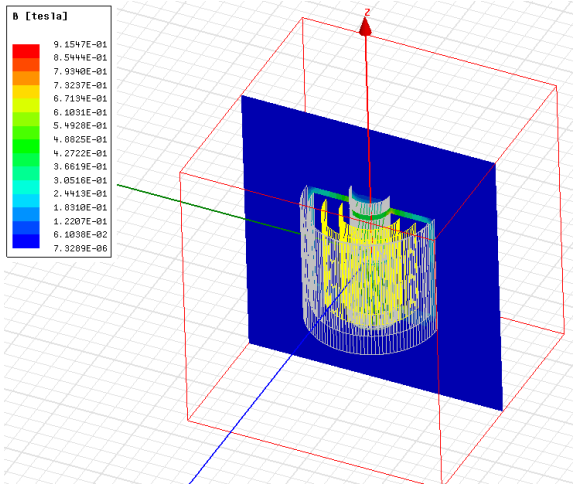
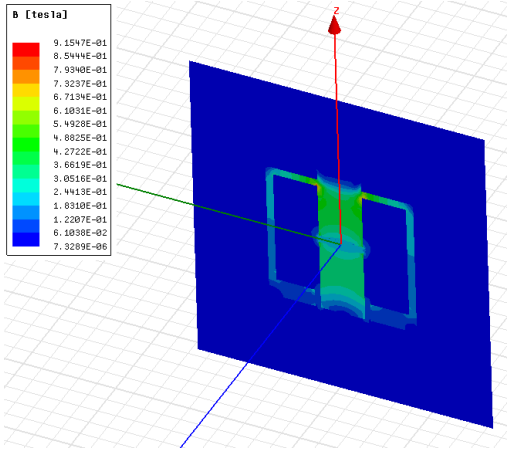
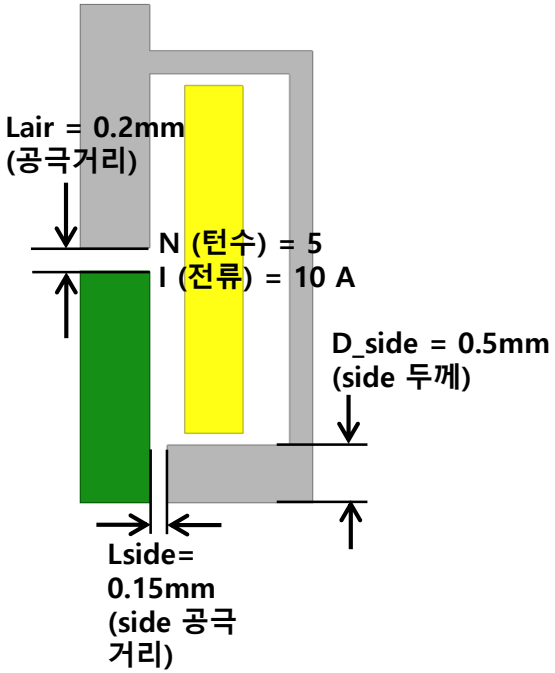
# Maxwell 3D Magnetostatic
## (Solenoid)

# Overview

- **해석 모델 : 솔레노이드 (Solenoid)**
  - Core, Plunger, Coil로 이루어 짐
- **해석 목적**
  - 전기강판 재질 생성 (BH Curve 입력)
  - Maxwell 결과와 수계산 결과의 차이점 확인
- **해석 솔버 : Maxwell 3D Magnetostatic(정자계 해석)**
- **해석 결과**
  - Force Value of Plunger
  - calculate Flux density in airgap
  - calculate Magnetic Flux in airgap

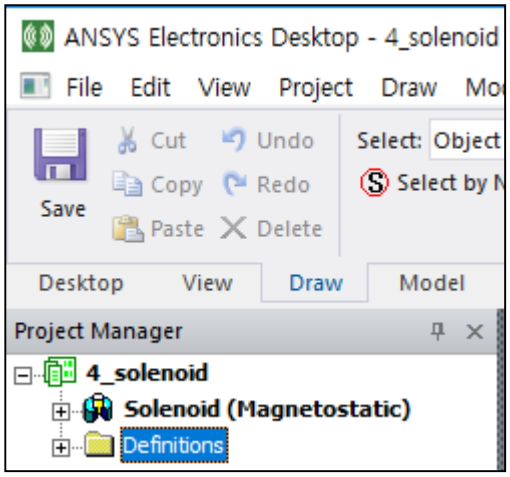


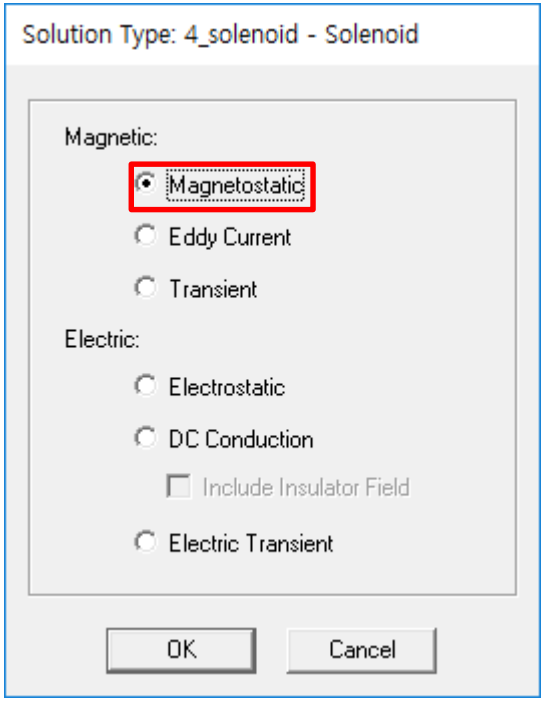



# Magnetostatic (Solenoid)

- **ANSYS Electronics Desktop 실행**

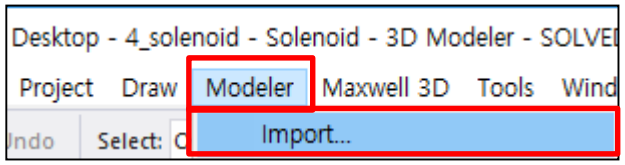


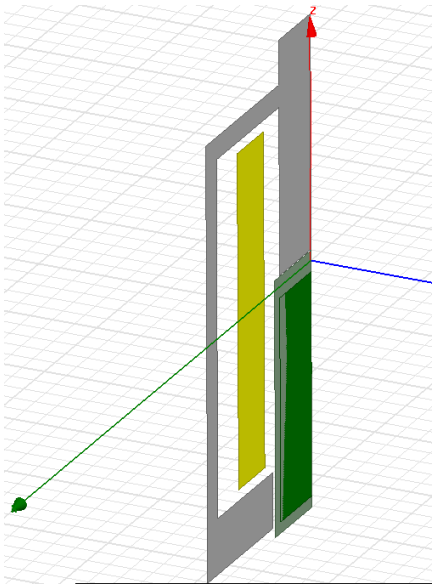




1. Save as… → Solenoid
2. 상단 메뉴 Project → **Insert Maxwell 3D Design** 클릭
3. Name 변경 → "Solenoid"
4. 상단 메뉴 Maxwell 3D → **Solution Type** 클릭
5. Magnetostatic 선택 후 "OK"

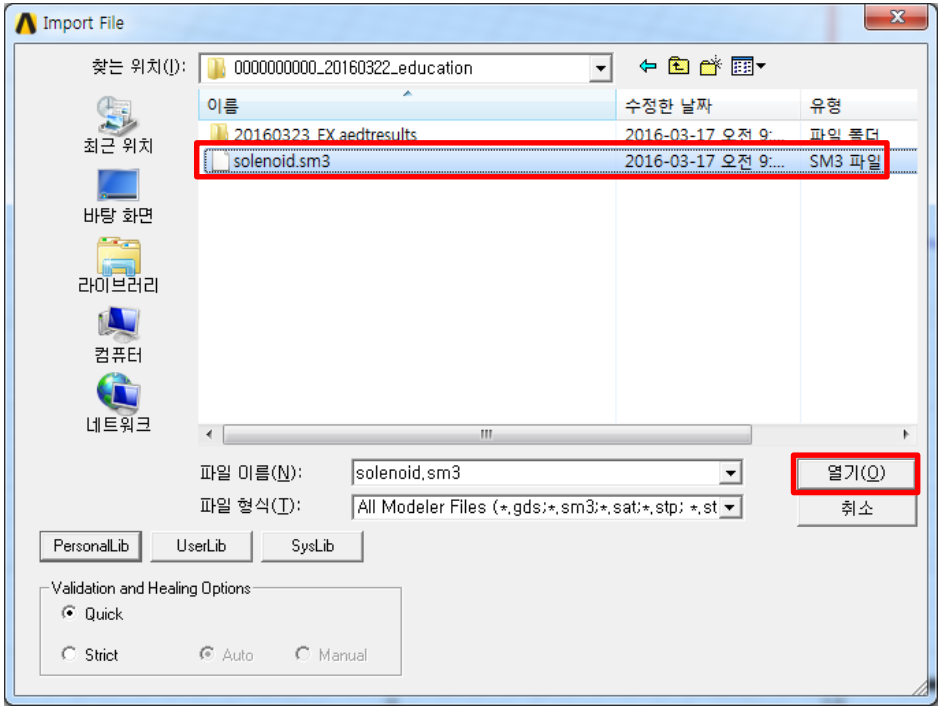
# Magnetostatic (Solenoid)

1. 상단 메뉴 Modeler → Import 클릭



2. Solenoid.sm3 선택후 열기

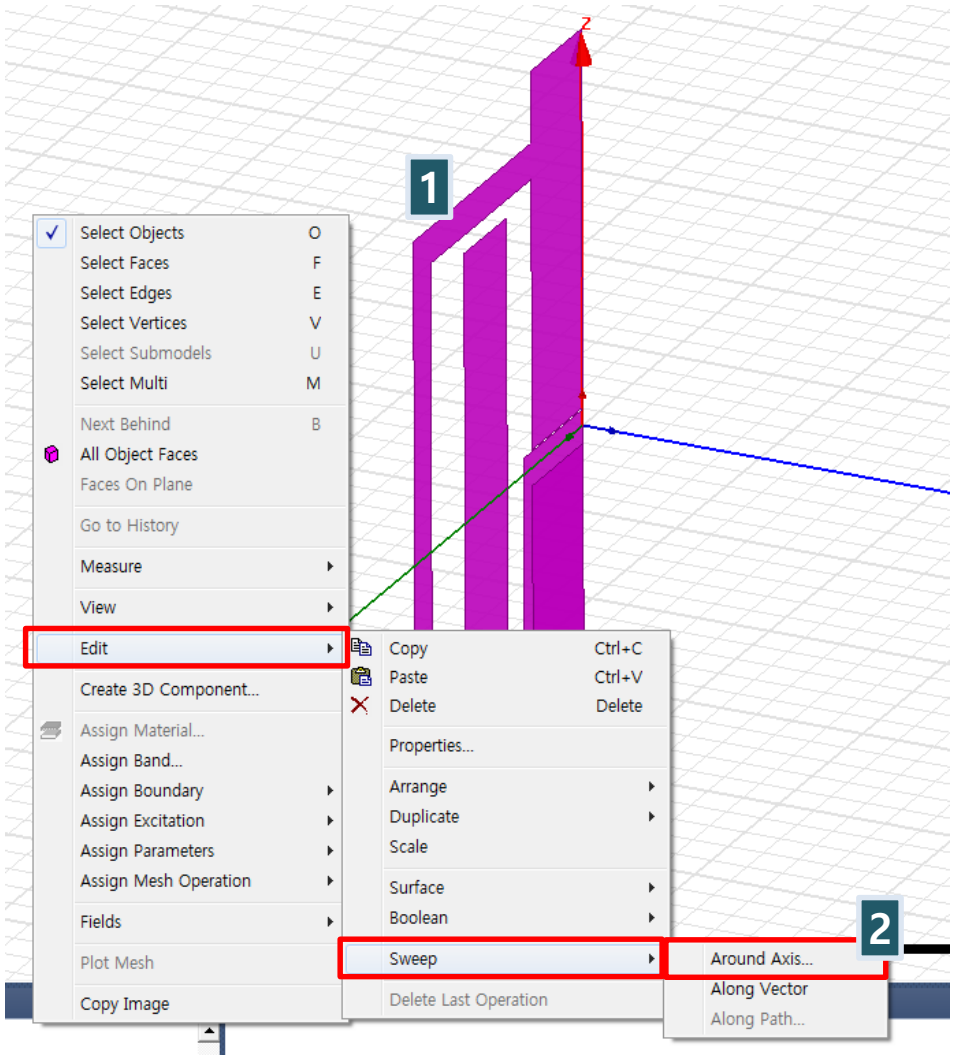


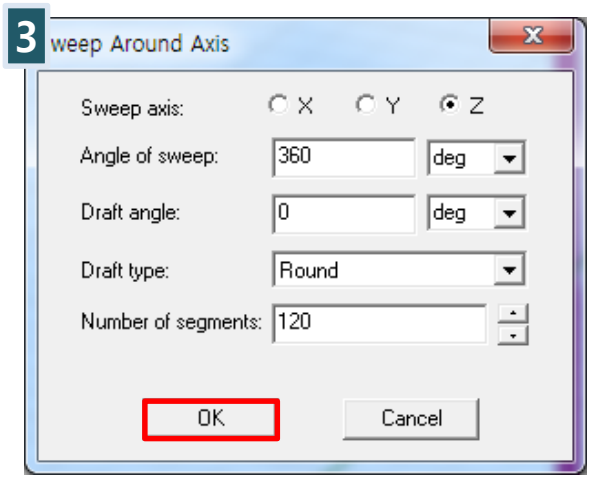
# Magnetostatic (Solenoid)

1. 도면에서 Ctrl + A 전체 선택

2. 마우스 우클릭
   > Edit
   > Sweep
   > Around Axis

3. Sweep Around Axis
   Sweep axis : Z축
   Angle of sweep : 360
   Draft angle : 0
   Draft type : Round
   Number of segments : 120
   "OK"

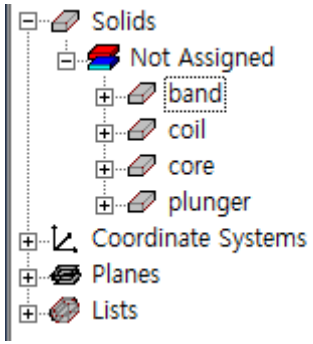


# Magnetostatic (Solenoid)

- History tree “band”, “coil”, “core”, “plunger”를 클릭하고 아래 그림과 같이 Properties 설정을 변경

**< History tree >**




Properties

| Name | Value | Unit | Evalua |
|---|---|---|---|
| Name | band | | |
| Material | "vacuum" | | "vacuu |
| Solve Inside | ☑ | | |
| Orientation | Global | | |
| Model | ☑ | | |
| Display Wireframe | ☑ | | |
| Color | | | |
| Transparent | 0,8 | | |

Properties

| Name | Value | Unit | Evalua |
|---|---|---|---|
| Name | coil | | |
| Material | "copper" | | "coppe |
| Solve Inside | ☑ | | |
| Orientation | Global | | |
| Model | ☑ | | |
| Display Wireframe | ☐ | | |
| Color | | | |
| Transparent | 0,8 | | |

Properties

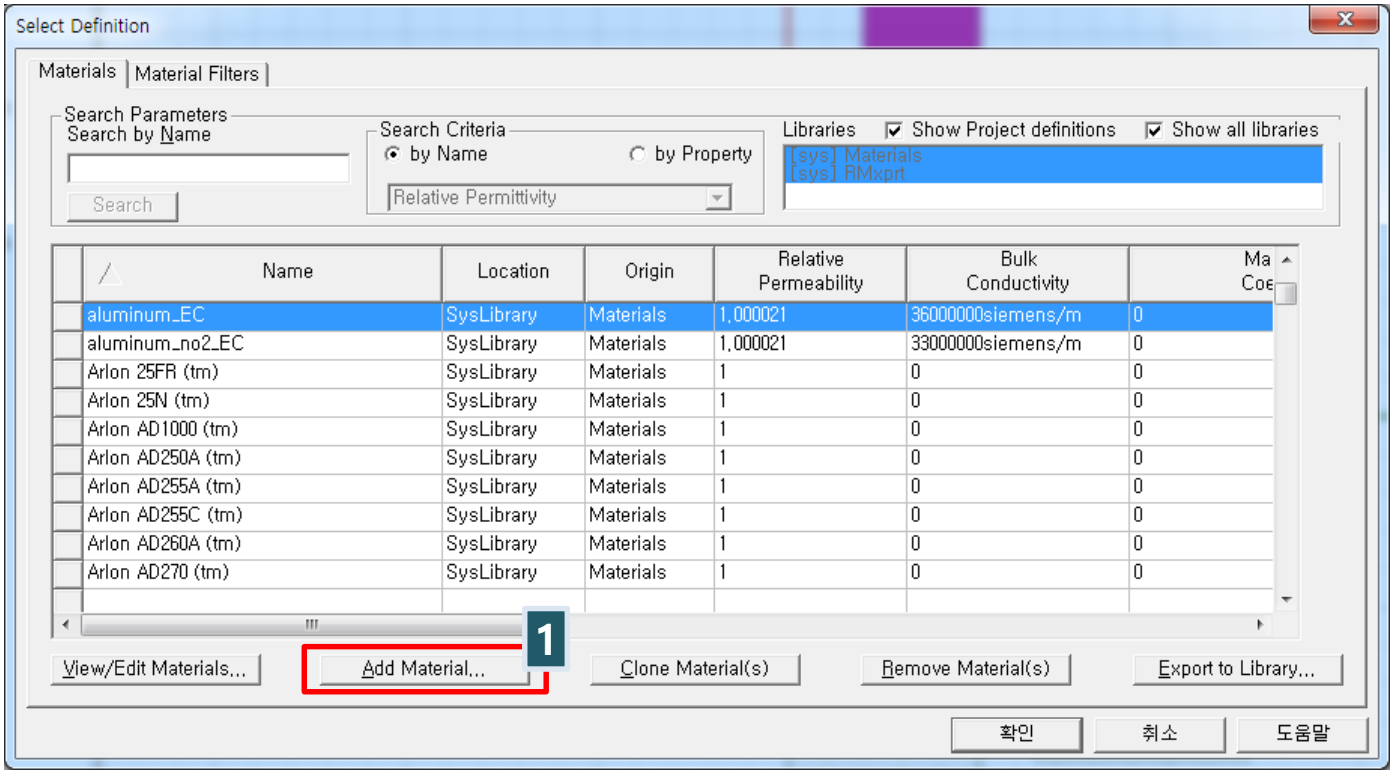
| Name | Value | Unit | Evalua |
|---|---|---|---|
| Name | core | | |
| Material | Edit... | | "Steel" |
| Solve Inside | ☑ | | |
| Orientation | Global | | |
| Model | ☑ | | |
| Display Wireframe | ☐ | | |
| Color | | | |
| Transparent | 0,8 | | |

Properties

| Name | Value | Unit | Eva |
|---|---|---|---|
| Name | plunger | | |
| Material | Edit... | | "Ste |
| Solve Inside | ☑ | | |
| Orientation | Global | | |
| Model | ☑ | | |
| Display Wireframe | ☐ | | |
| Color | | | |
| Transparent | 0 | | |

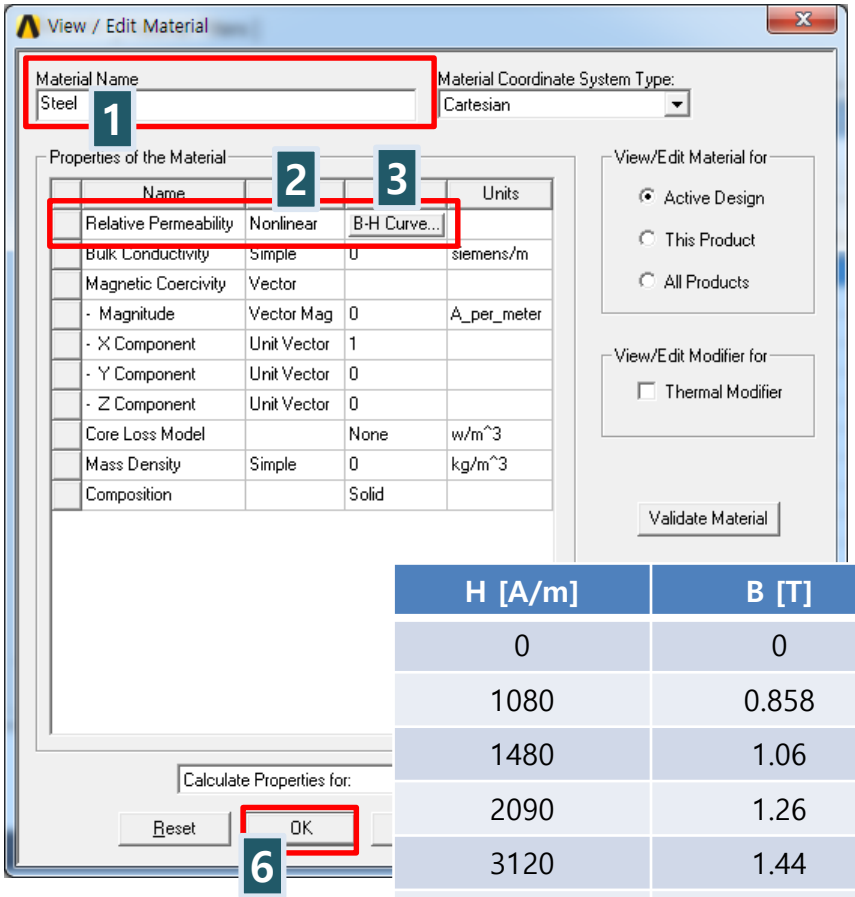
# Magnetostatic (Solenoid)

**“core”와 “plunger”의 재질은 Edit를 눌러서 아래 창을 띄웁니다.**



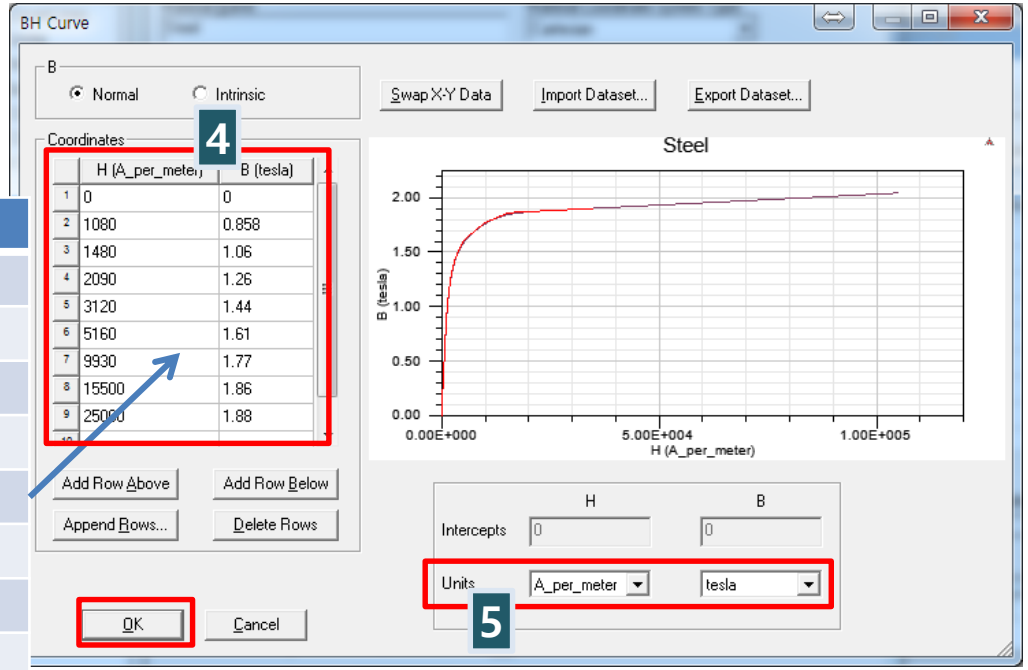

1. **Add Material... 클릭 (새로운 재질 생성)**

# Magnetostatic (Solenoid)




| H [A/m] | B [T] |
|---|---|
| 0 | 0 |
| 1080 | 0.858 |
| 1480 | 1.06 |
| 2090 | 1.26 |
| 3120 | 1.44 |
| 5160 | 1.61 |
| 9930 | 1.77 |
| 15500 | 1.86 |
| 25000 | 1.88 |
| 35000 | 1.9 |

1. Material Name : “steel”
2. Relative Permeability의 Type > Nonlinear 변경
3. B-H Curve… 클릭
4. 아래 테이블과 같이 BH값 입력
5. Units의 “A_per_meter”, “tesla” 확인 후 “OK”
6. 한번 더 “OK”



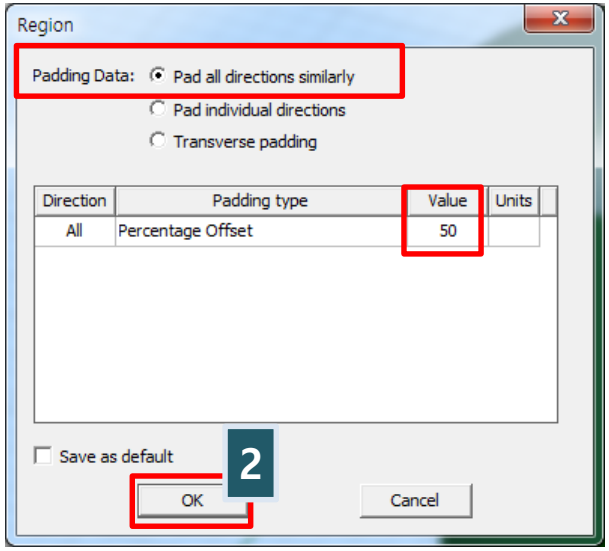
# Magnetostatic (Solenoid)

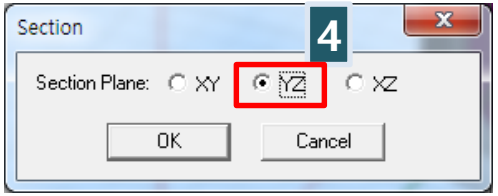
1. 상단메뉴 Draw > Region 클릭

2. Region
   Pad all direction simlarly 체크
   Value : 50
   “OK”

3. History tree > coil 우클릭 > Edit > Surface > Section 클릭

4. YZ 평면으로 “OK”



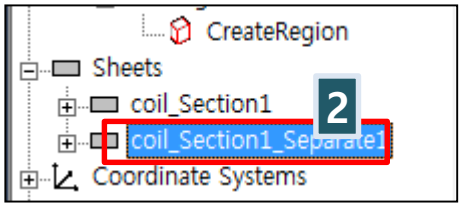
# Magnetostatic (Solenoid)

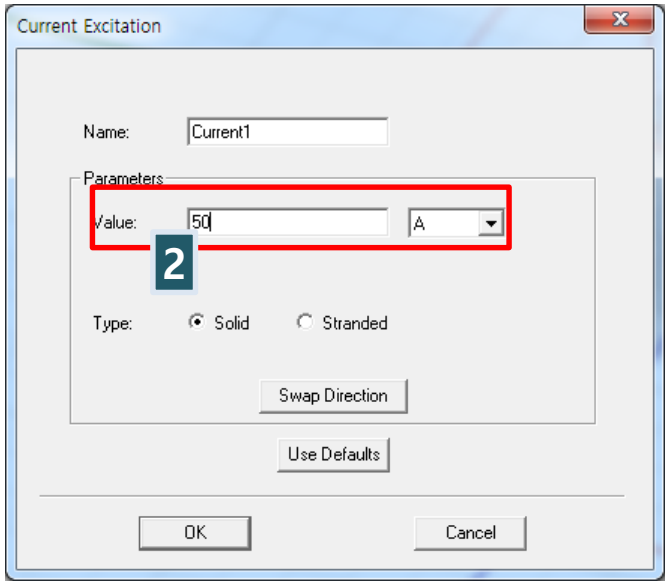
1. **Coil_section1 우클릭 > Edit > Boolean > Separate Bodies**

2. **Coil_Section1_Separate1 > Delete!**

3. **Coil_section1 우클릭 > Assign Excitation > Current.. 클릭**

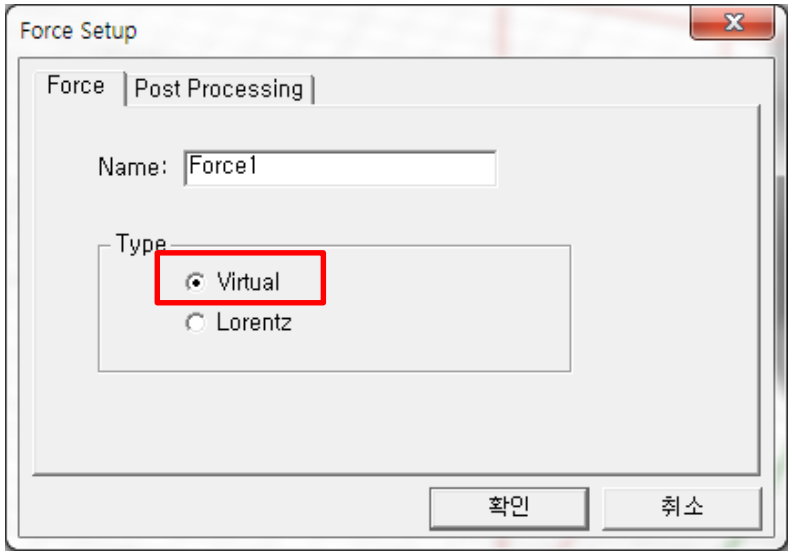
4. **Current Excitation**
   **> Value : 50A**
   **> Type : Solid**
   **> "OK"**

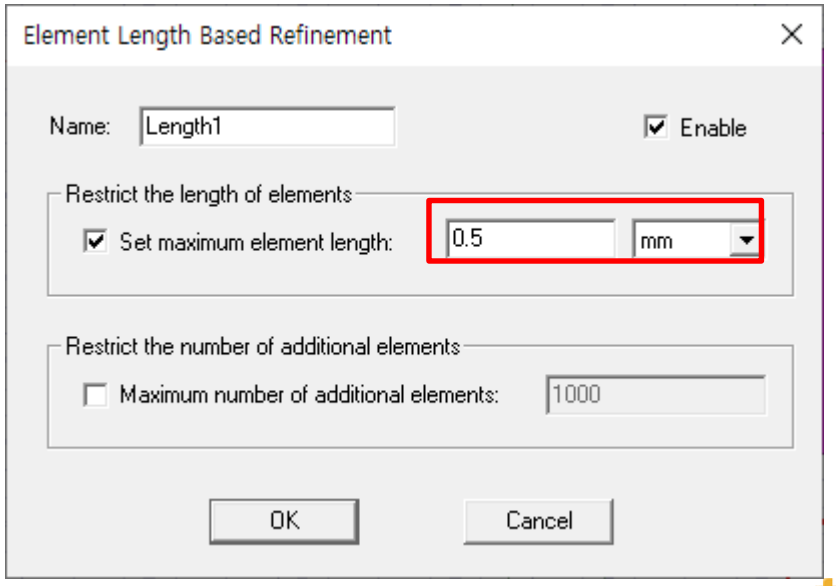


# Magnetostatic (Solenoid)

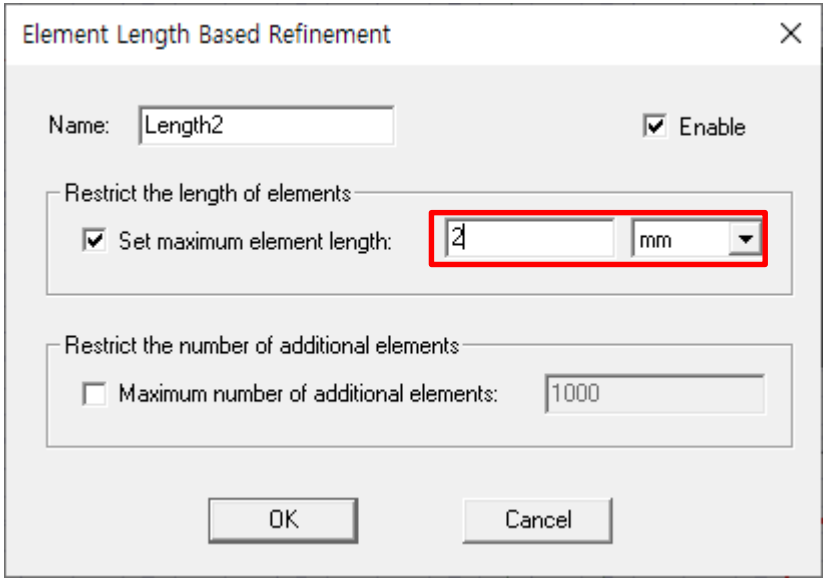
1. History tree에서 plunger 우클릭 > Assign Parameters > Force 클릭
2. 다른 설정 필요 없이 “확인”
3. Core와 Plunger Ctrl로 같이 우클릭 > Assign Mesh Operation > Inside Selection > Length Based
4. > Maximum Length of Elements : 0.5mm
   > “OK”

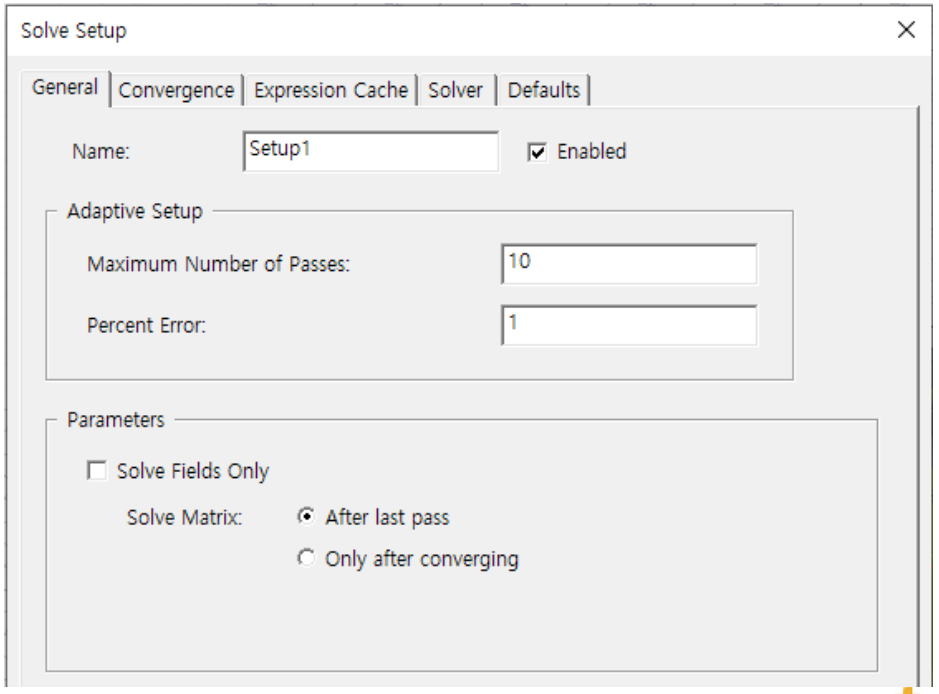


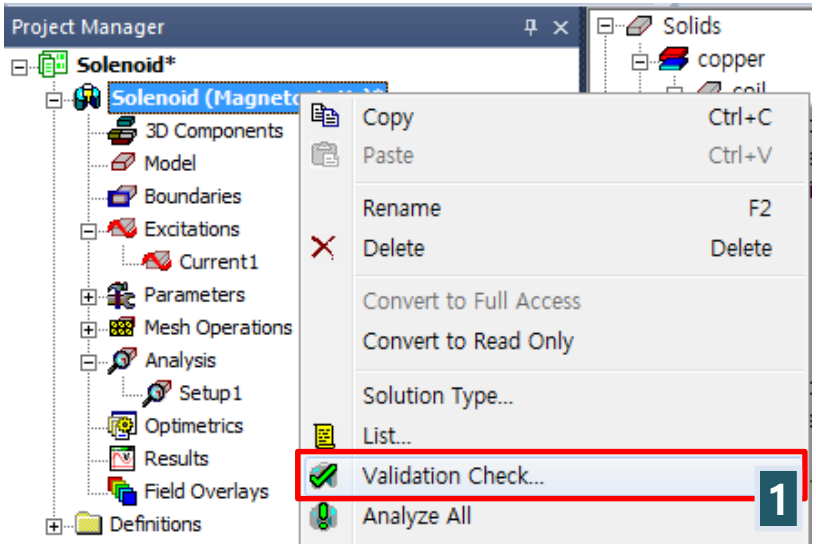
# Magnetostatic (Solenoid)

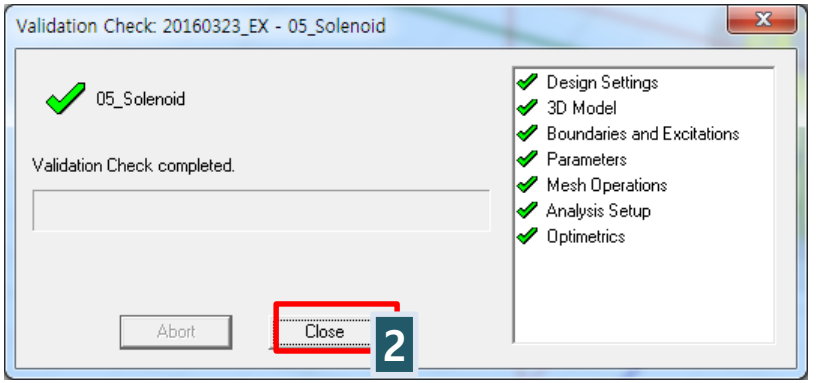
1. **Coil 우클릭 > Assign Mesh Operation > Inside Selection > Length Based 클릭**
2. **Maximum Length of Elecments : 2mm**
   **"OK"**
3. **상단메뉴 Maxwell 3D > Analysis Setup > Add Solution Setup 클릭**
4. **Solve Setup > 다른 설정 없이 "확인"**

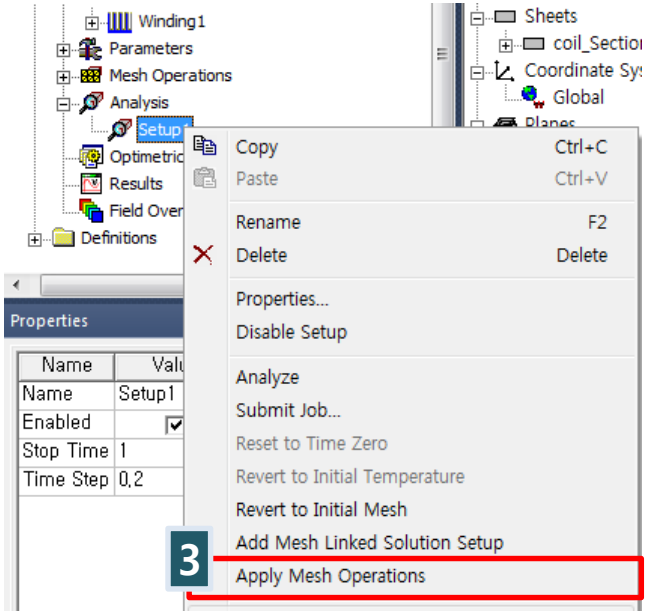


# Magnetostatic (Solenoid)



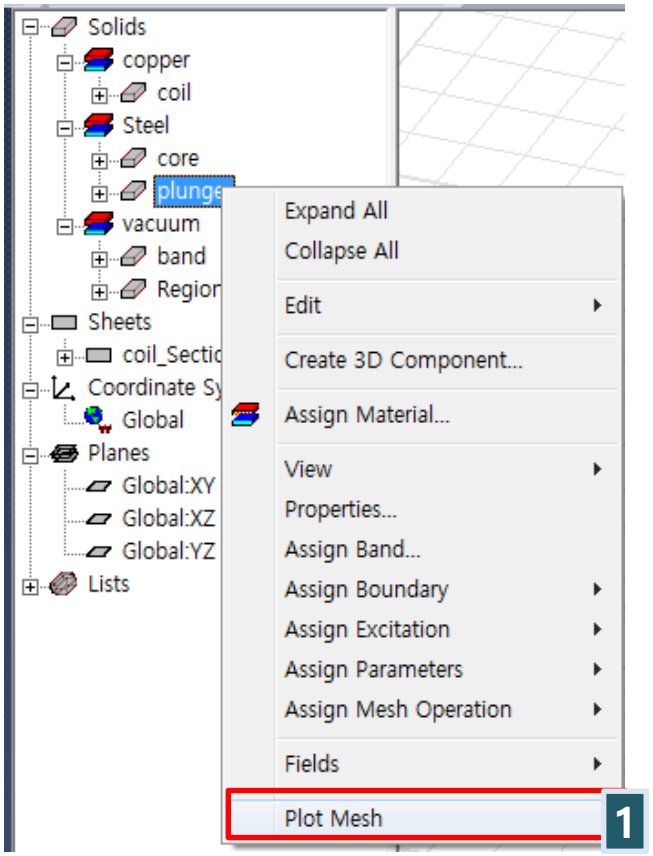



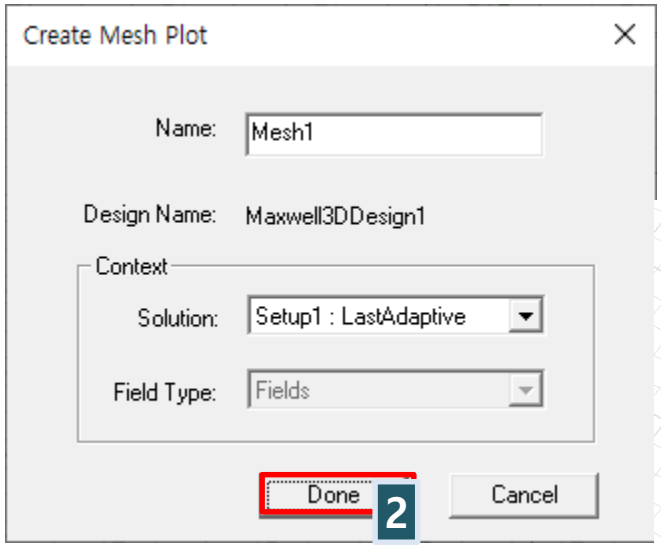

1. **Project Manager > Solenoid 우클릭 > Validation Check...** (현재 모델 이상유무 확인)

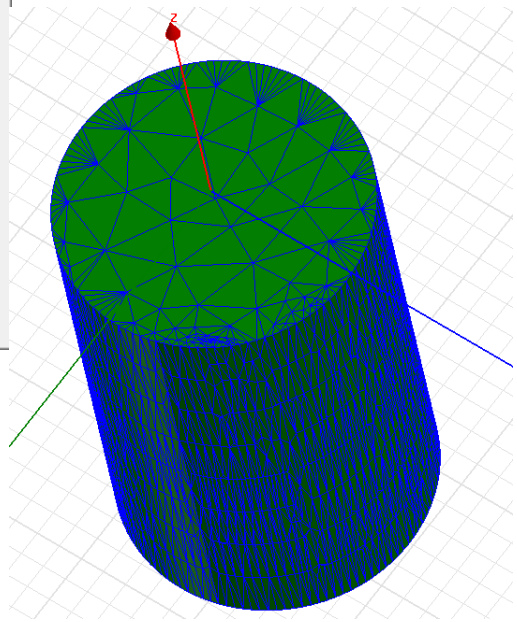
2. **Error 없으면 "Close"**

3. **Analysis > Setup1 우클릭 > Apply Mesh Operations** (Mesh 분포 확인)

# Magnetostatic (Solenoid)



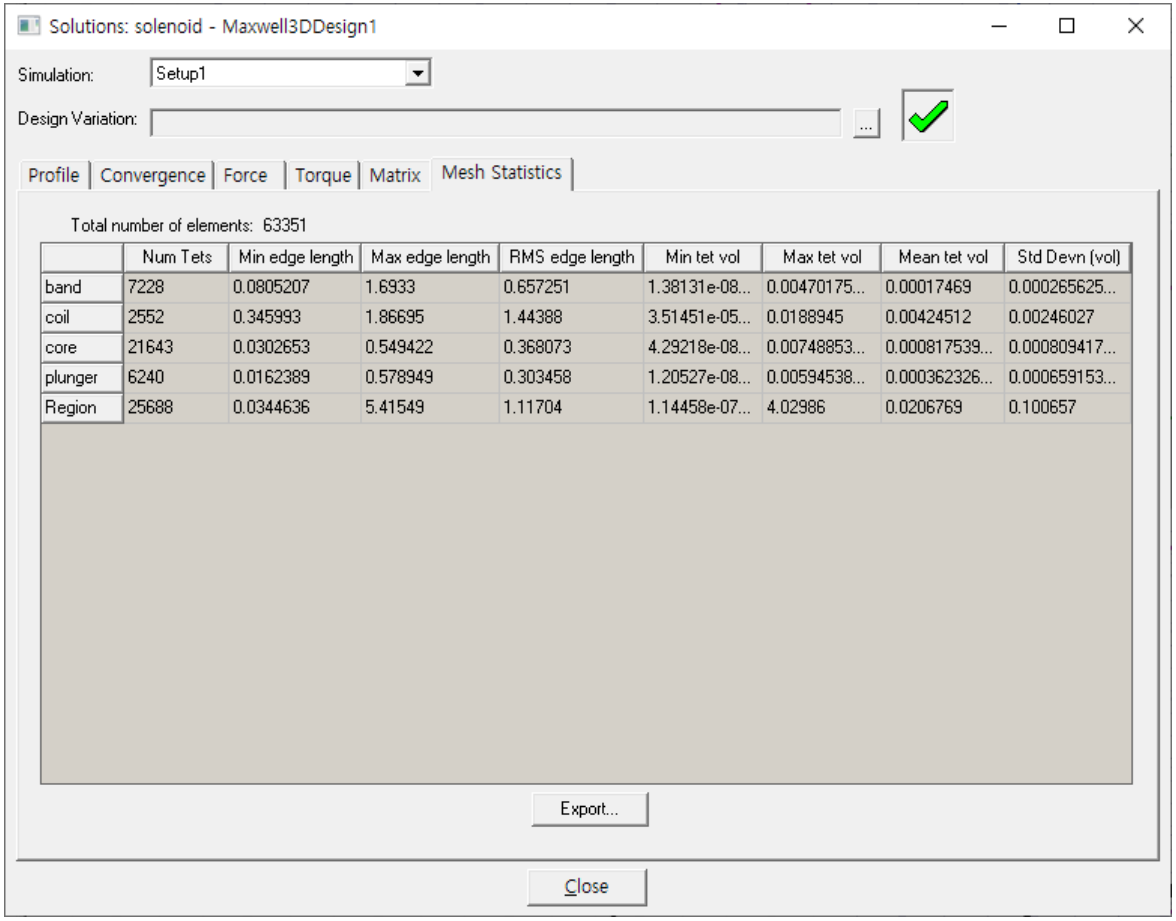



1. **History tree > Plunger 우클릭 > Plot Mesh 클릭**
2. **"Done"** (View 기능을 통해서 다른 모델들은 숨기고 보면 편리함.)

# Magnetostatic (Solenoid)

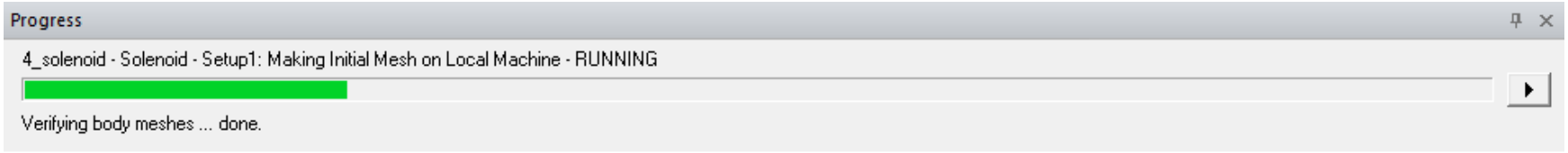
1. 상단 메뉴 Maxwell 3D > Results > Solution data 클릭

2. Mesh Statistics 탭 > Total number of elements : 63,351개



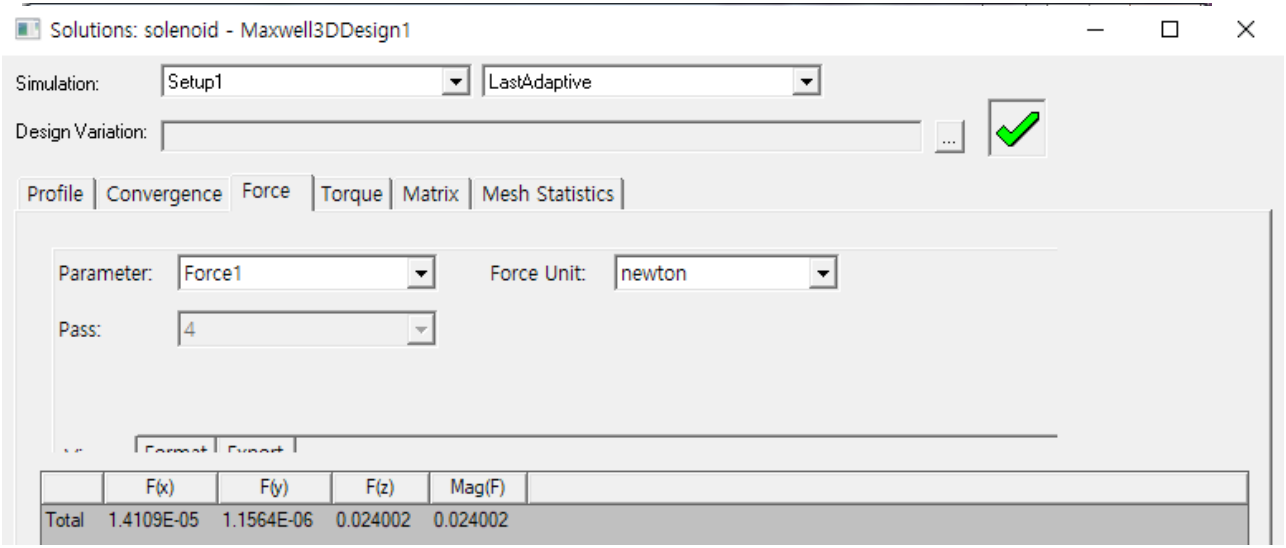
# Magnetostatic (Solenoid)

1. **Project Manager > Solenoid > Analysis > Setup1 우 클릭 > Analyze 클릭**



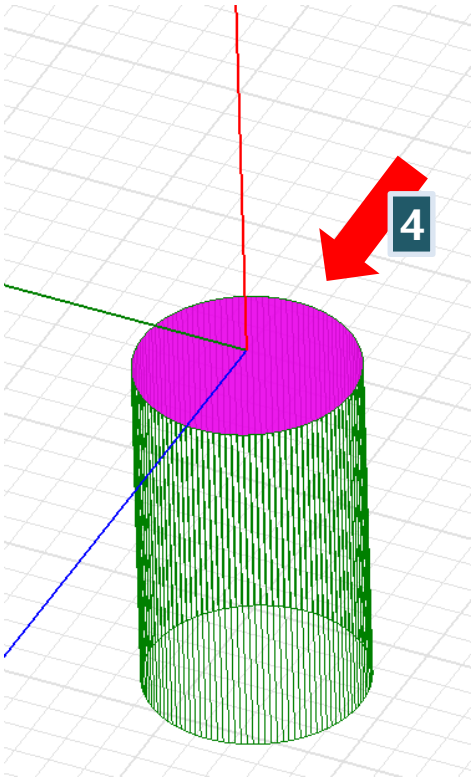

2. **상단 메뉴 Maxwell 3D > Results > Solution data 클릭**

3. **Force 탭 > plunger가 받는 힘 F(z) = 0.024 N**

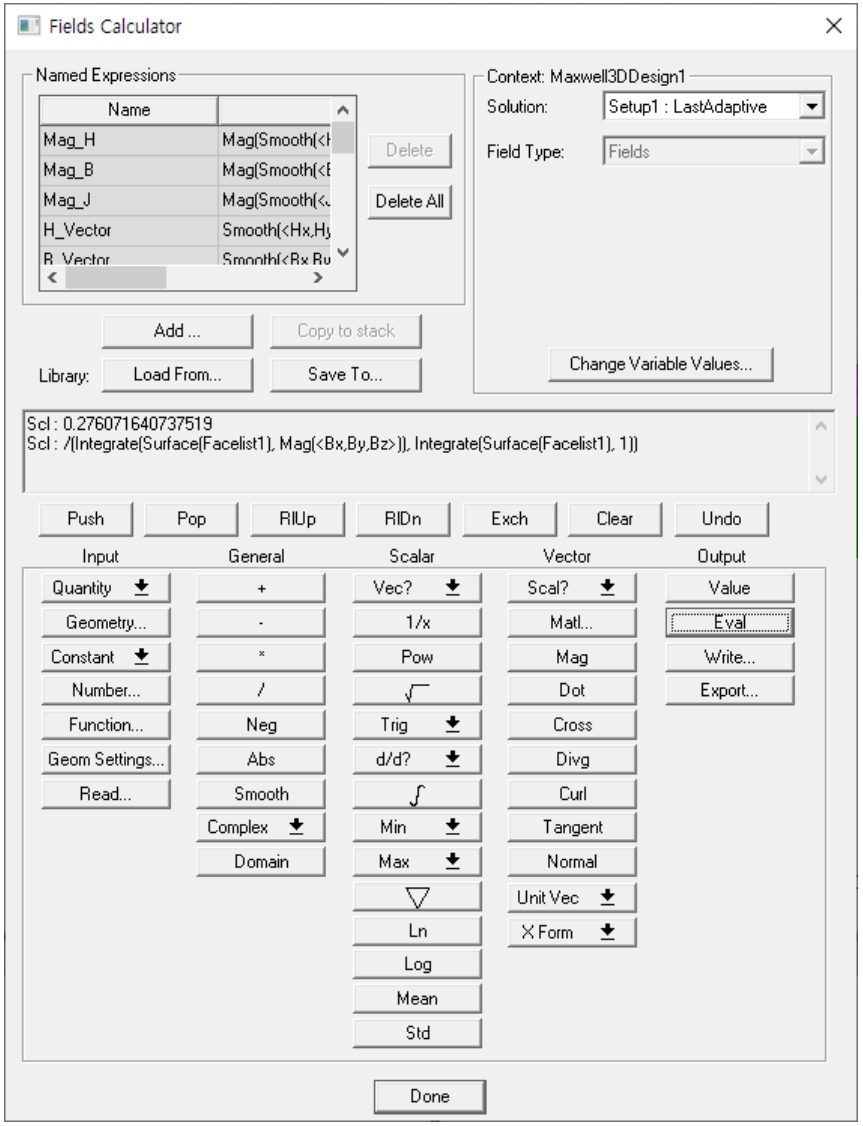


# Magnetostatic (Solenoid)

1. History tree > Plunger 클릭
2. 상단 메뉴 View > Visibility > Show Only Selection > Active View
3. 상단 메뉴 Edit > Selection Mode > Faces
4. plunger의 +Z축 위 표면 선택
5. 상단 메뉴 Modeler > List > Create > Face List
6. 상단 메뉴 Maxwell 3D > Fields > Calculator...



# Magnetostatic (Solenoid)



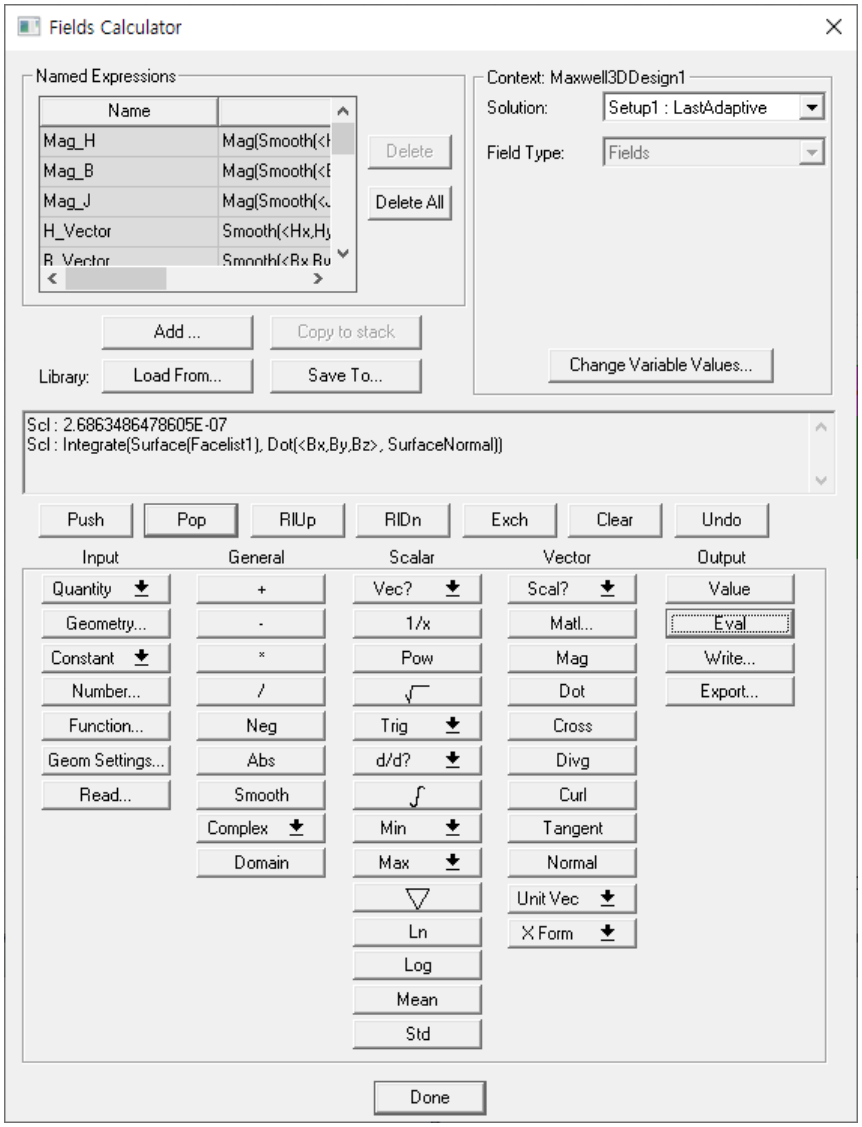

1. Input > Quantity > B
2. Vector > Mag
3. Input > Geometry > Surface > Facelist1 선택
4. Scalar > ∫ Integrate
5. Input > Number > Scalar > Value : 1 > OK
6. Input > Geometry > Surface > Facelist1 선택
7. Scalar > ∫ Integrate
8. General > / (Divide)
9. Output > Eval

$$B_{avg} = \frac{\iint B dS}{\iint 1 dS}$$

Scl : 0.276071640737519
Scl : /(Integrate(Surface(Facelist1), Mag(<Bx,By,Bz>)), Integrate(Surface(Facelist1), 1))

B_avg = 0.276 [T]

# Magnetostatic (Solenoid)



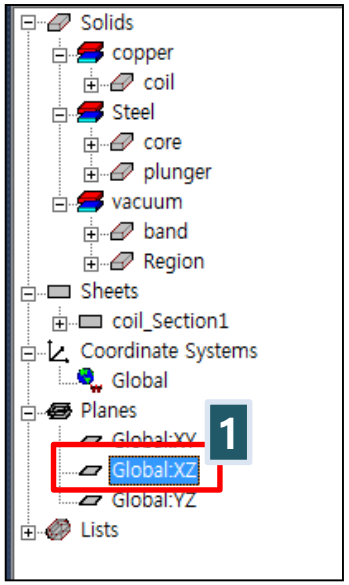

1. **Input > Quantity > B**
2. **Input > Geometry > Surface > Facelist1 선택**
3. **Vector > Normal**
4. **Scalar > ∫ Integrate**
5. **Output > Eval**

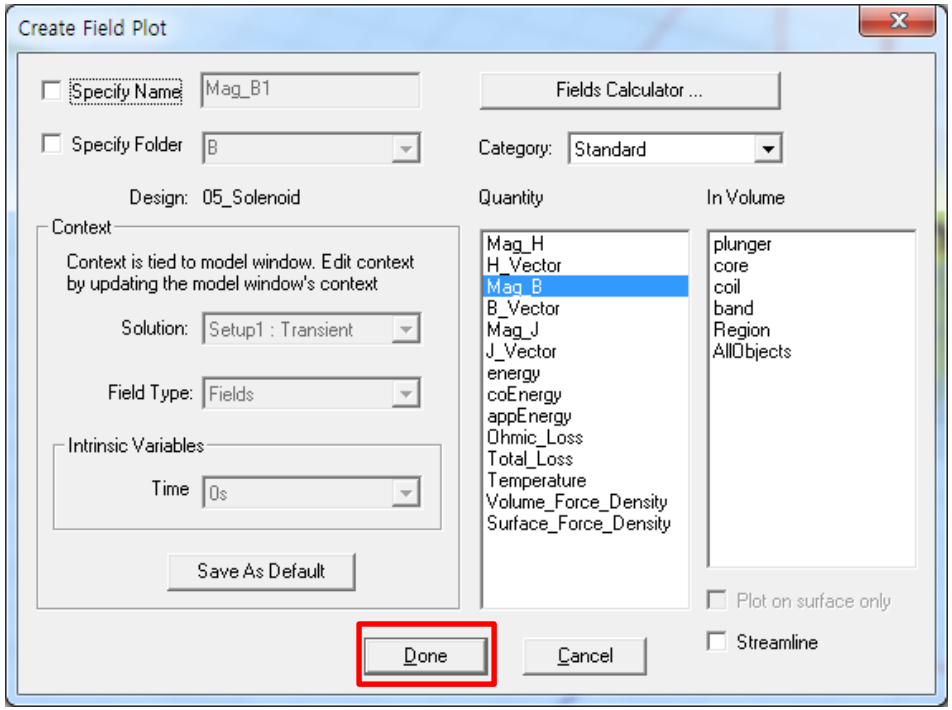
Scl : 2.6863486478605E-07
Scl : Integrate(Surface(Facelist1), Dot(<Bx,By,Bz>, SurfaceNormal))

**Magnetic Flux = 2.686*e(-07) Wb**

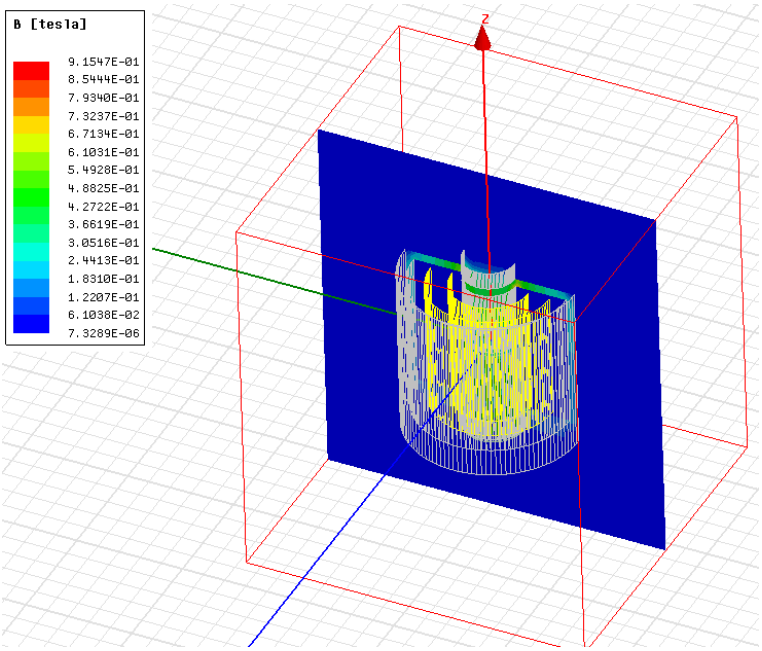
# Magnetostatic (Solenoid)

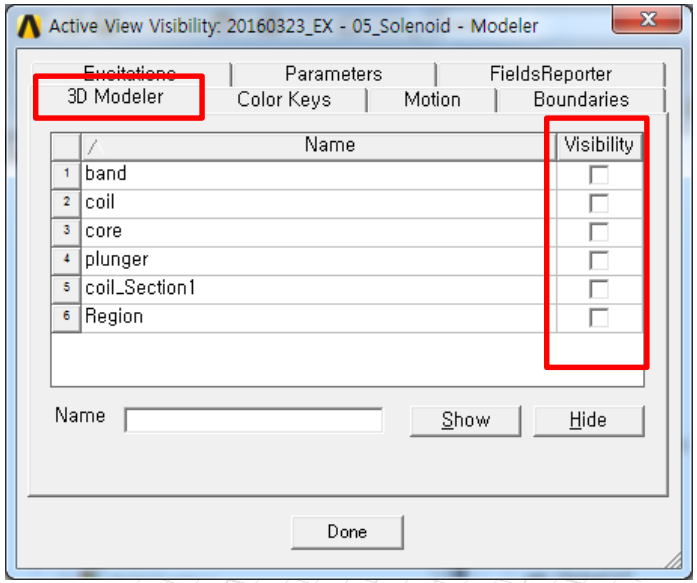
1. History tree > Planes > Global:XZ 선택
2. 상단메뉴 Maxwell 3D > Fields > Fields > B > Mag_B
3. “Done”

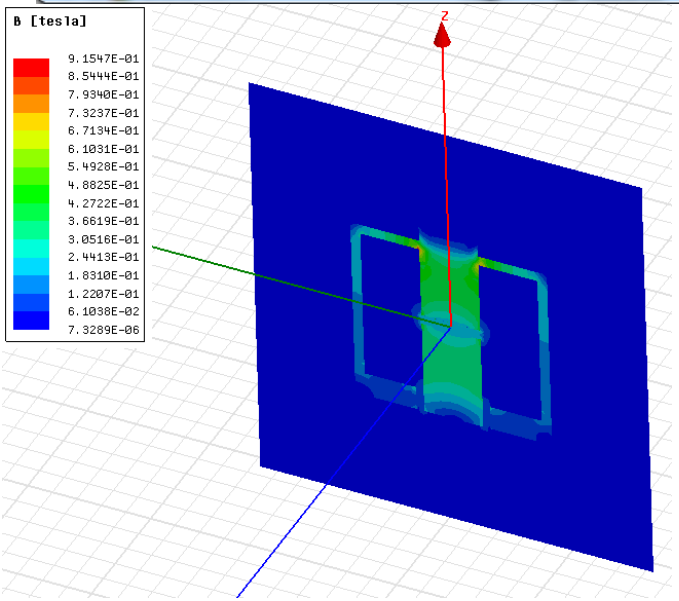


# Magnetostatic (Solenoid)

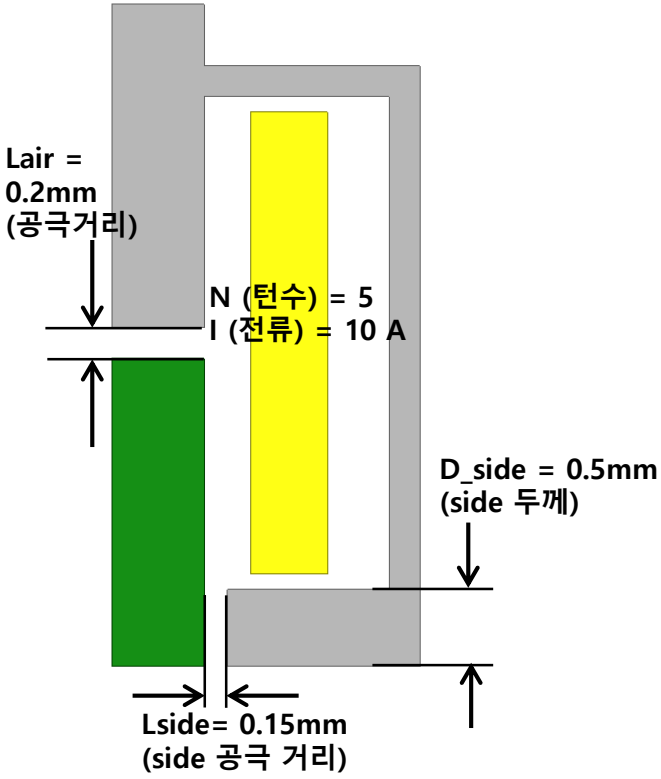


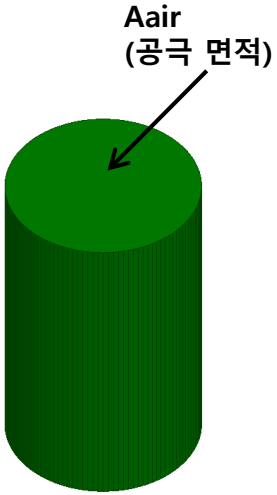



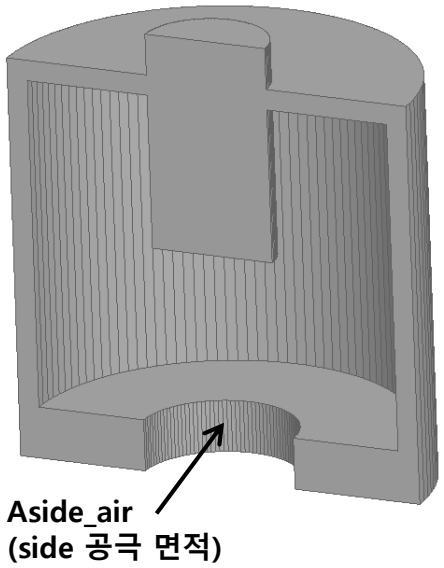




1. 도형때문에 자속분포가 잘 안보이면 View 기능을 통해서 모두 숨기고 보면 자속 분포만 볼 수 있음.

# Magnetostatic (Solenoid)




**Maxwell에서 출력된 값**

**Φ = 2.686*10^(-7) [Wb]**
**B = 0.276 [T]**
**F = 0.024 [N]**

$$R_m = R_{airgap} + R_{side\,gap}$$

$$R_{airgap} = \frac{L_{air}}{\mu_0 * A_{air}}$$

$$R_{side\,gap} = \frac{L_{side}}{\mu_0 * A_{side\_air}}$$

$$A_{air} = \pi * r^2$$

$$A_{side\_air} = 2 * \pi * r * D_{side}$$

$$\Phi = \frac{NI}{R_m} = \frac{10*5}{1.91*10^8} = 2.61*10^{(-7)}[\mathrm{Wb}]$$

$$B_{avg} = \frac{\Phi}{A_{air}} = \frac{2.61*10^{(-7)}}{1.131*10^{(-6)}} = 0.231[\mathrm{T}]$$

$$F_{plunger} = \frac{B^2 * A_{air}}{2 * \mu_0} = 0.024[\mathrm{N}]$$

감사합니다.