Specification for three solenoid types for the low-momentum regions of an electron accelerator

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Note 1: Vendors outside the USA may propose the use of standard metric material sizes provided the the OD is no more than 22.3 cm. Bare wire may be 1.6 mm square with nominal 0.1 mm build of polyimide film insulation with 240C temperature rating per a commercial or national specification comparable to NEMA MW-20. Copper sheet may be 2 mm. Steel sheet 6 or 7 mm.

Note 2: The coils described below will ultimately be used in two regions of the accelerator. In the low momentum (low P) region the maximum current used will be 3A or approximately 18W per coil with two coils per assembly. In the higher momentum (high P) region 10A typical and 16A maximum so up to 1000W per assembly. Bids for high P are not being solicited at this time. If the vendor asserts that unforced convective cooling will suffice for the low P condition, explain why. In two locations the low momentum assembly is captured inside a 9” ID by 4” recess so convection will be minimal.

Note 3: Vendor manufacturing drawings shall be approved by Jefferson Lab prior to fabrication. Drawings shall conform with ASME Y14.5-2009 or equivalent for non-US vendors.

Magnet coil

The magnet coil shall consist of 24 layers with 22 turns/layer. Layer width shall include a cross-over allowance equal to one additional turn width. All cross-overs between layers shall be made within a 30 degree segment of the coil, +- 15 degrees about the inner radial lead angular location. Cross-over regions may be filled with glass cord or similar (manufacturer's usual practice) to avoid neet epoxy volumes over 1 mm in cross-section. Coil shall be wound on a tool 2.250-2.254” (5.715-5.725 cm) radius. E or S glass fabric with epoxy-compatible surface treatment shall be laid over this radius to bring the inside radius of the coil proper to 2.260-2.264” (5.74-5.75 cm). E or S glass cloth annulli approximately 0.01” (0.25 mm) thick will be placed on the inner sides of the tool. Tool width shall be 1.632-1.634” (4.145-4.150 cm). At maximum material condition, 23 turns of #14 square copper wire with heavy film insulation is 1.612” (4.095 cm) wide. At minimum material condition 1.520” (3.862 cm). Winding machine pitch shall be set so turns are evenly distributed on the width of the tool independent of the actual wire width. Twenty-four layers are 1.682” (4.273 cm) thick at maximum material condition and 1.586” (4.029 cm) at minimum material condition. Glass fabric shall be laid on the coil as it is wound to make overall build to 3.94-3.95” (10.01-10.03 cm) radius including a fabric layer on the outside diameter. If the wire is at minimum material condition, 12 layers of 0.2 mm glass might be used every second layer. If larger, every fourth, sixth or even twelfth layer. The intent is to have the conductor uniformly located within the nominal volume 4.10 cm wide by radial build 4.27 cm so a constant current density approximation for the volume is appropriate.

The start lead shall be placed in a groove in the tool approximately 2 mm square. An E or S glass sleeve shall be placed over the lead so it will be better insulated from the copper annuli shown in the drawing after potting. Bend radius at the entrance to the coil shall be no less than 0.25” (0.64 cm) to keep strain less than 25%. Lower strain (larger radius) preferable.

Coil shall be potted with vendor's choice of process and epoxy subject to the need to bake the system at 225 C for a one day period once a year for five years. Vendor may choose to use additional glass-epoxy on the IR, OR and sides of the coils and machine after potting to indicated dimensions rather than rely on the tool to fix the dimensions. Again, conductor must be uniformly placed within the resulting 4.10 cm by 4.27 cm cross-section.

Electrical isolation: Each coil shall have less than 30 μA leakage to a ground plane with 300V applied to one lead and the other open aka 10 MΩ isolation. Manufacturer may half-lap 0.001” polyimide (e.g. Kapton) tape to the outside of the coil to improve standoff. If this choice is made it shall be applied to all coils. The leads shall be insulated with shrink tubing where they pass through the iron shell.

Magnetic material

Cold rolled low carbon steel plate in 0.25” (0.64 cm) thickness was assumed for the magnet annulli in modeling. Outer carbon steel cylinder was assumed to be a low carbon steel mechanical tube 8.5” OD with 0.25” wall (21.6 cm OD by 0.64 wall). Carbon content of the alloys chosen for sheet and cylinder shall be supplied by the vendor in bid response.

For water tubing exit/entrance two machined voids 7.5 mm radial extent by 15 mm circumferential extent on 2.1” (5.33 cm) radius may be milled in the end pieces, 180 degrees apart. See drawing for concept of water cooling channels in copper mandrel/datum. It is assumed that 6.35 mm OD aka 1/4” water tubing is used on the inner support of the coil assembly. Adjust voids if a smaller tube is used.

End pieces are 0.25” (0.64 cm) in all units for material procurement reasons; 0.125” suffices magnetically in the low momentum regions. Central half-annuli for the low momentum units are 0.25” (0.64 cm) thick as these are mostly used in a counter-wound configuration. The high momentum units do not have central steel.

Rust prevention: OD and ID of the steel cylinders should be laquered, painted or plated as the vendor prefers. Ends should remain uncoated. Flat annuli and half-annuli should be painted except where the ends are screwed into the ends of the cylinder, aka no coating where steel meets steel. Coating thickness 20 microns nominal, 40 microns (0.001”) maximum preferred. If nickel plated, all surfaces may be coated as nickel is a magnetic material, albeit with lower relative permeability and saturation than carbon steel. Steel half-annuli are required for the central part because the copper core is the reference part for assembly and should be a single piece. A rabbet joint between the halves would be nice; a butt joint with air gap under 20 microns acceptable.

Copper for heat transfer

Round copper bar stock nominal 4.5” OD is used for the coil and annuli survey reference. The ODs of this piece will be the datums to which the coils and annuli are referenced so larger round stock may be appropriate as starting material. The ID is sized to fit over CF-style vacuum flanges of standard size so the assemblies need not be welded in place. Acceptable copper is any alloy with at least 60% of the thermal conductivity of UNS C11000 (ETP) and which does not contain ferromagnetic elements.

As mentioned above, 1/4” (6.35 mm) OD water lines will be used for cooling on the inner radius of the coils. Under-depth grooves should be milled/turned into the OD of the round copper stock into which the tubes will be pressed to ensure good thermal contact. If both copper parts are clean the modestly distorted tubes should stay in the grooves. Grooves should be re-entrant so tubes enter and exit on the same side of the assembly. One location (with the 46 mm steel IR) complicates things since all the water and current must enter/exit on the same side of the assembly. It follows that the groove patterns are not the same under the two coils of the assembly. One groove choice is shown in the drawings. If better alternatives exist, the vendor is encouraged to submit them.

For the low momentum coils: To provide radial heat transfer and a Z location to get the inner lead out to the OD, 2.2 mm (0.0863", 11 gauge) nominal copper sheet annuli will be placed on either side of the coils between the glass-epoxy and the steel. A 2.5 mm wide radial slot will be cut in the copper annulus to guide the lead out. Deburr slot. All sheets may be the same though half will have leads.

For the high momentum coils: Crude heat transfer estimates suggest that 1 cm (or 0.375") thick chill plates with (again slightly underdepth) grooves into which 1/4" OD (6.35 mm) water tubing is pressed will be needed on either side of the coils. Since these units are always wired so the field direction is the same there is no steel between the coils. Three chill plates per assembly. Water lines of the chill plates enter and exit at OD through the steel cylinder, like the leads. Water lines at the ID enter and exit on ends. Since there is no center steel annulus the copper cylinder on which the coils and steel annuli are mounted can have a continuous water line. A simple spiral will suffice as water can enter one side and exit the other. The chill plates must have a radial groove about 2 mm square milled into the coil side in one location to get the inside electrical lead to the outside. If the vendor's analysis shows that the three chill plates and water tubes at IR will not suffice to remove 1 kW from the assembly with 35 C water inlet temperature at 10 bar pressure, please suggest alternatives.

Z assembly tolerance

Sheet steel and copper have thickness tolerances +- 0.13 mm in the US. Since there are three pieces of steel and four of copper (low P), MMC-LMC for these seven parts is 1.82 mm. In addition, the tolerance band on the two coil widths is 0.05 mm each, 0.1 mm total, so overall MMC-LMC is 1.92 mm. This is not acceptable for the matching of magnetic fields desired among the two low-P classes of solenoids. The two end plates of steel must be symmetric to the middle piece within 0.1 mm. The coils must be symmetric to each other and the steel within 0.3 mm. If all the sheet/plate stock purchased is of uniform thickness within 0.01 mm no filler will be necessary. If the sheet stock is of slightly less uniformity but not as bad as allowed, polyimide tape may be applied to the steel side of the copper as a spacer to ensure symmetry. Overall length does not matter within the 2 mm, the symmetry does.

Alternate: Glass-epoxy sheet up to 0.5 mm thick can be inserted on the steel side of the four copper pieces to bring all the assemblies to the same length within 0.25 mm. Glass-epoxy thickness chosen to ensure the coil centers are equidistant from the assembly center within 0.3 mm. Glass-epoxy placed on the steel side so copper has good thermal contact with the coil. Glass epoxy rated for 240 C use.

Magnetic measurement

When the low momentum assemblies are wired counter-wound, i.e. so that Bz fields of the two coils are opposed and net spin precession is zero, the Bx field integral along the axis over Z=[-25,25] cm shall be within [-5,5] G-cm when the series current is 3A. This is equivalent to the halves of the assembly, coil and steel, matching within about 0.5%. If cost will decrease substantially if this allowance is widened, please propose a new specification and cost reduction. If a few percent cost increase will tighten the matching of the paired coils, specify cost and precision improvement.

The high momentum assembly is to be wired so the coils produce field in the same direction. With 3A in the coil the integral of the Bz field along the axis over Z=[-25,25] should be ~3985 G-cm, assuming 1010 steel BH curve. Field integrals in all the assemblies of this type should match within ±0.5%. If a few percent cost increase will tighten the matching of the assemblies, specify cost and precision improvement. These assemblies are to be used in matched pairs with 12 cm gap to form a counter-wound set for use at 5-15 MeV KE. One of the assemblies is a spare, hence desire for all to match.

Bid packages: please provide pricing for the following packages

1. Eight low momentum solenoids with 38 mm IR steel (sketch 5) and two low momentum solenoids with 46 mm IR steel (sketch 2).

2. Seven high momentum solenoids (sketch 4)

3. (1) and (2) purchased together

4. Six?? bare coils, no steel or bulk copper (sketch 1)

Note: If coil winding tool described on page 1 would be discarded after job is complete, what is the cost to (a) store it at your facility for possible future use for JLab or another customer or (b) ship it to JLab. There is no intellectual property claim on the design. If you have other customers who might benefit from it, feel free.