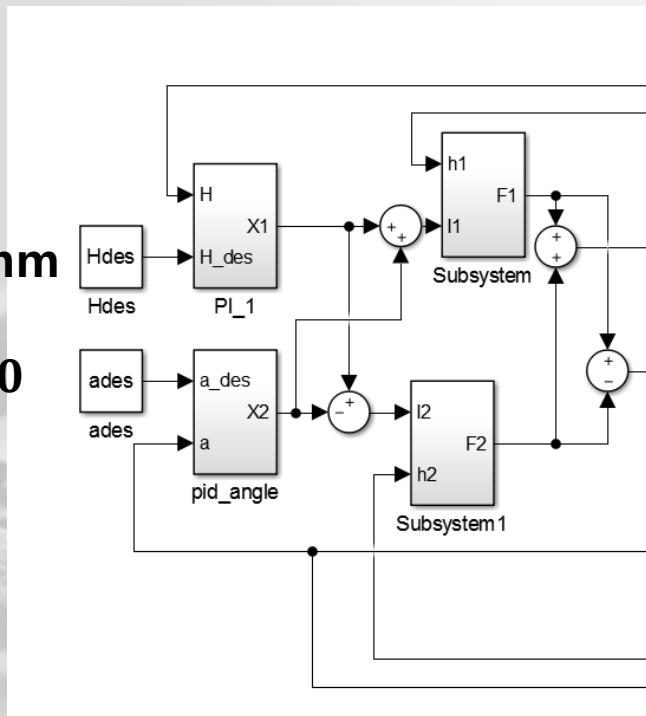


제어 요소에 따른 안정성

- Bogie의 H , θ 를 기준값

$H = 8\text{mm}$

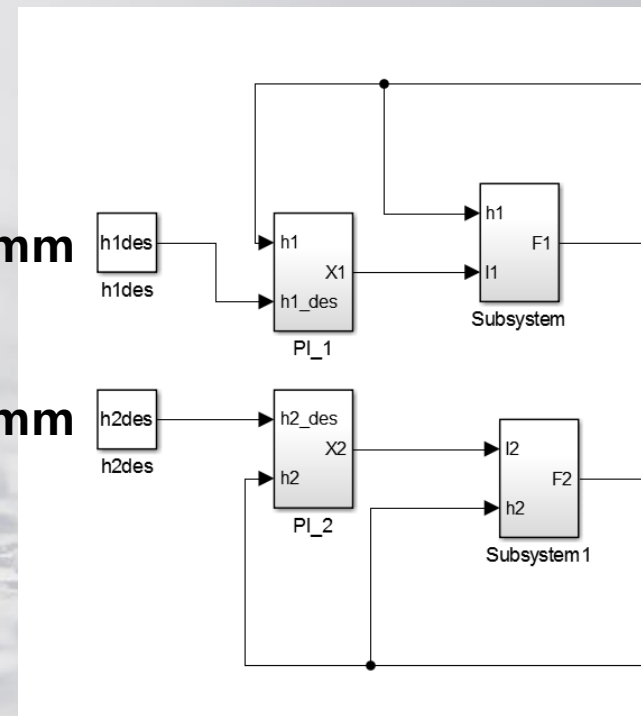
$\theta = 0$



- Bogie의 $h1$, $h2$ 를 기준값

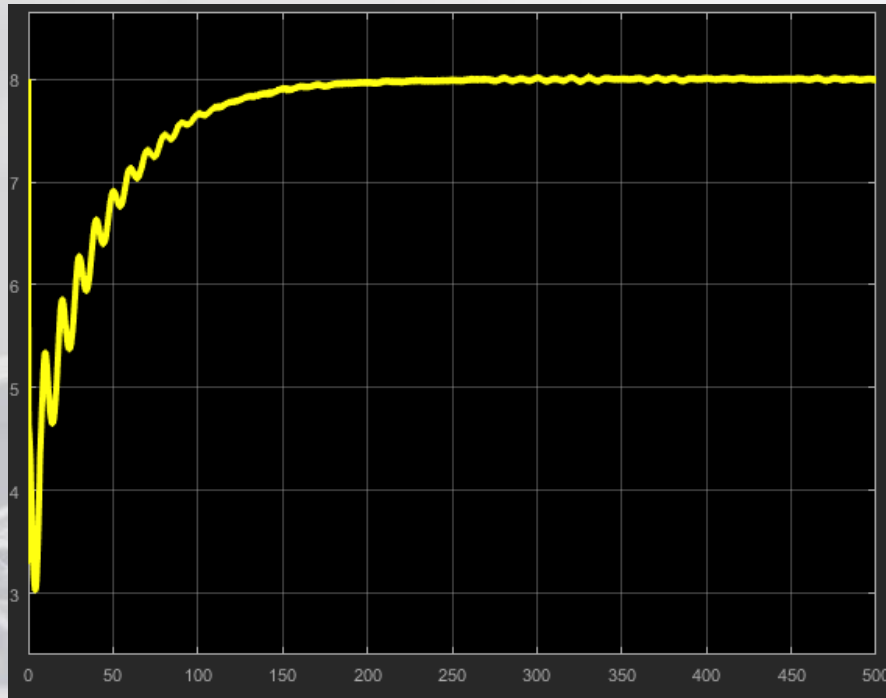
$h1 = 8\text{mm}$

$h2 = 8\text{mm}$

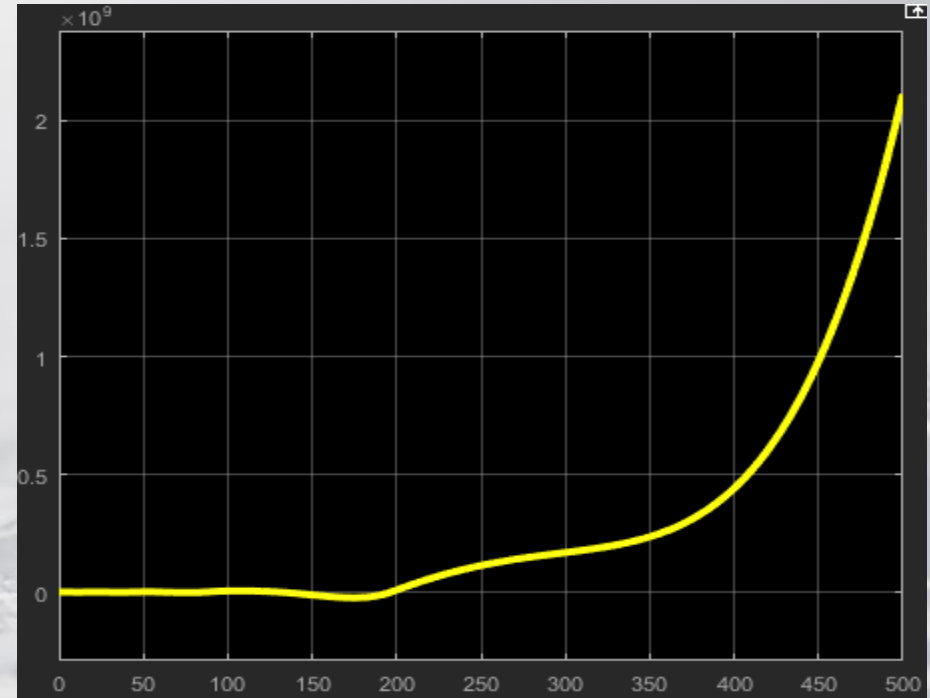


제어 요소에 따른 안정성

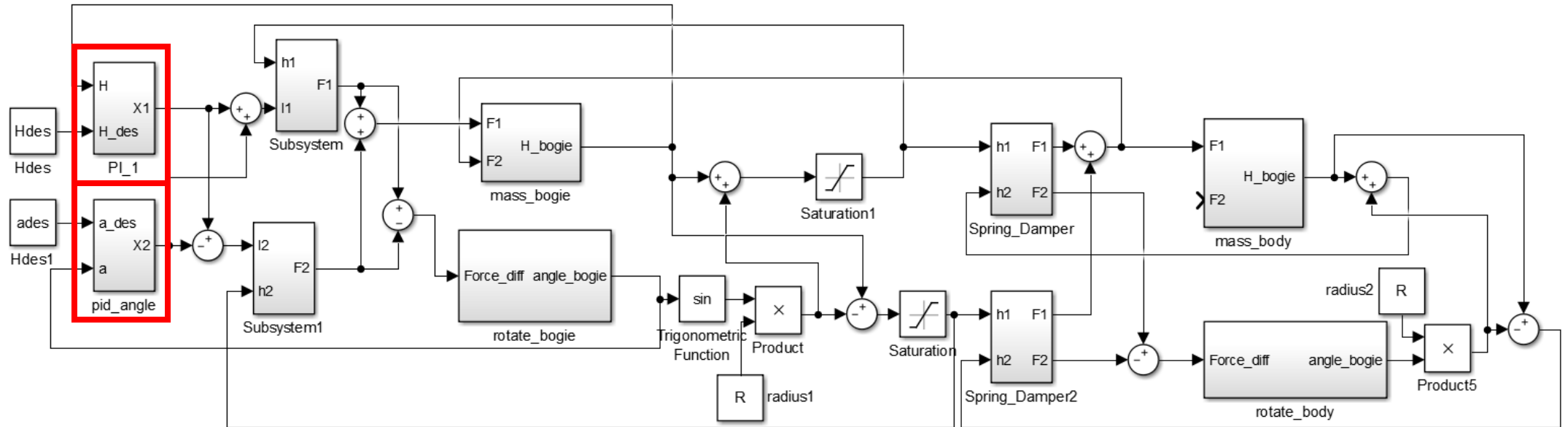
- Bogie의 H , θ 를 기준값



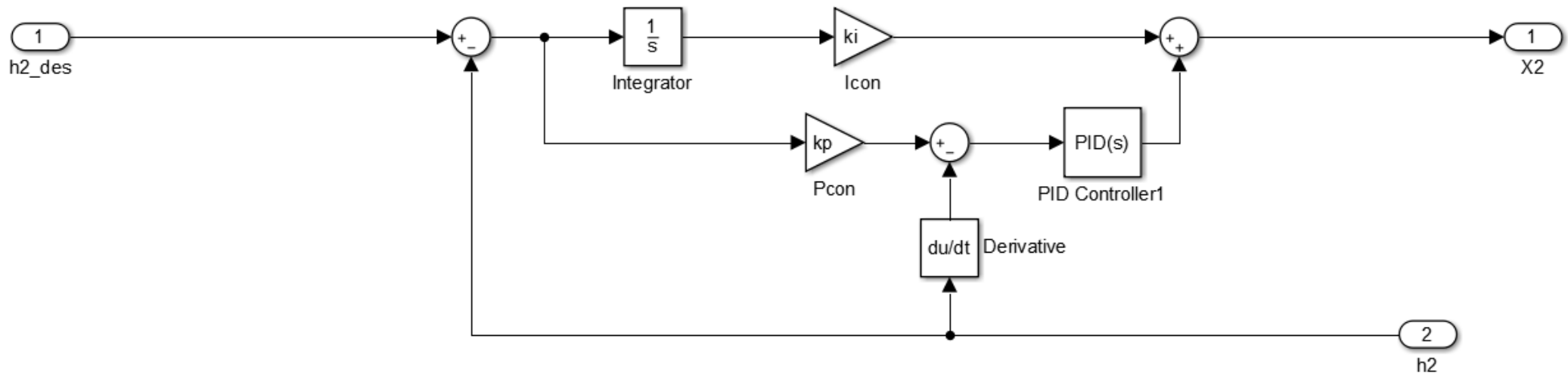
- Bogie의 h_1 , h_2 를 기준값



Components

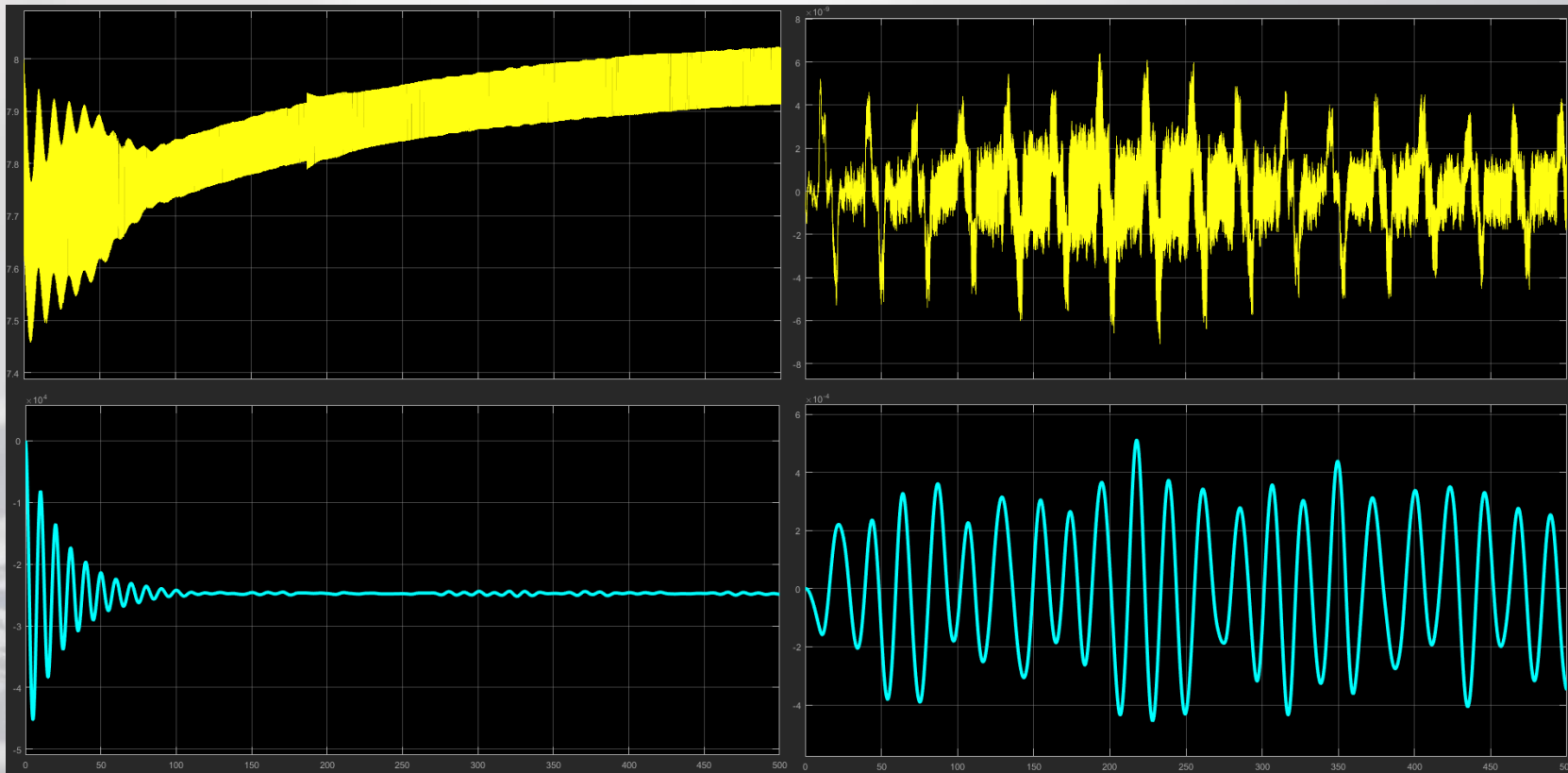


이중 PI 제어



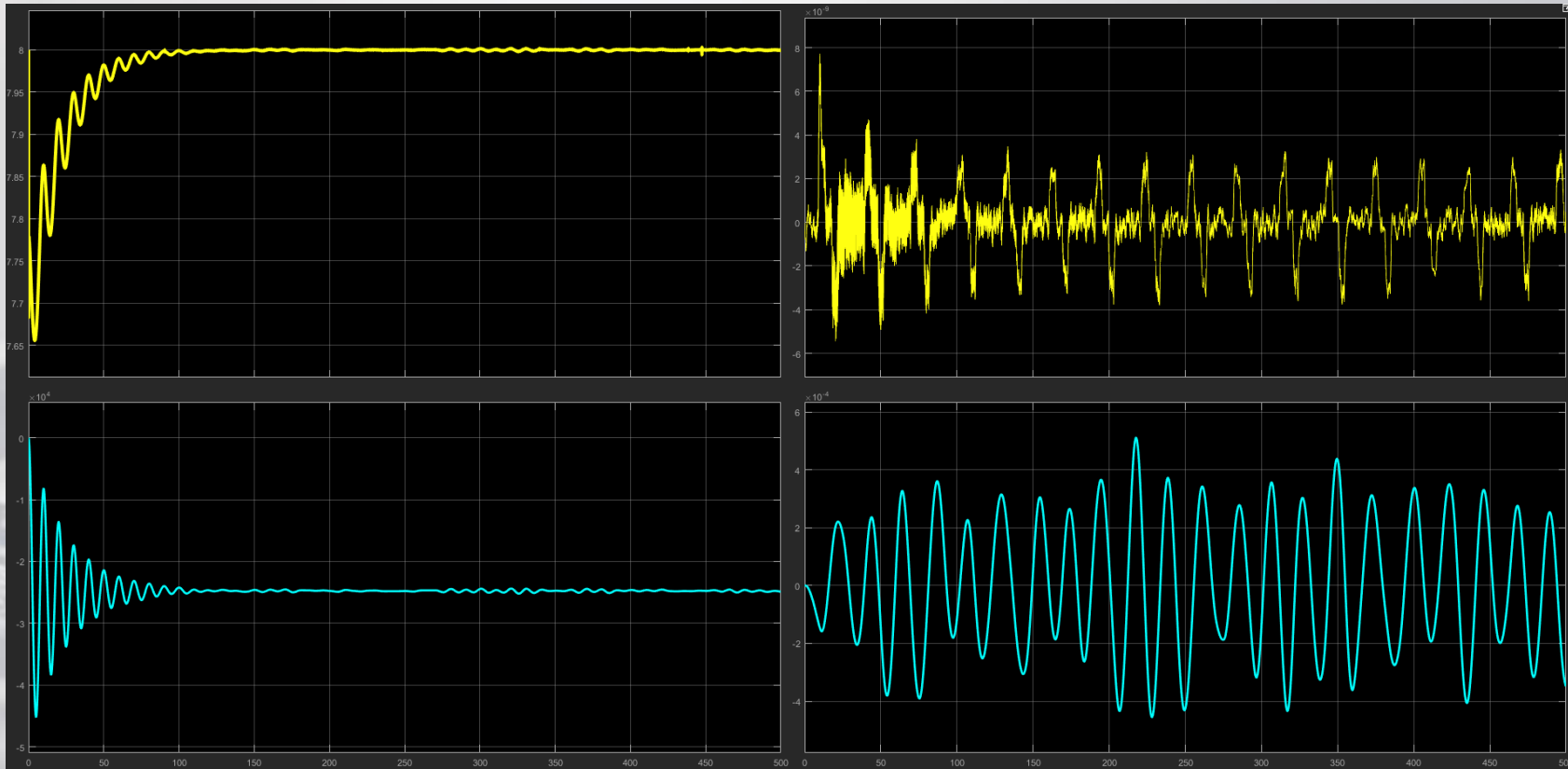
Normal PI control

- $K_p=1000000$, $k_i=5000$

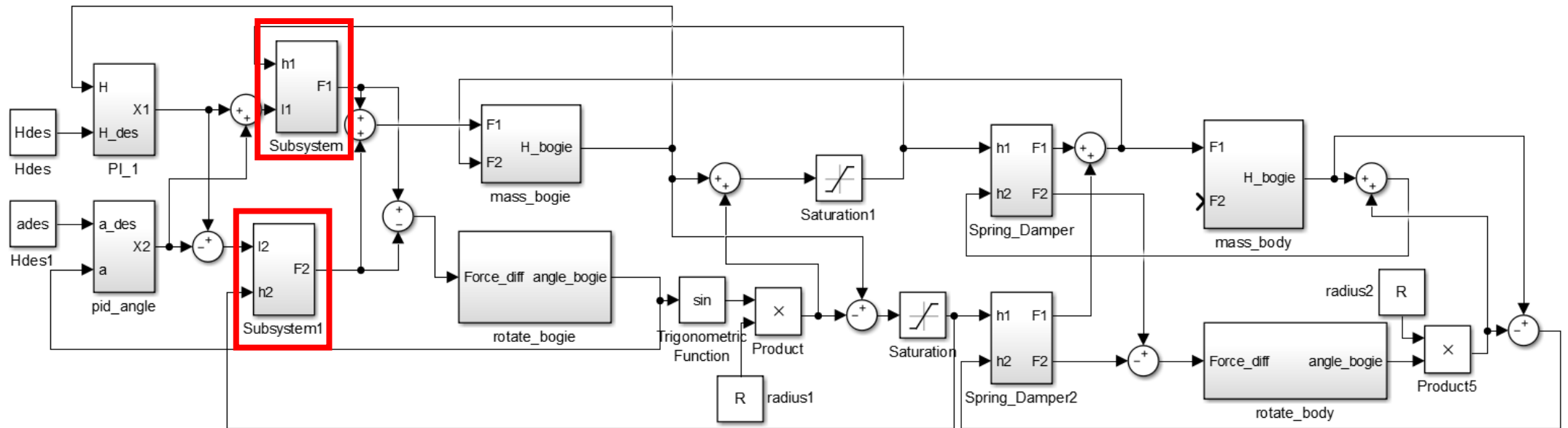


이중PI control

- $K_p=1000$, $k_i=50$

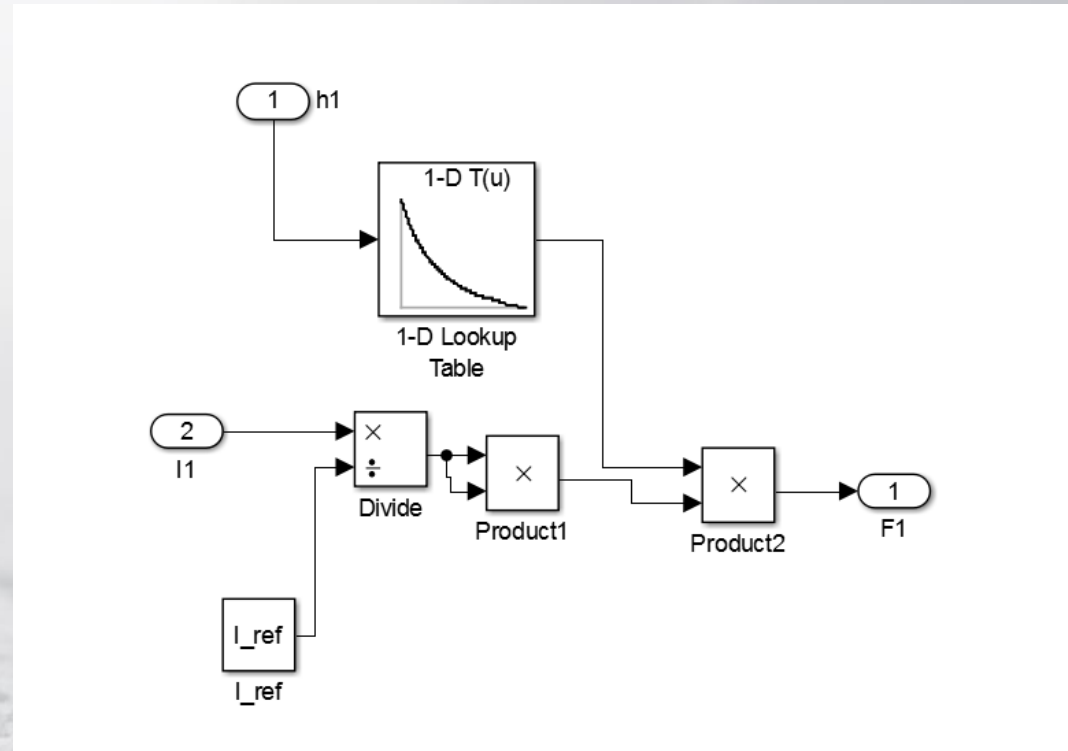


Components

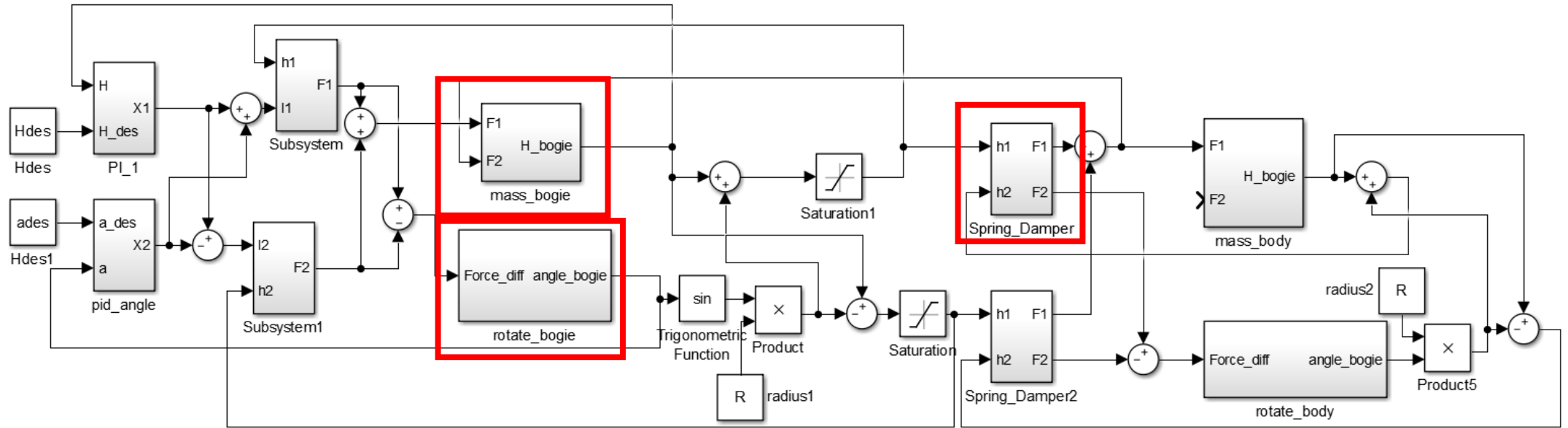


자기력 : h , I 의 함수

- 높이에 대한 비선형 힘 특성
 - COMSOL 해석 기반
 - 1-D Lookup Table 활용
- 전류에 대한 선형 힘 특성
 - 기준 I 값과의 비를 제공 후 곱셈

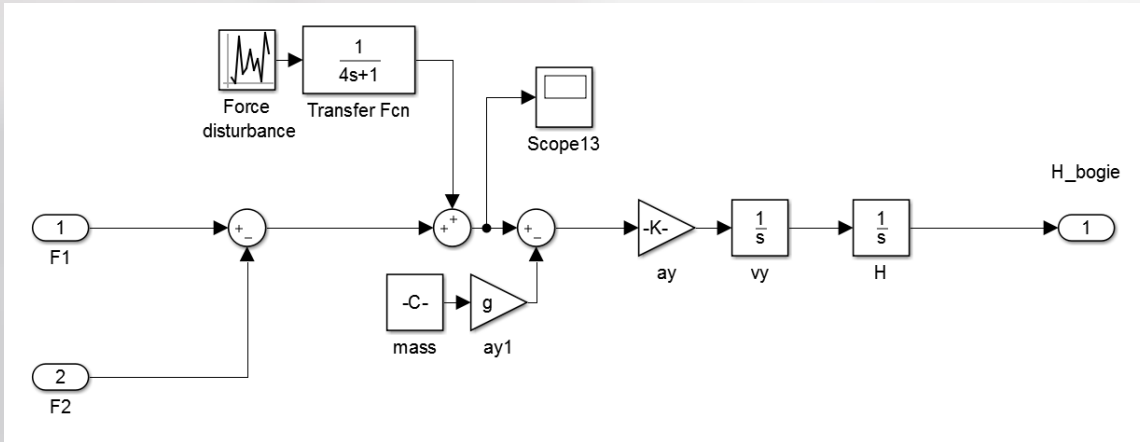


Components

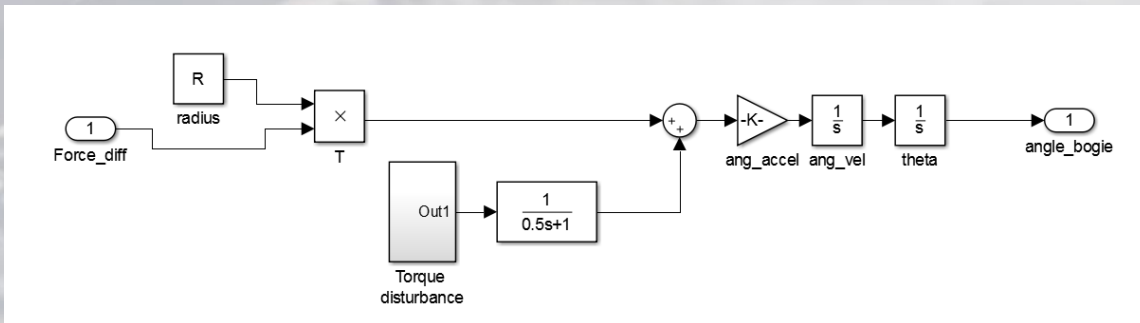


Components

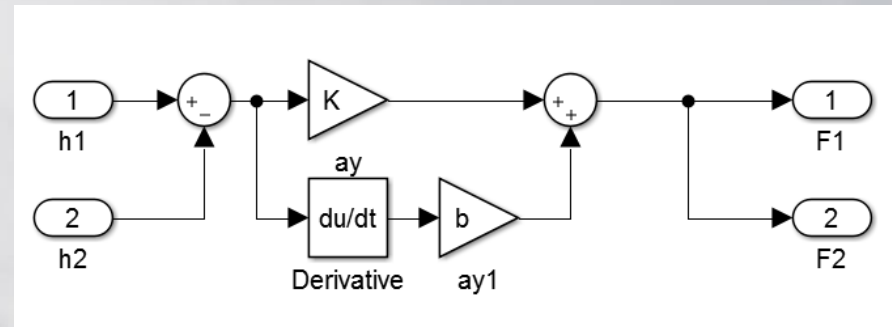
Mass



Inertia

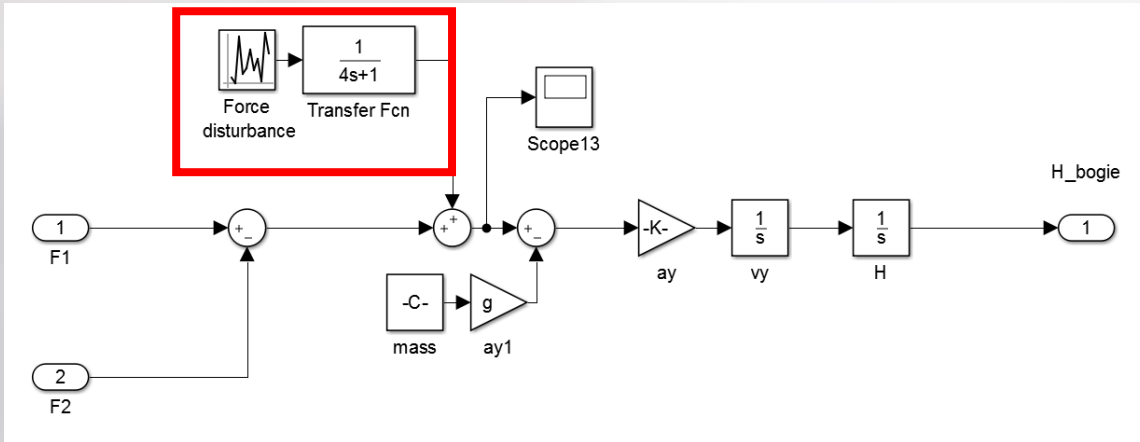


Spring-Damper

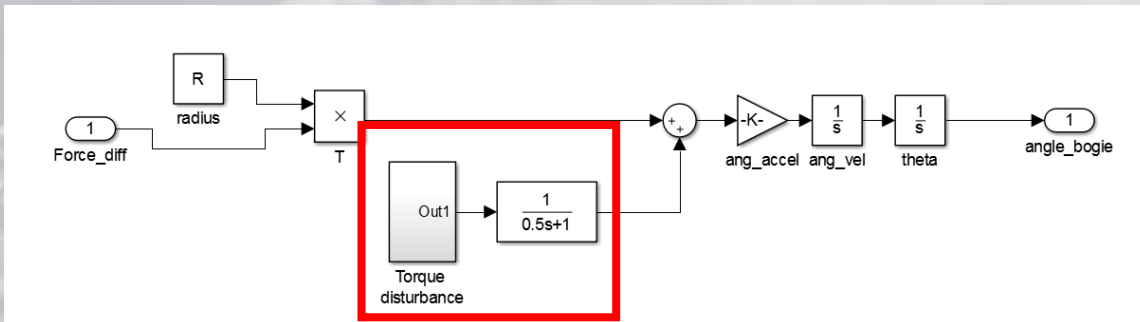


Components

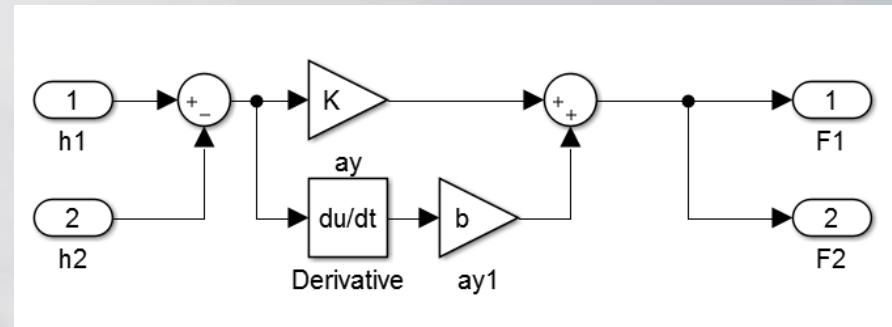
Mass



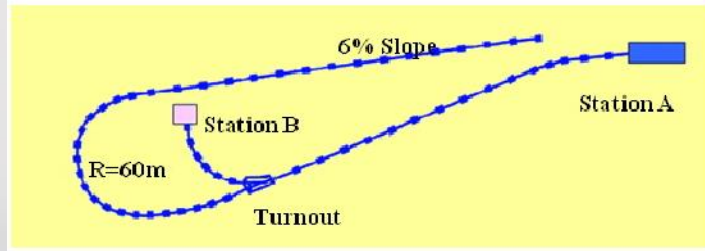
Inertia



Spring-Damper



회전반경에 의한 Torque 외란



원심력 : 무게중심에 작용

$$\text{크기} : \frac{mv^2}{R}$$

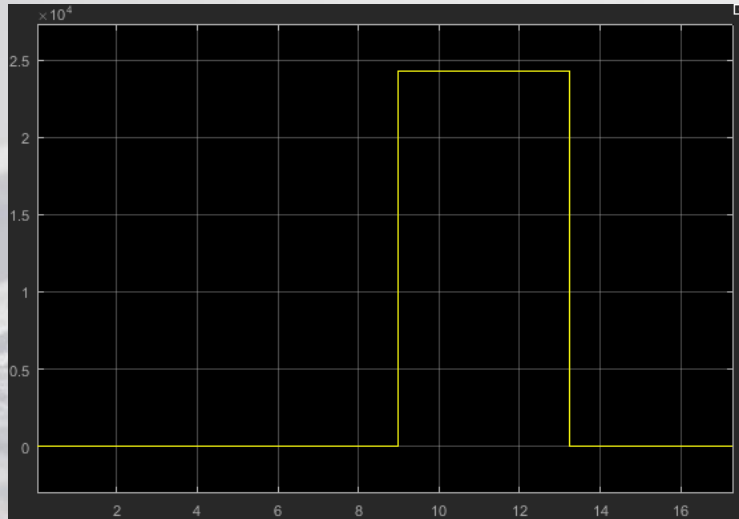
R : 회전반경

v = 평균 속도 (80km/h)

m = 열차 무게

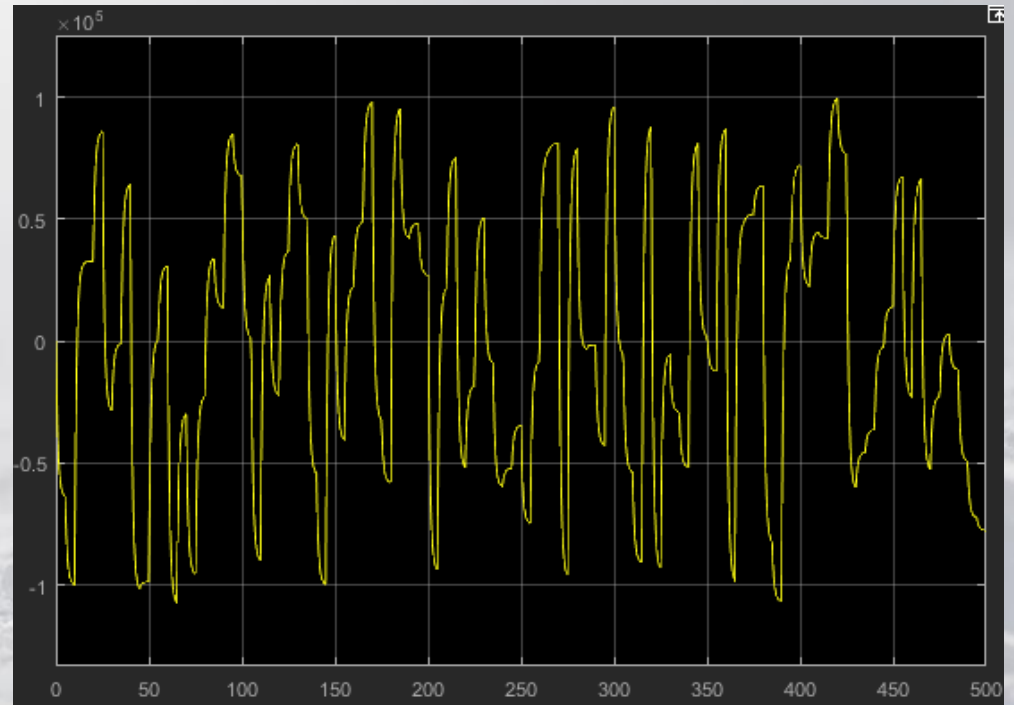
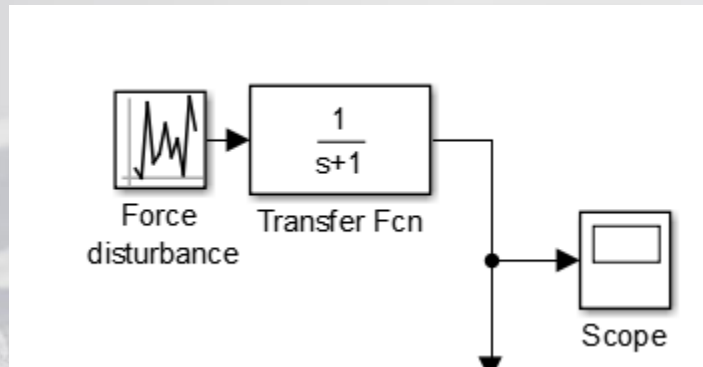
$$\text{작용 토크} : \frac{mv^2}{R} * r$$

r : 무게중심 ~ 회전중심 길이



불규칙 F, T 외란

- Random number generator 이용
- Step 변화 지양



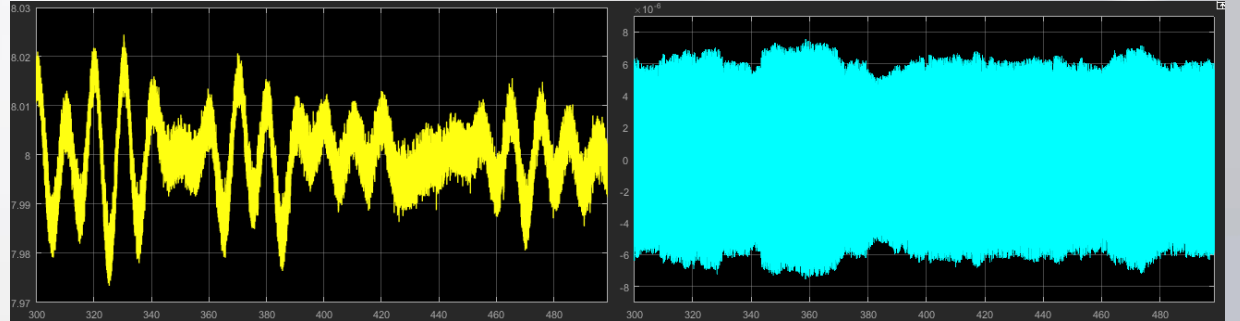


계수에 따른 제어 특성 확인

K_p 에 따른 제어 특성

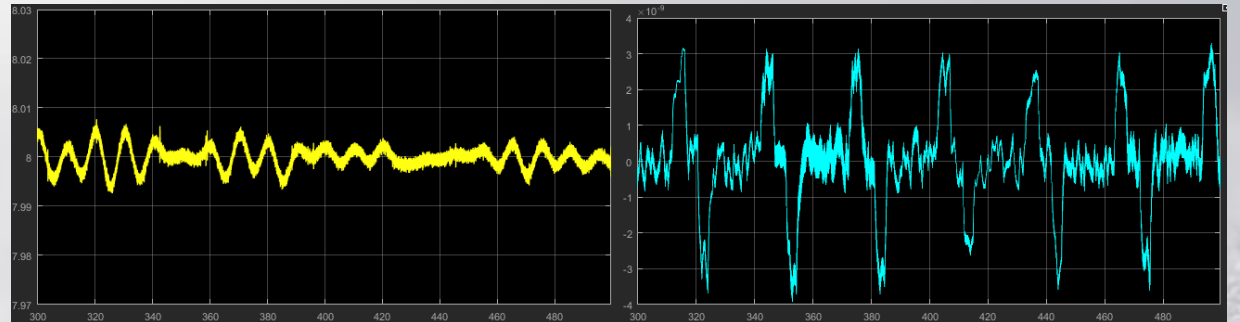
- $K_p = 200$ $K_i = 50$

- Peak-Peak : 0.04



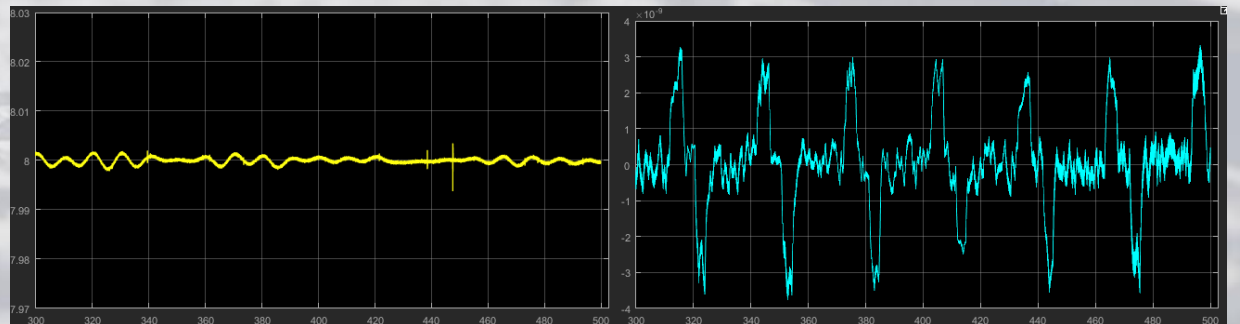
- $K_p = 500$ $K_i = 50$

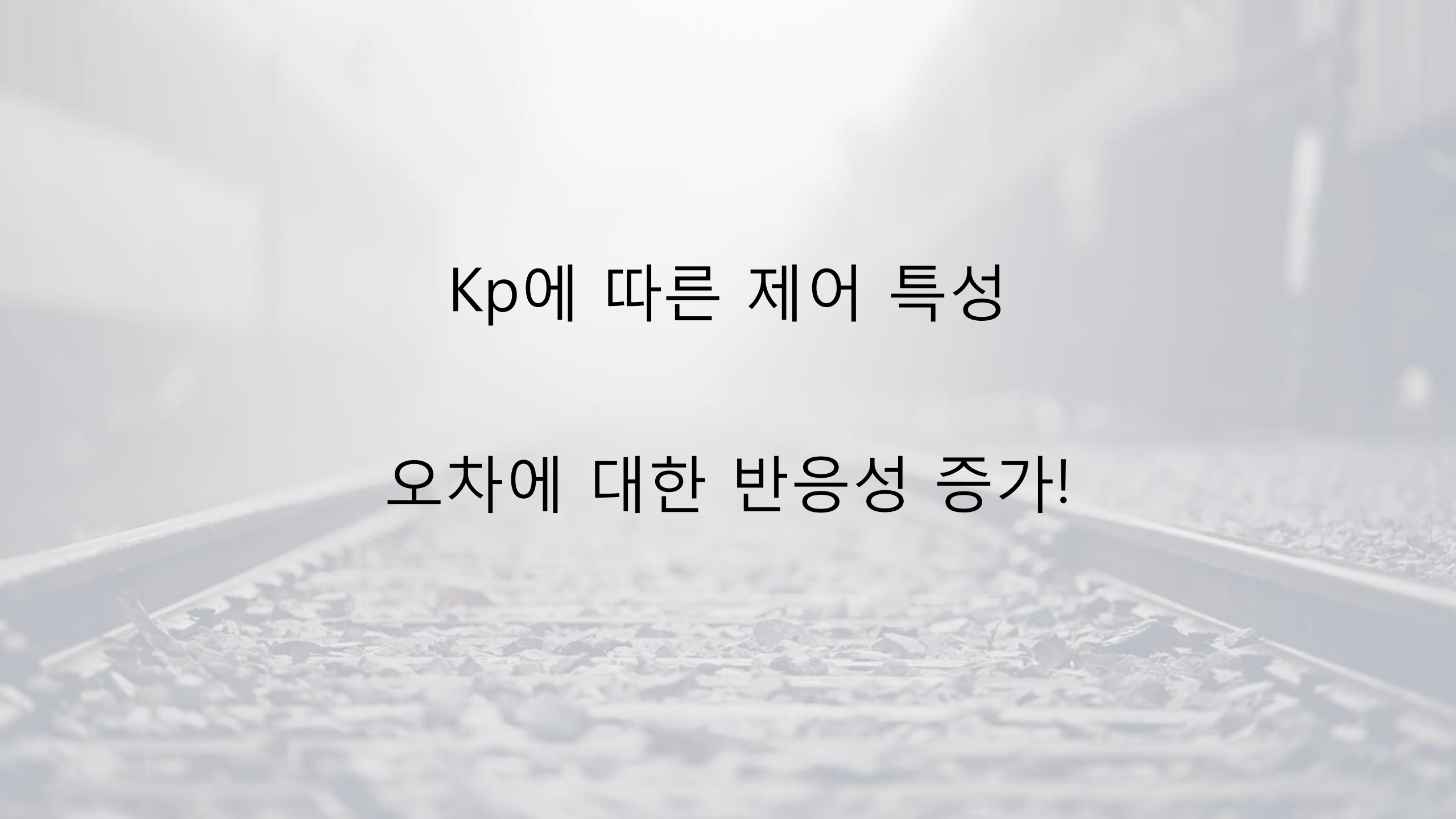
- Peak-Peak : 0.014



- $K_p = 1000$ $K_i = 50$

- Peak-Peak : 0.004



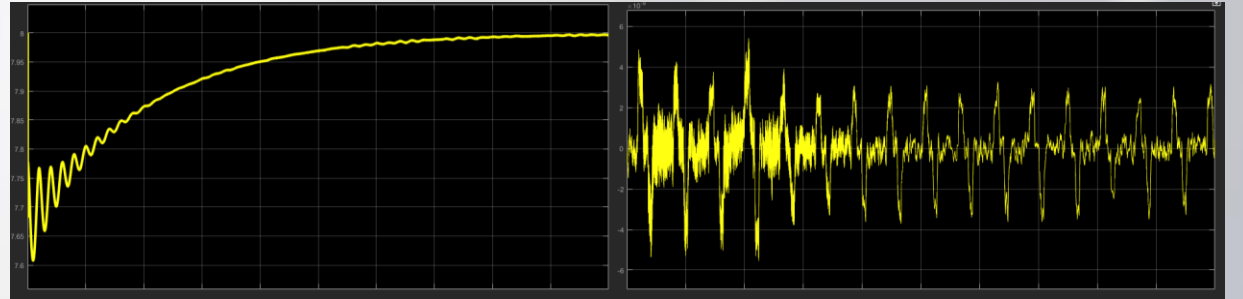


Kp에 따른 제어 특성

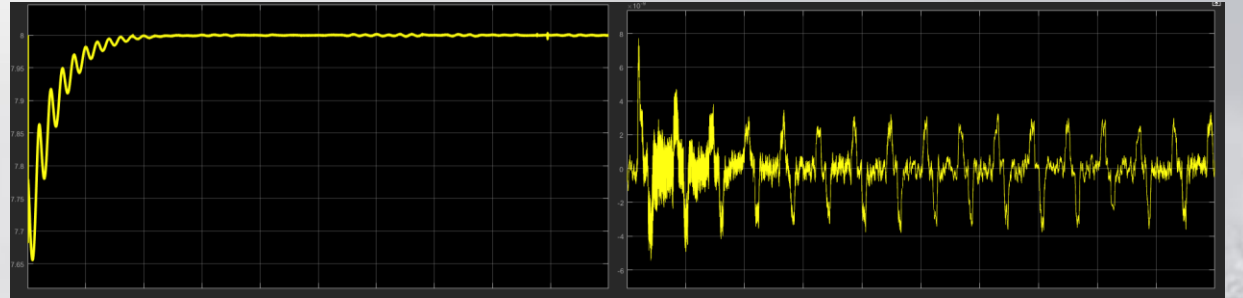
오차에 대한 반응성 증가!

K_i 에 따른 제어특성

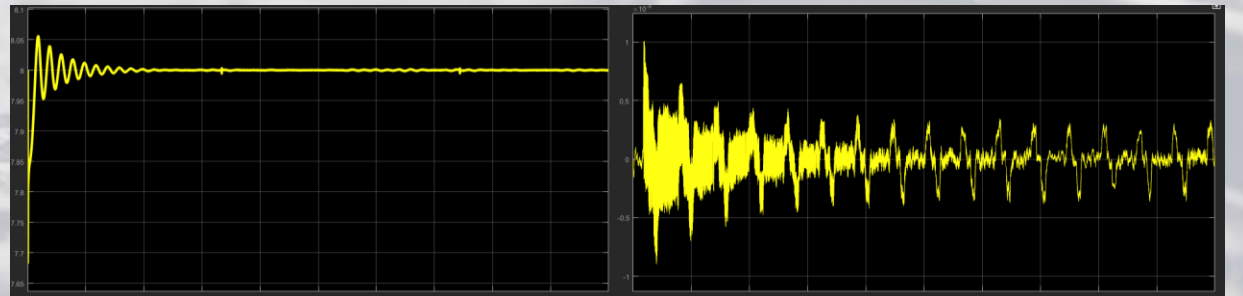
- $K_p = 1000$ $K_i=10$
- Long settling time




- $K_p=1000$ $K_i=50$
- Proper settling time



- $K_p=1000$ $K_i=200$
- Short settling time : Overshoot



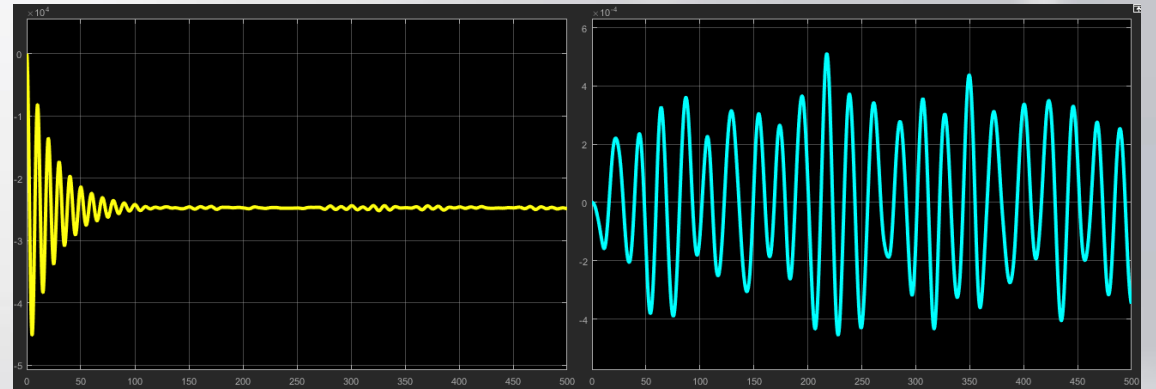


Ki에 따른 제어 특성

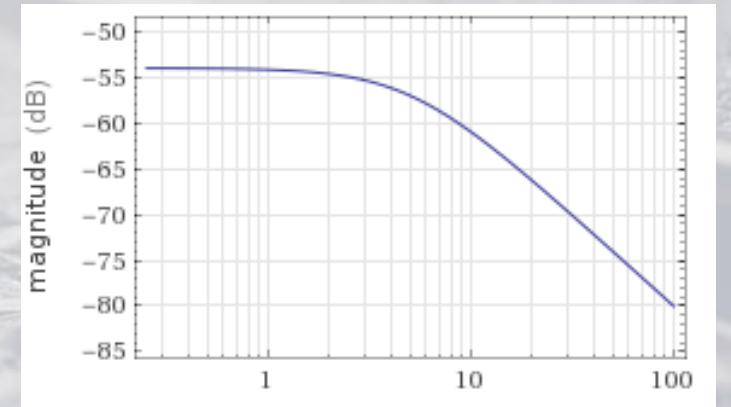
Settling time의 감소!

탑승 캐빈의 반응

- PI 제어기 계수에 따른 특성 변화가 거의 없다!
- Why???
- 제어 과정의 높이 편차 : high frequency
- Spring-Damper의 Low-Pass Filter 역할
- 캐빈에 작용하는 Force 외란에만 반응



$$\frac{h(s)}{F(s)} = \frac{1}{bs + k}$$



Conclusion

- K_p 가 클수록 오차에 대한 반응성이 좋아진다

- K_i 가 클수록 settling time이 작아진다

- 탑승 캐빈의 특성은 K_p , K_i 와 큰 관련이 없다



$$K_p = 1000$$

$$K_i = 50$$