



# Magnetostatic Analysis of Solenoid

**Author: EMWorks**

**Company: ElectroMagnetic Works Inc**

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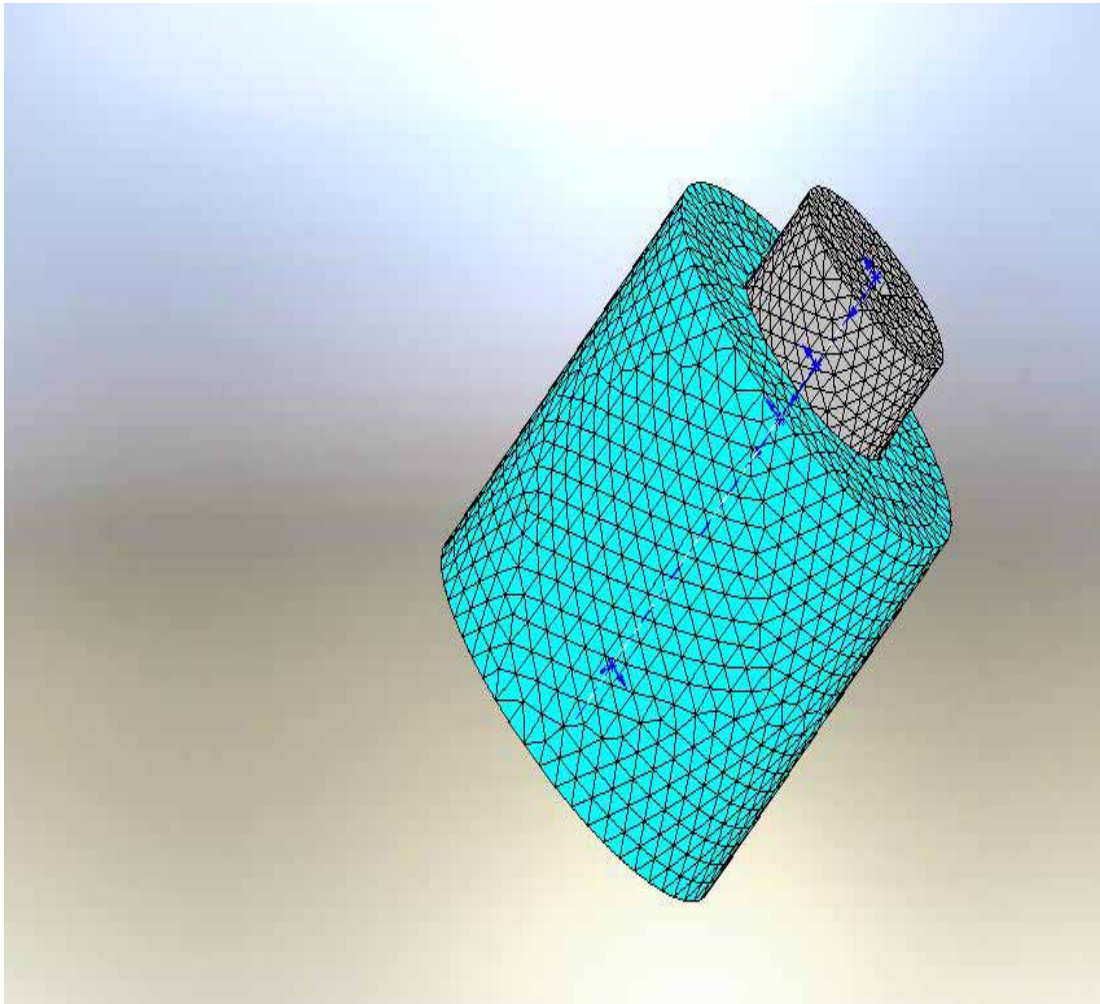
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## **1. Introduction**

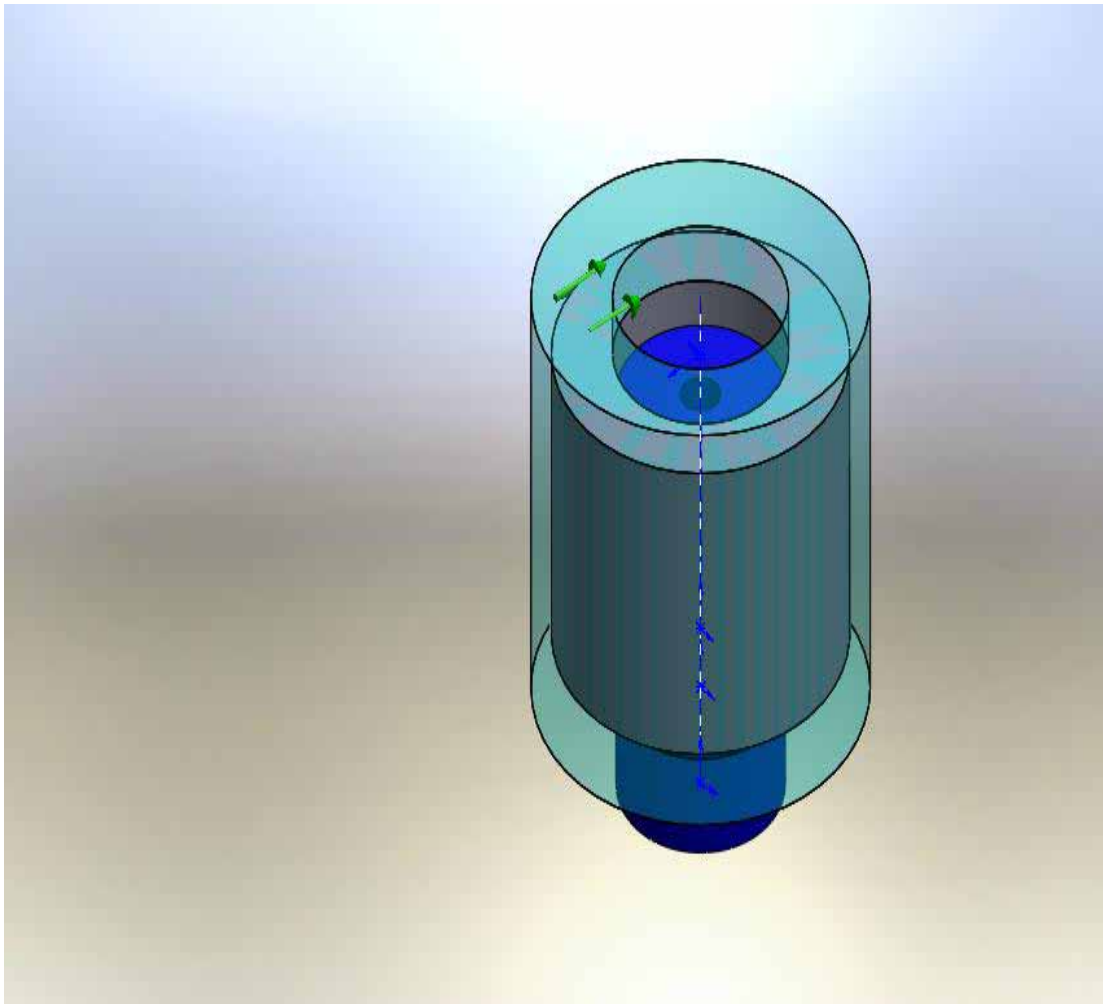
This is a Magnetostatic analysis of a solenoid. The study was coupled with motion to investigate the effect of the current induced electromagnetic force on the motion of the plunger. It was also coupled with thermal analysis to study the effect of Joule heating

## 2. Model View

**SOLENOID Current View (Mesh)**



# SOLENOID Isometric View



### 3. Materials

**Note:** R.P. stands for Relative Permeability

Nbr .	Part Name	Material Name	Permeability Type
1	air1^SOLENOID-1-Body 1 (Cavity1)	<a href="#">Air</a>	Isotropic
2	Band^SOLENOID-1-Body 1 (Cavity1)	<a href="#">Air</a>	Isotropic
3	coil-1-Body 1 (Split1[1])	<a href="#">Copper</a>	Isotropic
4	coil-1-Body 2 (Split1[2])	<a href="#">Copper</a>	Isotropic
5	Outer Air^SOLENOID-1-Body 1 (Cavity1)	<a href="#">Air</a>	Isotropic
6	plunger-1-Body 1 (Boss-Extrude1)	<a href="#">Mild Steel</a>	Isotropic
7	stator-1-Body 1 (Cut-Extrude1)	<a href="#">Mild Steel</a>	Isotropic

### 4. Load & Restraint Information

Nbr.	Name	Selected Faces	Selected Components
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#### Thermal Loads

Nbr.	Name	Convection Coefficient (W/(m <sup>2</sup> .K))	Ambient Temperature (Kelvin)	Selected Faces	Selected Components
1	Convection - 1	1.000e+001	3.000e+002	0	Outer Air^SOLENOID -1

## 5. Coils Information

Coils

Nbr.	Name	Coil Type	Nbr.Of Turns	Magnitude	Components & Bodies
1	Wound Coil - 1	Current driven coil	50	8.000000e-001	coil-1

## 6. Force and Torque Information

Nbr.	Name	Torque Center	Components & Bodies
1	Virtual Work - 1	At origin	plunger-1

## 7. Study Properties

Mesh Information

Motion Time Step	Nbr.Of Nodes	Nbr.Of Elements	Element Size (mm)	Tolerance (mm)
1	21260	124216	6	0.000006
2	21250	124143	6	0.000006
3	21200	123865	6	0.000006
4	21105	123302	6	0.000006
5	21036	122914	6	0.000006
6	21046	122970	6	0.000006
7	22117	128828	6	0.000006
8	22191	129321	6	0.000006
9	22368	130249	6	0.000006
10	22437	130739	6	0.000006
11	22502	131103	6	0.000006

### Solver information

<b>Solver Type</b>	Direct Solver
<b>Nbr. Current Increments</b>	1
<b>Compute circuit parameters</b>	Yes
<b>Thermal Analysis</b>	Yes
<b>Motion Analysis</b>	Yes

## 8. Results Table

Results for Motion Time Value: 0.000000000 sec

### Force Results

	<b>Fx-axis (N)</b>	<b>Fy-axis (N)</b>	<b>Fz-axis (N)</b>
Virtual Work - 1	-6.793357e-005	1.457917e-002	-1.815544e-004

### Torque Results

	<b>Tx-axis (N.m)</b>	<b>Ty-axis (N.m)</b>	<b>Tz-axis (N.m)</b>
Virtual Work - 1	-6.691595e-007	-1.066488e-007	1.740798e-006

### Resistance Results

<b>Coil Name</b>	<b>Resistance(Ohms)</b>
Wound Coil - 1	1.477570e-001

### Inductance Results (H)

<b>Coil Name</b>	<b>Wound Coil - 1</b>
Wound Coil - 1	5.250530e-004

### Flux Linkage Results

<b>Coil Name</b>	<b>Flux Linkage (Wb)</b>
Wound Coil - 1	4.200424e-004

### BACK EMF Results

<b>Coil Name</b>	<b>BACK EMF (V)</b>
Wound Coil - 1	0.000000e+000

### Energy Results

Energy (J)	Co-Energy (J)
1.680170e-004	1.680170e-004

Results for Motion Time Value: 0.100000001 sec

### Force Results

	Fx-axis (N)	Fy-axis (N)	Fz-axis (N)
Virtual Work - 1	-2.343442e-005	1.494142e-002	-1.517773e-004

### Torque Results

	Tx-axis (N.m)	Ty-axis (N.m)	Tz-axis (N.m)
Virtual Work - 1	-2.288155e-006	4.556477e-007	3.972127e-006

### Resistance Results

Coil Name	Resistance(Ohms)
Wound Coil - 1	1.477570e-001

### Inductance Results (H)

Coil Name	Wound Coil - 1
Wound Coil - 1	5.441097e-004

### Flux Linkage Results

Coil Name	Flux Linkage (Wb)
Wound Coil - 1	4.352878e-004

### BACK EMF Results

Coil Name	BACK EMF (V)
Wound Coil - 1	3.049063e-004

### Energy Results

Energy (J)	Co-Energy (J)
1.741151e-004	1.741151e-004

**Results for Motion Time Value: 0.200000003 sec**

**Force Results**

	<b>Fx-axis (N)</b>	<b>Fy-axis (N)</b>	<b>Fz-axis (N)</b>
Virtual Work - 1	8.897812e-005	2.175359e-002	-8.345780e-005

**Torque Results**

	<b>Tx-axis (N.m)</b>	<b>Ty-axis (N.m)</b>	<b>Tz-axis (N.m)</b>
Virtual Work - 1	1.899288e-006	-1.127149e-006	3.966033e-007

**Resistance Results**

<b>Coil Name</b>	<b>Resistance(Ohms)</b>
Wound Coil - 1	1.477570e-001

**Inductance Results (H)**

<b>Coil Name</b>	<b>Wound Coil - 1</b>
Wound Coil - 1	6.158430e-004

**Flux Linkage Results**

<b>Coil Name</b>	<b>Flux Linkage (Wb)</b>
Wound Coil - 1	4.926744e-004

**BACK EMF Results**

<b>Coil Name</b>	<b>BACK EMF (V)</b>
Wound Coil - 1	7.683624e-004

**Energy Results**

<b>Energy (J)</b>	<b>Co-Energy (J)</b>
1.970698e-004	1.970698e-004



**Results for Motion Time Value: 0.300000012 sec**

**Force Results**

	<b>Fx-axis (N)</b>	<b>Fy-axis (N)</b>	<b>Fz-axis (N)</b>
Virtual Work - 1	-2.500379e-004	6.297097e-002	6.138717e-005

**Torque Results**

	<b>Tx-axis (N.m)</b>	<b>Ty-axis (N.m)</b>	<b>Tz-axis (N.m)</b>
Virtual Work - 1	2.121146e-005	-2.000940e-006	9.059513e-006

**Resistance Results**

<b>Coil Name</b>	<b>Resistance(Ohms)</b>
Wound Coil - 1	1.477570e-001

**Inductance Results (H)**

<b>Coil Name</b>	<b>Wound Coil - 1</b>
Wound Coil - 1	8.611835e-004

**Flux Linkage Results**

<b>Coil Name</b>	<b>Flux Linkage (Wb)</b>
Wound Coil - 1	6.889468e-004

**BACK EMF Results**

<b>Coil Name</b>	<b>BACK EMF (V)</b>
Wound Coil - 1	2.492732e-003

**Energy Results**

<b>Energy (J)</b>	<b>Co-Energy (J)</b>
2.755787e-004	2.755787e-004

**Results for Motion Time Value: 0.400000006 sec**

**Force Results**

	<b>Fx-axis (N)</b>	<b>Fy-axis (N)</b>	<b>Fz-axis (N)</b>
Virtual Work - 1	7.594768e-004	5.597393e-002	-1.948300e-003

**Torque Results**

	<b>Tx-axis (N.m)</b>	<b>Ty-axis (N.m)</b>	<b>Tz-axis (N.m)</b>
Virtual Work - 1	-6.706260e-005	-7.012031e-006	1.032527e-005

**Resistance Results**

<b>Coil Name</b>	<b>Resistance(Ohms)</b>
Wound Coil - 1	1.477570e-001

**Inductance Results (H)**

<b>Coil Name</b>	<b>Wound Coil - 1</b>
Wound Coil - 1	1.974572e-003

**Flux Linkage Results**

<b>Coil Name</b>	<b>Flux Linkage (Wb)</b>
Wound Coil - 1	1.579658e-003

**BACK EMF Results**

<b>Coil Name</b>	<b>BACK EMF (V)</b>
Wound Coil - 1	1.235032e-002

**Energy Results**

<b>Energy (J)</b>	<b>Co-Energy (J)</b>
6.318631e-004	6.318631e-004

**Results for Motion Time Value: 0.500000000 sec**

**Force Results**

	<b>Fx-axis (N)</b>	<b>Fy-axis (N)</b>	<b>Fz-axis (N)</b>
Virtual Work - 1	5.883708e-003	-5.660642e-002	7.774945e-004

**Torque Results**

	<b>Tx-axis (N.m)</b>	<b>Ty-axis (N.m)</b>	<b>Tz-axis (N.m)</b>
Virtual Work - 1	-8.511491e-005	-1.791517e-006	-1.755431e-005

**Resistance Results**

<b>Coil Name</b>	<b>Resistance(Ohms)</b>
Wound Coil - 1	1.477570e-001

**Inductance Results (H)**

<b>Coil Name</b>	<b>Wound Coil - 1</b>
Wound Coil - 1	2.096822e-003

**Flux Linkage Results**

<b>Coil Name</b>	<b>Flux Linkage (Wb)</b>
Wound Coil - 1	1.677457e-003

**BACK EMF Results**

<b>Coil Name</b>	<b>BACK EMF (V)</b>
Wound Coil - 1	1.173716e-003

**Energy Results**

<b>Energy (J)</b>	<b>Co-Energy (J)</b>
6.709830e-004	6.709830e-004

**Results for Motion Time Value: 0.600000024 sec**

**Force Results**

	<b>Fx-axis (N)</b>	<b>Fy-axis (N)</b>	<b>Fz-axis (N)</b>
Virtual Work - 1	-1.274547e-004	-1.661855e-002	-1.156982e-004

**Torque Results**

	<b>Tx-axis (N.m)</b>	<b>Ty-axis (N.m)</b>	<b>Tz-axis (N.m)</b>
Virtual Work - 1	-8.302575e-006	-3.096911e-007	-1.535899e-006

**Resistance Results**

<b>Coil Name</b>	<b>Resistance(Ohms)</b>
Wound Coil - 1	1.477570e-001

**Inductance Results (H)**

<b>Coil Name</b>	<b>Wound Coil - 1</b>
Wound Coil - 1	5.653326e-004

**Flux Linkage Results**

<b>Coil Name</b>	<b>Flux Linkage (Wb)</b>
Wound Coil - 1	4.522661e-004

**BACK EMF Results**

<b>Coil Name</b>	<b>BACK EMF (V)</b>
Wound Coil - 1	-9.925817e-003

**Energy Results**

<b>Energy (J)</b>	<b>Co-Energy (J)</b>
1.809064e-004	1.809064e-004

**Results for Motion Time Value: 0.699999988 sec**

**Force Results**

	<b>Fx-axis (N)</b>	<b>Fy-axis (N)</b>	<b>Fz-axis (N)</b>
Virtual Work - 1	-6.624250e-006	-8.270898e-003	-5.411318e-006

**Torque Results**

	<b>Tx-axis (N.m)</b>	<b>Ty-axis (N.m)</b>	<b>Tz-axis (N.m)</b>
Virtual Work - 1	-2.143395e-006	-1.215897e-007	-1.195198e-006

**Resistance Results**

<b>Coil Name</b>	<b>Resistance(Ohms)</b>
Wound Coil - 1	1.477570e-001

**Inductance Results (H)**

<b>Coil Name</b>	<b>Wound Coil - 1</b>
Wound Coil - 1	3.493696e-004

**Flux Linkage Results**

<b>Coil Name</b>	<b>Flux Linkage (Wb)</b>
Wound Coil - 1	2.794957e-004

**BACK EMF Results**

<b>Coil Name</b>	<b>BACK EMF (V)</b>
Wound Coil - 1	-1.588907e-003

**Energy Results**

<b>Energy (J)</b>	<b>Co-Energy (J)</b>
1.117983e-004	1.117983e-004

**Results for Motion Time Value: 0.800000012 sec**

**Force Results**

	<b>Fx-axis (N)</b>	<b>Fy-axis (N)</b>	<b>Fz-axis (N)</b>
Virtual Work - 1	-5.107905e-005	-5.488443e-003	4.372090e-005

**Torque Results**

	<b>Tx-axis (N.m)</b>	<b>Ty-axis (N.m)</b>	<b>Tz-axis (N.m)</b>
Virtual Work - 1	8.569302e-008	-1.951790e-007	1.001087e-006

**Resistance Results**

<b>Coil Name</b>	<b>Resistance(Ohms)</b>
Wound Coil - 1	1.477570e-001

**Inductance Results (H)**

<b>Coil Name</b>	<b>Wound Coil - 1</b>
Wound Coil - 1	2.357989e-004

**Flux Linkage Results**

<b>Coil Name</b>	<b>Flux Linkage (Wb)</b>
Wound Coil - 1	1.886391e-004

**BACK EMF Results**

<b>Coil Name</b>	<b>BACK EMF (V)</b>
Wound Coil - 1	-8.680159e-004

**Energy Results**

<b>Energy (J)</b>	<b>Co-Energy (J)</b>
7.545566e-005	7.545566e-005

**Results for Motion Time Value: 0.899999976 sec**

**Force Results**

	<b>Fx-axis (N)</b>	<b>Fy-axis (N)</b>	<b>Fz-axis (N)</b>
Virtual Work - 1	-3.082236e-005	-3.890470e-003	-7.618725e-005

**Torque Results**

	<b>Tx-axis (N.m)</b>	<b>Ty-axis (N.m)</b>	<b>Tz-axis (N.m)</b>
Virtual Work - 1	-2.745116e-006	6.983304e-008	1.046635e-006

**Resistance Results**

<b>Coil Name</b>	<b>Resistance(Ohms)</b>
Wound Coil - 1	1.477570e-001

**Inductance Results (H)**

<b>Coil Name</b>	<b>Wound Coil - 1</b>
Wound Coil - 1	1.636523e-004

**Flux Linkage Results**

<b>Coil Name</b>	<b>Flux Linkage (Wb)</b>
Wound Coil - 1	1.309219e-004

**BACK EMF Results**

<b>Coil Name</b>	<b>BACK EMF (V)</b>
Wound Coil - 1	-5.588295e-004

**Energy Results**

<b>Energy (J)</b>	<b>Co-Energy (J)</b>
5.236874e-005	5.236874e-005

**Results for Motion Time Value: 1.000000000 sec**

**Force Results**

	<b>Fx-axis (N)</b>	<b>Fy-axis (N)</b>	<b>Fz-axis (N)</b>
Virtual Work - 1	-1.298306e-005	-2.578605e-003	-1.289843e-005

**Torque Results**

	<b>Tx-axis (N.m)</b>	<b>Ty-axis (N.m)</b>	<b>Tz-axis (N.m)</b>
Virtual Work - 1	-1.658983e-007	1.694995e-008	4.948084e-007

**Resistance Results**

<b>Coil Name</b>	<b>Resistance(Ohms)</b>
Wound Coil - 1	1.477570e-001

**Inductance Results (H)**

<b>Coil Name</b>	<b>Wound Coil - 1</b>
Wound Coil - 1	1.172929e-004

**Flux Linkage Results**

<b>Coil Name</b>	<b>Flux Linkage (Wb)</b>
Wound Coil - 1	9.383434e-005

**BACK EMF Results**

<b>Coil Name</b>	<b>BACK EMF (V)</b>
Wound Coil - 1	-3.620471e-004

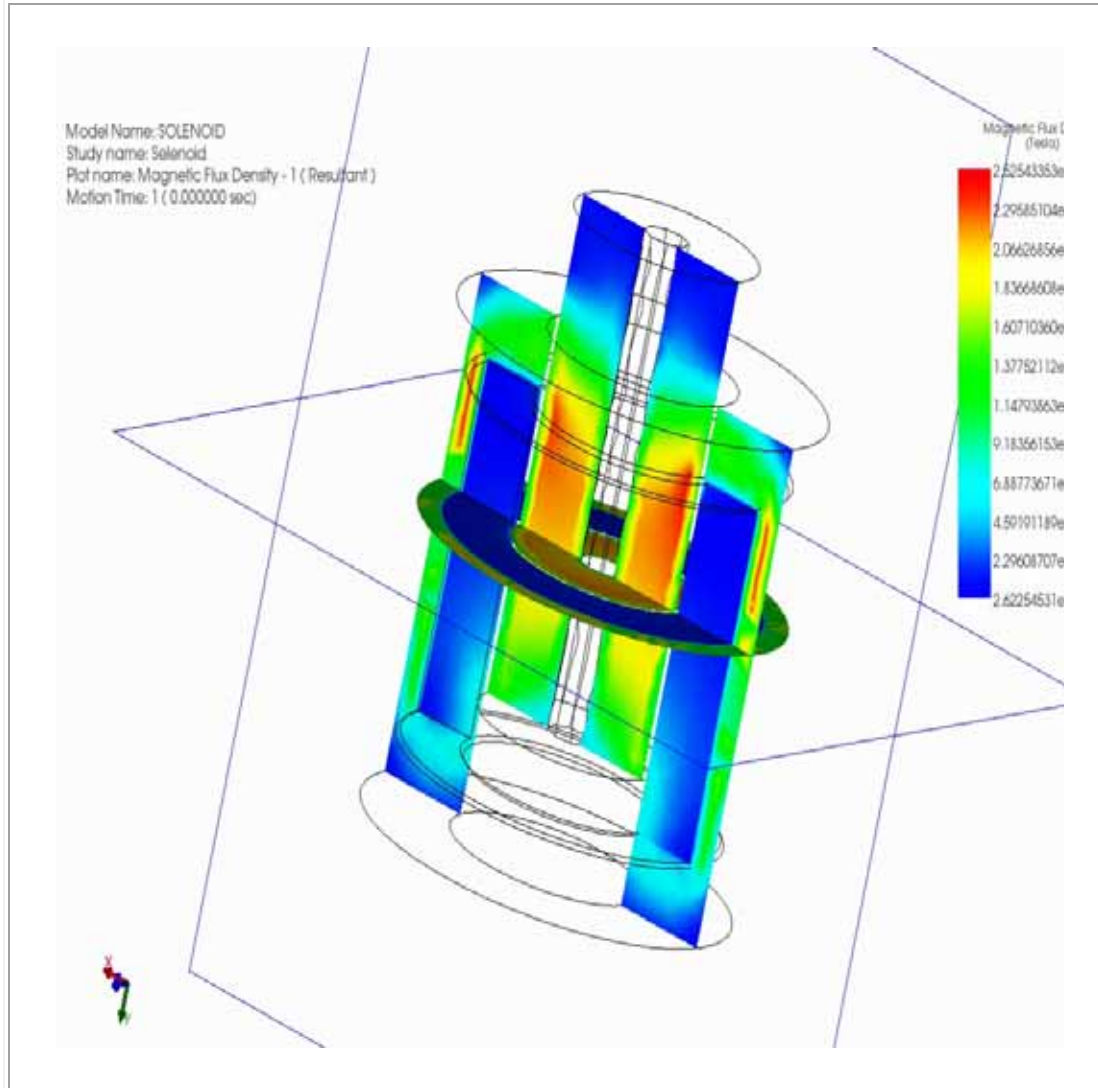
**Energy Results**

<b>Energy (J)</b>	<b>Co-Energy (J)</b>
3.753374e-005	3.753374e-005



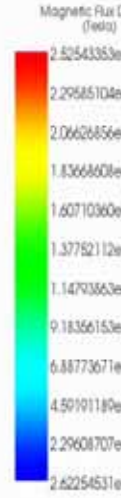
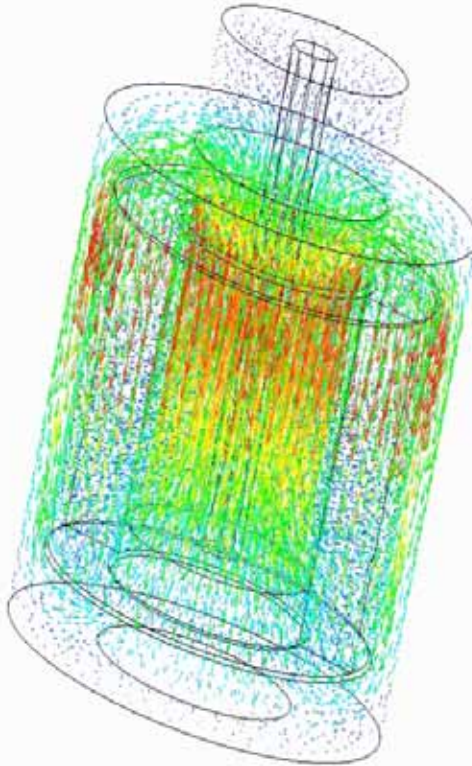
## 9. Magnetic Flux Density Results

**Magnetic Flux Density - 1**



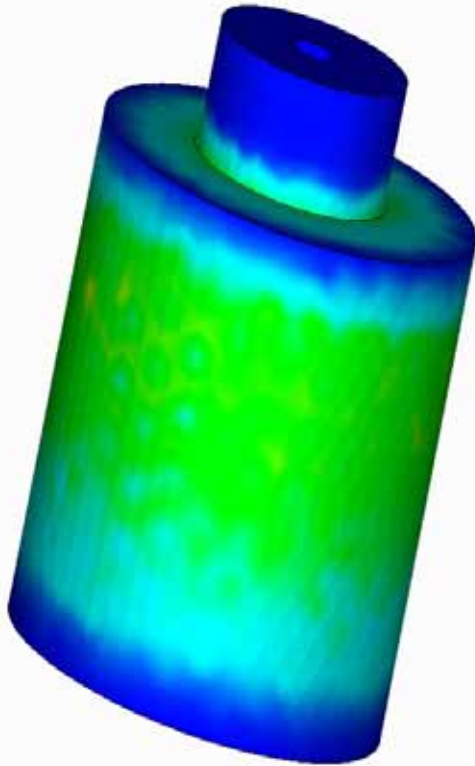
## Magnetic Flux Density - 2

Model Name: SOLENOID  
Study name: Solenoid  
Plot name: Magnetic Flux Density - 2 (Resultant)  
Motion Time: 1 (0.000000 sec)

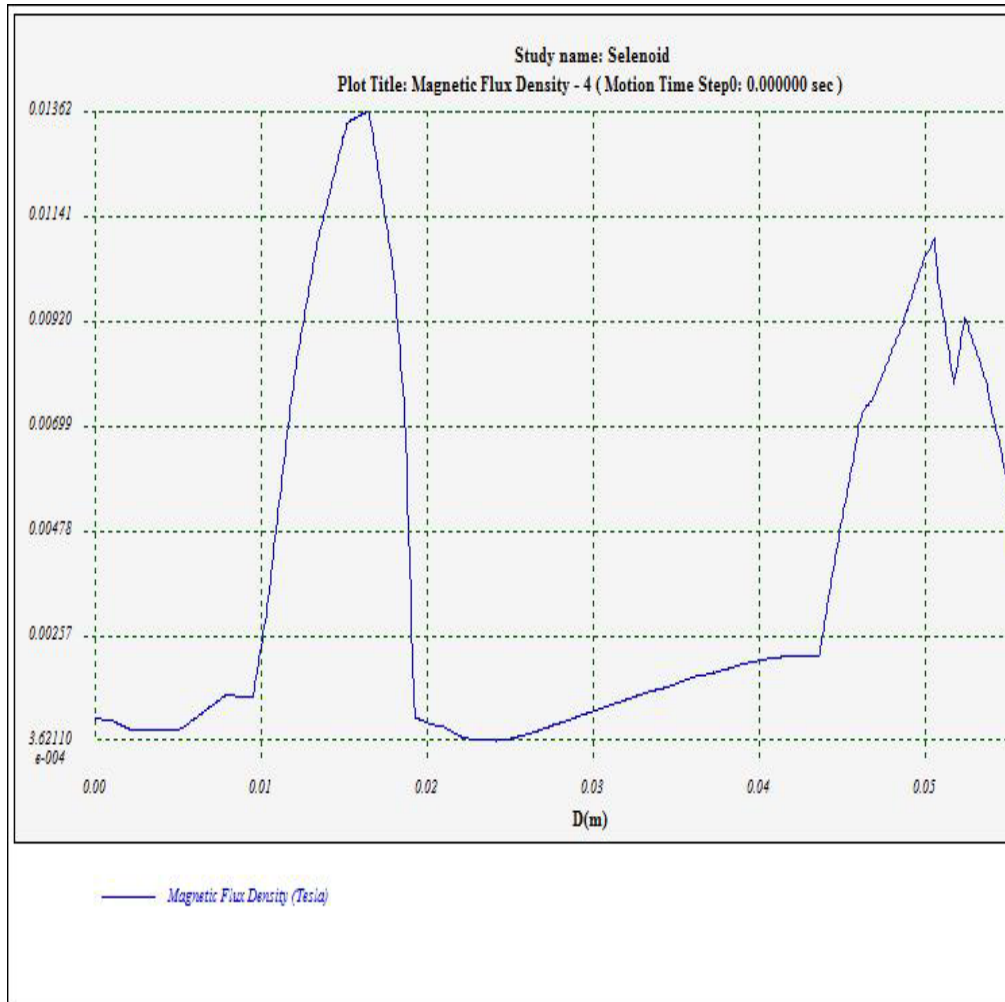


### Magnetic Flux Density - 3

Model Name: SOLENOID  
Study name: Solenoid  
Plot name: Magnetic Flux Density - 3 (Resultant)  
Motion Time: 1 (0.000000 sec)

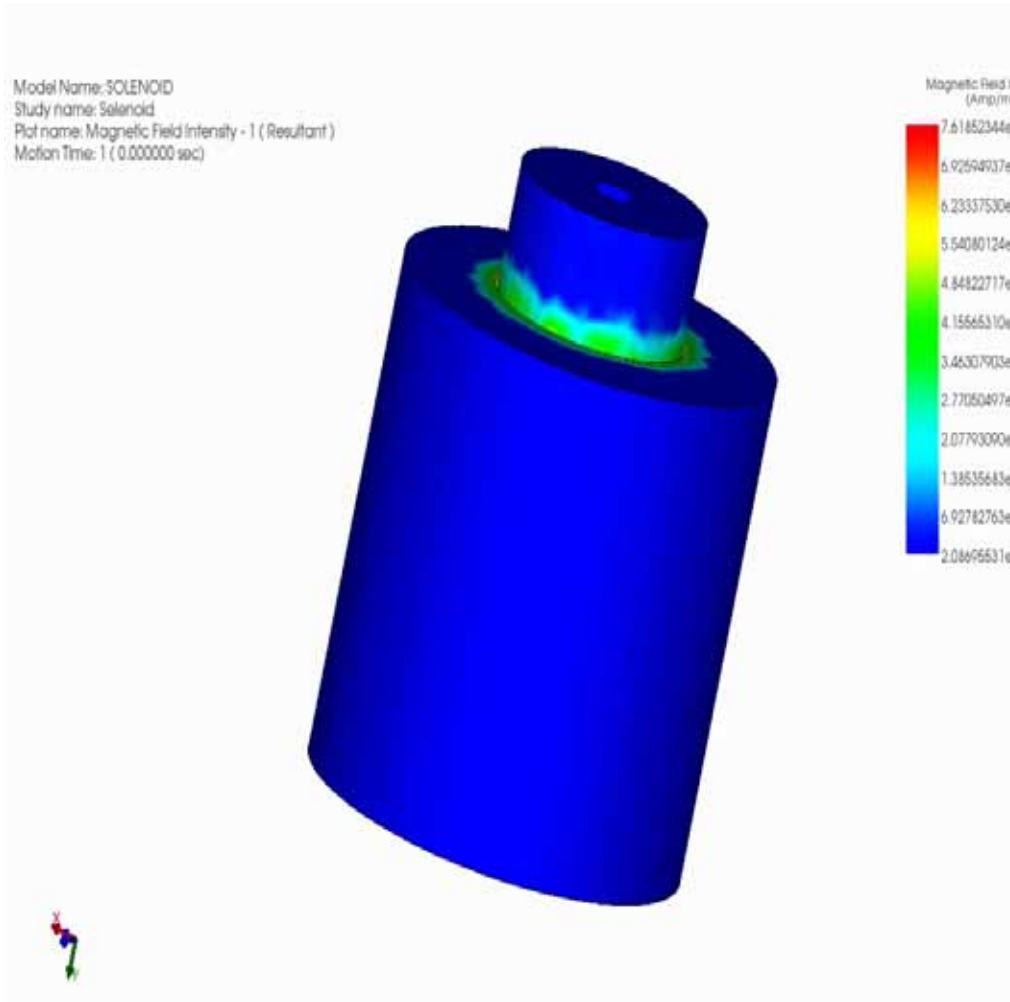


## Magnetic Flux Density - 4

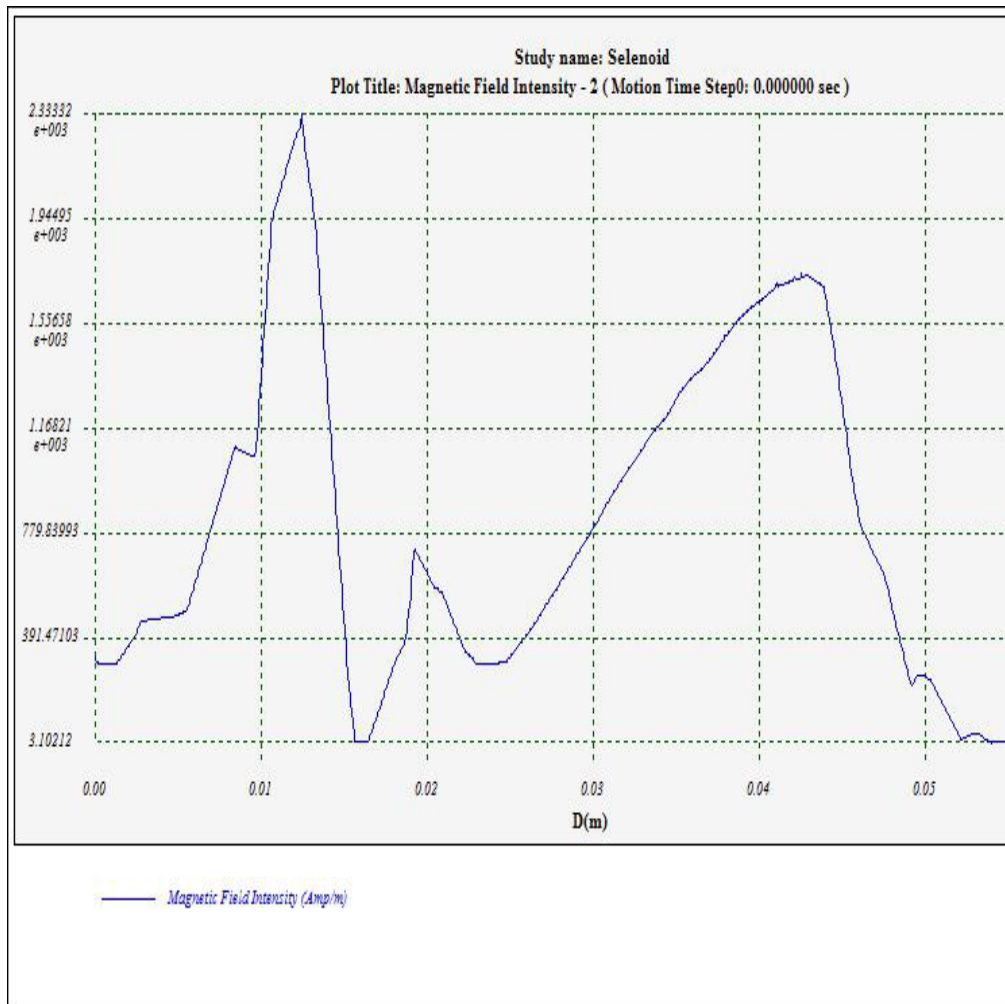


## 10. Magnetic Field Intensity Results

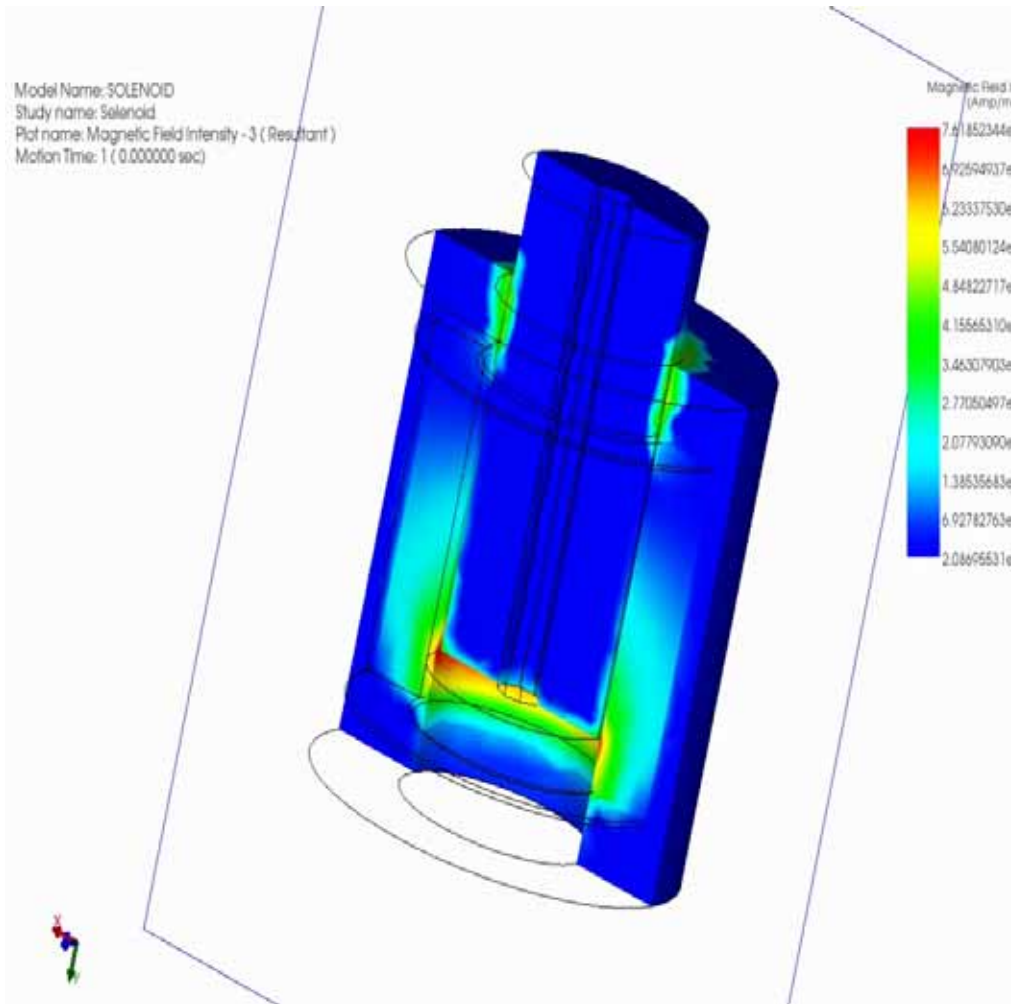
### Magnetic Field Intensity - 1



## Magnetic Field Intensity - 2

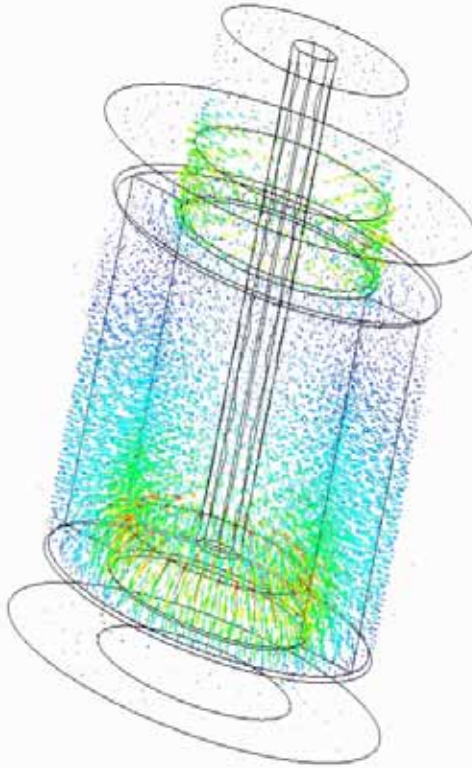


### Magnetic Field Intensity - 3



## Magnetic Field Intensity - 4

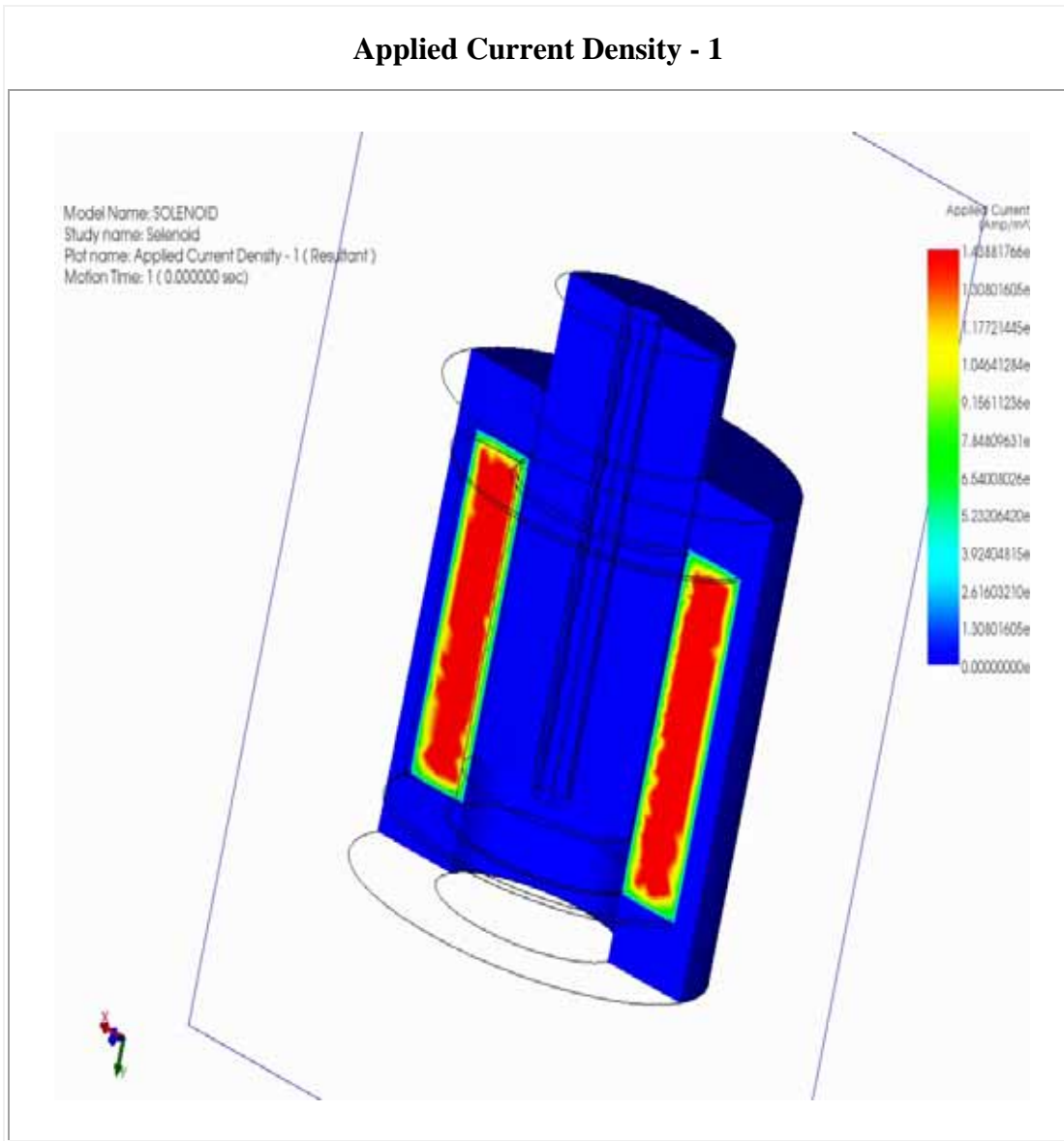
Model Name: SOLENOID  
Study name: Solenoid  
Plot name: Magnetic Field Intensity - 4 (Resultant)  
Motion Time: 1 (0.000000 sec)





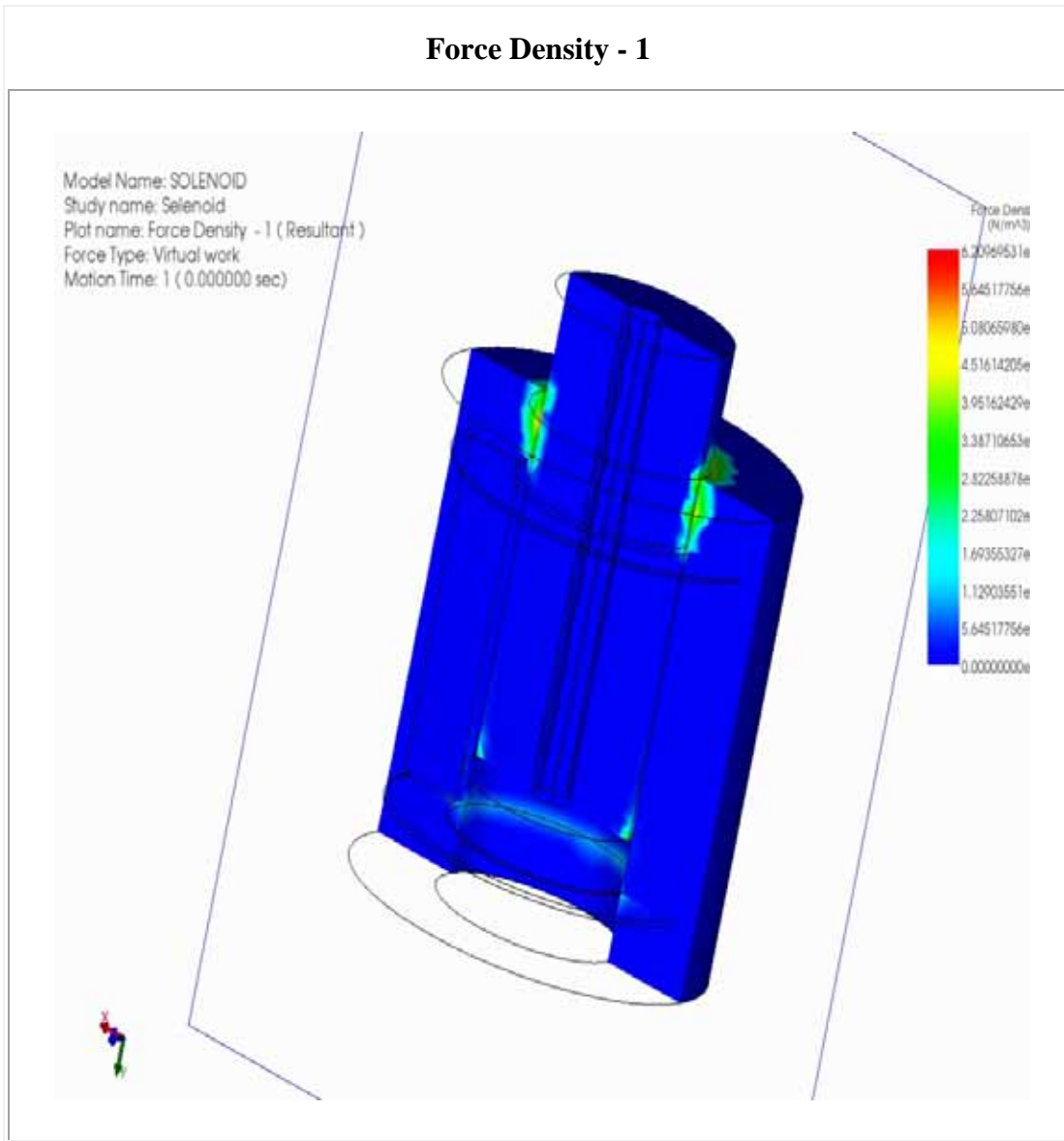
# 11. Applied Current Density Results

## Applied Current Density - 1



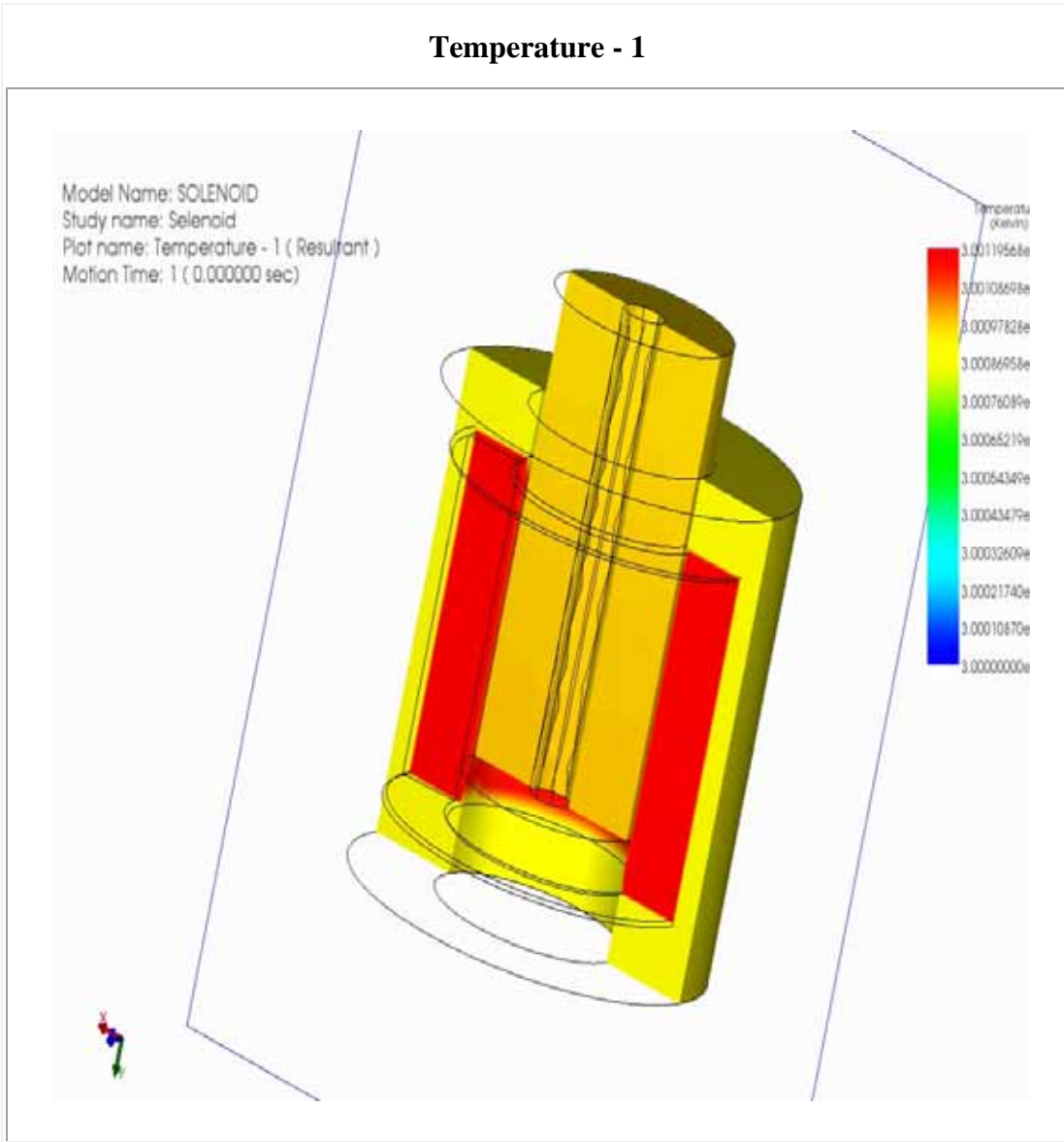
## 12. Force Density Results

**Force Density - 1**



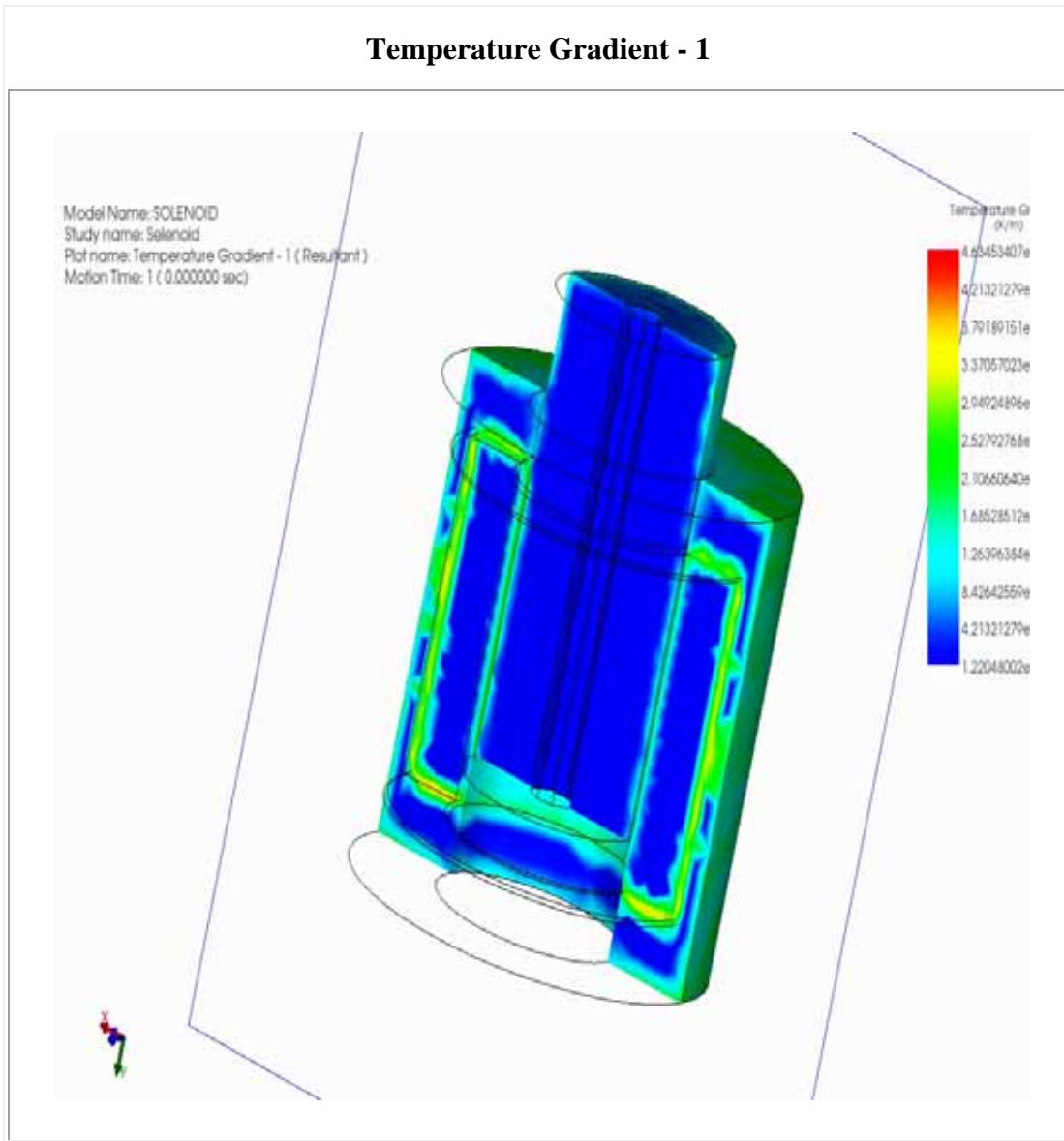
# 13. Temperature Results

Temperature - 1



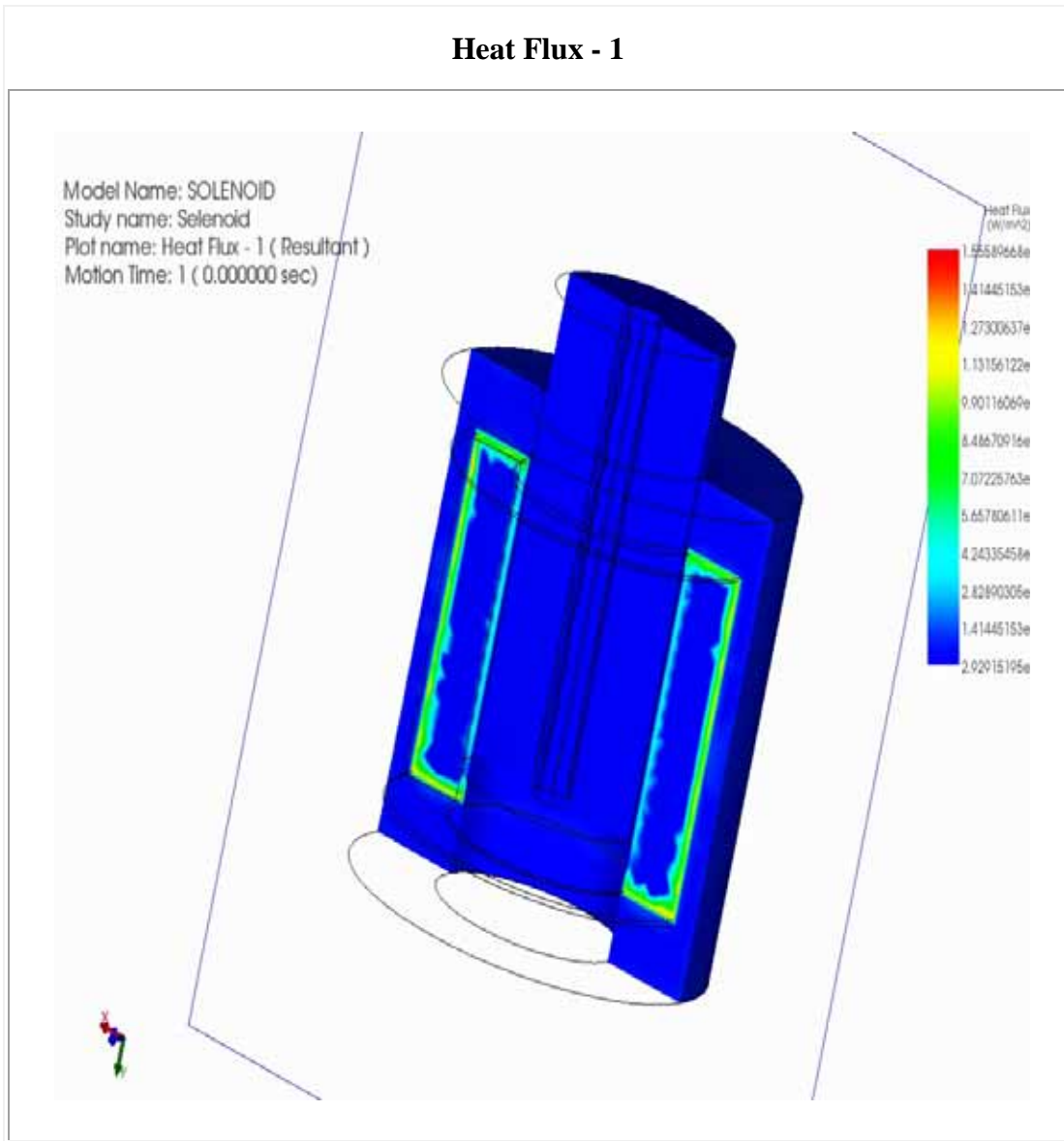
## 14. Temperature Gradient Results

Temperature Gradient - 1



## 15. Heat Flux Results

Heat Flux - 1



## 16. Appendix

**Material Name:** Air

**Permeability Type:** Isotropic

**Note:** R.P. stands for Relative Permeability

<b>R.P.</b>	<b>Permanent Magnet</b>	<b>Thermal Conductivity (W/m.K)</b>
1.000e+000	No	2.400e-002

**Material Name:** Copper

**Permeability Type:** Isotropic

**Note:** R.P. stands for Relative Permeability

<b>R.P.</b>	<b>Permanent Magnet</b>	<b>Thermal Conductivity (W/m.K)</b>
1.000e+000	No	4.010e+002

**Material Name:** Mild Steel

**Permeability Type:** Isotropic

**Note:** R.P. stands for Relative Permeability

<b>R.P.</b>	<b>Permanent Magnet</b>	<b>Thermal Conductivity (W/m.K)</b>
2.000e+003	No	4.000e+001