

인덕션 히팅 해석의 최신 기술 (Induction Heating)

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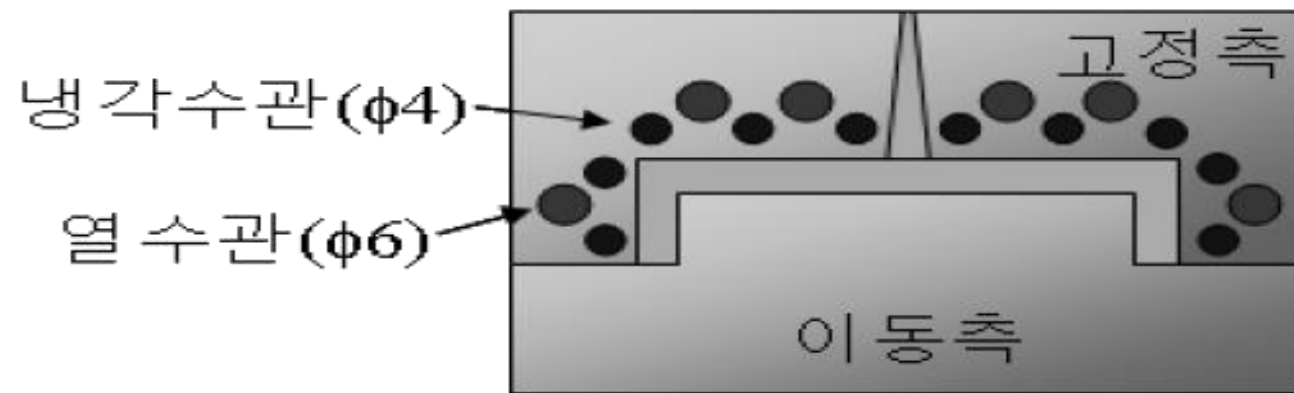
Induction Heating & RHCM(Steam해석)

- 급열급냉(Rapid Heat & Cool Molding)의 이란?
- **RHCM** 공정의 기본 원리는 수지가 금형 내부로 주입이 될 때 **금형 온도를 급속 가열하여** 열변형 온도 이상을 유지하고, **보압 및 냉각 공정**에서는 제품의 고화를 촉진하기 위하여 **금형의 온도를 급격히 떨어뜨리는 방식**이다.
- 주요 목적은 **제품의 외관 특성(웰드라인, 고광택)을 개선**하고자 하는 성형가공 기술이다.

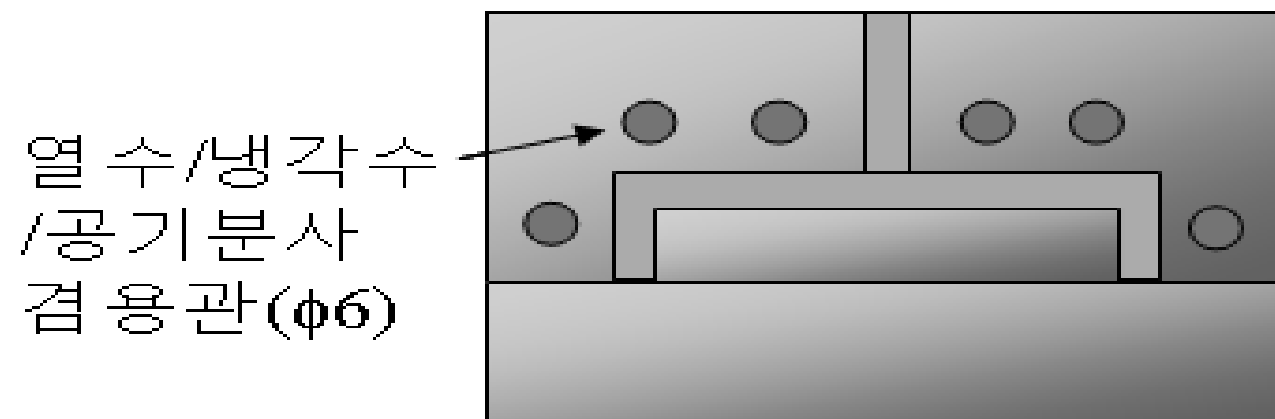
Induction Heating & RHCM(Steam해석)

- 급열급냉(Rapid Heat & Cool Molding)의 종류

RHCM (Rapid Heat & Cool Molding)



열수관과 냉각수관이 분리 열효율측면에서 매우 비효율적

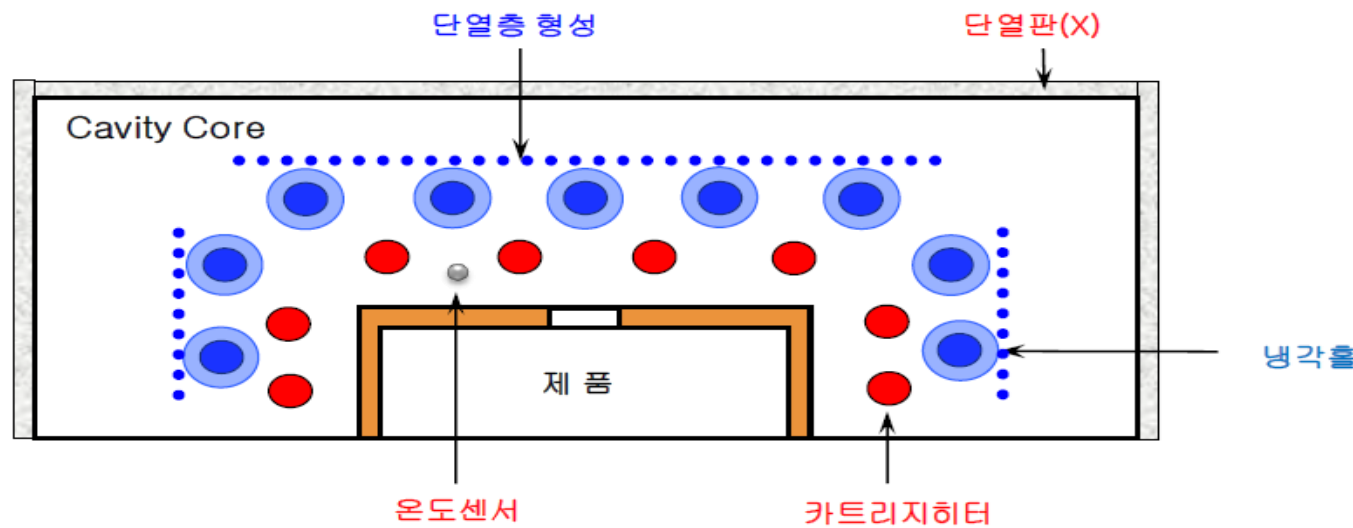


열수/냉각수/공기분사 검용관을 이용 - Moldflow RHCM 해석

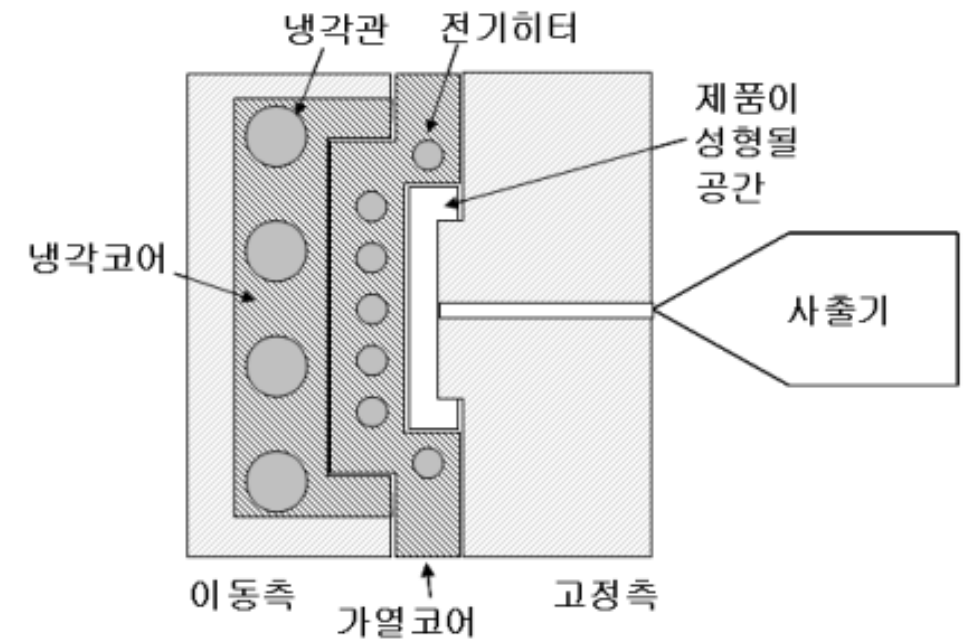
Induction Heating & RHCM(Steam해석)

- 급열급냉(Rapid Heat & Cool Molding)의 종류

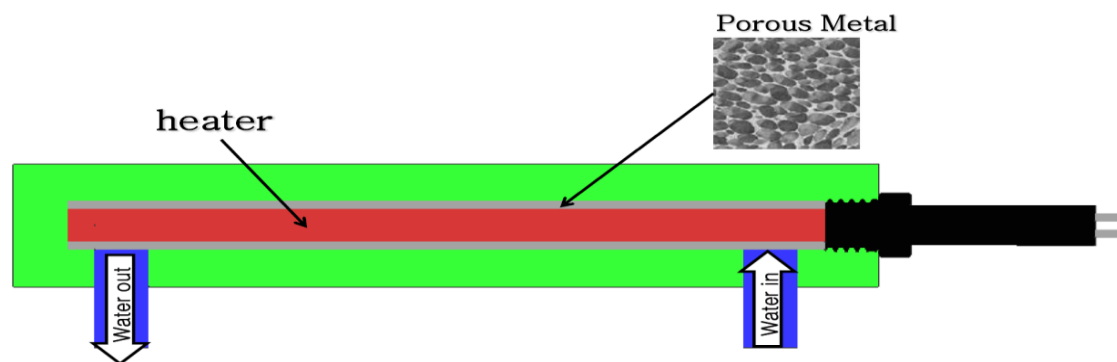
Electricity RHCM Mold



E-Mold



F-Mold



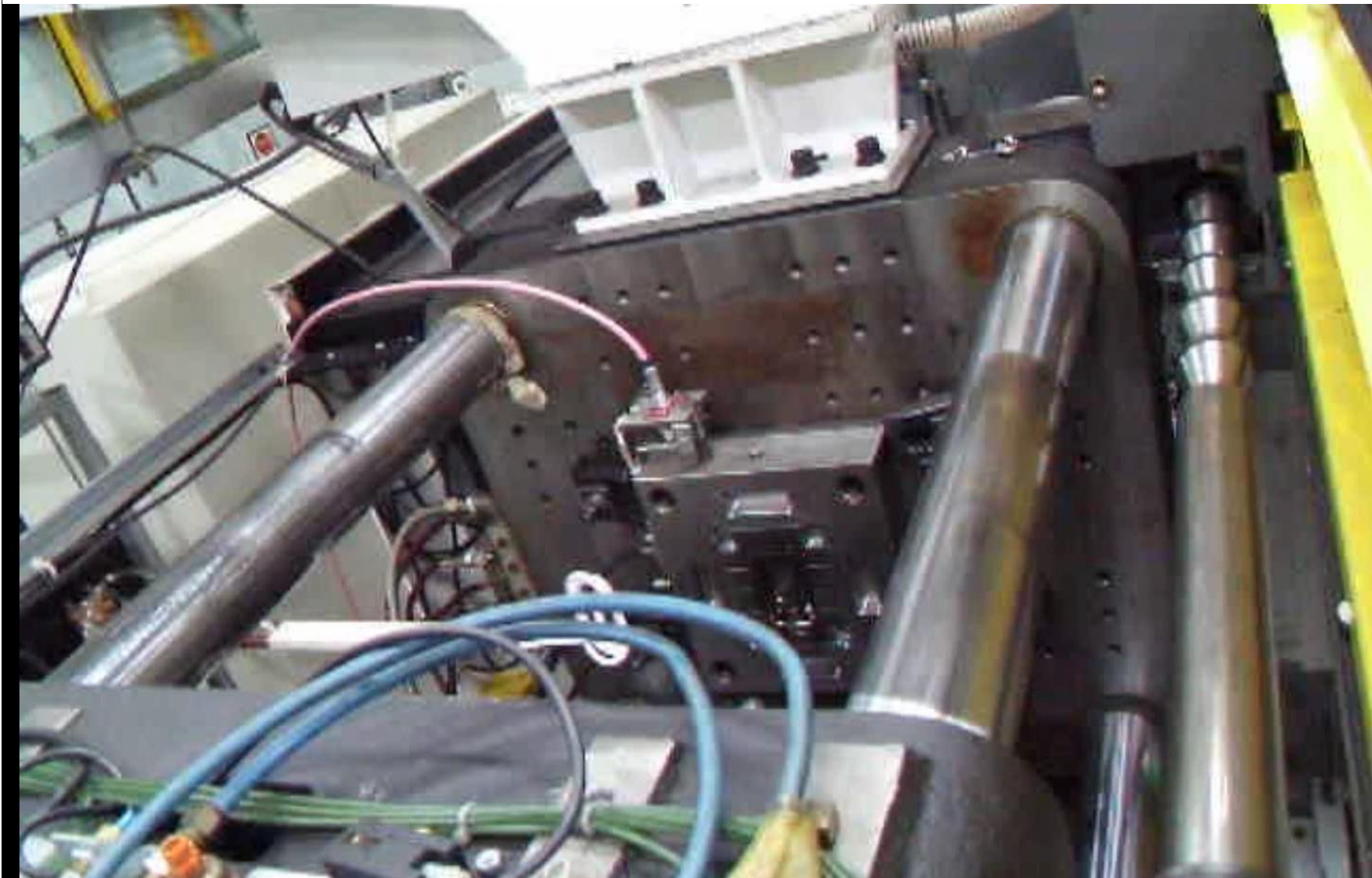
Induction Heating & RHCM(Steam해석)

- Induction Heating 소개



Induction Heating & RHCM(Steam해석)

- Induction Heating 소개



<http://www.hl-hf.com/index.htm>

목표

At the end of this class, you will be able to:

- Induction Heating 해석 방법을 익힘
 - 전기저항력의 개념은 알게 됨.
 - 투자율 or 상대투자율의 개념을 알게 됨.
- Induction Heating의 해석결과 확인

Induction Heating 소개

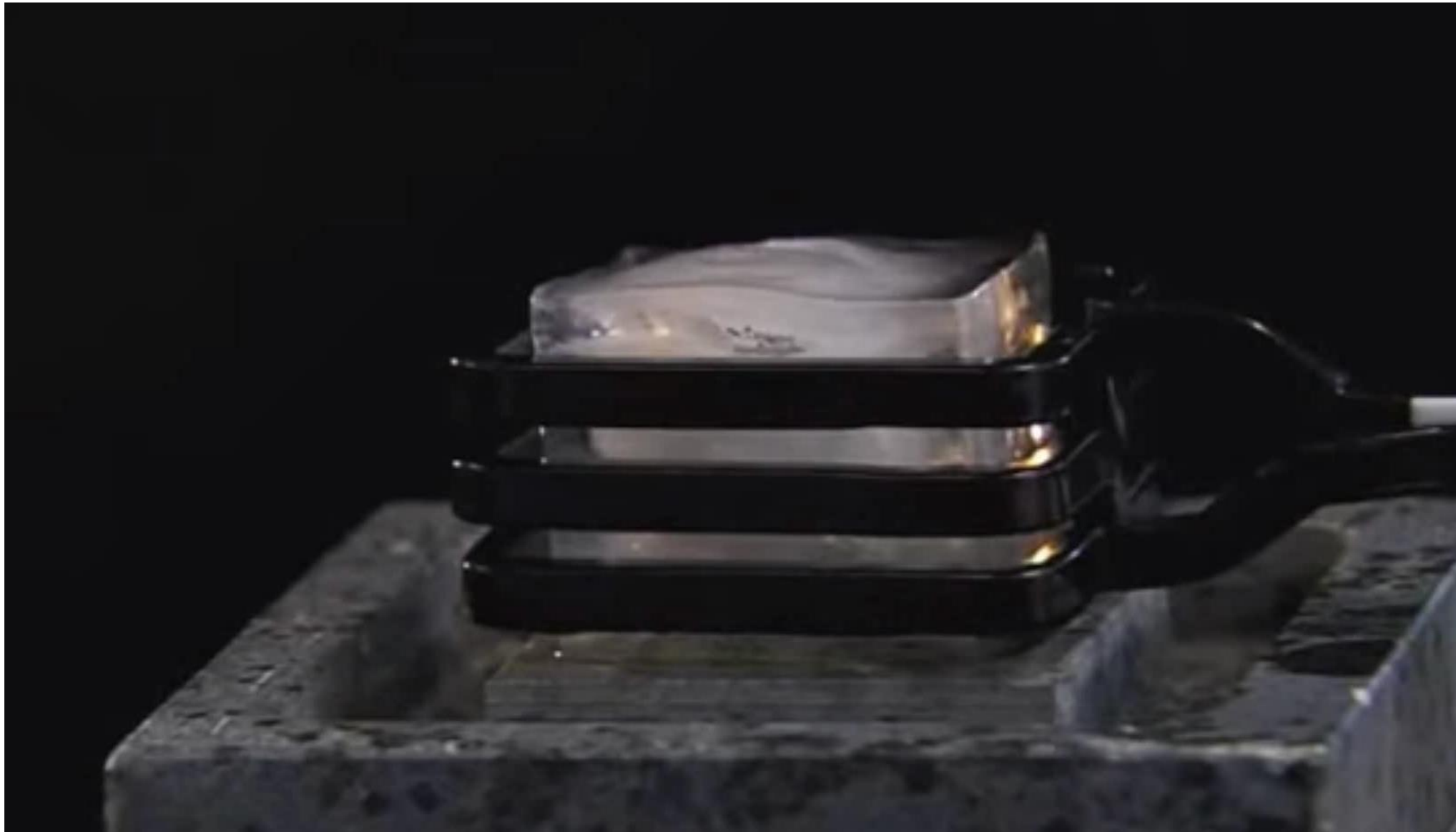
Induction Heating 해석 소개

1. Induction Heating 의 예



Induction Heating 해석 소개

1. Red-hot ice cube by induction heating



DESK.

ing
pecialized
pecialized

Product Support Specialized
Authorized Developer
Authorized Certification Center
Authorized Training Center

Induction Heating 해석

Induction Heating 해석 이론

1. Electrical 이란?

Electrical resistivity of material(단위: ohm-m)

재료의 전기저항률: 단위 길이를 갖는 물체 또는 어떤 물체의 단위 용적(1cm³)의 전기저항

Relative magnetic permeability of material

재료의 상대 투자율

Mold material

Description Thermal Mechanical **Electrical**

Electrical resistivity of material ohm-m [0:1e+020]

Relative magnetic permeability of material [0:1e+020]

Name

OK Cancel Help

Induction Heating 해석 이론

1. 재료의 전기저항률(Electrical resistivity of material)이란?

어떤 물체가 전기를 흐름성을 비교하기 위한 물성수치(단위: Ωm)

→ 전기저항률이 낮을수록 전기는 흐르기 쉽다.

금속

Metals (Ωm)

- Steel, low carbon $142e^{-8}$
- Titanium $42.0e^{-8}$
- Platinum $10.60e^{-8}$
- Nickel $6.84e^{-8}$
- Aluminum $2.65e^{-8}$
- Gold $2.35\sim 2.65e^{-8}$
- Copper $1.67\sim 2.65e^{-8}$
- Silver $1.59e^{-8}$

반도체

Semiconductors

- GaAs
- Silicon (pure)
- Silicon (.0025 ohm-cm)
- Silicon Dioxide (amorphous)
- Silicon Nitride .16 - .33
- Silicon Carbide

절연체

Insulators

- Air
- Diamond
- Epoxy
- Glass
- water
- Liquid Nitrogen(77K)
- Liquid Argon(85K)

전기저항률참고: http://www.reade.com/Particle_Briefings/elec_res.html

<http://www.matweb.com/>

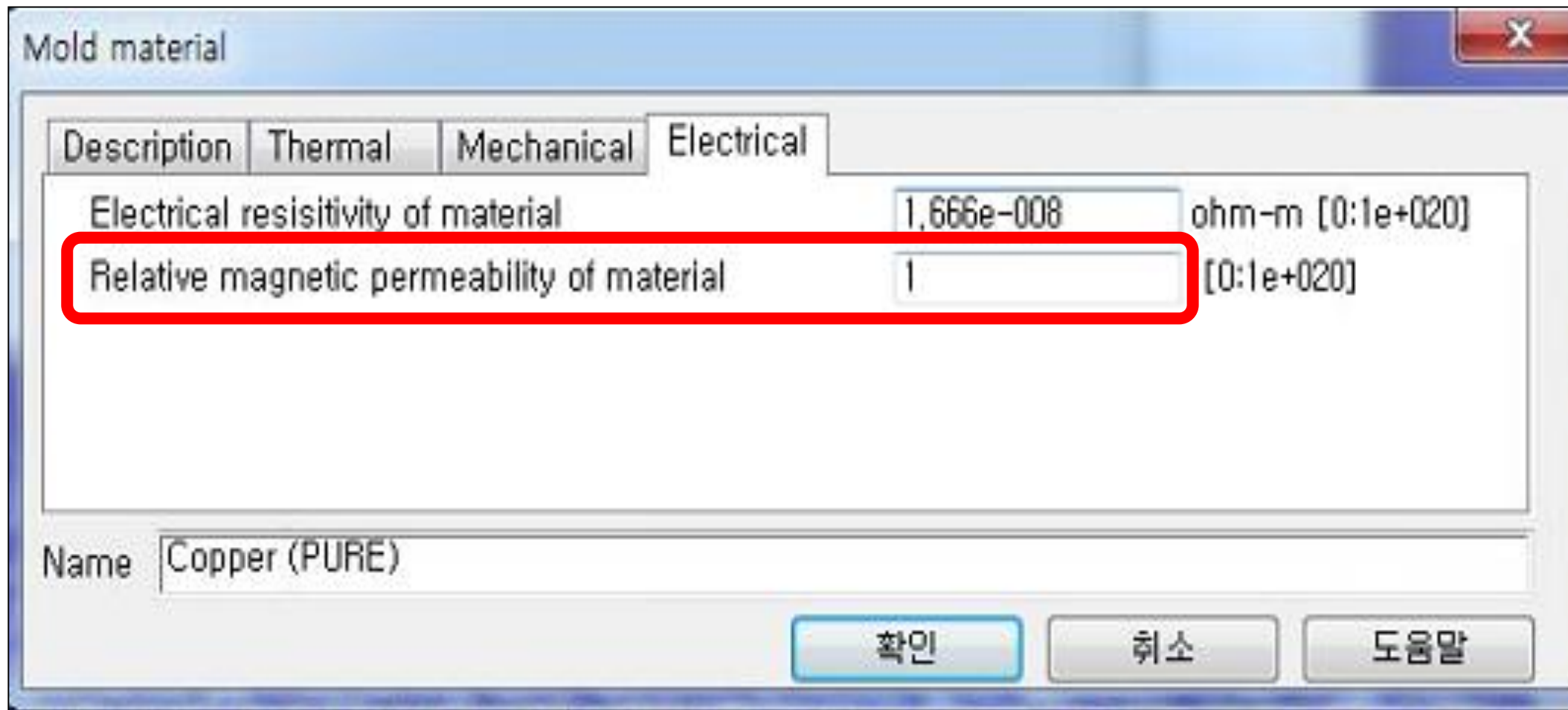
Induction Heating 해석 이론

1. 재료의 상대 투자율

(Relative magnetic permeability of material)?

magnetic permeability = 투자율 = 透 투과하다(투) 磁 자석(자) 率 비율(율)

상대 투자율 μ_r = 물질의 투자율 μ / 진공의 투자율 μ_0



Induction Heating 해석 이론

1. 재료의 상대 투자율

(Relative magnetic permeability of material)?

상대 투자율 = 물질의 투자율 / 진공의 투자율

물질 투자율

물질의 자기적 성질을 나타내는 양
물질의 종류에 따라 달라진다.

강자성체 > 1 (철, 코발트, 니켈 종류의 원소 또는 합금)

상자성체 = 1 (산화알루미늄...)

반자성체 < 1 (구리, 안티몬, 물...)

진공 투자율

물질이 진공 환경에서 자기적 성질을 나타내는 양

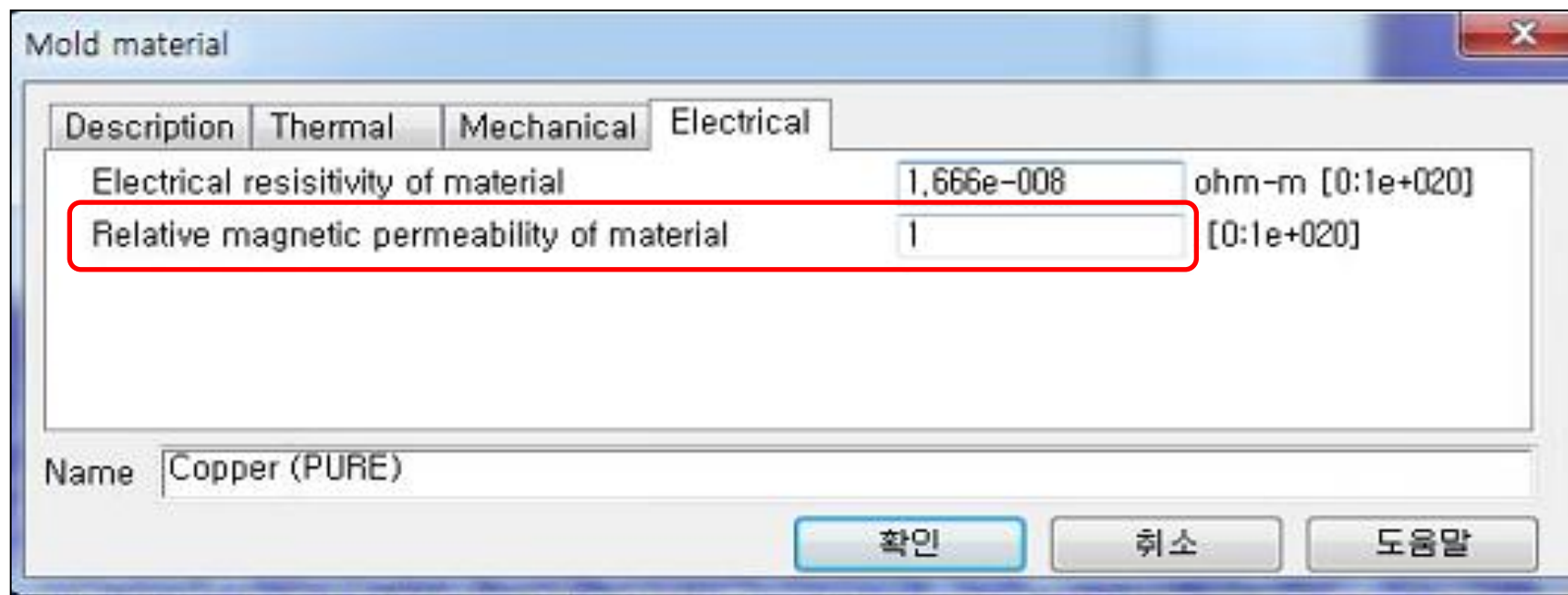
매우 작은 값으로 거의 0에 가깝다. ($\mu_{\text{진공}} = 4\pi \times 10^{-7} \approx 1.26 \times 10^{-6} \text{ H}\cdot\text{m}^{-1}$)

자기장: 자석이나 전류, 변화하는 전기장 등의 주위에 자기력이 작용하는 공간.

Induction Heating 해석 이론

1. 재료의 상대 투자율

(Relative magnetic permeability of material)?



이하

$1.2566368 \times 10^{-6} \text{ H}\cdot\text{m}^{-1}$)

$$\begin{aligned} \text{구리의 상대 투자율} &= \frac{\text{순수 구리의 투자율}(\text{H}\cdot\text{m}^{-1})}{\text{진공의 투자율}(\text{H}\cdot\text{m}^{-1})} \\ &= \frac{1.2566368 \times 10^{-6}}{4\pi \times 10^{-7}} = 0.999999791955 \approx 1 \end{aligned}$$

자기장의 세기 H [단위(A/m)]

재료의 투자율 확인 : [http://en.wikipedia.org/wiki/Permeability_\(electromagnetism\)](http://en.wikipedia.org/wiki/Permeability_(electromagnetism))

자기장: <http://ko.wikipedia.org/wiki/%EC%9E%90%EA%B8%B0%EC%9E%A5> 16

Induction Heating 해석 이론

1. 재료의 상대 투자율

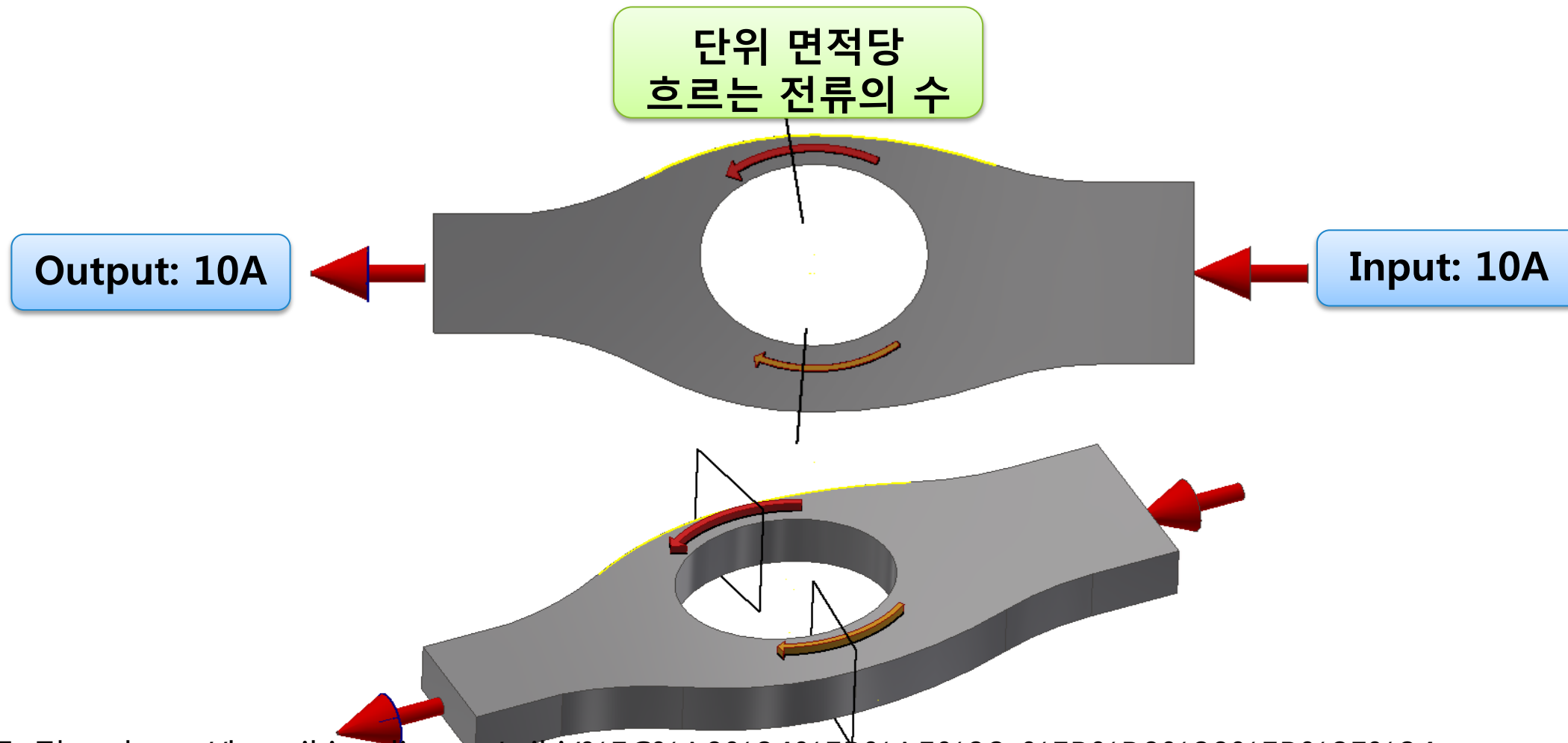
(Relative magnetic permeability of material)?

자력선속밀도: 단위 면적을 수직으로 지나가는 자기력선의 수, 이를 자속밀도

$Wb/m^2 = N/(Am)$ [단위: 국제단위계 가우스(G), CGS 테슬라(T)]

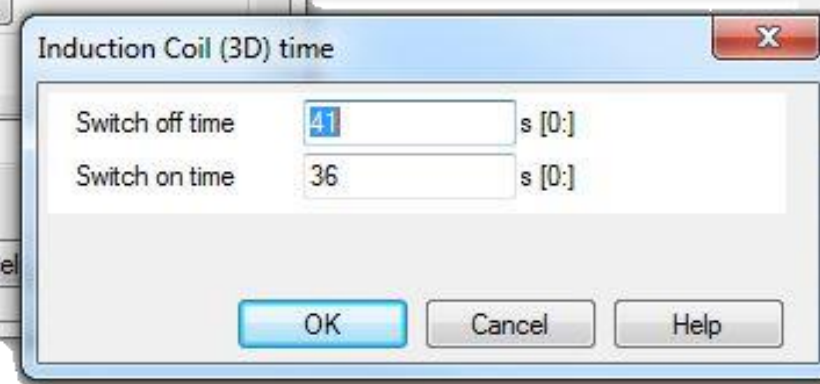
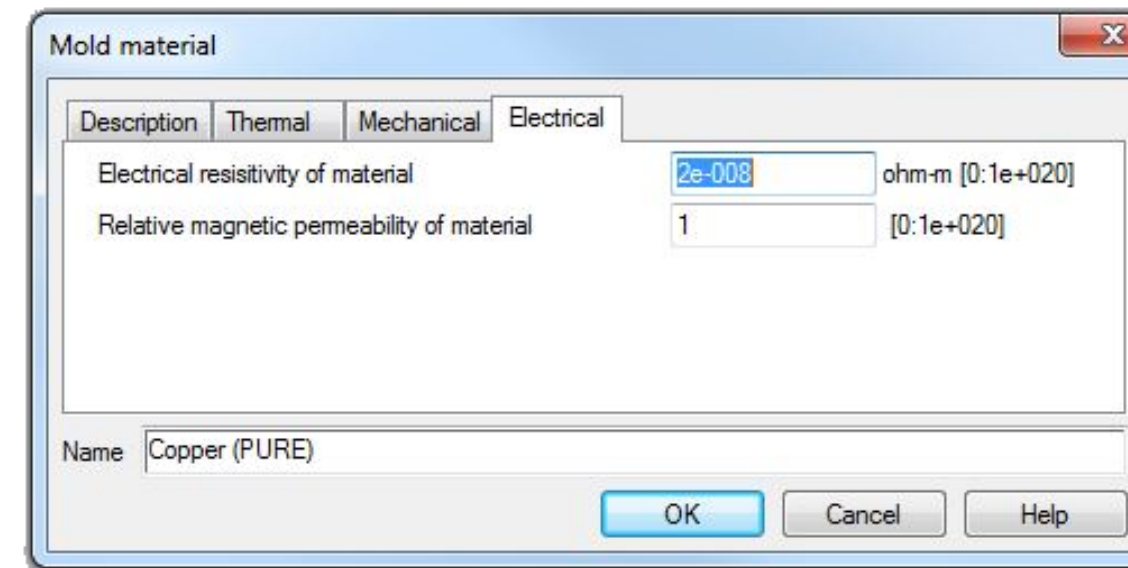
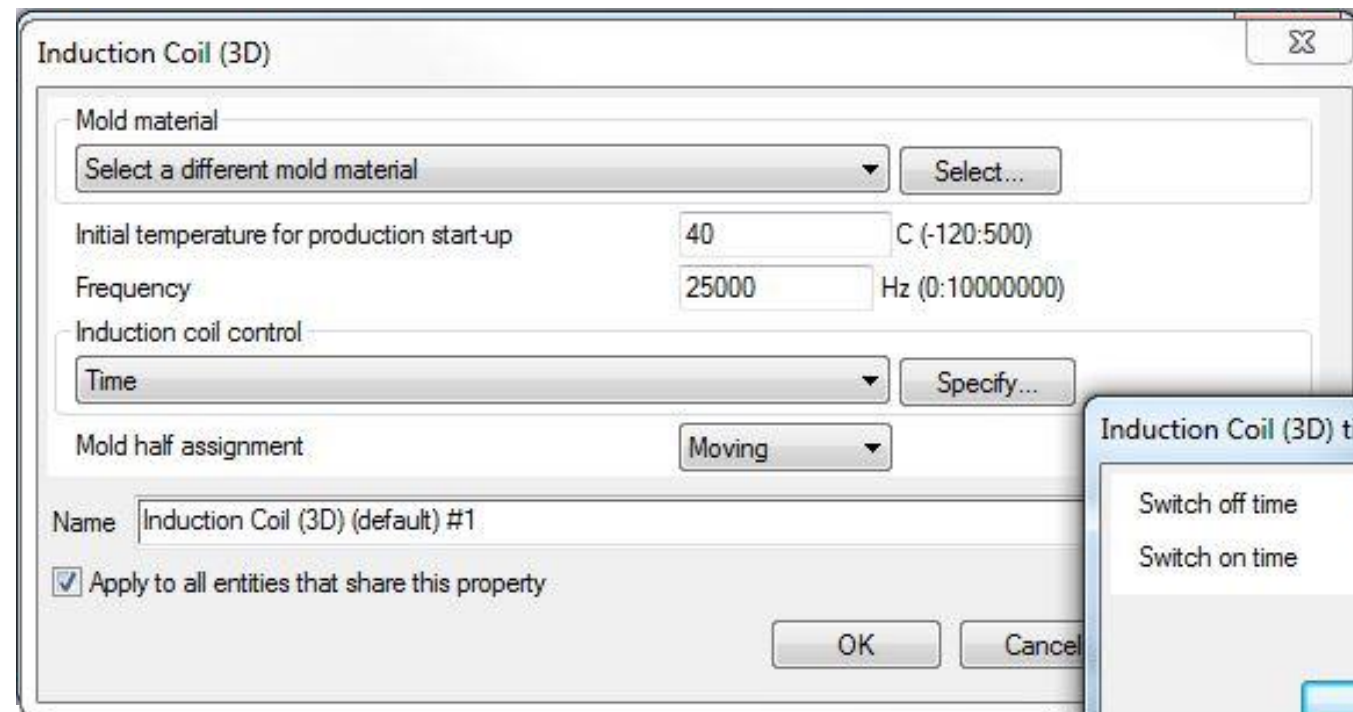
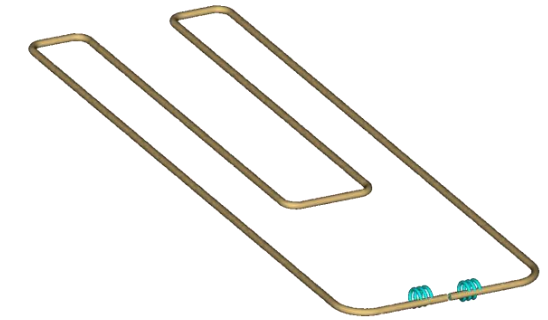
전류 밀도 = $\frac{A}{m^2} \propto$ **자속 밀도** = $\frac{Wb}{m^2}$

단위 면적당 흐르는 전류 \propto 단위 면적당 흐르는 자기력



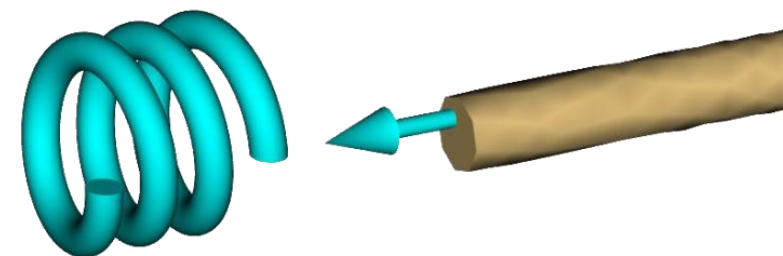
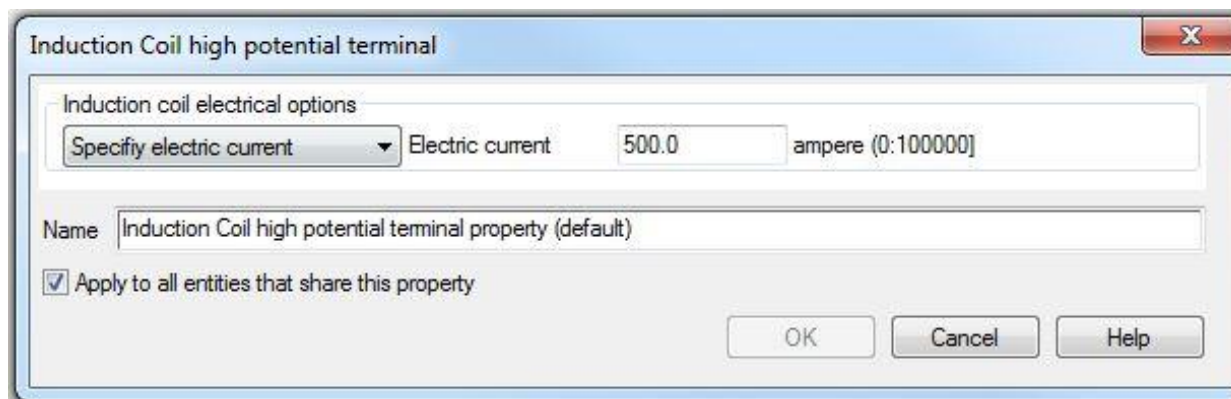
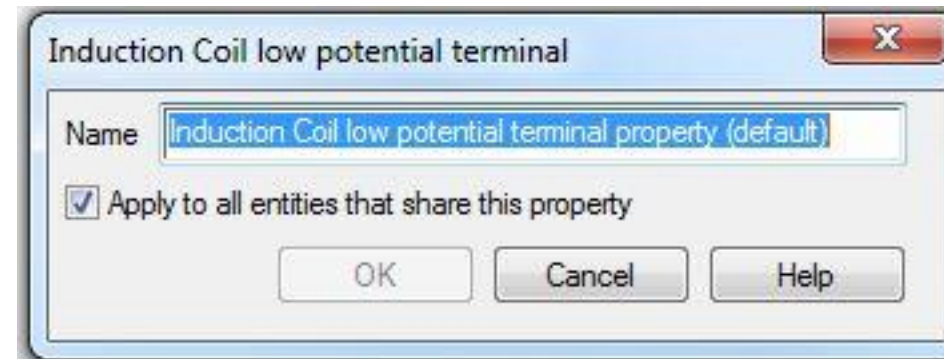
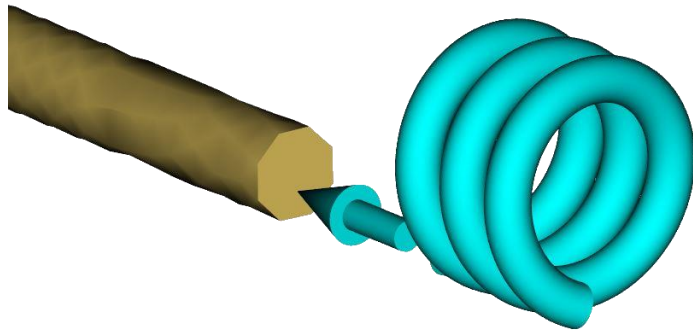
Induction Heating 해석 이론

1. Elemental properties는 Coil로 지정 해야 함.
유도가열을 목적으로 하는 coil은 동을 추천



Induction Heating 해석 이론

1. 전류 또는 전압의 크기 지정.(전류의 방향)



Induction Heating 해석 이론

- Induction heating 해석에서 신뢰도를 높이기 위한 도체의 매싱 기법
- 유도전류의 86%가 도체 표면 레이어에 집중되어 있음.

- (최외곽 표면층의 두께) $\delta = \frac{1}{\sqrt{\pi f \mu \sigma}}$

f : 발전기의 주파수(s^{-1}),

μ : 재료의 투자율($H \cdot m^{-1} = kg \cdot m^2 \cdot s^{-2} \cdot A^{-2} \cdot m^{-1}$),

σ : 재료의 전기 전도율 ($S \cdot m^{-1} = kg^{-1} \cdot m^{-2} \cdot s^3 \cdot A^2 \cdot m^{-1}$)

- $\delta = \frac{1}{\sqrt{\pi f \mu \sigma}} = 1 / \sqrt{\pi (s^{-1})(kg \cdot m^2 \cdot s^{-2} \cdot A^{-2} \cdot m^{-1})(kg^{-1} \cdot m^{-2} \cdot s^3 \cdot A^2 \cdot m^{-1})} = m$

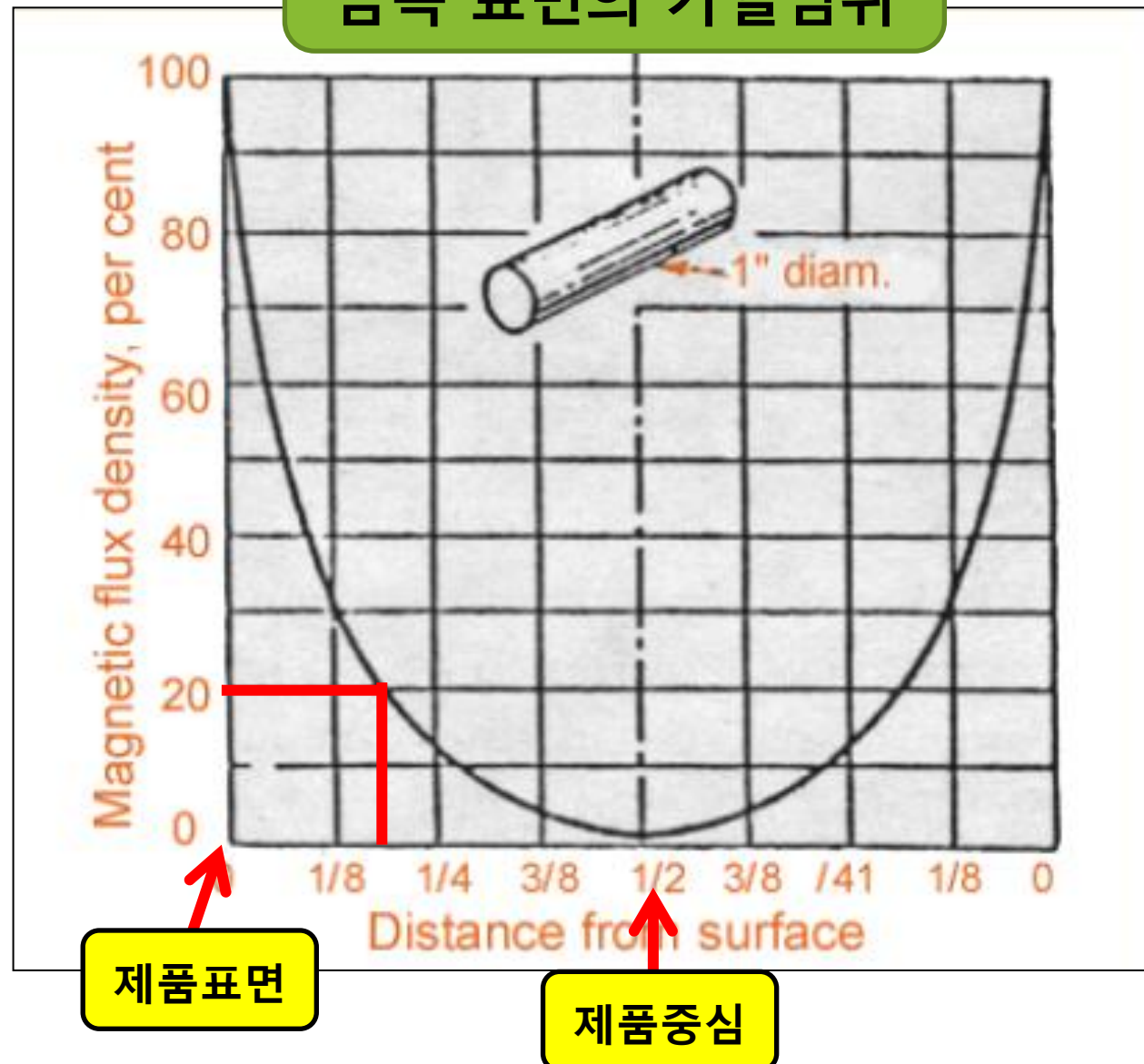
- 도움말 참고 « meshing guidelines for induction heating »

유도단위 : <http://terms.naver.com/entry.nhn?docId=1661982&cid=42330&categoryId=42330>

Induction Heating 해석 이론

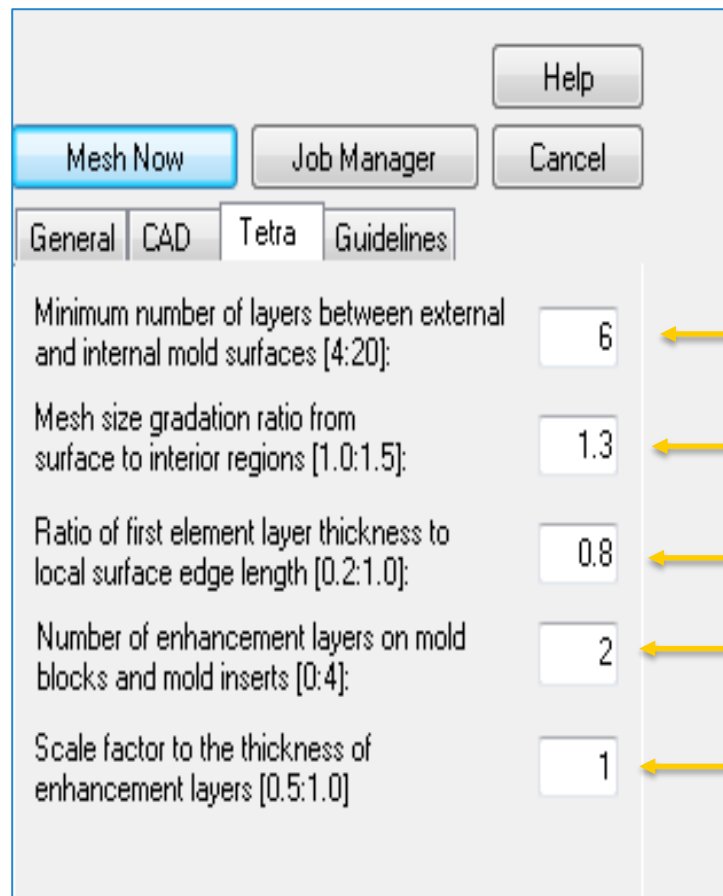
- 해석 신뢰도를 높이기 위해 Mold Insert(가열체)의 1st layer 두께는 δ (델타)가 중요한 이유는?

자기장 밀도에 따른
금속 표면의 가열범위



Induction Heating 해석 이론

- Meshing 고려대상
 - Mold Insert(가열체)
- Mold Insert(가열체)표면 Mesh size
 - $mesh\ size = \frac{\delta}{0.8}$
- Mold Insert(가열체)의 1st layer 두께는 δ (델타) 로 지정
- 표면부위는 4 Layer를 추천함.



표면에서 중심까지의 Layer 수(6-Layer 생성)

표면에서 중심까지의 두께 증가비율(1.3배로 증가)

1st Layer 두께 사이즈(1st layer 두께 0.8mm)

1st Layer 두께의 개수 결정(1st layer 0.8mm가 2개)

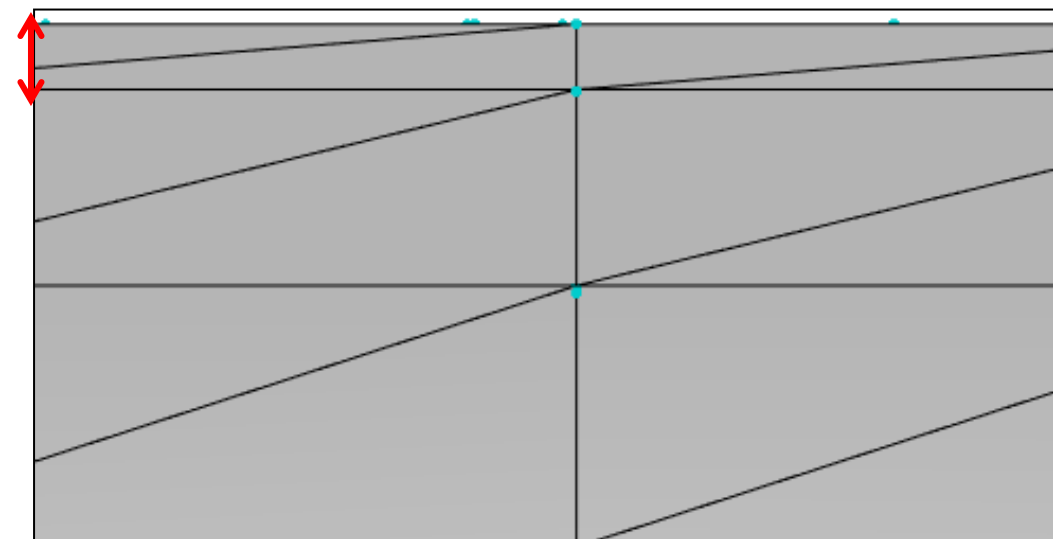
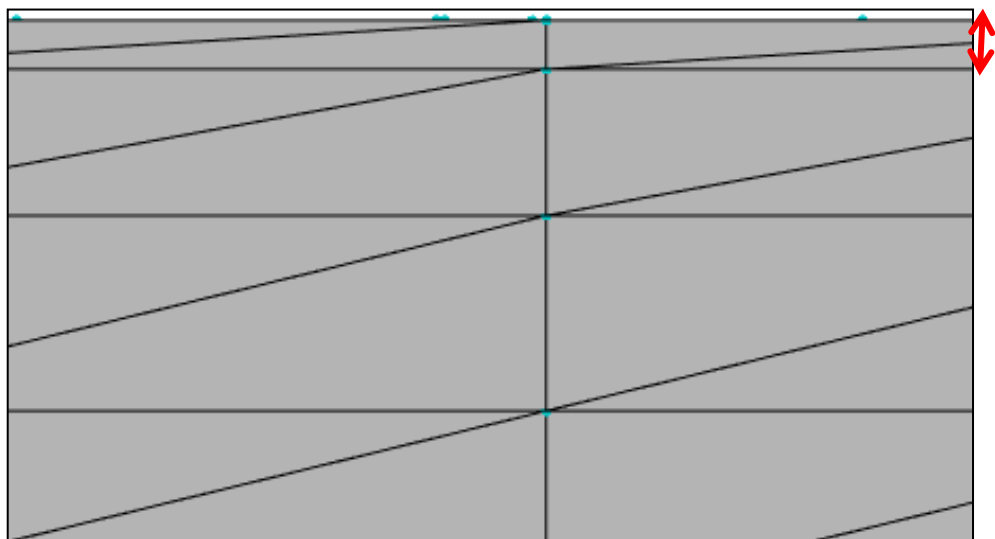
1st Layer 두께 사이즈에 Scale 적용
Ex) 1st layer 0.8mm 일때 0.5를 입력하면 0.4mm 두께

Induction Heating 해석 이론

1st Layer 두께 사이즈(1st layer 두께 0.2mm / 1mm)

General	Tetra	Guidelines
Minimum number of layers between external and internal mold surfaces [4:20]:		<input type="text" value="5"/>
Mesh size gradation ratio from surface to interior regions [1.0:1.5]:		<input type="text" value="1.5"/>
Ratio of first element layer thickness to local surface edge length [0.2:1.0]:		<input type="text" value="0.2"/>
Number of enhancement layers on mold blocks and mold inserts [0:8]:		<input type="text" value="1"/>
Scale factor to the thickness of enhancement layers [0.5:1.0]		<input type="text" value="1"/>

General	Tetra	Guidelines
Minimum number of layers between external and internal mold surfaces [4:20]:		<input type="text" value="5"/>
Mesh size gradation ratio from surface to interior regions [1.0:1.5]:		<input type="text" value="1.5"/>
Ratio of first element layer thickness to local surface edge length [0.2:1.0]:		<input type="text" value="1"/>
Number of enhancement layers on mold blocks and mold inserts [0:8]:		<input type="text" value="1"/>
Scale factor to the thickness of enhancement layers [0.5:1.0]		<input type="text" value="1"/>

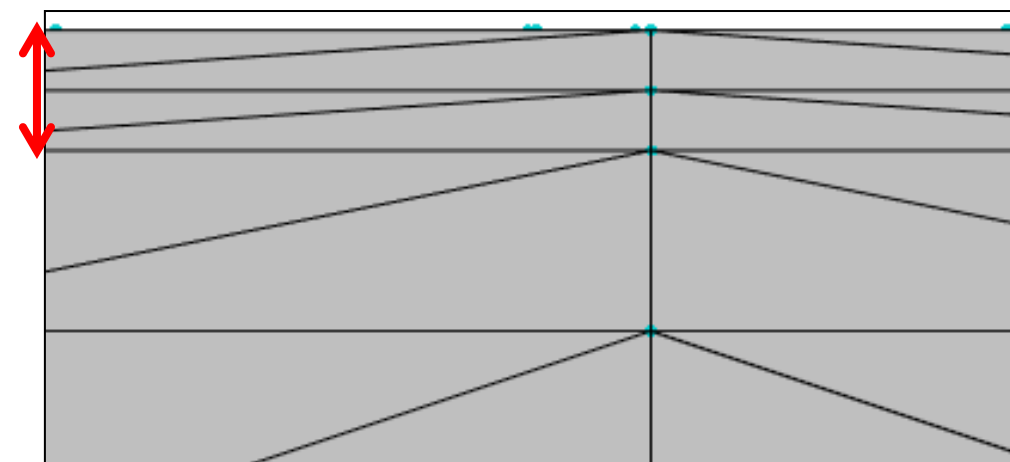
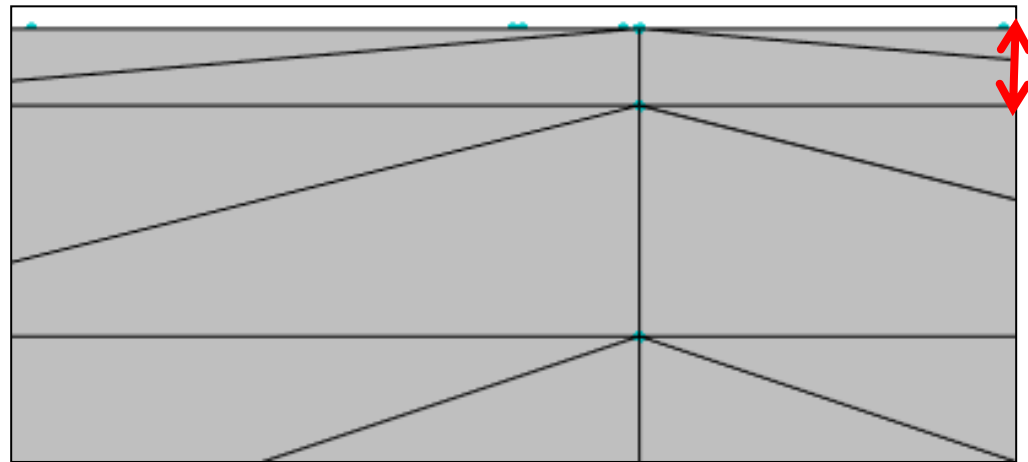


Induction Heating 해석 이론

1st Layer 두께의 개수 결정(1st layer 1mm가 1개 / 2개)

General	Tetra	Guidelines
Minimum number of layers between external and internal mold surfaces [4:20]:		<input type="text" value="5"/>
Mesh size gradation ratio from surface to interior regions [1.0:1.5]:		<input type="text" value="1.5"/>
Ratio of first element layer thickness to local surface edge length [0.2:1.0]:		<input type="text" value="1"/>
Number of enhancement layers on mold blocks and mold inserts [0:8]:		<input type="text" value="1"/>
Scale factor to the thickness of enhancement layers [0.5:1.0]		<input type="text" value="1"/>

General	Tetra	Guidelines
Minimum number of layers between external and internal mold surfaces [4:20]:		<input type="text" value="5"/>
Mesh size gradation ratio from surface to interior regions [1.0:1.5]:		<input type="text" value="1.5"/>
Ratio of first element layer thickness to local surface edge length [0.2:1.0]:		<input type="text" value="1"/>
Number of enhancement layers on mold blocks and mold inserts [0:8]:		<input type="text" value="2"/>
Scale factor to the thickness of enhancement layers [0.5:1.0]		<input type="text" value="1"/>

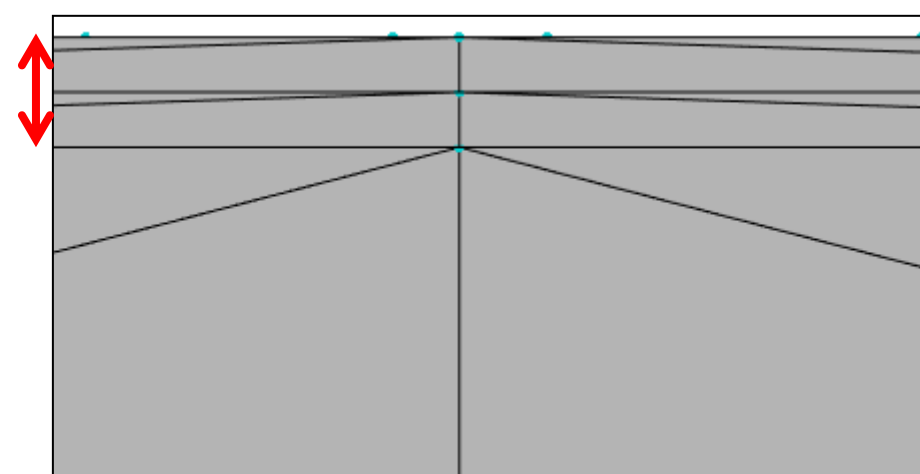
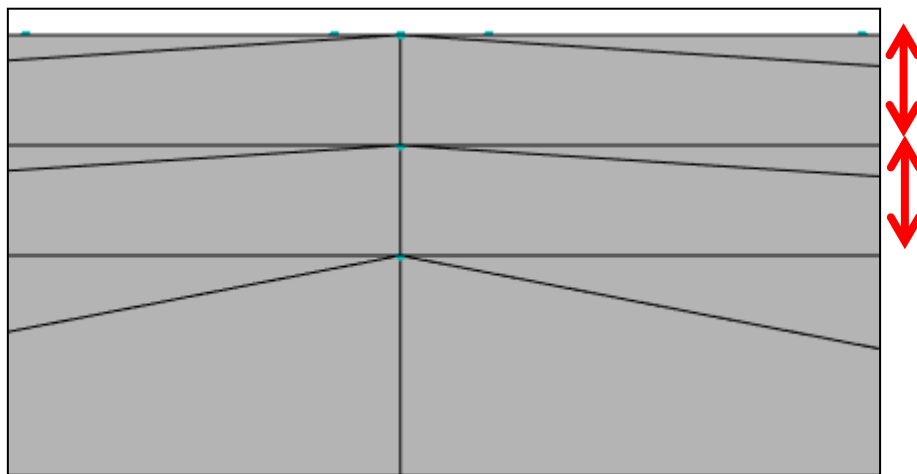


Induction Heating 해석 이론

1st Layer 두께 사이즈에 Scale 적용
Ex) 1st layer 1mm 일 때 1 / 0.5

Minimum number of layers between external and internal mold surfaces [4:20]:	<input type="text" value="5"/>
Mesh size gradation ratio from surface to interior regions [1.0:1.5]:	<input type="text" value="1.5"/>
Ratio of first element layer thickness to local surface edge length [0.2:1.0]:	<input type="text" value="1"/>
Number of enhancement layers on mold blocks and mold inserts [0:8]:	<input type="text" value="2"/>
Scale factor to the thickness of enhancement layers [0.5:1.0]	<input type="text" value="1"/>

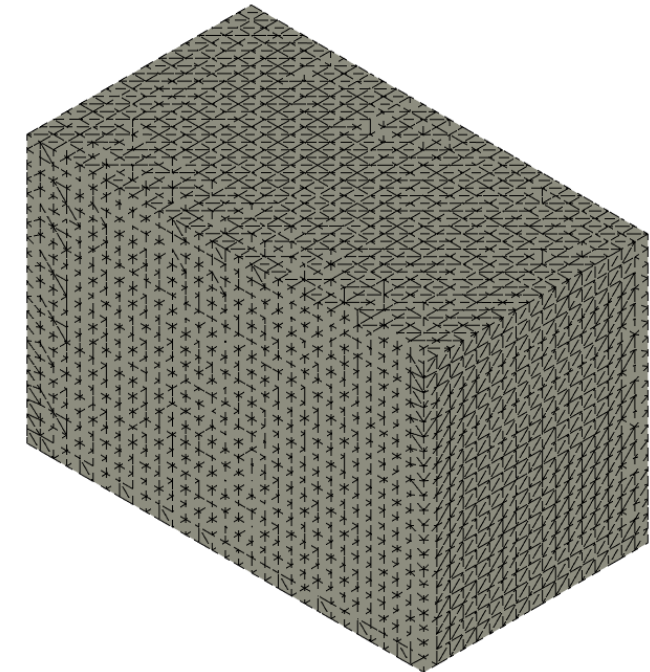
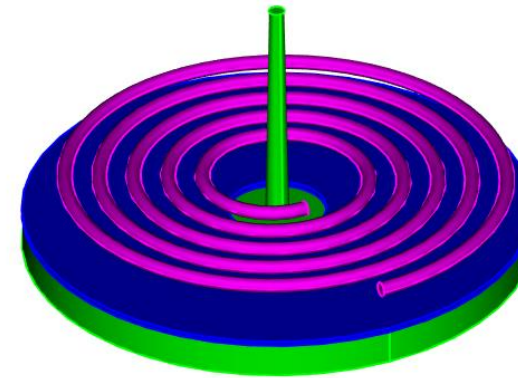
Minimum number of layers between external and internal mold surfaces [4:20]:	<input type="text" value="5"/>
Mesh size gradation ratio from surface to interior regions [1.0:1.5]:	<input type="text" value="1.5"/>
Ratio of first element layer thickness to local surface edge length [0.2:1.0]:	<input type="text" value="1"/>
Number of enhancement layers on mold blocks and mold inserts [0:8]:	<input type="text" value="2"/>
Scale factor to the thickness of enhancement layers [0.5:1.0]	<input type="text" value="0.5"/>



Induction Heating 해석 실습

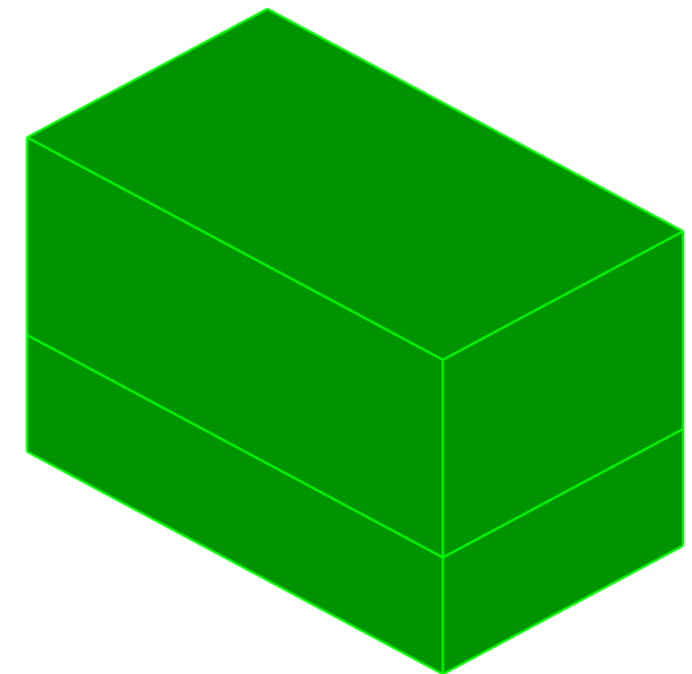
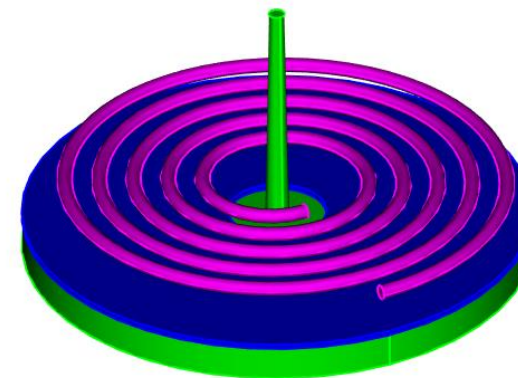
1. Mold Surface Wizard(FEM)

1. 제품 모델링
2. Runner 모델링 (Beam or 3D CAD)
3. Channel 모델링 (Beam)
4. Coil 모델링(3D CAD)
5. Insert 모델링(3D CAD)



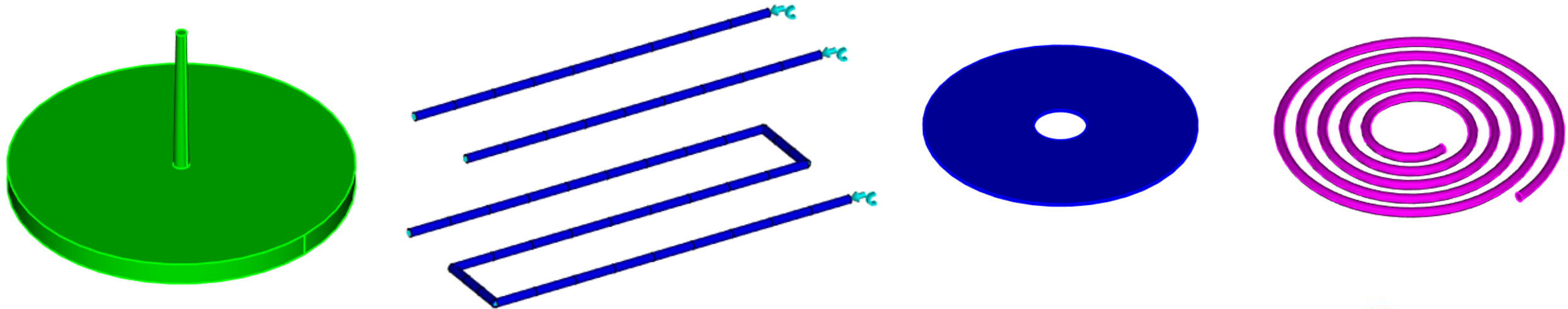
2. Mold Block(FEM)

1. 제품 모델링
2. Runner 모델링 (Beam or 3D CAD)
3. Channel 모델링 (Beam)
4. Coil 모델링(3D CAD)
5. Insert 모델링(3D CAD)
6. 금형 모델링 (3D CAD)



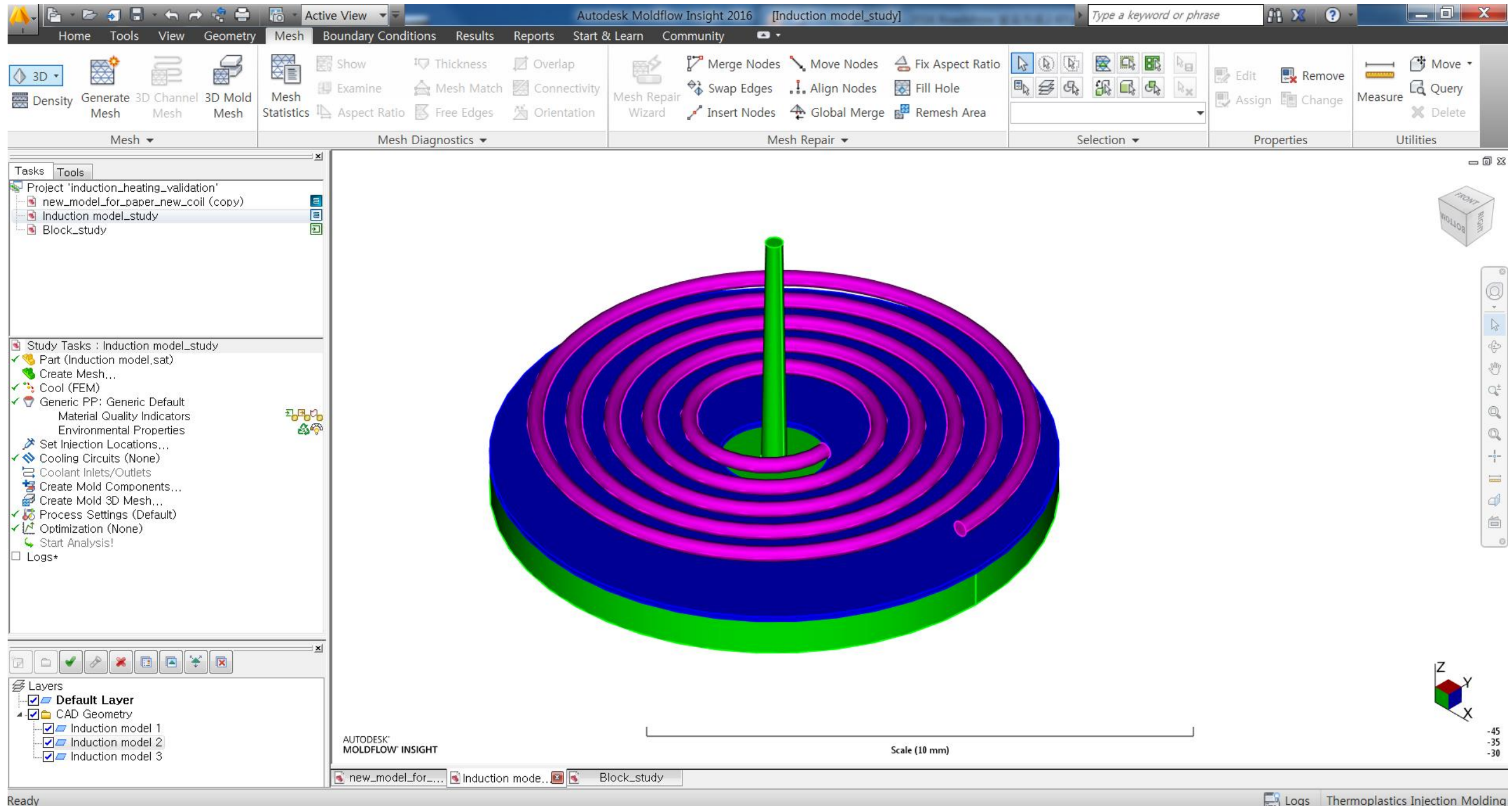
Induction Heating 해석 실습

- 제품 모델링
- Runner 모델링 (Beam or 3D CAD)
- Channel 모델링 (Beam)
- Coil 모델링(3D CAD)
- Insert 모델링(3D CAD)



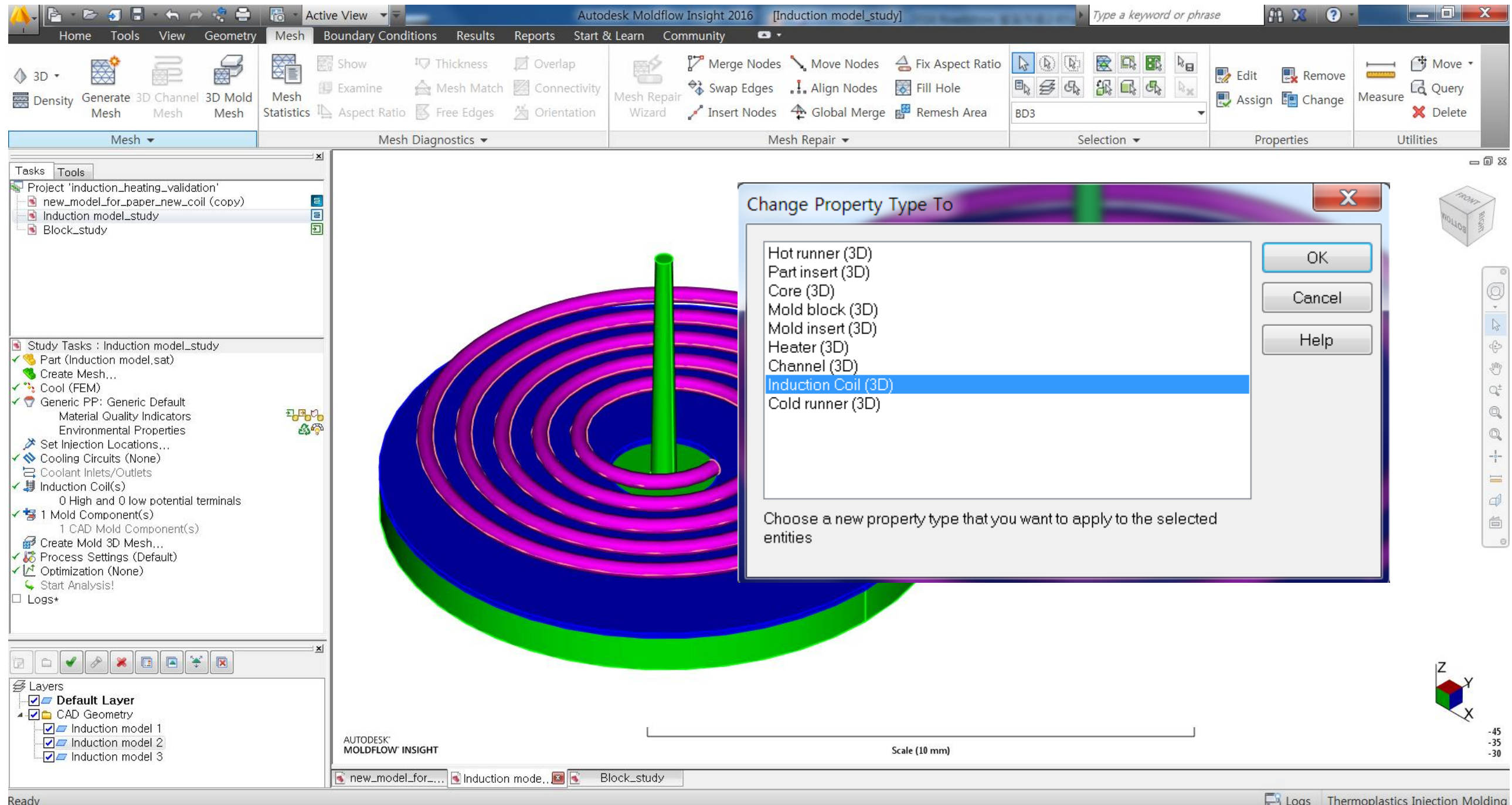
Induction Heating 해석 실습

- 제품, Runner, Coil, Mold insert - Import



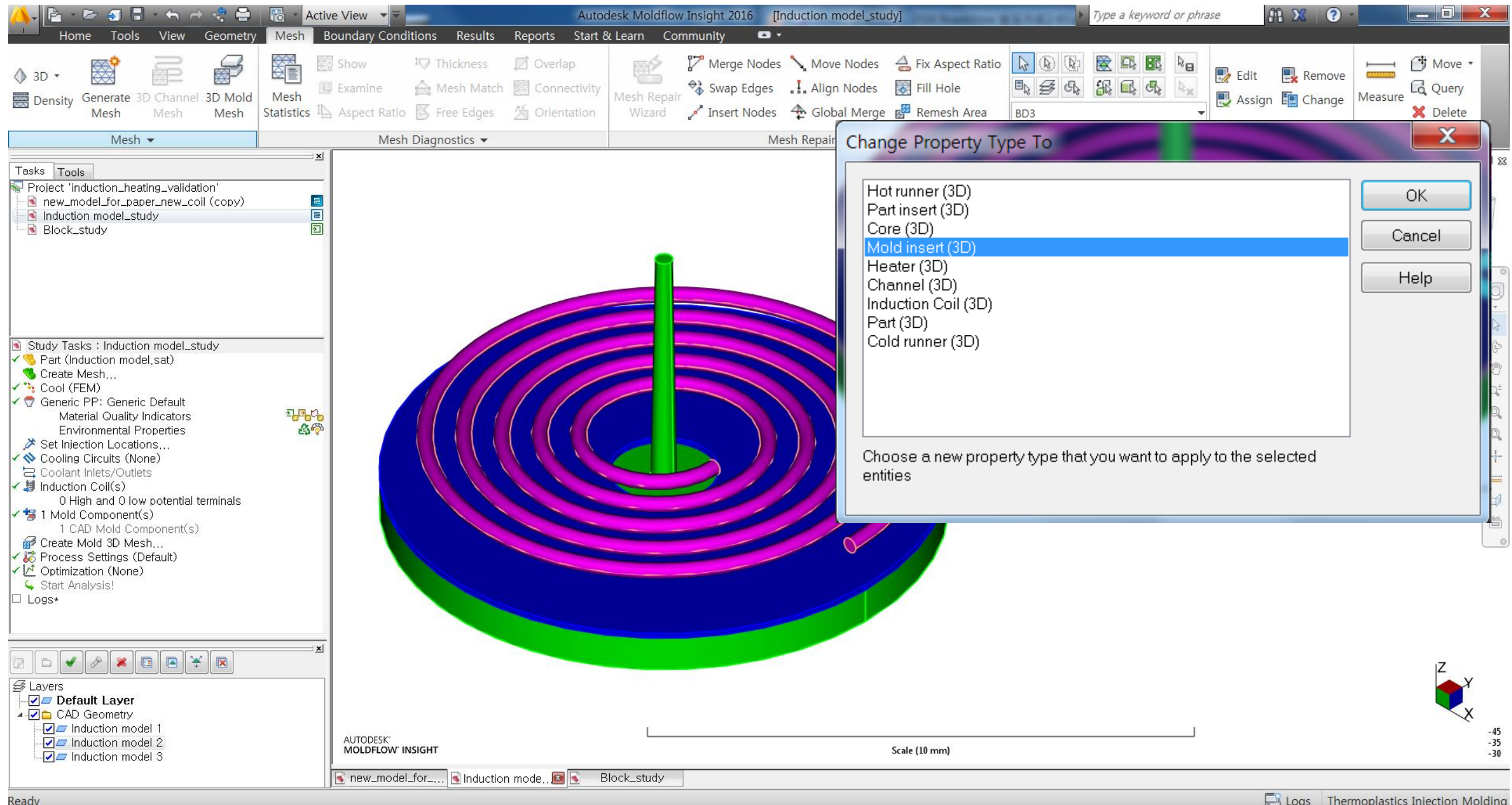
Induction Heating 해석 실습

■ Induction Coil 로 속성 설정



Induction Heating 해석 실습

- Mold insert 로 속성 설정



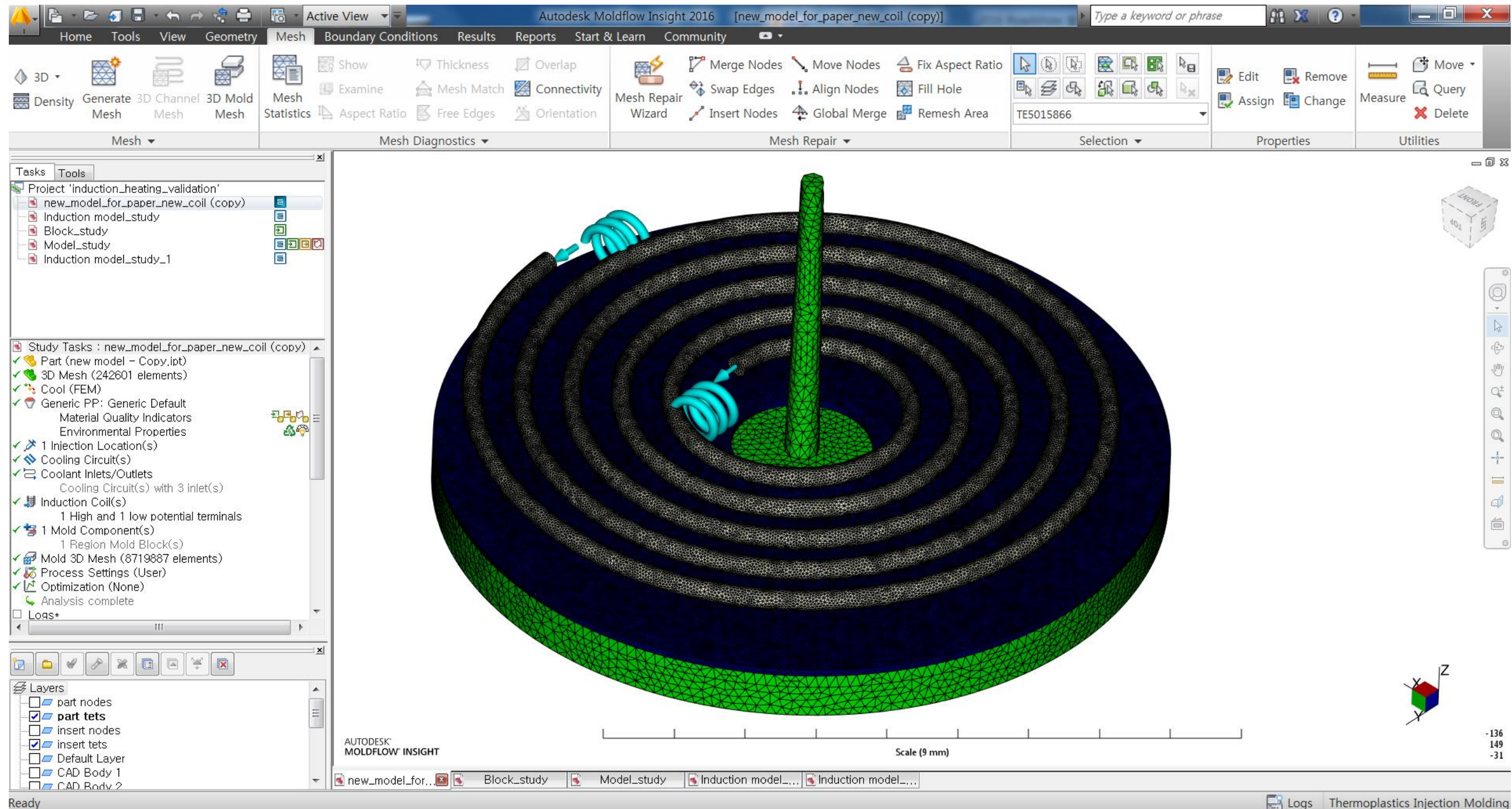
Induction Heating 해석 실습

- Induction Coil High/Low Potential Terminal 설정(Boundary Condition)

The screenshot displays the Autodesk Moldflow Insight 2016 interface for an induction heating simulation. The main workspace shows a 3D model of a mold cavity with a central green rod and a purple spiral induction coil. A yellow arrow points to the coil's terminals. A dropdown menu on the right lists boundary conditions, with 'Induction Coil High Potential Terminal' and 'Induction Coil Low Potential Terminal' highlighted. The left sidebar shows a tree view of the model components, including 'Induction Coil(s)' with '1 High and 1 low potential terminals'.

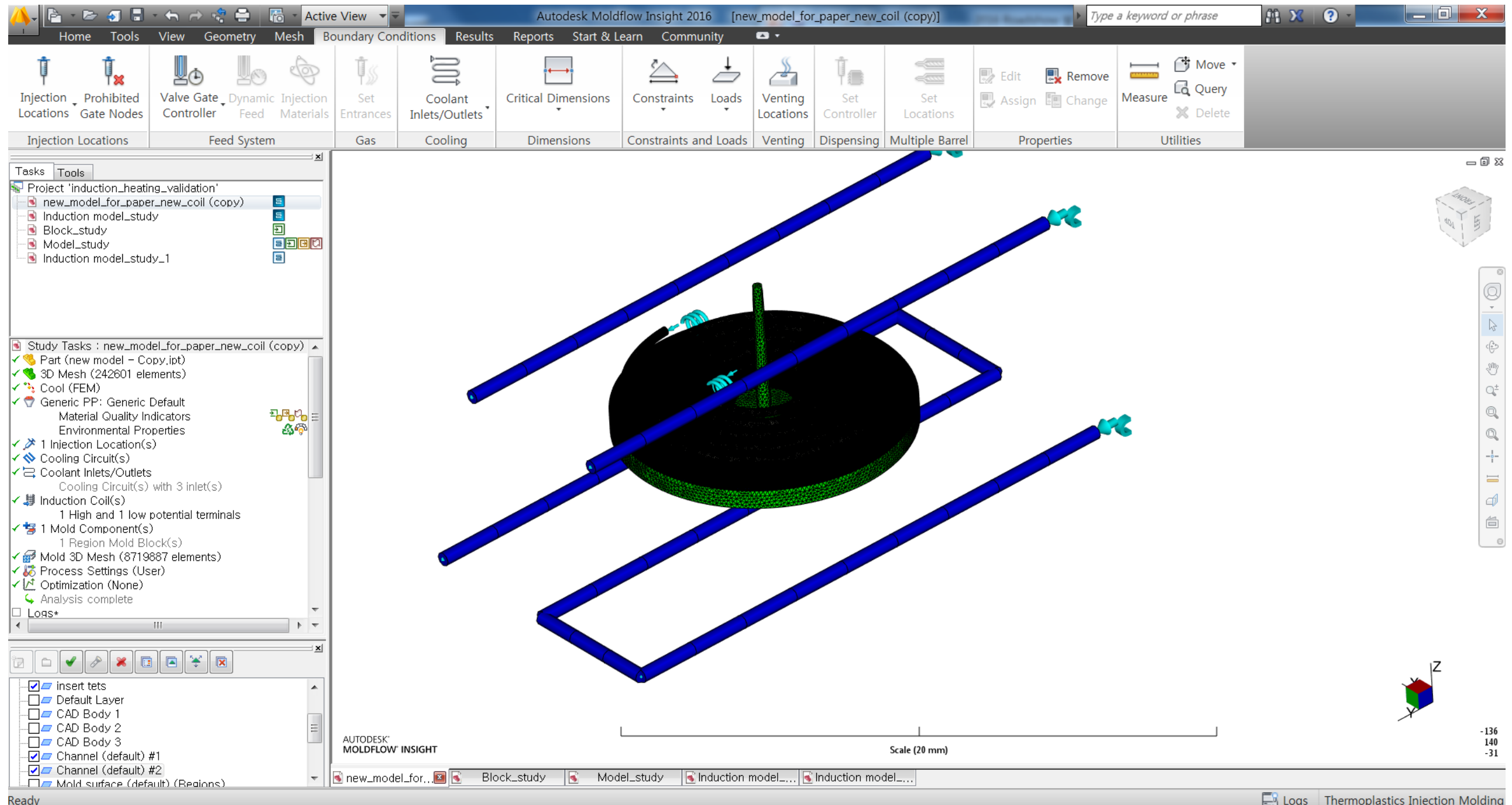
Induction Heating 해석 실습

■ Induction Coil Mesh 생성



Induction Heating 해석 실습

■ Channel Beam Mesh 생성



Induction Heating 해석 실습

■ Mold Surface 생성

The screenshot displays the Autodesk Moldflow Insight 2016 software interface. The main window shows a 3D model of a mold with a central induction coil and cooling channels. The interface includes a top menu bar with options like Home, Tools, View, Geometry, Mesh, Boundary Conditions, Results, Reports, Start & Learn, and Community. A toolbar below the menu bar contains various icons for injection, gate, valve, dynamic feed, materials, set entrances, coolant inlets/outlets, critical dimensions, constraints, loads, venting locations, set controller, set locations, edit, remove, assign, change, measure, move, query, and delete. The left-hand tree view shows the project structure, including 'induction_heating_validation', 'new_model_for_paper_new_coil (copy)', and various study tasks. The bottom status bar indicates 'AUTODESK MOLDFLOW INSIGHT' and 'Scale (40 mm)'. The bottom right corner shows the status 'Ready' and 'Thermoplastics Injection Molding Product Support Specialized Authorized Developer Authorized Certification Center Authorized Training Center'.

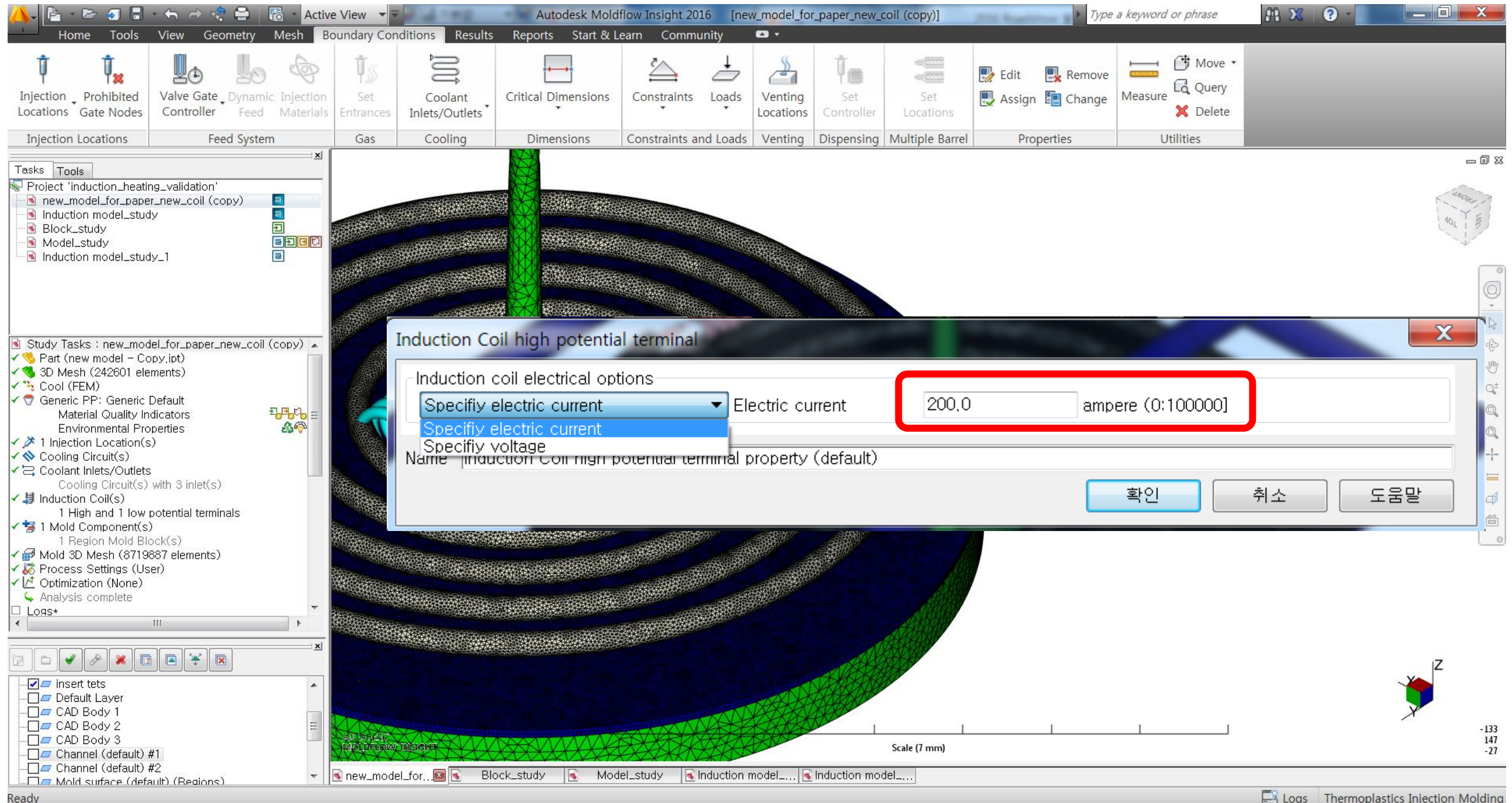
Induction Heating 해석 실습

■ Mold Surface Mesh 생성

The screenshot displays the Autodesk Moldflow Insight 2016 software interface. The main window shows a 3D model of a mold with a fine mesh applied to its surface. The interface includes a top menu bar with options like Home, Tools, View, Geometry, Mesh, Boundary Conditions, Results, Reports, Start & Learn, and Community. Below the menu is a ribbon with various tool icons for Injection, Prohibited Gate Nodes, Valve Gate Controller, Dynamic Feed, Injection Materials, Set Entrances, Coolant Inlets/Outlets, Critical Dimensions, Constraints, Loads, Venting Locations, Set Controller, Set Locations, Edit, Remove, Assign, Change, Measure, Move, Query, and Delete. The left-hand side features a tree view showing the project structure, including 'Project: induction_heating_validation', 'new_model_for_paper_new_coil (copy)', 'Induction model_study', 'Block_study', 'Model_study', and 'Induction model_study_1'. Below the tree view is a 'Study Tasks' section for 'new_model_for_paper_new_coil (copy)', listing tasks such as 'Part (new model - Copy.ipt)', '3D Mesh (242601 elements)', 'Cool (FEM)', 'Generic PP: Generic Default', 'Material Quality Indicators', 'Environmental Properties', '1 Injection Location(s)', 'Cooling Circuit(s)', 'Coolant Inlets/Outlets', 'Induction Coil(s)', '1 Mold Component(s)', 'Mold 3D Mesh (8719887 elements)', 'Process Settings (User)', 'Optimization (None)', and 'Analysis complete'. At the bottom, there is a 'Layer hidden' section with checkboxes for 'Channel (default) #2', 'Mold surface (default) (Regions)', 'coil nodes', 'coil tets', 'Mold Nodes', 'Mold Tetras', and 'Mold surface (default) (Regions)'. The bottom status bar shows 'AUTODESK MOLDFLOW INSIGHT' and a scale of 40 mm. The bottom right corner of the software window displays the page number '-136' and '-31'.

Induction Heating 해석 실습

- Induction Coil high potential terminal에 전류 및 전압 설정



Induction Heating 해석 실습

- Induction Coil 속성 설정(Electrical- 전기저항 및 상대투자율)

The screenshot displays the Autodesk Moldflow Insight 2016 interface. The main window shows a 3D model of an induction coil with a green mesh. Overlaid on this is the 'Induction Coil (3D)' property dialog box. Within this dialog, the 'Electrical' tab is selected, showing the following settings:

- Electrical resistivity of material:** 1.666e-008 ohm-m [0:1e+020]
- Relative magnetic permeability of material:** 1 [0:1e+020]
- Name:** Copper (PURE)

Other tabs visible in the dialog include 'Description', 'Thermal', and 'Mechanical'. The background shows the software's taskbar and a list of study tasks on the left side.

Induction Heating 해석 실습

■ Induction Coil 속성 설정 (시간설정)

The screenshot displays the Autodesk Moldflow Insight 2016 interface. The main window shows a 3D model of a mold with a mesh. The 'Induction Coil (3D)' dialog box is open, showing the following settings:

- Mold material: Select a different mold material
- Initial temperature for production start-up: 40 C (-120:500)
- Frequency: 10000 Hz (0:10000000)
- Induction coil control: Time
- Mold half assignment: Automatic
- Name: Induction Coil (3D) (default) #1
- Apply to all entities that share this property

The 'Induction Coil (3D) time' dialog box is also open, showing the following settings:

- Switch off time: 0 s [0:]
- Switch on time: 30 s [0:]

The 'Induction Coil (3D) time' dialog box has buttons for '확인' (OK), '취소' (Cancel), and '도움말' (Help).

Induction Heating 해석 실습

- Mold Insert 속성 설정(Electrical- 전기저항 및 상대투자율)

The screenshot displays the Autodesk Moldflow Insight 2016 interface. The main window shows a 3D model of a mold insert with a green mesh overlay. The 'Mold insert (3D)' dialog box is open, showing the following settings:

- Mold material:** Select a different mold material (with a 'Select...' button)
- External heat transfer coefficients:** Air
- Mold block conductance:** (empty field)
- Initial temperature for production start:** (empty field)
- Mold half assignment:** (empty field)
- Name:** Mold insert (3D) (default) #2
- Apply to all entities that share this

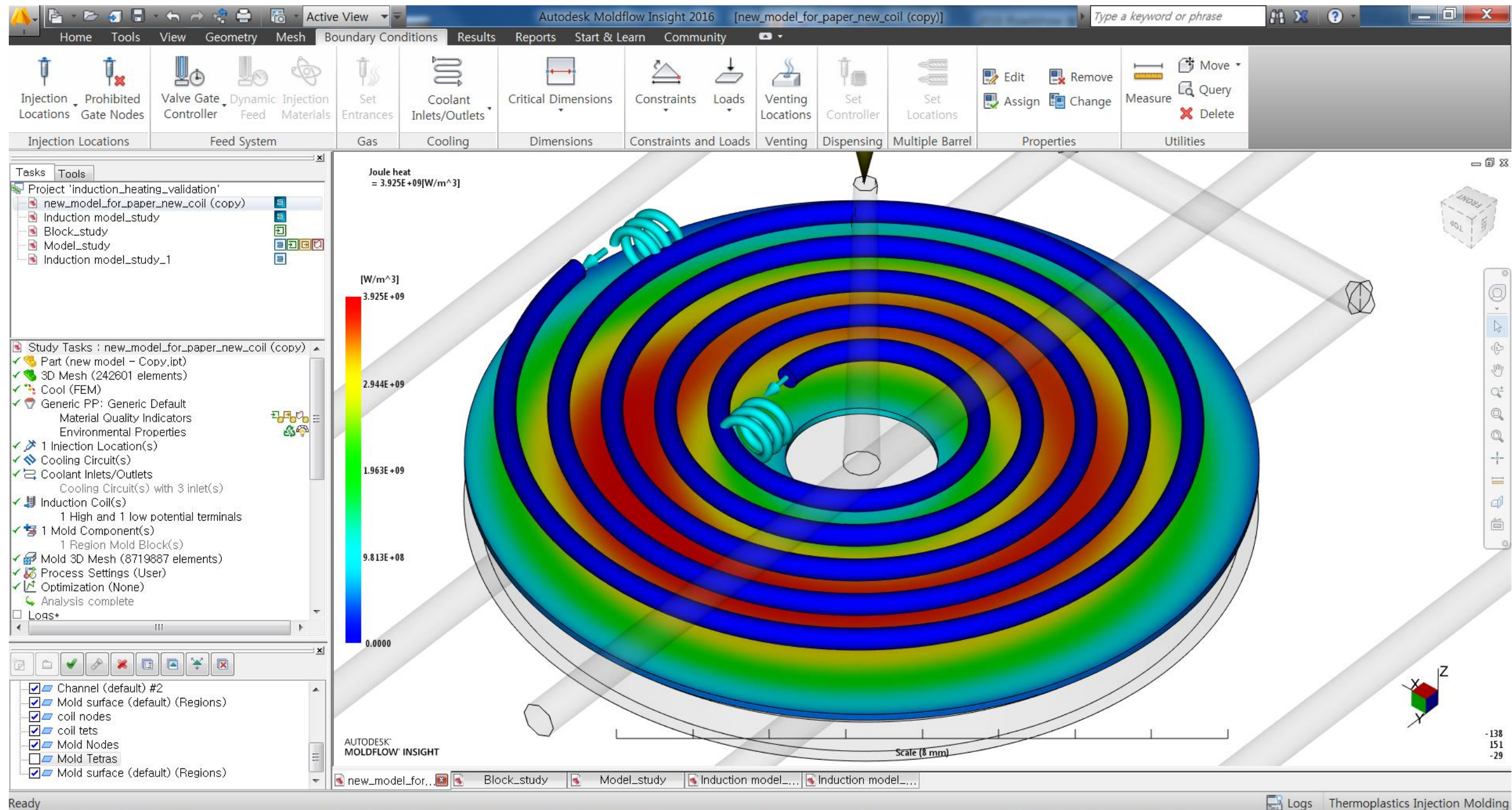
The 'Mold material' sub-dialog box is also open, showing the 'Electrical' tab with the following values:

- Electrical resistivity of material:** 1.666e-008 ohm-m [0:1e+020]
- Relative magnetic permeability of material:** 1 [0:1e+020]
- Name:** Copper (PURE)

Buttons at the bottom of the dialog include '확인' (OK), '취소' (Cancel), and '도움말' (Help). The background shows a 3D model of a mold insert with a green mesh overlay. The status bar at the bottom indicates 'Ready' and 'Scale (7 mm)'. The bottom right corner shows a coordinate system and page numbers: -133, 147, -27.

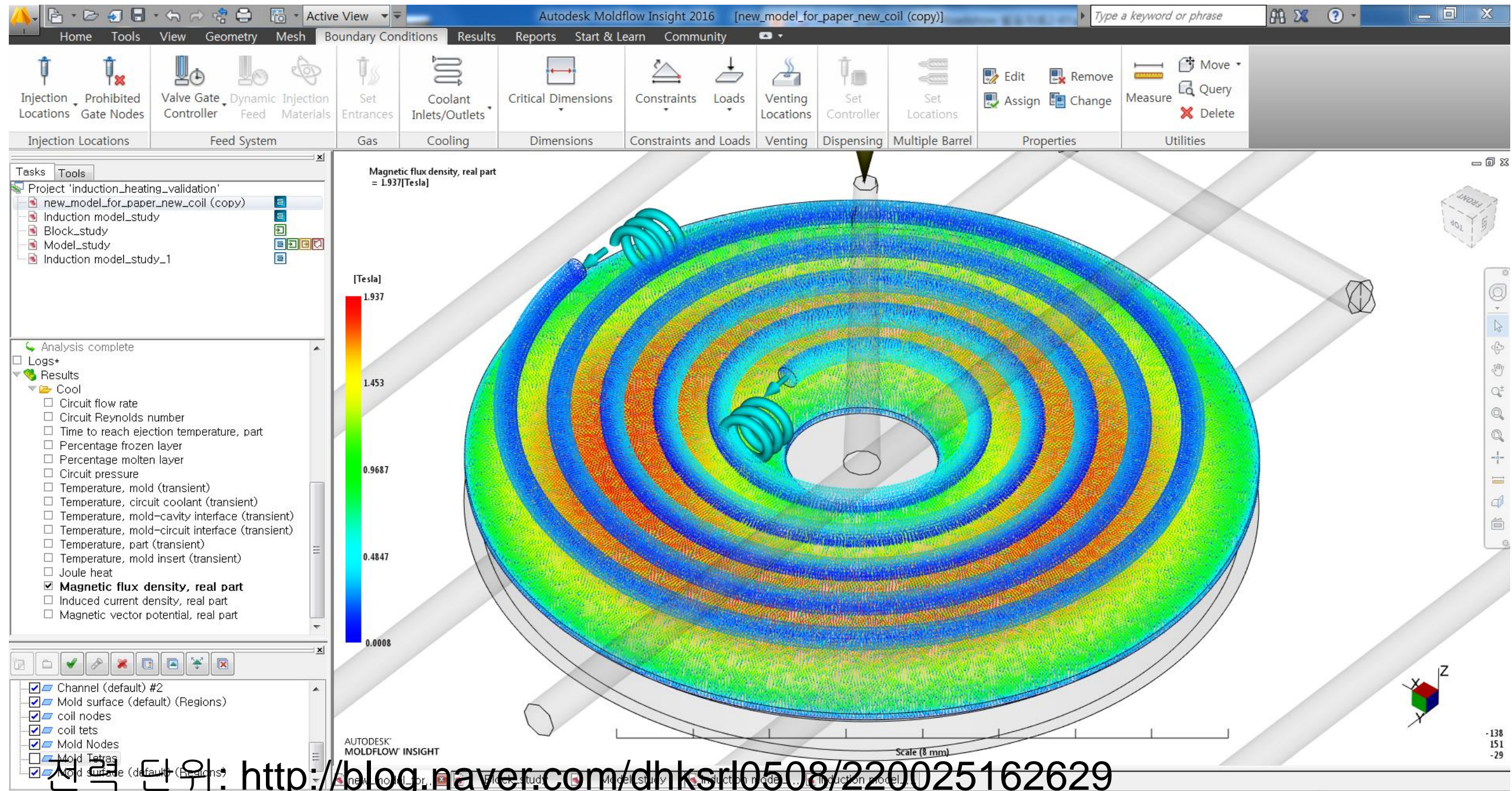
Induction Heating 해석 결과

- Joule heating 결과 - 단위 체적당(m^3) 발생하는 전력(W) $1W=1J/s$, $1J=1Nm$



Induction Heating 해석 실습

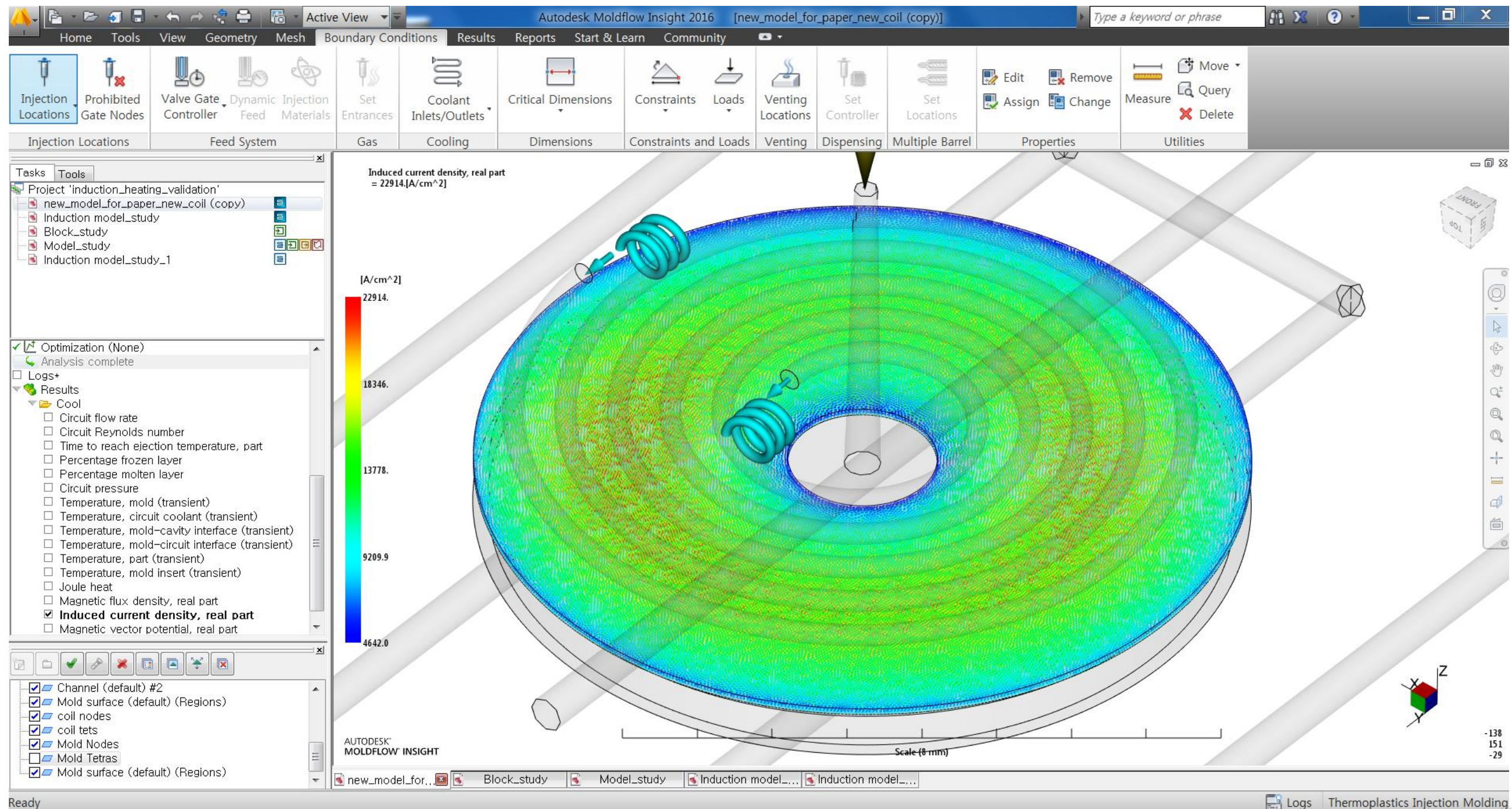
- Magnetic flux density, real part – 제품에 생성되는 자속 밀도 단위 T



전력 단위: <http://blog.naver.com/dhksrl0508/220025162629>

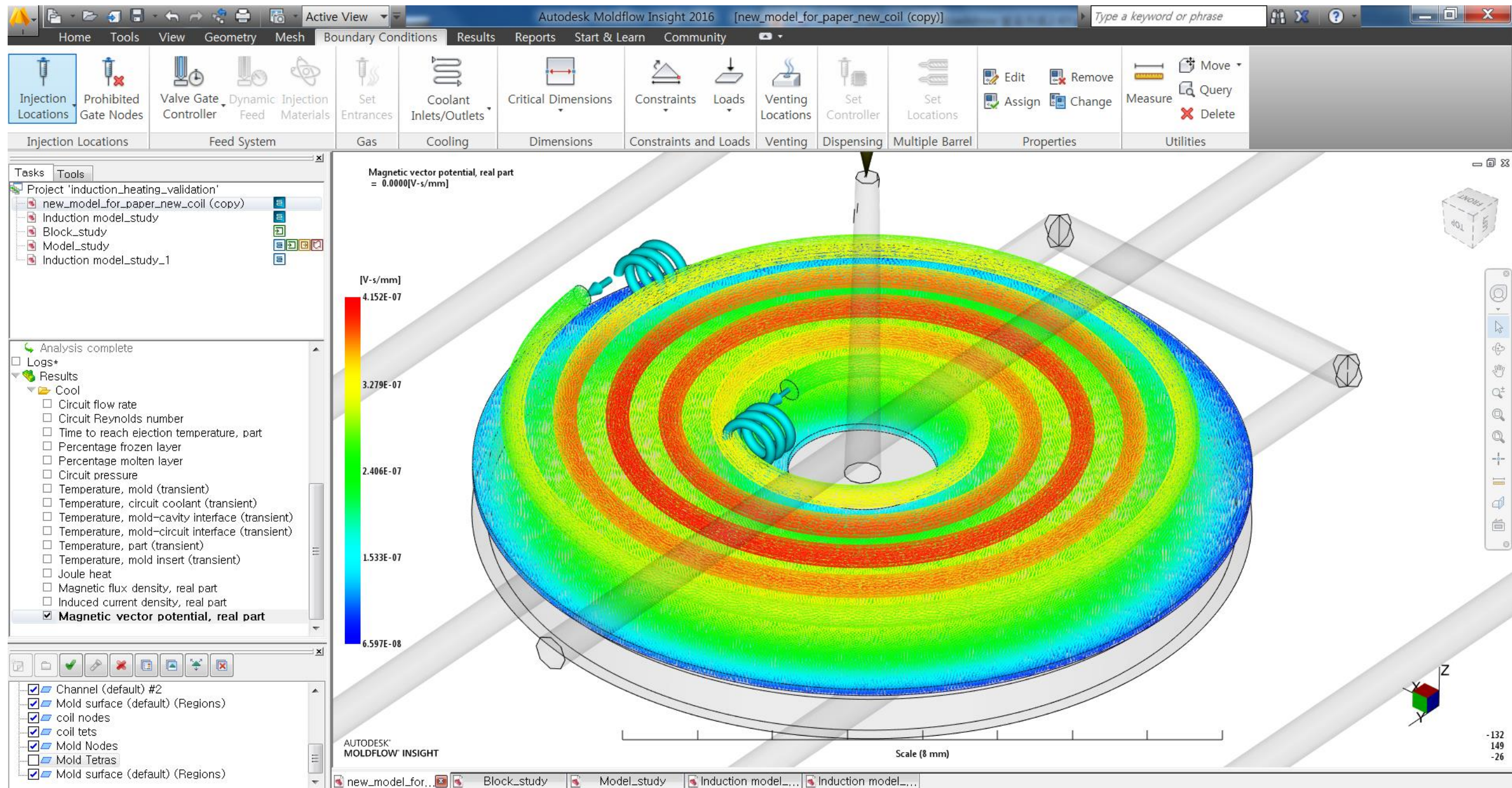
Induction Heating 해석 실습

- Induced current density, real part- 제품에 발생하는 유도전류 밀도 $H/m=A/m$



Induction Heating 해석 실습

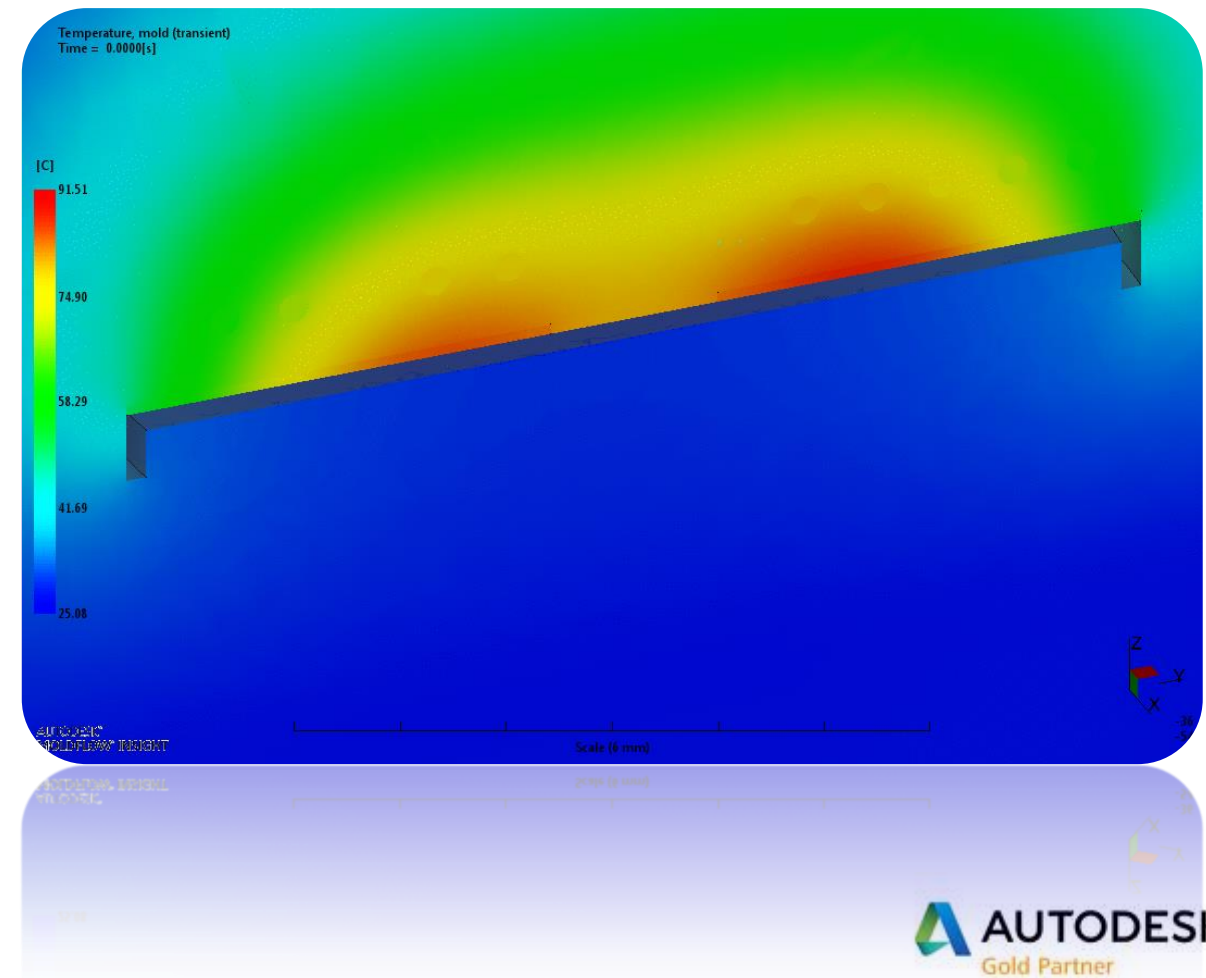
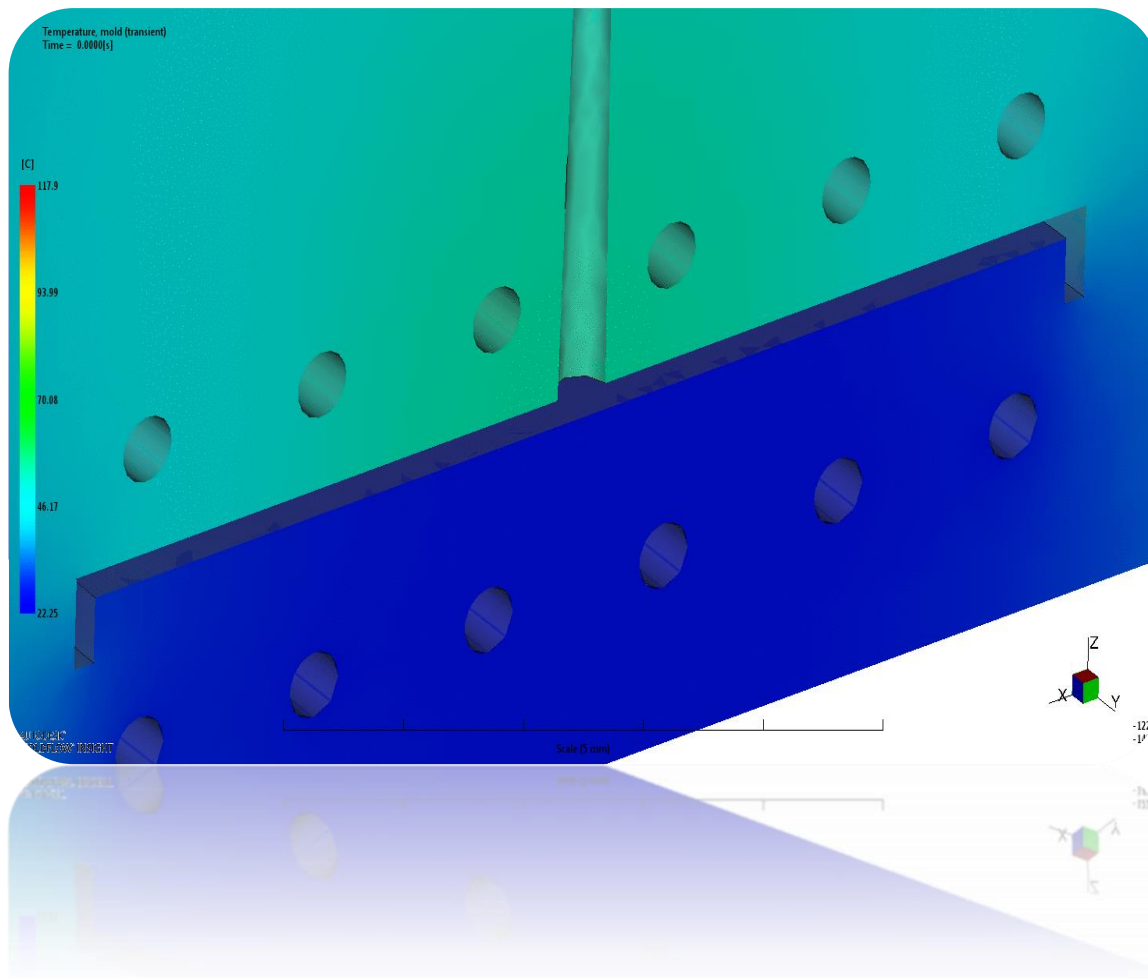
- Magnetic vector potential, real part – 잠재적인 자기벡터 결과
 - Joule heating 결과를 생성시키기 위한 중간 결과로 자기장의 방향 및 크기를 확인



Induction Heating 해석 실습

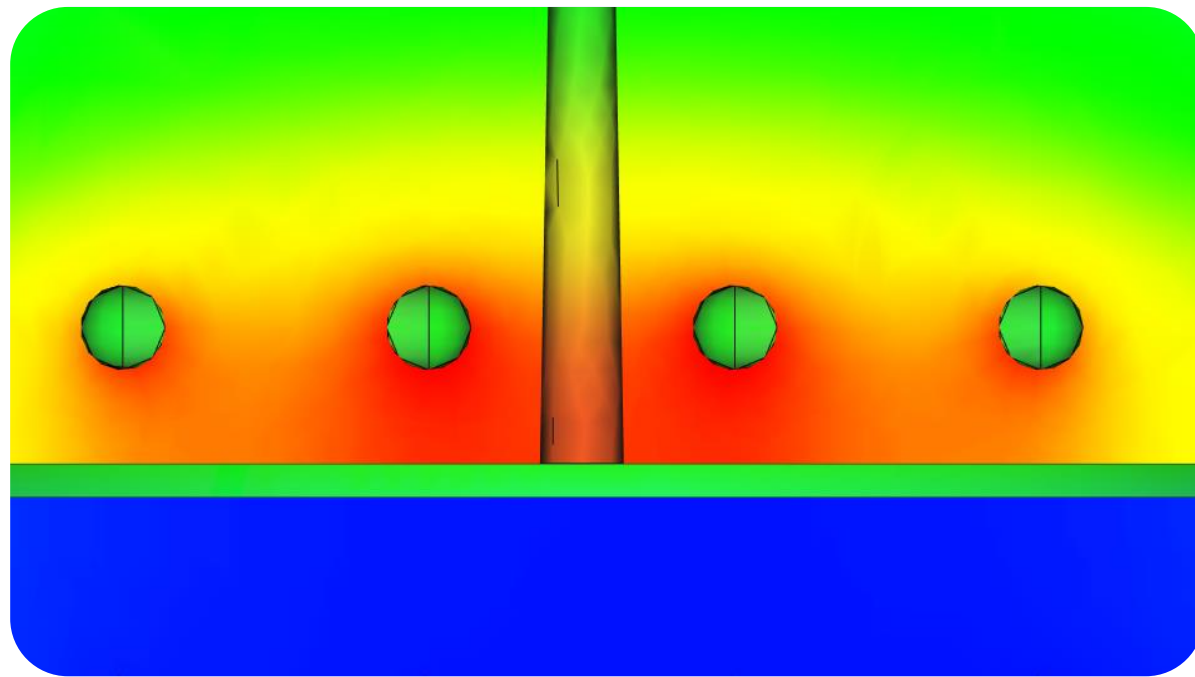
- Temperature, mold(transient) – 금형온도 결과

Induction Heating 결과는?

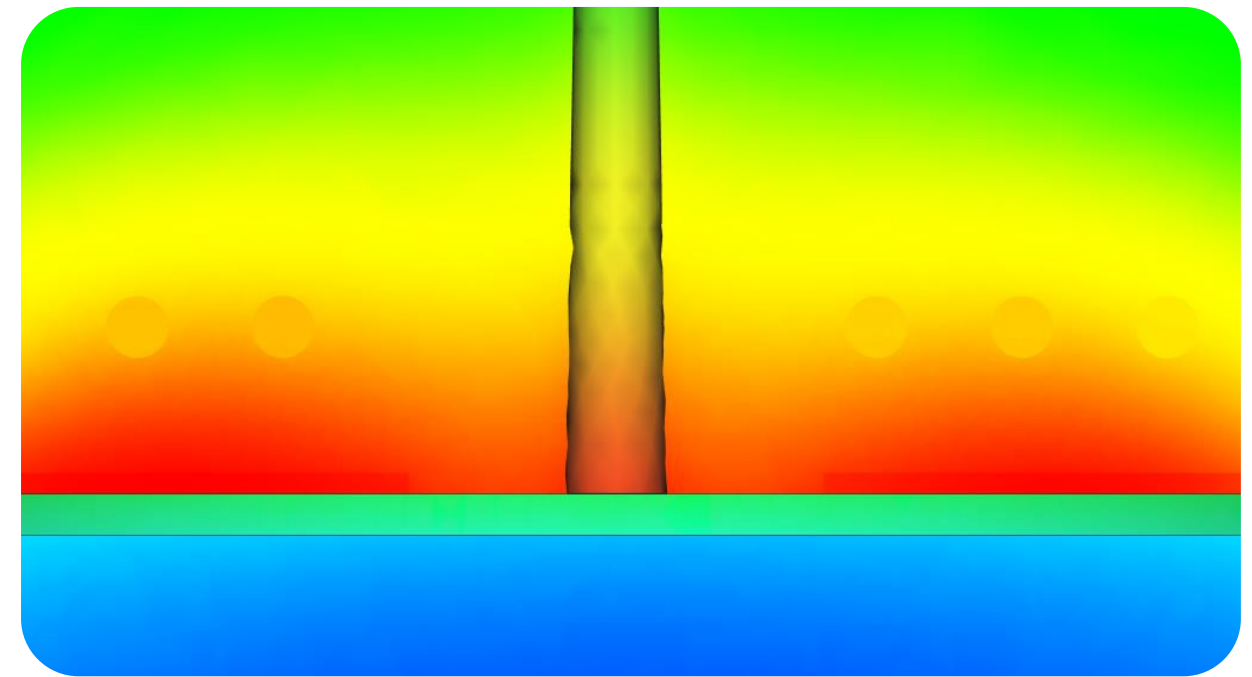


Induction Heating 해석 실습

- 어떤 결과가 Induction Heating 일까요?



Steam 해석



Induction Heating

Conclusions

1. Induction Heating 해석을 위해서는...

재료의 전기저항, 상대투자율, 전류 or 전압을 정확히 입력해야 함.

2. Mold Insert 의 표면에서 1st Layer의 두께는...

$$\delta = \frac{1}{\sqrt{\pi f \mu \sigma}}$$

→ **전력 주파수, 재료의 투자율, 재료의 전기 전도율**을 알아야 함.

3. Mold Insert 의 표면 메시 사이즈는...

$$\text{mesh size} = \frac{\delta}{0.8} \text{ 로 정해야 한다.}$$

4. Induction Heating의 장점으로...

복잡한 형상도 균일한 가열이 가능하다.

급속 가열이 가능하다.

열전도에 대한 손실이 우수하다.

감사합니다