

PSS Kicker Magnet for 200 keV Upgrade: Magnet Design and Results (V03.01)

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Previous meetings

V03: Oct 19, 2020 (Magnet design with three conductor options, Bobbin, Cube Assembly and PS requirements)

V02: April 27, 2020 (Magnet Design, Bobbin, Cube Assembly +PS (500mA)

V01 : April 9, 2020 (Conceptual coil design (2 geometries)+PS (200mA)

Contents

- Design Requirements (V03 design indicates the need for the Power Supply with higher capacity and upgrade to the other hardware components)
- Assumptions (same as the previous design analysis V02)
- Design
 - Coil geometry, physical dimensions
 - Conductor choice
 - Coil Bobbin
 - Cube Assembly
- Results
- Summary
- Next Steps...

Magnet Performance Requirements

- The PSS kicker magnet deflects the beam onto the “A2” mask in the injector beamline.

Parameter	Unit	Value
Central gap (to accommodate beam pipe) (requirement)	mm	19.05
Distance from the center of the magnet assembly to the center of the A2 mask (requirement)	cm	33.7***
Max. deflection height (for design calculations)	cm	1
Nominal energy of the electron beam	KeV	200
Magnetic rigidity of the beam particles	T.m	1.649×10^{-3}
Max. deflection angle of the beam particle (horizontal/ vertical kick)	radians	0.030
Integrated field strength along the longitudinal axis (Z-axis) of the magnet (requirement)	T.m	4.894×10^{-5}
Maximum supply current to the coils (current capacity of the PSS relay)	mA	500***

** Magnet homogeneity requirements: Unspecified

*** Revised specification (V02)

**** New Requirement

**** New requirement: 1.5 A or 2A

Assumptions made for the Magnetic Design Calculations

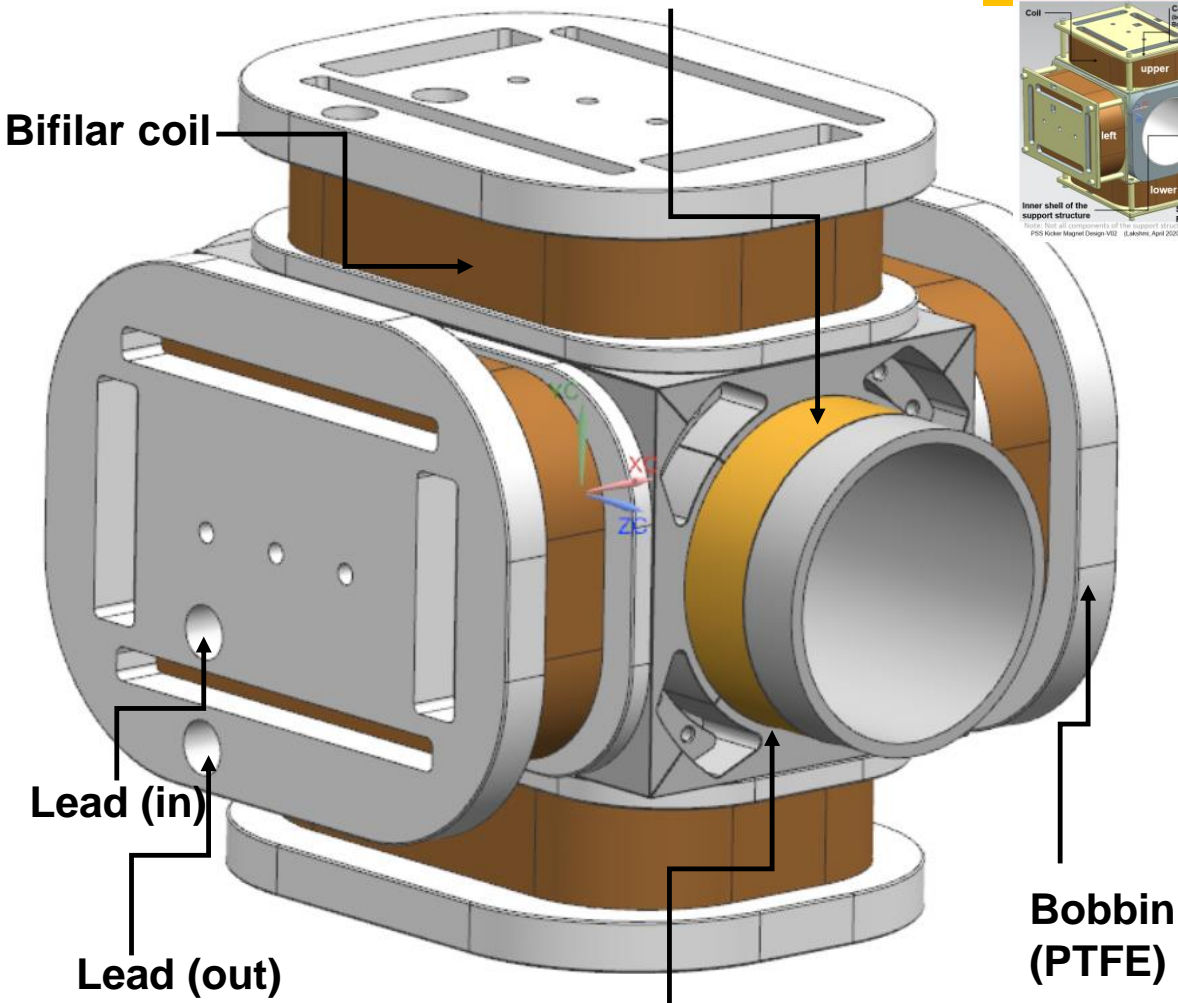
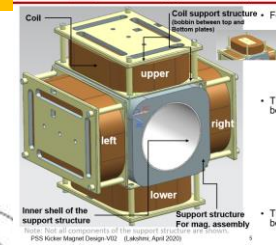
- The conceptual design uses solid model for bifilar coils. The model accounts for the optimum lay out of the copper conductor to allow a compact bifilar winding pack meeting the performance requirements for the kicker magnet.
 - Previous calculations (V01) suggest that bifilar coils in racetrack geometry provides an optimum configuration for the magnet assembly.
- Central gap of the magnet assembly provides the space to install beam pipe.
- Copper coils are air-cooled.
- No magnetic materials are allowed in the magnet assembly.
- Allow a reasonable operating current margin for the (coils) control relay.
- The electromagnetic coupling between the kick windings and bias windings are not considered (Needs 3D model of the bifilar coil with detailed conductor layout).
- The fringe field of the neighboring coil assemblies have no impact on the kicker magnet performance.
- The overall field homogeneity requirements: unspecified.

PSS Kicker Magnet- New Design

Magnet assembly model number: JL0091130-0308-00

New design (V03)

Beam pipe (SS) with Kapton insulation

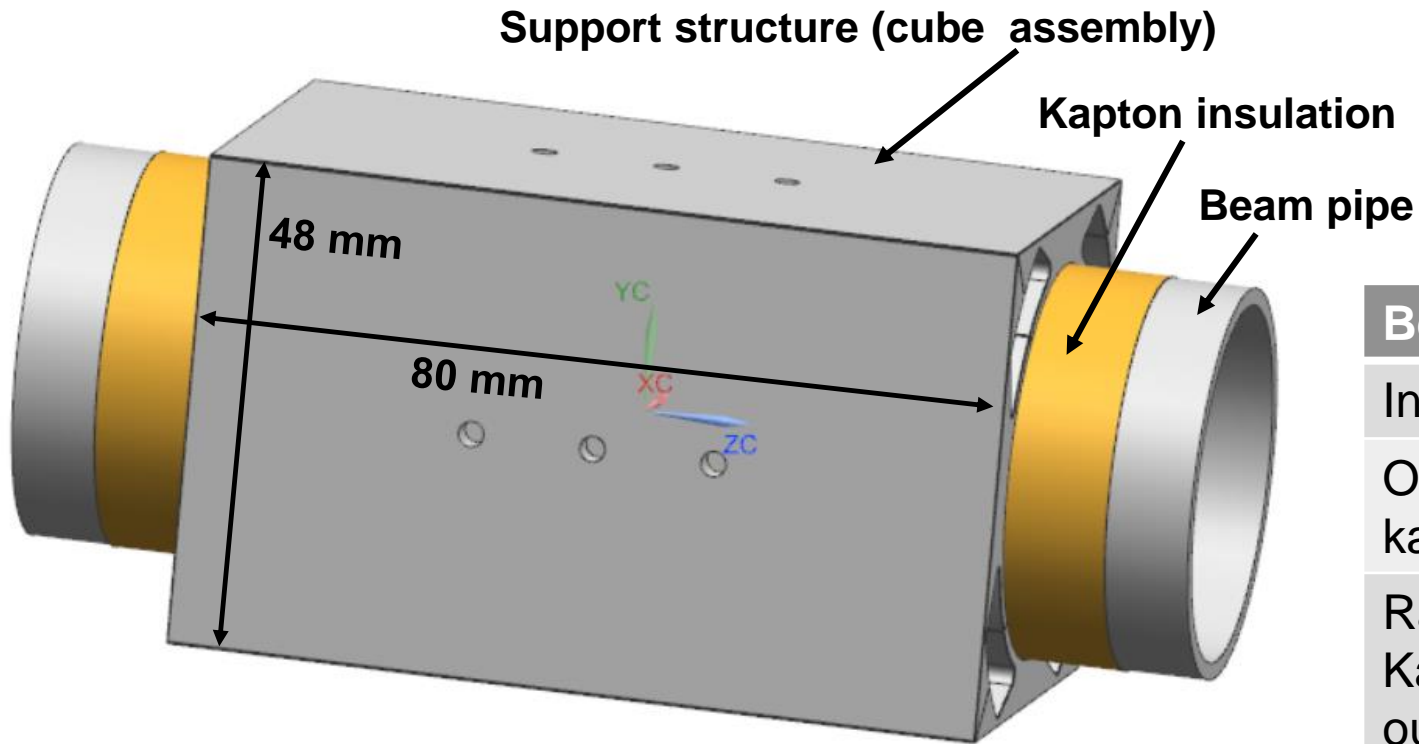


Support structure-Cube (4 pieces, SS)

- Four identical bifilar coils in racetrack geometry
 - The vertical coil assembly (upper+lower coils) and the horizontal coil assembly (right+left coils) are energized using two separate (identical) power supplies.
 - The kick and bias windings in each bifilar coil form a parallel electrical circuit, whereas the upper and lower or left and right bifilar coil windings are connected in series.
- The coils are arranged symmetrically around the beam pipe.
 - Magnet support structure (Material: Stainless steel) consists of four (diagonally cut) pieces. These components are assembled together using mechanical fasteners
 - The central opening is to accommodate the beam pipe
 - The outer surface of the beam pipe is wrapped with two layers of 0.0635 mm thick kapton with adhesive.
- The coil support structure (Bobbin) : PTFE

Beam Pipe

- Material : SS 304.
- Wrapped the outer surface of the beam pipe with 2 layers of 0.0635 mm thick Kapton tape (with adhesive).



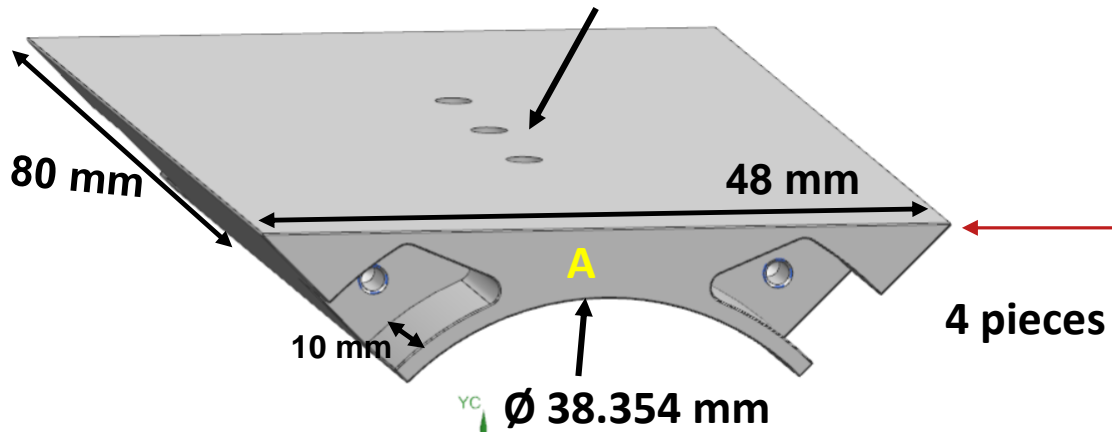
New design for the cube assembly (magnet support structure). See next slide for details.

Beam pipe	Unit	Value
Inner diameter	mm	34.8
Outer Diameter (before kapton wrap)	mm	38.1
Radial thickness of the Kapton insulation (on the outer surface of the beam pipe)	mm	0.127
Beam pipe length	mm	TBD

Support Structure : Cube Assembly (New Design)

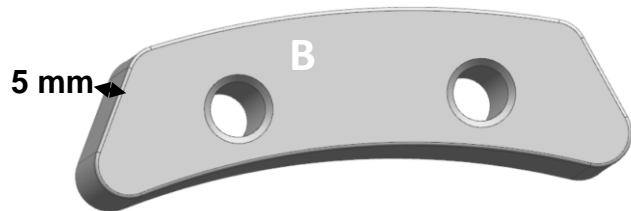
- Material; SS 304

For fasteners (Cube- coil bobbin)



Individual piece for the cube assembly (Magnet support structure)

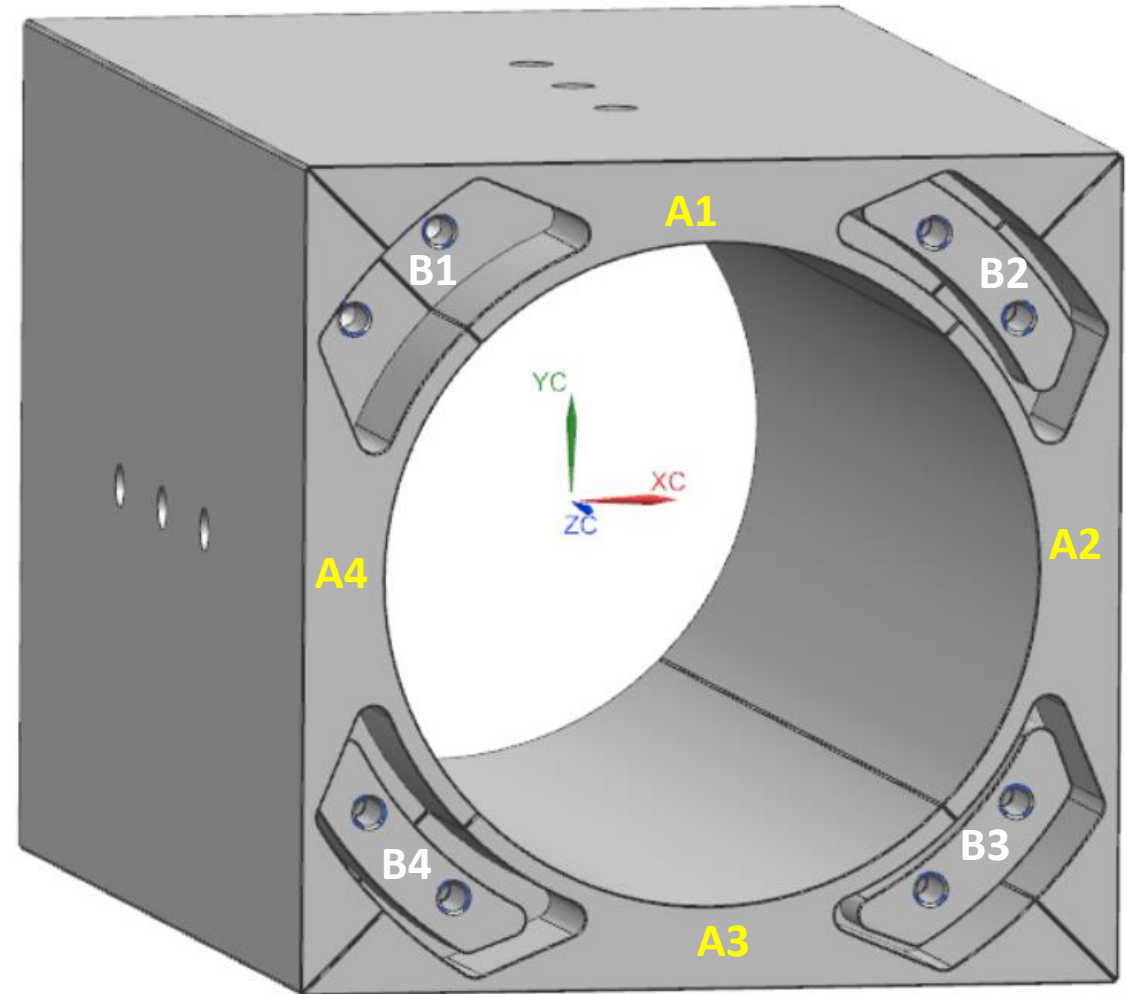
Part number: JL0091130-0308-03



4 x 2 pieces
(front side+ back side)

To clamp the support structure pieces together

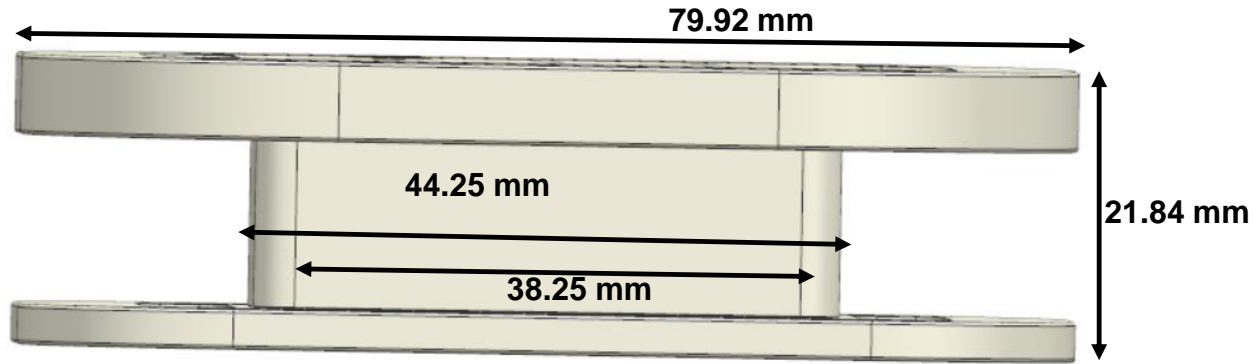
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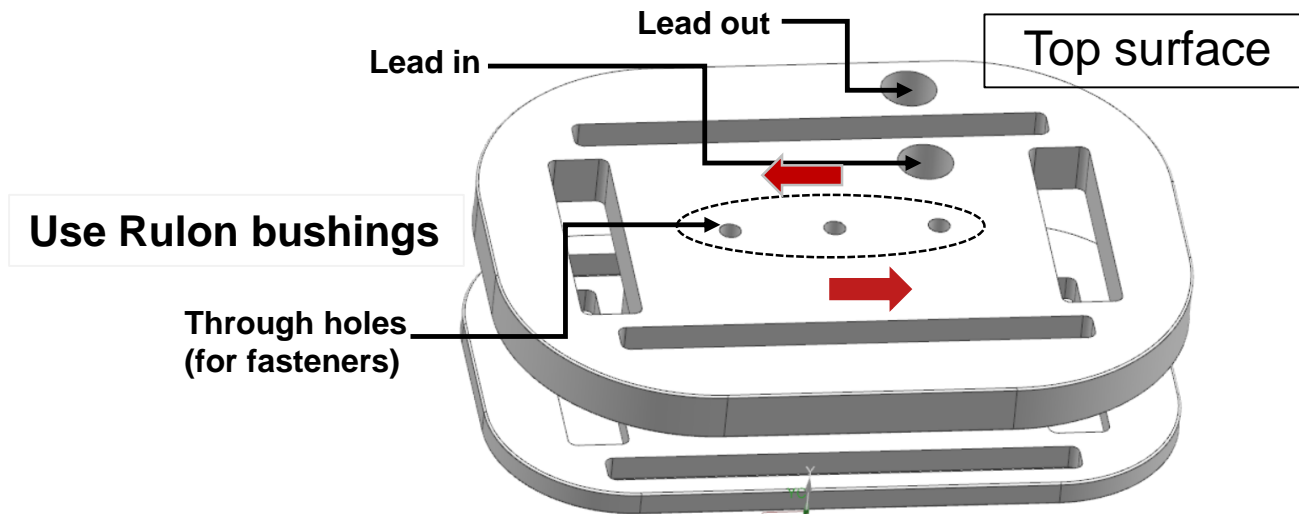
Cube assembly from four machined pieces (A1-A4)

Coil Bobbin (New Design)

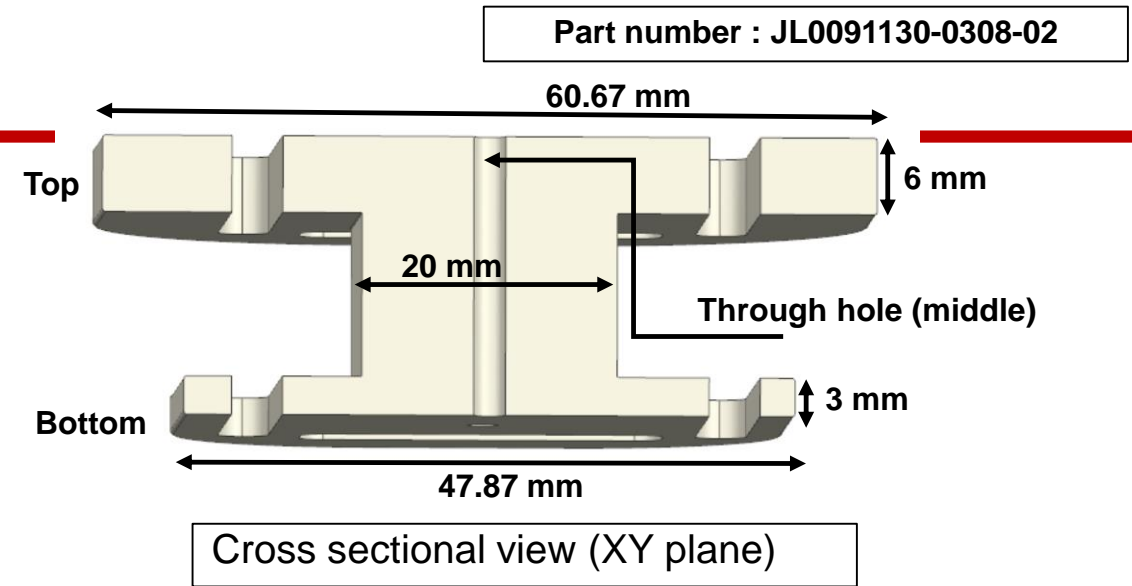
- Material: PTFE



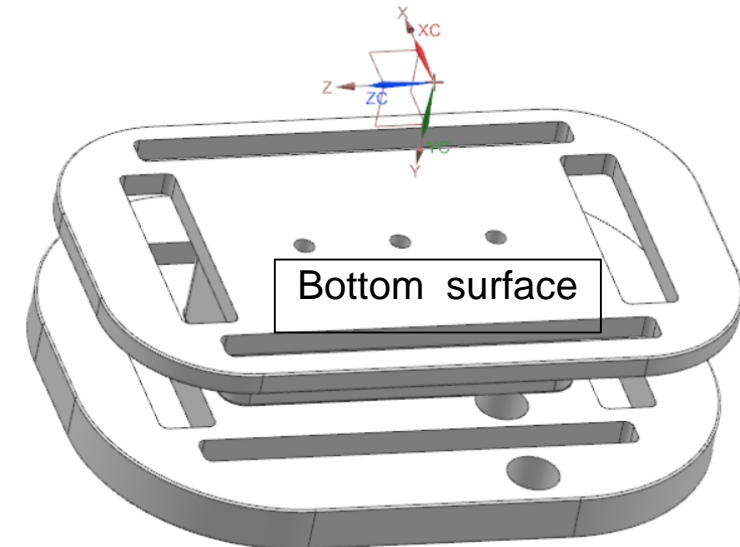
Longitudinal view (Z direction)



Red arrows indicate the direction of the conductor progression in the coil winding. (etch the arrows+ the turn counts on the top surface of the bobbin plate). Also see #c in slide 11.



Cross sectional view (XY plane)

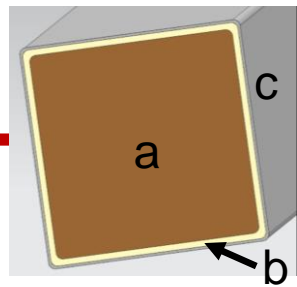


Use non-metallic fasteners

Copper Conductor (Magnet Wire) Specification

- Size- AWG 20
- Shape- Square conductor with round corners
- Insulation- Kapton (Heavy-build)
- Bifilar coil made out of two spools of identical single strand conductor

a- bare copper conductor
b- insulation wrap
c- epoxy filling

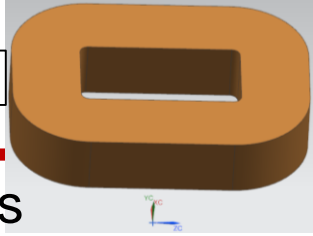


Conductor cross section

Magnet wire parameters (Max. dimensions)	Unit	Value
Shape		Square with round corners
Copper grade		C101 or C102
Potential supplier		MWS (preferred) or equivalent conductor
Conductor size (equivalent AWG)		20
Bare conductor width (= height)	mm	0.8230
Corner radius of the bare conductor	mm	0.1778
Width (=height) of the insulated, epoxy filled conductor	mm	0.9169

Racetrack Coil Parameters (New Design)

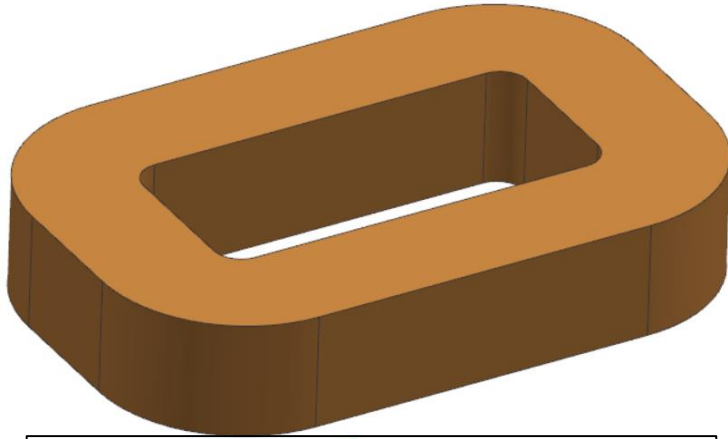
Part number : JL0091130-0308-01



- Bifilar coils wet wound (Epoxy: CTD 100 series) using two identical single strand conductors

Racetrack bifilar coil parameters (for the optimized geometry) (using the max. dimensions of the conductor)	Unit	Value
Conductor size (Equivalent AWG)		20
Width (= height) of the epoxy coated insulated conductor in the bifilar coils	mm	0.9169
Design version		V03-I4 (10/28/20)
Inner gap (radial) of the bifilar coil	mm	20
Radial thickness, and height of the bifilar coil	mm	12.8372, 12.8372
Inner corner radius of the bifilar winding	mm	3
Straight length, and overall length of the bifilar coil	mm	38.25, 69.92
No. of layers of Bifilar winding, No. of turns per layer in the bifilar coil		7,14
Turn count in the bias /kicker windings in the bifilar coil		98/98
Estimated length of conductor per bifilar coil (+1m for each lead wire)	m	36.1
Req. length of conductor for kicker magnet (four bifilar coils+ lead wires)	m	144.4

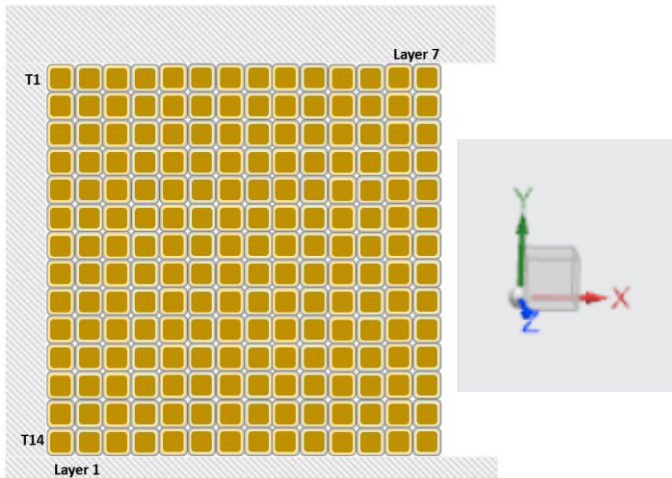
Coil Model and conductor layout in the bifilar winding



Coil

Part number: JL0091130-0308-01

ZC
XC



Conductor layout in the bifilar winding

- The solid model accounts for the conductor layout+ epoxy filling between the turns in the winding.
- The coil is wound on the PTFE bobbin. No additional ground insulation is required.
- Make a slot on the bobbin core to guide the “lead-in” wire from the top plate to the bottom plate surface of the bobbin. Start the winding from the bottom surface of the bobbin. The winding should be tight against the bottom plate of the bobbin. The winding ends at the top surface of the bobbin plate (*I will discuss the winding plan with the coil manufacturer and accordingly change the location of the “lead-in” slot on the top plate of the bobbin*)
- Use a single piece length of conductor in each coil.
- Turn counts should be the same for all bifilar coils.
- The coils are wet wound using CTD 100 series epoxy (Assumption: 0.013 mm thick epoxy surrounding the conductor)
- Use G-10 filler as needed in the coil winding.
- Paint the outer surface of the coil additionally with a uniform layer of epoxy (assumption: 0.02 mm thick) to ensure that the winding is intact. Cure the coil. Wrap the outer surface with two layers of 0.0635 mm thick Kapton with adhesive.
- The finished coil dimensions should conform to the dimensional specifications provided in the drawing
- Label the bifilar lead wires (color-coded)
- The winding scheme should follow the suggested direction for the wire progression (indicated by etched arrows on the top plate of the coil bobbin, see slide 8 for details)
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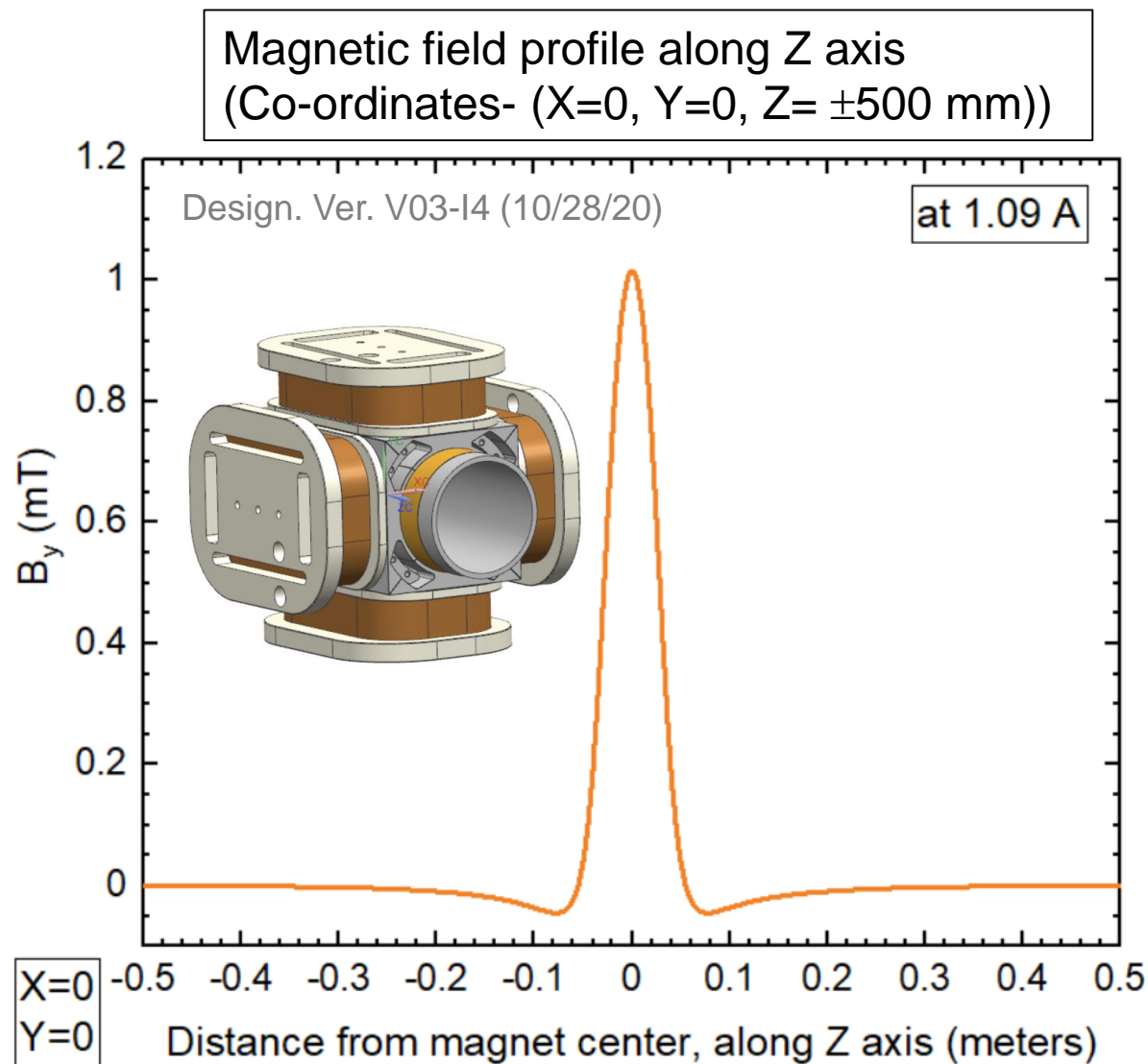
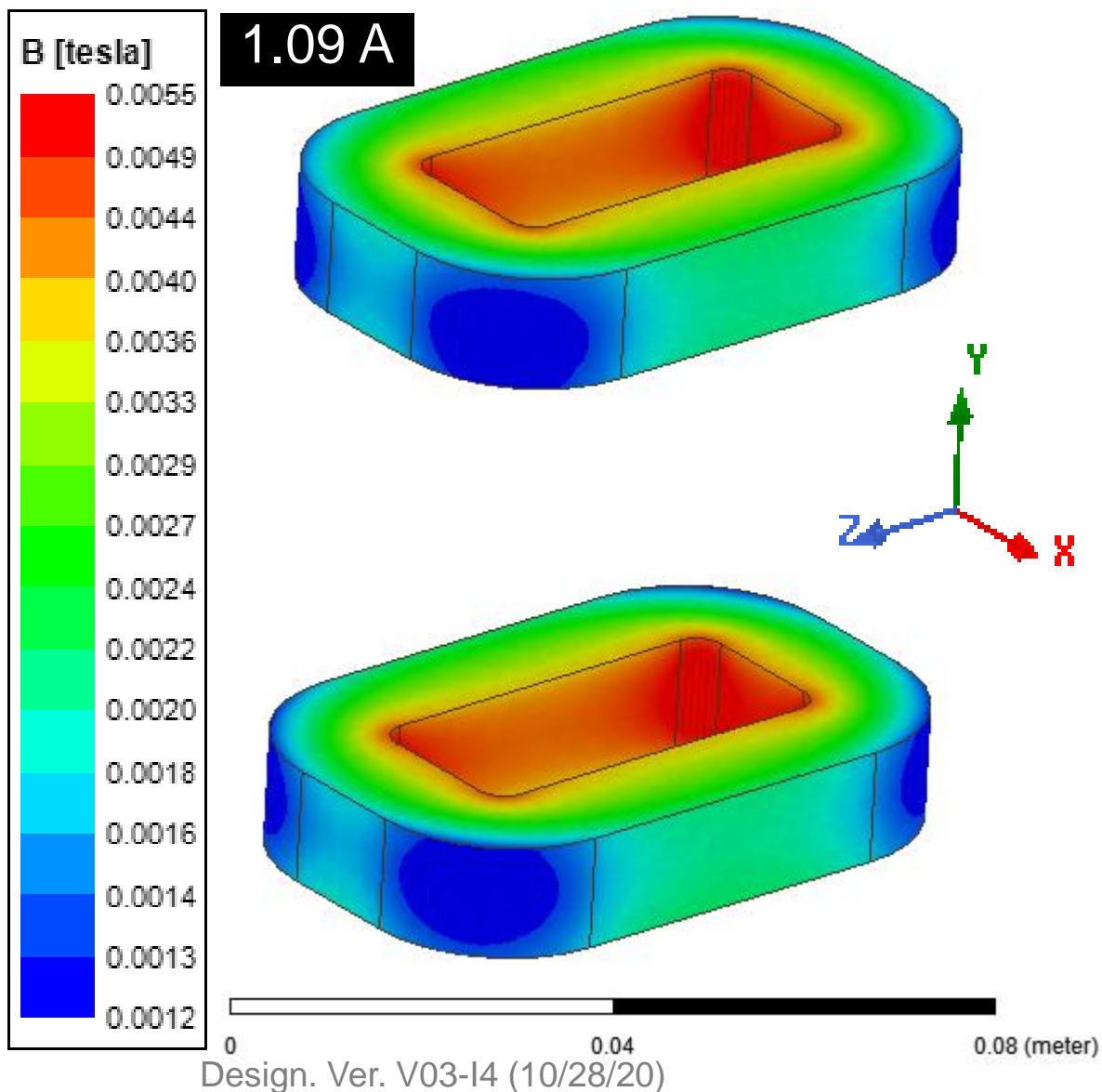
Magnetic Performance Parameters (Fault scenario: Only the bias windings are energized)

- Performance parameters at the max. operating conditions

Parameter (Note : all the listed parameters are at $I_{\text{max-coil}}$)	Unit	Value
Conductor grade		AWG 20
Distance between upper-lower/ left-right bifilar coil packs	mm	54
$\int B_y \cdot dz$ of the dipole bifilar assembly (V/H) (req: 4.894×10^{-5} T.m)	T.m	4.90×10^{-5}
Turn count per bifilar winding (kick winding/ bias winding)		98/98
Operating current ($I_{\text{max-coil}}$)	A	1.09
Current density in the copper conductor	A/mm ²	1.68
Magnetic field strength at the center of the magnet	mT	1.02
Max. field strength on the kick/ bias winding	mT	5.5
Effective magnetic length of the dipole bifilar assembly (V/ H)	mm	48.2
Cumulative strength of Lorentz forces on the bifilar coil pack	mN	0.60
Magnetic Stored Energy of the dipole bifilar assembly	μJ	525
Self inductance of the kick/ bias windings in the bifilar coil	mH	0.43
Resistance of the kick/ bias windings in the bifilar coil	Ω	0.48

Magnetic Field Distribution in the Vertical Dipole Bifilar Coil Assemblies

(Fault scenario: Only the bias coils are energized)



Conductor lead time + Coil delivery schedule

- Provide the 3D models (SLL) to MD to prepare the basic drawings.
 - To import the models into Team Center (need the model numbering scheme. Awaiting details from SG ,09/20)
- ME 's estimate to prepare the basic drawings (3 weeks, according to DM)
 - Can coil and bobbin draft drawings be made available in 10 days?
- contact coil manufacturers further for a price quote when the draft drawings are ready (SLL)

Parameter (Note : all the listed parameters are at $I_{\text{max-coil}}$)	Unit	Value
Conductor grade		AWG 20
Conductor availability (after receiving PO) (Coil manufacturer can procure the wire directly from the supplier we suggest)	wks	2.5 (max.)
Coil manufacturer (conductor purchase + coil winding + shipping) (after receiving PO)	wks	8-12
Coil delivery at J Lab (guesstimate)		Feb 2021

Summary

- Three design variations were presented (10/19/2020). The coil design with AWG 20 conductor is selected.

- Meets the physics, design and performance requirements.
- Offers compact geometry
- Square conductor simplifies the tooling and coil winding process.
- Offers reasonable operating current margin.

Tech. note will be prepared later

- Next Plans

- Provide the 3D models to Danny and team to prepare basic drawings (Lakshmi)
 - uploaded the models in Team center-11/02. Updated ME.
- Contact the potential coil manufacturers when the draft drawings are ready (Lakshmi)
 - 11/10 (will the coil and bobbin draft drawings be ready by then? (need feedback from Danny)
- Verify the calculations to support the electrical integration of the magnet assembly (Jerry+ Lakshmi)
 - The data presented in this document gives a good starting point.
 - Need the transient response (L and V decay) characteristics from JK to further verify or do any additional calculations (Awaiting data from JK, when it will be ready?). Polarity definition (to confirm with JK)
- Lead termination plate design-TBD (Lakshmi)
 - To confirm the electrical circuit diagram and component layout with JK.
 - Verify the space constraints after ME update the girder model with the new PSS kicker magnet model
 - Provide the 3D model to ME (TBD)

Lead plate design+ electrical wiring details (TBD)
