# 픽미핑미

전자석 기중기 모델링

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YOO, DONGHAN

# 전자석 기중기 모델링

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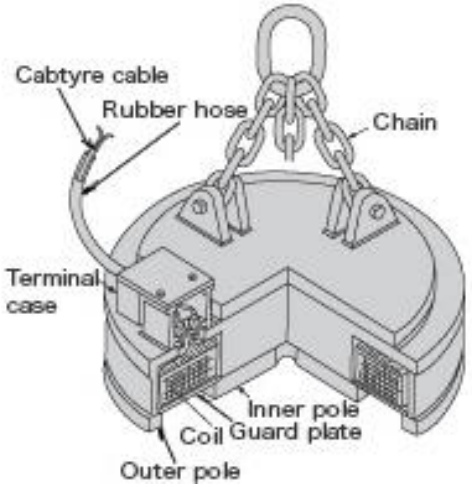
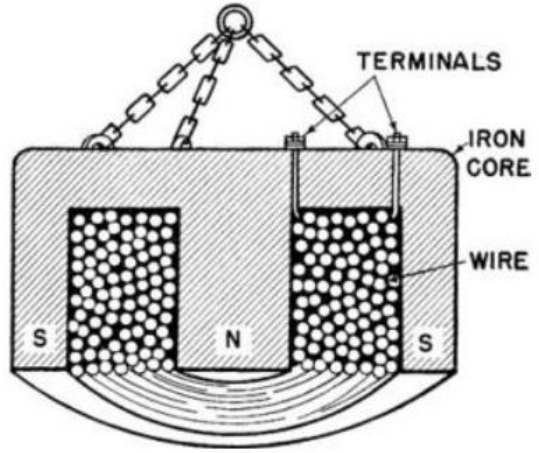
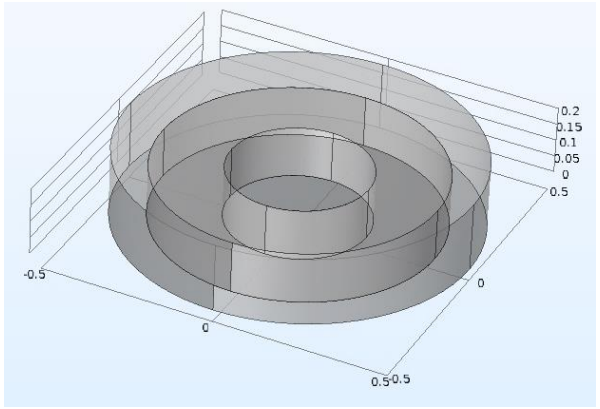
## 전자석 기중기-산업 현장에서의 다양한 이용

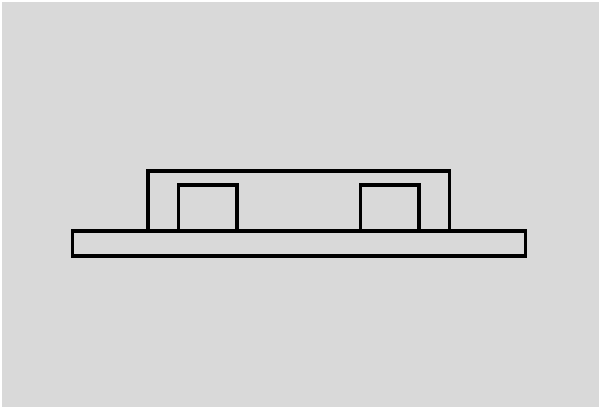
# 02 모델링 근거-형상 모델링





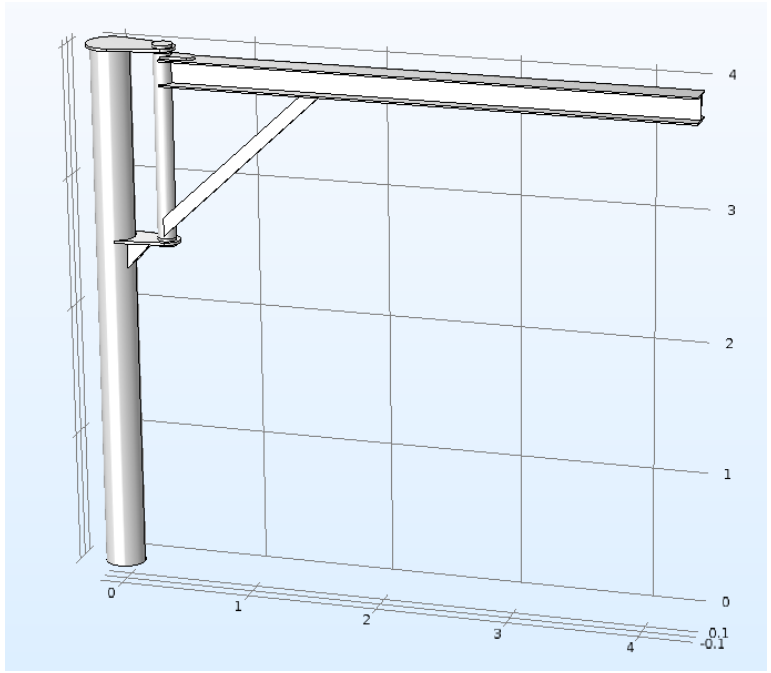



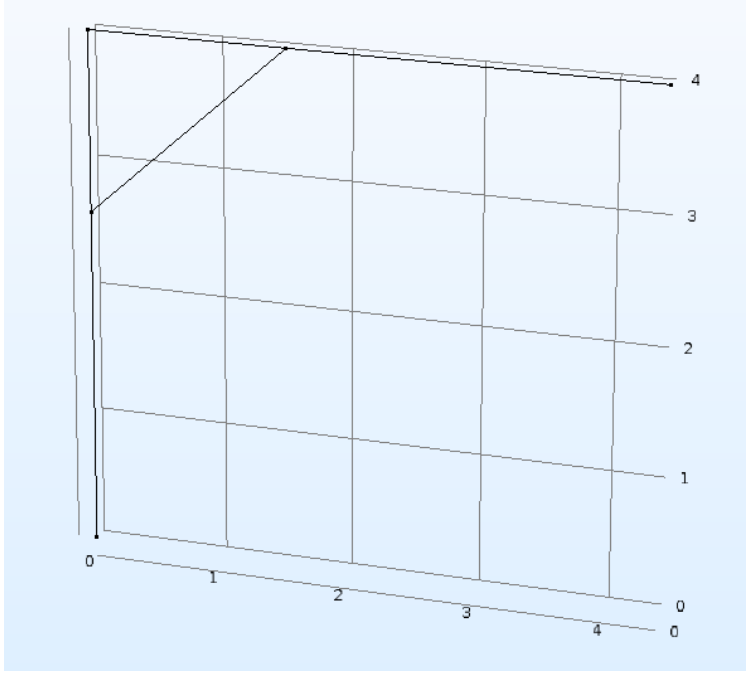
참고 : Electricity - Basic Navy Training Courses Electromagnetism NAVPERS 10622

# 02 모델링 근거-형상 모델링



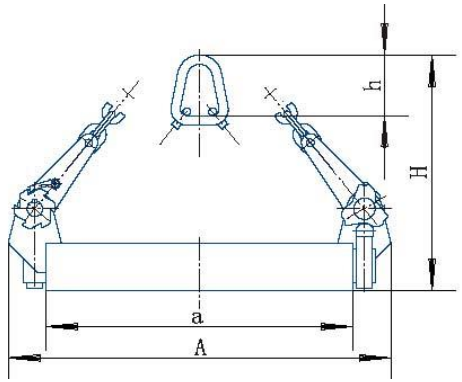

Solid model



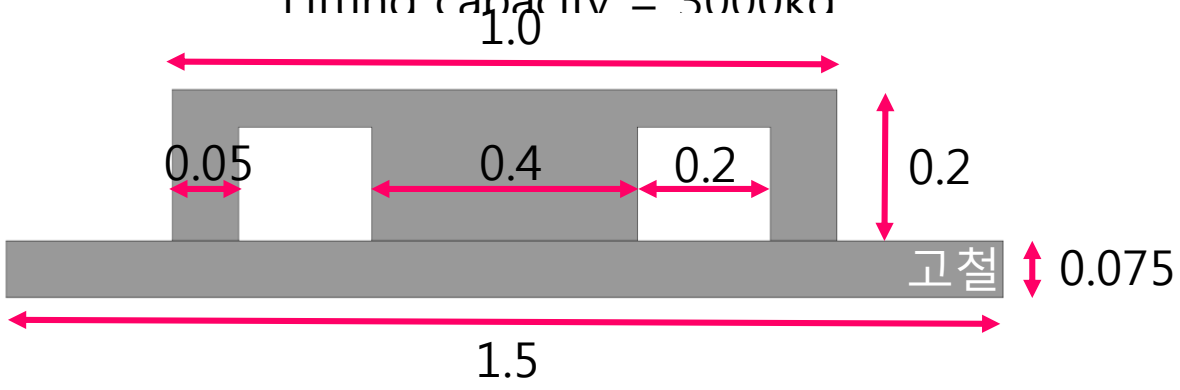

Beam model

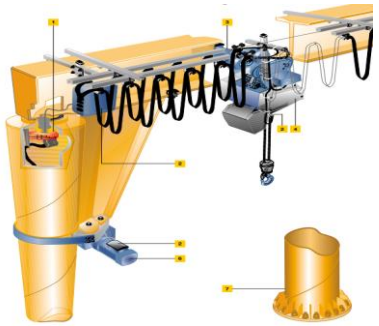
참고 : http://www.abuscranes.co.uk/cranes/jib-cranes/pillar-jib-crane-vs

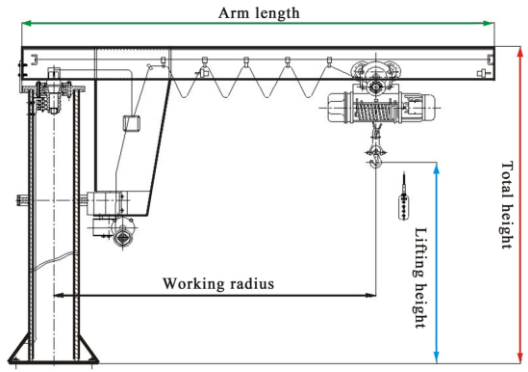
# 02 모델링 근거-치수




상품명 : HLM4-3000
제조사 : KEHAO crane (China)
Lifting capacity = 3000kg



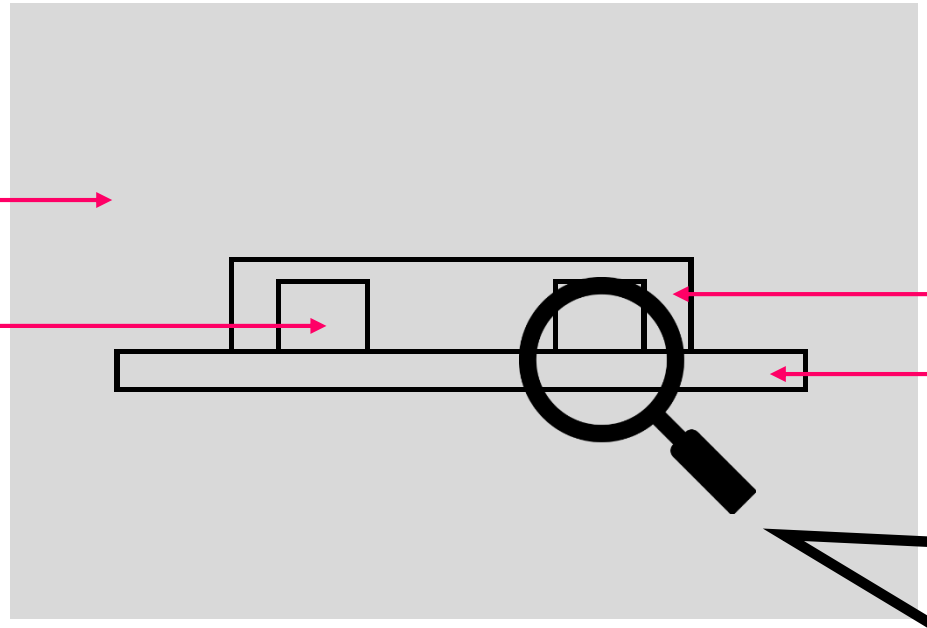





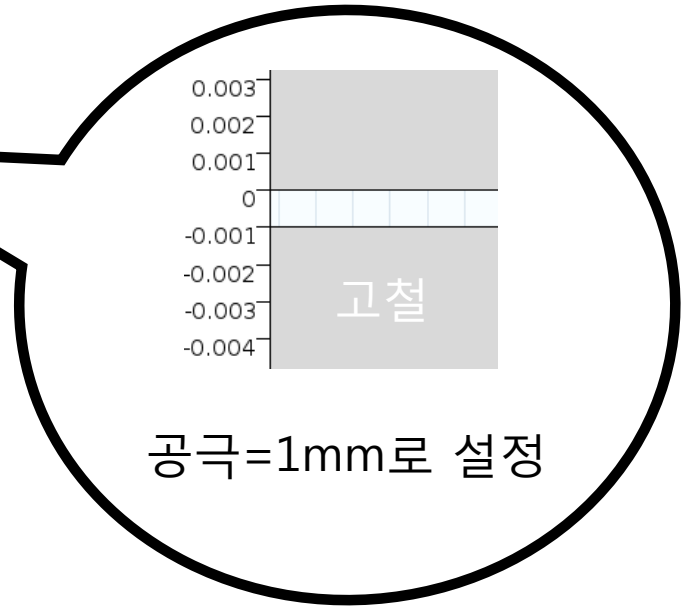

상품명 : Pillar jib crane VS
제조사 : ABUS crane

**공기**
Relative permeability:1

**코일(구리 도선)**
Relative permeability:1
Conductivity: 5.96e7

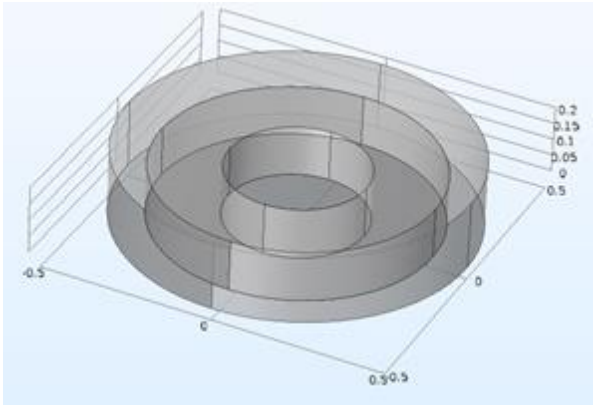


**순철**
Relative permeability:200000



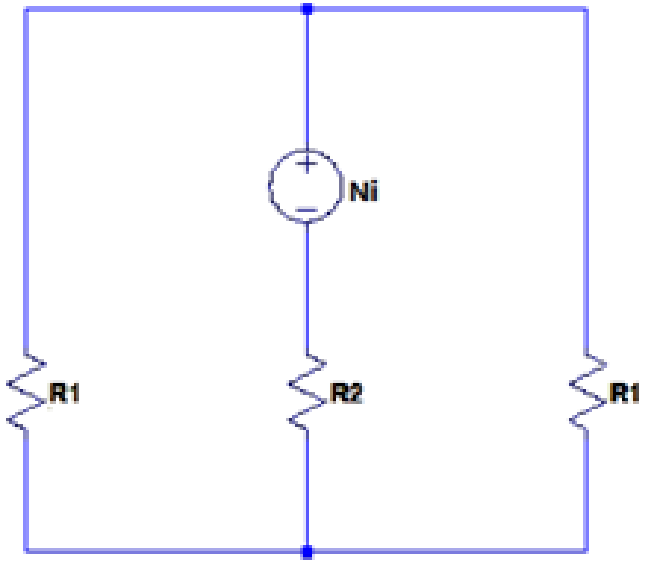

공극=1mm로 설정

# 3D Model-Analytical Analysis



등가 자기회로

$$R_m = \frac{l}{\mu_0 \mu_r A}, \quad Ni = R_m \psi$$




$\mu_0 = 4\pi \times 10^{-7}$, $\mu_r|_{air} = 1$, $\mu_r|_{magnetic} = 200000$,

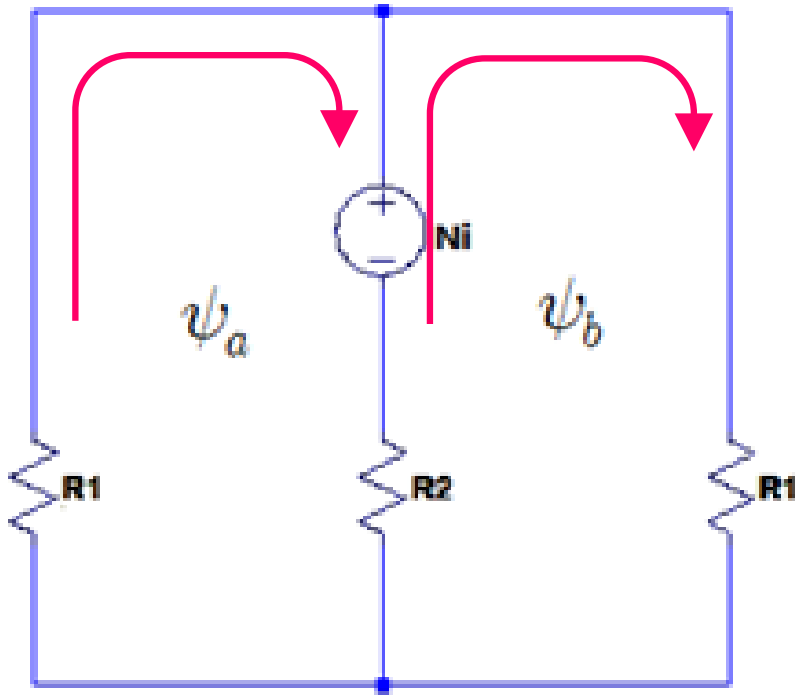
$N = 1000$, $i = 1\mathrm{A}$, $A_1 = 0.045\pi\, m^2$, $A_2 = 0.04\pi\, m^2$, $l = 0.001\mathrm{m}$

※ $R_{air} \gg R_{magnetic}$ 이므로 등가자기회로에서 $R_{magnetic}$ 무시

$$R_1 = \frac{l}{\mu_0 \mu_{air} A_1} = \frac{0.001}{4\pi \times 10^{-7} \times 1 \times 0.045\pi} = 5628.95$$

$$R_2 = \frac{l}{\mu_0 \mu_{air} A_2} = \frac{0.001}{4\pi \times 10^{-7} \times 1 \times 0.04\pi} = 6332.57$$

$$Ni = 1000 \times 1 = 1000[\mathrm{A}]$$




① 자속밀도 $B$ 구하기 $\left( B = \frac{\psi}{A} \right)$

By Mesh analysis

$\psi_a R_1 + (\psi_a - \psi_b) R_2 = Ni \quad \rightarrow \quad (R_1 + R_2)\psi_a - R_2\psi_b = Ni$

$(\psi_a - \psi_b) R_2 - \psi_b R_1 = -Ni \quad \rightarrow \quad -R_2\psi_a + (R_1 + R_2)\psi_b = -Ni$

$\psi_a = 0.0547\,[\mathrm{Wb}], \quad \psi_b = -0.0547\,[\mathrm{Wb}]$

$$\therefore B_1 = \frac{\psi_1}{A_1} = \frac{\psi_a}{A_1} = \frac{0.0547}{0.045\pi} = 0.3869\,[\mathrm{T}]$$

$$B_2 = \frac{\psi_2}{A_2} = \frac{\psi_a - \psi_b}{A_2} = \frac{0.1094}{0.04\pi} = 0.8706\,[\mathrm{T}]$$

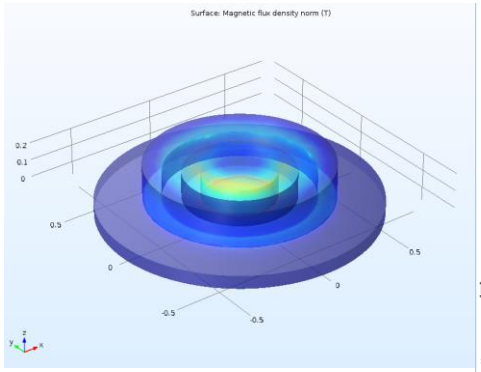
② 자기력 $F_m$ 구하기 $\left( F_m = \frac{B^2 A}{2\mu_0} \right)$

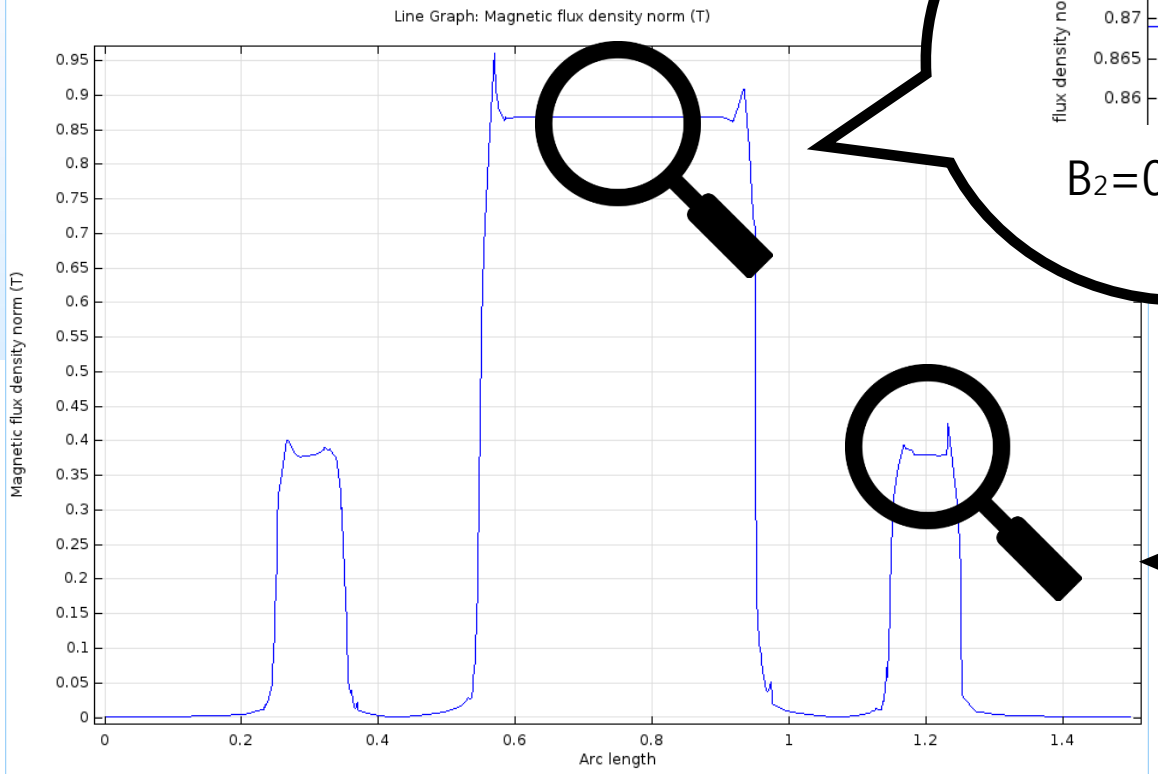
$$F_m = \frac{B_1^2 A_1}{2\mu_0} \times 2 + \frac{B_2^2 A_2}{2\mu_0} = \frac{1}{2\mu_0}\left(B_1^2 A_1 \times 2 + B_2^2 A_2\right)$$

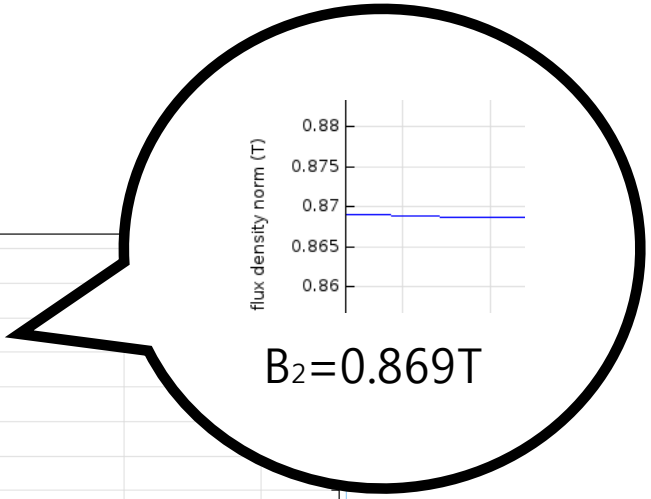
$$= \frac{1}{2 \times 4\pi \times 10^{-7}} \times \left(0.3869^2 \times 0.045\pi \times 2 + 0.8706^2 \times 0.04\pi\right)$$

$$= 54737.5\,[\mathrm{N}]$$

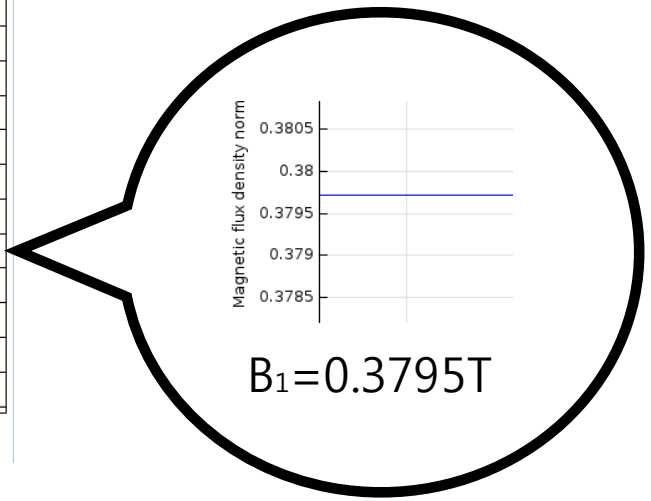
# 3D Model-COMSOL Analysis




$B_2$=0.869T




$B_1$=0.3795T

# 3D Model-COMSOL vs Analytic

## COMSOL Analysis

$$B_1 = 0.3795\,[\mathrm{T}]$$

$$B_2 = 0.8690\,[\mathrm{T}]$$

$$F_{3D} = \frac{(0.3795^2 \times 0.045\pi \times 2 + 0.869^2 \times 0.04\pi)}{2 \times 4\pi \times 10^{-7}}$$

$$= \underline{53960.3\,[\mathrm{N}]}$$

## Analytic Analysis

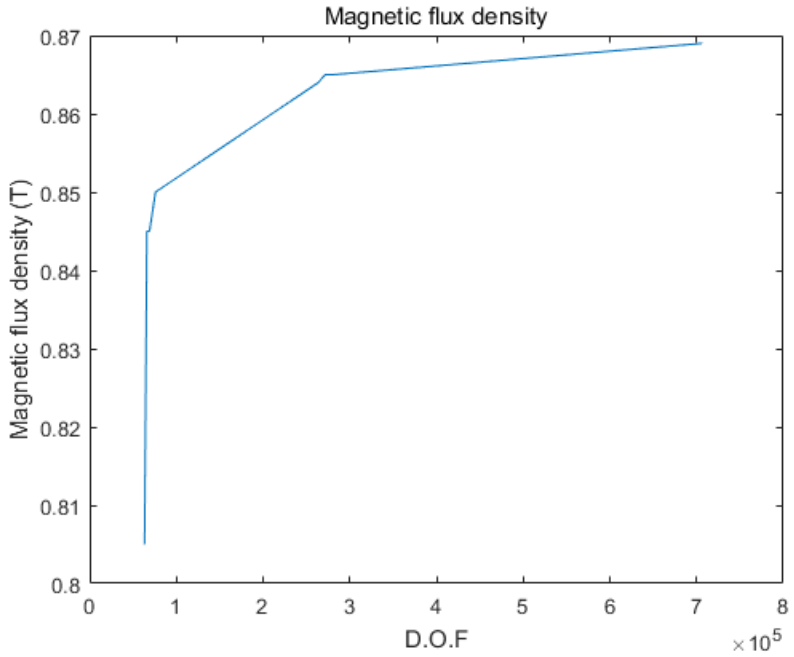
$$B_1 = 0.3869\,[\mathrm{T}]$$

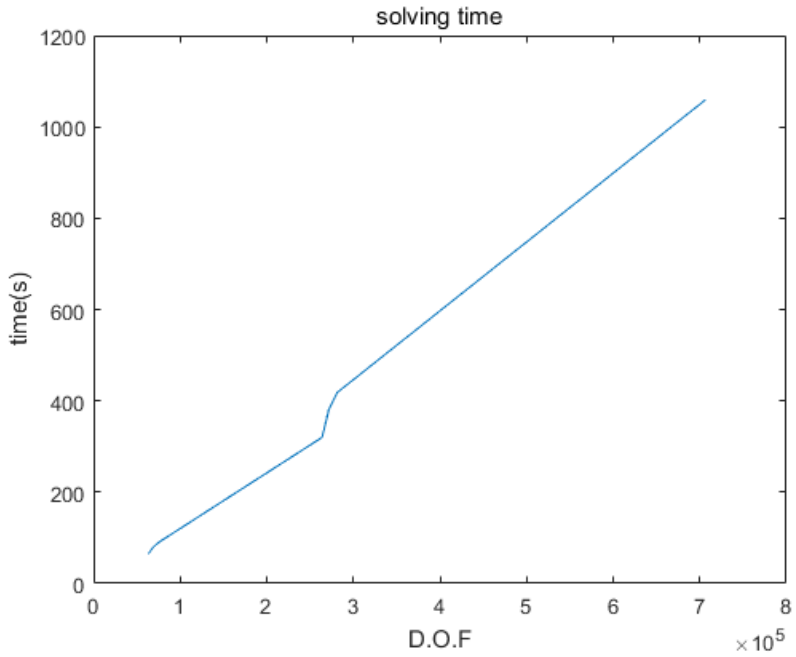
$$B_2 = 0.8706\,[\mathrm{T}]$$

$$F_{3D\ analytic} = \underline{54737.5\,[\mathrm{N}]}$$

$$\mathrm{Error} = \left|\frac{\mathrm{Analytic} - \mathrm{Comsol}}{\mathrm{Analytic}}\right| \times 100 = \left|\frac{54737.5 - 53960.3}{54737.5}\right| \times 100 = 1.420\%$$

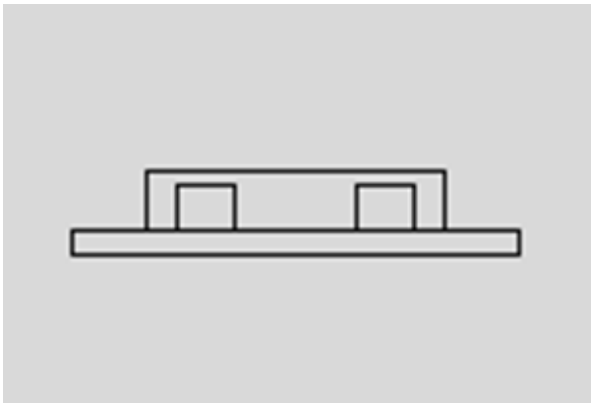
## 3D Model의 한계




D.O.F 의 증가에 따라 해석 값의 정확도는 증가하였지만,
시간이 지나치게 오래 걸리는 문제 발생

# 2D Model-Analytical Analysis

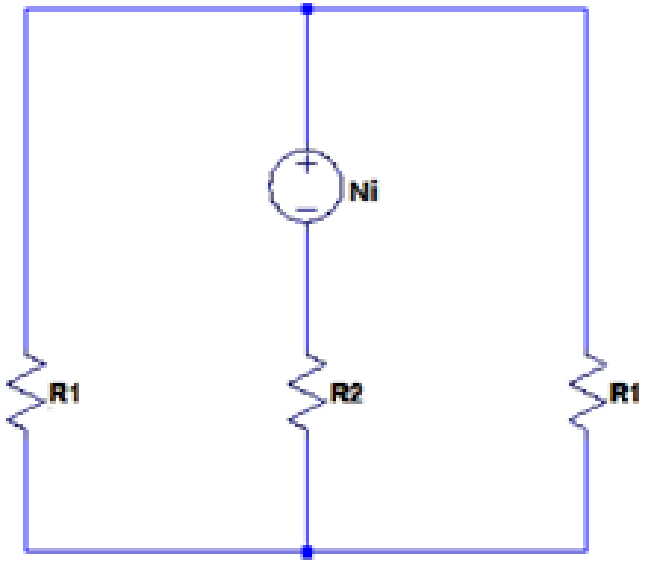


$A_1 = 0.1\mathrm{m}^2,\ A_2 = 0.4\mathrm{m}^2$

나머지는 동일.

등가 자기회로

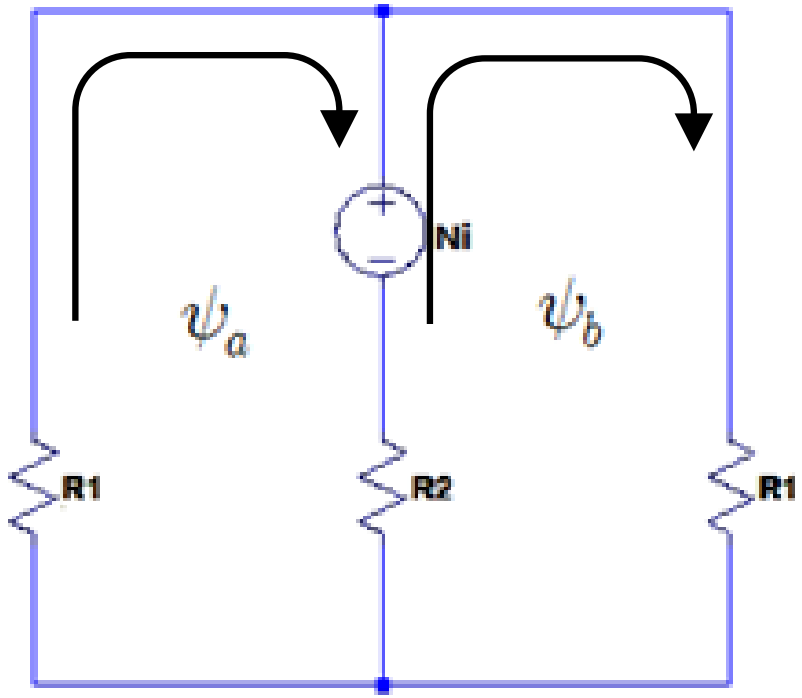
$$R_m = \frac{l}{\mu_0 \mu_r A},\quad Ni = R_m \psi$$




$$R_1 = \frac{l}{\mu_0 \mu_{air} A_1} = \frac{0.001}{4\pi \times 10^{-7} \times 1 \times 0.1} = 7957.75$$

$$R_2 = \frac{l}{\mu_0 \mu_{air} A_2} = \frac{0.001}{4\pi \times 10^{-7} \times 1 \times 0.4} = 1989.44$$

$$Ni = 1000 \times 1 = 1000[\mathrm{A}]$$




① 자속밀도 $B$ 구하기 $\left( B = \frac{\psi}{A} \right)$

By Mesh analysis

$$\psi_a R_1 + (\psi_a - \psi_b) R_2 = Ni \quad \text{->} \quad (R_1 + R_2)\psi_a - R_2 \psi_b = Ni$$
$$(\psi_a - \psi_b) R_2 - \psi_b R_1 = -Ni \quad \text{->} \quad -R_2 \psi_a + (R_1 + R_2)\psi_b = -Ni$$

$$\psi_a = 0.0838\,[\mathrm{Wb}], \quad \psi_b = -0.0838\,[\mathrm{Wb}]$$

$$\therefore B_1 = \frac{\psi_1}{A_1} = \frac{\psi_a}{A_1} = \frac{0.0838}{0.1} = \underline{0.838[\mathrm{T}]}$$

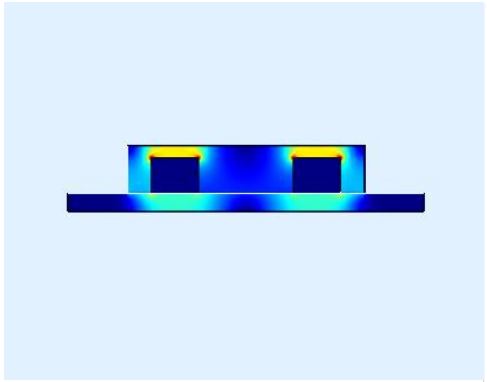
$$B_2 = \frac{\psi_2}{A_2} = \frac{\psi_a - \psi_b}{A_2} = \frac{0.0838 \times 2}{0.4} = \underline{0.419[\mathrm{T}]}$$

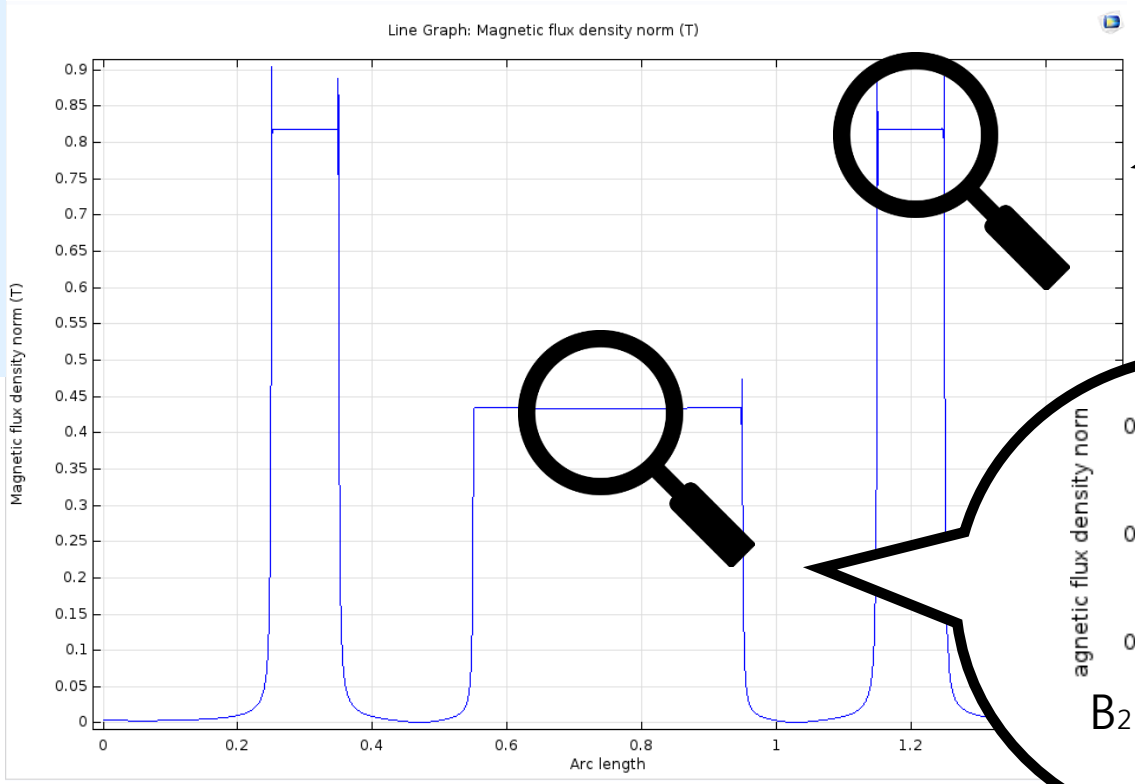
② 자기력 $F_m$ 구하기 $\left( F_m = \frac{B^2 A}{2\mu_0} \right)$

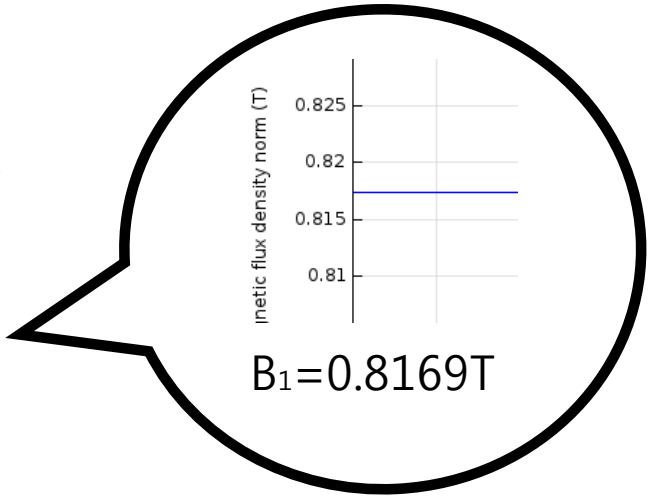
$$F_m = \frac{B_1^2 A_1}{2\mu_0} \times 2 + \frac{B_2^2 A_2}{2\mu_0} = \frac{1}{2\mu_0}\left(B_1^2 A_1 \times 2 + B_2^2 A_2\right)$$
$$= \frac{1}{2 \times 4\pi \times 10^{-7}} \times \left(0.838^2 \times 0.1 \times 2 + 0.419^2 \times 0.4\right) \; 4\pi)$$

$$= \underline{83824.2[\mathrm{N}]}$$

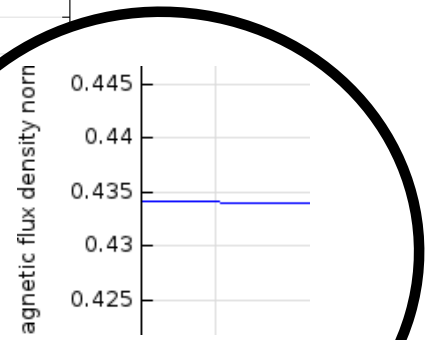
# 2D Model-COMSOL Analysis






$B_1$=0.8169T




$B_2$=0.4348T

# 2D Model-COMSOL vs Analytic

## COMSOL Analysis

$$B_1 = 0.8169\,[\mathrm{T}]$$

$$B_2 = 0.4348\,[\mathrm{T}]$$

$$F_{2D} = \frac{(0.8169^2 \times 0.1 \times 2 + 0.4348^2 \times 0.4)}{2 \times 4\pi \times 10^{-7}}$$

$$= \underline{83192.4\,[\mathrm{N}]}$$

## Analytic Analysis

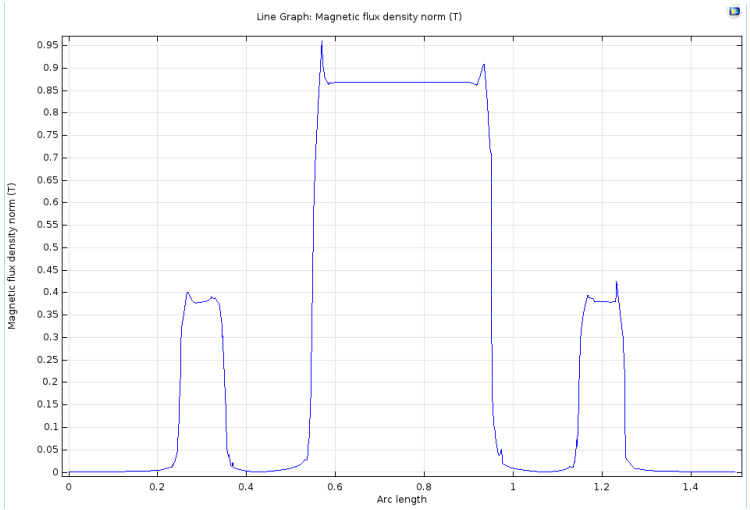
$$B_1 = 0.838[\mathrm{T}]$$

$$B_2 = 0.419[\mathrm{T}]$$

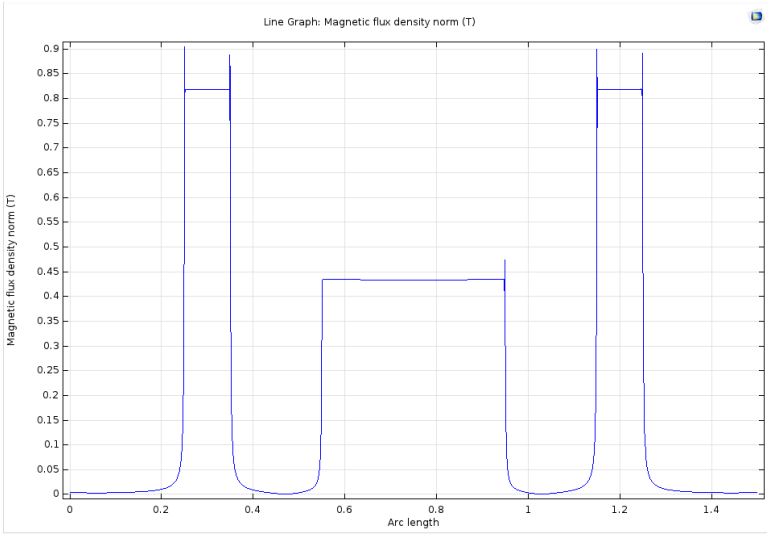
$$F_{2D\ analytic} = \underline{83824.2\,[\mathrm{N}]}$$

$$\mathrm{Error} = \left|\frac{\mathrm{Analytic} - \mathrm{Comsol}}{\mathrm{Analytic}}\right| \times 100 = \left|\frac{83824.2 - 83192.4}{83824.2}\right| \times 100 = 0.754\%$$

# 2D 해석의 문제점




<3D 모델>

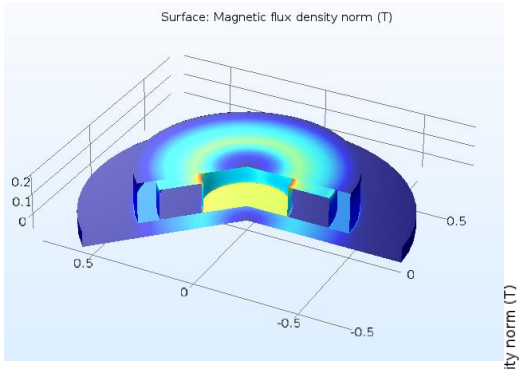


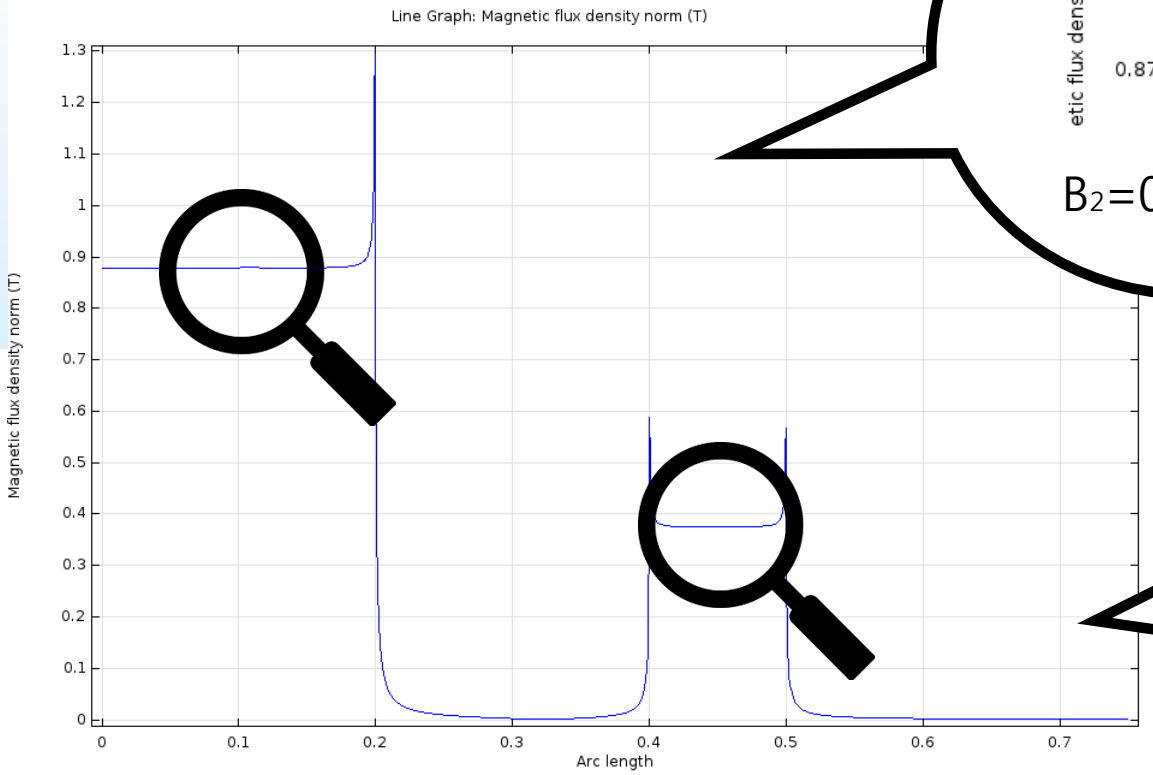

<2D 모델>

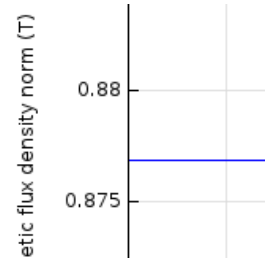
너무 다른 자속 밀도의 그래프 개형,

왜 이럴까?

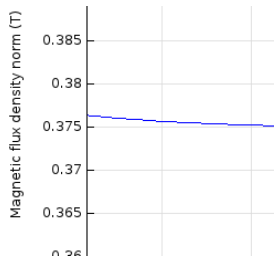
# 2D Axis symmetry Model-COMSOL Analysis




$B_2$=0.8768T




$B_1$=0.3756T

# 2D Axis symmetry Model-COMSOL vs Analytic

## COMSOL Analysis

$$B_1 = 0.3756\,[\mathrm{T}]$$

$$B_2 = 0.8768\,[\mathrm{T}]$$

$$F_{2D\ axis} = \frac{(0.3756^2 \times 0.045\pi \times 2 + 0.8768^2 \times 0.04\pi)}{2 \times 4\pi \times 10^{-7}}$$

$$= \underline{54309.9\,[\mathrm{N}]}$$

## Analytic Analysis

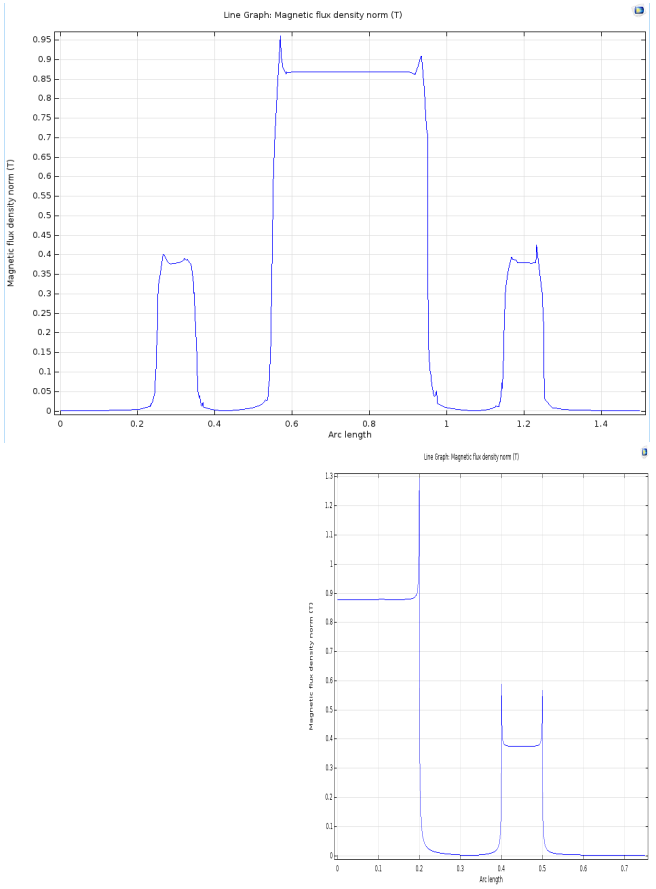
$$B_1 = 0.3869\,[\mathrm{T}]$$

$$B_2 = 0.8706\,[\mathrm{T}]$$

$$F_{3D\ anlaytic} = \underline{54737.5\,[\mathrm{N}]}$$

$$\mathrm{Error} = \left|\frac{\mathrm{Analytic} - \mathrm{Comsol}}{\mathrm{Analytic}}\right| \times 100 = \left|\frac{54737.5 - 54309.9}{54737.5}\right| \times 100 = 0.781\,\%$$

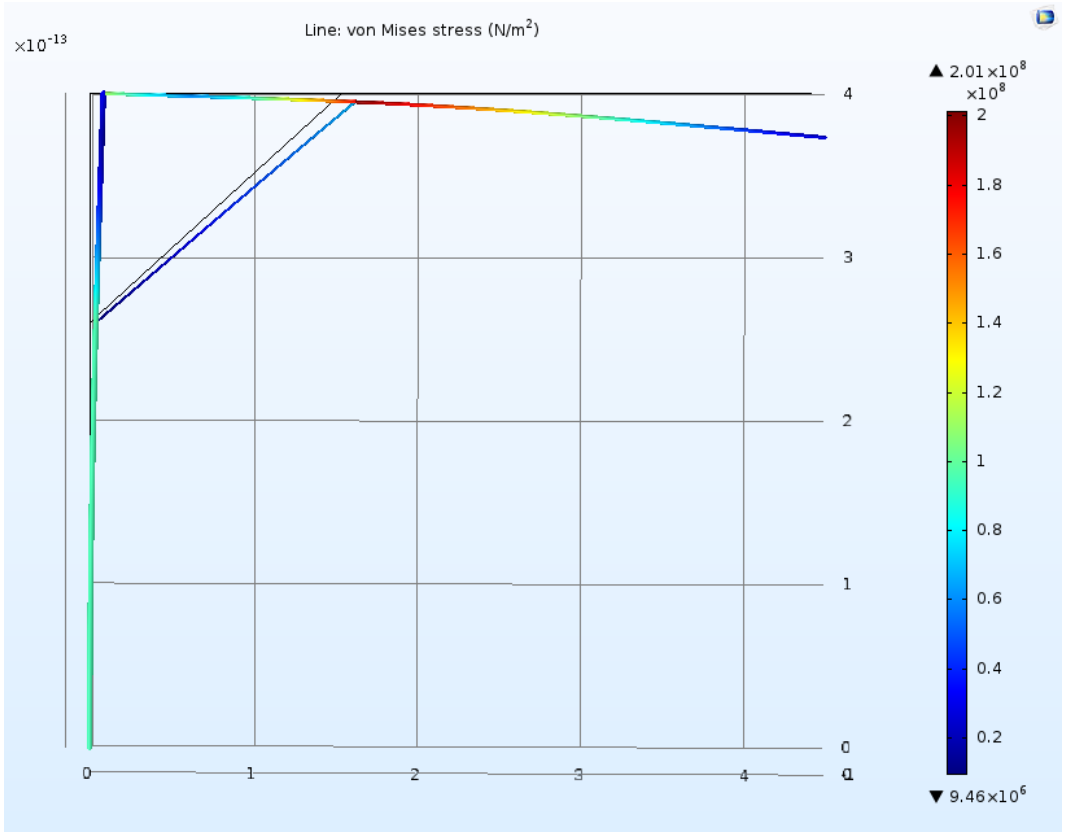
# 2D Axis symmetry 해석의 타당성



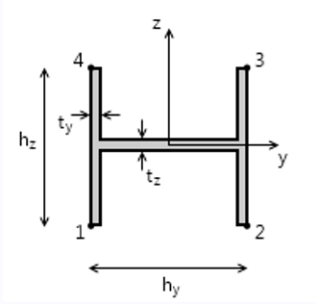

Extra fine mesh 일 때의 해석 비교

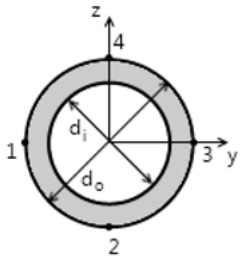
| | 3D | 2D | 2D Axis sym |
|---|---|---|---|
| D.O.F | 706382 | 67849 | 33078 |
| Solving time | 1059 | 3 | 3 |
| Magnetic Force | 53960N | 82389N | 54309N |

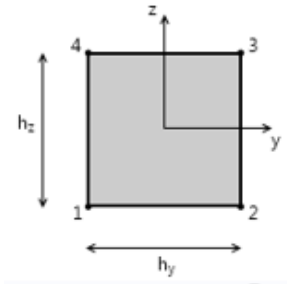
# Beam analysis

# 수치 최적화 모델




## 기존 모델

Section height:
$h_y$ 0.2 m
Flange width:
$h_z$ 0.2 m
Flange thickness:
$t_y$ 0.012 m
Web thickness:
$t_z$ 0.012 m

Outer diameter:
$d_o$ 0.3 m
Inner diameter:
$d_i$ 0.24 m

Width in local y-direction:
$h_y$ 0.14 m
Width in local z-direction:
$h_z$ 0.14 m

## 최적화 후 모델

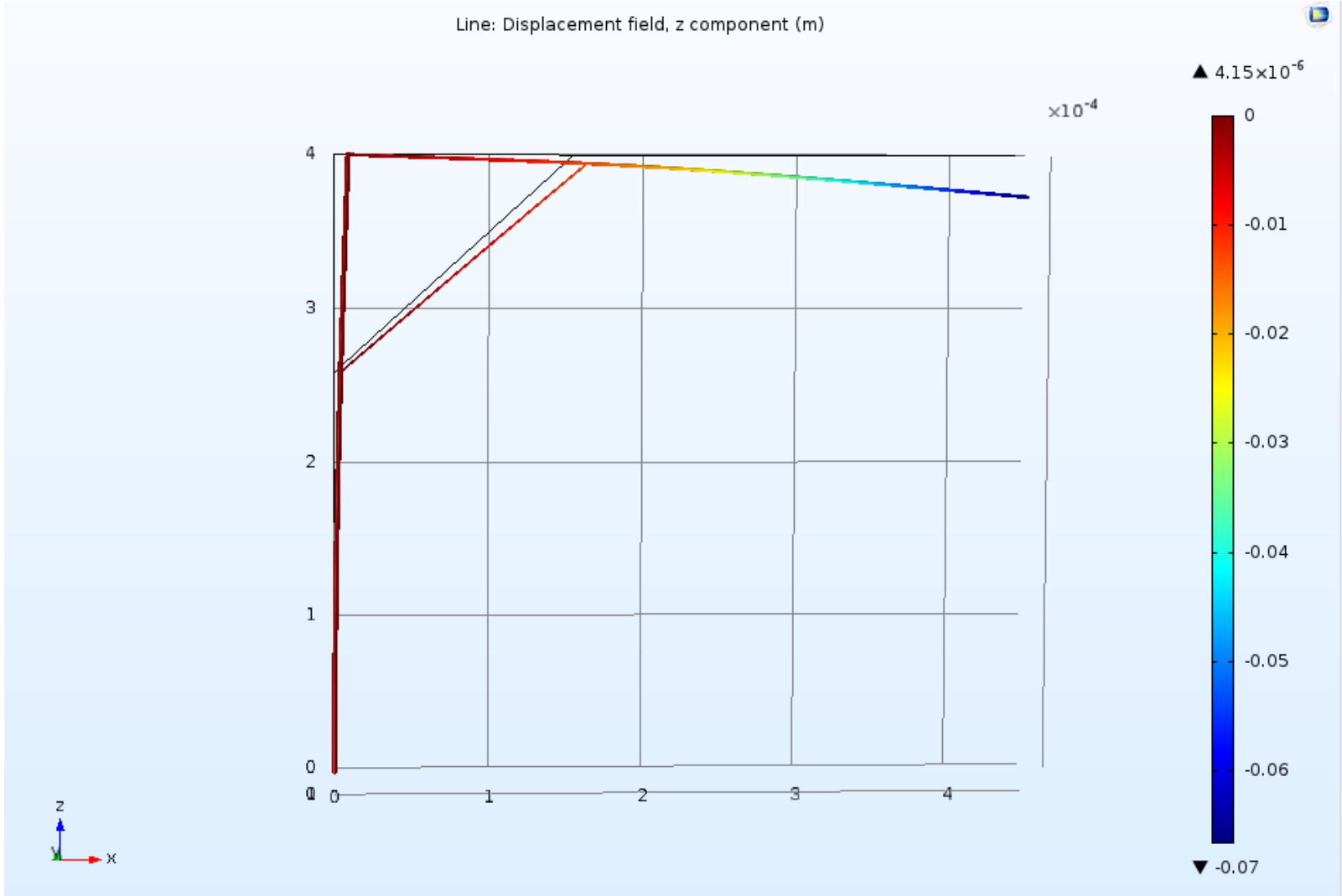
Section height:
$h_y$ 0.21552 m
Flange width:
$h_z$ 0.21055 m
Flange thickness:
$t_y$ 0.01268 m
Web thickness:
$t_z$ 0.01217 m

Outer diameter:
$d_o$ 0.31343 m
Inner diameter:
$d_i$ 0.25822 m

Width in local y-direction:
$h_y$ 0.13911 m
Width in local z-direction:
$h_z$ 0.13224 m

# 04 Solid mechanics 해석



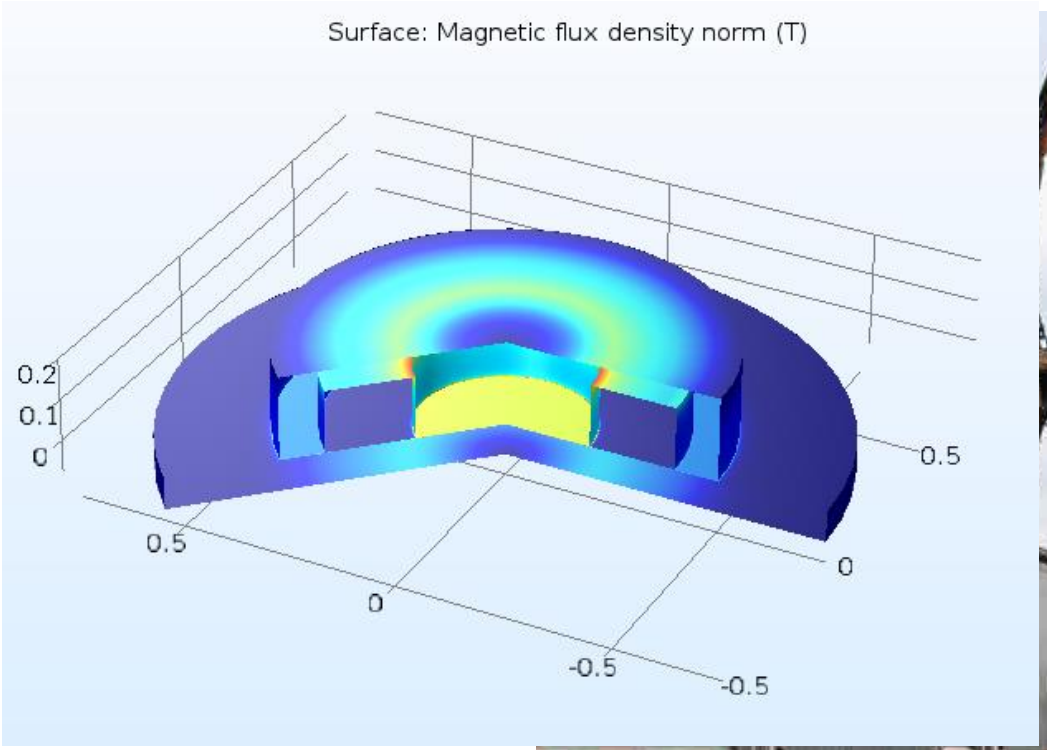


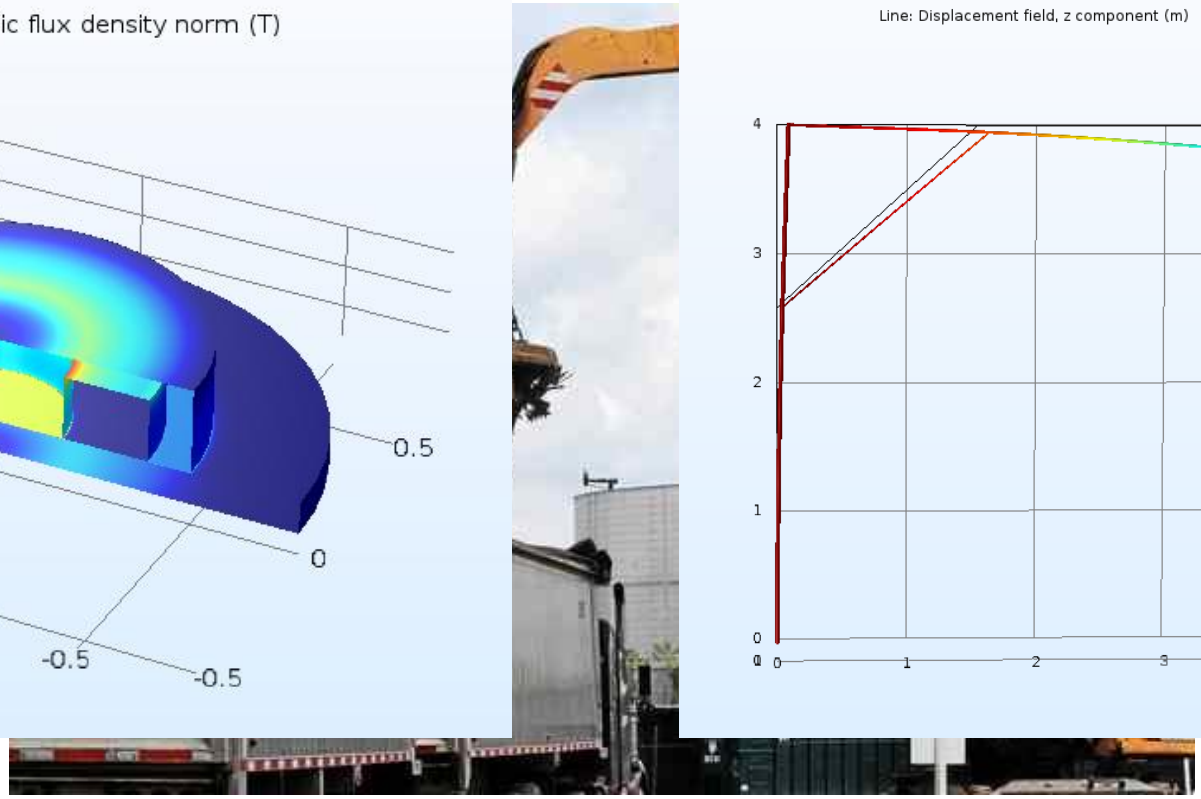

Displacement field, z component (m), Point: 5

-0.077326

Displacement field, z component (m), Point: 5

-0.066637


Surface: Magnetic flux density norm (T)
0.2
0.1
0
0.5
0
-0.5
0.5
0
-0.5




Line: Displacement field, z component (m)
×10⁻⁴
4
3
2
1
0
0
1
2
3
4
▲ 4.15×10⁻⁶
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
▼ -0.07

Q&A TIME

Thank you for your attention