Magnetic Bearing

돌리고

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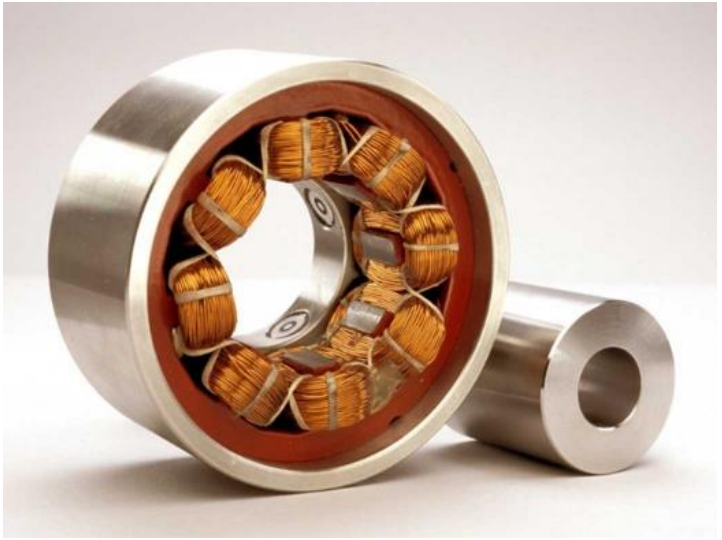
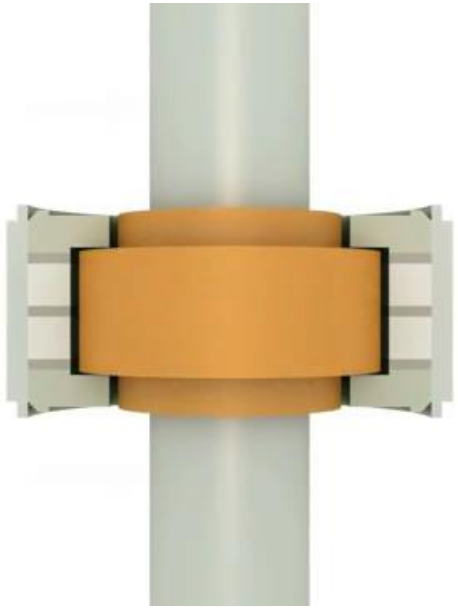
Contents

팀 소개, 주제

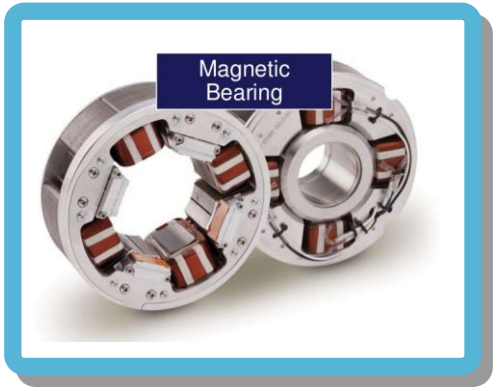
돌리고



Magnetic bearing 원리



Magnetic Bearing 의 장점



vs

No contact
No abrasion
Close to zero friction
No noise or vibration
Extreme life time expectancy
No lubricants

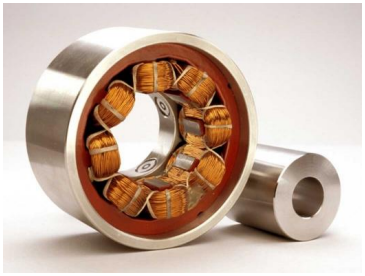
Active Magnetic Bearing vs Passive Mechanical Bearing

Passive Magnetic Bearing

영구 자석을 사용

-> 설계의 어려움 ∵언쇼의 정리
-> 재료 특성에 의존

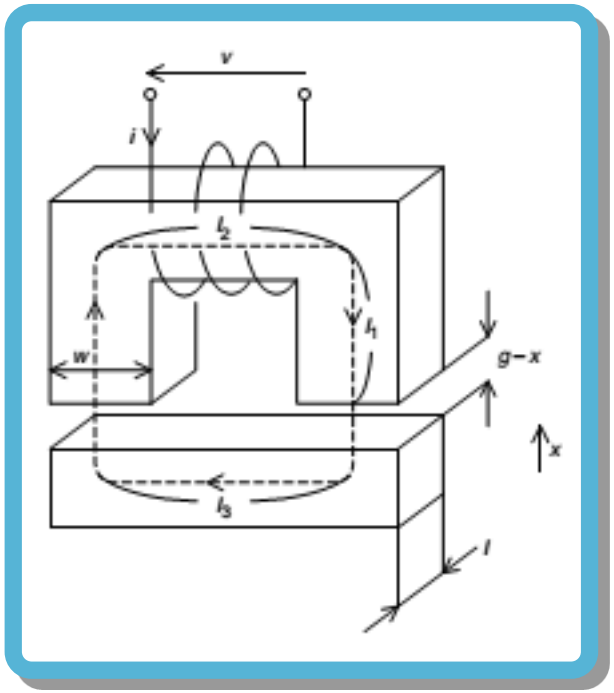
Active Magnetic Bearing



전자석을 사용

-> 전류를 통한 제어 가능

Active Magnetic Bearing – Equation



$$F_x = \frac{1}{2} u_0 H^2 * yz = \frac{1}{2} u_0 \frac{Ni}{2(g-x)}^2 * wl$$

$$\frac{Ni}{2(g-x)}^2 = \left(\frac{Ni}{2g}\right)^2 * \left(\frac{1}{1-\frac{x}{g}}\right)^2$$

$$\left(\frac{1}{1-x}\right)^2 = (1 + x + \cdots) * (1 + x + \cdots) \cong (1 + 2x)$$

$$\left(\frac{1}{1-\frac{x}{g}}\right)^2 \cong 1 + \frac{2 * x}{g}$$

$$F_x = \frac{1}{2} u_0 \frac{Ni}{2(g-x)}^2 * wl = \frac{1}{2} u_0 \left(\frac{Ni}{2g}\right)^2 * \left(1 + \frac{2x}{g}\right) * wl$$

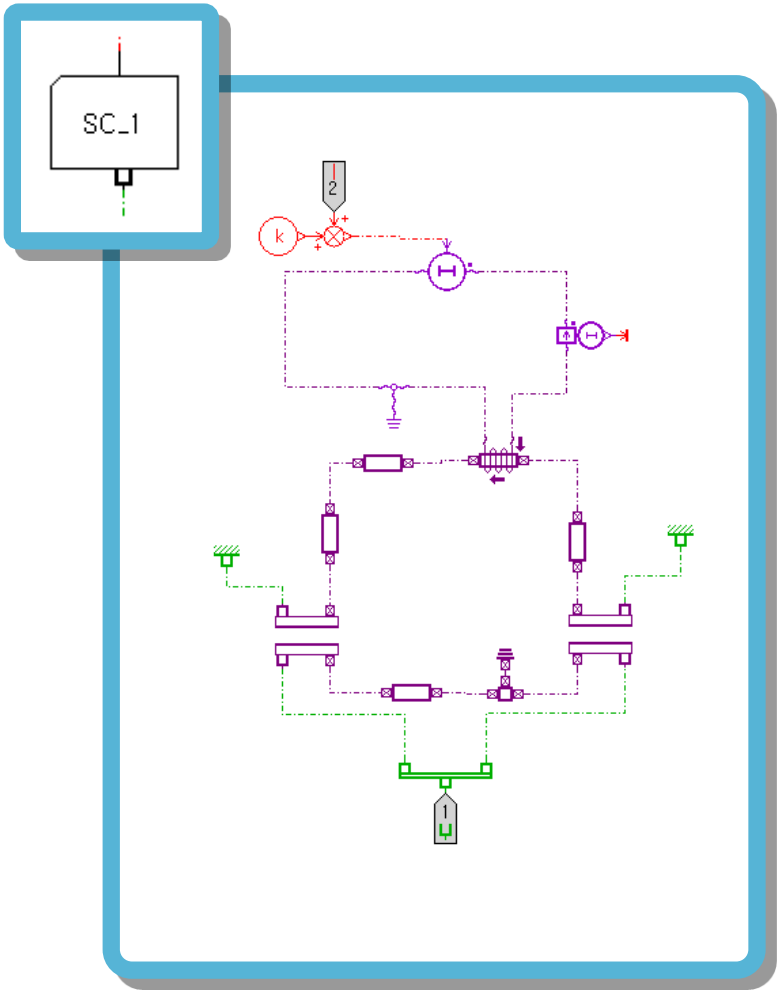
TABLE I: DESIGN PARAMETERS FOR ELECTROMAGNETS

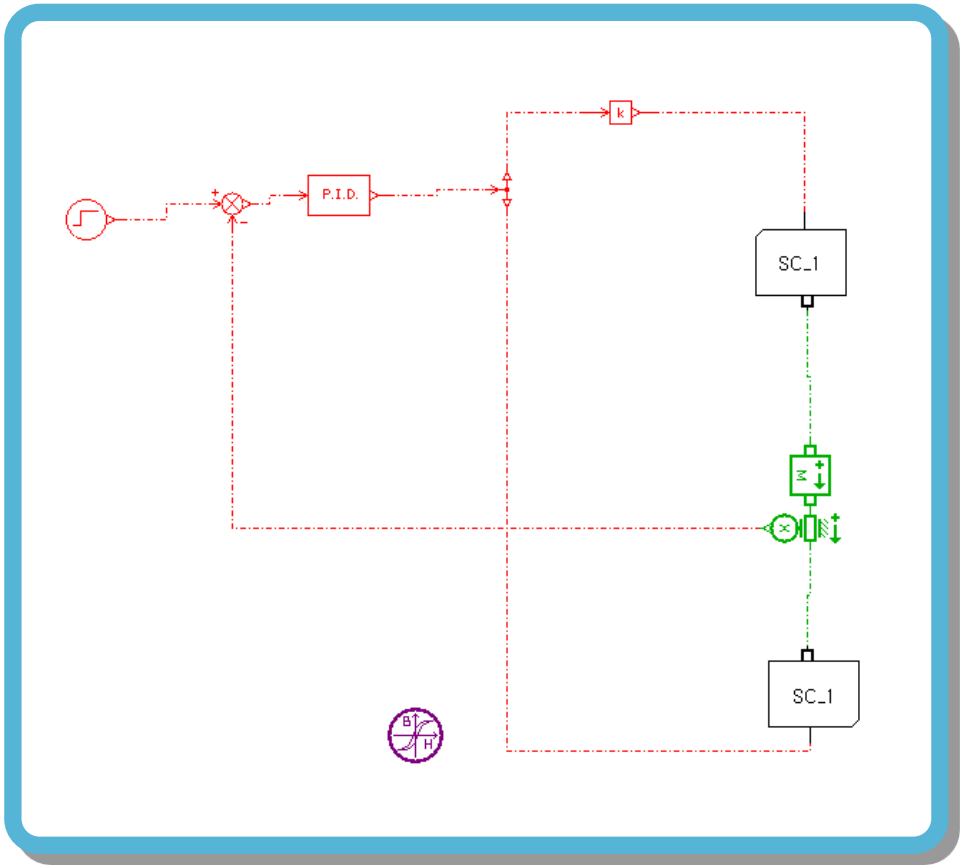
g	Nominal air gap	5 [mm]
N	Coil turns	500 [turns]
w	Core width	1 [cm]
l	Slack length	1 [cm]
l1	Pole lenght	1 [cm]
l2	Core length	4 [cm]
l3	*I* Core length	4 [cm]
m	Rotor Mass	0.1 [kg]
Ib	Bias Current	2 [A]

참고 자료 :

Dynamic Simulation of a One DOF Radial Active Magnetic Bearing Using SIMULINK and AMESim Co-simulation - Abdollah Ebadi and Mahdi Aliyari Sh

Active Magnetic Bearing – Amesim Model





PID 제어

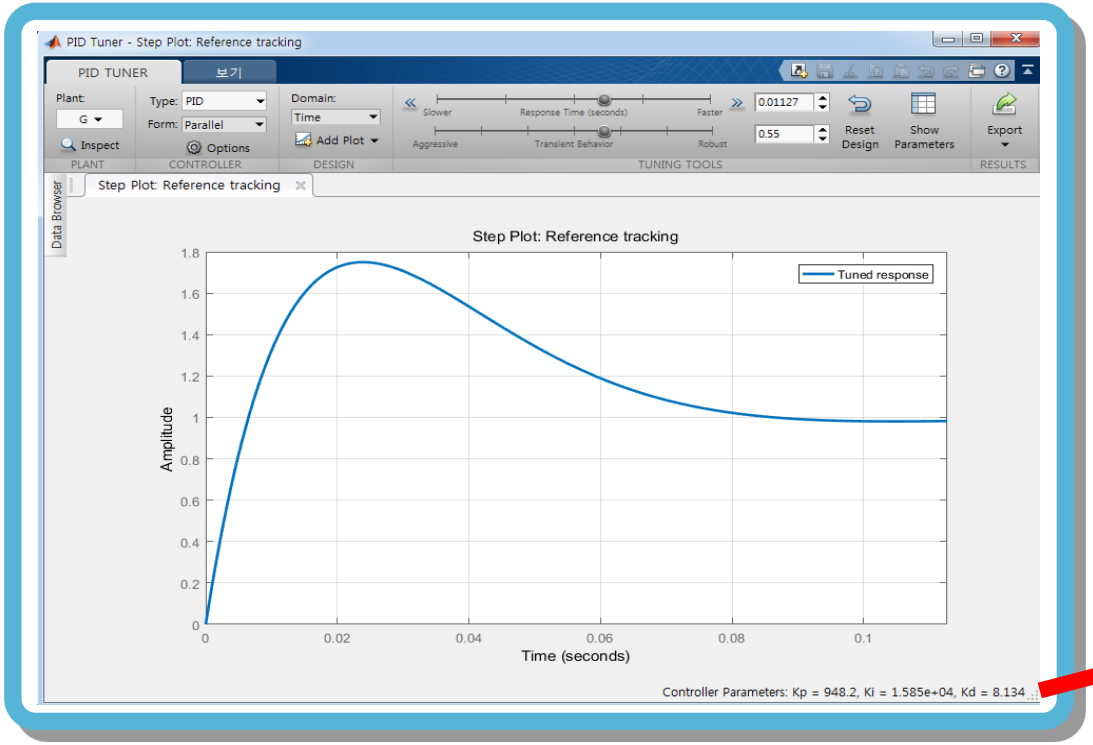
$$F_{m1}: i = I_0 + i_x \; F_{m2}: i = I_0 - i_x$$

$$F_m = F_{m1} - F_{m2}$$

$$= 2 * \frac{1}{2} u_0 \left(\frac{N(I_0+i_x)}{2g}\right)^2 * \left(1 + \frac{2x}{g}\right) * wl - 2 * \frac{1}{2} u_0 \left(\frac{N(I_0-i_x)}{2g}\right)^2 * \left(1 - \frac{2x}{g}\right) * wl$$

$$F_m = k_i i_x + k_x x$$

$$k_i = 2L\frac{I_0}{g}\,,\; k_x = 2L(\frac{I_0}{g})^2\,,\; L = \frac{N^2 u_0 wl}{2g}$$



Kp=947.8

Ki=15839

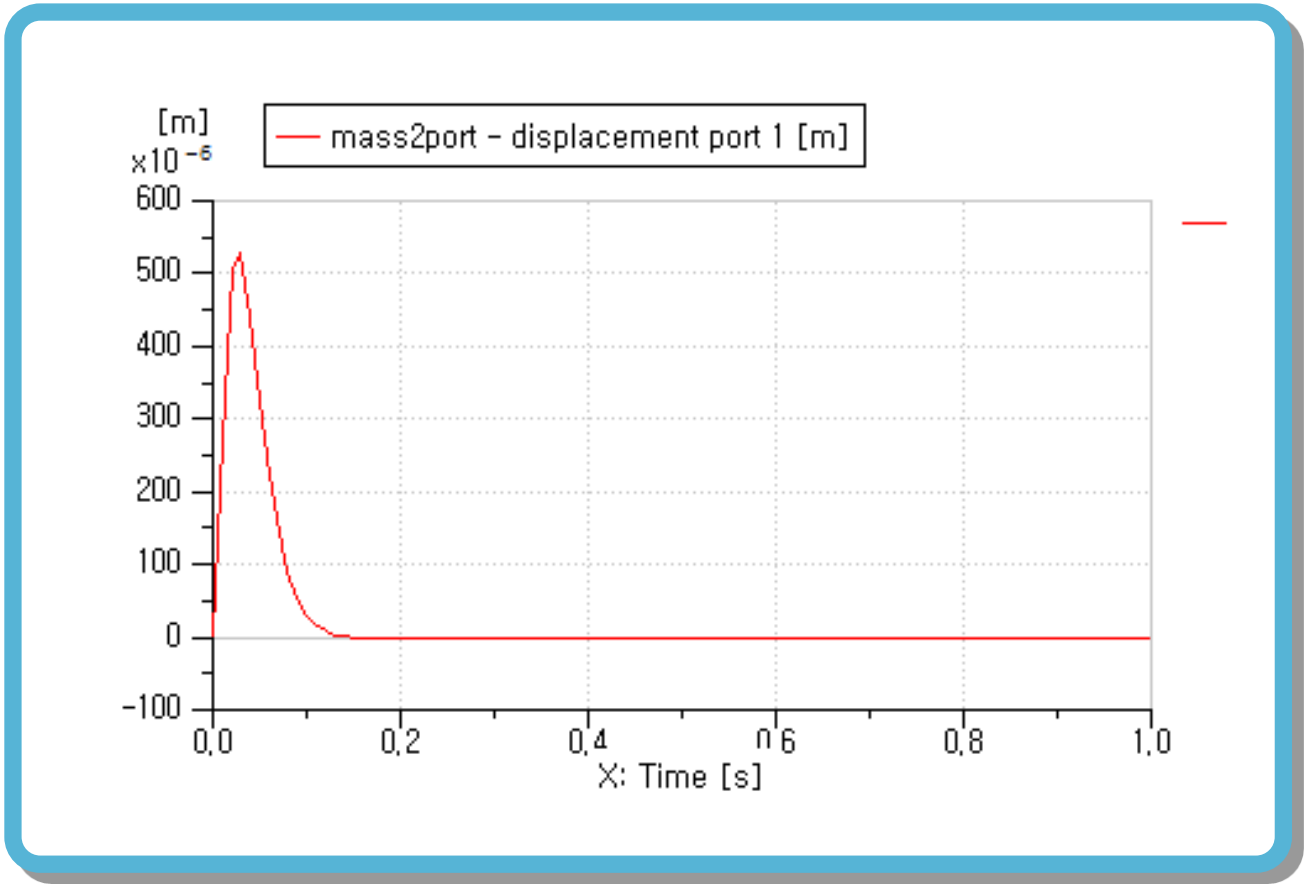
Kd=8.13

$$m\ddot{x} = k_i i_x + k_x x - mG$$

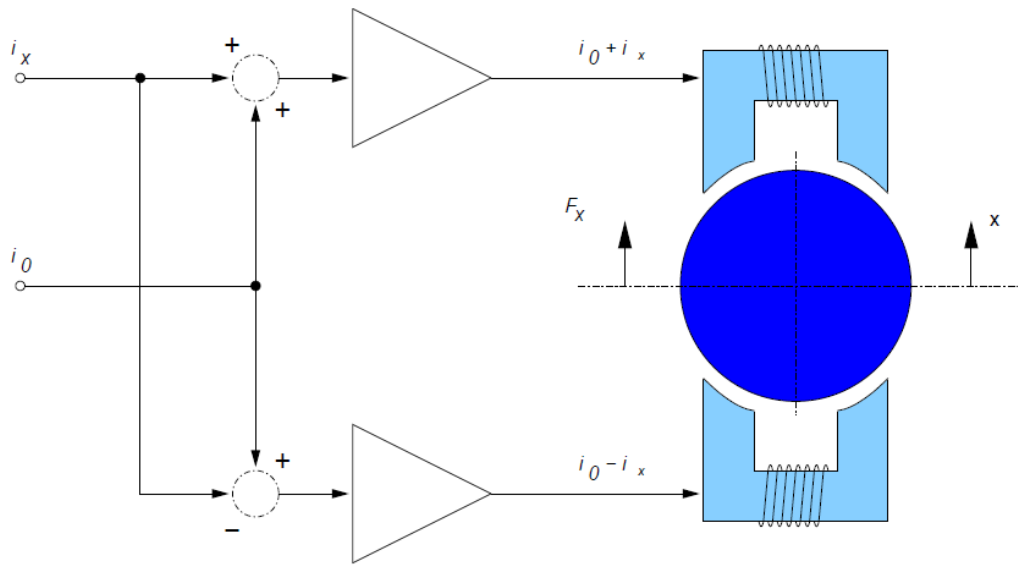
$$(ms^2 - k_x) * x(s) = k_i i_x(s) - mG$$

$$x(s) = \frac{k_i}{(ms^2 - k_x)} i_x(s) - \frac{mG}{(ms^2 - k_x)}$$

Amesim Model – 축 위치 제어 결과

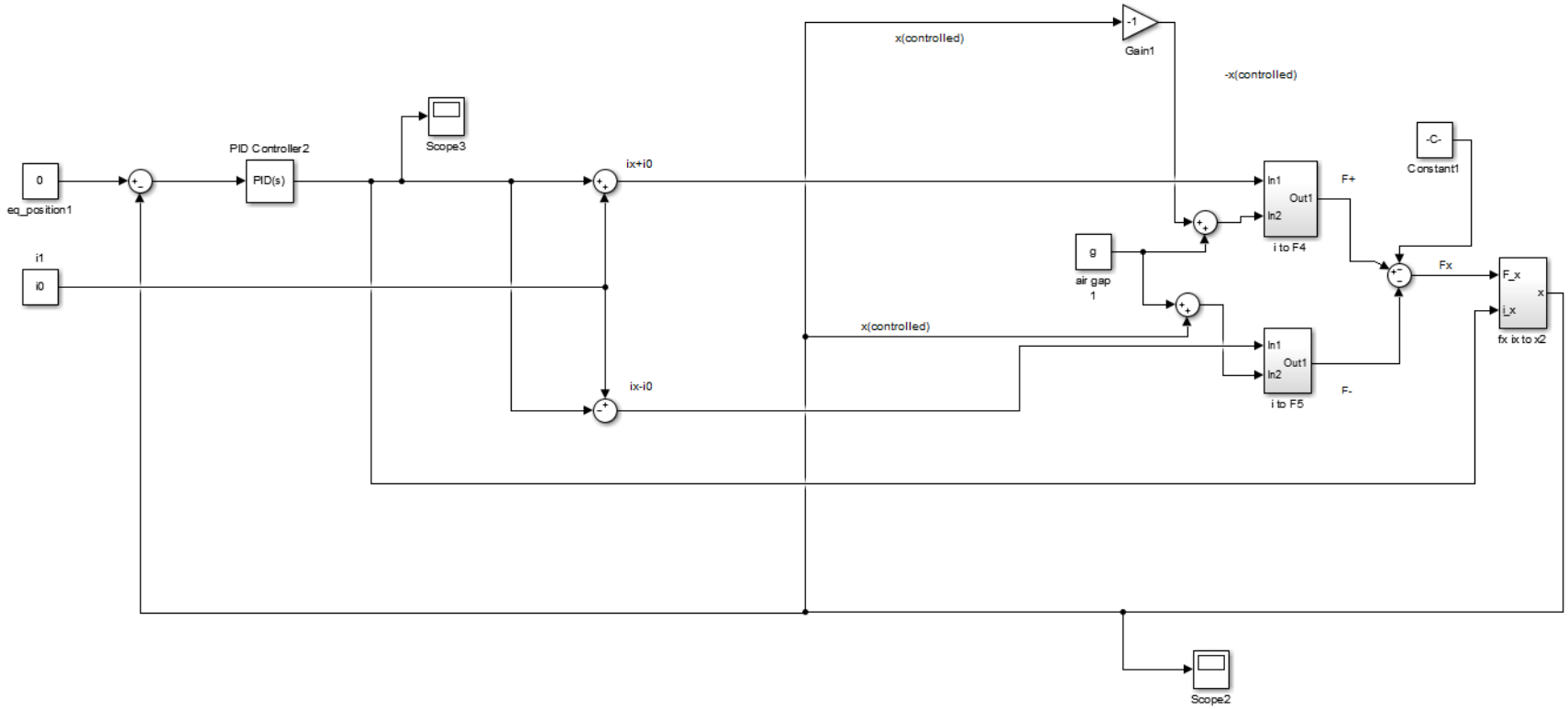


Active Magnetic Bearing – Simulink Model

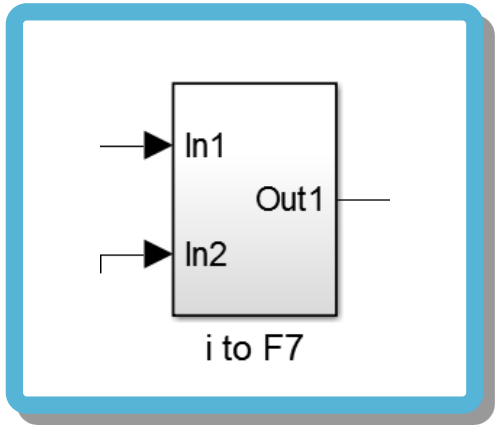


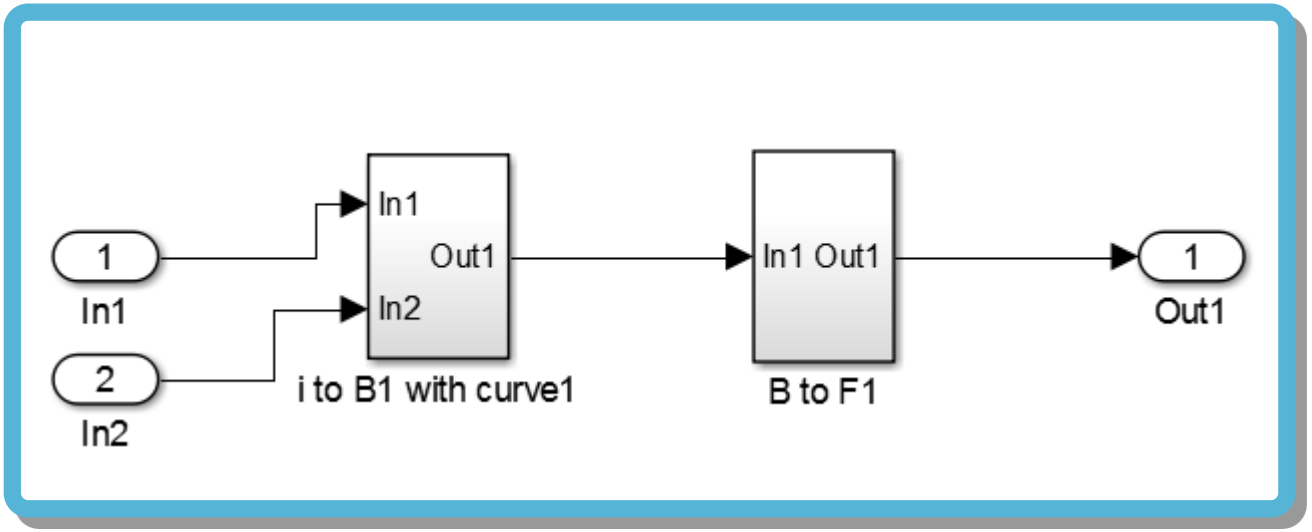
$$F_x = \frac{4ki_0}{s_0^2}(\cos\alpha)i_x + \frac{4ki_0^2}{s_0^3}(\cos\alpha)x = k_i i_x + k_s x$$

Active Magnetic Bearing

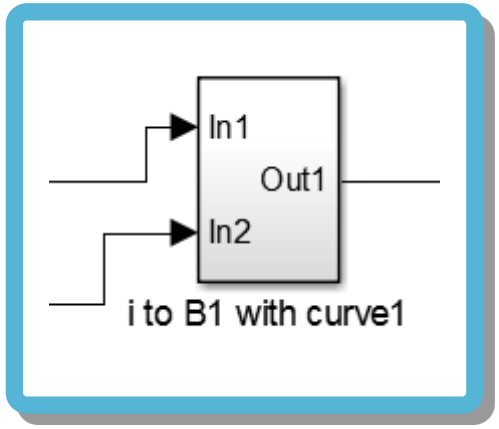


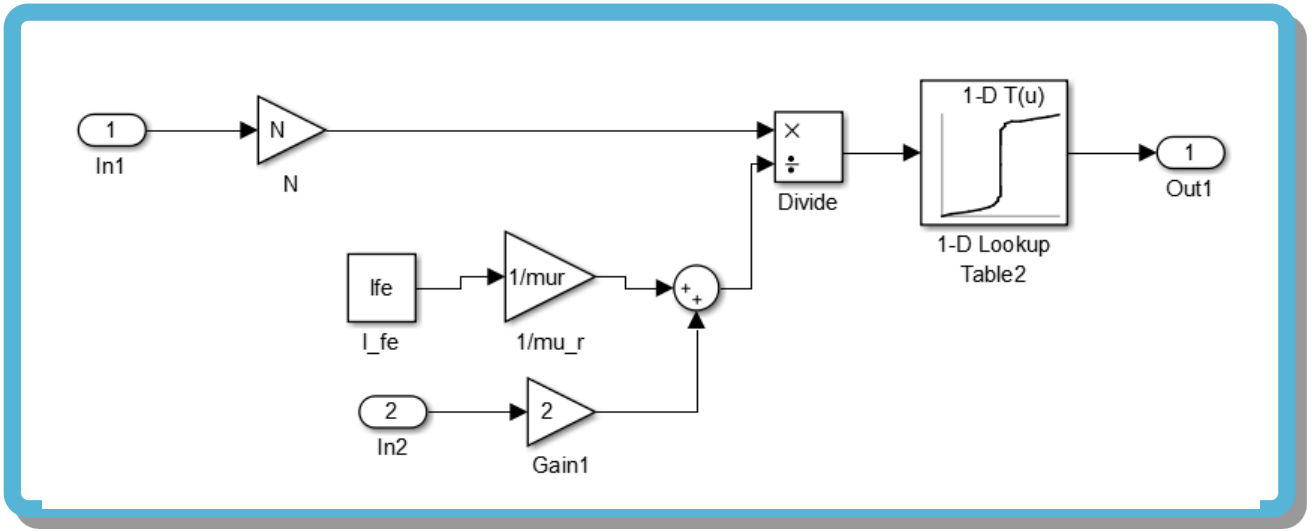
I to F


In1
Out1
In2
i to F7

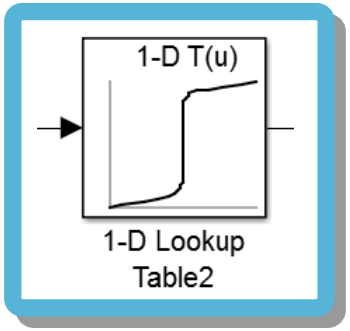

1
In1
2
In2
In1
Out1
In2
i to B1 with curve1
In1 Out1
B to F1
1
Out1

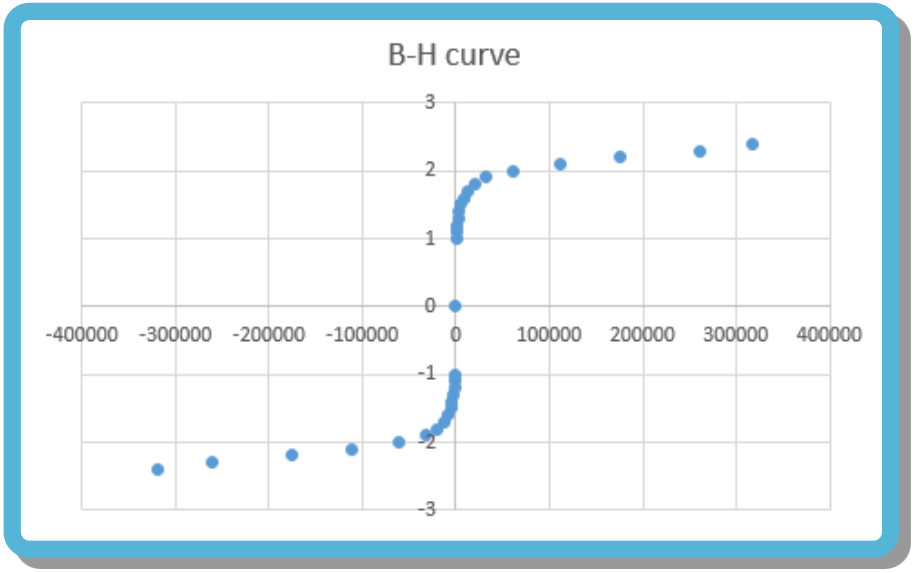
I to B


In1
Out1
In2
i to B1 with curve1


1
In1
N
N
Divide
1-D T(u)
1-D Lookup
Table2
1
Out1
Ife
I_fe
1/mur
1/mu_r
2
In2
2
Gain1

B-H curve (Soft iron from COMSOL database)





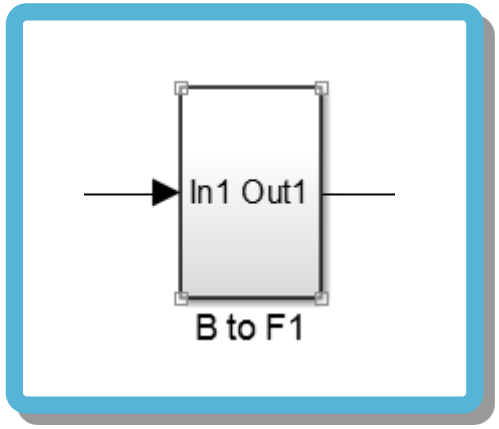
Lookup Table Editor: BHBH/i to F4/i to B1 with c

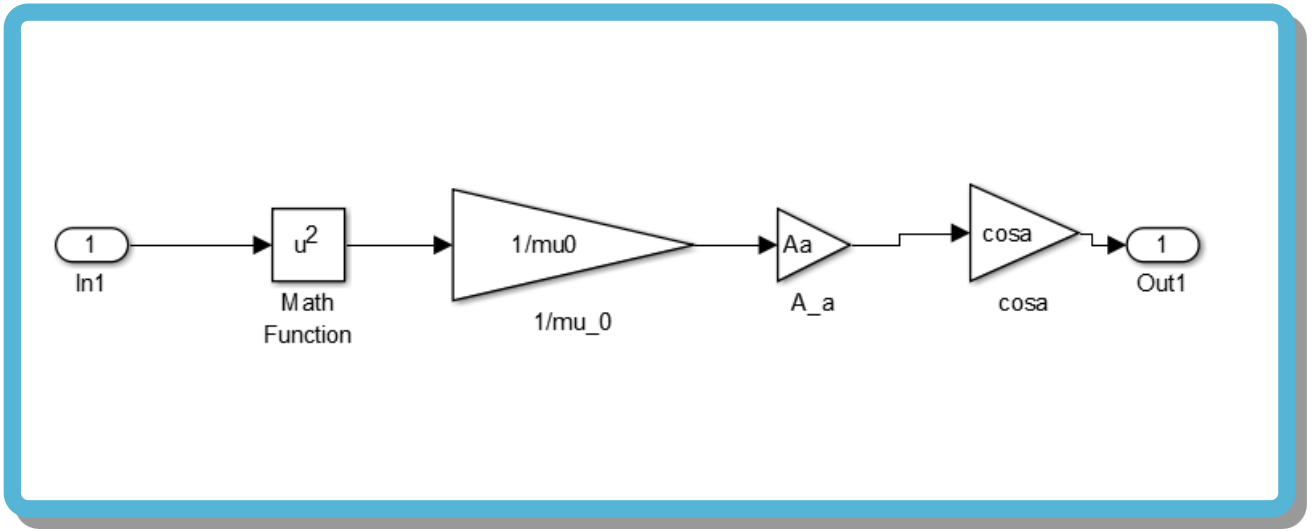
File Edit Plot Help

Viewing "n-D Lookup Table" block data [T(:)]:

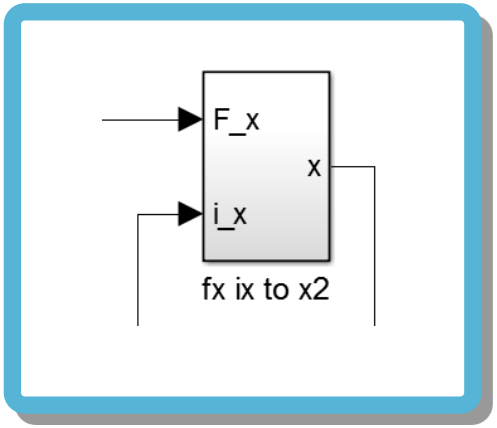
Breakpoints	Column	(1)
Row		--
(1)	-318310	-2.4
(2)	-261469	-2.3
(3)	-175070	-2.199999...
(4)	-111408	-2.099999...
(5)	-61213.4	-2
(6)	-32169.6	-1.9
(7)	-20462.8	-1.799999...
(8)	-12298.3	-1.699999...
(9)	-7957.75	-1.599999...
(10)	-5425.74	-1.5
(11)	-3841.67	-1.4
(12)	-2463.11	-1.299999...
(13)	-1705.23	-1.199999...
(14)	-1067.5	-1.099999...
(15)	-663.146	-0.999999...
(16)	0	0
(17)	663.146	1
(18)	1067.5	1.1
(19)	1705.23	1.2
(20)	2463.11	1.3
(21)	3841.67	1.4
(22)	5425.74	1.5
(23)	7957.75	1.6
(24)	12298.3	1.7
(25)	20462.8	1.8
(26)	32169.6	1.9
(27)	61213.4	2
(28)	111408	2.1

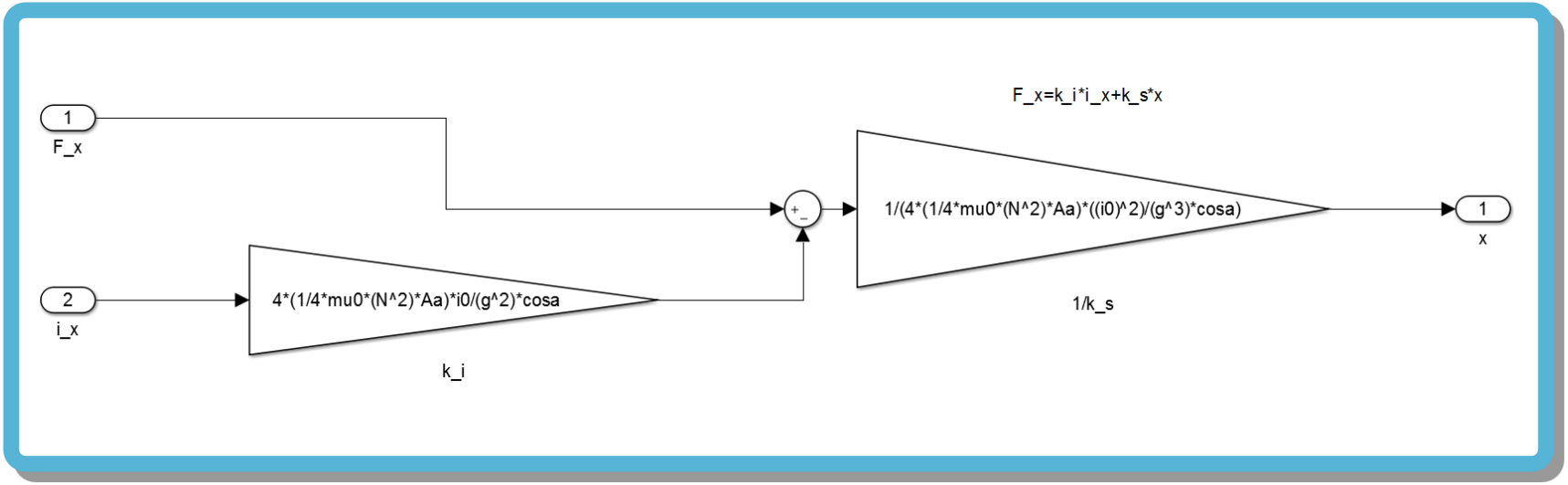
B to F


In1 Out1
B to F1


1
In1
u2
Math
Function
1/mu0
1/mu_0
Aa
A_a
cosa
cosa
1
Out1

F to x

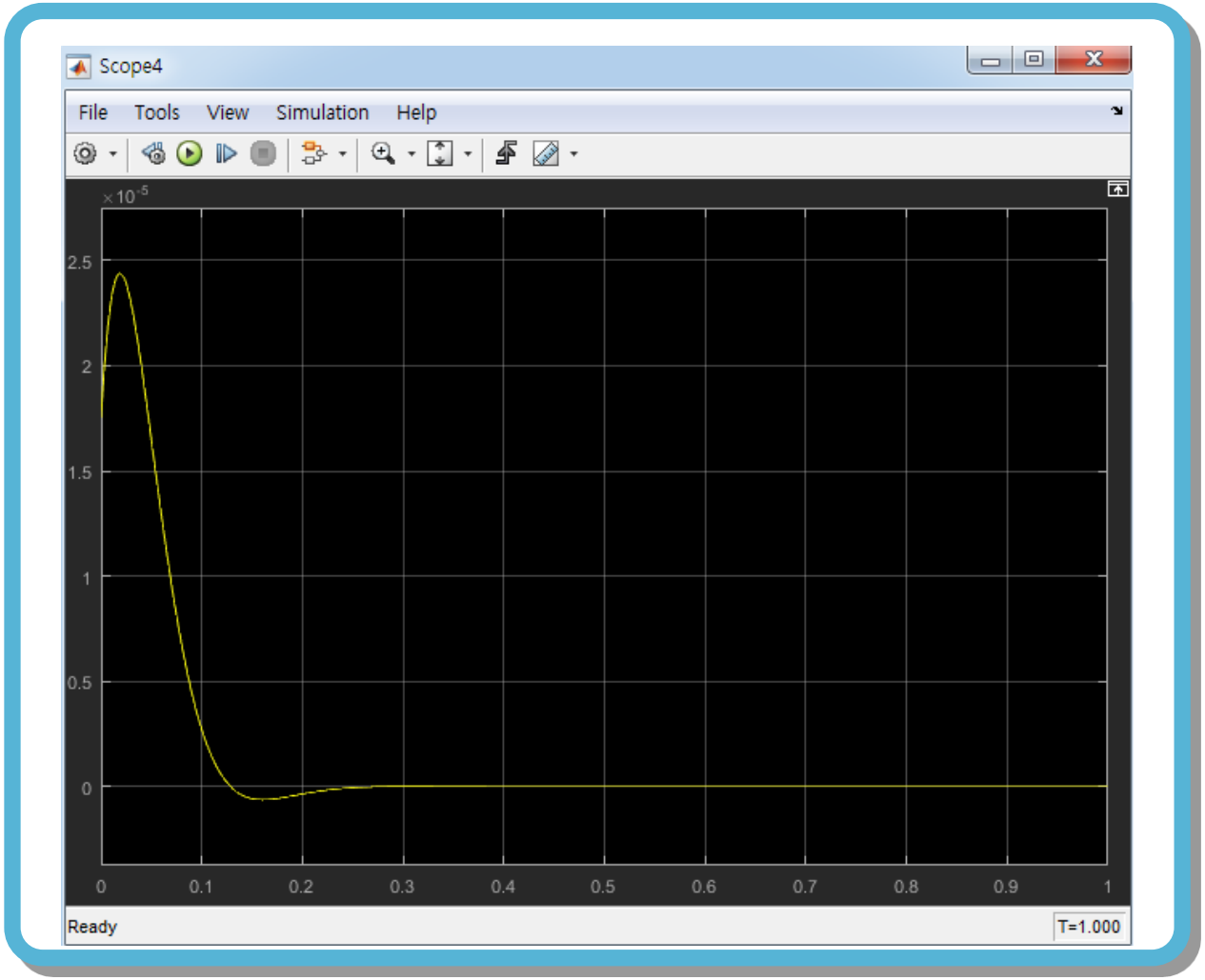

F_x
x
i_x
fx ix to x2


F_x=k_i*i_x+k_s*x
1
F_x
2
i_x
4*(1/4*mu0*(N^2)*Aa)*i0/(g^2)*cosa
k_i
+
-
1/(4*(1/4*mu0*(N^2)*Aa)*((i0)^2)/(g^3)*cosa)
1/k_s
1
x

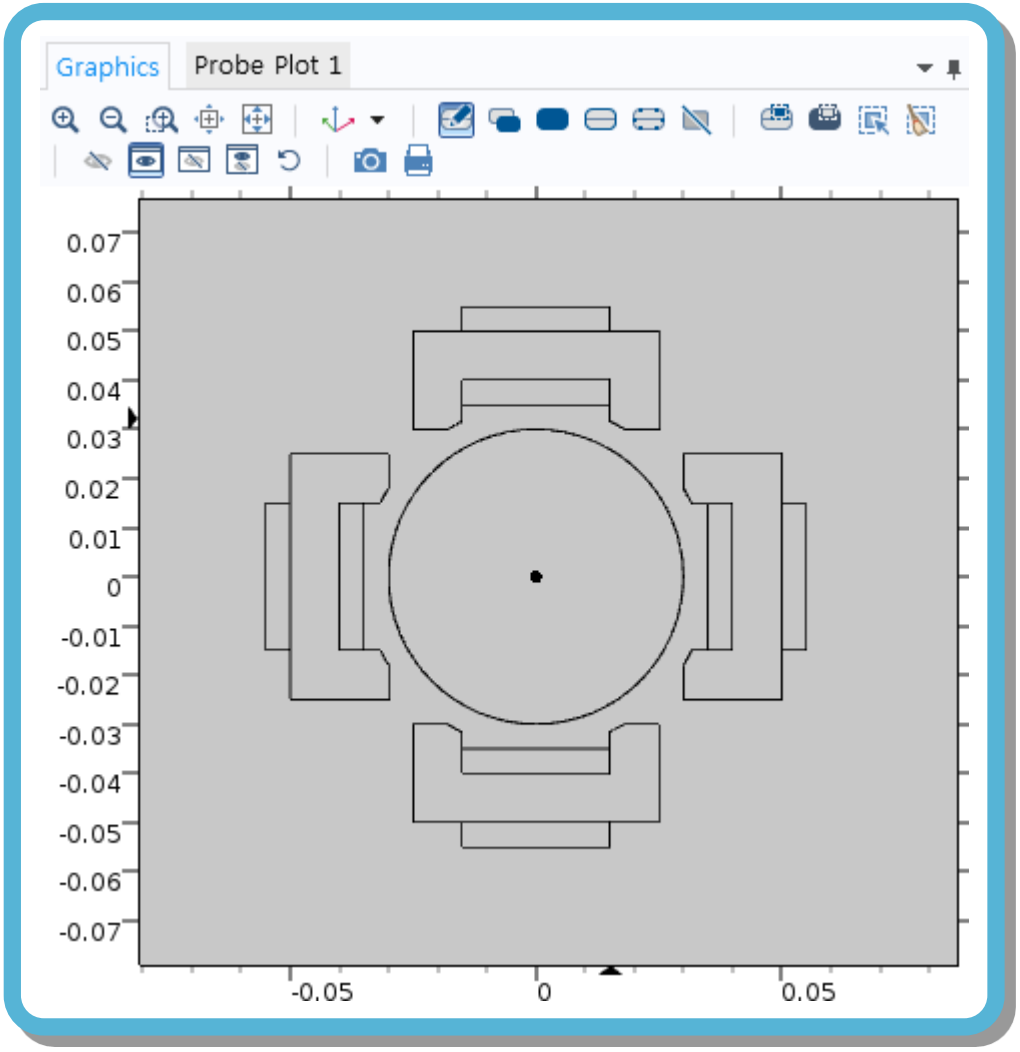
constants.m

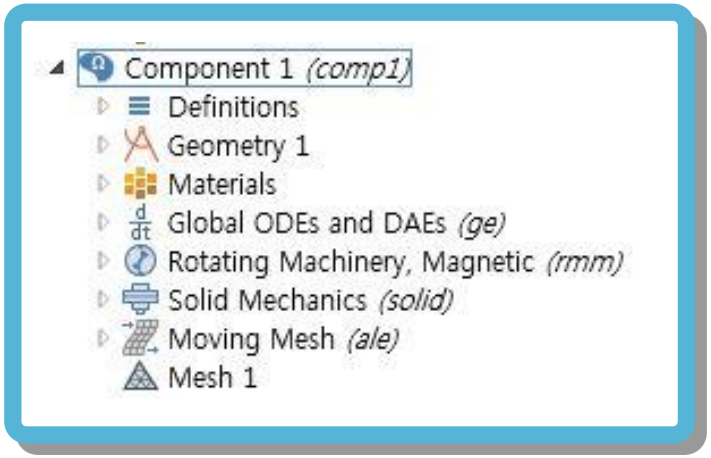
```
1 -     mu0=4*pi*10^(-7);
2 -     mur=10000;
3 -     l1=0.01;
4 -     l2=0.04;
5 -     l3=0.04;
6 -     lfe=l2+2*(l1)+l3;
7 -     N=500;
8 -     Aa=0.01*0.01;
9 -     cosa=cos(22.5*pi/180);
10 -    i0=2;
11 -    g=0.005;
```

Simulink Model – 축 위치 제어 결과



Active Magnetic Bearing – COMSOL Model





$$u(t) = K_P\, e(t) + K_I \int_0^t e(\tau)d\tau + K_D \frac{d}{dt} e(t)$$

- Definitions
  - Variables 1
  - Waveform 2 *(wv2)*
  - Step 1 *(step1)*
  - Step 2 *(step2)*
  - Domain Point Probe 1
    - Point Probe Expression 1 *(xdisp)*
    - Point Probe Expression 2 *(xvel)*
    - Point Probe Expression 3 *(ydisp)*
    - Point Probe Expression 4 *(yvel)*
  - Global Variable Probe 1 *(var1)*
  - Global Variable Probe 2 *(var2)*

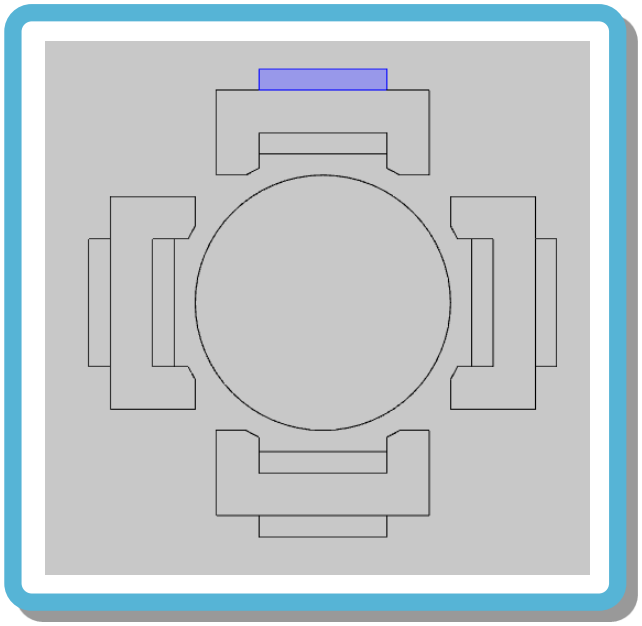
Ix	Kp*(0-xdisp)+Kd*(0-xvel)+Ki*(0-xsum)
Iy	Kp*(0-ydisp)+Kd*(0-yvel)+Ki*(0-ysum)

Global ODEs and DAEs *(ge)*

Global Equations 1

$f(u,u_t,u_{tt},t) = 0,\ u(t_0) = u_0,\ u_t(t_0) =$

Name	f(u,ut,utt,t) (1)
xsum	d(xsum,t)-xdisp
ysum	d(ysum,t)-ydisp

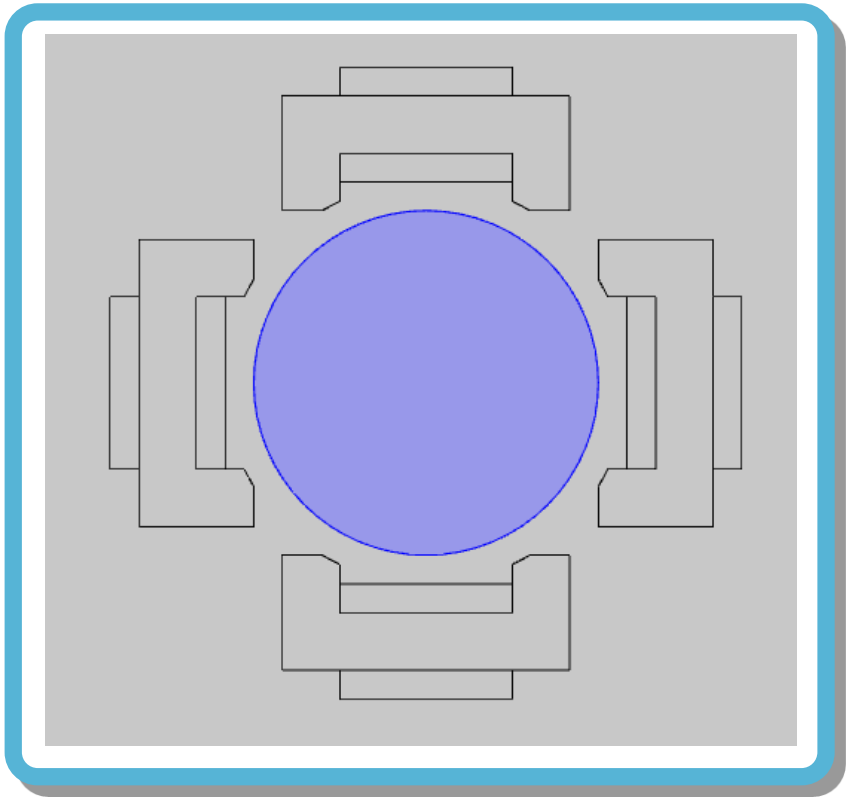


External Current Density 1

External Current Density

External current density:

J_e	0	x	A/m²
	0	y	
	(I0+Iy)*N/(0.03*0.005)	z	



Force Calculation 1

Force Calculation

Force name:

Ar

Torque axis:

r_{ax}

0	x
0	y
1	z

Torque rotation point:

r_0

0	x
0	y

m

Body Load 1

Force

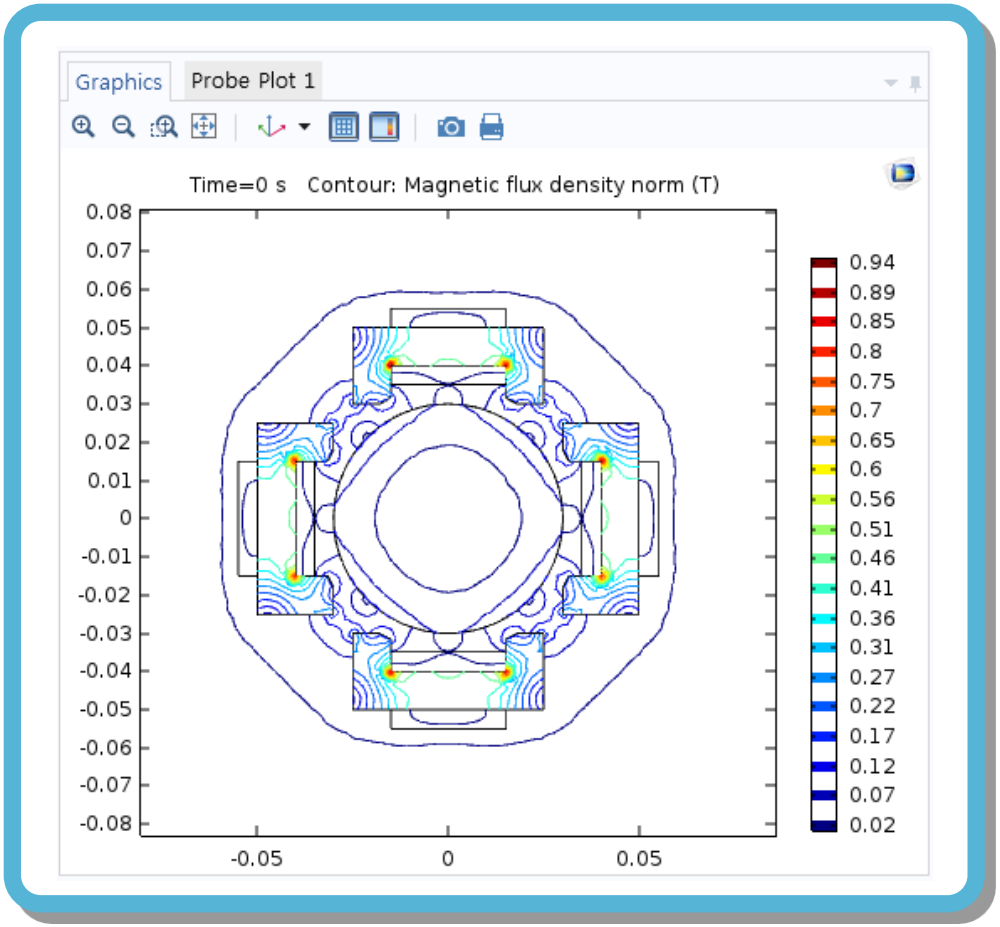
Load type:

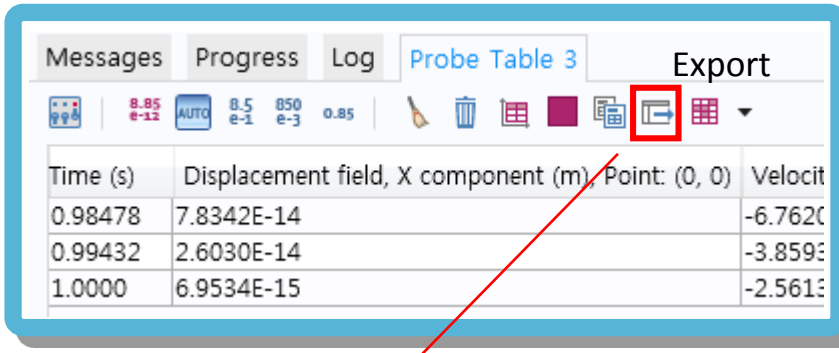
Total force

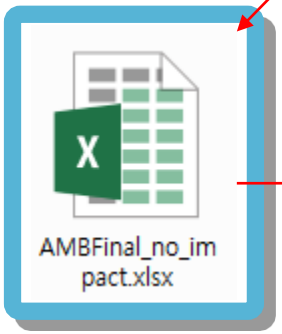
F_{tot}

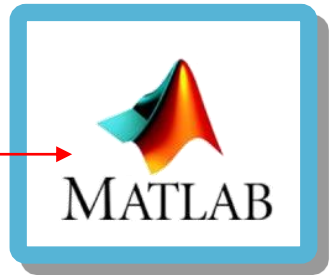
rmm.Forcex_Ar+5*step1(t)
rmm.Forcey_Ar-4*9.8+20*step2(t)

$$0.03^2\pi * 0.2[m^3] * 7000\left[\frac{kg}{m^3}\right] \cong 4kg$$

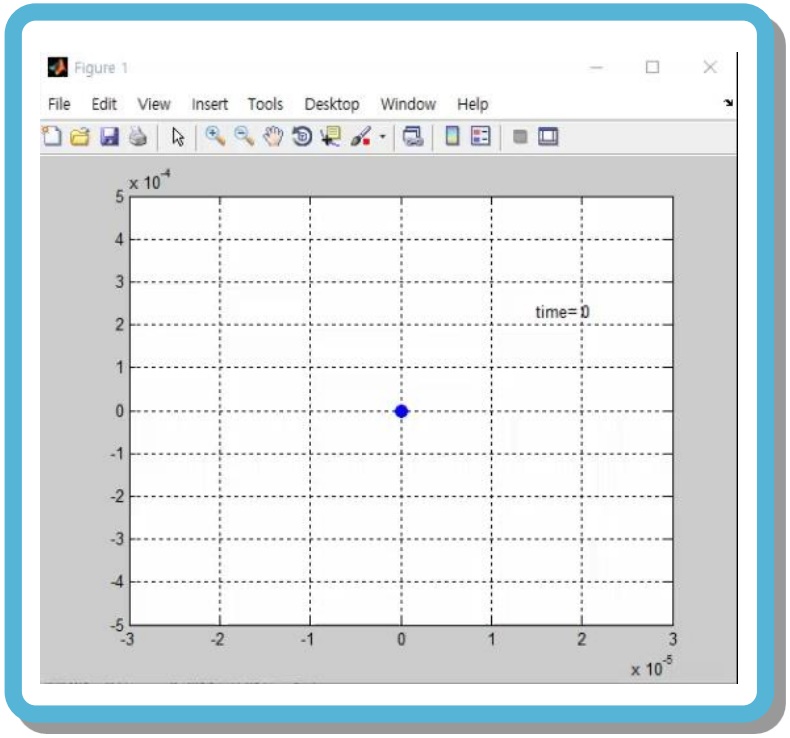

Graphics
Probe Plot 1
Time=0 s Contour: Magnetic flux density norm (T)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.05
0
0.05
0.94
0.89
0.85
0.8
0.75
0.7
0.65
0.6
0.56
0.51
0.46
0.41
0.36
0.31
0.27
0.22
0.17
0.12
0.07
0.02


Messages
Progress
Log
Probe Table 3
Export
Time (s)
Displacement field, X component (m), Point: (0, 0)
Velocit
0.98478
7.8342E-14
-6.762(
0.99432
2.6030E-14
-3.859
1.0000
6.9534E-15
-2.561

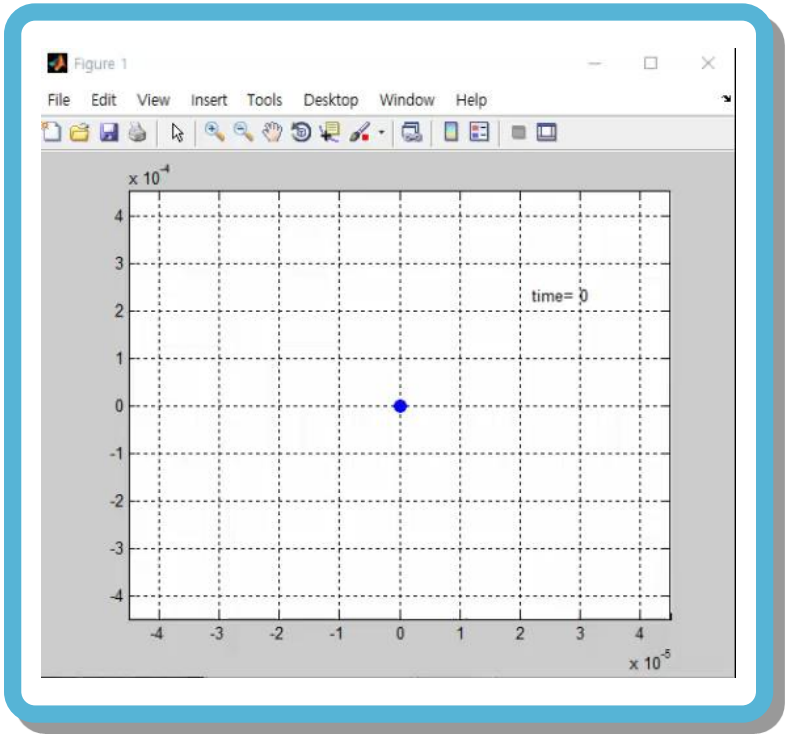

AMBFinal_no_impact.xlsx


MATLAB

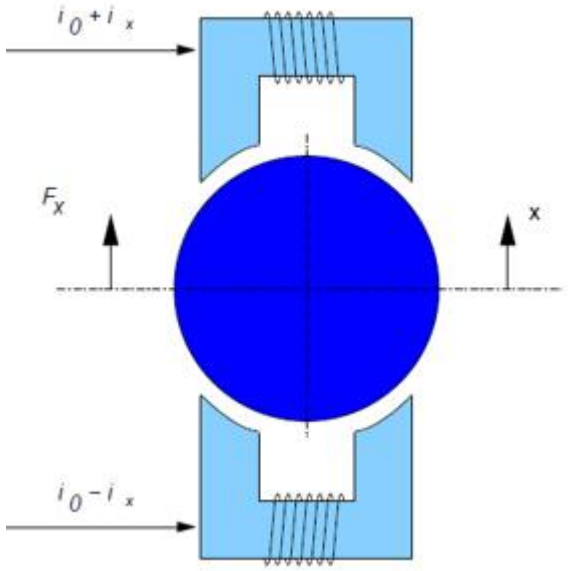
Simulation with MATLAB (Without Impact)



Simulation with MATLAB (With Impact)

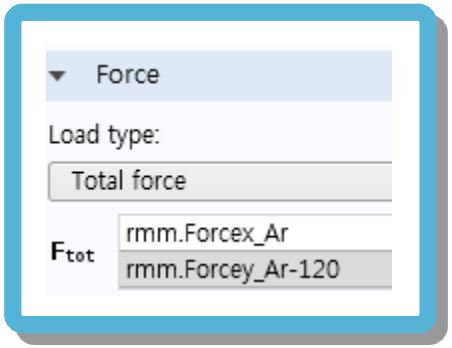


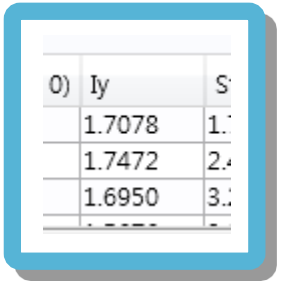
Maximum impact



If $|I_0| < |i_x|$ => 의도한대로 제어되지 않음

Tolerance 0.25A 적용 : $|i_x| < 1.75A$

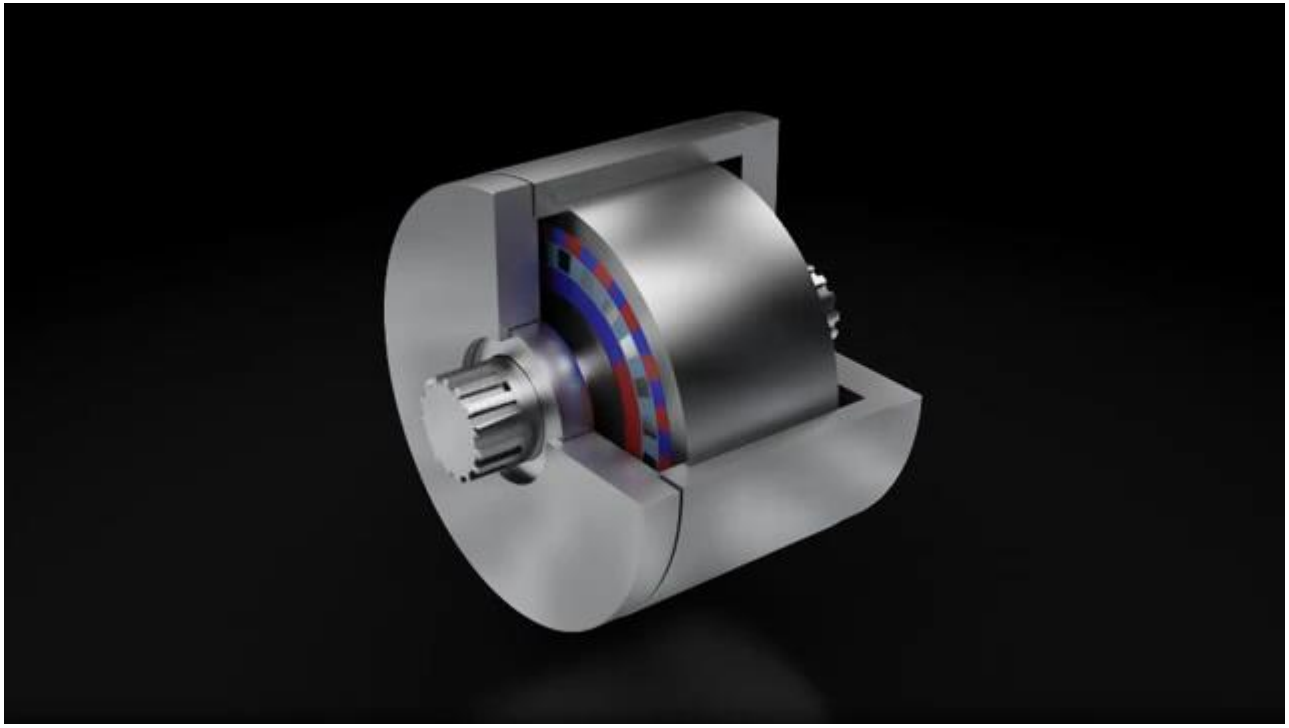


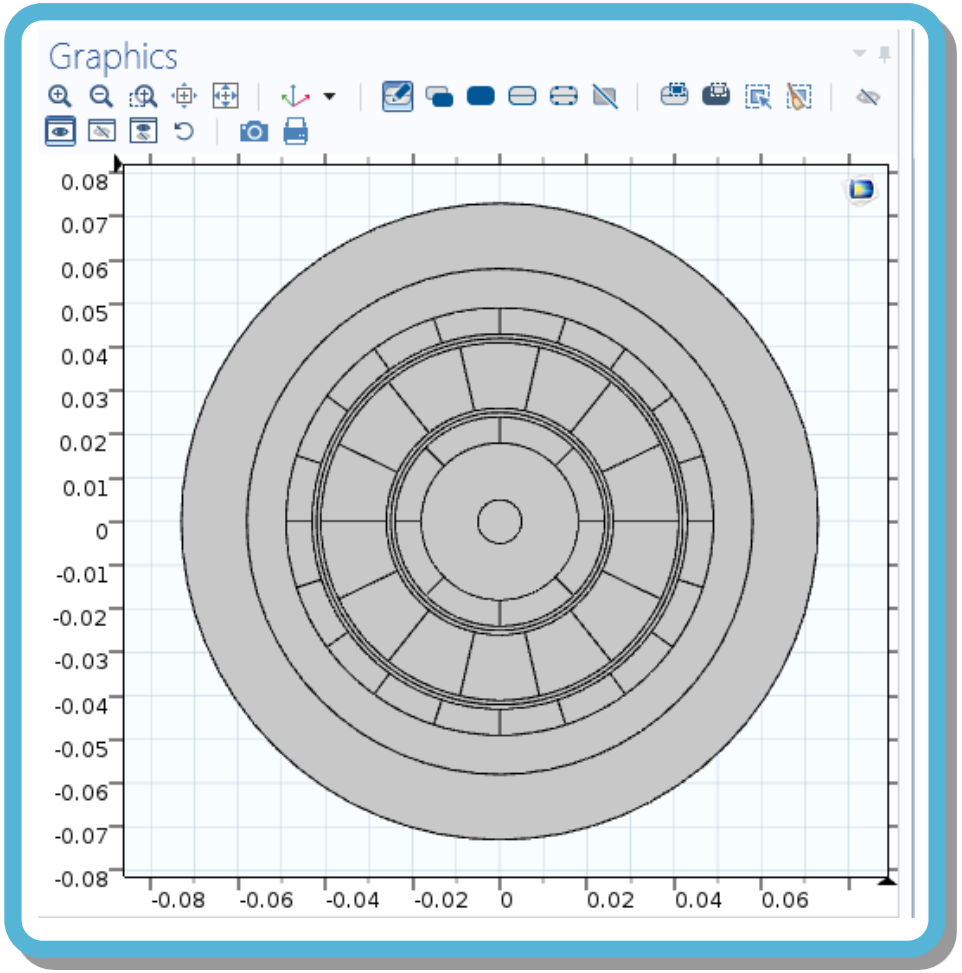


최대 120N ->
중력 40N 고려시 중력방향 최대 80N 추가 가능

Magnetic Gear

Magnetic Gear 영상

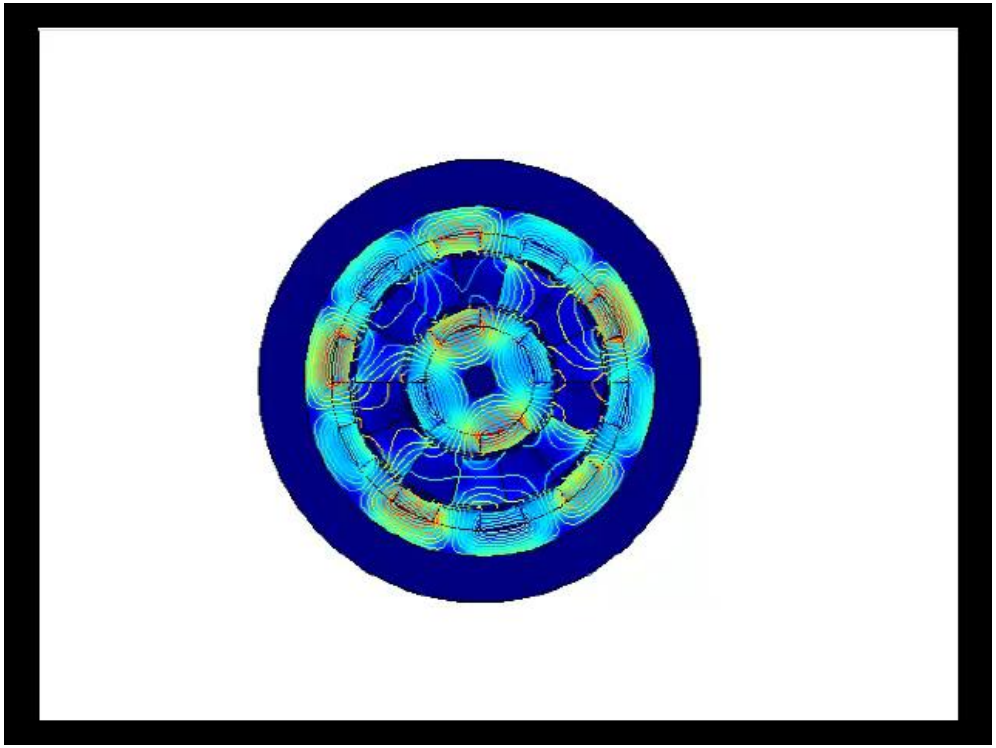


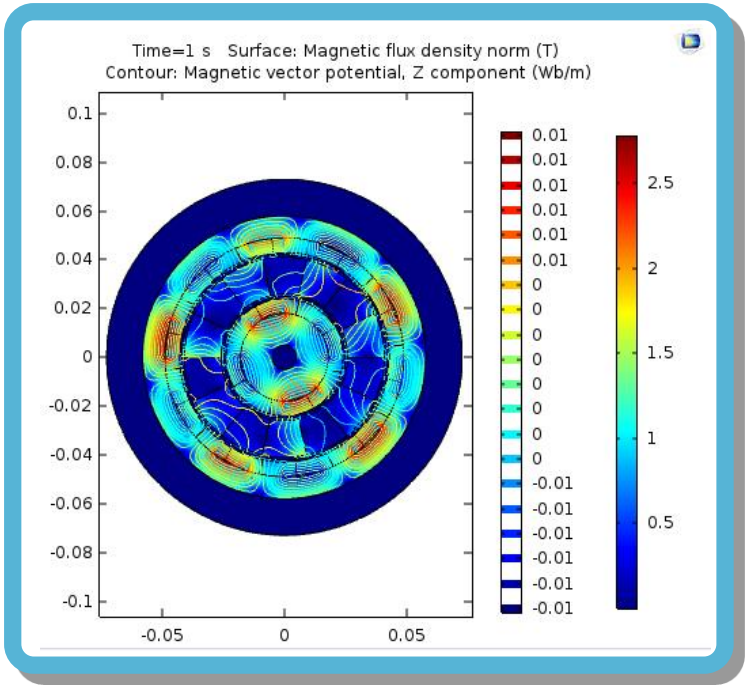


Outer rotor p = 5

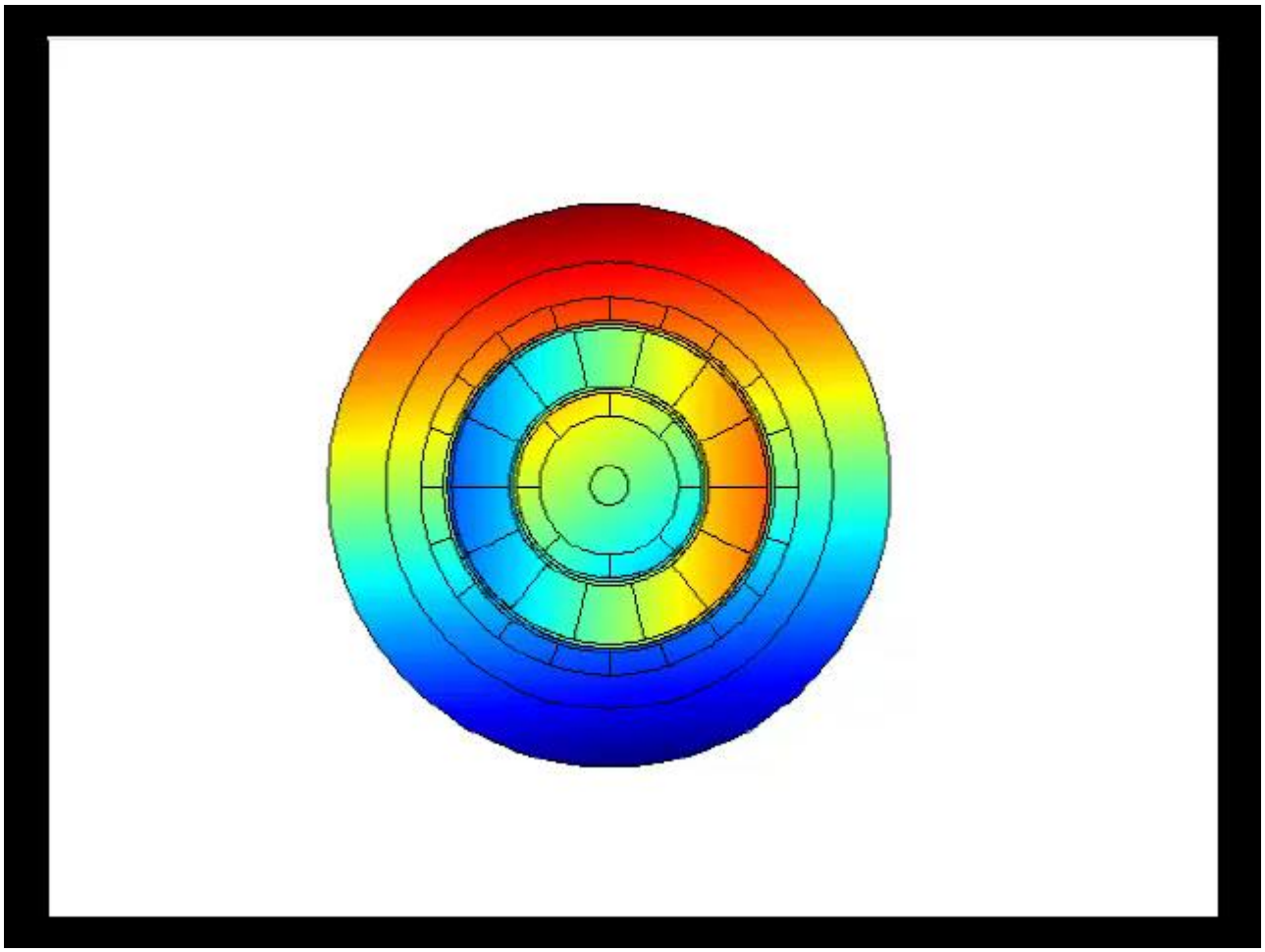
inner rotor p = 2

Magnetic Gear - 자속밀도와 자기포텐셜

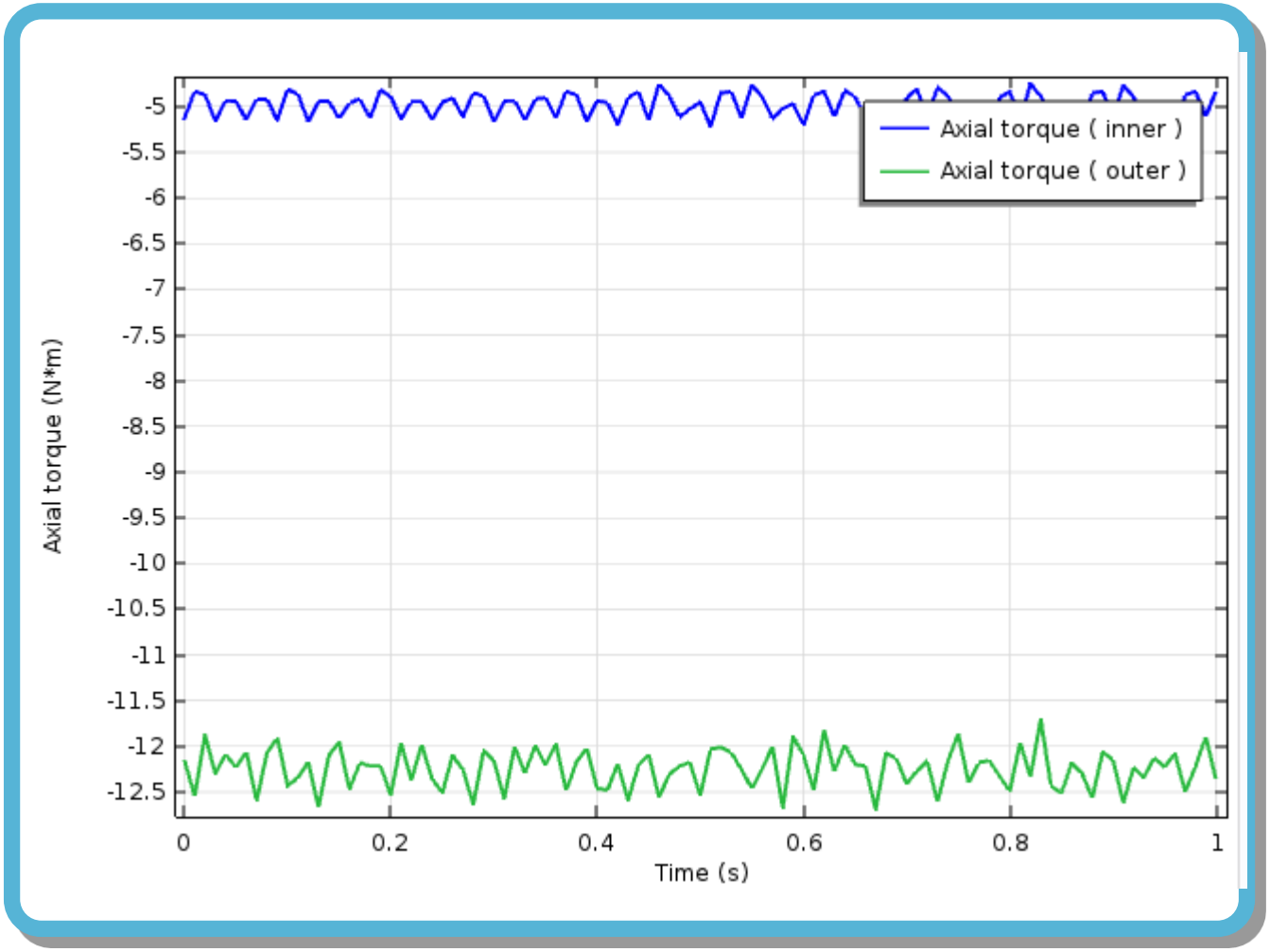




Magnetic Gear – 회전자 변위



Magnetic Gear



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감사합니다