MHD Steering Magnet: Conceptual Magnetic Design and Results (V01)

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Magnet Performance Requirements

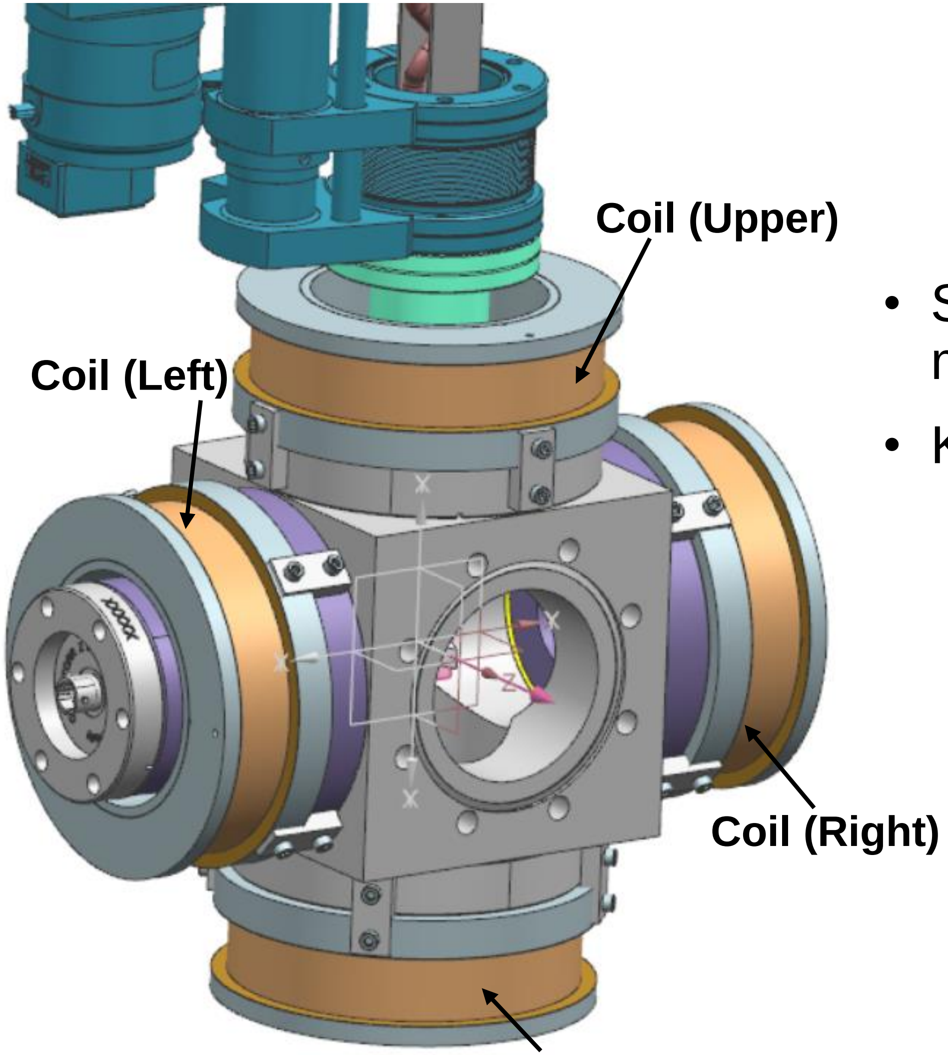
- The steering magnets (MHD) mounted onto the A1 and A2 cube should be identical in design and performance.
- The new coil assembly should fit within the space available on the A1/A2 cube assembly.
- The maximum integrated field along the longitudinal axis for the vertical/ horizontal dipole coil assembly : 5.5×10^{-5} T.m
- Magnetic field homogeneity requirements- TBD (No specification available. It will be optimized through magnetic design analysis and quantified using multipole field analysis).

Assumptions made for the Magnetic Design Calculations

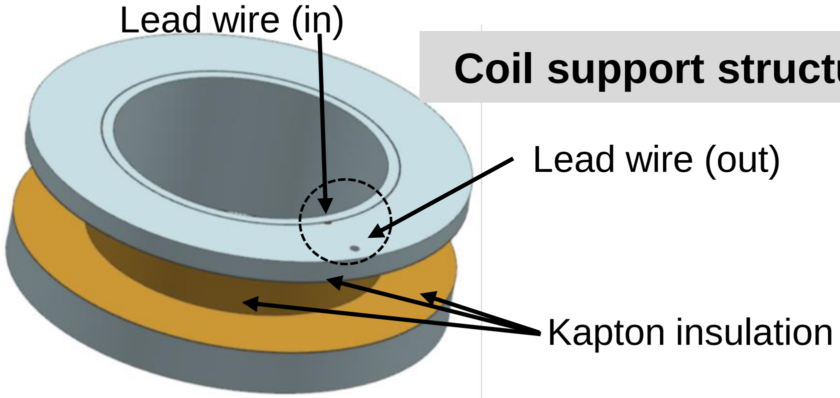
- Steering magnet uses air-core copper coils.
- The components used in the coil winding should be able to withstand a maximum of 200 °C.
- The fringe field of the neighboring coil assemblies have no impact on the magnet performance.

Design Considerations

MHD steering magnet on A1 cube



- MHD steering magnet consists of four identical pancake coils
  - Forms two independent dipole coil assemblies for steering the beam in vertical or horizontal direction.
    - The vertical coil assembly (upper + lower coils) and the horizontal coil assembly (right + left coils) can be energized separately.
- Stainless steel support structure (base plate, top plate and mandrel) for coils.
- Kapton for electrical insulation between the coil and bobbin
  - 0.254 mm thick kapton film wrapped around the bobbin core.
  - 0.254 mm thick kapton spacers (pre-cut) placed between the flat surface of the coil and bobbin end plates.



Coil support structure

Design Considerations : Copper Conductor (Magnet Wire)

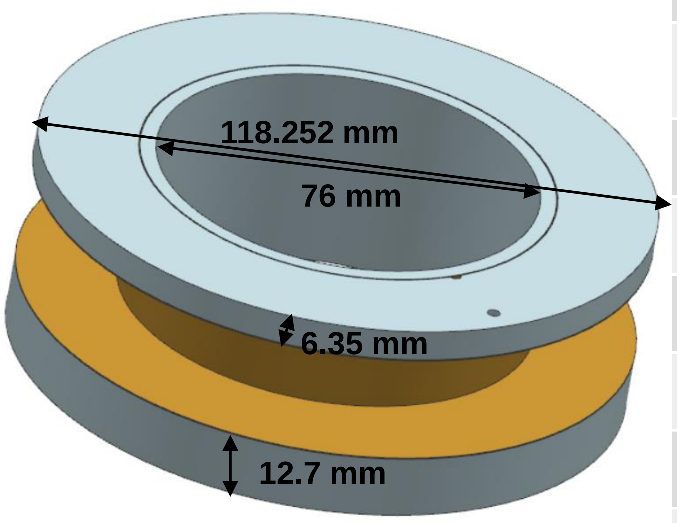
- The coil design is optimized for the use of 14 AWG insulated round copper conductor (potential supplier- MWS Wire Industries, CA)

Magnet wire parameters (Max. dimensions)	Unit	Value
Shape		Round wire
Copper grade		C101 or C102
Bare conductor size (equivalent AWG)		14
Bare wire diameter	mm	1.643
Radial thickness of the insulation	mm	0.044
Diameter of the insulated wire (Kapton heavy film insulation)	mm	1.732

Coil Bobbin Dimensions

Bobbin is made of stainless steel

Bobbin for MHD pancake coils (based on the dimensions of the new coil)	Unit	Value
Inner diameter of the mandrel	mm	76
Radial thickness of the mandrel	mm	3.175
Outer diameter of the mandrel	mm	82.35
Radial thickness of the Kapton insulation on the mandrel	mm	0.254
Outer diameter of the base plate/top plate for the bobbin	mm	118.252
Bobbin base plate height	mm	12.7
Bobbin top plate height	mm	6.35

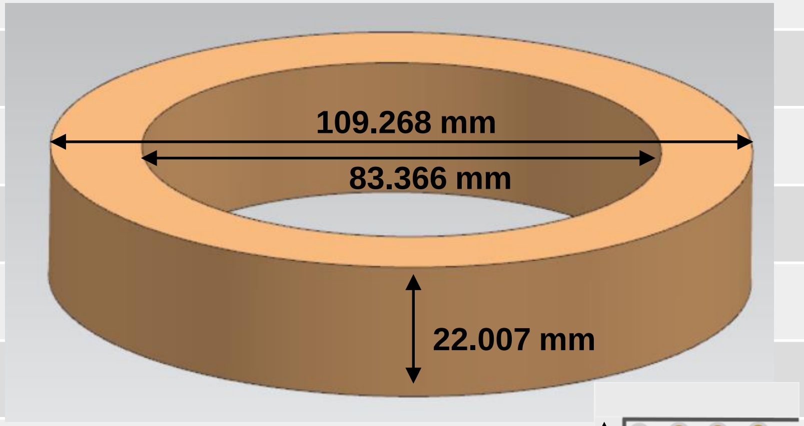


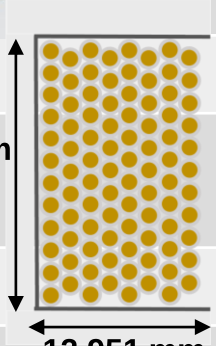
Coil Dimensions

Note: uses single piece length of conductor; winding tight against the thick flange of the bobbin; filler can be used, as needed, against the thin flange of the bobbin)

- wet wound coils (Epoxy: AREMCO 526 N)

MHD pancake coil parameters (estimated using the max. dimensions of the conductor)	Unit	Value
Distance between the opposite coils in the MHD steering magnet	mm	174.752
Radial thickness of the epoxy surrounding the wire (assumed)	mm	0.051
Inner diameter of the coil *	mm	83.366
Radial thickness of the winding	mm	12.951
Height of the winding	mm	22.007
Outer diameter of the coil	mm	109.268
Total turn counts in the coil winding		92
Number of layers (L) of winding		8
Number of turns per layer (Hexagonal close pack winding); (2 layers of 0.1 mm thick E-glass wrap under tension and painted with epoxy on the outer surface of the coil)		12 (L1, 3, 5, 7), 11 (L 2, 4, 6, 8)
Estimated length of conductor per coil (+1m for each lead wire)	m	29.84
Req. length of conductor per magnet (four coils+ lead wires)	m	~120





* *Based on the dimensions of the bobbin that can be accommodated on the A1 cube assembly*

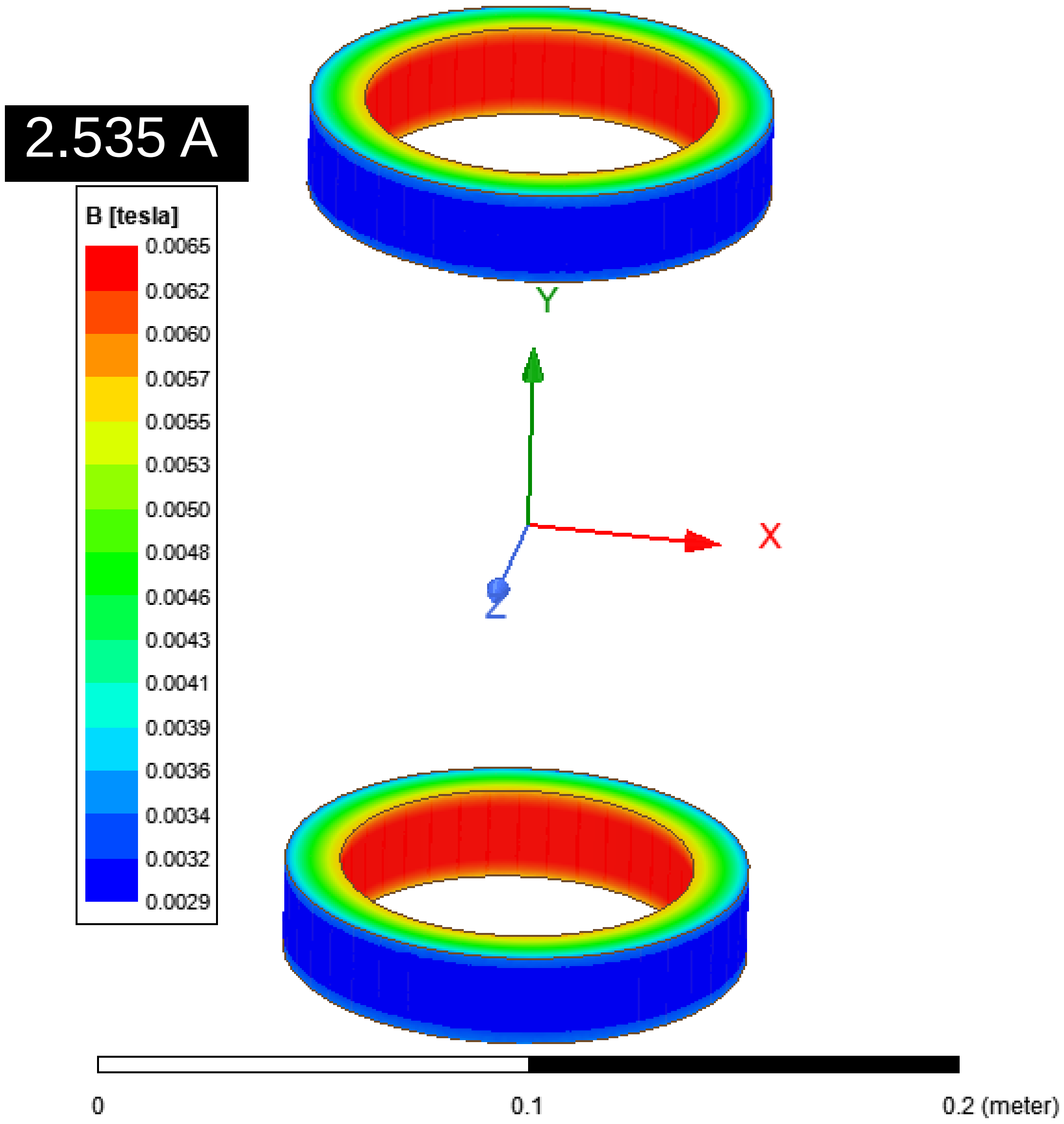
Magnetic Performance Parameters- Dipole Coil Assembly

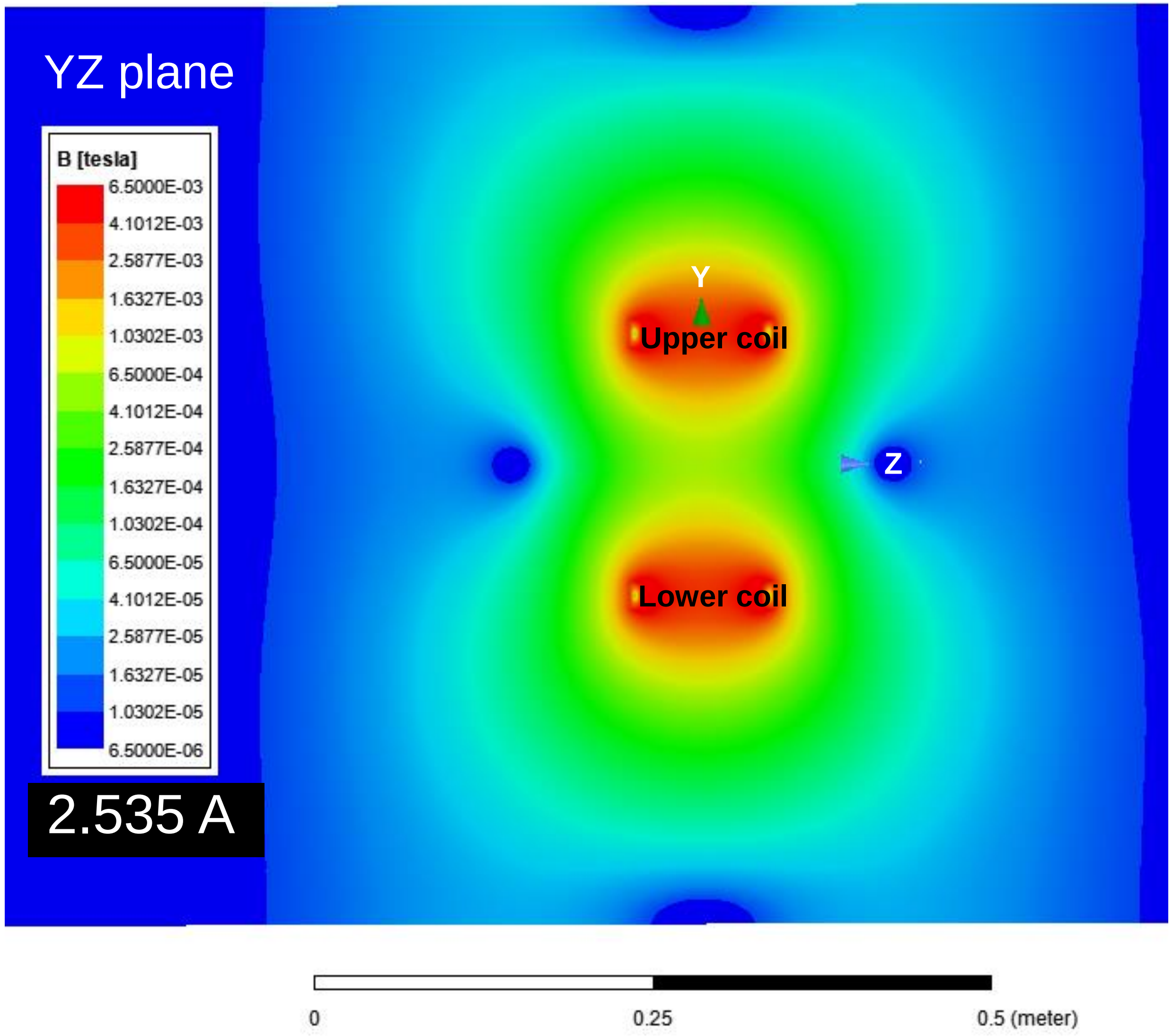
- The EM design fulfills the sufficient operating margin

Parameter	Unit	Value	
Operating current	A	**2.535**	**3.18**
Current density in the copper conductor	A/mm^2	1.12	1.5
Magnetic field strength at the center of the magnet	mT	0.514	0.644
Max. field strength in the coil	mT	6.45	8.09
Integrated field strength along the longitudinal axis (Z-axis) of the dipole assembly (Vertical/ Horizontal) (required: 5.5×10^{-5} T.m)	T.m	5.51×10^{-5}	6.91×10^{-5}
Effective magnetic length of the dipole assembly (Vertical / horizontal)	m	0.107	0.107
Integrated dipole field homogeneity within GFR (2 mm radius) (only the 6-pole higher order harmonics is present)	%	99.91	99.91
Cumulative strength of Lorentz force	mN	0.9	1.41
Magnetic stored energy of the dipole assembly	mJ	6.32	9.95
Inductance of each coil	mH	0.97	0.97
Resistance of each coil at 20°C	Ω	0.24	0.24

With margin for integrated field

Magnetic Field Distribution in the Vertical Dipole Coil Assemblies





Summary

- The new coil design meets the performance requirements.
- 3A and 10 A power supply (trim card) can be used. The max. operating current should be limited to 4.1 A.
- Use a clamp shell around the coils when the magnet together with other beamline components undergo 200 °C heat treatment (Recommendation).
- Structural analysis is performed to support the coil support structure design.

Note: Technical note describing the magnet design and engineering, and the performance characteristics will be prepared later.