



Magnetostatic Analysis of Solenoid

Author: EMWorks

Company: ElectroMagnetic Works Inc

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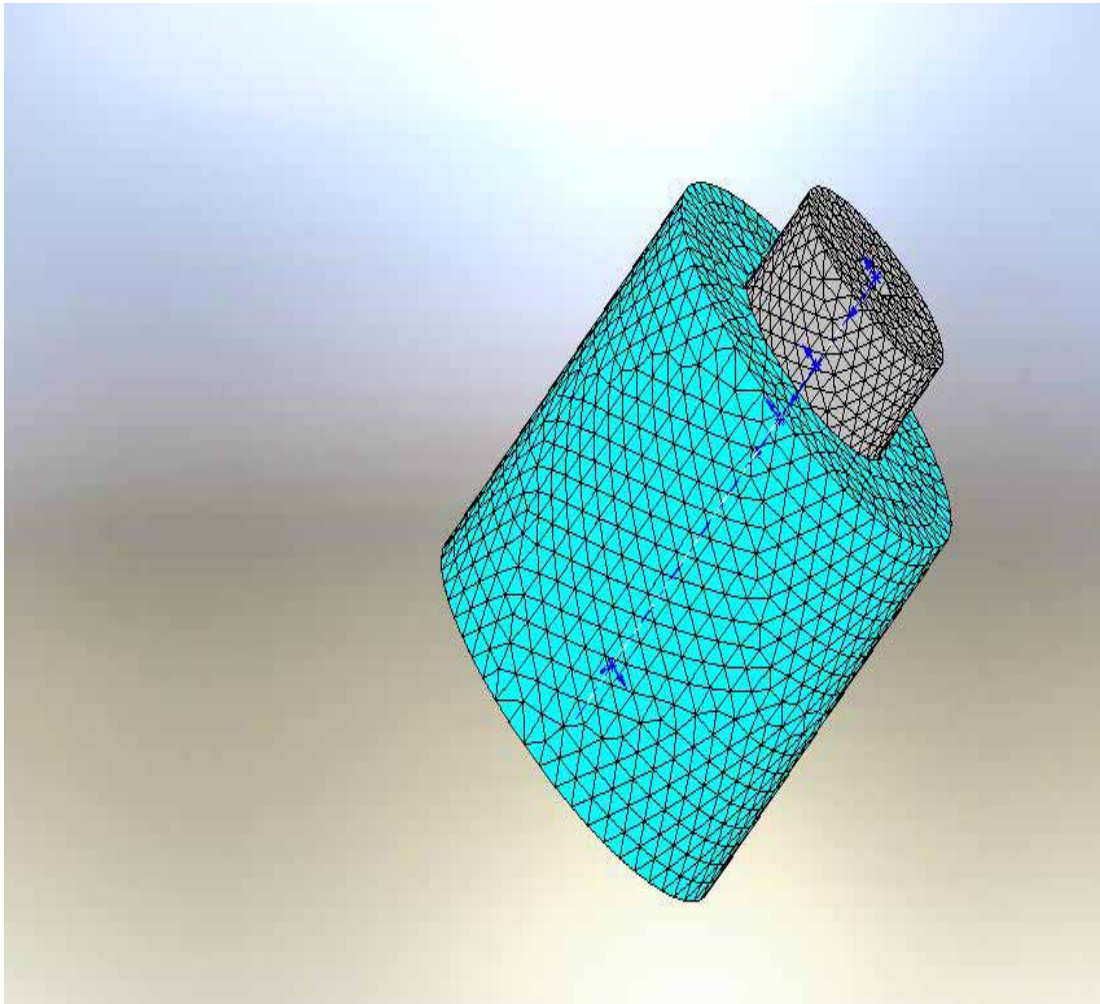
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1. Introduction

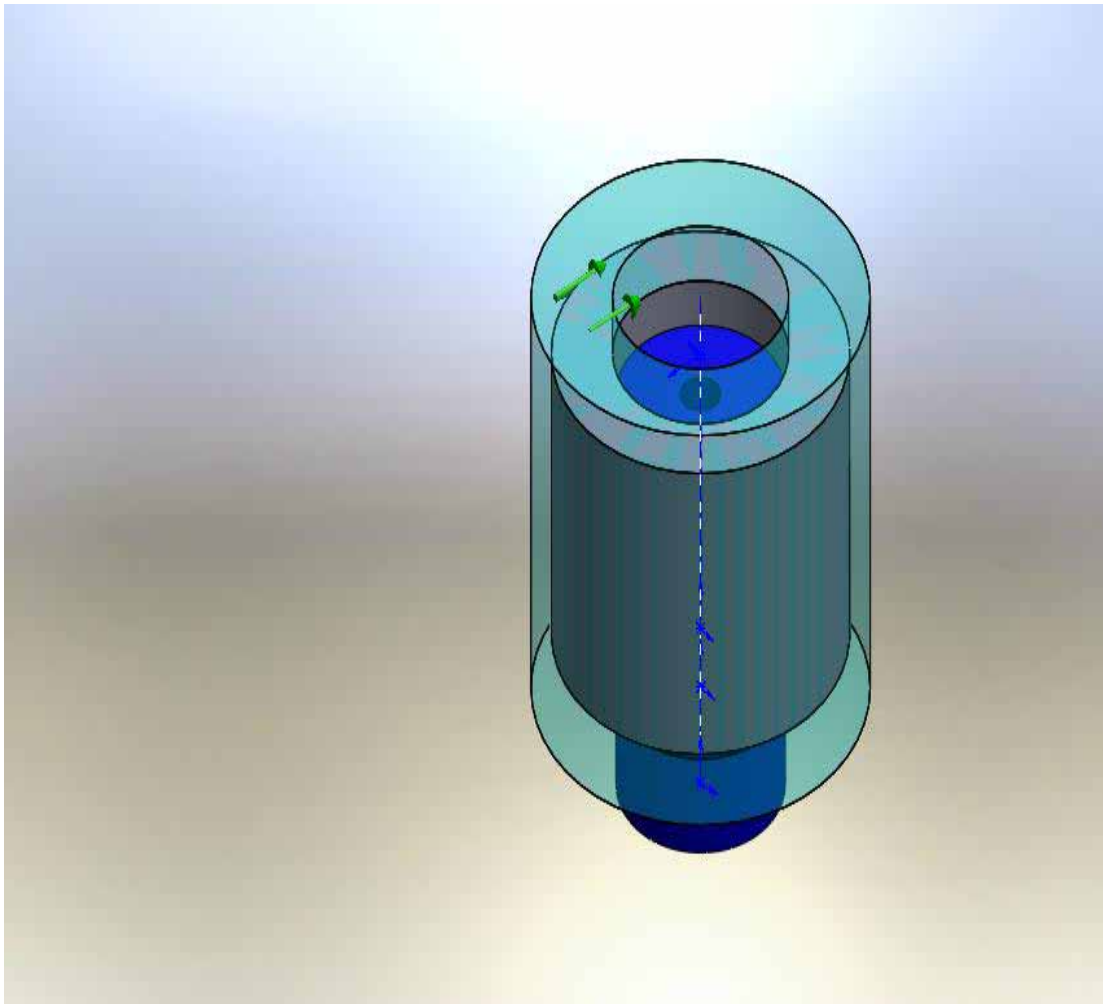
This is a Magnetostatic analysis of a solenoid. The study was coupled with motion to investigate the effect of the current induced electromagnetic force on the motion of the plunger. It was also coupled with thermal analysis to study the effect of Joule heating

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)	Air	Isotropic
2	Band^SOLENOID-1-Body 1 (Cavity1)	Air	Isotropic
3	coil-1-Body 1 (Split1[1])	Copper	Isotropic
4	coil-1-Body 2 (Split1[2])	Copper	Isotropic
5	Outer Air^SOLENOID-1-Body 1 (Cavity1)	Air	Isotropic
6	plunger-1-Body 1 (Boss-Extrude1)	Mild Steel	Isotropic
7	stator-1-Body 1 (Cut-Extrude1)	Mild Steel	Isotropic

4. Load & Restraint Information

Nbr.	Name	Selected Faces	Selected Components
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Thermal Loads

Nbr.	Name	Convection Coefficient (W/(m².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

Solver Type	Direct Solver
Nbr. Current Increments	1
Compute circuit parameters	Yes
Thermal Analysis	Yes
Motion Analysis	Yes

8. Results Table

Results for Motion Time Value: 0.000000000 sec

Force Results

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

Torque Results

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

Resistance Results

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

Inductance Results (H)

Coil Name	Wound Coil - 1
Wound Coil - 1	5.250530e-004

Flux Linkage Results

Coil Name	Flux Linkage (Wb)
Wound Coil - 1	4.200424e-004

BACK EMF Results

Coil Name	BACK EMF (V)
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

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

Torque Results

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

Resistance Results

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

Inductance Results (H)

Coil Name	Wound Coil - 1
Wound Coil - 1	6.158430e-004

Flux Linkage Results

Coil Name	Flux Linkage (Wb)
Wound Coil - 1	4.926744e-004

BACK EMF Results

Coil Name	BACK EMF (V)
Wound Coil - 1	7.683624e-004

Energy Results

Energy (J)	Co-Energy (J)
1.970698e-004	1.970698e-004

Results for Motion Time Value: 0.300000012 sec

Force Results

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

Torque Results

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

Resistance Results

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

Inductance Results (H)

Coil Name	Wound Coil - 1
Wound Coil - 1	8.611835e-004

Flux Linkage Results

Coil Name	Flux Linkage (Wb)
Wound Coil - 1	6.889468e-004

BACK EMF Results

Coil Name	BACK EMF (V)
Wound Coil - 1	2.492732e-003

Energy Results

Energy (J)	Co-Energy (J)
2.755787e-004	2.755787e-004

Results for Motion Time Value: 0.400000006 sec

Force Results

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

Torque Results

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

Resistance Results

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

Inductance Results (H)

Coil Name	Wound Coil - 1
Wound Coil - 1	1.974572e-003

Flux Linkage Results

Coil Name	Flux Linkage (Wb)
Wound Coil - 1	1.579658e-003

BACK EMF Results

Coil Name	BACK EMF (V)
Wound Coil - 1	1.235032e-002

Energy Results

Energy (J)	Co-Energy (J)
6.318631e-004	6.318631e-004

Results for Motion Time Value: 0.500000000 sec

Force Results

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

Torque Results

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

Resistance Results

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

Inductance Results (H)

Coil Name	Wound Coil - 1
Wound Coil - 1	2.096822e-003

Flux Linkage Results

Coil Name	Flux Linkage (Wb)
Wound Coil - 1	1.677457e-003

BACK EMF Results

Coil Name	BACK EMF (V)
Wound Coil - 1	1.173716e-003

Energy Results

Energy (J)	Co-Energy (J)
6.709830e-004	6.709830e-004

Results for Motion Time Value: 0.600000024 sec

Force Results

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

Torque Results

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

Resistance Results

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

Inductance Results (H)

Coil Name	Wound Coil - 1
Wound Coil - 1	5.653326e-004

Flux Linkage Results

Coil Name	Flux Linkage (Wb)
Wound Coil - 1	4.522661e-004

BACK EMF Results

Coil Name	BACK EMF (V)
Wound Coil - 1	-9.925817e-003

Energy Results

Energy (J)	Co-Energy (J)
1.809064e-004	1.809064e-004

Results for Motion Time Value: 0.699999988 sec

Force Results

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

Torque Results

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

Resistance Results

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

Inductance Results (H)

Coil Name	Wound Coil - 1
Wound Coil - 1	3.493696e-004

Flux Linkage Results

Coil Name	Flux Linkage (Wb)
Wound Coil - 1	2.794957e-004

BACK EMF Results

Coil Name	BACK EMF (V)
Wound Coil - 1	-1.588907e-003

Energy Results

Energy (J)	Co-Energy (J)
1.117983e-004	1.117983e-004

Results for Motion Time Value: 0.800000012 sec

Force Results

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

Torque Results

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

Resistance Results

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

Inductance Results (H)

Coil Name	Wound Coil - 1
Wound Coil - 1	2.357989e-004

Flux Linkage Results

Coil Name	Flux Linkage (Wb)
Wound Coil - 1	1.886391e-004

BACK EMF Results

Coil Name	BACK EMF (V)
Wound Coil - 1	-8.680159e-004

Energy Results

Energy (J)	Co-Energy (J)
7.545566e-005	7.545566e-005

Results for Motion Time Value: 0.899999976 sec

Force Results

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

Torque Results

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

Resistance Results

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

Inductance Results (H)

Coil Name	Wound Coil - 1
Wound Coil - 1	1.636523e-004

Flux Linkage Results

Coil Name	Flux Linkage (Wb)
Wound Coil - 1	1.309219e-004

BACK EMF Results

Coil Name	BACK EMF (V)
Wound Coil - 1	-5.588295e-004

Energy Results

Energy (J)	Co-Energy (J)
5.236874e-005	5.236874e-005

Results for Motion Time Value: 1.000000000 sec

Force Results

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

Torque Results

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

Resistance Results

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

Inductance Results (H)

Coil Name	Wound Coil - 1
Wound Coil - 1	1.172929e-004

Flux Linkage Results

Coil Name	Flux Linkage (Wb)
Wound Coil - 1	9.383434e-005

BACK EMF Results

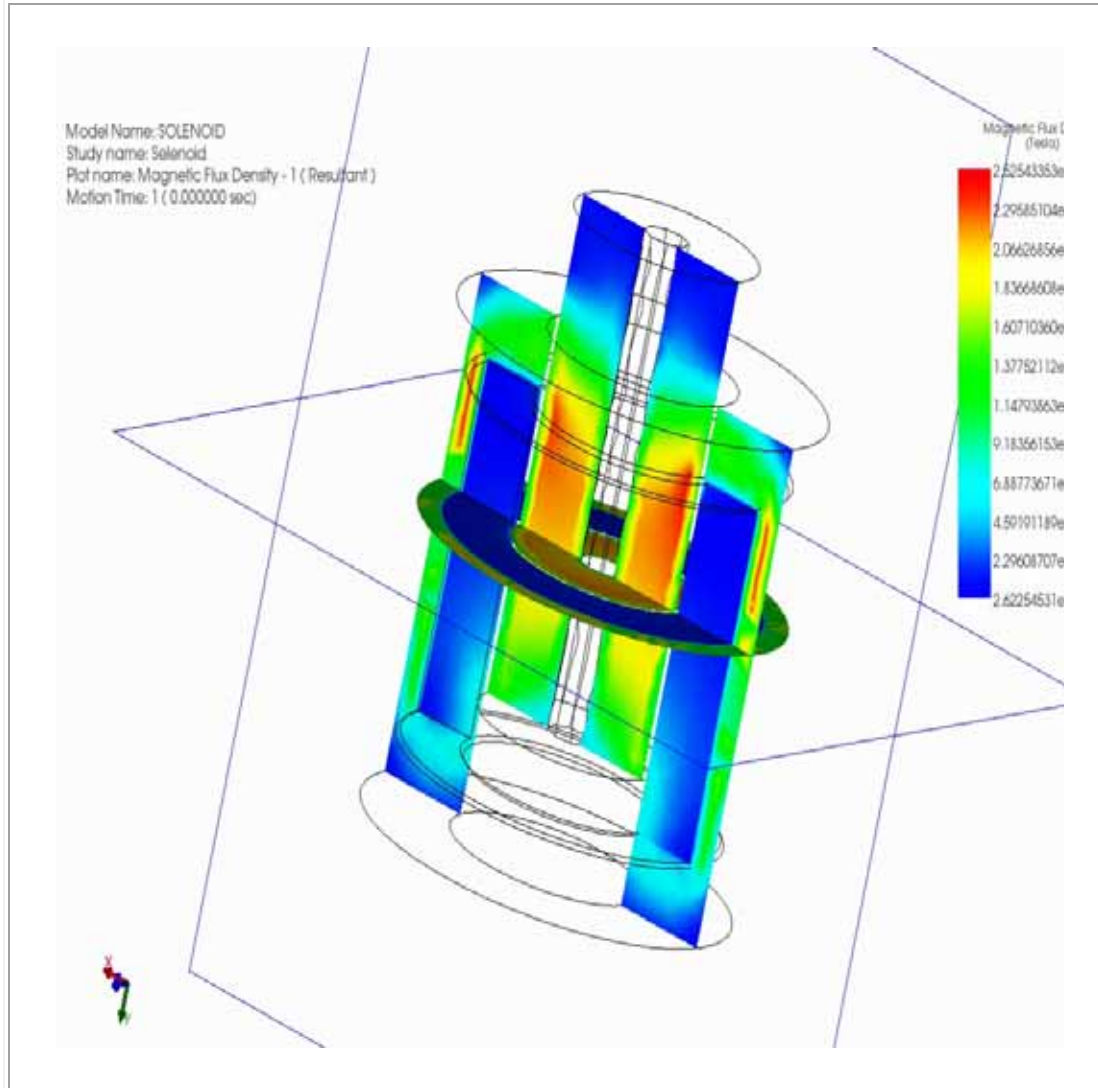
Coil Name	BACK EMF (V)
Wound Coil - 1	-3.620471e-004

Energy Results

Energy (J)	Co-Energy (J)
3.753374e-005	3.753374e-005

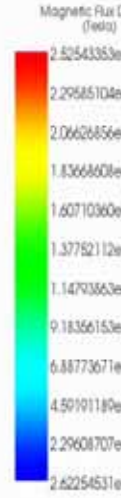
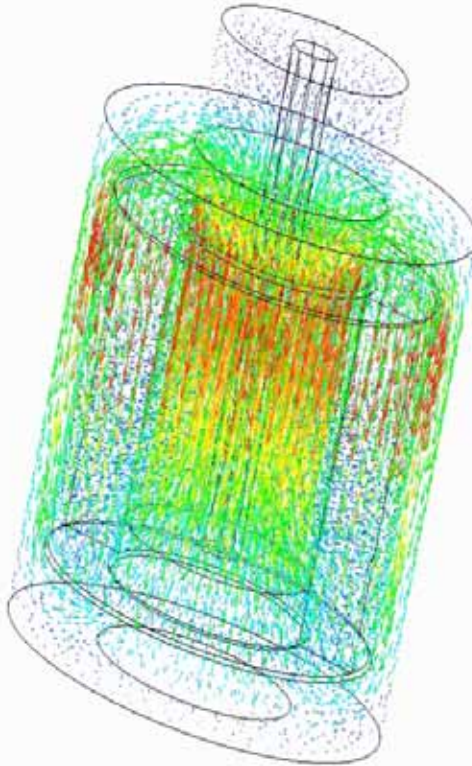
9. Magnetic Flux Density Results

Magnetic Flux Density - 1



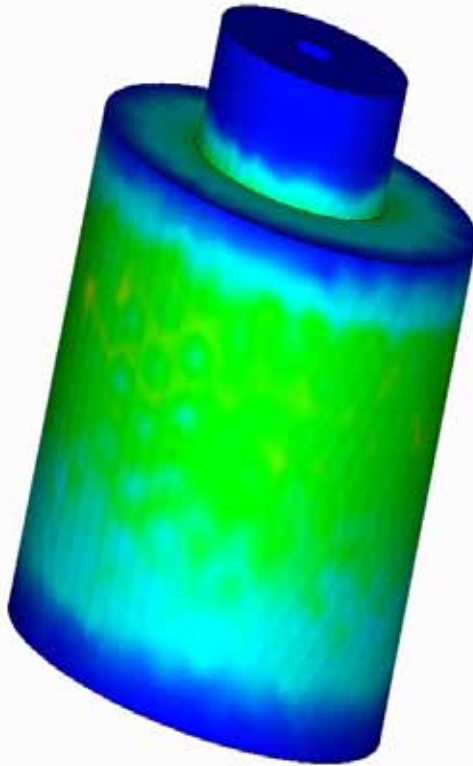
Magnetic Flux Density - 2

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

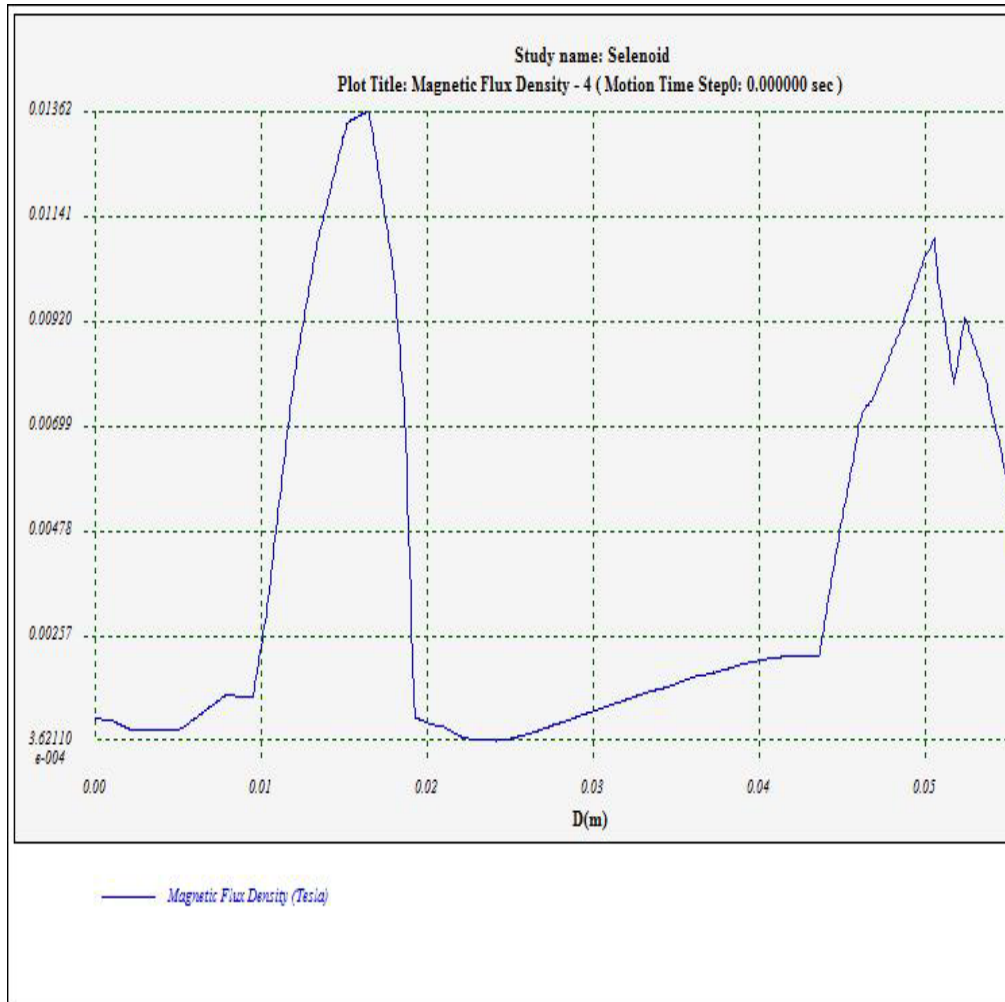


Magnetic Flux Density - 3

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

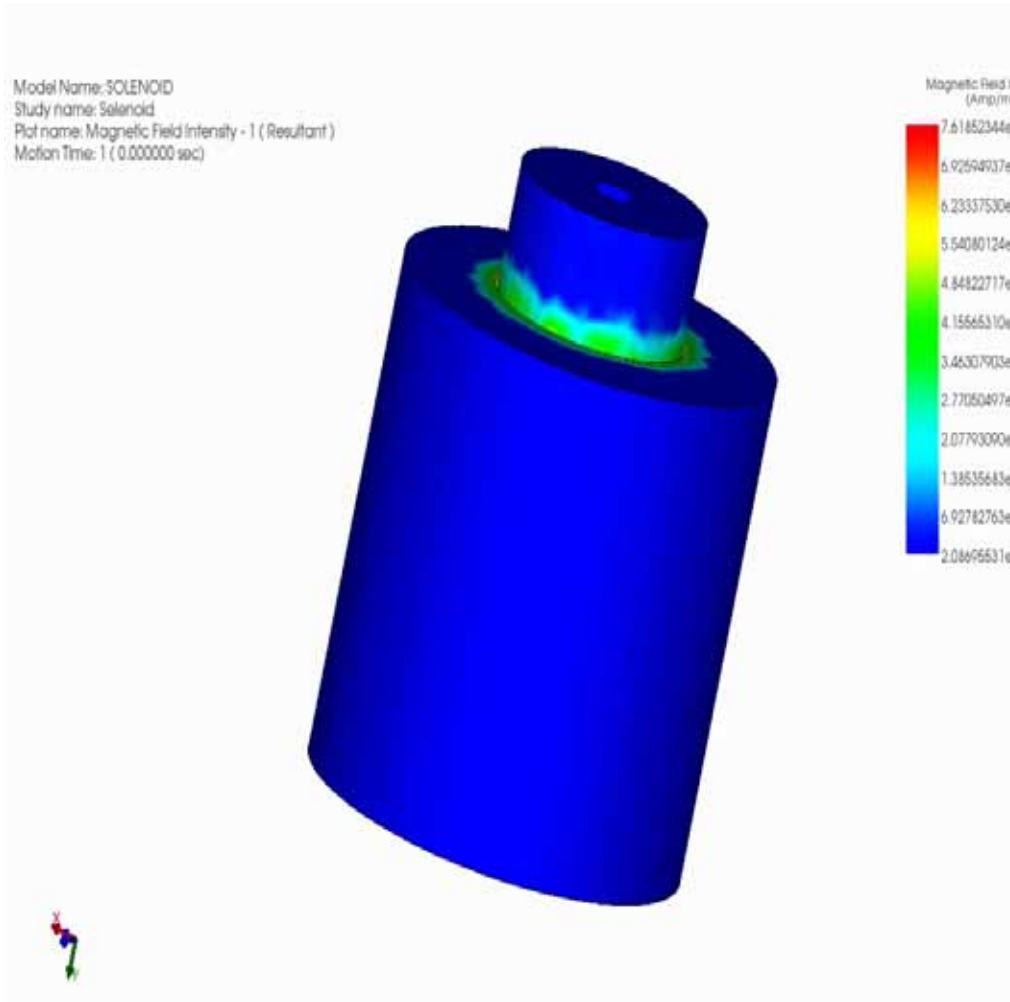


Magnetic Flux Density - 4

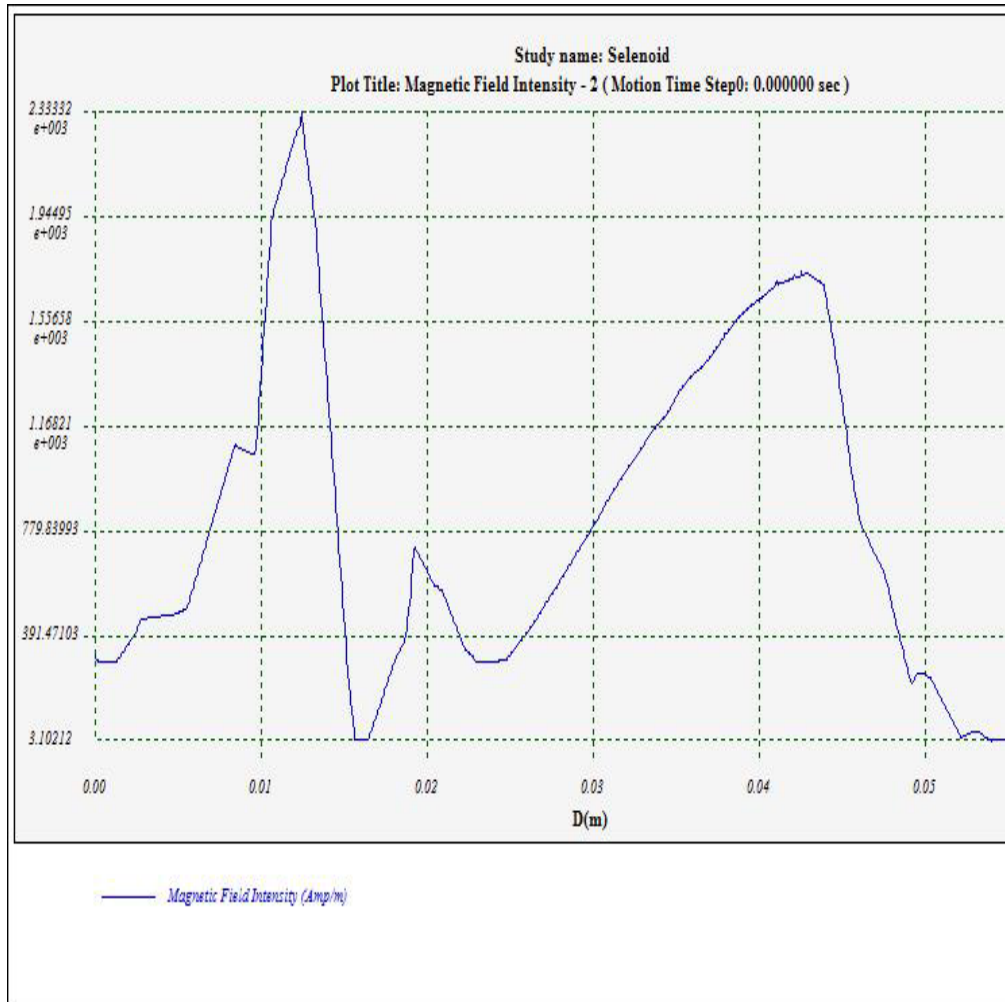


10. Magnetic Field Intensity Results

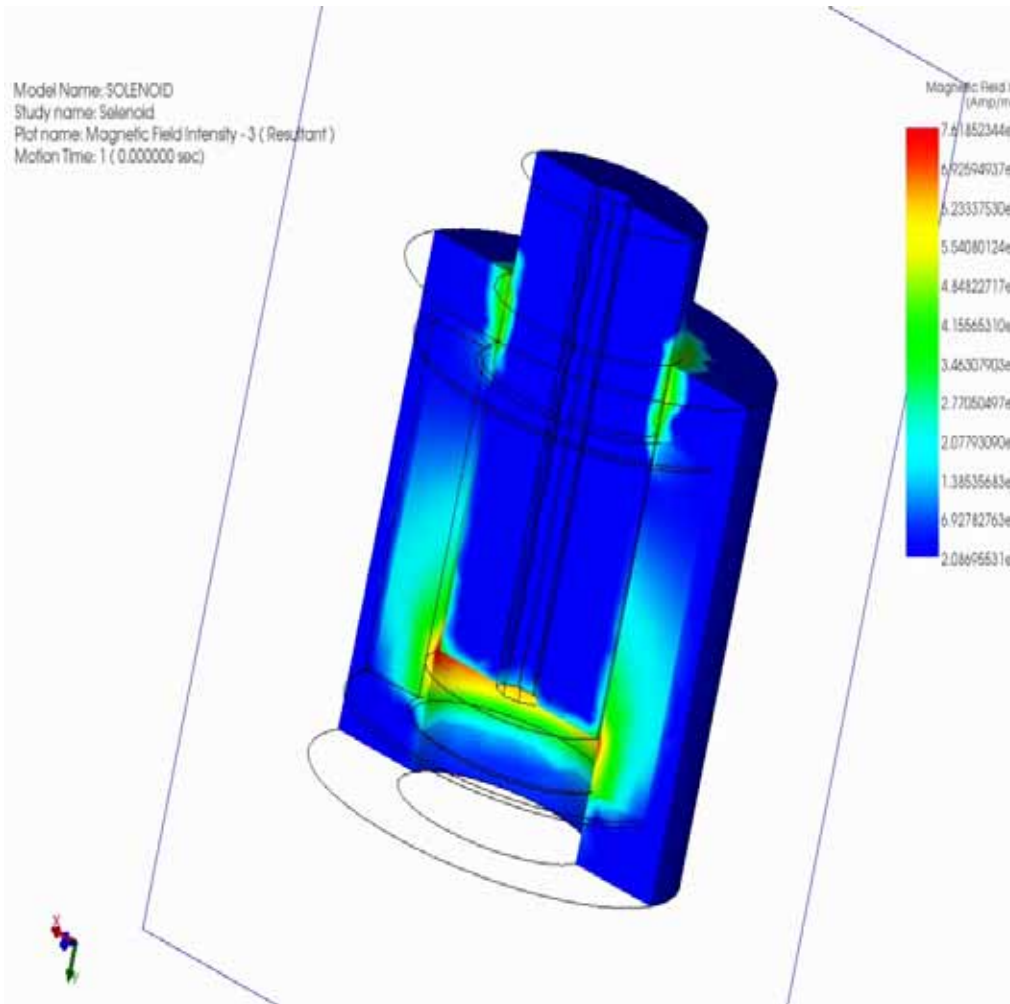
Magnetic Field Intensity - 1



Magnetic Field Intensity - 2

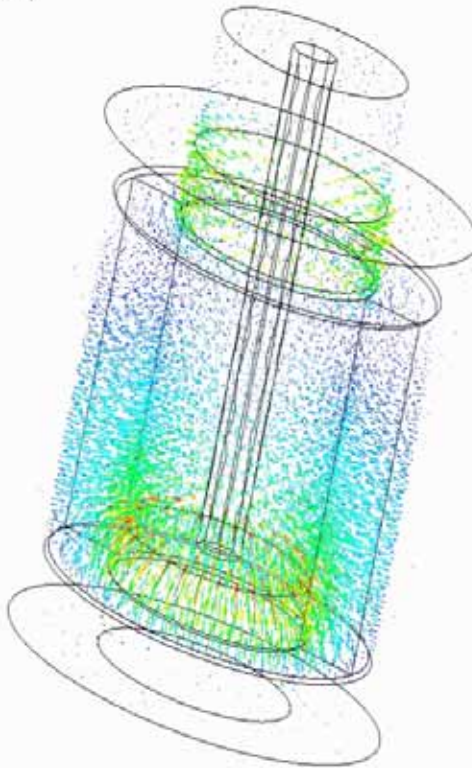


Magnetic Field Intensity - 3



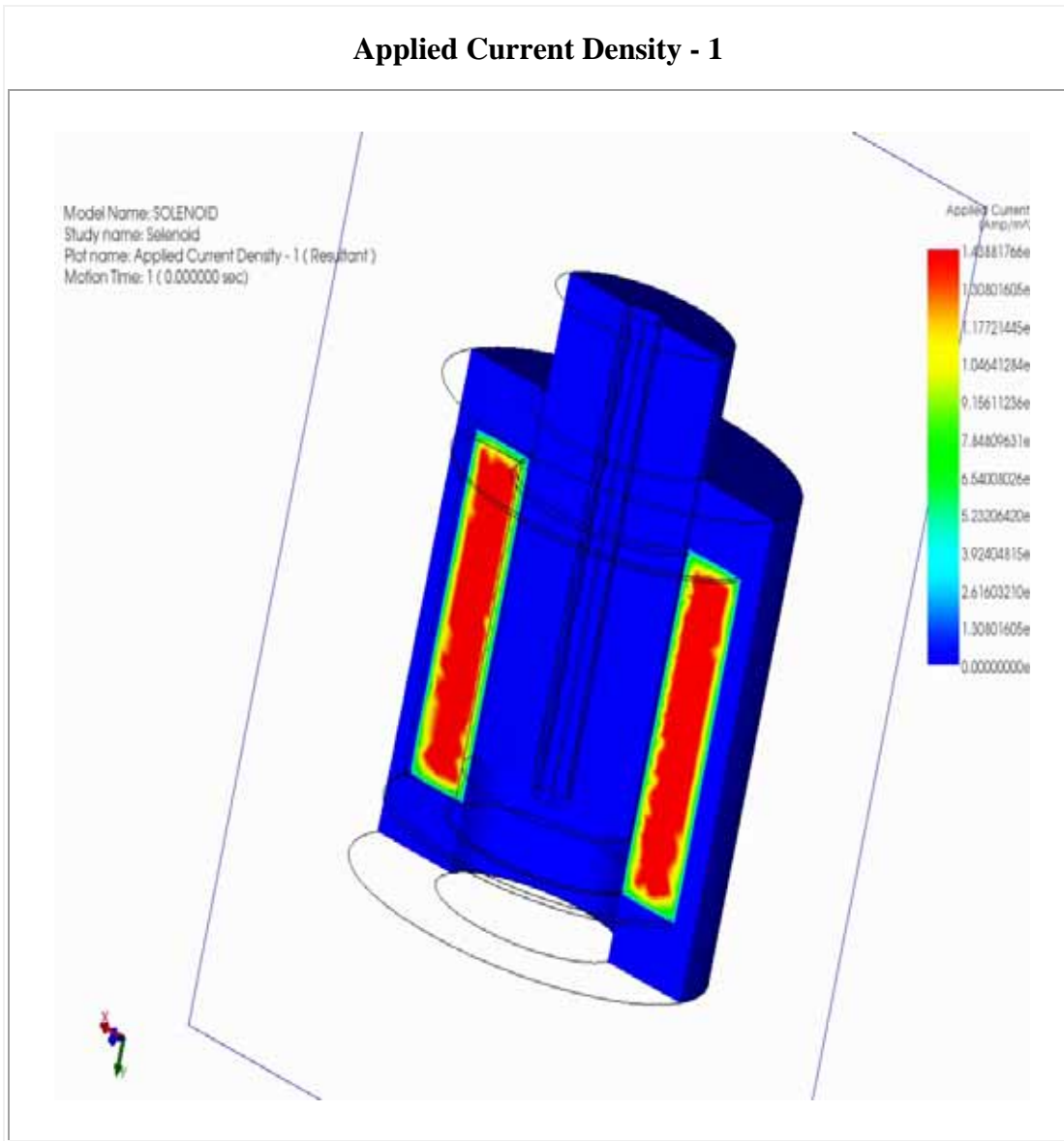
Magnetic Field Intensity - 4

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



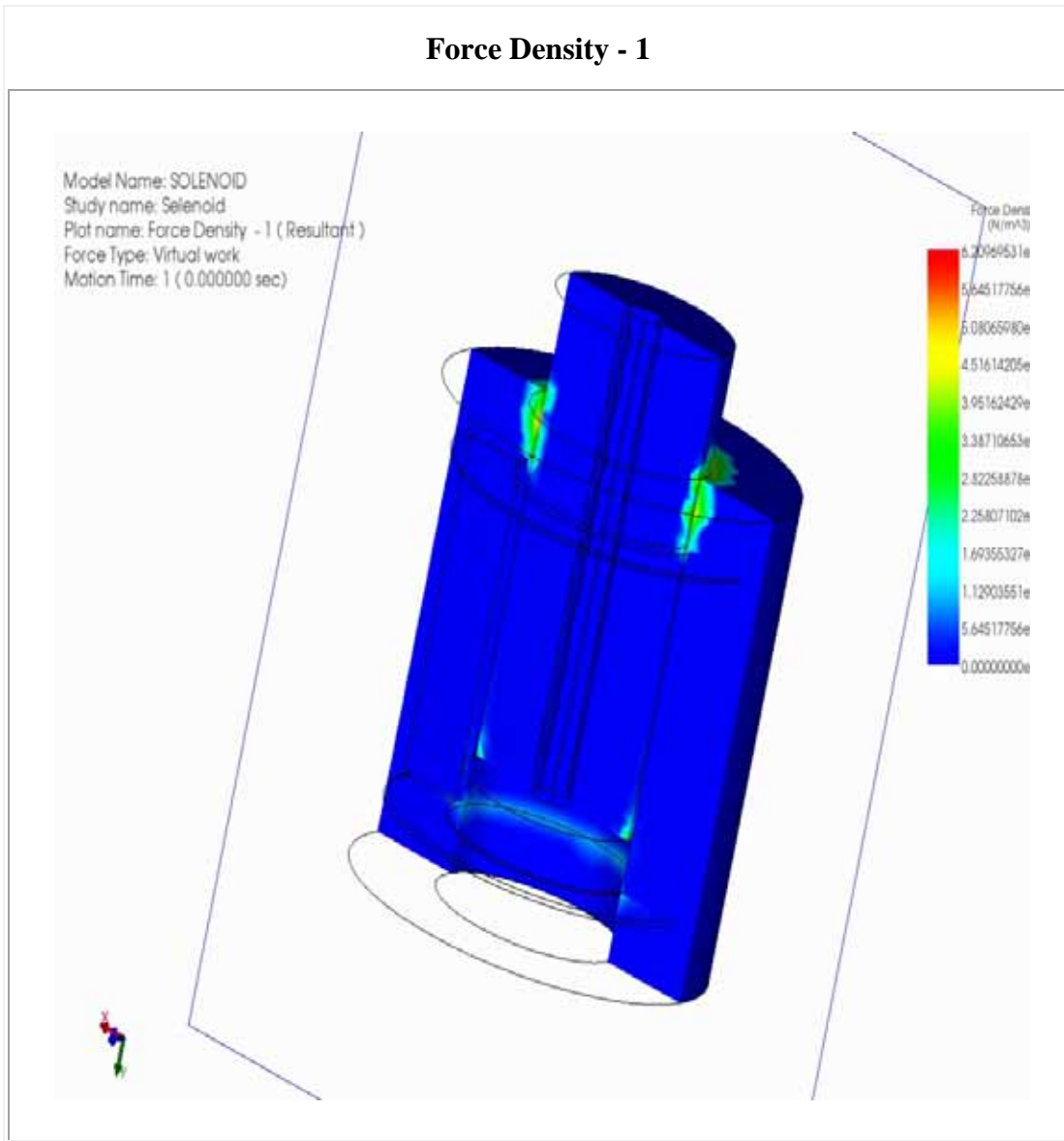
11. Applied Current Density Results

Applied Current Density - 1



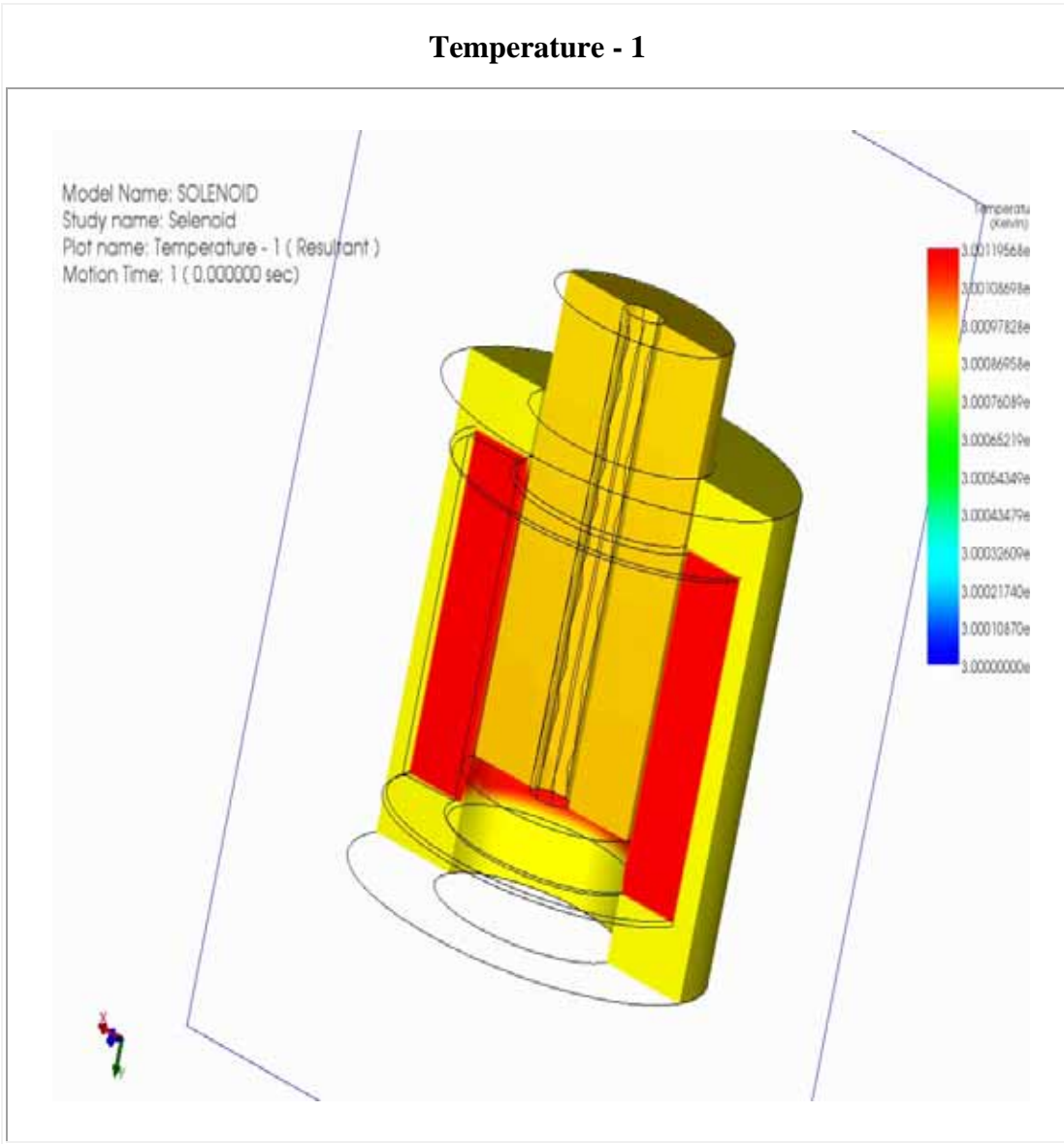
12. Force Density Results

Force Density - 1



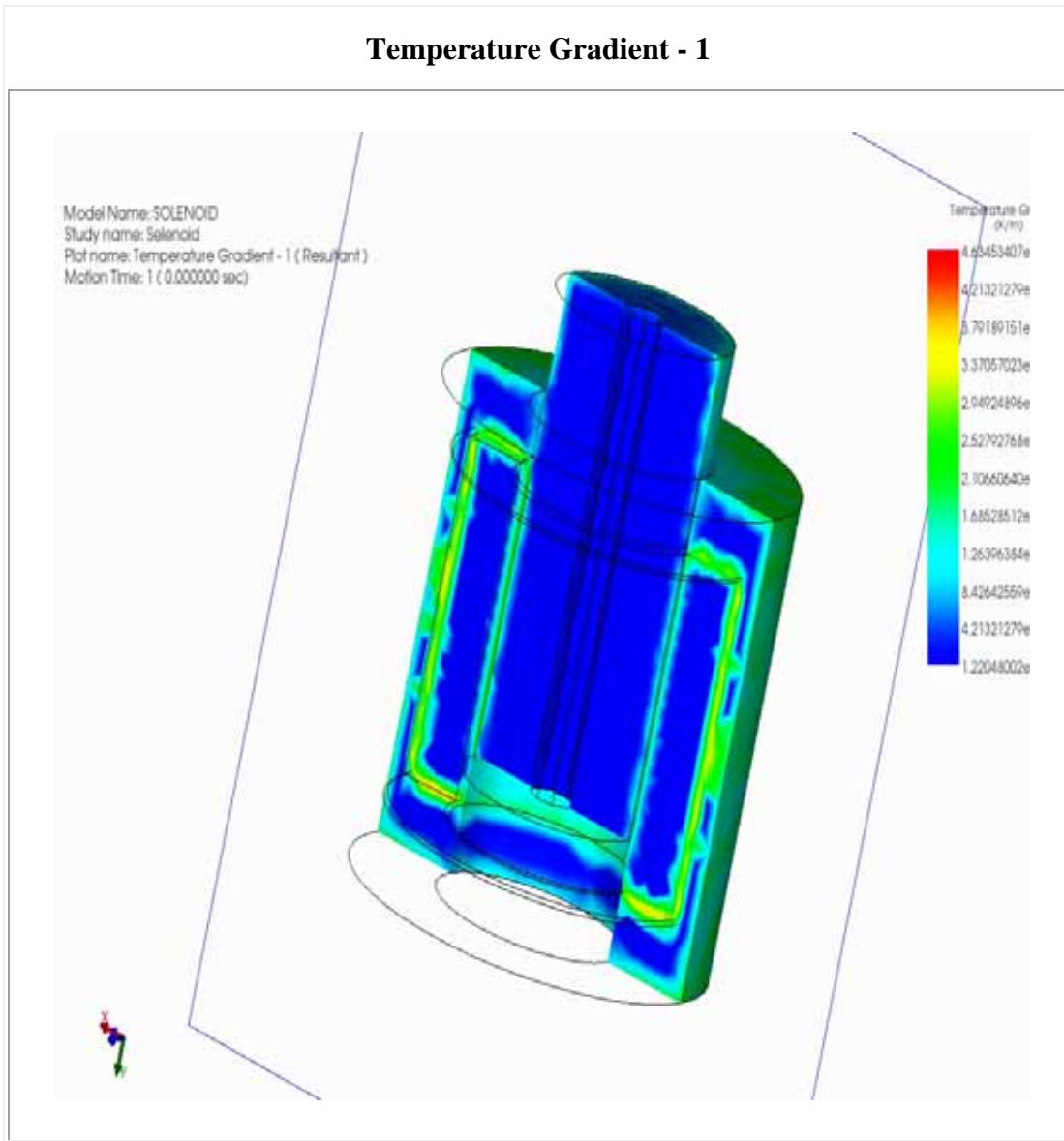
13. Temperature Results

Temperature - 1



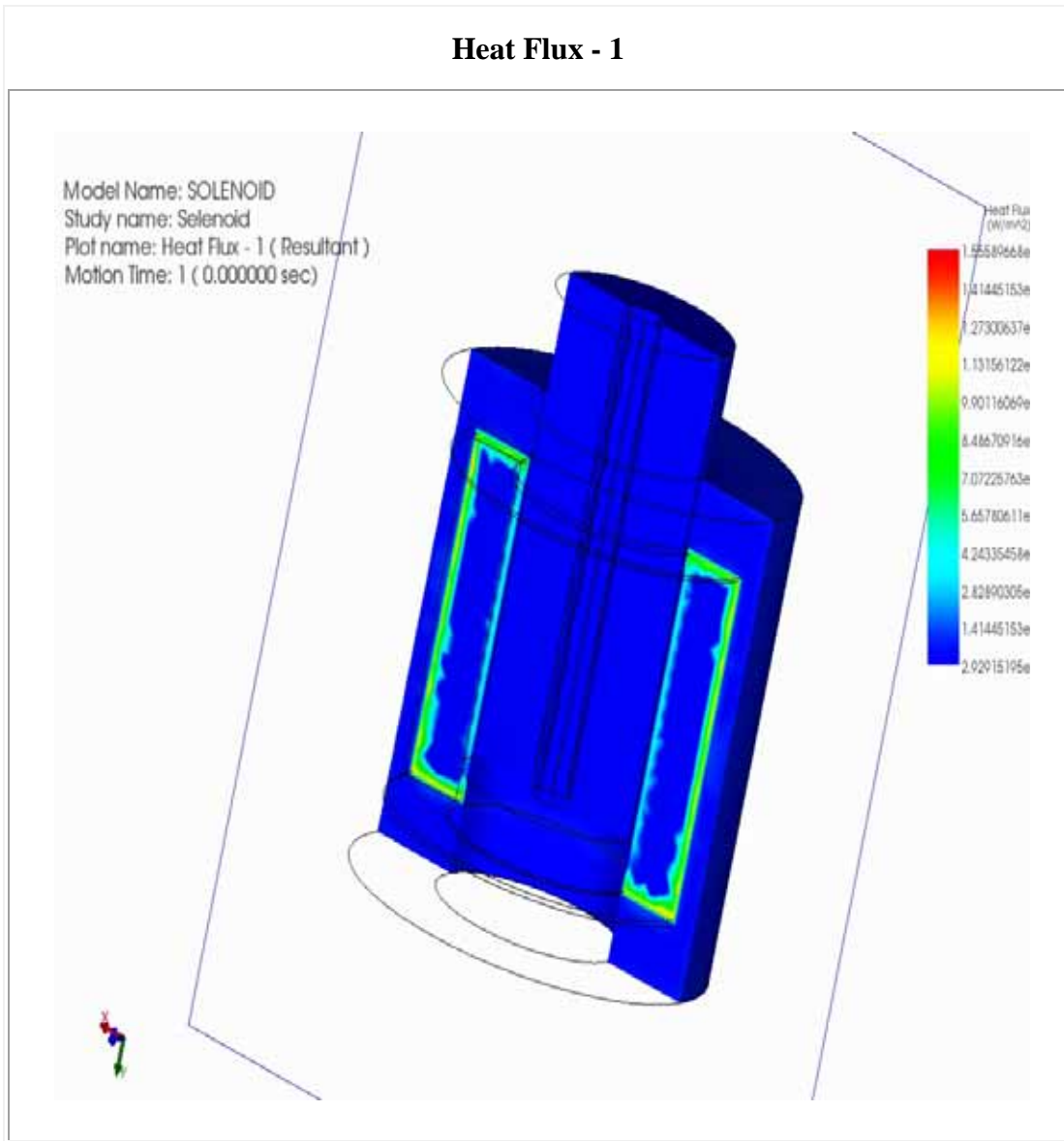
14. Temperature Gradient Results

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

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

Material Name: Copper

Permeability Type: Isotropic

Note: R.P. stands for Relative Permeability

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

Material Name: Mild Steel

Permeability Type: Isotropic

Note: R.P. stands for Relative Permeability

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