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**ADVANCED SUPER CONDUCTING MHD MAGNET DESIGN FOR A
RETROFIT POWER PLANT ***

Marston, P.G., Hale, J.R., Dawson, A.M.

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**Plasma Fusion Center
Massachusetts Institute of Technology
Cambridge, M.4 02139**

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P.G. Marston, J. R. Hale, A.M. Dawson
Plasma Fusion Center
Massachusetts Institute of Technology
Cambridge, MA 02139 USA

Abstract

A magnet system has been designed for an MHD topping cycle retrofit of a conventional power plant. The channel power output will be ~35 MWe. The 4.5 T peak on-axis field magnet will be constructed of an unusual NbTi superconductor wound into four subunits per dipole half. These will be three 45° saddle coils with circular or ellipsoidal end turns and a single planar coil with a modified racetrack shape that will serve principally as a field shaping coil. This planar coil also enables a substantial reduction in the ratio of peak to central field strength. Among the unique features of this design will be the use of flexible bands in tension as the primary element of the transverse force containment structure. The conductor will be of the cable-in-conduit type with a low copper-to-superconductor ratio cable and a thick-walled aluminum conduit sheath. The sheath will support the axial loads on the saddles and will also provide thermal mass for protection against overheating in the event of an energy dump. The analysis and design of this magnet system and its projected advantages in both performance and economics are discussed.

Introduction

The superconducting magnet is the the largest, most costly and most difficult to repair component of an MHD generator. The intent of the conceptual design presented herein is thus both to reduce cost and improve reliability. The design is made possible by a novel conductor which has been under development for the past year.¹ Both are adequately advanced to firmly establish credibility.

Reference Design

The reference design for this effort is a 35 MWe MHD generator intended as a retrofit (for a topping cycle) to an existing coal-fired steam power plant. This system is the focus of the present Department of Energy five-year proof-of-concept (POC) MHD development program. The required magnet and its characteristics are shown in Figs. 1 through 4 and are listed in Tables I and II. These represent the general configuration of a circular saddle dipole magnet except that the bore is rectangular and that one of the winding modules has a racetrack shape and extends under the saddle coils. This coil both improves field uniformity and substantially reduces the peak field in the winding.

Eighty to 90% of the cost of a commercial-scale MHD magnet will be distributed nearly equally among the conductor, force containment structure, cryostat and installation assembly. The proposed design affects each of these cost drivers as follows:

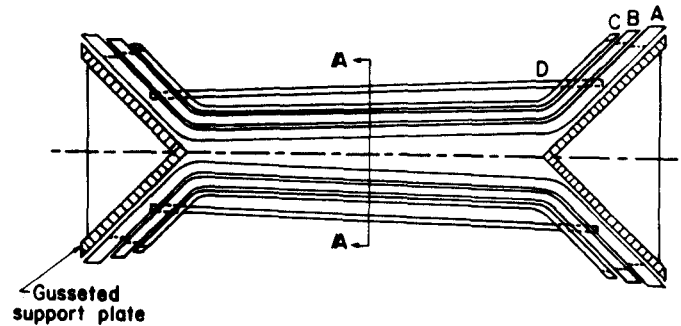


Figure 1 Schematic Illustration of Coils and Structure - Cryostat, Supports Not Shown.

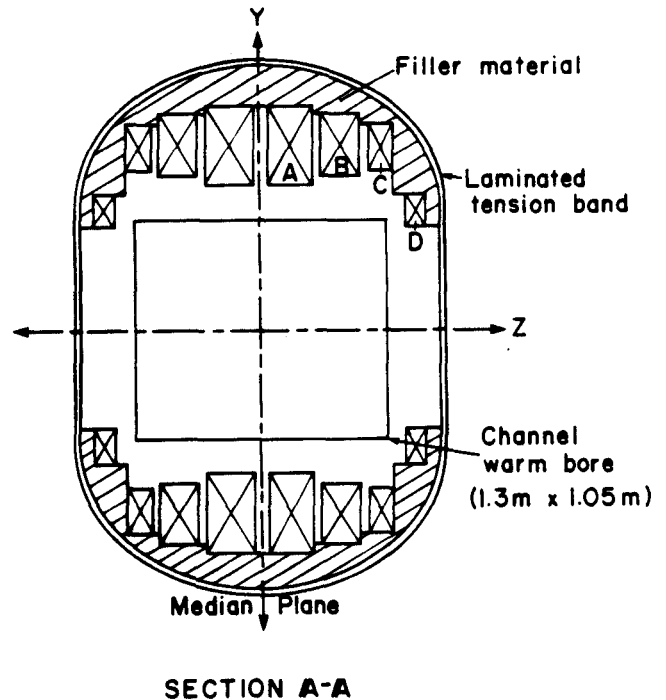


Figure 2 Section A-A Showing Coil Modules and Tension Bands

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Table I
Parameters of Advanced Magnet System

Channel power output	MWe	35 to 40
Magnet type		Circ. saddle,
Field, peak-on-axis	T	4.5
Active length	m	9.0
Field, start of act. len.	T	3.75
Field, end of act. len.	T	3.0
Aperture ^a , start of act. len.	m	0.8×1.0
Aperture ^a , end of act. len.	m	1.3×1.6
Vac. vessel overall len.	m	12.3
Vac. vessel O.D.	m	5.0
Conductor type		ICCS
Conductor material		NbTi/Cu
Design current	kA	13
Winding current density	10 ⁷ A/m ²	2.2
Ampere turns	10 ⁶ A	12
Inductance	H	~ 3
Stored energy	MJ	254
Total weight	tonnes	320

^a inside warm bore liner

Conductor

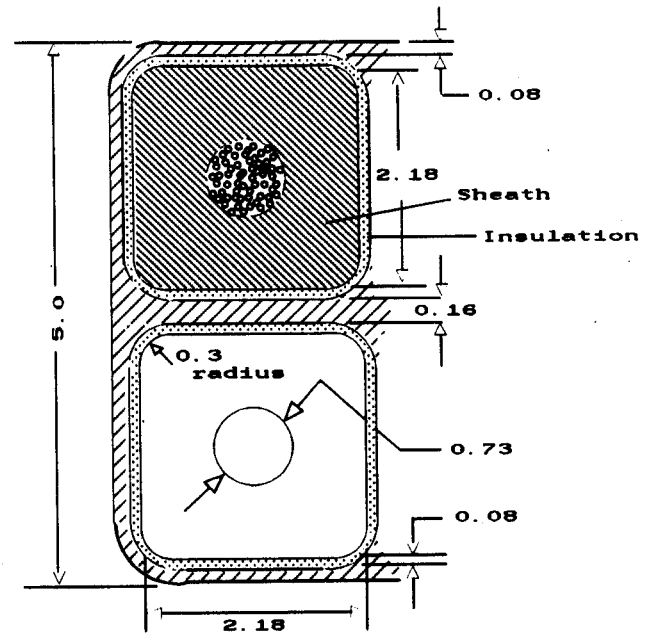
The conductor (see Fig. 3 and Table II) is an internally cooled, cabled superconductor (ICCS) specifically developed for DC applications in which the primary source of transient thermal disturbance is frictional heat from relative motion between conductors. In view of the fact that such heat is generated at the outer surface of the ICCS sheath and must penetrate all thermal barriers before heating the superconductor, virtually 100% of the total conductor enthalpy is available for thermodynamic stabilization, and conductor joule heating (from current sharing) does not contribute to the energy margin required for recovery. The "outside in" thermal behavior is different from all other superconducting winding configurations and enables the following important design advantages:

- The thermal mass and high-conductivity normal material required for protection against conductor overheating during a quench transient do not need to be in intimate contact with the superconductor; they can be located in the sheath.
- Conductor manufacture is simplified by virtue of the low copper:superconductor ratio (1.35:1) in the multifilamentary strands of the cable.
- It should be possible to extrude the proposed aluminum sheath continuously around the cable to eliminate seams or joints.^{2,3} The conductor can thus be manufactured in arbitrarily long lengths.

This conductor also shares the following characteristics that

are inherent in the cable-in-conduit concept:

- The sheath enables adequate mechanical strength and integrity so that the conductor composite can be used as a major part of the force-containment structure.
- As with existing ICCS conductors, the sheath also serves as the helium vessel.
- The many parallel strands of the cable eliminate any reasonable risk of performance degradation due to flaws in the multifilamentary superconductor.



Double Pancake Configuration
(Dimensions in cm)

Cable: 80 strands, 0.076 cm diameter, 1.35:1 Cu/sc ratio
Conduit: Aluminum, square cross section, circular bore
Void Fraction: 35%

Critical Current: 20.4 kA Operating Current: 13 kA

Figure 3 Schematic Illustration of Conductor

Table II
Conductor and Double Pancake Characteristics

Conductor Void Fraction (%)	35
Cross section of strands (cm ²)	0.272
Helium space (cm ²)	0.147
Total cable space (cm ²)	0.419
Conduit section (cm ²)	4.256
Hydraulic diameter (cm)	0.04
I _c , 5.5 T, 4.2 K (kA)	20.4
I _{op} (kA)	12.87
T _{op} (K)	4.5
T _{c2} (K)	5.26
T _c , 5.5 T (K)	6.6
I _{op} /I _c	0.63

Force Containment Structure

The principal electromagnetic forces acting on a saddle coil winding are shown in Fig. 4. The excellent mechanical properties which result from the heavy-walled sheath of the ICCS enable a "momentless" support of all such forces.⁴ The only additional structural members required are thin isotensoidal bands surrounding the main body of the windings to restrain the transverse, Y-directed forces on the longitudinal sections of the coils, and a gusseted plate structure to hold the saddle sections of the coils open at the ends of the magnet. (See Fig. 1.)

All X-directed saddle forces are taken as tension in the conductor.

The radially inward loads from the tension bands are reacted by the coil winding. These loads add to the Z-directed magnetic load in the straight sections of the coil and have the effect of doubling the cumulative compressive stress at the median plane. These loads are taken by the conductor in transverse compression.

The tension bands are made up from a number of U-shaped laminate elements, each having a cross section of 4 cm × 4 cm. These subunits are preassembled and tested and connected at the construction site with interlocking joints that permit modest prestress during assembly.

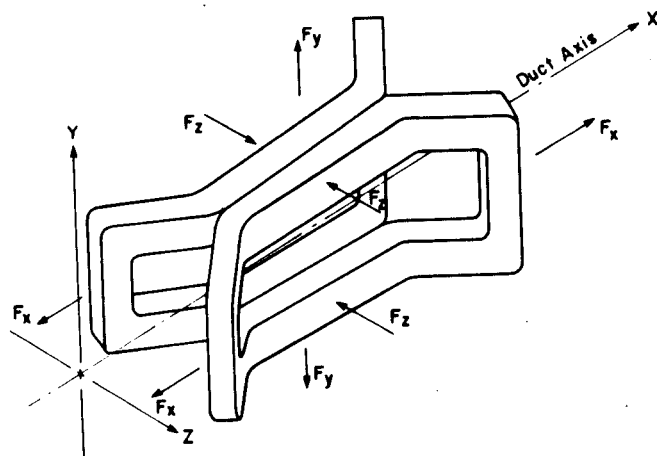


Figure 4 Force Vectors in an MHD Magnet System

Cryostat

The heavy-walled liquid helium vessel for a large "pool-cooled" superconducting magnet represents a large cost, a large reliability risk and a large safety hazard, particularly when viewed in the context of the 20 to 30 year lifespan required of equipment in a commercial power plant environment.

- Properties of materials (and, in particular, of welds) in heavy sections and at liquid helium temperatures are not well characterized and many materials are prone to brittle failure.
- On-site welding is costly, the welds are difficult to inspect and experience and skill are required that is not readily available in most parts of the country.
- The vessel must be carefully and reliably vented to prevent pressure buildup under various failure conditions. For example, plugging or other failure of such venting could create a potentially explosive device.

- Other design issues related to the liquid-filled vessel increase both the size and complexity of the refrigeration system.

The proposed design thus eliminates the most massive, costly and failure-prone element of the cryostat.

On-Site Installation

Even at the relatively small 35 MWe retrofit size, the superconducting magnet is too large to make factory assembly and test prior to shipment a reasonable consideration. By virtue of the self-contained helium of the coil windings, it is possible to fully and rigorously test winding modules of modest size prior to shipment. This possibility, combined with the structural simplicity of the proposed concept, will not only greatly reduce site assembly cost and risk, but will enable a manufacturing process, sequence and flow which is consistent with that already in place with large utility equipment suppliers.

Other system components such as cold-mass support, radiation shield, vacuum vessel, refrigeration, power instrumentation and control will be of conventional design except for the special care and conservatism required for commercial reliability.

Conclusions

The advanced magnet concept described herein and the novel conductor design that it incorporates should offer a system with several advantages over conventional pool-cooled MHD magnet systems. Among these are a conductor that may be produced in very long lengths, thereby minimizing or eliminating the need for internal electrical joints within individual coil modules; a lighter-weight conductor achieved by using aluminum sheath and reducing the amount of copper necessary for stabilization; a support structure that is simple, light weight and ideal for field installation; and a simpler, more reliable cryostat since the conductor sheath acts as the helium vessel. These and other characteristics described above lead to a lighter system and hence, to a lower cost system.

References

- [1] J.R. Hale, P.G. Marston and A.M. Dawson, "Development and Test of an Internally Cooled, Cabled Superconductor (ICCS) for Large Scale MHD Magnets," Semiannual Progress Report, DOE PETC Contract DE-AC22-84PC70512, DOE/PC70512-13, PFC/RR-88-7, June 1988.
- [2] E. Baynham, V. Edwards, R.K. Maix, H.P. Marti, C. Meltzer and G. Mier, "The Aluminium Stabilized Superconductor for the DELPHI Magnet," *Proc. 9th Int. Conf. on Magnet Techn.* (MT-9), pp. 639-642, Sept. 1983.
- [3] R.K. Maix, D. Salathé, "Practical Scaling Formulas for the Determination of Critical Currents of NbTi Superconductors," *Proc. 9th Int. Conf. on Magnet Techn.*, (MT-9), pp. 535-538, 1985.
- [4] E.S. Bobrov, P.G. Marston and E. Kusnetsov, "Theoretical and Engineering Aspects of Momentless Structures and Coil End Turns in Superconducting MHD Magnets," *Adv. Cryo. Eng.*, Vol. 27, pp. 47-56, 1981.