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CONSTRUCTION PROGRAM FOR A LARGE SUPERCONDUCTING MHD MAGNET SYSTEM AT THE COAL-FIRED FLOW FACILITY*

S.-T. Wang, L. Genens, J. Gonczy, H. Ludwig, M. Lieberg,
E. Kraft, D. Gacek, Y.-C. Huang and C.-J. Chen
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

Summary

The Argonne National Laboratory has designed and is constructing a 6 T large aperture superconducting MHD magnet for use in the Coal-Fired Flow Facility (CFFF) at the University of Tennessee Space Institute (UTSI) at Tullahoma, Tennessee. The magnet system consists of the superconducting magnet, a magnet power supply, an integrated instrumentation for operation, control and protection, and a complete cryogenic facility including a CTI Model 2800 helium refrigerator/liquefier with two compressors, helium gas handling system and a 7500 liter liquid helium dewar. The complete system will be tested at Argonne, IL in 1981. This paper first briefly reviews the magnet design. Second, the coil fabrication programs are described in detail.

Magnet Design[1]

The magnet consists of fourteen concentric layers with a shorter coil (coil layer No. 1) close to the bore tube. This generates a linear tapered field with a maximum on-axis intensity of 6 T. The coil shape is a circular saddle which will support the hoop stress of the coil end itself. The significant magnet characteristics are listed in Table I. The CFFF MHD magnet configuration, MHD field profile, and cryostat details are shown in Figs. 1 and 2 respectively.

The conductor is a soldered assembly of a superconducting cable wire of Nb-48% Ti superconducting composite wire that fits into the longitudinal groove of OFHC copper stabilizer. Three grades of conductor are used: Grade A with a 4.2 K short sample critical current of 4400 A at 7.5 T; Grade B, 4400 A at 6.5 T; and Grade C, 4400 A at 4.5 T. The operating point is 3670 A at 4.2 K with a field margin of 0.5 T for each grade of conductor. All conductor has a height of 3.1 cm with conductor thickness varying according to the field grades. The surface of superconducting cable is recessed below stabilizer surface by 0.76 mm, thus forming a longitudinal cooling channel for the cable. Since it is difficult to predict the size of the worst disturbance the magnet will encounter, the conductor is designed based on steady state cryostability. The coil structure is shown in Fig. 3. The short sample critical current, the minimum propagating current, the recovery current, the operating point and the load line are shown in Fig. 4. Also shown is the turn-to-turn insulation which is a pultruded fiberglass strip with keystone cross-section. It is punched in a fishbone-like pattern for providing about 30% cooling on both of the conductor broad faces.

The conductor in the high field cross section exerts a burst force of 30,180 kgf/cm outward which is contained by girder rings made of casting 316L stainless steel arc segments and 2219-T87 aluminum tie plates (see Fig. 1). A clamping force of 24,287 kgf/cm pushes the two coil halves of the magnet together. The decentering force of 219,500 kgf, resulting from the asymmetric field distribution, is supported by the end flange at the high field end and by a step in the bore tube.

The cryostat configuration is shown in Fig. 1. The cryostat consists of a helium vessel, a liquid nitrogen cooled shield and a vacuum vessel serving as a pressure vessel and a support structure for cold mass. Steady state heat fluxes to the helium vessel and the thermal shield have been minimized by the use of multilayer insulation around the nitrogen shield and helium vessel, and by use of low heat leak support structures. The steady state heat flux to the helium vessel is 14.0 W; i.e. 19.6 L/h. The steady state flux to the thermal shield is 179 W; i.e. 4.3 L/h boil-off.

Coil Fabrication

To provide for efficient and accurate construction of the coils, a servomechanized winding machine was developed as shown in Fig. 5. The Micarta coil form is fastened to a winding drum which is supported by a turntable. As the table rotates about its vertical axis, the drum revolves about its horizontal axis. Molded plywood forms are used to provide the required radius of the winding drum. Four sets of hold-down fixtures are used to anchor each conductor winding as it is bent around the winding drum to form the saddle coils. Nylon straps and supporting arms which are pneumatically powered are used to support the conductor at straight regions. Figure 5 shows a coil winding for coil layer No. 7.

Conductor Splice

During the coil winding, different field grades of conductors are used. To perform these joints, resistance welder[2] was used to weld the stabilizer of one grade to one end of prefabricated OFHC transition stabilizer. Likewise, the other end of it was welded with a stabilizer of another field grade. The excess copper in these welds was removed and the superconducting cables were lapped jointed over the transition stabilizer. During the coil assembly, splices are made to connect the coil halves in the same layer and to connect the coils in adjacent layers. These are soft-solder lapped joints with copper rivets bonding as reinforcement.

Coil Assembly

As shown in Fig. 6, the coil assembly starts by first installing the bore tube mandrel to the bore tube. The assembly is then lifted onto the power rolls. the bore tube is insulated with an epoxy fiberglass cylinder with grooves machined for liquid helium perforation as shown in Fig. 7.

Each layer coil assembly begins by lifting a pair of coils onto the assembly tube. Then the coil is compressed radially by a set of stainless steel bands. Parting jacks are used to jack apart the gaps between the two halves performing the azimuthal compression. Micarta spacers of proper width are placed between the two halves. A set of inflatable yellow bags are now installed between the stainless steel bands to execute the final radial precompression as shown in Fig. 8.

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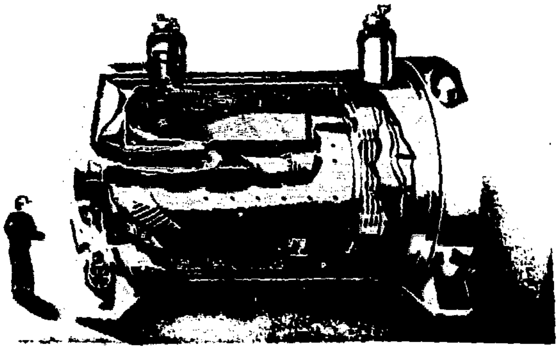


Fig. 1 CFFF MHD Magnet Configuration

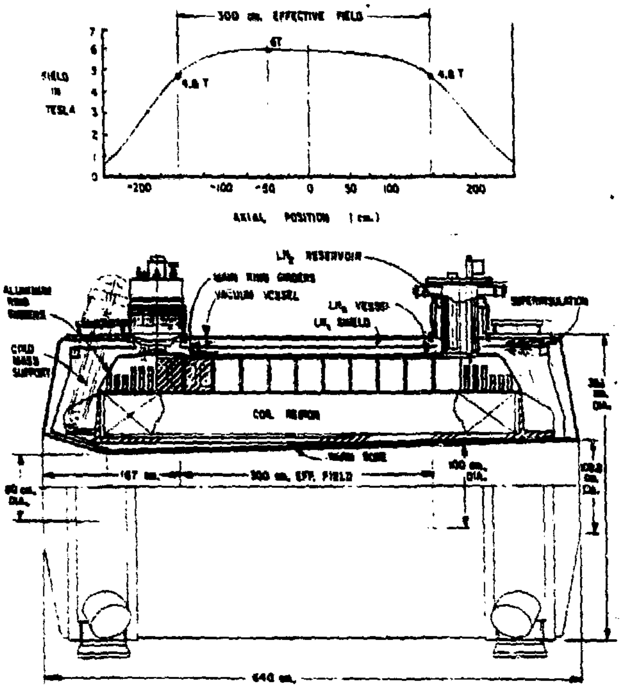


Fig. 2 MHD Field Profile and Cryostat Details

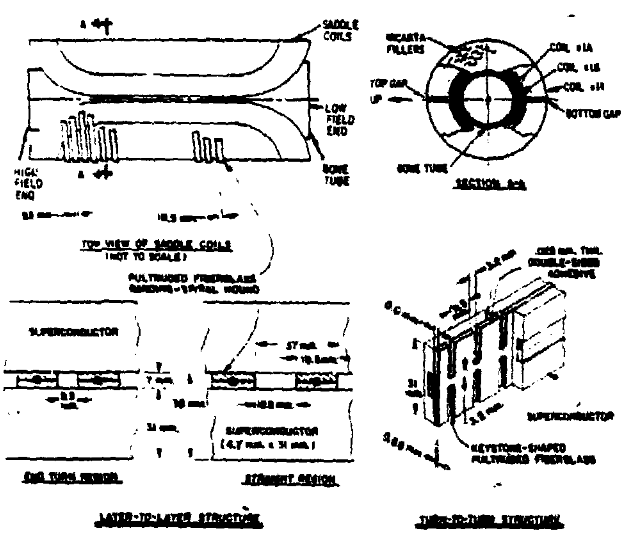
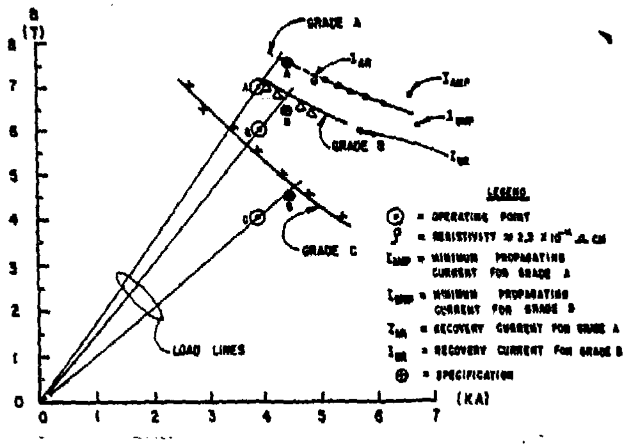
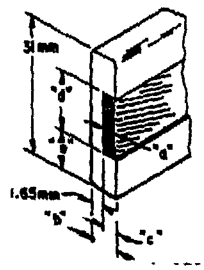


Fig. 3 Coil Structure





GRADE	DIMENSION (mm)				
	a	b	c	d	e
A	2,29	4,7	2,92	10.33	10.33
B	2,05	4,45	2.57	9	11
C	1,78	4,2	2.4	8.86	12.1

Fig. 4 Conductor Short Sample Characteristics

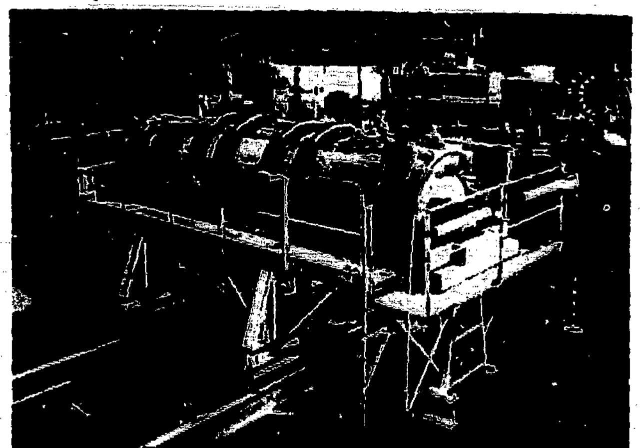


Fig. 5 Coil Winding Operation

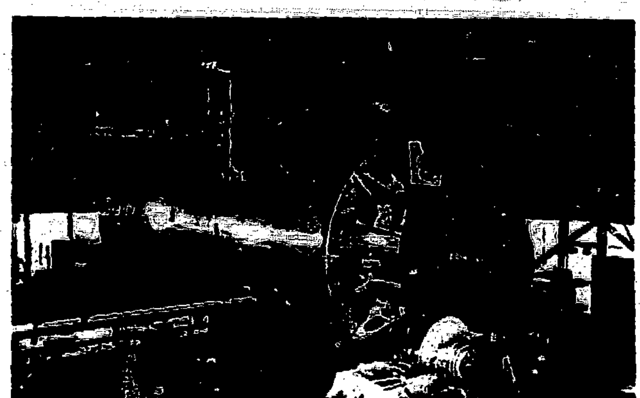


Fig. 6 Bore Tube Installation on Power Rolls

Conductor splices are made, then follows the installation of coil end fillers and the application of A + B epoxy to fill the voids at coil ends. Spiral permanent bandings of pultruded fiberglass, 18.5 mm wide x 7 mm thick, are finally installed progressively to replace all the temporary straps leaving a 18.5 mm spacing between two bands in the straight conductor region and 6.2 mm in the coil end region. The banding tension used is about 2000 kg. This final compression solidly secures the coil layer against the previous layer and tolerates little buildup within the winding, thus restraining any movement of the coil and provides layer-to-layer separation and adequate liquid helium flow passages. Figure 9 shows the bandings for the coil layer No. 6.

Assembly of Ring Girders and Cryostat

Figure 10 shows the step-by-step procedure for the assembly of the ring girders and cryostat.

Once the fourteen layers of coils are secured to the bore tube, a series of eleven main girder rings will be positioned over the straight conductor region to resist against the burst forces from the winding. In the coil end region four smaller end rings will be installed. These girders will be clamped tightly against a surface of fiberglass rings which were installed to provide a machined surface with curvature matching that of the ring girder.

The coil assembly is now ready to be sealed in its helium vessel. A tower assembly is then added to house the many wires and piping that would be used to communicate with the magnet.

The nitrogen coolant is carried by copper tubing soldered to the walls of the shield which is made of stainless steel to eliminate the risk of shield collapse should the magnet have a rapid discharge. More superinsulation of the aluminized Mylar is added to reduce the radiation load on the nitrogen shield. The entire assembly is then placed into an insulating vacuum. The magnet is now ready for the installation of the assembly of magnet warm bore tube and the inner liquid nitrogen shield. The final assembly is the installation of end shield and the end caps of the vacuum vessel.

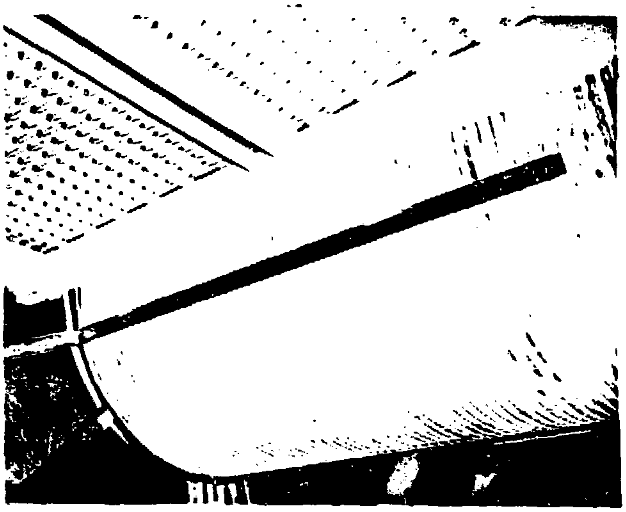


Fig. 7 Bore Tube Insulation

Table I
CFFF SCMS Magnet Parameters

I.	**MHD Related Parameters**	
	MHD On-Axis Field	Inlet 4.8 T, peak 6 T, Outlet 4.8 T
	Field Taper	Liner taper with a gradient of 0.2 T/m
II.	**Magnet Coil Characteristics**	
	Winding ID	119 cm
	Winding OD	225.7 cm
	Winding Length	488 cm
	Winding Type	Circular Saddle
	Conductor	Soldered Cable of NbTi composite stabilized with copper
	Operational Current	3675 A
	Peak Field	6.9 T at conductor
	Current Density	2890 A/cm^2 in copper; 200 A/cm^2 in winding
	Cooling	Pool Boiling at 4.5 K
	Stored Energy	168 MJ
	Total Ampere-Turns	137 x 10^5
	Total Ampere-Meters	145 x 10^6
	Conductor Weight	48,000 kg
III.	**Cryostat Parameters**	
	4.2 K Cold Mass Weight	145 tons
	4.2 K Cold Mass Dimen.	3.16 m dia. x 5.05 m l
	Liquid Helium Inventory	9000 liters
	Heat Leak to LHe	14 W (20 liter/hr)
	Vacuum Vessel Weight	42 tons
	Vacuum Vessel Dimen.	3.6 m dia. x 6.4 m l
	Total Magnet Weight	190 tons

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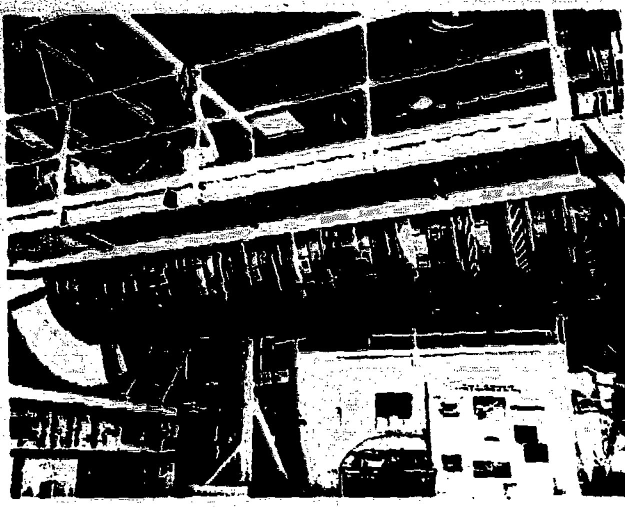

Fig. 8 Coil Precompression

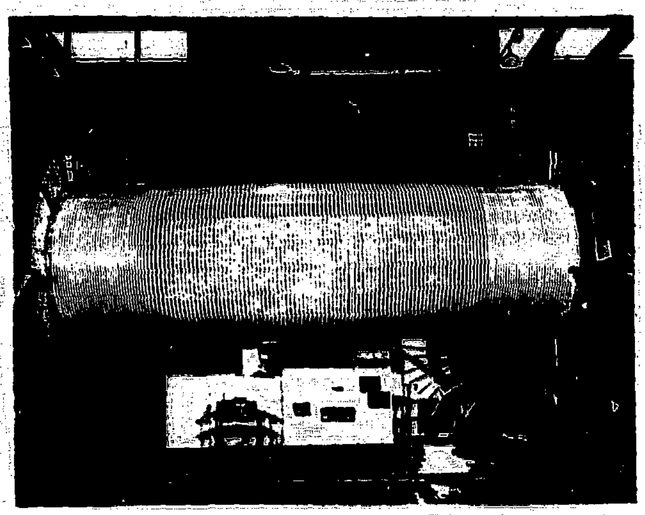

Fig. 9 Coil Banding

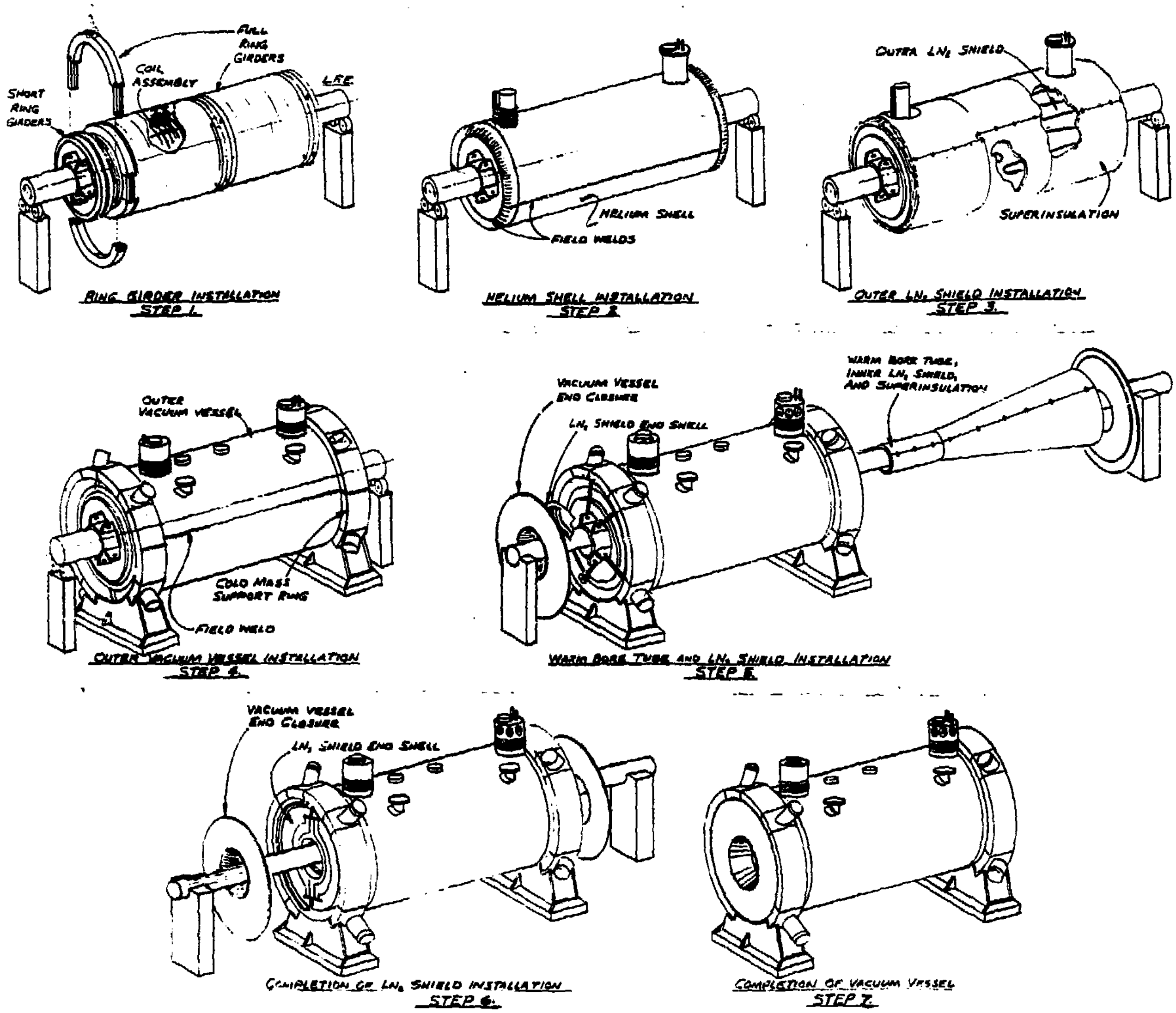

Fig. 10 Schematic of Ring Girder and Cryostat Assembly