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Simulation of Flux Density in a Hybrid Coil Superconducting Magnetic Energy Storage Using COMSOL Multiphysics

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Introduction

- Why is storage important ?
- Energy storage is a must for hybrid power systems using non-conventional resources to avoid energy dumping.
- Stored energy can be used as and when required.

- Various energy storage technologies : -
- Compressed Air Energy Storage (CAES)
- Batteries
- Flywheel
- Supercapacitors
- Superconducting Magnetic Energy Storage (SMES)

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Why should we choose SMES ?

- Direct storage of electrical energy in the form of field energy
- No loss due to resistance of the conductors of the SMES as they are made of superconducting materials which practically offer no resistance to current.
- Huge energy can be stored by increasing the magnetic field which is otherwise not possible with the conventional conductors.
- Energy can be supplied by discharging the SMES using power electronic switches.

What is an SMES ?

When current is passed through a conductor a magnetic field is produced. Energy is stored in this field which can be returned to the system by discharging the conductor or a coil made of a conductor. Superconductors practically offer almost no resistance to current flow and can carry high current for a given cross section as compared to a conventional conductor [1]. So a huge field can be created resulting in higher energy storage and compact size of the SMES which uses such coils.

Different parts of an SMES

- Superconducting Coil
- Power Conditioning System
- Cryogenic system
- Cooling Unit

Different parts of an SMES

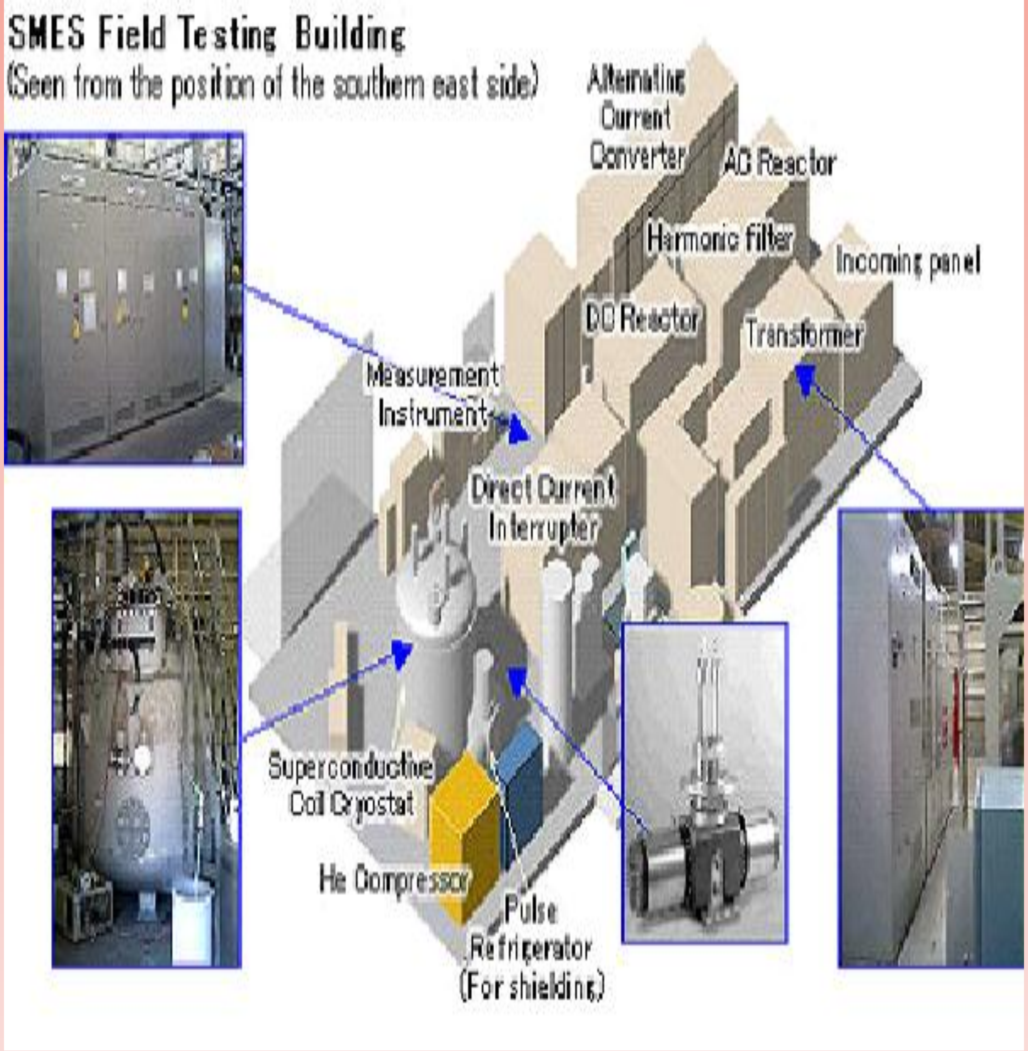

Figure 1: The parts of an SMES[2]

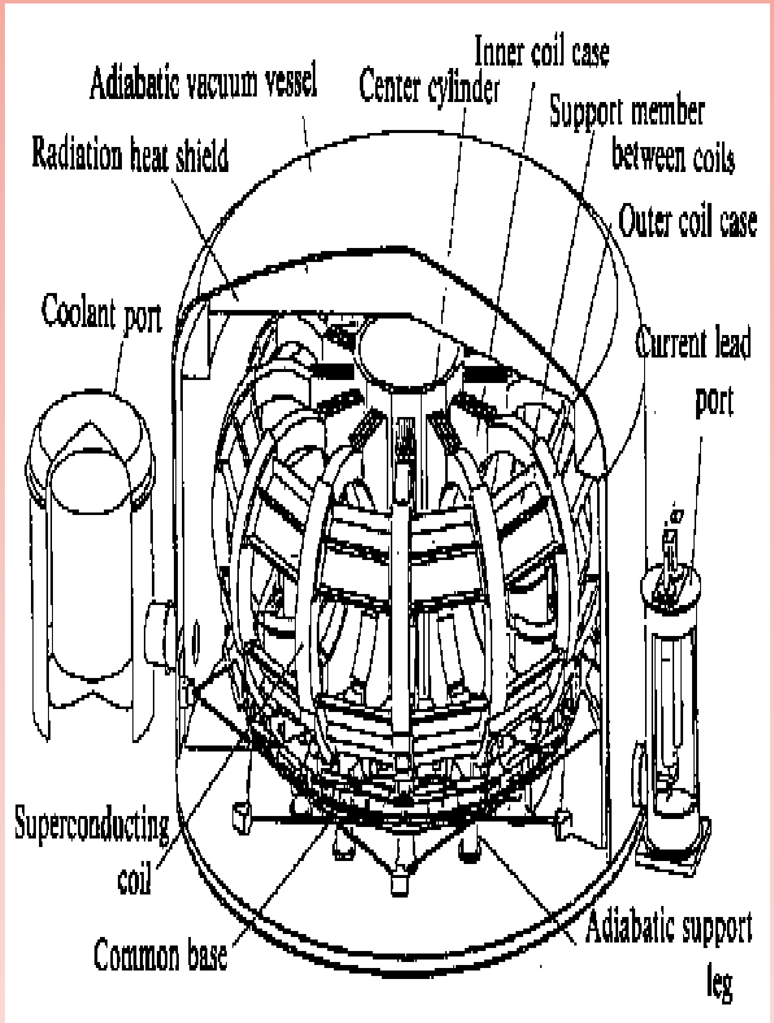

Figure 2: The superconducting coil (toroid) with the cryogenic system [3]

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About the coil model used in the work

- A hybrid coil [4] made of an outer Low Temperature Superconducting (LTS) material (NbTi) and an insert coil of High Temperature Superconducting (HTS) material (Bi-2212).
- Both the coils are solenoids.
- Both use pancake coils (of Rutherford cable) – single pancake coils for outer one and double pancake coils for insert one.

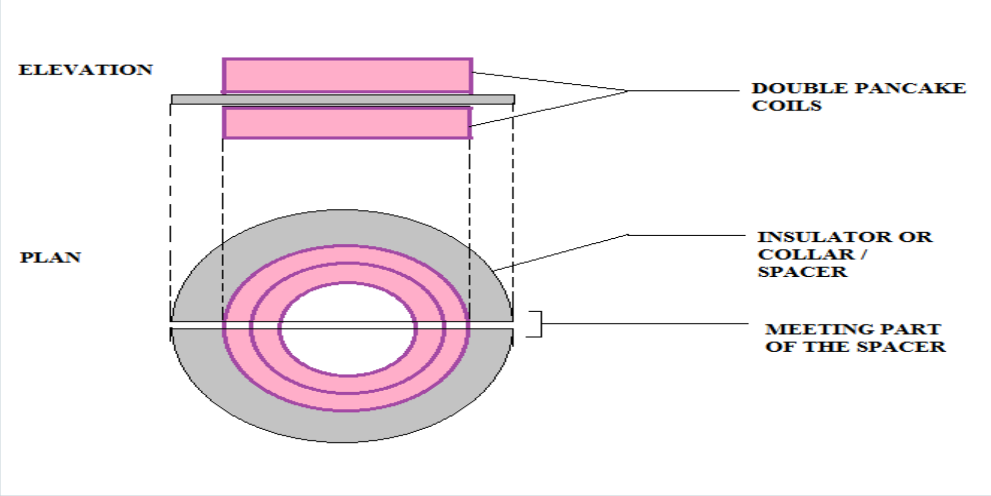

Figure 3: Structure of a single Double Pancake coil

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Coil Design Parameters for Simulation Work

Coil	HTS	LTS
Material used	Bi-2212	NbTi
Conductor dimension, mm	13.5 × 1.6	12.36 × 1.46
Type of winding	Double pancake	Single pancake
Inner diameter, mm	370	870
Outer diameter, mm	720	969.6
Coil Height, mm	525	949.2
Total no. of turns	1600	2100
Operating current, A	1655	1553
Operating temperature, K	4.2	
Peak field, T	7.5	2.4
Central Field, T	6.95	
Current Density, A/mm^2	28.820	68.993

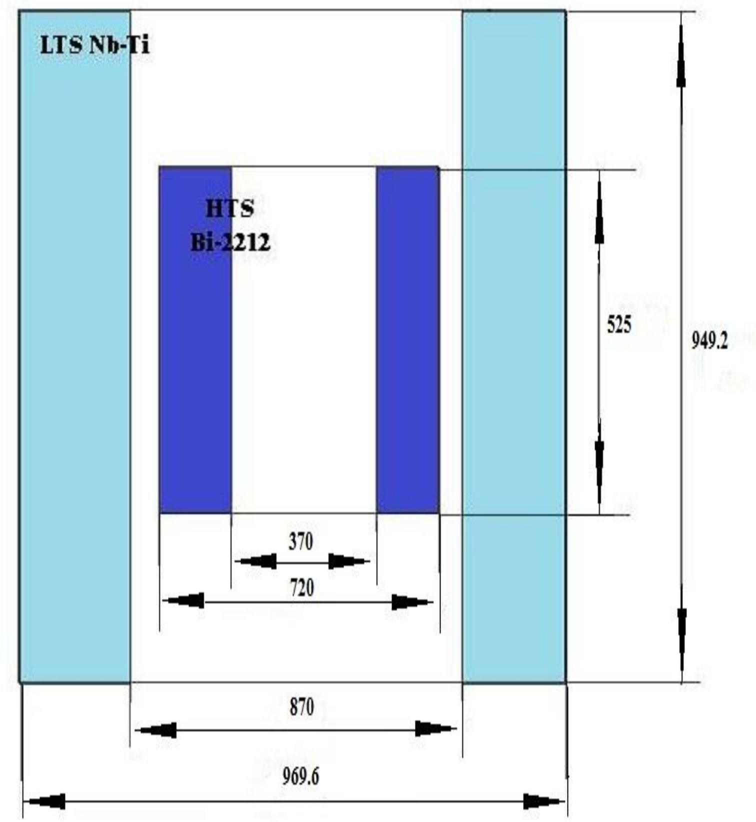

Figure 4: Schematic diagram of the hybrid coil longitudinal section.

Use of COMSOL Multiphysics

Physics of the chosen model

Since field distribution vector **B** is to be simulated and DC has been used we use the following equations

$$\nabla \times \left(\mu^{-1} \nabla \times A \right) = J^{e}$$

$$B = \nabla \times A$$

$$H = \mu^{-1} B$$

where **A** = magnetic vector potential

J^{e} = external current density

B = magnetic field

H = magnetic field strength

Parameters and Equations for Simulation

- HTS coil current density is J_{h0} = 28.82 A/mm^2.
- LTS coil current density is J_{l0} = 68.993 A/mm^2. These are defined in the **Global Definitions**>**Parameters** section.
- Use of **Workplane** and **Revolve** options to build model geometry
- Ampere's law is applied to all the domains

$$\nabla \times H = J^e$$

where $$B = \nabla \times A$$

and $$H = \mu^{-1} B$$

- Expression for current density vector components in the Cartesian coordinate for LTS coil

COMPONENTS	EXPRESSION
x	$-J_{l0} \times z / \mathrm{sqrt}\ (x^2 + z^2)$
y	0
z	$J_{l0} \times x / \mathrm{sqrt}\ (x^2 + z^2)$

- Expression for current density vector components in the Cartesian coordinate for HTS coil

COMPONENTS	EXPRESSION
x	$-J_{h0} \times z / \mathrm{sqrt}\ (x^2 + z^2)$
y	0
z	$J_{h0} \times x / \mathrm{sqrt}\ (x^2 + z^2)$

Boundary Conditions

Magnetic insulation is applied to the entire sphere and the equation is

$$n \times A = 0$$

where n is the unit normal.

Meshing

- Mesh settings section - **Coarse** elements selection
- **Free Tetrahedral** meshing

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Figures for Model Geometry and Meshing

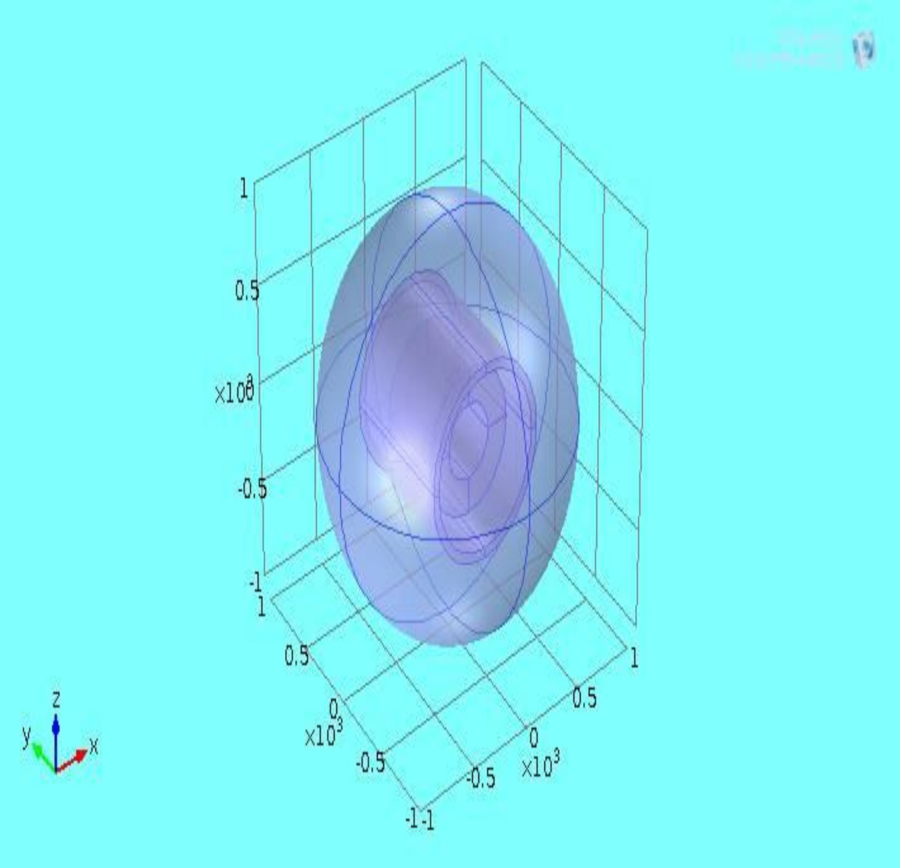

Figure 5: The model geometry.

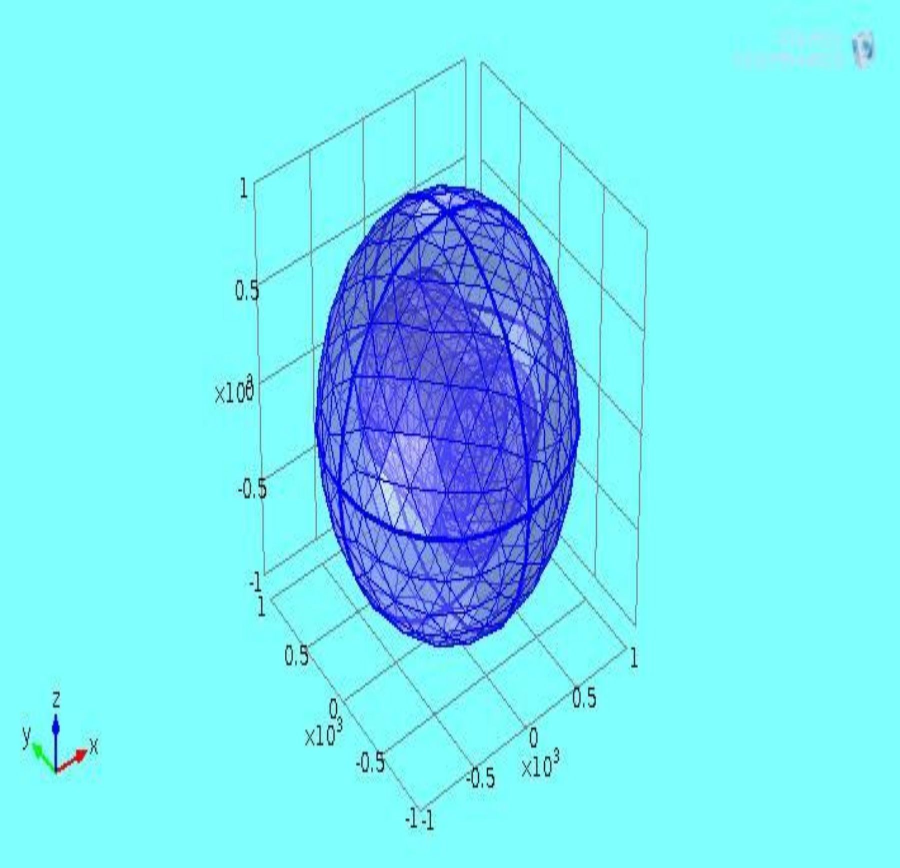

Figure 6: Meshing in 3D for hybrid coil.

Results and Discussion

Magnetic field distribution simulation has been done using the 3D **Plot Group** option and using **Arrow Volume** plot and **Slice plot.**

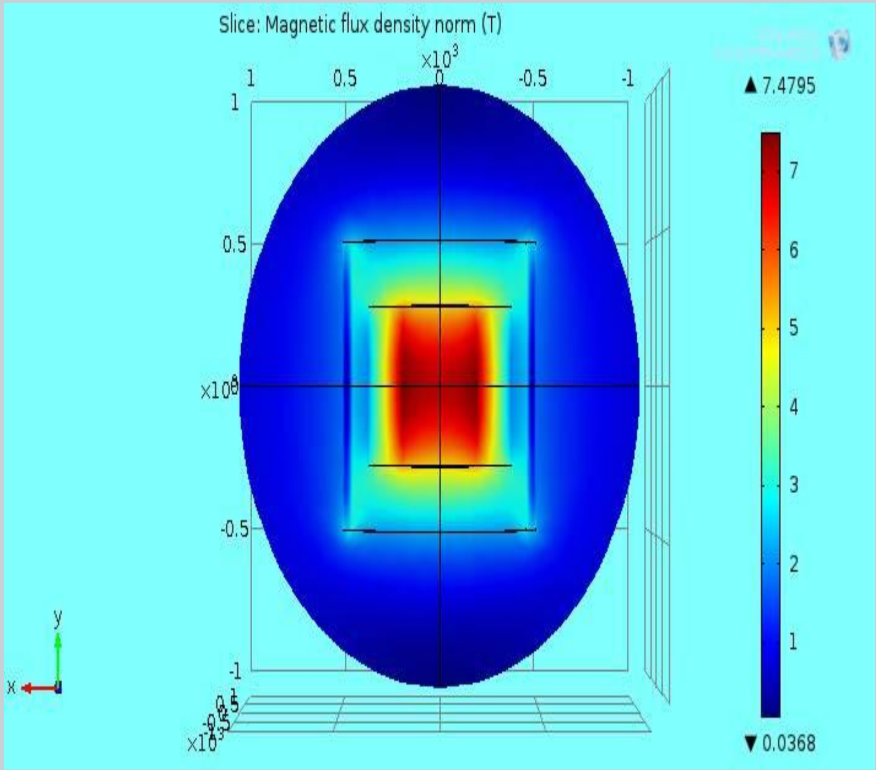

Figure 7: Slice plot showing the field distribution

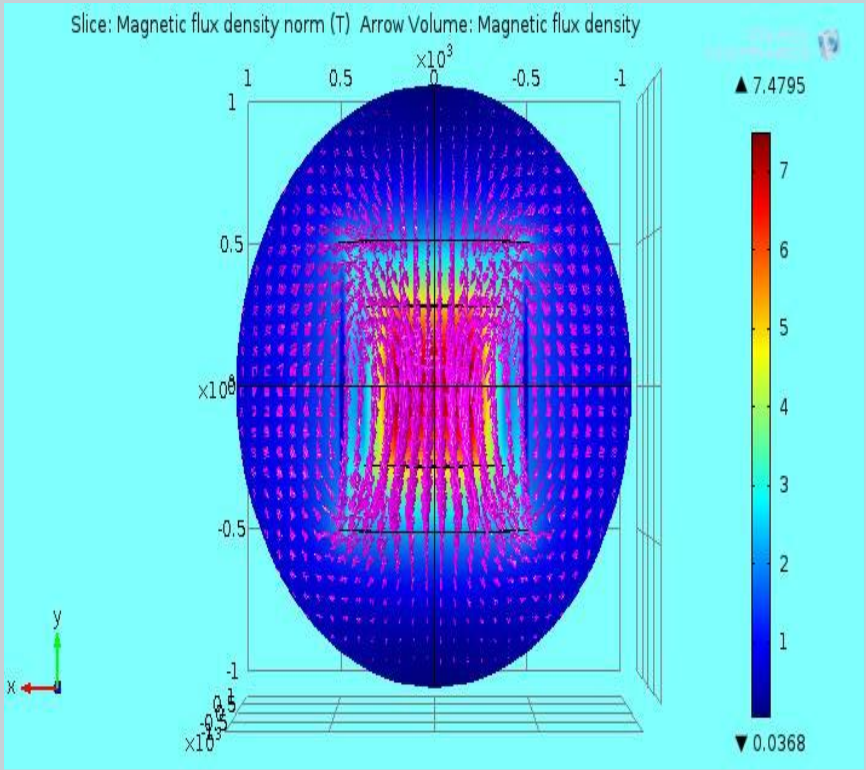

Figure 8: Arrow volume and slice plots showing the field distribution

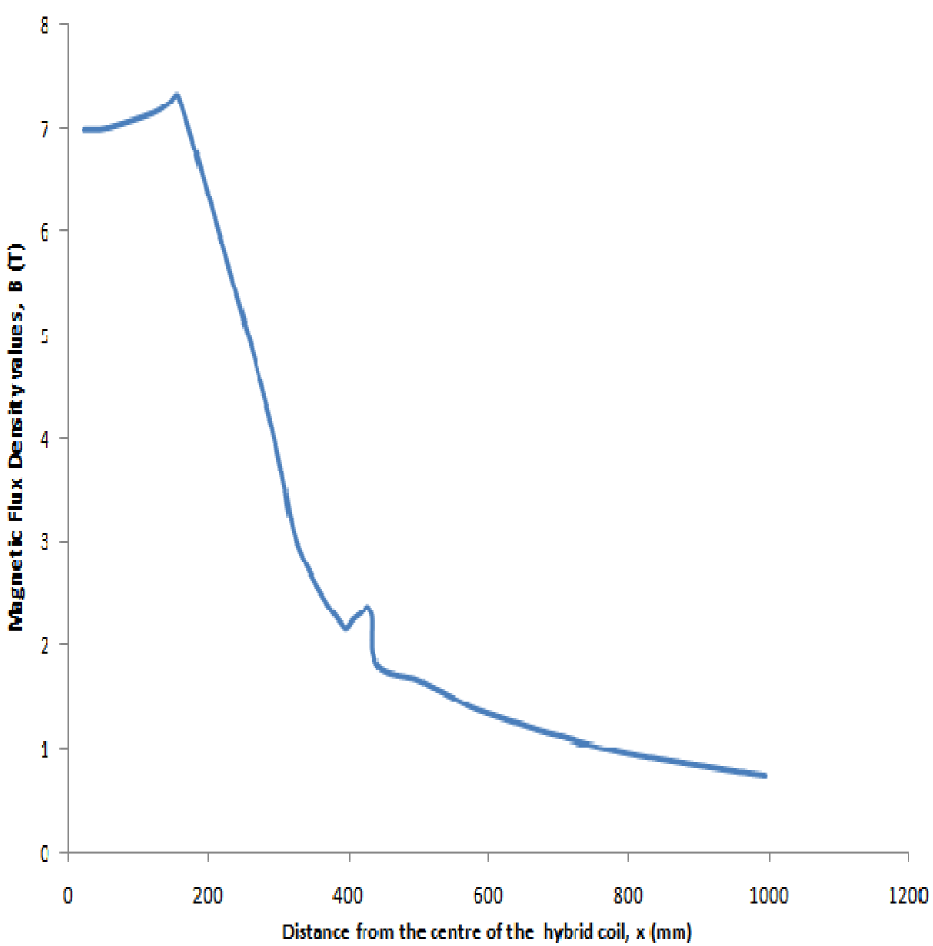

Figure 9: Field distribution values for different x coordinates but fixed y and z values.

- The peak field is 7.5 T and the central field is 6.9 T. The results agree with the published test data of a previous work.
- The overall flux density profile also matches that of the previous work.
- There are two peaks of flux density at fixed y and z coordinates but with varying x distance.
- This happens as there are two coils and each coil produces maximum field in the region next to it.

Conclusion

- Simulation results agree with the published test results of an earlier work [4].
- Model uses solenoid coils ; use of toroids can be investigated for less leakage.
- Production of even higher fields leads to a more compact SMES.

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Reference & Acknowledgment

1. M.N. Wilson, Superconducting Magnets. : Oxford University Press, 1983.
2. http://www.chuden.co.jp/english/corporate/press2007/0615_1.html
3. http://www.theoildrum.com/story/2006/9/1/91214/68010
4. K. Koyanagi, K. Ohsemochi. M. Takahashi, T. Kurusu, T. Tosaka, M. Ono, Y. Ishii, K. Shimada, S. Nomura, K. Kidoguchi, H. Onoda, N. Hirano & S. Nagaya, Design of a High Energy-Density SMES Coil With Bi-2212 Cables, *IEEE Transaction on Applied Superconductivity*, **Volume 16(**2), 586-589 (2006).

Question/Answer Session