

QW Magnet Design and Analysis Results (V03)

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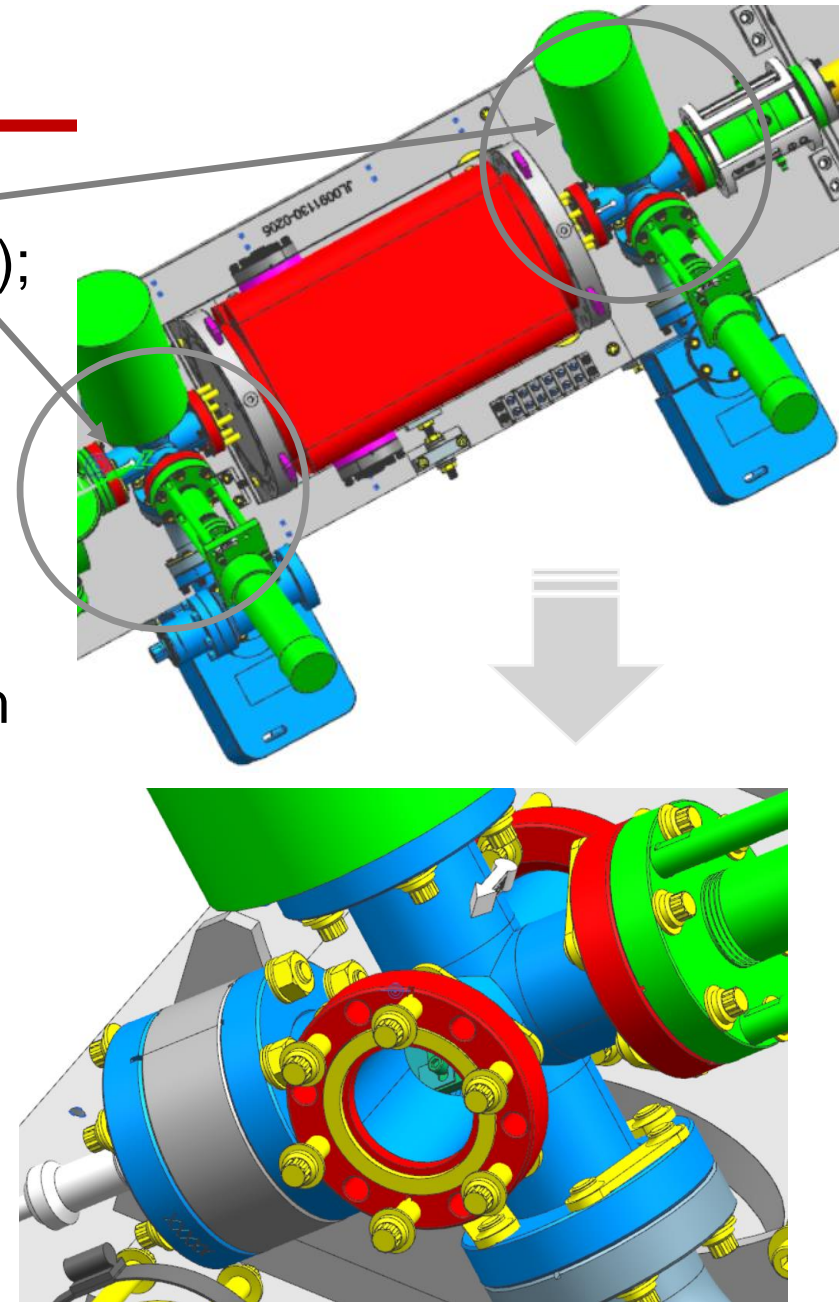
September 13, 2020

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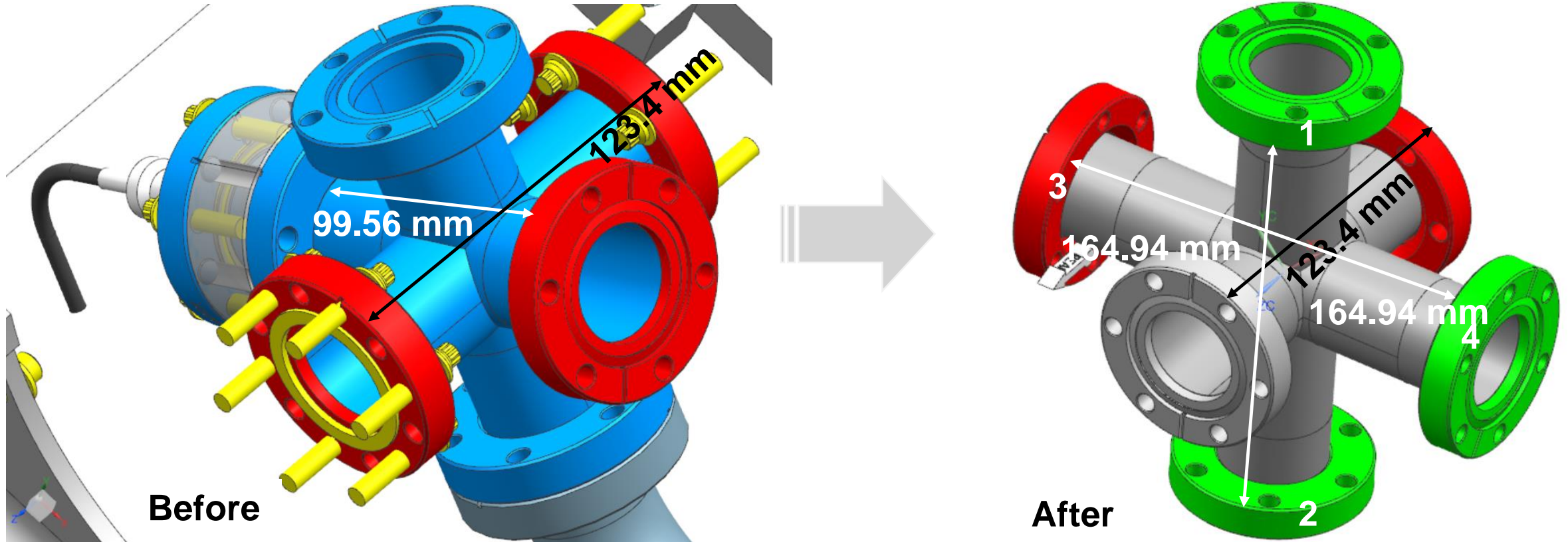
Design and Performance Requirements

- The QW quadrupole coils should be able to fit over a six way vacuum cross CF flange fitting (pipe OD- 38.1 mm (1.5 inch); flange OD 69.85 mm (2.75 inch)).
 - The assembly is rotated 45° from horizontal axis (X-axis) .
- The components used in the coil winding and magnet assembly should be able to withstand heat treatment at a max. of 200 °C for 72 h.
- The quadrupole magnet should be able to deliver a maximum integrated field gradient of 0.01 T (100 Gauss)
- Radius of the GFR (R_{ref}): 7.5 mm
- Field homogeneity requirements-None for the design
 - Estimate from the EM design analysis.
- Fringe field requirements: none



Space Available for QW Magnet Assembly

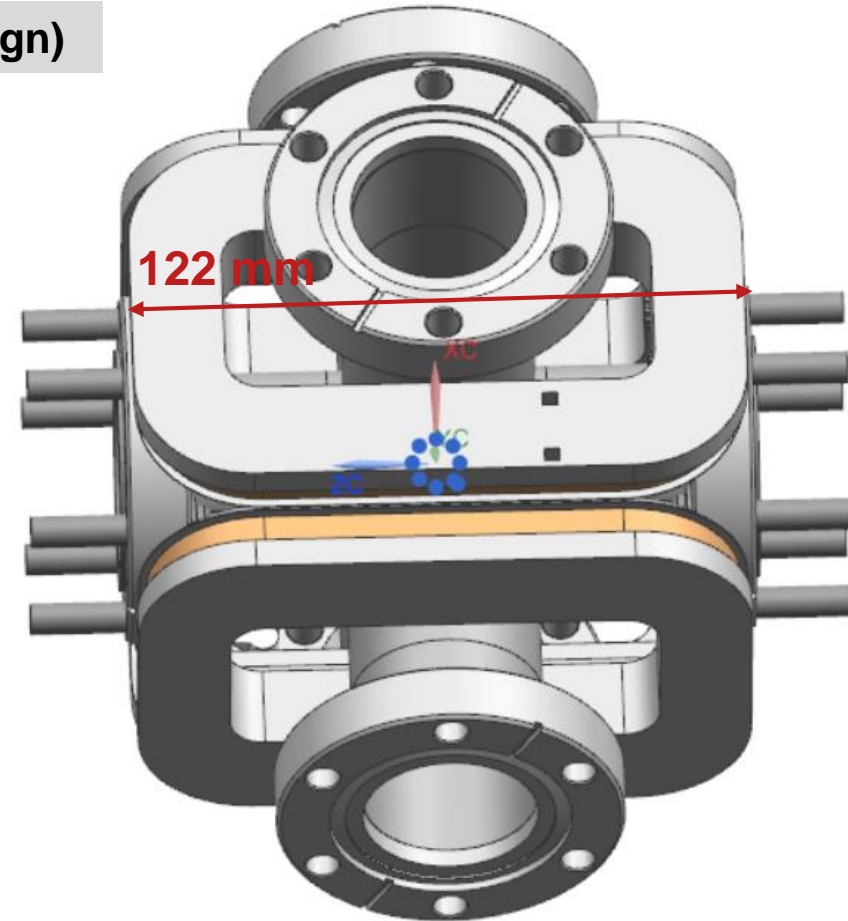
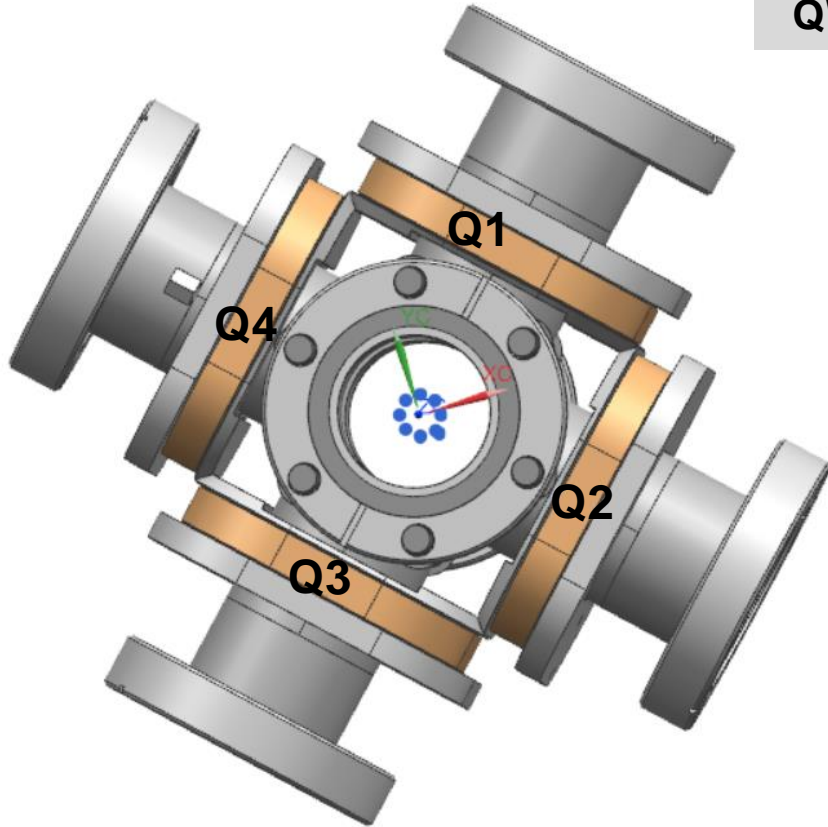
- Design changes (since QW design (V02) meeting Aug 31, 2020)
- Extended the pipe length radially (from 99.56 mm to 164.94 mm)+ added tapped-bored flanges (1-4).
- No change made to (A) the cross length length-wise and (B) upstream and downstream CF flange configuration or hardware (bolts and spring washers).



Design Considerations: QW Coil Layout on the Vacuum Cross Fitting

- Racetrack coils (Q1, Q2, Q3, Q4) arranged in quadrupole geometry.
 - 76 mm gap between the opposite coils.
- The coil bobbin is made out of stainless steel.

QW Magnet (new design)



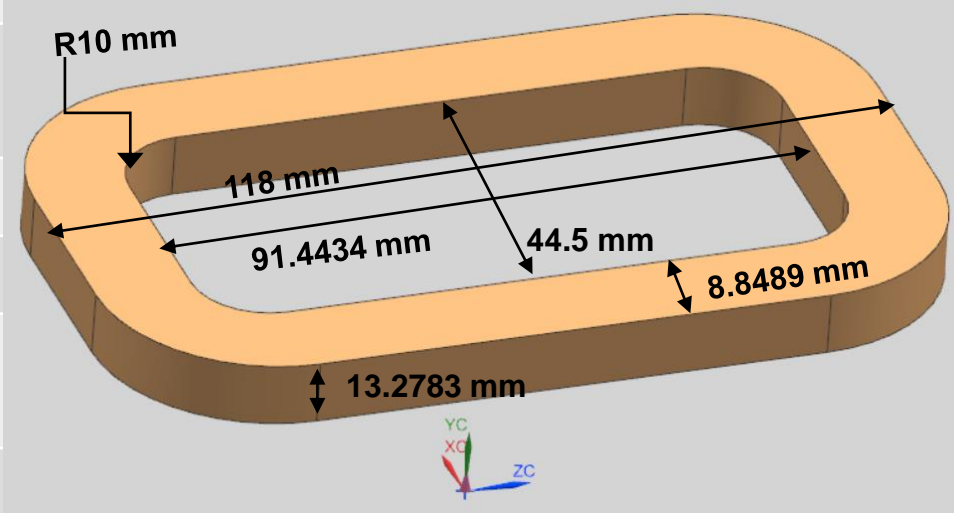
Design Considerations: Conductor Selection

- Kapton insulated 12 AWG square conductor with round corner.
(potential supplier- MWS Wire Industries, CA)

Magnet wire parameters (Max. dimensions)	Unit	Value
Shape		Square with round corner
Copper grade		C101 or C102
Bare conductor size (equivalent AWG)		12
Bare conductor dimensions: width = thickness	mm	2.0777
Corner radius	mm	0.508
Radial thickness of the Kapton insulation	mm	0.0635
Insulated conductor dimensions: width = thickness	mm	2.2047

Design Considerations: Coils

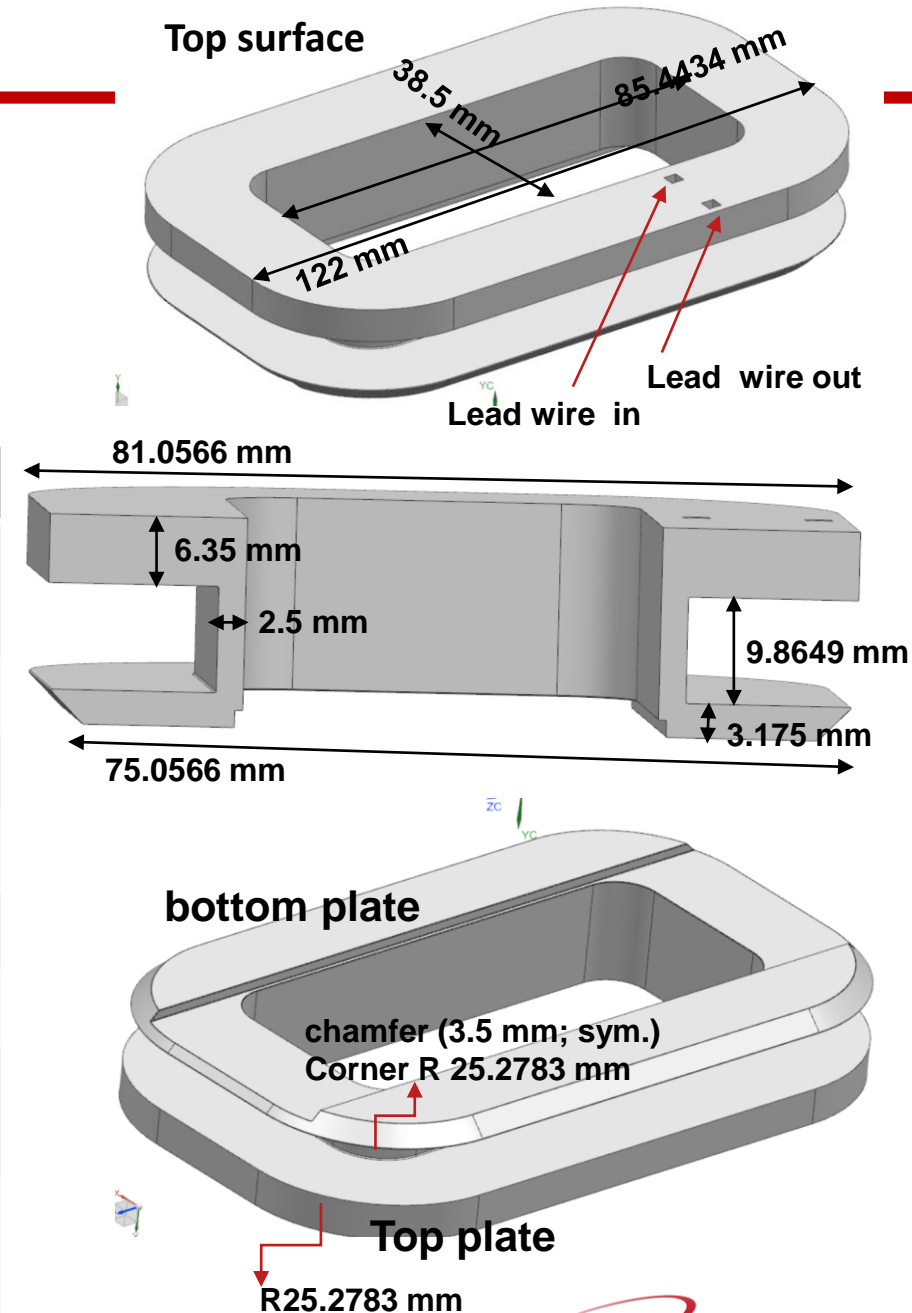
- Flat coils (“easy to wind” geometry. Simplifies the tooling for the coil winding and the requirements for the support structure for magnet assembly)
- Wet wound with AREMCO 526 N epoxy.

QW coil parameters (Assumption: Coil wound on a PTFE bobbin) (estimated using the max. dimensions of the conductor)		Unit	Value
Distance between the opposite coils in the quadrupole assembly		mm	76
Radial thickness of the epoxy between the turns (assumed)		mm	0.01
Inner gap- radial (X direction), longitudinal (Z direction)		mm	44.5, 91.4434
Radial thickness of the winding (X direction)		mm	8.8489
Height of the winding (Y direction)		mm	13.2783
Straight length, Overall length of the coil		mm	71.4434, 118
Inner corner radius		mm	10
Total turn count (Number of layers, Number of turns per layer)			24 (6,4)
Estimated length of conductor per coil (5% extra for unknowns) (+1m for each lead wire)		m	~ 8.9
Req. length of conductor per magnet (four coils+ lead wires)		m	~35.6

Design Considerations: Coil Former

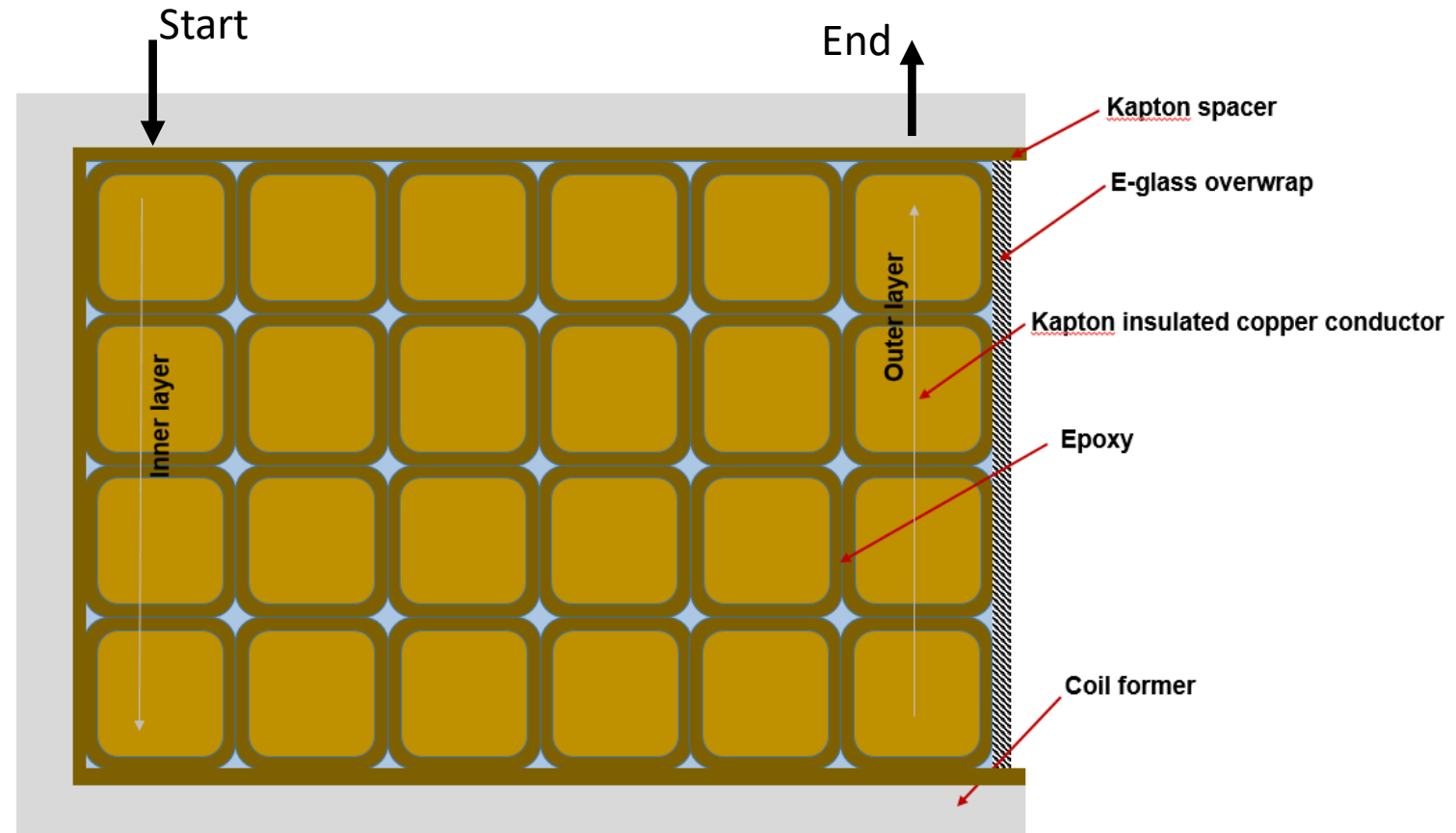
- Material: SS(304 grade)
 - Bottom plate is shaped to fit the coil pack in the quadrupole geometry with 76 mm gap between the opposite coils.
 - The lead wires route through the top plate of the coil former.
 - Kapton insulation between the coil and bobbin.

Coil Former dimensions	Unit	Value
Inner gap-radial (X direction), longitudinal (Z direction)	mm	38.5, 85.4434
Corner radius of the inside surface of the core	mm	7
Thickness of the core	mm	2.5
Thickness of the bottom plate, top plate	mm	3.175, 6.35
Overall length	mm	122
Overall height	mm	19.3899
Radial thickness of Kapton around the core (two layers of 0.254 mm thick film)	mm	0.508
Thickness of pre-cut Kapton spacer between coil and top and bottom plates of the bobbin	mm	0.508



Conductor Layout in the Coil

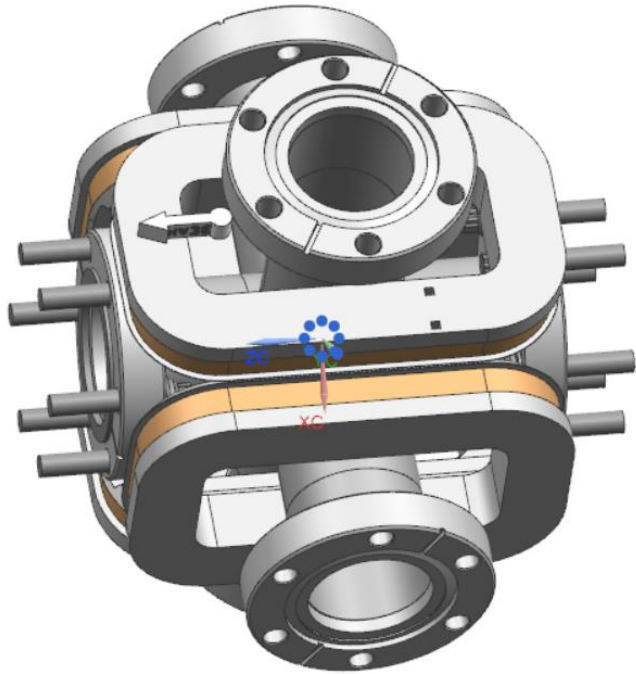
- The coil is wound directly on the SS former.
- Uses single piece length of the copper conductor.
- Wet wound with AREMCO 526 N Epoxy. (assumption: 0.01 mm thick epoxy filling between the coil turns)
- The coil winding should be tight against the bottom plate of the former.
- Filler could be used, as needed, in the gap between the top surface of the coil and former plate.
- Additionally 2 layers of 0.1 mm thick E-glass wrapped under tension on the outer surface of the finished coil and painted with the same epoxy.



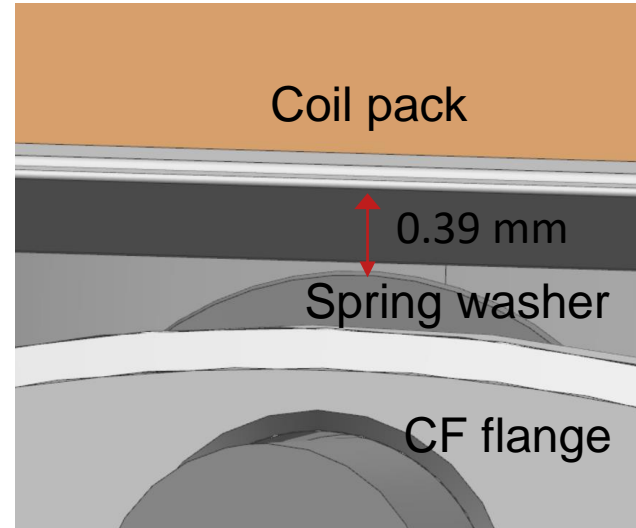
Conductor layout in the QW coil

Note: flat coils, “easy to wind” geometry and tooling requirements; Considering the overall space constraints, the coil manufacturing process should strictly adhere to the suggested layout of the conductor and overall dimensional specification of the coils

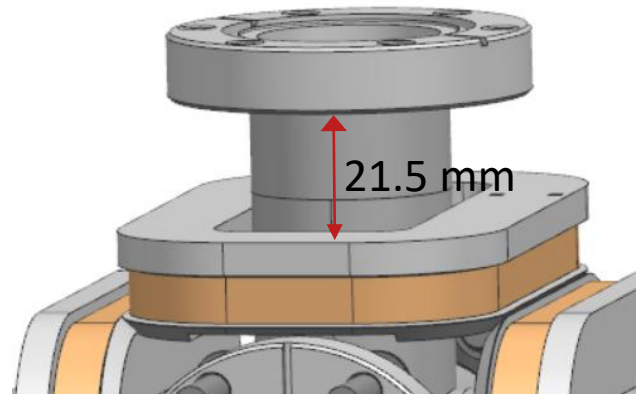
Design Considerations: Coil Assembly on the Vacuum Cross Fitting



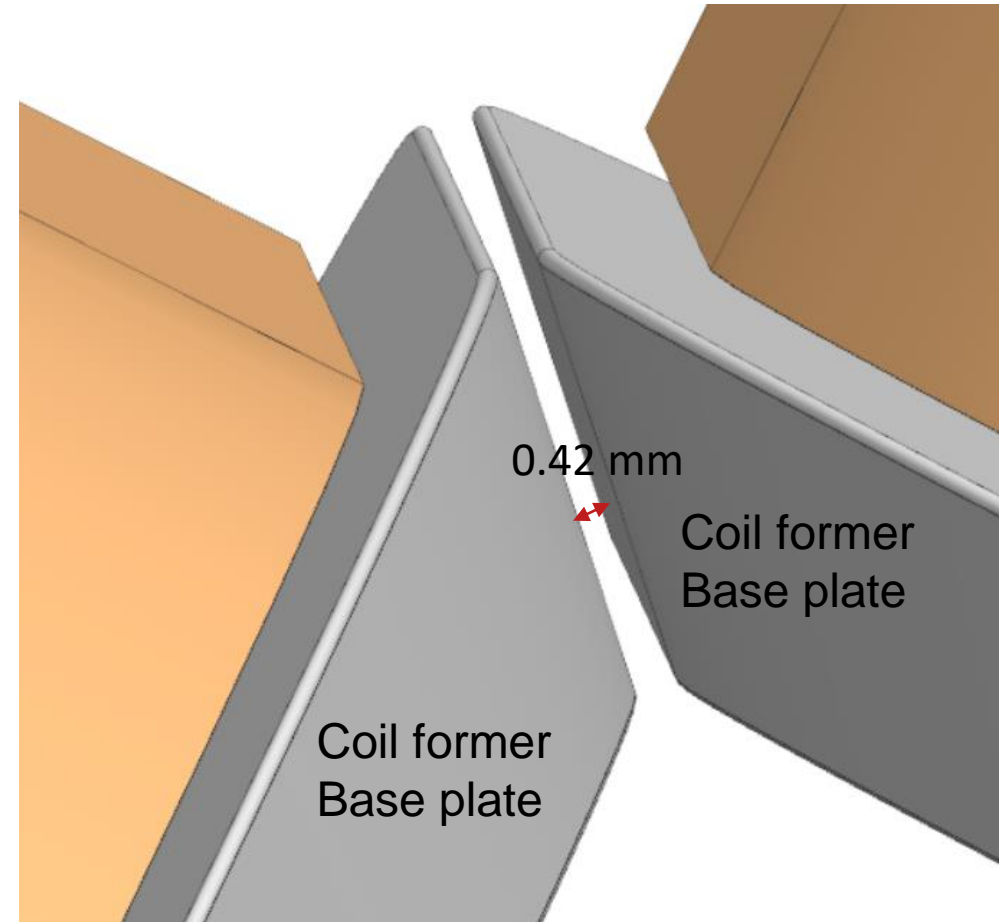
Flexibility to move or rotate the coil pack during the assembly stage.



Sufficient clearance between the CF flange hardware and the coil pack

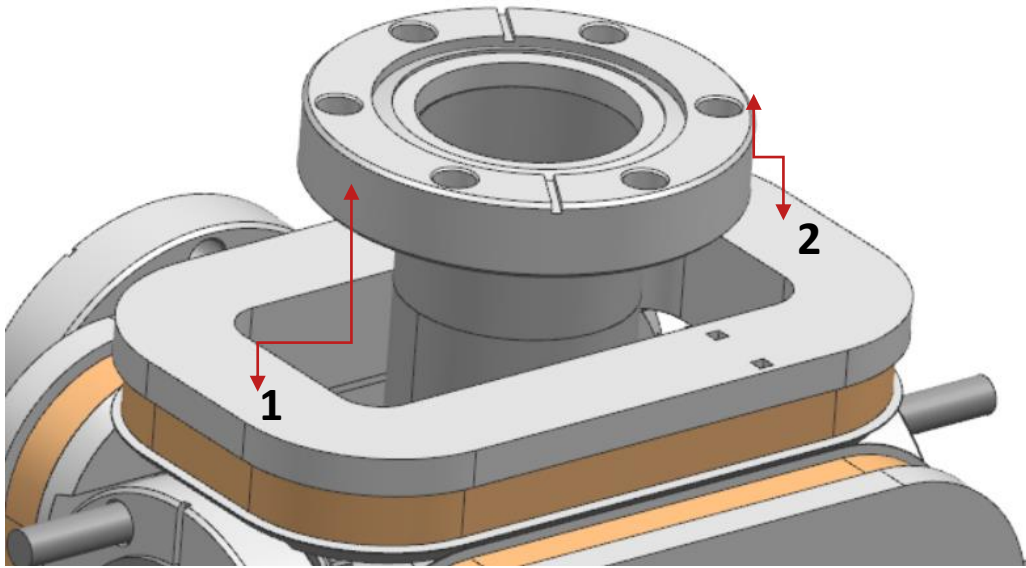


~21.5 mm clearance between the CF flange and coil (in radial direction)

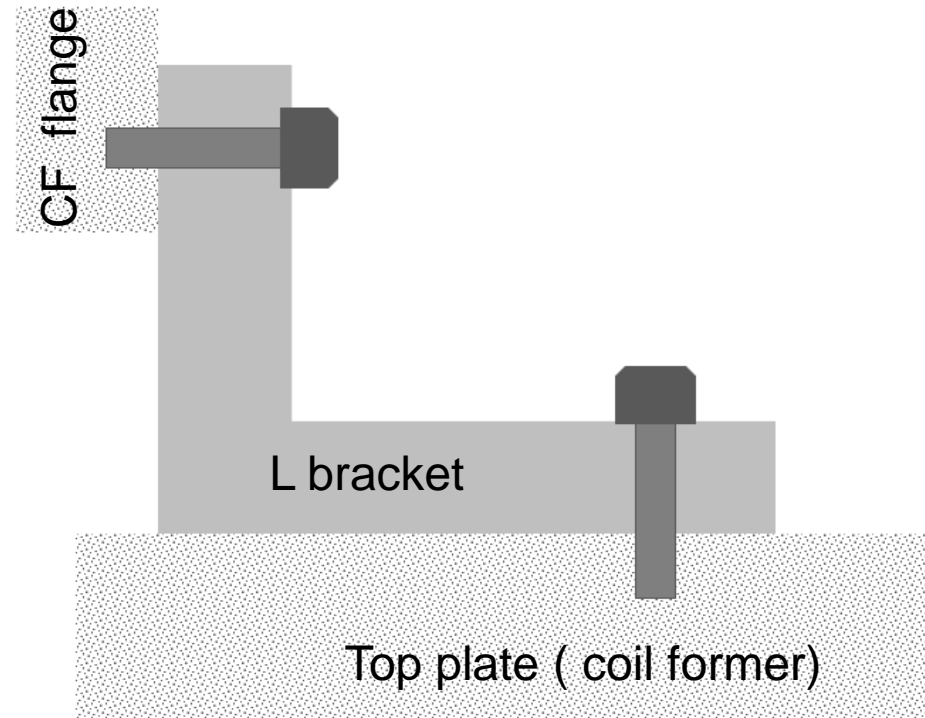


~0.4 mm clearance radially between the base plate for the neighboring quad coils

Design Considerations: Magnet Support Structure



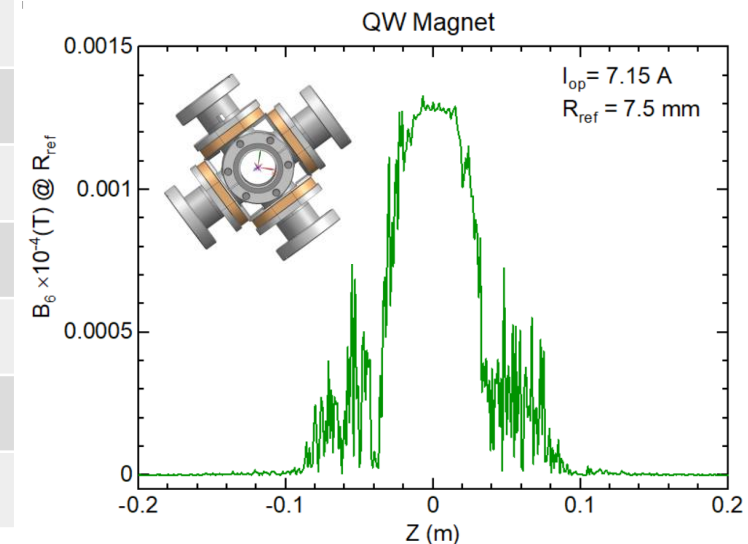
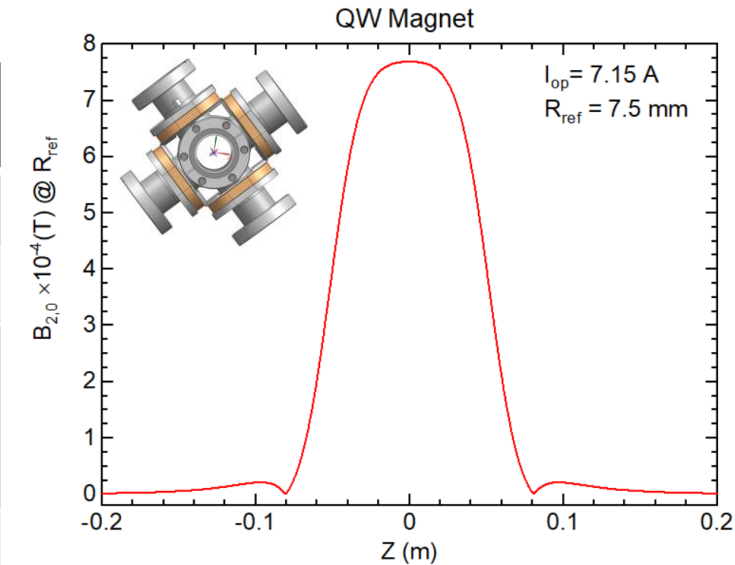
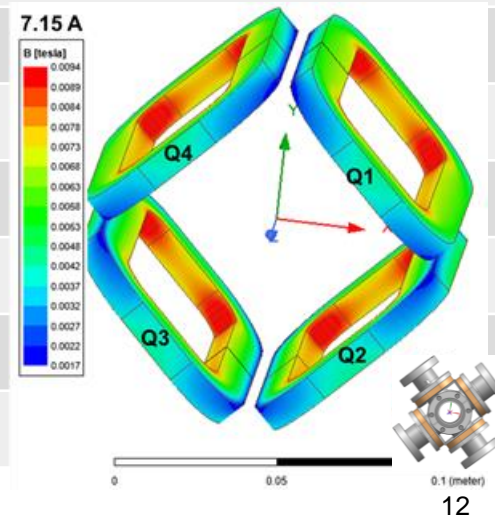
- L bracket or angled pipe bracket (SS 304): between the top plate of the coil former and CF flange; at locations 1 and 2 as shown



Magnetic Performance Parameters (@ Max. Operating Conditions)

- EM design fulfills the performance requirements and provides sufficient operating margin (~12.5 %).
- 10 A power supply is required.

Parameter	Unit	Value
Operating current	A	7.15
Operating current density in the copper conductor	A/mm ²	1.75
Integrated quadrupole (n=2) field strength at R _{ref} (Requirement: 0.01 T integrated field gradient corresponds to 7.5×10 ⁻⁵ T.m int. field strength)	T.m	7.502×10 ⁻⁵
Integrated quadrupole field uniformity at R _{ref} (only the 12 pole (n=6) component present)	%	99.99
Effective magnetic length at R _{ref}	m	0.975
Max. field strength of the coil	mT	9.38
Inductance of each coil	μH	71.12
Magnetic Stored Energy	mJ	8.71
Resistance of the coil at 20 °C	mΩ	37.18
Cumulative force on each coil pack	mN	9.38



Summary and Recommendation

Note: Tech note will be prepared later.

- The new QW magnet design fulfills the performance requirements.
 - Need to energize the coils at 7.15 A to achieve a maximum of 0.01T integrated quadrupole field gradient.
 - 10 A power supply is required.
 - Provides additional 12.5% performance margin.
 - Integrated quadrupole field homogeneity better than 99.99%.
 - Structural evaluation- in progress
 - No room to include field clamp to minimize the fringe field interaction between the QW magnet and the neighboring (Haimson) steering magnet
 - The magnet to magnet interaction will be quantified.
 - We can add a stand-alone shield between these magnets if needed.
 - Limit the max. operating current to 8.3 A (recommendation).
 - Keep the bake temp to 180° C (recommendation)
 - To prevent the local hotspot exceeding 200 ° C .

