Specification for solenoids to be used in 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 ID is at least 8.6 cm and the OD no more than 22 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 3, 6 or 7 mm.

Note 2: The coils described below will be used in two regions of the accelerator. In the low momentum region the maximum current used will be 3A or approximately 18W per coil with two coils per assembly. In the higher momentum region 10A typical and 16A maximum so up to 1000W per assembly. A distinct cooling system is required for the latter. If the vendor asserts that unforced convective cooling will suffice for the former condition, explain why. In two locations the loq momentum assembly is captured inside a 9” ID by 4” recess so convection will be minimal.

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 2.260-2.268” (5.74-5.76 cm). E or S glass cloth annuli approximately 0.01” (0.25 mm) 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 twelth 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 sheet in 0.125” (0.32 cm) and 0.25” (0.64 cm) thicknesses were assumed for the magnet annuli 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 a machined void 4.1 mm radial extent by 9 mm circumferential extent on 2” (5.1 cm) radius may be milled in the end pieces. If the water lines do not enter and exit at the same location on the circumference, four 4.1 mm diameter holes may be drilled in the end plates and only two utilized so water entry and exit are 90 degrees apart, relying on the copper (see below) thermal conductance to move the heat to the water. (It is assumed that 4 mm OD aka 5/32” water tubing is used on the inner support of the coil assembly.).

End pieces are 0.125” (0.32 cm) thick for the low momentum units and 0.25” (0.64 cm) for the high momentum units. 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 of the steel cylinder should be laquered, painted or plated as the vendor prefers. ID and ends should remain uncoated. Flat annuli and half-annuli should be painted except on OD and where the ends are screwed into the ends of the cylinder, aka no coating where steel meets steel, including slide fit of half-annuli to ID of cylinder. Coating thickness 20 microns nominal, 40 microns (0.001”) maximum preferred.

Copper for heat transfer

Round copper bar stock nominal 4.5” OD must be drilled to 3.38” (8.6 cm) ID for the coil and annuli mounting 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 a CF-style vacuum flange of standard size to accept 2” (5 cm) tube so the assemblies need not be welded in place.

As mentioned above, 5/32” (4 mm) OD water lines will be used for cooling on the inner radius of the coils. 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. Grooves should be re-entrant so tubes enter and exit on the same side of the assembly. The chopper location 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. Each should cover about three-fourths of the circumference but there must be a groove to convey the water tubes of the inner segment to the outer one. I suppose the grooves could be machined the same but the water tubing pressed in different segments thereof to get them all out the same side. While this is only needed at the chopper, we ought to make them all the same.

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”) 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.

For the high momentum coils: Crude heat transfer estimates suggest that 0.375” (0.95 or 1 cm) thick chill plates with grooves into which 1/4” (6 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 as above. 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. Entry and exit again must be on the same side of the magnet so the groove pattern cannot be a simple spiral. 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.

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 ~3950 G-cm. 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 seven 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 seven is a spare, hence desire for all to match.

nominal Z extent, inch and metric versions

	low p	high p	low p	high p
steel	0.125	0.25	3	6
copper	0.0863	0.375	2	10
coil	1.633	1.633	41.475	41.475
copper	0.0863	0.375	2	10
steel	0.25		6	
copper	0.0863		2	
coil	1.633	1.633	41.475	41.475
copper	0.0863	0.375	2	10
steel	0.125	0.25	3	6
total inch	4.1112	4.891		
total cm	10.442	12.423	10.295	12.495