

# 가우스 $X$ 의 헌신

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01

# 팀명 선정배경

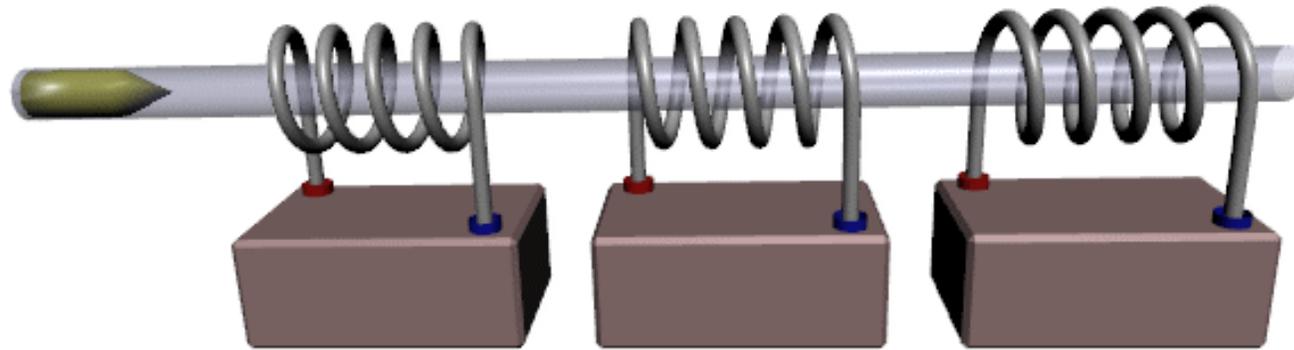
# 01. 팀명 선정배경

## 가우스X의 헌신



# 01. 팀명선정배경

## 가우스X의 헌신

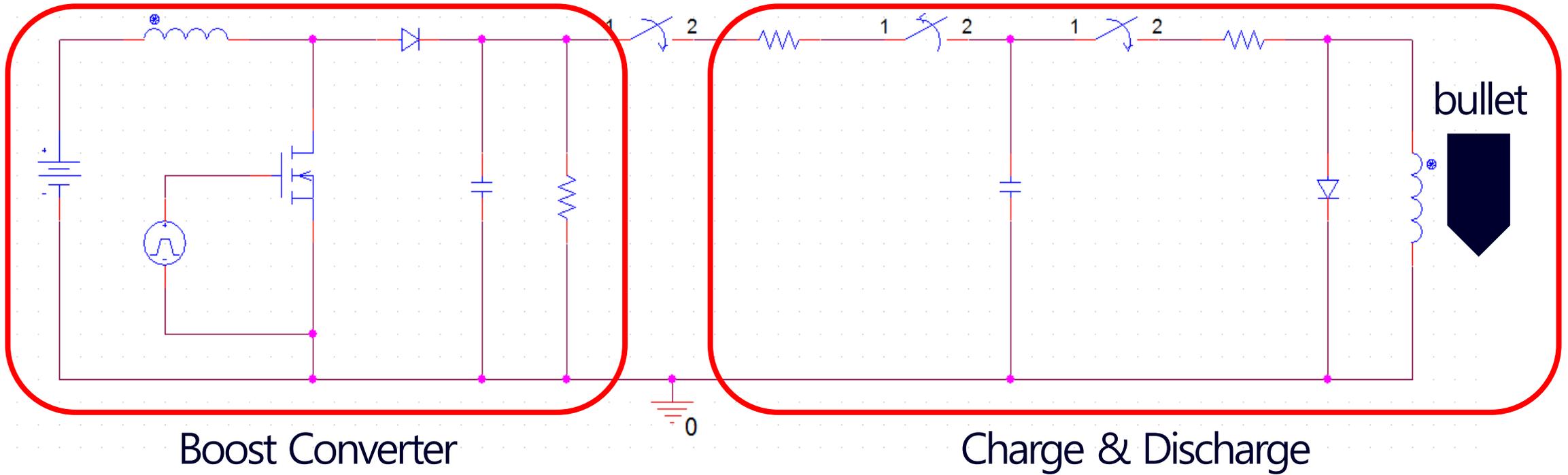


02

# 회로설계

# 02. 회로설계

개요

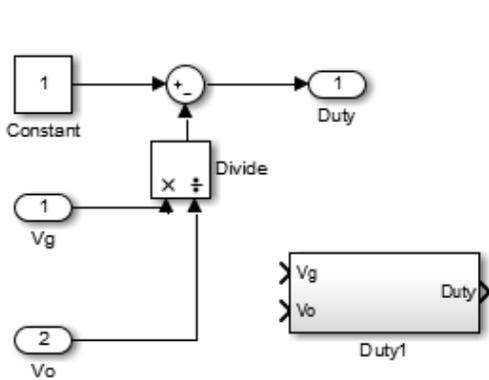


Coilgun Circuit

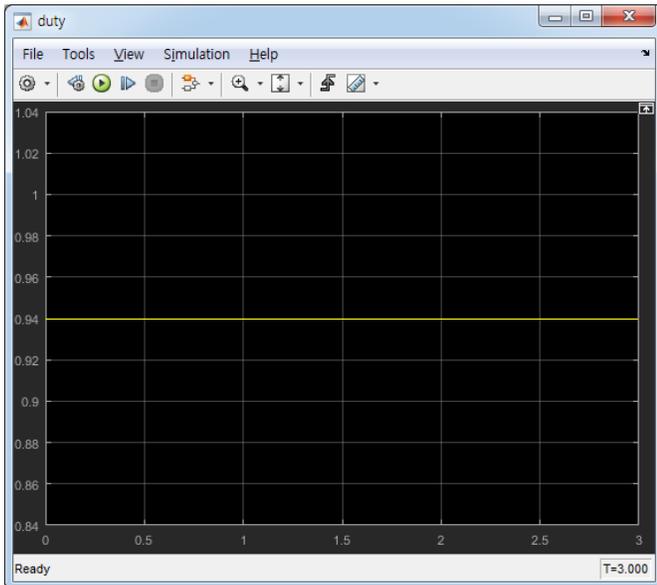


# 02. 회로설계

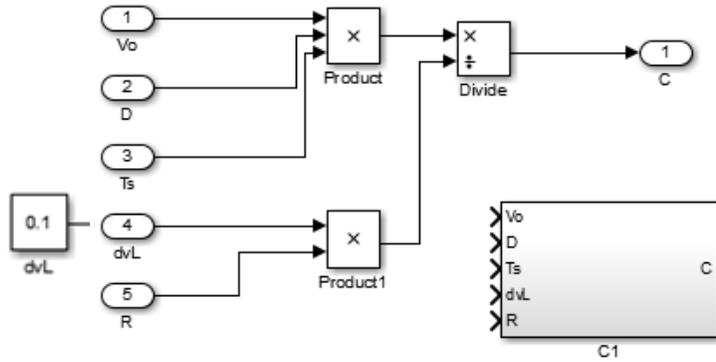
simulink



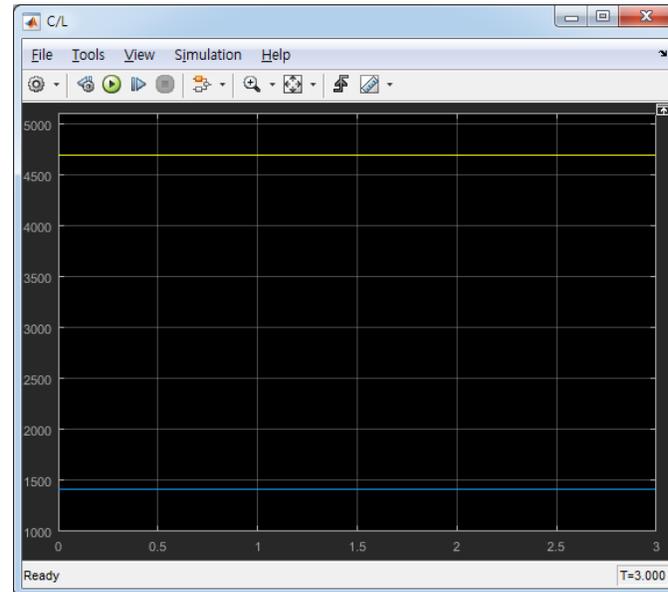
Duty cycle 결정



Duty=0.94



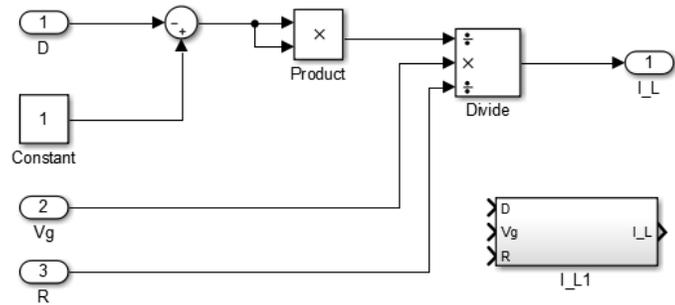
Ripple 값에 따른 CL 결정



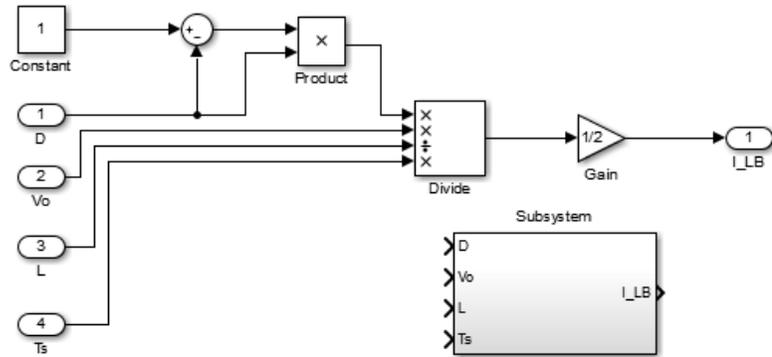
C=4600uF  
L=1410mH

# 02. 회로설계

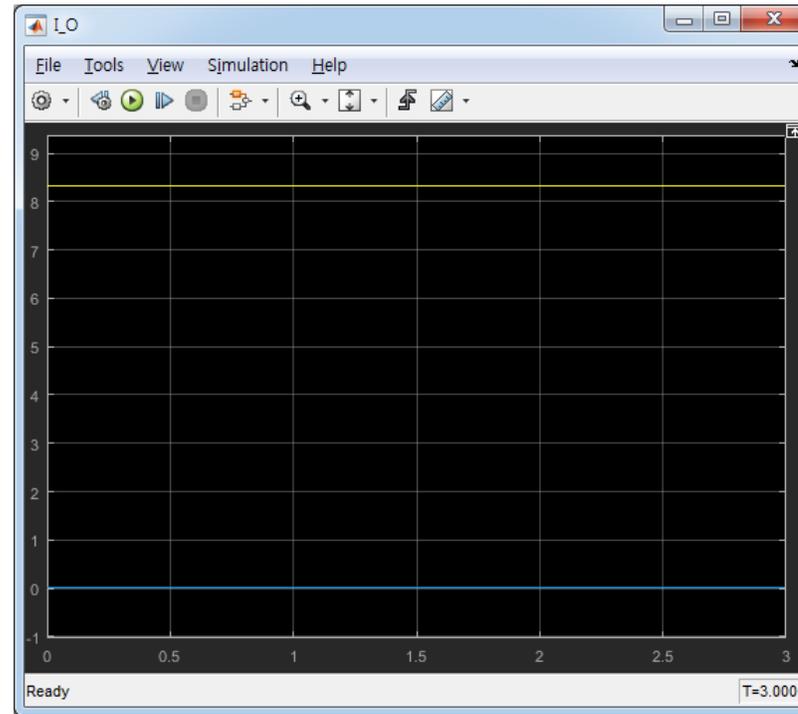
simulink



L에 흐르는 전류



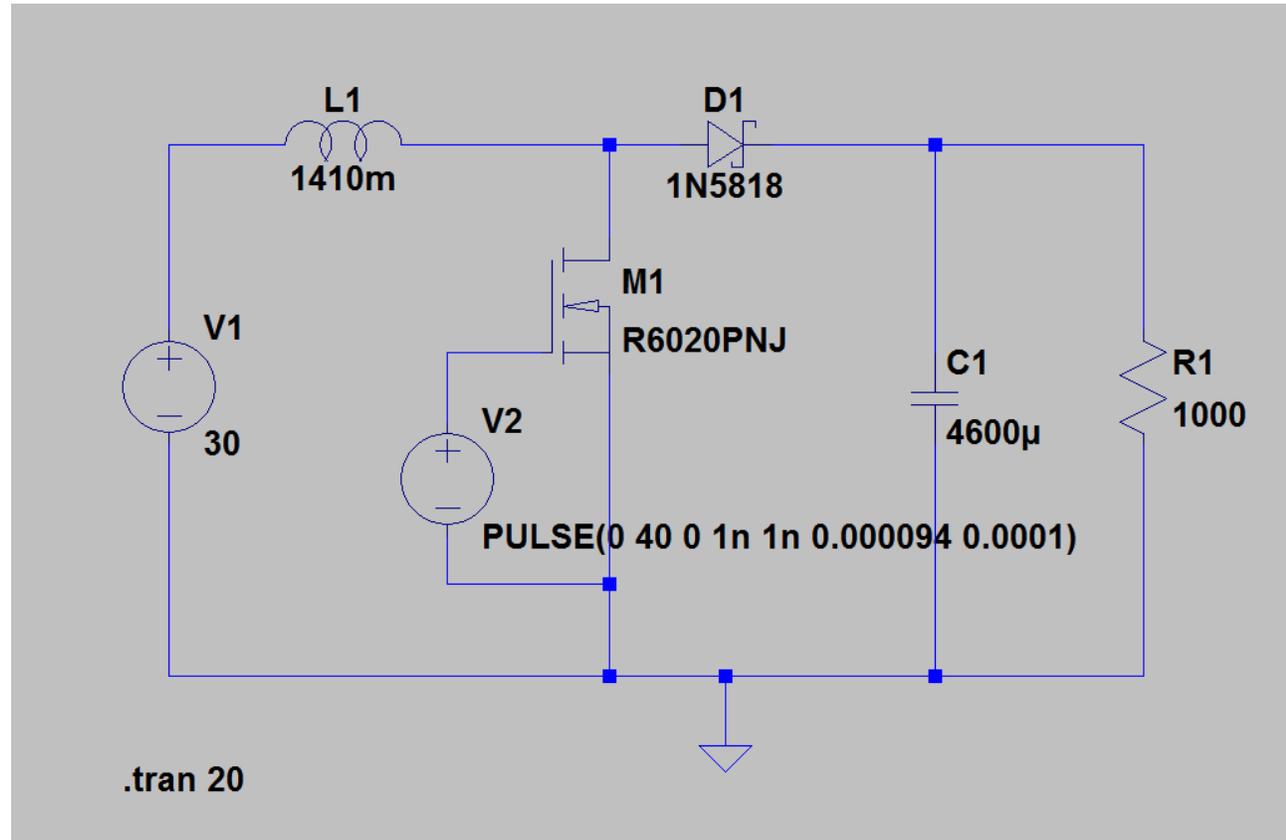
전류의 경계조건



$I_L > I_{LB}$   
=> continuous

## 02. 회로설계

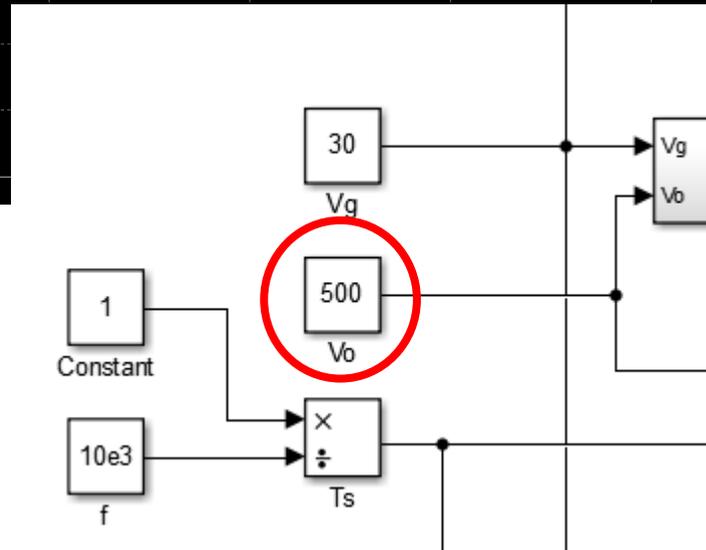
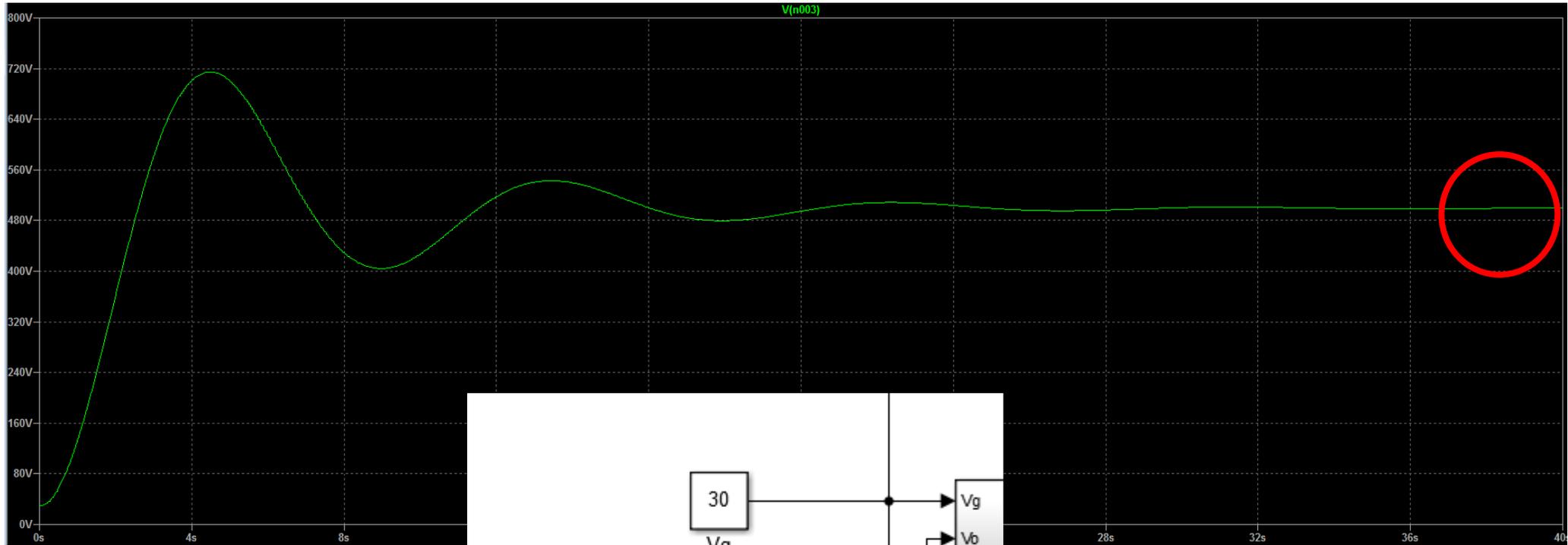
LTspice



Boost converter

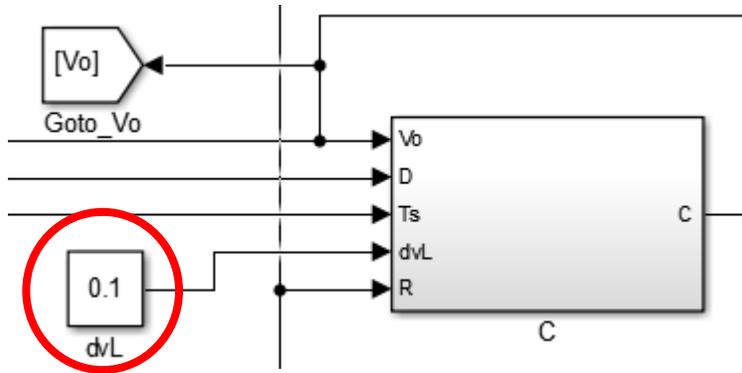
## 02. 회로설계

LTspice

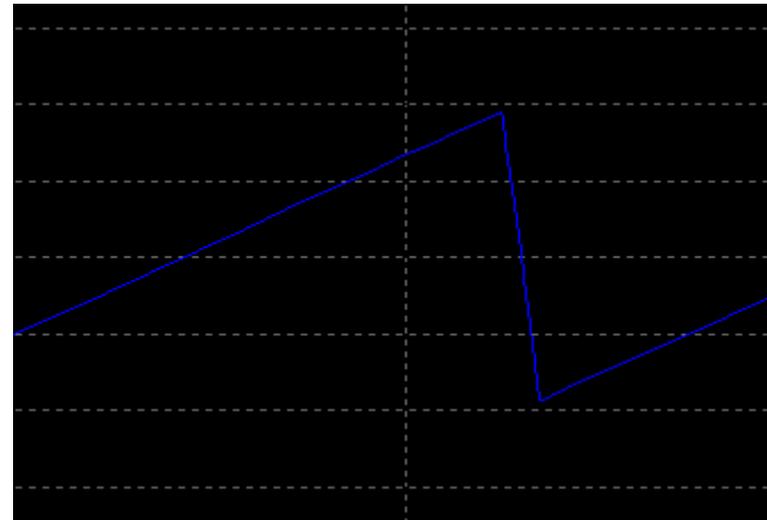
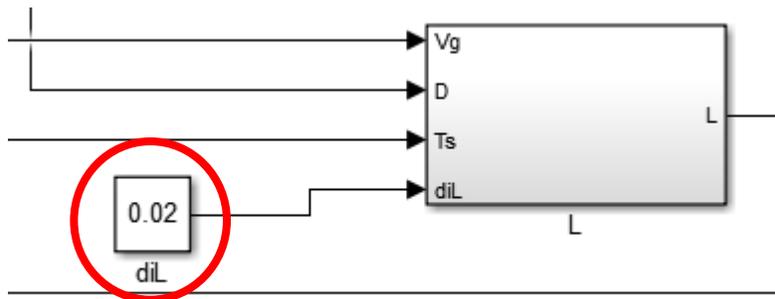


## 02. 회로설계

Simulink



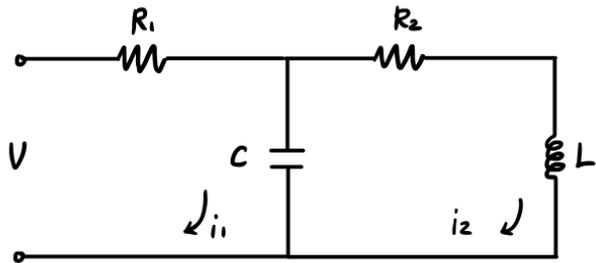
$V_{ripple} = 109 \text{ mV}$



$I_{ripple} = 19 \text{ mA}$

## 02. 회로설계

Analytically



$$q_1(0) = 0, \quad \dot{q}_1(0) = 0$$

$$q_2(0) = V/C, \quad \dot{q}_2 = 0$$

(1) 충전 회로

키르히호프 법칙을 쓰면

$$V - R_1 i_1(t) - \int \frac{1}{C} i_1(t) dt = 0$$

$$\Rightarrow V - R_1 \frac{dq_1(t)}{dt} - \int \frac{1}{C} \frac{dq_1(t)}{dt} dt = 0$$

$$q_1(t) = CV [1 - e^{-\frac{t}{RC}}]$$

$$i_1(t) = \frac{dq_1(t)}{dt} = \frac{V}{R_1} e^{-\frac{t}{RC}} = \frac{V}{R_1} e^{-\frac{t}{RC}}$$

$$v_1(t) = \frac{q}{C} = V [1 - e^{-\frac{t}{RC}}]$$

(2) 방전 회로

$$v_2(t) + R_2 i_2(t) + L \frac{di_2(t)}{dt} = 0$$

$$\Rightarrow \frac{q_2}{C}(t) + R_2 \frac{dq_2(t)}{dt} + L \frac{d^2 q_2(t)}{dt^2} = 0$$

$$\text{Let } A = \frac{R_2}{2L}, \quad B = \sqrt{\frac{1}{LC} - \frac{R_2^2}{4L^2}}$$

$$q_2(t) = \frac{1}{L} \left[ \frac{R_2 CV}{B} \cdot \sin Bt \cdot e^{-At} + LCV \cos Bt \cdot e^{-At} \right]$$

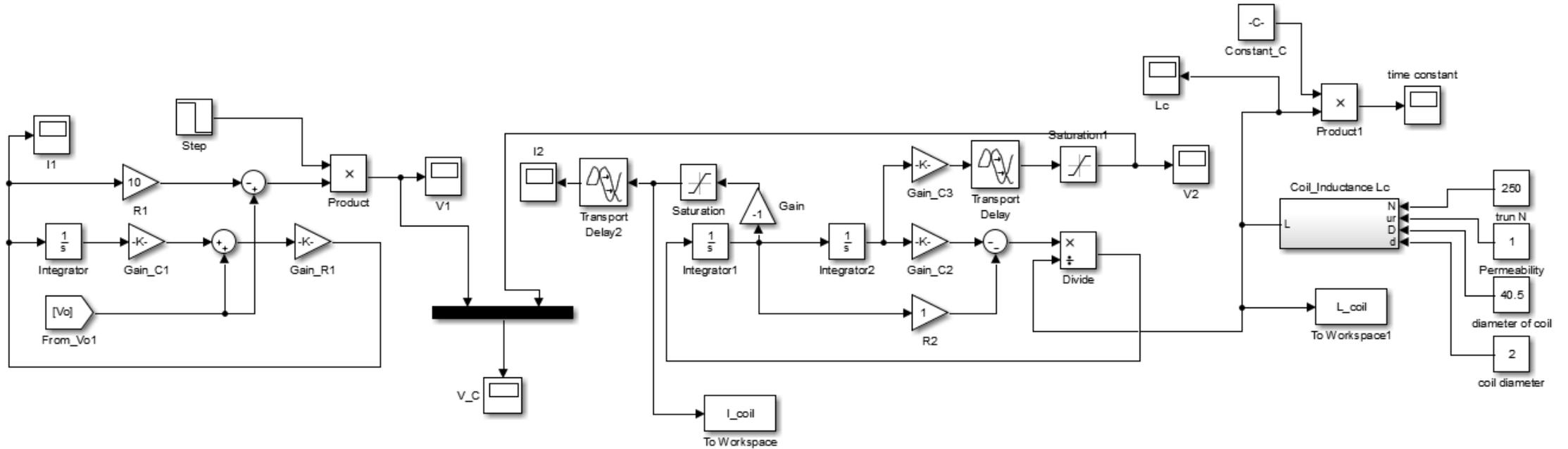
$$i_2(t) = \frac{1}{L} \left[ \frac{R_2 CV}{B} (B \cos Bt \cdot e^{-At} - A \sin Bt \cdot e^{-At}) + LCV (-B \sin Bt \cdot e^{-At} - A \cos Bt \cdot e^{-At}) \right]$$

$$v_2(t) = \left[ \frac{R_2 V}{B} \cdot \sin Bt \cdot e^{-At} + LV \cdot \cos Bt \cdot e^{-At} \right]$$

Charge & Discharge circuit

# 02. 회로설계

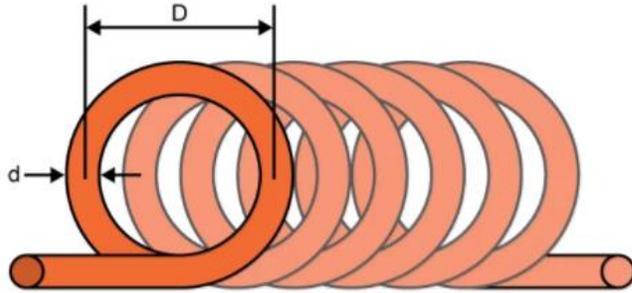
Simulink



Charge & Discharge circuit

## 02. 회로설계

Simulink



Equation

$$L_{coil} \approx N^2 \mu_0 \mu_r \left( \frac{D}{2} \right) \left[ \ln \left( \frac{8D}{d} \right) - 2 \right]$$

Where:

$L_{coil}$  = inductance of the coil in henries (H)

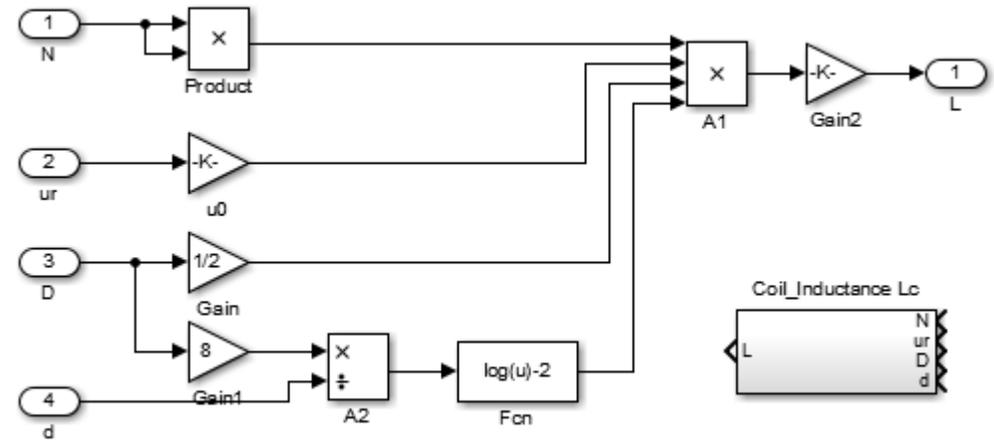
$N^2$  = number of turns

$\mu_0$  = permeability of free space =  $4\pi \times 10^{-7}$

$\mu_r$  = relative permeability

$D$  = loop diameter

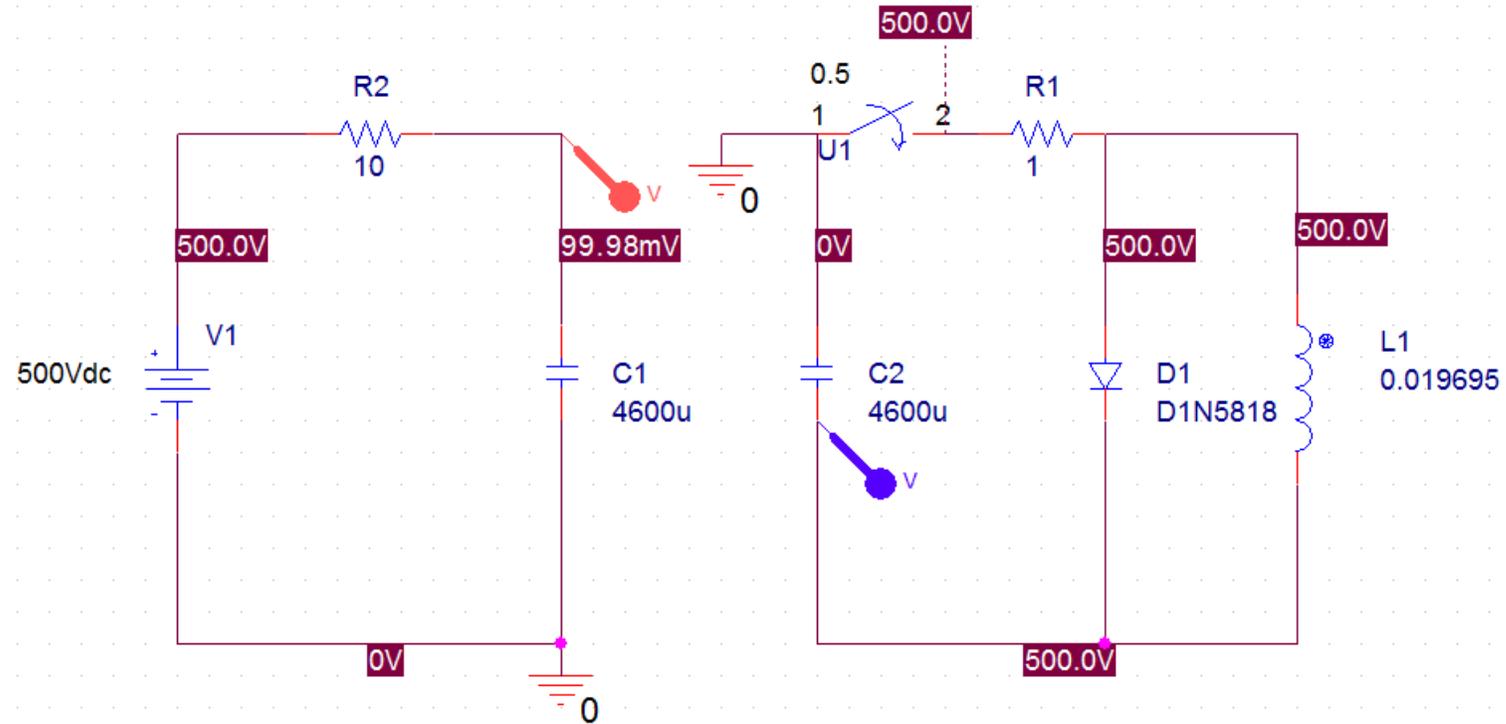
$d$  = wire diameter



코일의 인덕턴스 계산

## 02. 회로설계

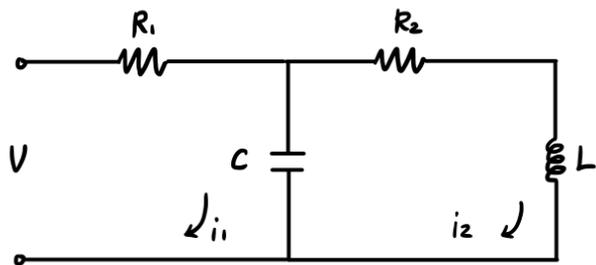
Pspice



Charge & Discharge circuit

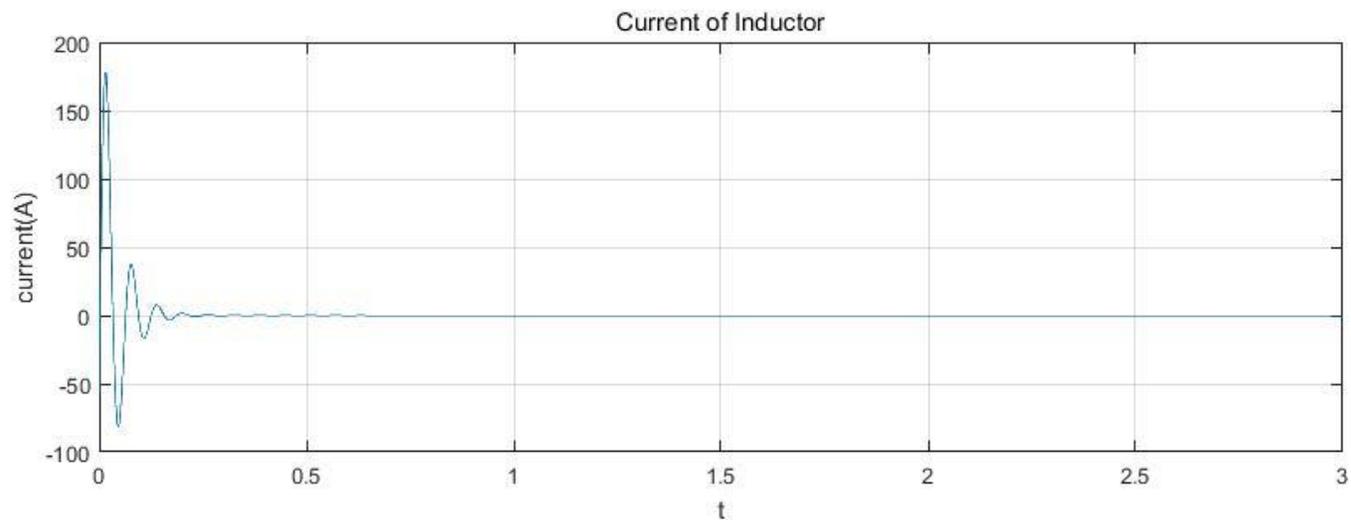
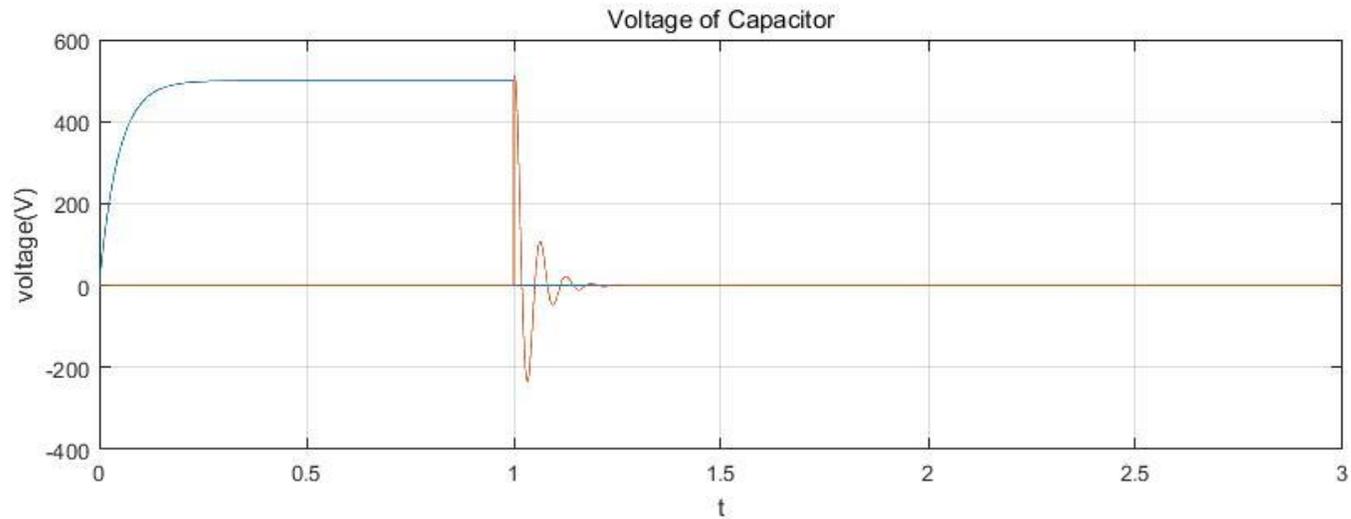
## 02. 회로설계

Analytically



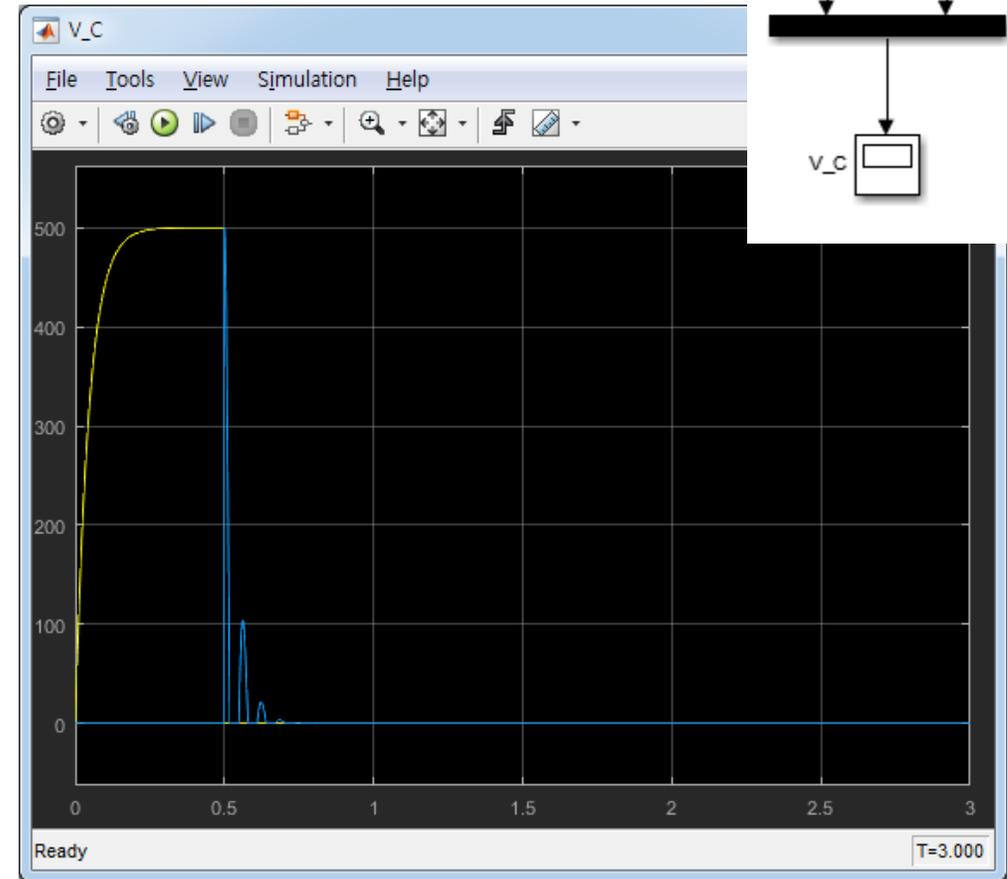
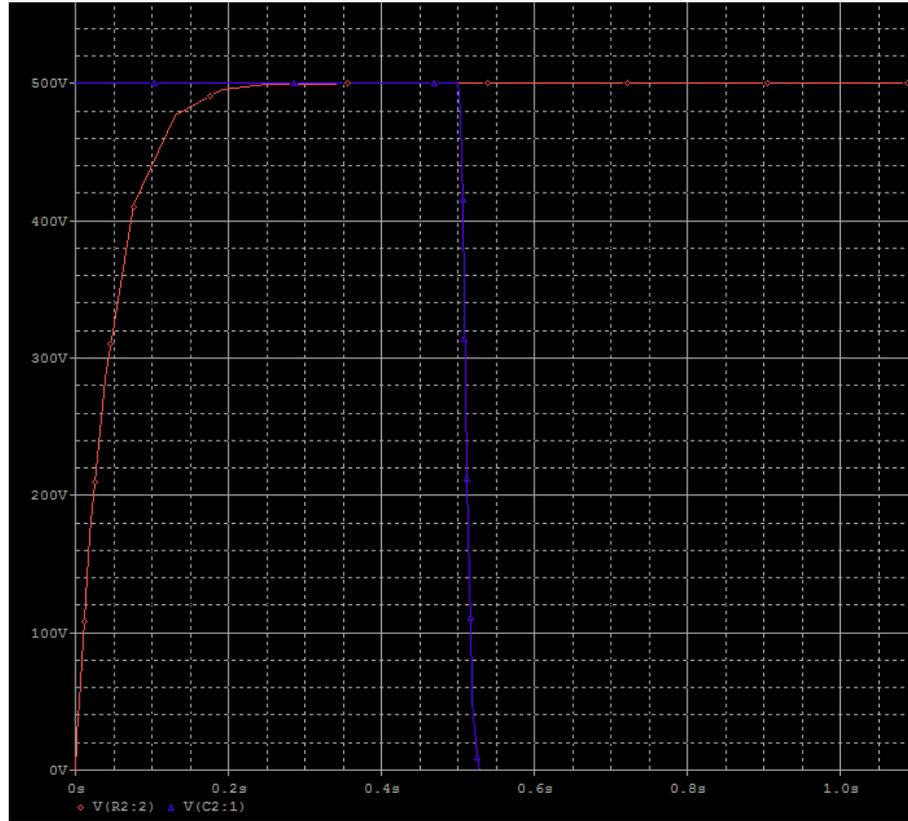
$$q_1(0) = 0, \dot{q}_1(0) = 0$$

$$q_2(0) = V/C, \dot{q}_2 = 0$$



## 02. 회로설계

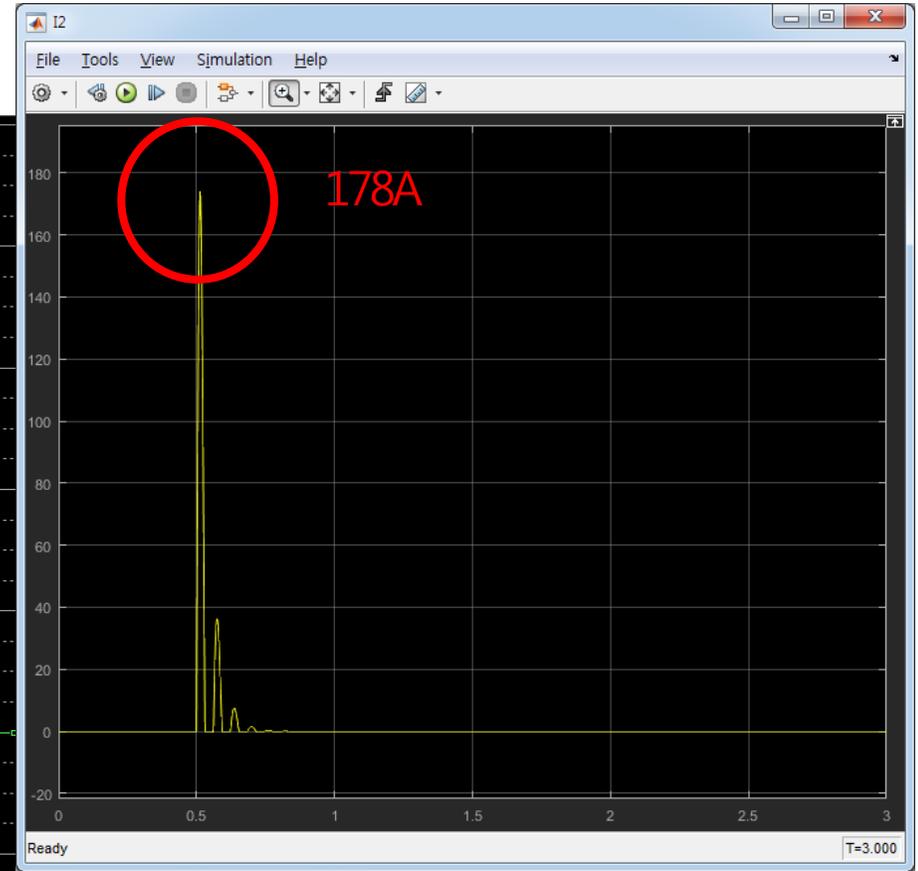
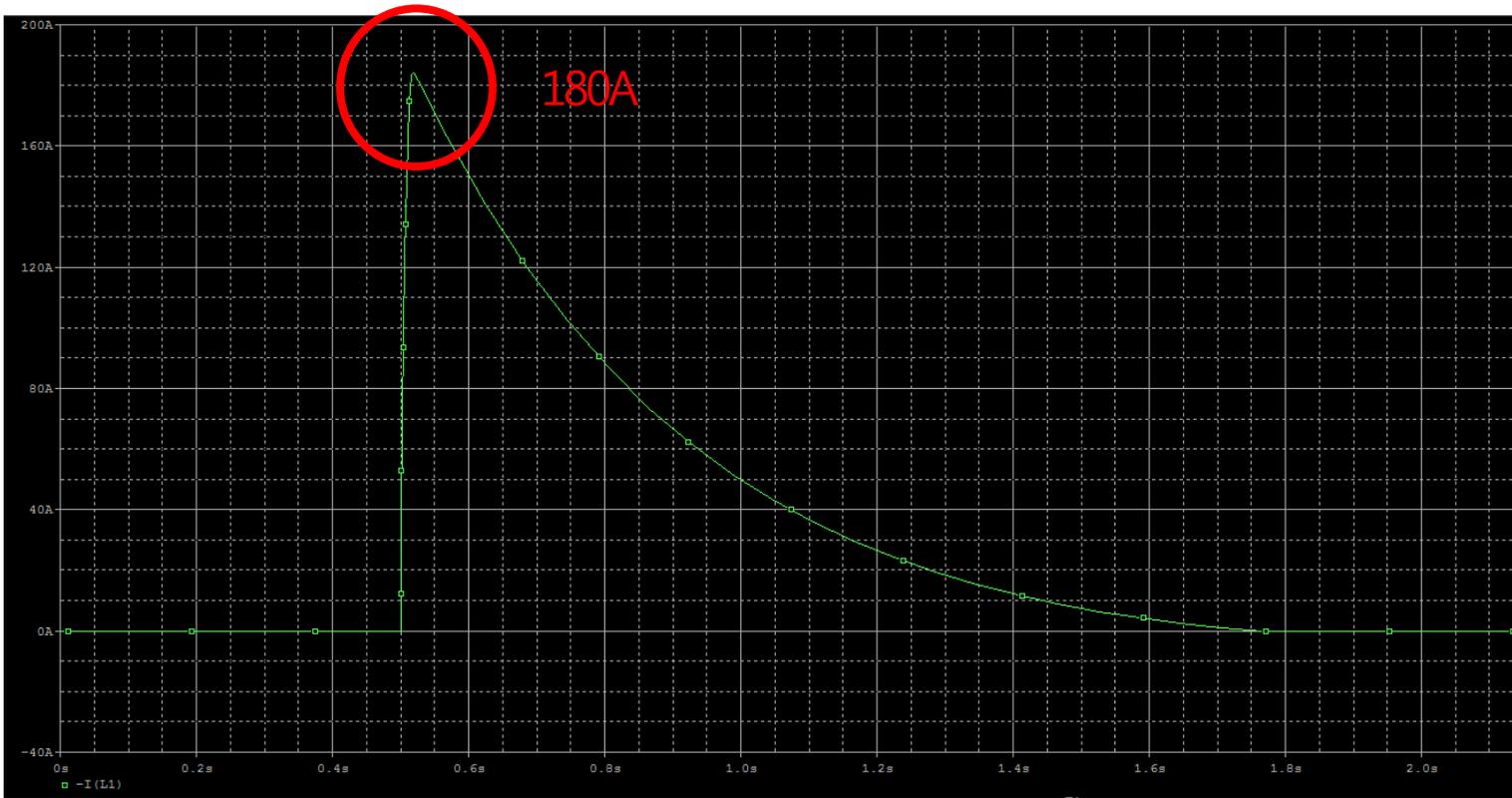
Pspice



충 방전시 V 비교

## 02. 회로설계

Pspice



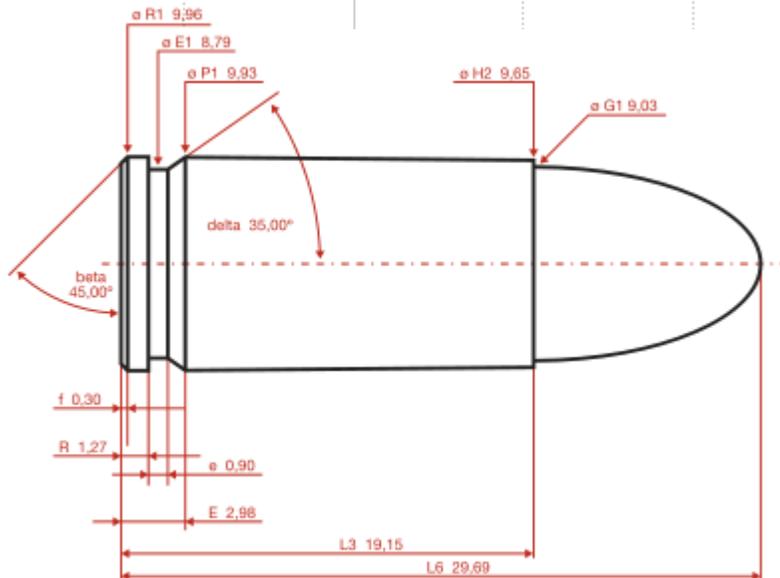
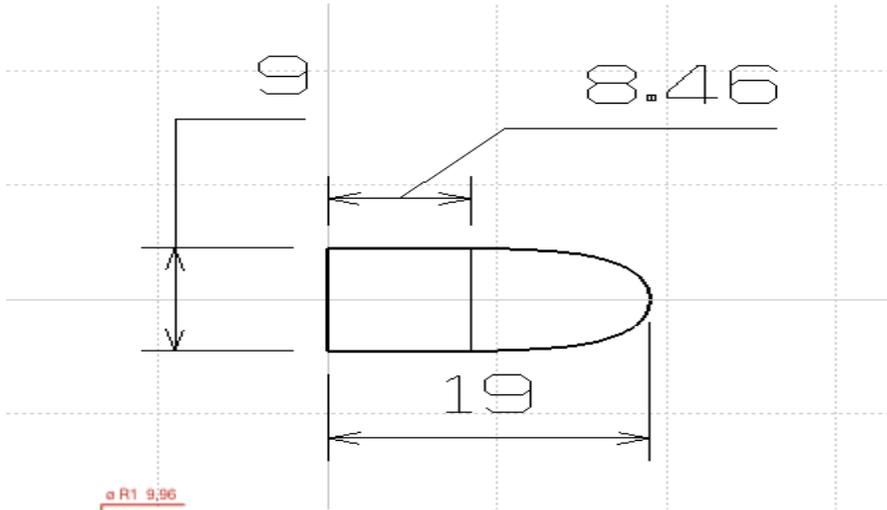
코일에 인가되는 전류 비교

03

# 코일건 모델링

# 03.코일건모델링

CATIA

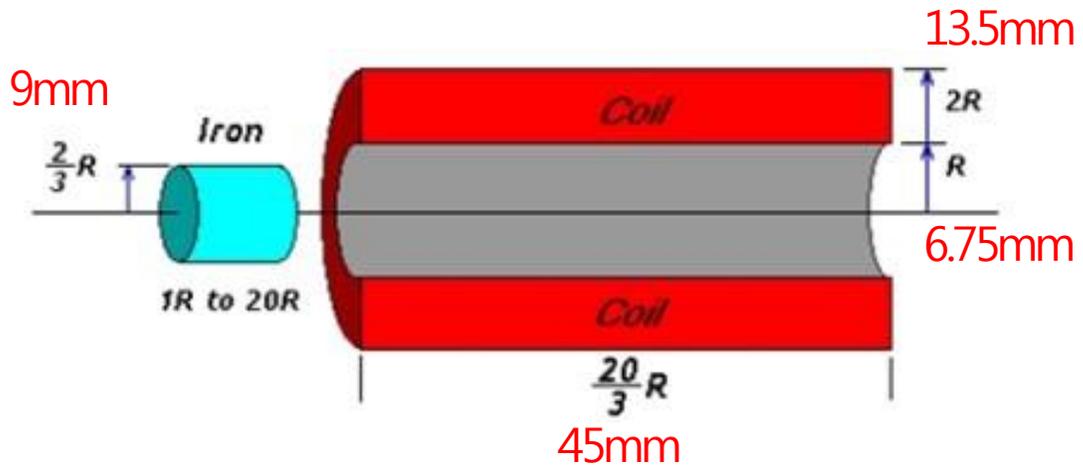
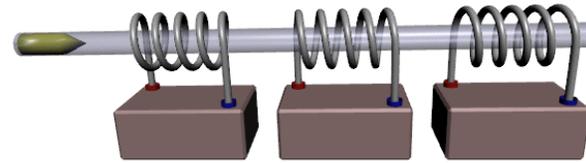


Bullet- Iron

총알 모델링

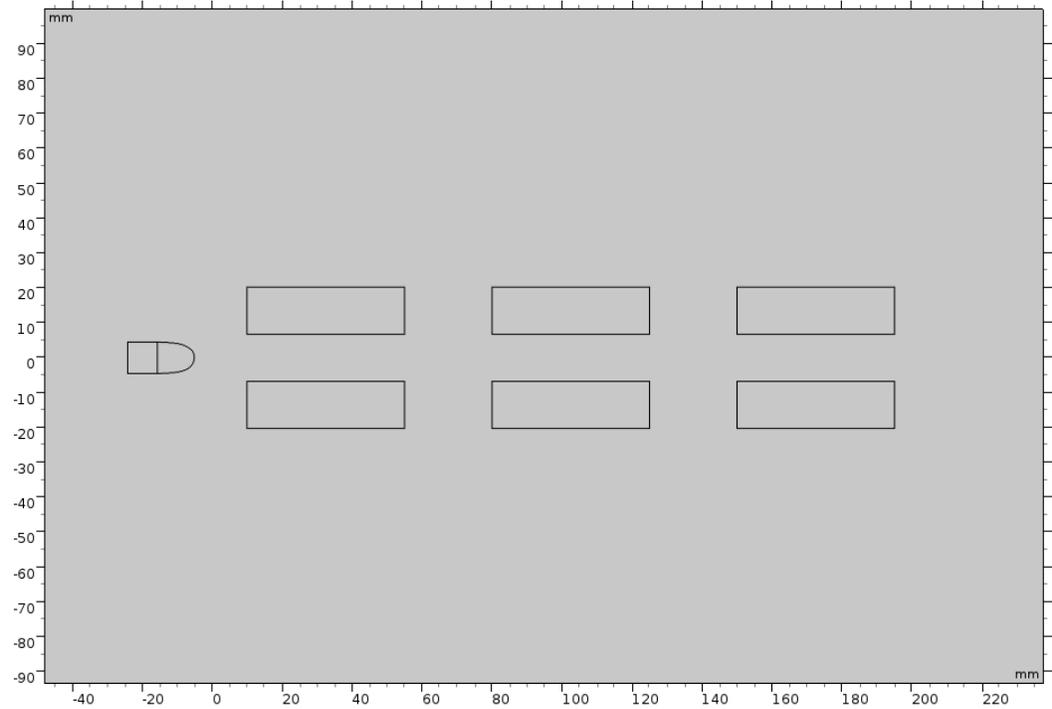
# 03. 코일건 모델링

COMSOL



$R=27/4$

코일건 규격

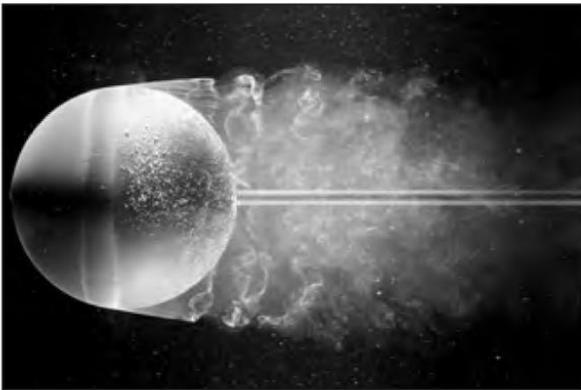


COMSOL 모델링

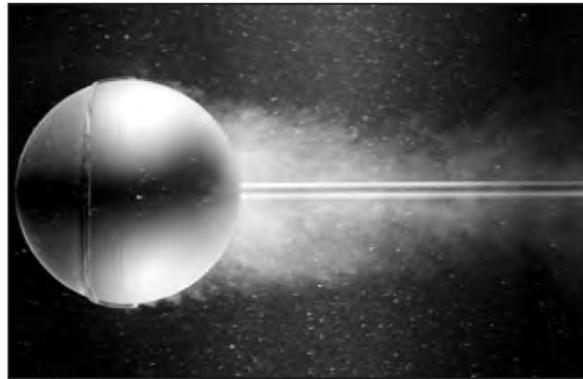
### 03.코일건모델링

#### COMSOL

- In the moderate range of  $10^3 < Re < 10^5$ , the drag coefficient remains relatively constant. This behavior is characteristic of blunt bodies. The flow in the boundary layer is laminar in this range, but the flow in the separated region past the cylinder or sphere is highly turbulent with a wide turbulent wake.
- There is a sudden drop in the drag coefficient somewhere in the range of  $10^5 < Re < 10^6$  (usually, at about  $2 \times 10^5$ ). This large reduction in  $C_D$  is due to the flow in the boundary layer becoming *turbulent*, which moves the separation point further on the rear of the body, reducing the size of the wake and thus the magnitude of the pressure drag. This is in contrast to streamlined bodies, which experience an increase in the drag coefficient (mostly due to friction drag) when the boundary layer becomes turbulent.

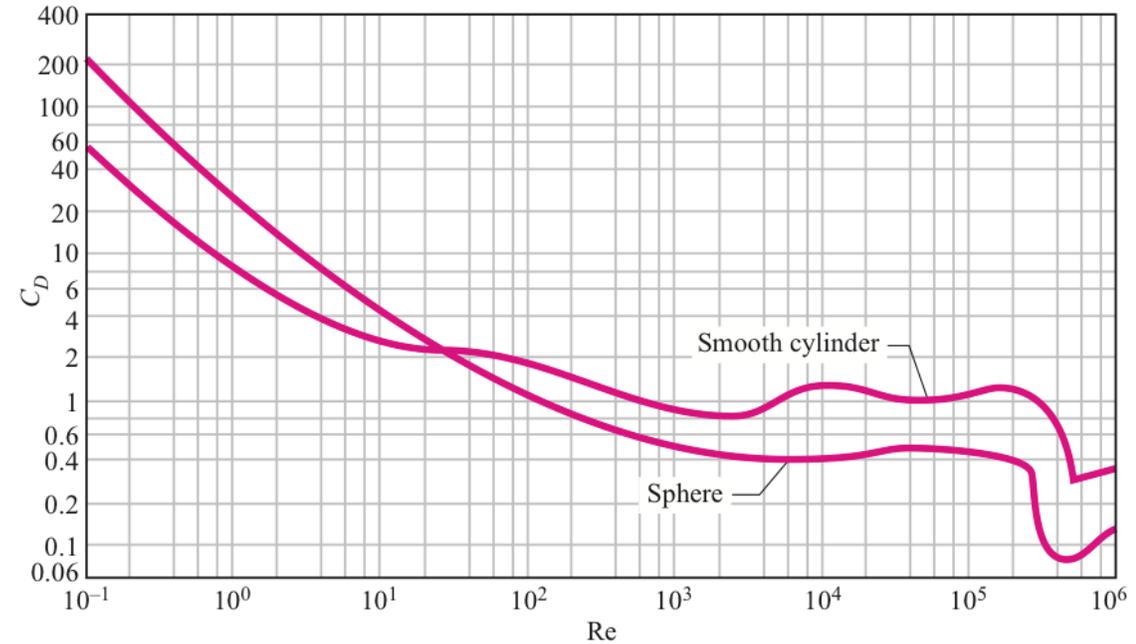


(a)



(b)

### Fluid Mechanics Cengel & Cimbala



$$Re = \frac{v_{avg} D}{\nu} = \frac{100 * 0.0135}{1.48 * 10^{-5}} = 91216.2$$

# 03.코일건모델링

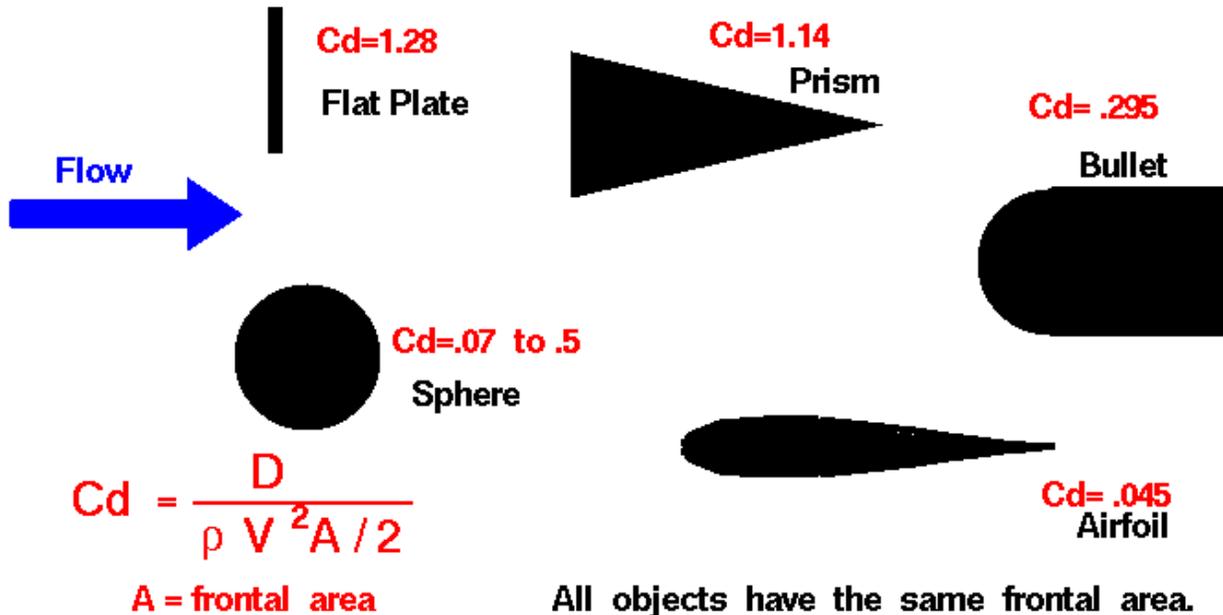
COMSOL



## Shape Effects on Drag

Glenn  
Research  
Center

The shape of an object has a very great effect on the amount of drag.



$$F_D = \frac{1}{2} \rho v^2 C_D A$$

Analytically

$$F_D = 0.111N$$

Numerically

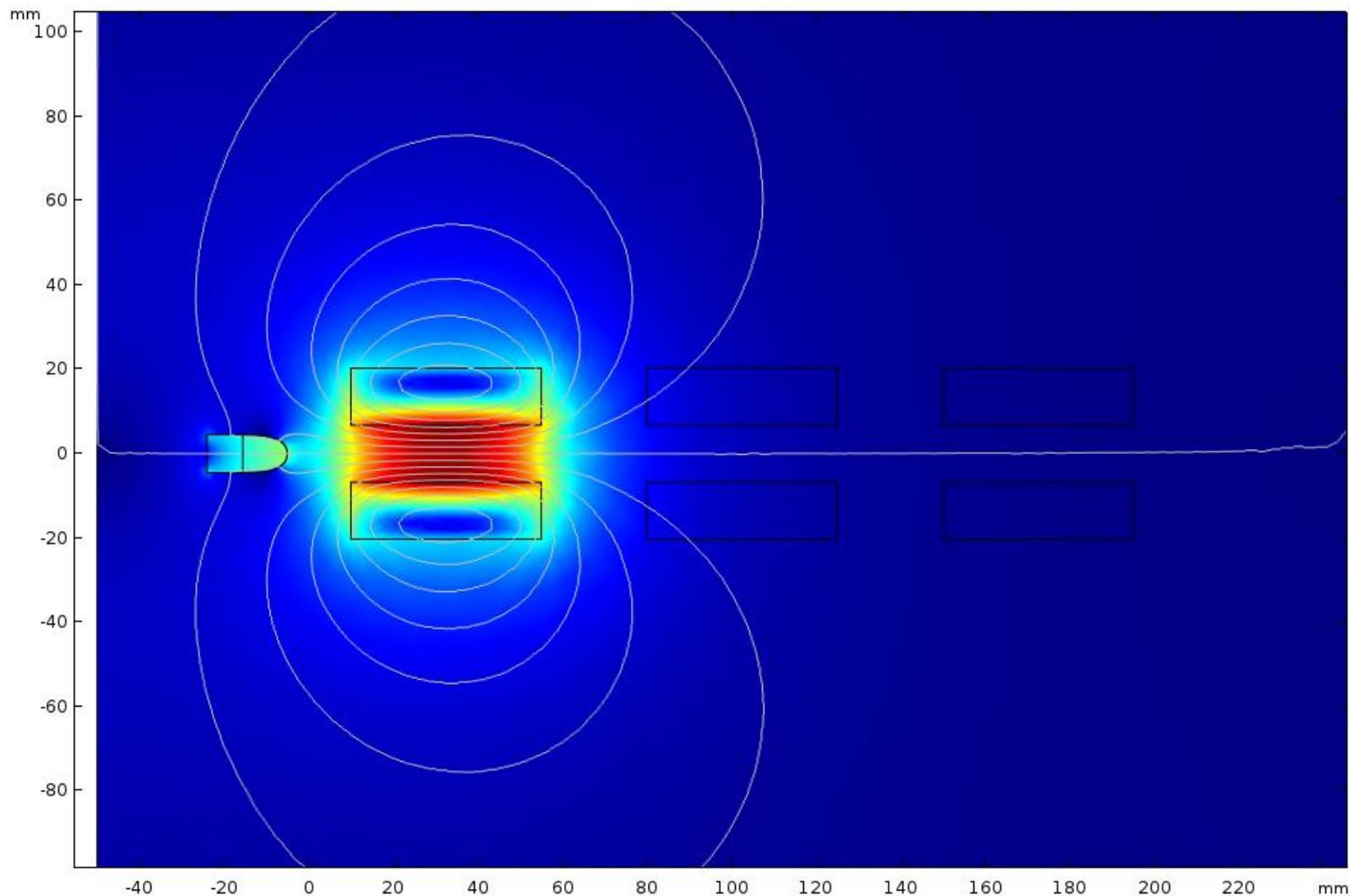
$$F_D = 0.160N$$

04

# 코일건 분석

# 04. 코일건분석

COMSOL



- 자기장 (mf)
- ▶ 암페어 법칙 1
- ▶ 자기 절연 1
- ▶ 초기 값 1
- ▶ 암페어 법칙 2
- ▶ 암페어 법칙 3
- ▶ 외부 전류 밀도 1
- ▶ 외부 전류 밀도 2
- ▶ 힘 계산 1

전자기력 (#0), #1 성분, x 성분 (N)

829.40

# 04. 코일건분석

MATLAB

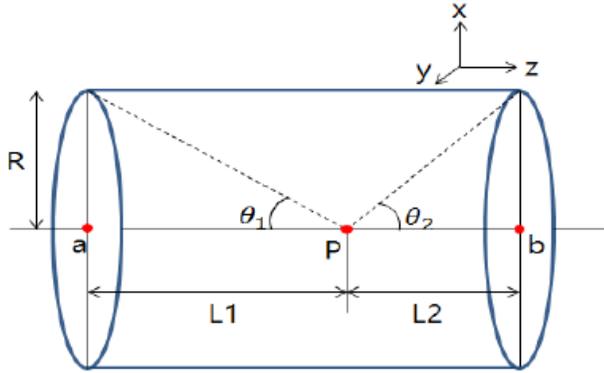


Fig. 2. Magnetic flux density at point P

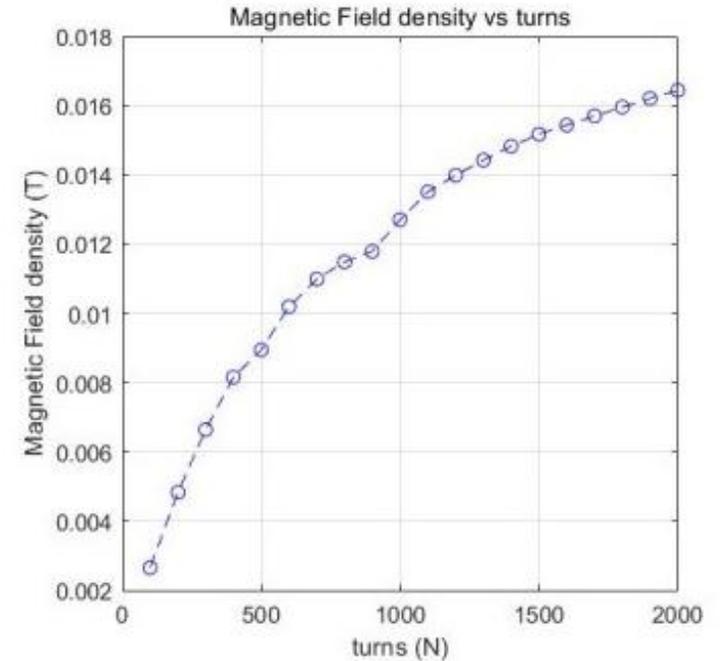
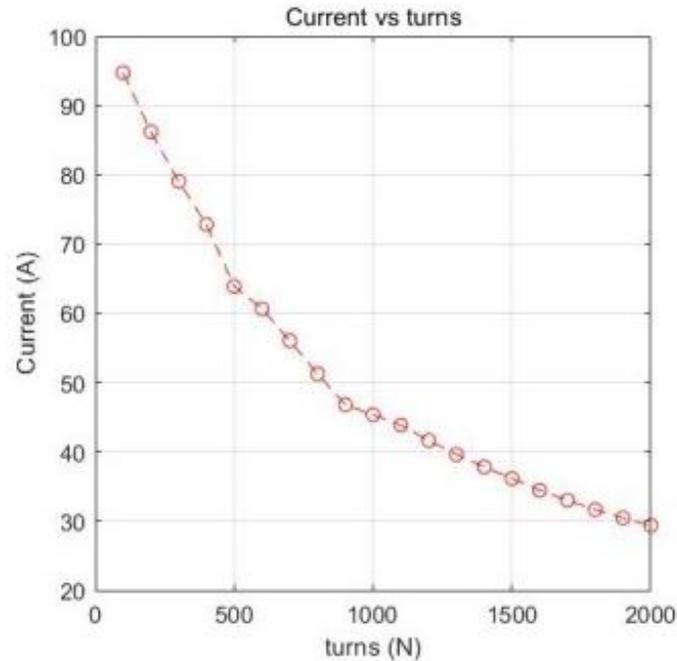
P에서의 자기장 B값은 식 (3)과 (4)를 통해 구할 수 있다.

$$dB_z = \frac{\mu_0 n R i}{4\pi r^3} ds dz \quad (3)$$

$$B_z = \frac{\mu_0}{4\pi} n R i \int_0^{2\pi R} ds \int_{-a}^b \frac{dz}{r^3} \quad (4)$$

$$= \frac{\mu_0 n i}{2} \left[ \frac{a}{\sqrt{R^2 + a^2}} + \frac{b}{\sqrt{R^2 + b^2}} \right]$$

$$= \frac{\mu_0 n i}{2} (\cos \theta_1 + \cos \theta_2)$$



Turns와 Current, Magnetic field density 사이의 관계 예측

# 04. 코일건분석

COMSOL

The screenshot displays the COMSOL Multiphysics interface. On the left is the 'Model Builder' tree, showing a project named 'Untitled.mph' with a 'Component 1' containing 'Geometry 1'. The 'Import' option is selected in the 'Geometry 1' context menu. In the center, the 'Import Geometry' dialog box is open, showing the file path '내 PC > 다운로드 > Desktop > bullet' and a search bar containing 'bullet 검색'. The file explorer shows various folders and files, with '다운로드' (Downloads) selected. On the right, the 'Graphics' window shows a 3D model of a bullet. The bullet is a cylinder with a rounded nose, positioned in a 3D coordinate system. The x-axis ranges from -4 to 4, the y-axis from -4 to 4, and the z-axis from 0 to 15. The bullet's length is 15 m, its diameter is 10 m, and its radius is 5 m. A coordinate system with x, y, and z axes is visible in the bottom left corner of the Graphics window.

# 04. 코일건분석

## COMSOL

### Settings

Block

Build Selected Build All Objects

Label: Block 1

Object Type

Type: Solid

Size and Shape

Width: 50 mm

Depth: 500 mm

Height: 50 mm

Position

Base: Center

x: 0 mm

y: -100 mm

z: 0 mm

Axis

Axis type: z-axis

Rotation Angle

Rotation: 0 deg

Coordinate System

Work plane: xy-plane

### Graphics

mm

20

-20

0

mm

-200

20

0

-20

mm

Messages Progress Log Table 1

COMSOL Multiphysics 5.3.0.260  
Opened file: D:\Download\Desktop\bullet\successful\_laminar\_dragforce.mph  
Some geometric entities are hidden.

# 04. 코일건분석

## COMSOL

The screenshot displays the COMSOL Multiphysics software interface for a project named 'successful\_laminar\_dragforce.mph'. The interface is divided into several main sections:

- Model Builder:** Shows a hierarchical tree of the model. Under 'Component 1 (comp1)', 'Geometry 1' contains 'Block 1 (blk1)', 'Import 1 (imp1)', and 'Form Union (fin)'. Under 'Materials', 'Air (mat1)' and 'Iron (mat2)' are listed. 'Laminar Flow (spf)' and 'Mesh 1' are also present. Under 'Study 1', 'Results' includes 'Data Sets', 'Derived Values', 'Tables', 'Velocity (spf)', 'Slice', 'Streamline 1', 'Contour 1', and 'Arrow Volume 1'. 'Pressure (spf)', 'Export', and 'Reports' are also available.
- Settings:** The 'Material' section is active, showing 'Iron' as the selected material. The 'Geometric Entity Selection' section shows 'Domain' as the entity level and 'Manual' as the selection method. A table of material properties is displayed below:

Property	Name	Value	Unit	Pr...
Relative permeability	mur	4000	1	Bas...
Electrical conductivity	sigma	1.12e7[S...	S/m	Bas...
Coefficient of thermal expan...	alpha	12.2e-6[...	1/K	Bas...
Heat capacity at constant pre...	Cp	440[J/(k...	J/(kg·K)	Bas...
Relative permittivity	epsilo...	1	1	Bas...
Density	rho	7870[kg...	kg/m³	Bas...
Thermal conductivity	k	76.2[W/...	W/(m...	Bas...
Young's modulus	E	200e9[Pa]	Pa	Yoi...
Poisson's ratio	nu	0.29	1	Yoi...

- Graphics:** Displays a 3D perspective view of a rectangular coil. The dimensions are indicated as 20 mm in width and height, and -200 mm in length. The coordinate system (x, y, z) is shown at the bottom left.
- Messages:** A message box at the bottom right states: 'COMSOL Multiphysics 5.3.0.260. Opened file: D:\Download\Desktop#\bullet#successful\_laminar\_dragforce.mph. Some geometric entities are hidden.'

At the bottom of the interface, the system status shows '975 MB | 1259 MB'.

# 04. 코일건분석

## COMSOL

The screenshot displays the COMSOL Multiphysics software interface for a simulation titled "successful\_laminar\_dragforce.mph". The interface is divided into several main panels:

- Model Builder:** Shows the hierarchical structure of the model. The "Inlet 1" boundary condition is selected under the "Laminar Flow (spf)" physics.
- Settings:** Displays the configuration for the "Inlet 1" boundary condition. The "Boundary Selection" is set to "Manual" with a value of "5". The "Boundary Condition" is set to "Velocity". Under the "Velocity" section, "Normal inflow velocity" is selected, and the velocity  $U_0$  is set to 70 m/s.
- Graphics:** Shows a 3D perspective view of a rectangular duct. The duct has a length of 200 mm and a cross-section of 20 mm by 20 mm. The inlet face is highlighted in blue. A coordinate system (x, y, z) is shown at the bottom left of the graphics area.
- Messages:** Displays the following text: "COMSOL Multiphysics 5.3.0.260", "Opened file: D:\#Download#\Desktop#\bullet#\successful\_laminar\_dragforce.mph", and "Some geometric entities are hidden."

# 04. 코일건분석

## COMSOL

The screenshot displays the COMSOL Multiphysics software interface for a file named 'successful\_laminar\_dragforce.mph'. The interface is divided into several main sections:

- Top Ribbon:** Contains tabs for File, Home, Definitions, Geometry, Materials, Physics, Mesh, Study, Results, and Developer. Below these are icons for various tools like Application Builder, Component, Parameters, Import, Add Material, Laminar Flow, Add Physics, Build Mesh, Mesh, Compute, Study, Add Study, Velocity, Add Plot Group, Windows, and Reset Desktop.
- Model Builder (Left):** A tree view showing the model's structure. The 'Outlet 1' boundary condition is currently selected. The tree includes: successful\_laminar\_dragforce.mph (root), Global Definitions, Mesh Parts, Materials, Component 1 (comp1), Definitions, Geometry 1 (with sub-items: Block 1 (blk1), Import 1 (imp1), Form Union (fin)), Materials (with sub-items: Air (mat1), Iron (mat2)), Laminar Flow (spf) (with sub-items: Fluid Properties 1, Initial Values 1, Wall 1, Inlet 1, Outlet 1, Symmetry 1), Mesh 1, Study 1, and Results (with sub-items: Data Sets, Derived Values, Tables, Velocity (spf) (with sub-items: Slice, Streamline 1, Contour 1, Arrow Volume 1), Pressure (spf), and Export).
- Settings (Middle):** The 'Outlet 1' settings are displayed. The 'Boundary Selection' is set to 'Manual' with '2' selected as the active boundary. The 'Boundary Condition' is set to 'Pressure'. Under 'Pressure Conditions', the pressure  $P_0$  is set to 0 Pa, and the 'Suppress backflow' checkbox is checked.
- Graphics (Right):** A 3D perspective view of a rectangular coil. The dimensions are labeled in millimeters (mm): a length of 200 mm, a width of 20 mm, and a height of 20 mm. A coordinate system with x, y, and z axes is shown at the bottom left of the graphics area.
- Messages (Bottom):** A status bar at the bottom of the window shows '981 MB | 1244 MB'. The Messages pane contains the following text: 'COMSOL Multiphysics 5.3.0.260', 'Opened file: D:\#Download#\Desktop#\bullet#\successful\_laminar\_dragforce.mph', and 'Some geometric entities are hidden.'

# 04. 코일건분석

## COMSOL

The screenshot displays the COMSOL Multiphysics software interface for a file named 'successful\_laminar\_dragforce.mph'. The interface is divided into several main sections:

- Top Bar:** Contains the 'File' menu and tabs for 'Home', 'Definitions', 'Geometry', 'Materials', 'Physics', 'Mesh', 'Study', 'Results', and 'Developer'.
- Toolbars:** Below the tabs are toolbars for 'Application Builder', 'Model', 'Definitions', 'Geometry', 'Materials', 'Physics', 'Mesh', 'Study', 'Results', and 'Layout'.
- Model Builder:** A tree view on the left showing the project hierarchy. The 'Symmetry 1' node is selected.
- Settings:** A central panel showing the configuration for 'Symmetry 1'. The 'Boundary Selection' is set to 'Manual', and a list of active boundaries (1, 3, 4, 8) is displayed.
- Graphics:** A 3D view on the right showing a blue rectangular coil. The dimensions are labeled in millimeters (mm): length 200, width 20, and height 20. A coordinate system (x, y, z) is shown at the bottom left.
- Messages:** A panel at the bottom right showing system messages, including the version 'COMSOL Multiphysics 5.3.0.260' and the file path.

# 04. 코일건분석

COMSOL

The screenshot displays the COMSOL Multiphysics interface. On the left, the 'Model Builder' tree shows a 'Success' node expanded to 'Global Evaluation', with 'Integration' selected. The 'Settings' dialog for 'Surface Integration' is open, showing the following configuration:

- Label: Surface Integration 1
- Data: Study 1/Solution 1 (sol1)
- Selection: Manual
- Active: 6, 7
- Expressions table:

Expression	Unit	Description
spf.T_stressy	N	Total stress, y component

On the right, the 'Graphics' window shows a 3D plot of a coil with a stress distribution. The plot is a blue, elongated, rounded shape. The vertical axis is labeled 'mm' and ranges from -4 to 4. The horizontal axis is labeled 'mm' and ranges from 0 to 15. A coordinate system is shown at the bottom left of the plot area, with the y-axis pointing left and the z-axis pointing down.

# 04. 코일건분석

## COMSOL

The screenshot displays the COMSOL Multiphysics software interface. On the left is the **Model Builder** tree, showing a project named 'successful\_laminar\_dragforce.mph (root)'. Under 'Study 1', 'Step 1: Stationary', 'Solver Configurations', 'Solution 1 (sol1)', the 'Velocity (spf)' result is selected. The middle panel shows the **Settings** for the '3D Plot Group' and 'Plot' of 'Velocity (spf)'. The 'Data' section is set to 'Study 1/Solution 1 (sol1)'. The 'Plot Settings' section shows 'View: Automatic' and 'Plot data set edges' checked. The 'Color Legend' section has 'Show legends' checked and 'Position' set to 'Right'. The right panel is the **Graphics** window, titled 'Convergence Plot 1', showing a 3D visualization of the velocity magnitude field around a blue, coil-shaped object. A color bar on the right indicates velocity values from 0 to 400 m/s. At the bottom, the **Messages** and **Table 1** tabs are visible. The table shows the 'Total stress, y component (N)' with a value of 2.4028, which is circled in red. The system status bar at the bottom indicates '1.31 GB | 1.98 GB'.

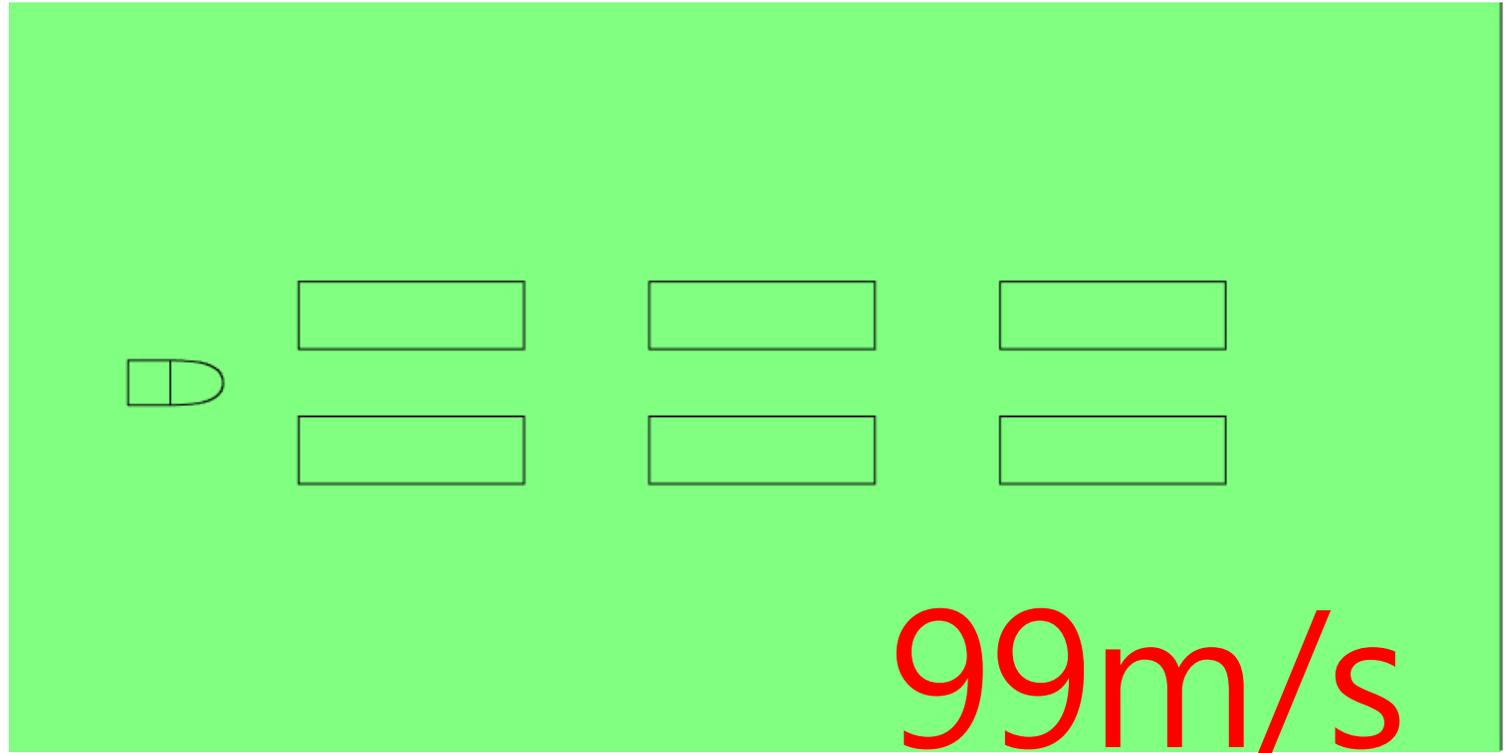
Total stress, y component (N)
2.4028

# 04. 코일건분석

EXCEL

1000turns

J	A	B	C	D	E	F	G	H	I
1	time(s)	Current	Force(N)	Force(D)	Accel	Velocity	distance	distance(sum)	mass
2	0.5000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0103018
3	0.5001	0.63	0.05	0.00	4.94	0.00	0.00	0.00	
4	0.5002	1.27	0.21	0.00	19.82	0.00	0.00	0.00	
5	0.5003	1.90	0.46	0.00	44.58	0.01	0.00	0.00	
6	0.5004	2.53	0.82	0.00	79.52	0.01	0.00	0.00	
7	0.5005	3.16	1.27	0.00	123.14	0.03	0.00	0.00	
8	0.5006	3.79	1.83	0.00	177.64	0.04	0.00	0.01	
9	0.5007	4.42	2.49	0.00	241.55	0.07	0.01	0.01	
10	0.5008	5.05	3.24	0.00	314.23	0.10	0.01	0.02	
11	0.5009	5.68	4.12	0.00	399.56	0.14	0.01	0.03	
12	0.5010	6.30	5.08	0.00	492.70	0.19	0.02	0.05	
13	0.5011	6.93	6.15	0.00	596.62	0.25	0.02	0.07	
14	0.5012	7.55	7.34	0.00	712.03	0.32	0.03	0.10	
15	0.5013	8.18	8.60	0.00	834.56	0.40	0.04	0.14	
16	0.5014	8.80	9.99	0.00	969.90	0.50	0.05	0.18	
17	0.5015	9.42	11.59	0.00	1124.65	0.61	0.06	0.24	
18	0.5016	10.04	13.15	0.00	1276.37	0.74	0.07	0.31	
19	0.5017	10.56	14.76	0.00	1433.14	0.88	0.08	0.39	
20	0.5018	11.28	16.96	0.00	1646.31	1.05	0.10	0.48	
21	0.5019	11.89	19.18	0.00	1861.71	1.24	0.11	0.60	
22	0.5020	12.51	21.51	0.00	2087.88	1.44	0.13	0.73	
23	0.5021	13.13	24.06	0.00	2335.60	1.68	0.16	0.89	
24	0.5022	13.74	26.79	0.00	2600.70	1.94	0.18	1.07	
25	0.5023	14.35	29.96	0.00	2907.92	2.23	0.21	1.28	
26	0.5024	14.96	33.33	0.00	3295.53	2.55	0.24	1.52	
27	0.5025	15.57	37.43	0.00	3693.13	2.92	0.27	1.79	
28	0.5026	16.18	41.99	0.00	4075.86	3.32	0.31	2.10	
29	0.5027	16.79	46.98	0.00	4560.43	3.78	0.36	2.46	
30	0.5028	17.40	53.00	0.00	5144.21	4.29	0.40	2.86	
31	0.5029	18.00	59.73	0.00	5797.48	4.87	0.46	3.32	
32	0.5030	18.60	67.45	0.00	6547.43	5.53	0.52	3.84	
33	0.5031	19.21	76.84	0.00	7458.53	6.27	0.59	4.43	
34	0.5032	19.81	87.73	0.00	8516.28	7.13	0.67	5.10	
35	0.5033	20.41	102.86	0.00	9884.54	8.12	0.76	5.86	
36	0.5034	21.01	120.34	0.00	11681.30	9.29	0.87	6.73	
37	0.5035	21.61	144.01	0.00	13978.92	10.69	1.00	7.73	
38	0.5036	22.20	175.40	0.00	17025.90	12.39	1.15	8.88	
39	0.5037	22.80	218.15	0.00	21175.59	14.51	1.35	10.23	
40	0.5038	23.39	278.42	0.00	27025.91	17.21	1.59	11.82	
41	0.5039	23.98	368.25	0.01	35745.57	20.79	1.90	13.72	
42	0.5040	24.57	508.44	0.01	49953.61	25.72	2.33	16.04	
43	0.5041	25.16	733.41	0.01	71191.09	32.84	2.93	18.97	
44	0.5042	25.75	1085.00	0.02	105319.28	43.37	3.81	22.78	
45	0.5043	26.33	1560.30	0.03	151455.37	58.52	5.09	27.88	
46	0.5044	26.92	1971.90	0.06	191406.87	77.66	6.81	34.68	
47	0.5045	27.50	2650.20	0.10	260175.06	93.68	8.57	43.25	
48	0.5046	28.08	408.96	0.15	39683.17	97.65	9.57	52.82	
49	0.5047	0.63	0.01	0.16	-14.95	97.64	9.76	62.58	
50	0.5048	1.27	0.09	0.16	-6.85	97.64	9.76	72.35	
51	0.5049	1.90	0.67	0.16	48.96	97.65	9.76	82.11	
52	0.5050	2.53	4.40	0.16	410.96	97.69	9.77	91.88	
53	0.5051	3.16	21.49	0.16	2070.41	97.90	9.78	101.66	
54	0.5052	3.79	37.53	0.16	3626.96	98.26	9.81	111.46	
55	0.5053	4.42	19.74	0.17	1899.68	98.45	9.84	121.30	
56	0.5054	0.63	0.01	0.17	-15.36	98.45	9.84	131.14	
57	0.5055	1.27	0.08	0.17	-8.27	98.45	9.84	140.99	
58	0.5056	1.90	0.55	0.17	36.89	98.45	9.84	150.83	
59	0.5057	2.53	3.59	0.17	332.20	98.48	9.85	160.68	
60	0.5058	3.16	19.38	0.17	1865.14	98.67	9.86	170.54	
61	0.5059	3.79	37.71	0.17	3644.28	99.03	9.89	180.42	
62	0.5060	4.42	21.03	0.17	2024.66	99.24	9.91	190.34	



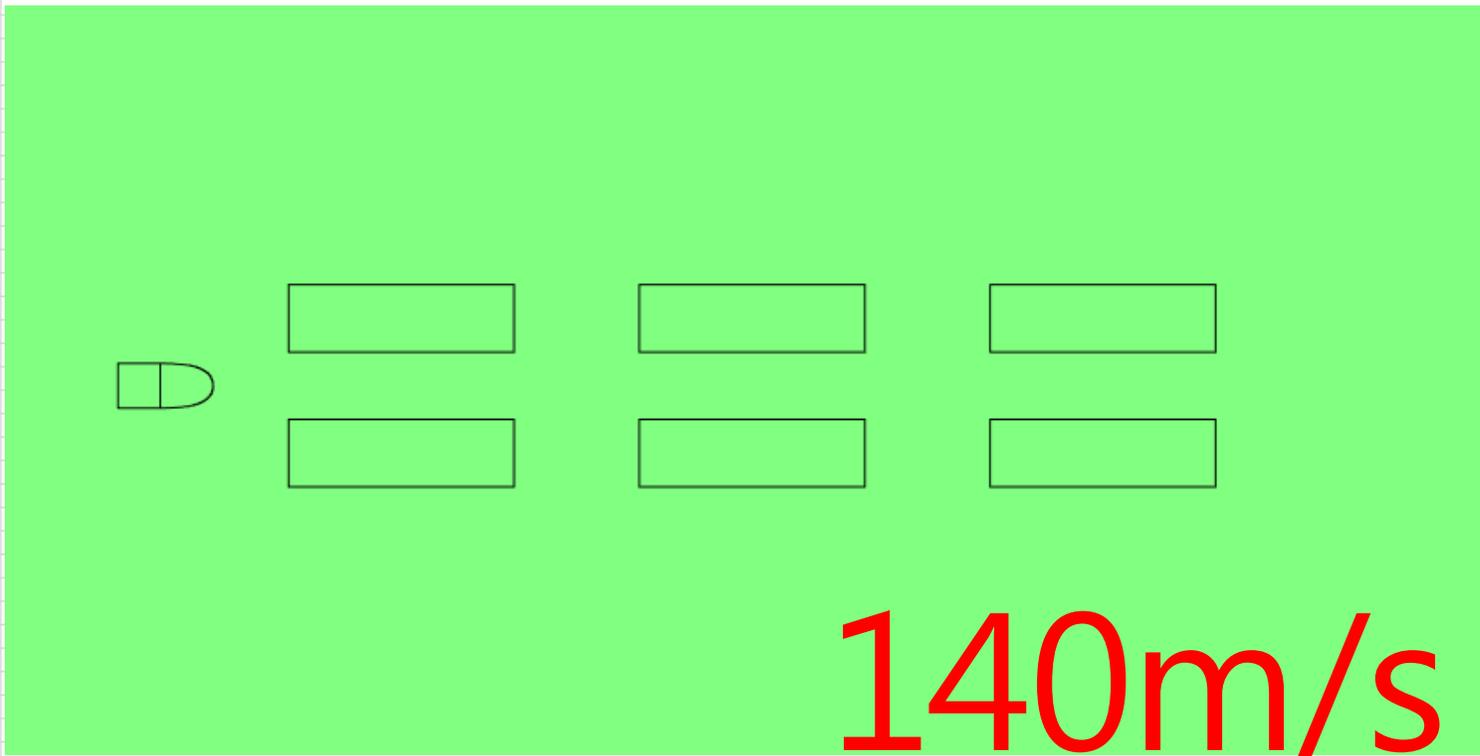
99m/s

# 04. 코일건분석

EXCEL

500turns

#	A	B	C	D	E	F	G	H	I
1	time(s)	Current	Force(M)	Force(D)	Acceleration	Velocity	distance	distance(sum)	mass
2	0.5000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01030183
3	0.5001	2.53	0.20	0.00	19.68	0.00	0.00	0.00	
4	0.5002	5.05	0.81	0.00	78.90	0.01	0.00	0.00	
5	0.5003	7.56	1.82	0.00	176.80	0.03	0.00	0.00	
6	0.5004	10.05	3.19	0.00	309.95	0.06	0.00	0.01	
7	0.5005	12.53	5.01	0.00	485.89	0.11	0.01	0.02	
8	0.5006	14.99	7.20	0.00	698.81	0.18	0.01	0.03	
9	0.5007	17.44	9.74	0.00	945.55	0.27	0.02	0.05	
10	0.5008	19.88	12.67	0.00	1229.88	0.39	0.03	0.09	
11	0.5009	22.30	15.94	0.00	1546.91	0.55	0.05	0.13	
12	0.5010	24.71	19.65	0.00	1907.14	0.74	0.06	0.20	
13	0.5011	27.10	23.87	0.00	2316.77	0.97	0.09	0.28	
14	0.5012	29.47	28.51	0.00	2767.76	1.25	0.11	0.39	
15	0.5013	31.84	33.85	0.00	3285.34	1.58	0.14	0.53	
16	0.5014	34.18	39.47	0.00	3831.26	1.96	0.18	0.71	
17	0.5015	36.51	46.39	0.00	4503.17	2.41	0.22	0.93	
18	0.5016	38.83	53.86	0.00	5227.89	2.93	0.27	1.20	
19	0.5017	41.13	62.70	0.00	6086.67	3.54	0.32	1.52	
20	0.5018	43.41	72.19	0.00	7007.37	4.24	0.39	1.91	
21	0.5019	45.68	84.90	0.00	8241.32	5.07	0.47	2.38	
22	0.5020	47.92	99.44	0.00	9652.90	6.03	0.55	2.93	
23	0.5021	50.16	116.08	0.00	11267.84	7.16	0.66	3.59	
24	0.5022	52.37	139.56	0.00	13547.02	8.51	0.78	4.37	
25	0.5023	54.57	167.30	0.00	16239.71	10.14	0.93	5.31	
26	0.5024	56.76	205.48	0.00	19945.79	12.13	1.11	6.42	
27	0.5025	58.92	255.75	0.00	24825.43	14.61	1.34	7.76	
28	0.5026	61.07	333.64	0.00	32386.11	17.85	1.62	9.38	
29	0.5027	63.20	451.10	0.01	43787.80	22.23	2.00	11.38	
30	0.5028	65.31	641.62	0.01	62281.30	28.46	2.53	13.92	
31	0.5029	67.40	983.24	0.01	95441.87	38.00	3.32	17.24	
32	0.5030	69.48	1628.60	0.02	158085.99	53.81	4.59	21.83	
33	0.5031	71.54	2694.70	0.05	261570.04	79.97	6.69	28.52	
34	0.5032	73.58	3669.80	0.11	356217.30	115.59	9.78	38.30	
35	0.5033	75.60	2283.50	0.23	221637.38	137.76	12.67	50.97	
36	0.5034	2.53	0.03	0.33	-28.37	137.75	13.78	64.74	
37	0.5035	5.05	0.48	0.33	14.54	137.75	13.78	78.52	
38	0.5036	7.56	5.91	0.33	541.89	137.81	13.78	92.30	
39	0.5037	10.05	55.80	0.33	5384.59	138.35	13.81	106.10	
40	0.5038	12.53	81.88	0.33	7916.51	139.14	13.87	119.98	
41	0.5039	2.53	0.03	0.33	-29.31	139.14	13.91	133.89	
42	0.5040	5.05	0.43	0.33	9.61	139.14	13.91	147.81	
43	0.5041	7.56	5.21	0.33	473.60	139.18	13.92	161.72	
44	0.5042	10.05	52.87	0.33	5099.83	139.69	13.94	175.67	
45	0.5043	12.53	81.39	0.33	7868.43	140.48	14.01	189.67	



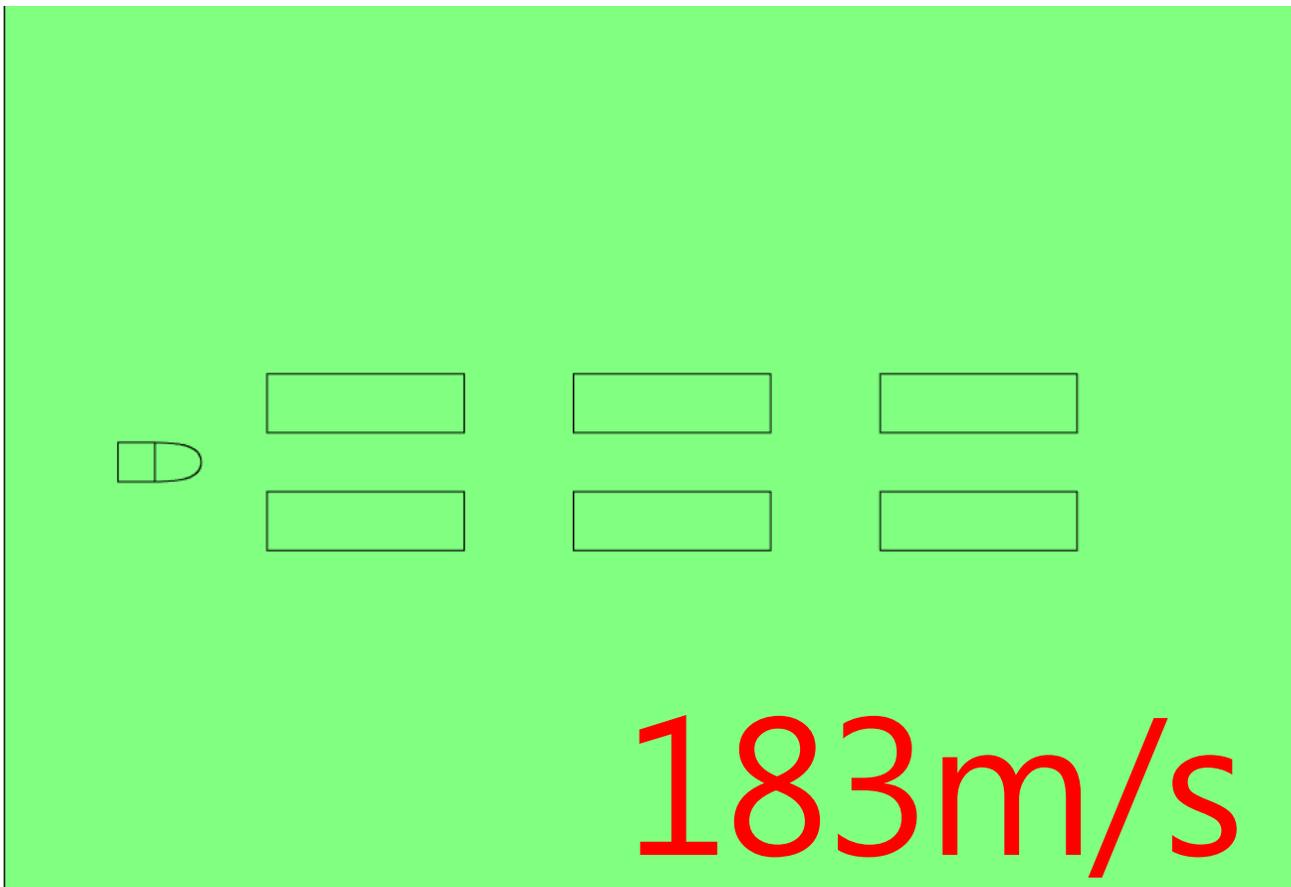
140m/s

# 04. 코일건분석

EXCEL

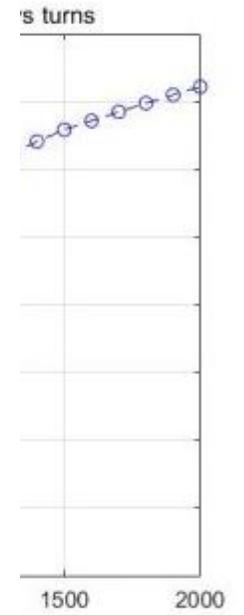
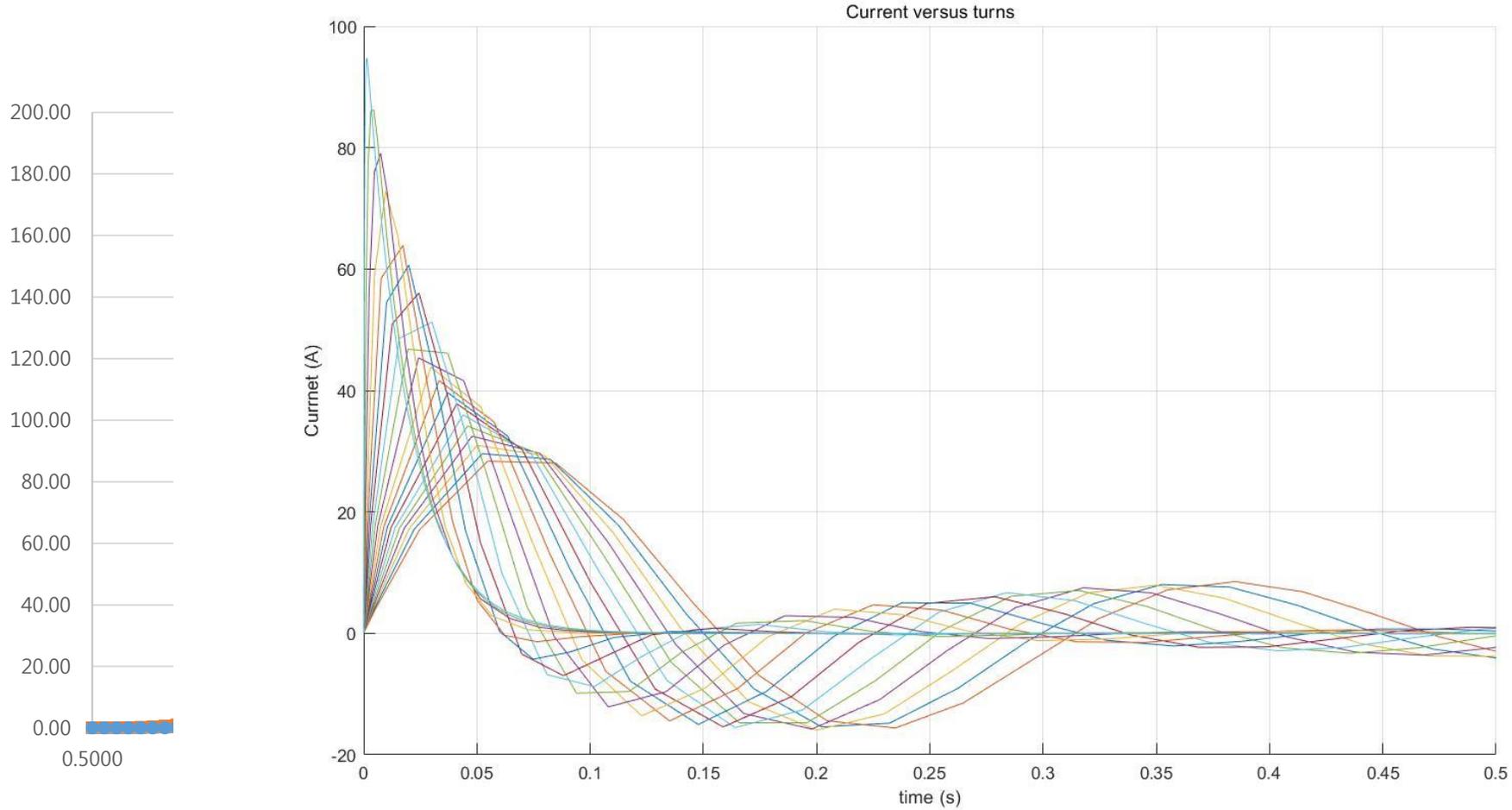
250turns

	A	B	C	D	E	F	G	H	I
1	time(s)	Current	Force(M)	Force(D)	Acceleration	Velocity	distance	distance(sum)	mass
2	0.5000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.010302
3	0.5001	10.03	0.80	0.00	77.25	0.01	0.00	0.00	
4	0.5002	19.87	3.14	0.00	304.46	0.04	0.00	0.00	
5	0.5003	29.51	6.93	0.00	672.82	0.11	0.01	0.01	
6	0.5004	38.94	12.10	0.00	1174.55	0.22	0.02	0.03	
7	0.5005	48.17	18.53	0.00	1798.52	0.40	0.03	0.06	
8	0.5006	57.19	26.17	0.00	2540.42	0.66	0.05	0.11	
9	0.5007	66.00	35.03	0.00	3400.46	1.00	0.08	0.19	
10	0.5008	74.61	45.45	0.00	4412.22	1.44	0.12	0.31	
11	0.5009	83.01	56.70	0.00	5503.58	1.99	0.17	0.49	
12	0.5010	91.20	70.33	0.00	6827.03	2.67	0.23	0.72	
13	0.5011	99.19	85.81	0.00	8329.48	3.50	0.31	1.03	
14	0.5012	107.00	103.86	0.00	10081.68	4.51	0.40	1.43	
15	0.5013	114.60	125.16	0.00	12149.26	5.73	0.51	1.94	
16	0.5014	121.90	150.94	0.00	14651.71	7.19	0.65	2.59	
17	0.5015	129.10	186.07	0.00	18061.75	9.00	0.81	3.40	
18	0.5016	136.10	229.55	0.00	22282.31	11.23	1.01	4.41	
19	0.5017	142.90	287.60	0.00	27917.15	14.02	1.26	5.67	
20	0.5018	149.50	374.72	0.00	36373.78	17.66	1.58	7.25	
21	0.5019	155.80	503.92	0.01	48915.05	22.55	2.01	9.26	
22	0.5020	162.00	726.43	0.01	70513.79	29.60	2.61	11.87	
23	0.5021	168.00	1132.50	0.02	109930.45	40.59	3.51	15.38	
24	0.5022	173.80	2001.60	0.03	194292.81	60.02	5.03	20.41	
25	0.5023	179.40	3761.60	0.06	365132.99	96.53	7.83	28.24	
26	0.5024	184.80	5827.40	0.16	565650.95	153.10	12.48	40.72	
27	0.5025	190.10	2754.40	0.40	267330.95	179.83	16.65	57.37	
28	0.5026	10.03	0.22	0.55	-32.63	179.83	17.98	75.35	
29	0.5027	19.87	6.45	0.55	571.90	179.89	17.99	93.34	
30	0.5028	29.51	128.81	0.55	12449.75	181.13	18.05	111.39	
31	0.5029	38.94	97.22	0.56	9382.36	182.07	18.16	129.55	
32	0.5030	10.03	0.27	0.57	-29.28	182.07	18.21	147.75	
33	0.5031	19.87	8.96	0.57	814.43	182.15	18.21	165.96	
34	0.5032	29.51	142.11	0.57	13739.42	183.52	18.28	184.25	
35	0.5033	38.94	49.73	0.58	4770.95	184.00	18.38	202.62	
36	0.5034	0.00	0.00	0.58	-56.35	183.99	18.40	221.02	
37	0.5035	0.00	0.00	0.58	-56.34	183.99	18.40	239.42	
38	0.5036	0.00	0.00	0.58	-56.34	183.98	18.40	257.82	



# 04. 코일건분석

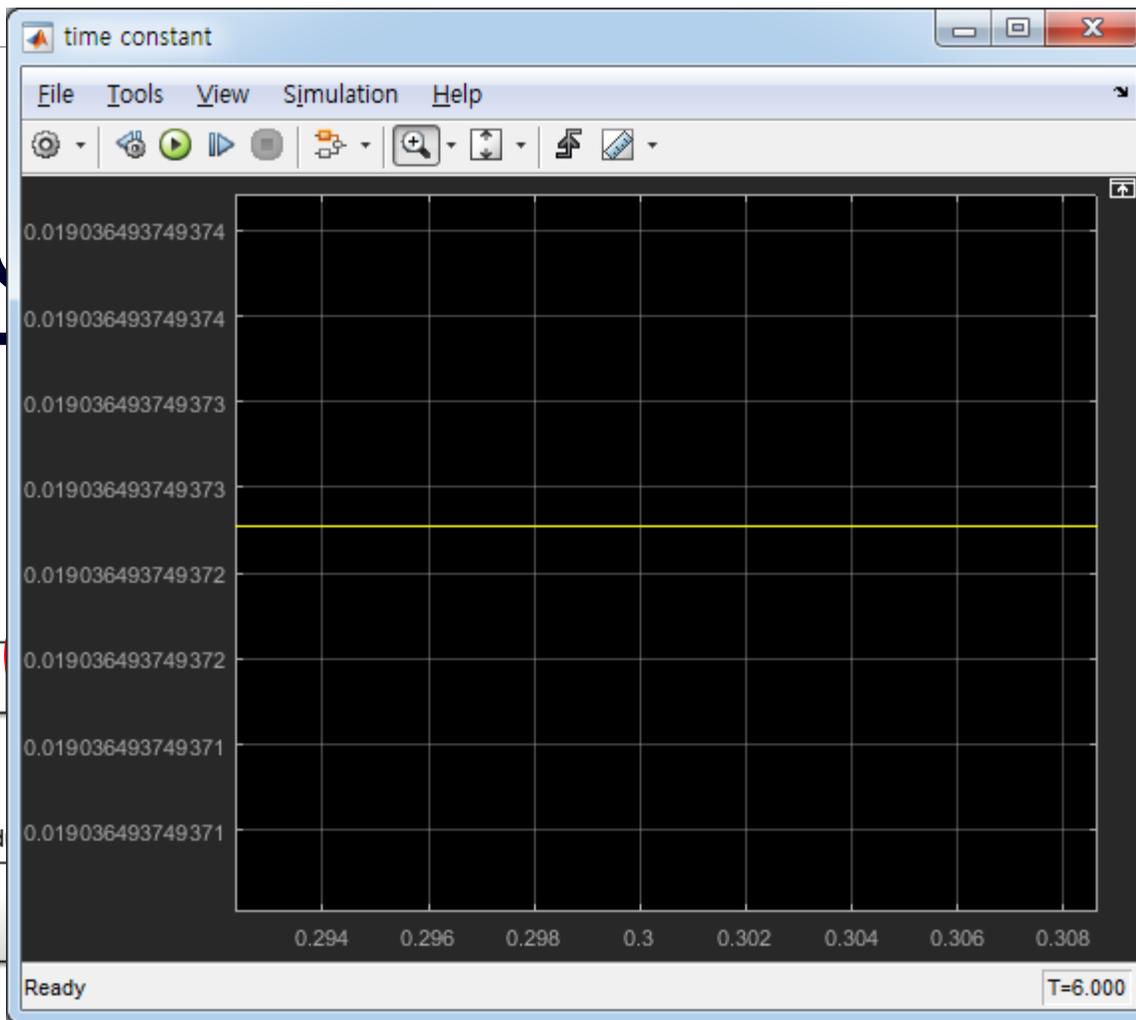
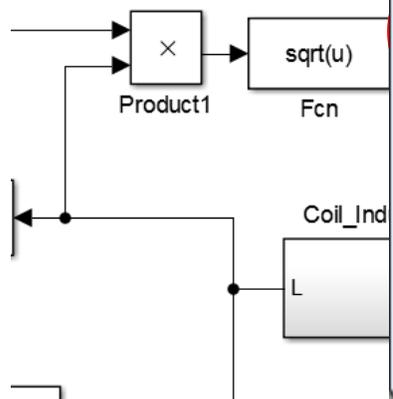
EXCEL



# 04. 코일건분석

EXCEL

# 시상수



$$t(t - \theta_p)$$

$$\frac{di_2(t)}{dt} = 0$$

$$e_1 + L \frac{d^2 i_2(t)}{dt^2} = 0$$

$$\tau = \sqrt{LC}$$

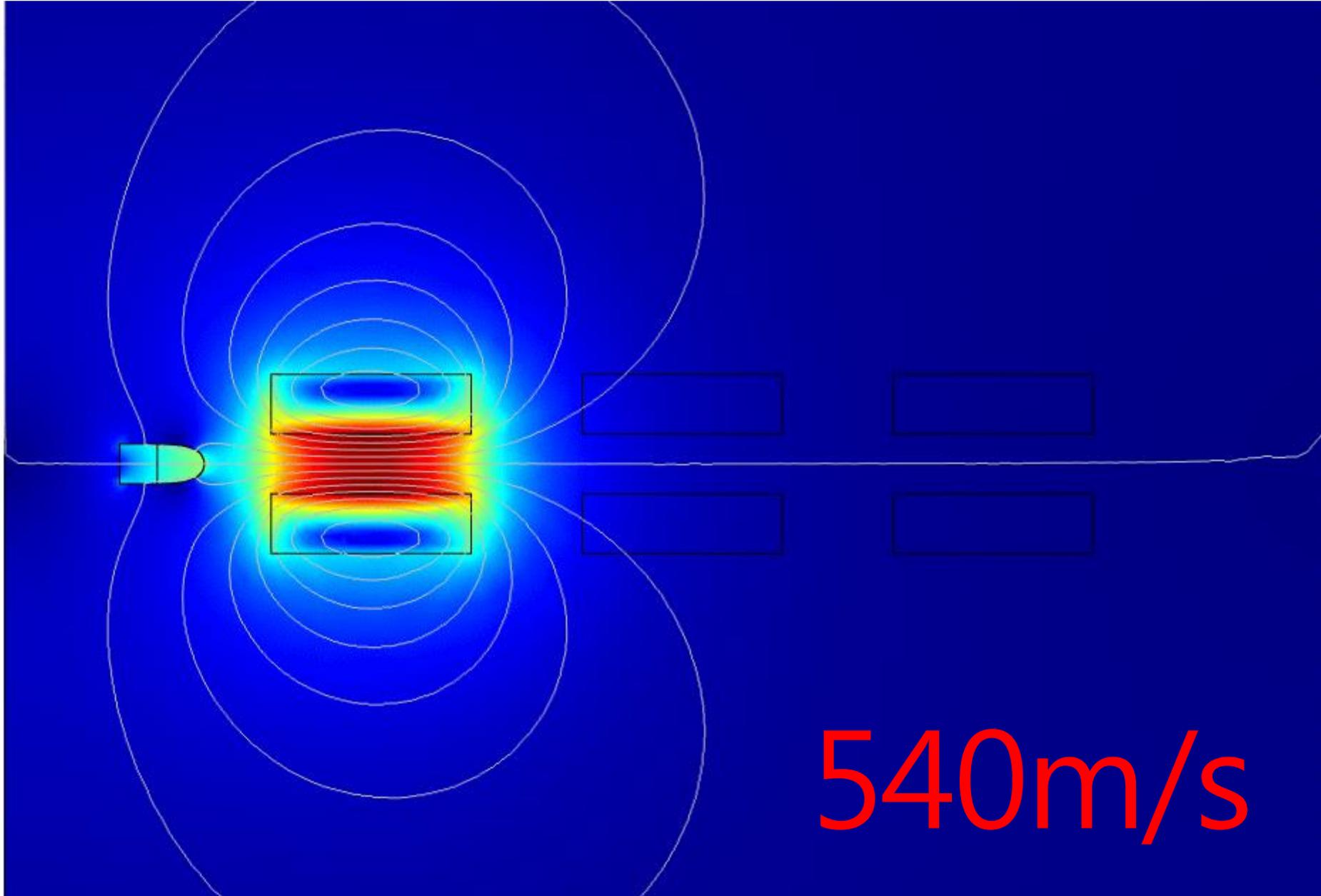
# 04. 코

EXCEL

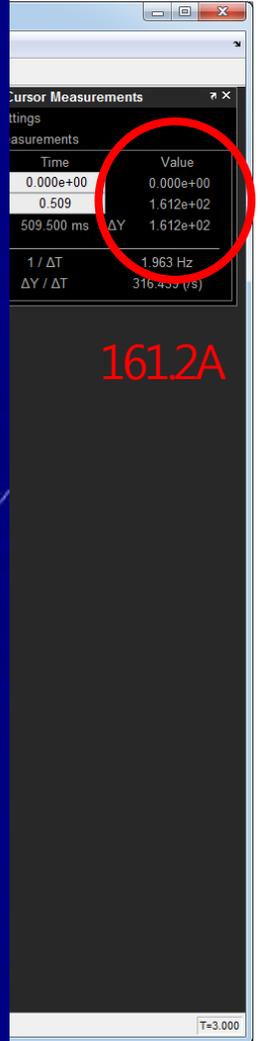
500turns

	A	
1	time(s)	Current
2	0.5094	
3	0.5095	1
4	0.5096	1
5	0.5097	1
6	0.5098	1
7	0.5099	1
8	0.5100	1
9	0.5101	1
10	0.5102	1
11	0.5103	1
12	0.5104	1
13	0.5105	1

기존의 0s



540m/s



## 04. 코일건분석

토의

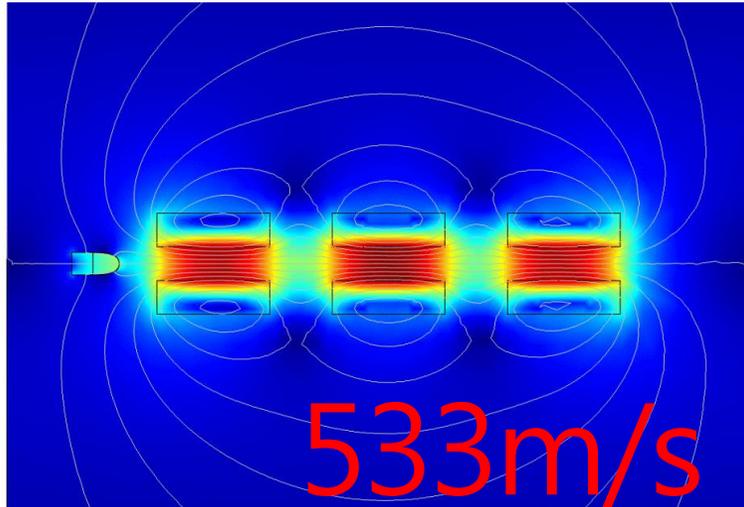
3개의 코일에 가하는 전류를 시상수 일 때부터 인가하려면?

 3개의 코일에 전류를 동시에 흘리자!

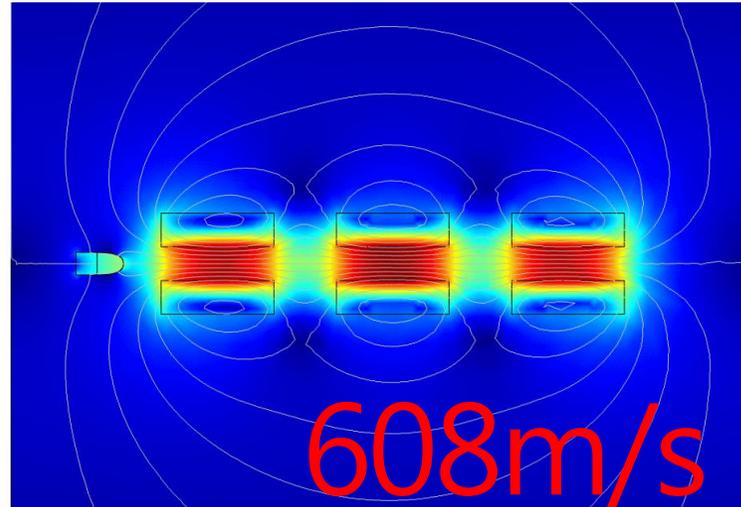
# 04. 코일건분석

EXCEL+COMSOL

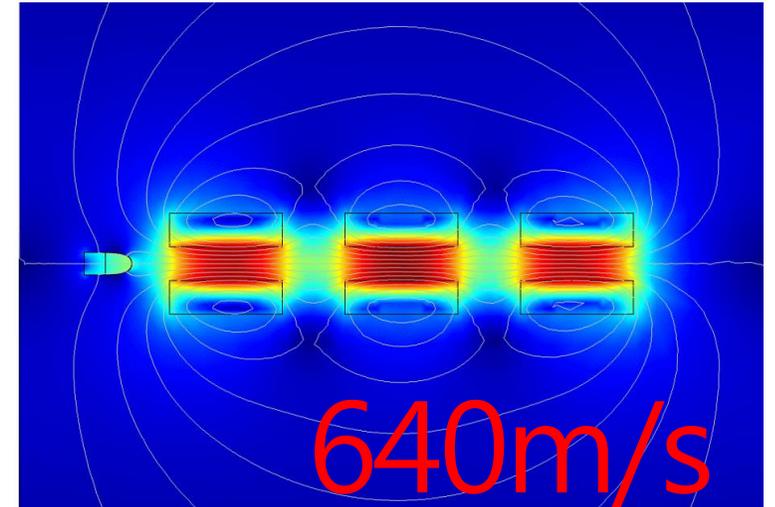
250turns



500turns



1000turns

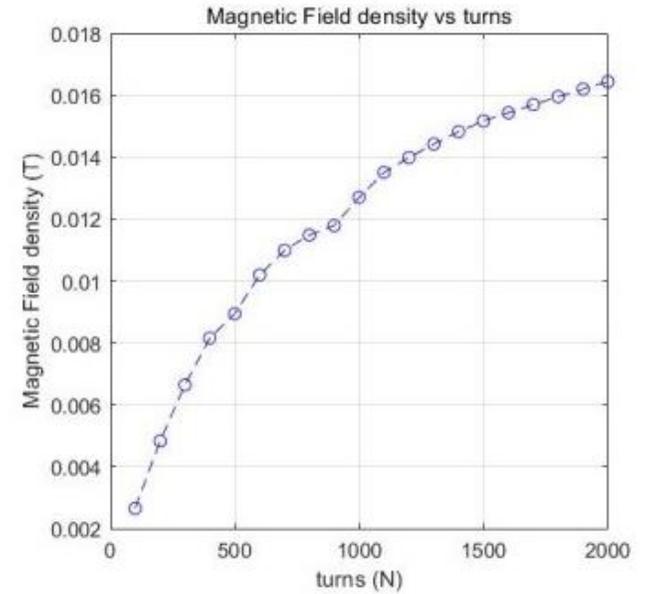
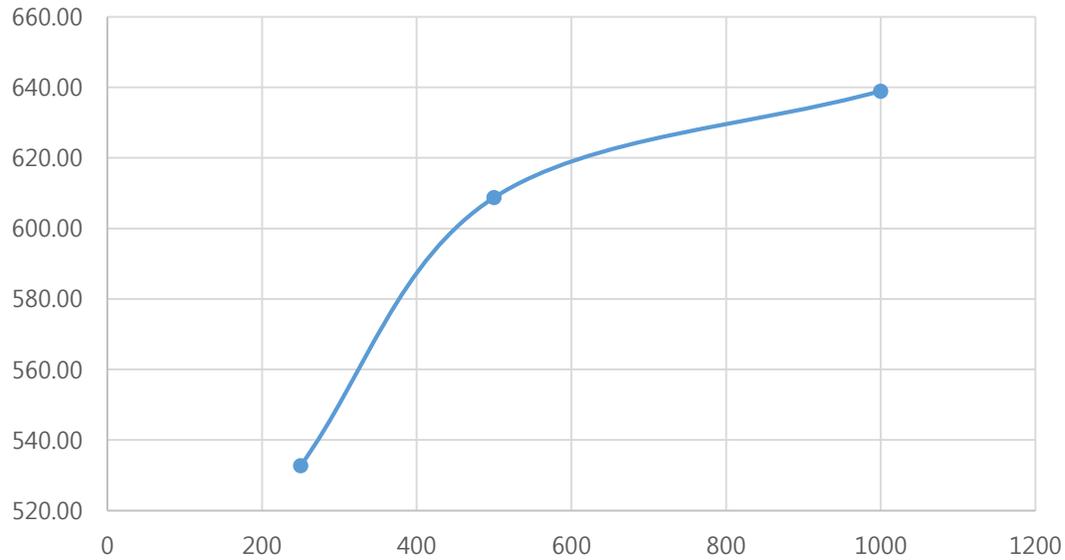


시상수 고려 후 총알속도

# 04. 코일건분석

## 결론

최대 속도(m/s) vs turns



예측했던 결과와 같은 경향을 보인다.

## 04. 코일건분석

### 결론

탄자 중량	115 그레인(7.5 그램)~85 그레인(5.5 그램) <sup>[1]</sup>
총구 초속	340~450 m/s
운동 에너지	약 450~650 J <sup>[2]</sup>

실제 권총의 속도와 에너지

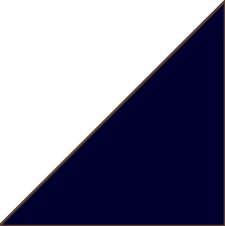
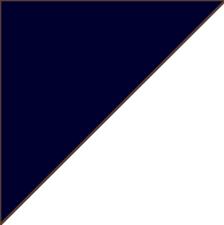
탄자 중량	<b>10.3 그램</b>
총구 속도	533~640 m/s (시상수)
운동 에너지	약 1463~2110 J

코일건의 속도와 에너지 (실험값)

## 04. 코일건분석

결론+제언

1. turns 마다 전류의 시상수가 다르므로 제어에 고려해야 한다.
2. 같은 길이 내에 더 많은 코일을 감을 수록 속도는 빨라진다.
3. 코일의 개수를 늘려도 속도는 무한히 증가하지 않는다.
4. 정밀한 제어를 할 수 있다면 엄청난 파괴력을 얻을 수 있다.
5. 미래의 상용화 가능성



# Thank you

가우스 X의 헌신