PSS Kicker Magnet for 200 KeV Upgrade: Magnetic Design and Results (V03)

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- Assumptions (same as the previous design analysis V02)
- Magnetic Design
  - Coil geometry, physical dimensions
  - Conductor choice (Three options)
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- Summary
- Next Steps…

Scope: Discuss the coil design variations considering the long lead time for the original conductor and rely (supply current) requirements

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

New requirement: 1 A or 2A

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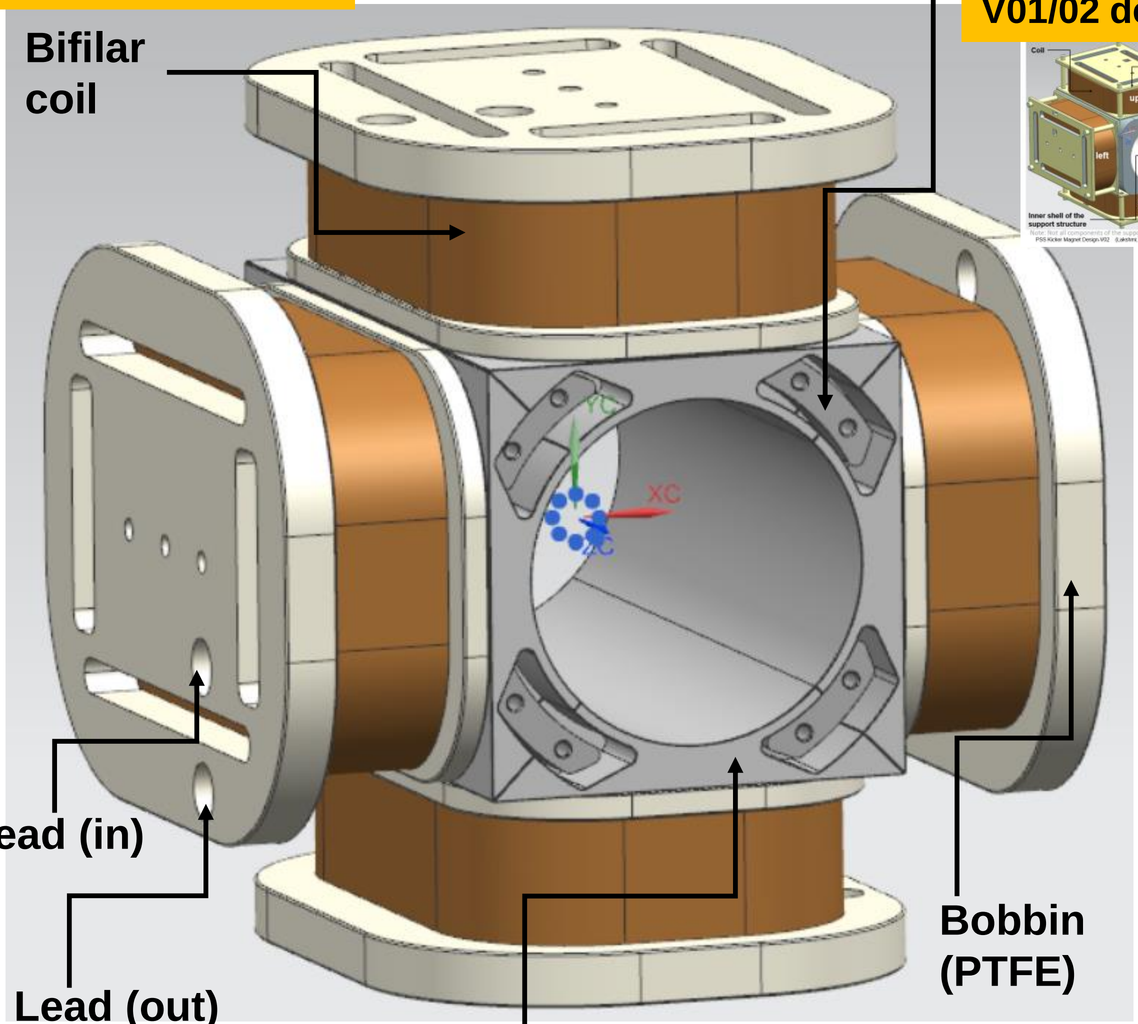
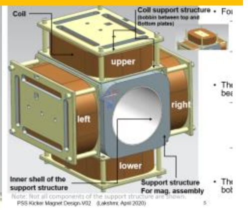
Assumptions made for the Magnetic Design Calculations

- 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 and the support structure for the horizontal and vertical coil assemblies.
- 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

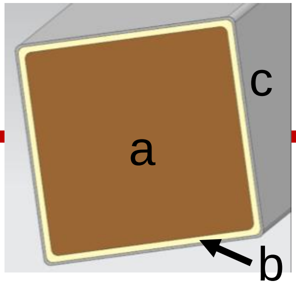


V01/02 design



- 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 (diameter-38.1 mm) is to accommodate the beam pipe
  - The outer surface of the beam pipe is wrapped with two layers of 0.0635 mm thick kapton.
- The coil support structure (Bobbin) : PTFE

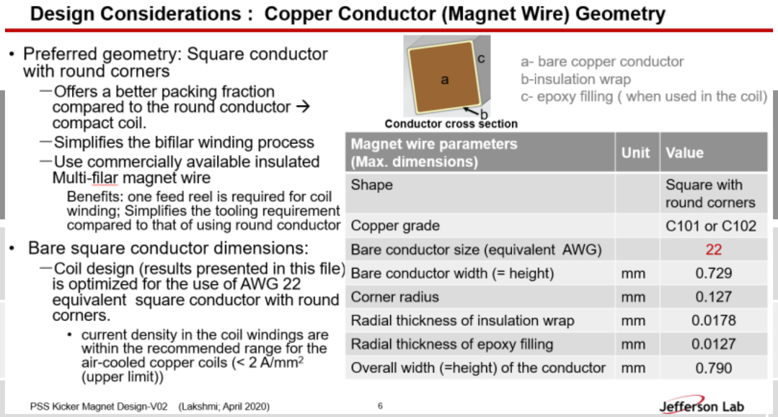
Copper Conductor (Magnet Wire) Specification



- Preferred geometry: Square conductor with round corners (color coded, bifilar bondable wire (preferred), or else two separate spools of single strand bonded wire)

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

Conductor cross section



Design Considerations : Copper Conductor (Magnet Wire) Geometry

- Preferred geometry: Square conductor with round corners
  - Offers a better packing fraction compared to the round conductor → compact coil.
  - Simplifies the bifilar winding process
  - Use commercially available insulated Multi-filar magnet wire

    Benefits: one feed reel is required for coil winding; Simplifies the tooling requirement compared to that of using round conductor
- Bare square conductor dimensions:
  - Coil design (results presented in this file) is optimized for the use of AWG 22 equivalent square conductor with round corners.
    - current density in the coil windings are within the recommended range for the air-cooled copper coils (< 2 A/mm^2 (upper limit))

a- bare copper conductor
b-insulation wrap
c- epoxy filling (when used in the coil)

Conductor cross section

Magnet wire parameters (Max. dimensions)	Unit	Value
Shape		Square with round corners
Copper grade		C101 or C102
Bare conductor size (equivalent AWG)		22
Bare conductor width (= height)	mm	0.729
Corner radius	mm	0.127
Radial thickness of insulation wrap	mm	0.0178
Radial thickness of epoxy filling	mm	0.0127
Overall width (=height) of the conductor	mm	0.790

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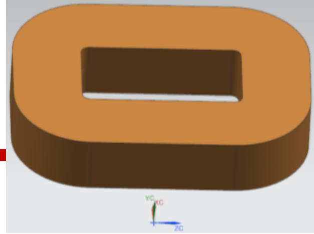
Magnet wire parameters (Max. dimensions)	Unit	Value		
Shape		Square with round corners		
Copper grade		C101 or C102		
Potential supplier		MWS (preferred) or whoever provides equivalent conductor		
Conductor size (equivalent AWG)		22	20	18
Bare conductor width (= height)	mm	0.6502	0.8230	1.0363
Corner radius	mm	0.1778	0.1778	0.2032
Overall width (=height) of the insulated, bondable conductor	mm	0.7417	0.9220	1.1430

Racetrack Coil Parameters



- Three design variations (depends on the conductor choice)

Racetrack bifilar coil parameters (for the optimized geometry) (using the max. dimensions of the conductor)	Unit	Value		
Conductor size (Equivalent AWG)		**22**	**20**	**18**
Overall dimensions of the wire used in the bifilar coils (Ins.+bondable)	mm	0.7417	0.9220	1.1430
Design ver.		V05-I1	V03-I4	V04-I6
Inner gap (radial) of the bifilar coil	mm	20	20	18
Radial thickness, and height of the bifilar coil	mm	13.3502, 14.8336	12.9083, 12.9083	13.7160, 16.0020
Inner corner radius of the bifilar winding	mm	3	3	3
Straight length, and overall length of the bifilar coil	mm	37, 69.7	38, 69.8	40, 73.4
No. of layers of Bifilar winding, No. of turns per layer in the bifilar coil		9, 20	7,14	6,14
Turn count in the bias /kicker windings in the bifilar coil		180/180	98/98	84/84
Estimated length of conductor per bifilar coil (+1m for each lead wire)	m	62.6	36	31.9
Req. length of conductor for kicker magnet (four bifilar coils+ lead wires)	m	250.4	144	127.5

Magnetic Performance Parameters (Fault scenario: Only the bias windings are energized)

- A comparison of performance of magnet with different conductor selection (AWG 18, 20 and 22)

Original Design (coil dimensions adjusted as per the dimensions of the available cond.)

Parameter (Note : all the listed parameters are at $I_{max\text{-}coil}$)		Value		
Conductor grade		**AWG 22**	**AWG 20**	**AWG 18**
Distance between upper-lower/ left-right bifilar coil packs	mm	54	54	54
$\int B_y$ .dz of the dipole bifilar assembly (V/H) (req: 4.894×10^{-5} T.m)	T.m	4.894×10^{-5}	4.92×10^{-5}	4.90×10^{-5}
Turn count per bifilar winding (kick winding/ bias winding)		180/180	98/98	84/84
Operating current ($I_{max\text{-}coil}$)	A	0.627	1.10	1.35
Current density in the copper conductor	A/mm^2	1.59	0.73	0.59
Magnetic field strength at the center of the magnet	mT	1.02	1.02	0.98
Max. field strength on the kick/ bias winding	mT	5.26	5.47	5.07
Effective magnetic length of the dipole bifilar assembly (V/ H)	mm	47.9	48	50
Cumulative strength of Lorentz forces on the bifilar coil pack	mN	0.62	0.61	0.59
Magnetic Stored Energy of the dipole assembly	µJ	549	532	538
Self inductance of the kick/ bias windings in the bifilar coil	mH	1.36	0.43	0.29
Resistance of the kick/ bias windings in the bifilar coil	Ω	1.36	0.48	0.27

Conductor lead time + Coil delivery schedule

- Lakshmi to provide the 3D models to ME (2 days after the design approval by JG)
- ME 's estimate to prepare the basic drawings (3 weeks, according to DM)
  - Will check with DM if draft drawings can be made available within a week to further contact the vendor for the preliminary estimate.

Earliest available date: third /fourth week of Jan 2021

Parameter (Note : all the listed parameters are at $I_{max\text{-}coil}$)	Unit	Value		
Conductor grade		**AWG 22**	**AWG 20**	**AWG 18**
Conductor availability (after receiving PO)	wks	13+	9 (max.)	9 (max.)
Coil manufacturing + shipping	wks	8-12	8-12	8-12
Coil Vendor (Conductor purchase+ Coil winding+Shipping) (after receiving PO)	wks	20	8-12	8-12
Possible delivery (guesstimate)		March 2021	Jan/ Feb 2021	Jan/ Feb 2021

Summary

- Three design variations are presented..
  - Meets the physics, design and performance requirements.
  - Offers compact geometry
  - Square conductor simplifies the tooling and coil winding process.
  - Offers reasonable operating current margin.
- Design variation: To decide in this meeting

- Next Plans
  - 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
  - Already developed the mechanical assembly model (Lakshmi).

Back up

V02 design results

Magnetic Performance Parameters (Fault scenario: Only the bias windings are energized)

- A comparison of performance of magnet with two types of coil geometries (Option 1 and 2)

Parameter (Note : all the listed parameters are at $I_{max\text{-}coil}$)	Unit	Value	
Coil layout in the magnet assembly		Option 1	Option 2
Distance between upper-lower/ left-right bifilar coil packs	mm	**54**	**56**
Integrated field strength along the longitudinal axis (Z-axis) of the dipole bifilar assembly (Vertical/ Horizontal) (required: 4.894×10^{-5} T.m)		4.90×10^{-5}	4.90×10^{-5}
Operating current ($I_{max\text{-}coil}$)	mA	455	446
Current density in the copper conductor	A/mm^2	0.88	0.86
Magnetic field strength at the center of the magnet	mT	0.756	0.742
Max. field strength on the bifilar coil	mT	3.46	3.54
Effective magnetic length of the dipole bifilar assembly (Vertical / horizontal)	mm	64.8	65.9
Cumulative strength of Lorentz forces on the bifilar coil pack	mN	0.34	0.342
Magnetic Stored Energy of the dipole assembly	μJ	293.4	328.8
Self inductance of the kick/ bias windings in the bifilar coil	mH	1.37	1.6
Resistance of the kick/ bias windings in the bifilar coil	Ω	1	1.1

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