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STATUS OF THE GA/MCA 12 TESLA COIL DEVELOPMENT PROGRAM

by
J. S. ALCORN, J. R. PURCELL, W. Y. CHEN
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MASTER

SEPTEMBER 1980

GENERAL ATOMIC COMPANY

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STATUS OF THE GA/MCA 12 TESLA COIL DEVELOPMENT PROGRAM*

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Abstract

The current status of the Team One effort of the DOE/OFE/D&T 12 Tesla Coil Development Program is presented. Subatmospheric, helium bath cooled, NbTiTa alloy is employed for the test coil, and ETF TF-coil concept. General Atomic is the Team One leader, with Magnetic Corporation of America as industrial subcontractor.

The Program

The objective of the Team One effort is to demonstrate the feasibility of, and establish an engineering data base for utilizing bath cooled NbTi alloy to generate a peak toroidal field of 12 tesla in a tokamak reactor.

This four year effort is being implemented in four closely related phases. The present schedule for this program is shown in Table 1.

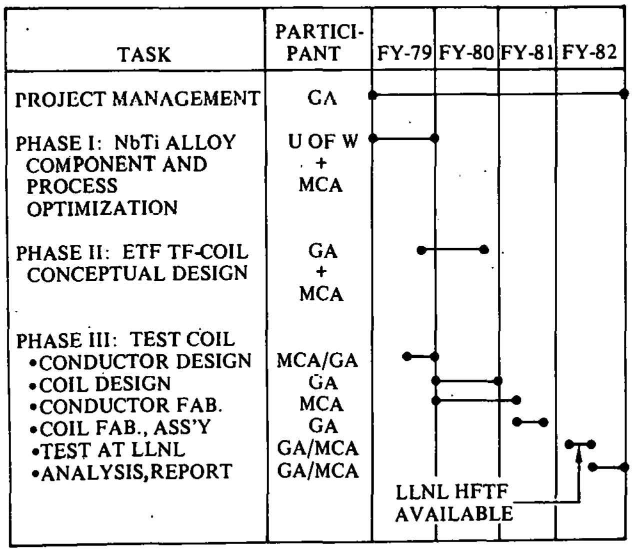
I. Experimental development of a NbTi alloy, compositionally and process optimized for 12 tesla operation at bath temperatures below 4 K.

II. Conceptual design of an ETF reactor compatible toroidal field coil system, employing the NbTi alloy selected by Phase I, and an appropriate bath cooling regime.

III. Design, construction and testing of a solenoid test coil utilizing the selected reactor prototypical conductor and bath conditions. This coil will be tested at the LLNL high field test facility.

IV. Tests performed at the GA high field test facility to supplement and aid interpretation of results from the Phase III coil tests at LLNL.

TABLE 1
TEAM ONE SCHEDULE



TASK	PARTICIPANT	FY-79	FY-80	FY-81	FY-82
PROJECT MANAGEMENT	GA	●—	—	—	—●
PHASE I: NbTi ALLOY COMPONENT AND PROCESS OPTIMIZATION	U OF W + MCA	●—●			
PHASE II: ETF TF-COIL CONCEPTUAL DESIGN	GA + MCA	●—	—●		
PHASE III: TEST COIL					
•CONDUCTOR DESIGN	MCA/GA	●—●			
•COIL DESIGN	GA		●—●		
•CONDUCTOR FAB.	MCA		●—	—●	
•COIL FAB., ASS'Y	GA			●—●	
•TEST AT LLNL	GA/MCA				●—●
•ANALYSIS,REPORT	GA/MCA				●—●

Phase I: NbTi Alloy Development

The NbTiTa alloy employed in this program was selected during Phase I, completed during FY 79. Dr. David Larbalestier, *et al.,* of the Materials Science Center, University of Wisconsin, working under subcontract to GA, performed upper critical field (B_{c2}) tests upon a large number of candidate NbTi binary, ternary and quaternary alloys with the goal of selecting one or more possessing the best high field performance at temperatures below 4 K. Eventually a ternary alloy of NbTiTa, 32/43/25 by weight percent, was found to exhibit the most promising B_{c2} performance; specifically, 13.85 tesla at 3 K. This indicated that such material would offer acceptable design current densities at 12 tesla and practical bath temperatures (2.3–3 K). This study is reported upon in Refs. 1 and 2.

In order to verify and optimize the selected material's J_c performance, and ensure its manufacturing practicality, MCA performed a series of process parameter tests upon a series of composite filamentary wire samples. J_c was determined over a range of magnetic fields and temperatures, as a function of heat treatment and cold work. No unusual manufacturing difficulties were encountered, and as anticipated, cold area reduction of 10^5 or more is desirable for J_c optimization. This work is reported upon in Ref. 3.

The MCA performance data upon which the Phase II and III designs are based is shown in Fig. 1. This data is based upon an area reduction of 1.6×10^5:1 from an initial 4 inch diameter billet.

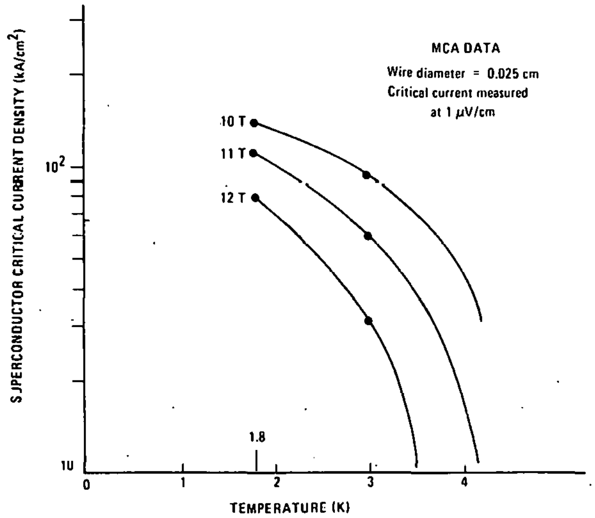


Fig. 1. Short sample performance of 32 Nb/43 Ti/25 Ta

Phase II: ETF TF-Coil Concept

Fulfillment of Phase II is provided by the General Atomic report GA-A15974: 12 Tesla ETF Toroidal Field Coil, Helium Bath Cooled NbTi Alloy Concept.[4] This study provides continuity of the entire Team One effort, ensuring that the prototypical conductor as developed is reactor compatible, and establishing the viability of an actual reactor TF-coil concept employing such conductor.

Overall Design Parameters. Although this design concept has been under development for over a year, it was adjusted in mid-1980 to reflect the ETF Design Center Interim "Design No. 1" parameters

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as regards number (10) and size of TF-coils.[5] Also, the peak field was reduced to 11-1/2 tesla, since it now appears that ETF will not require more than this.

Figure 2 is an elevation view of ETF Design 1 showing one TF-coil. The number (10) and overall dimensions of the Team One coil shown match those of ETF. However, its 11-1/2 tesla peak field (at 2.87 m R) corresponds to a major axis field (B_t) of 6.1 tesla.

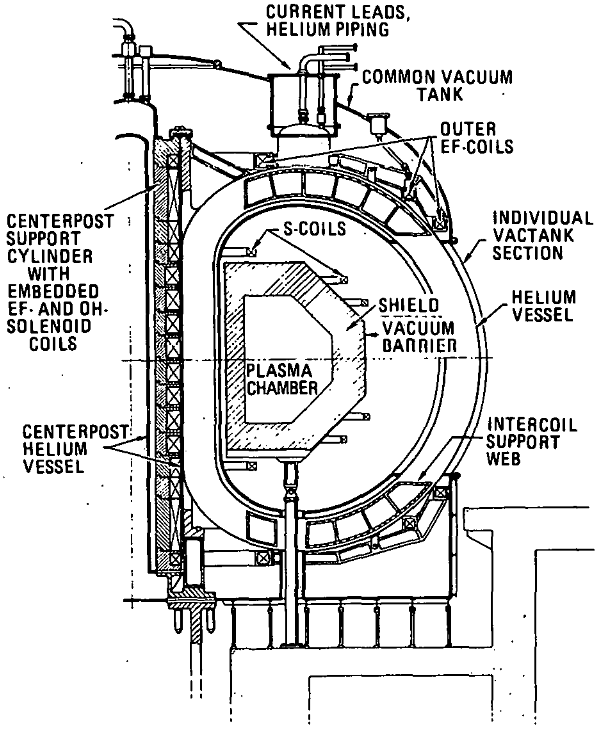

Fig. 2. One Team One TF-coil installed within ETF Interim Design 1

The coil shown is 110 cm thick in the centerpost region, corresponding to its overall coil/helium vessel current density of 1000 A/cm^2. This necessitates embedding the solenoidal OH- and EF-coils within the centerpost support cylinder, as shown. This concept was employed for the superconducting OH-coils of the General Atomic TNS Reactor Study, as described in Ref. 6.

Conductor. The 10 kA conductor is a three-level, unsoldered, uninsulated "Rutherford" cable. The conductor consists of ten 1000 ampere cables, each of which is a six-around-one bundle of similarly configured subcables. Four conductor grades are employed, the high field grade being shown in Fig. 3.

Conductor Support. The conductor is housed within a multicomponent stainless steel strip support frame. Collectively, these support elements carry almost all of the hoop, radial bearing (centerpost) and circumferential bearing (outer region) loads generated within the coil. Allowable combined stress is 80 Kpsi (316 LN, or equivalent).

Coil/Cryostat Design. Figure 4 shows cross-sections of one coil/helium vessel in both the centerpost and outer region. Each coil is independently immersed in liquid helium within its own stainless steel helium vessel. However, all 10 coil/helium vessels (plus the centerpost support cylinder, and superconducting OH- and EF-coils) share a common vacuum volume.

The coils are spiral wound, the 22 full height pancakes having 58 turns each. The pancakes are wound directly onto the weldment consisting of the minimum perimeter wall and the central radial spine of the helium vessel. One-half of a coil is wound and its side and outer perimeter wall elements installed. The coil/helium vessel is then inverted, and the process is repeated for the other half.

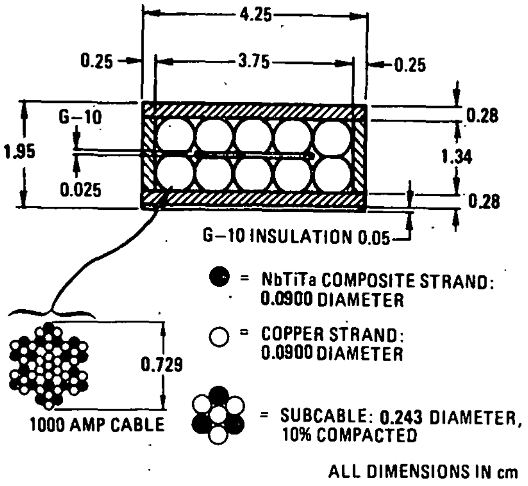

Fig. 3. 10 kA cabled conductor (high field region shown)

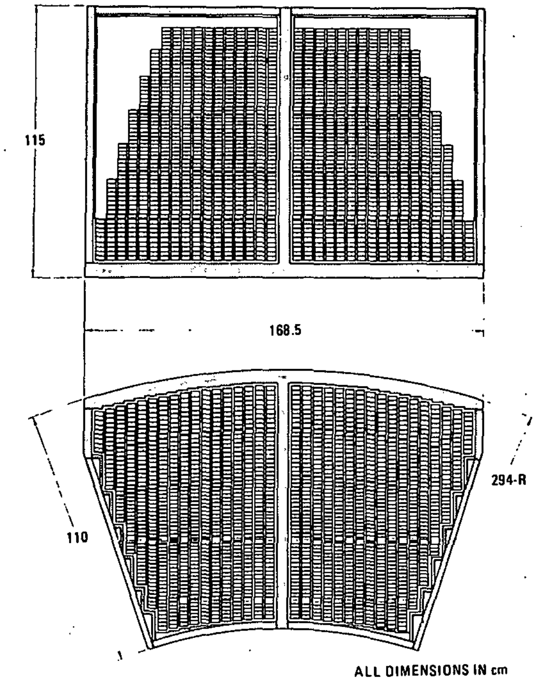

Fig. 4. Coil cross-sections

Figure 5 is a detail section of the coil/helium vessel, at the inner corner of the outer coil region.

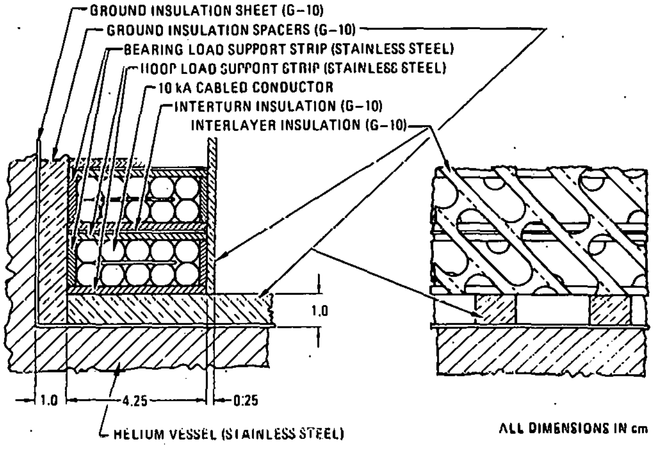

Fig. 5. Coil detail (high field conductor region)

The coil/helium vessel component fractions in the centerpost region are as indicated:

	Area (cm^2)	Fraction Percent
Conductor, Net	3,442	20.8
Support strip	5,447	33.0
Insulation	698	4.2
Helium vessel	2,635	16.0
Helium	4,297	26.0
	16,519	100

Coil Cooling Method. Bath cooling has been selected in lieu of forced flow, based upon considerations of design simplicity and operational reliability.

A bath saturation temperature of 3 K was selected, which corresponds to 4/3 x the current sharing temperature of NbTiTa superconductor at its design current density of 30 kA/cm^2 and 11-1/2 tesla. The corresponding operating bath temperature is 182 torr (0.24 atm, or 3.5 psia). During normal operation, the bath is subcooled to a nominal temperature of 2.5 K. This is achieved through a heat exchanger located in the outer leg of each TF-coil. The coil cooling method is shown in the helium phase diagram, Fig. 6.

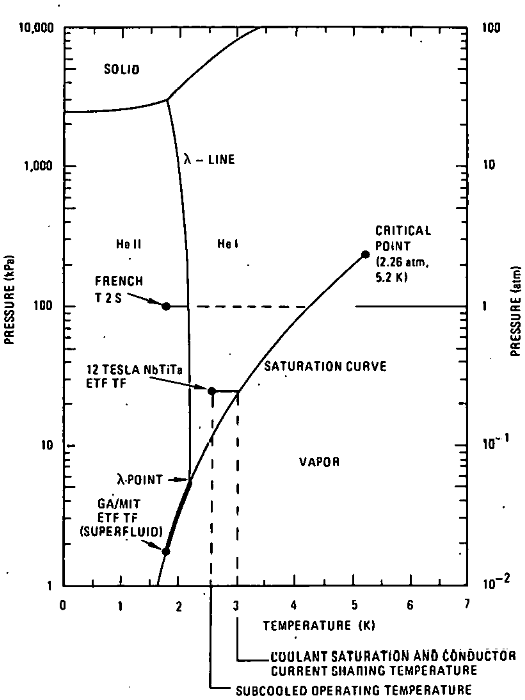

Fig. 6. Coil cooling method

The relatively modest neutron heat load of 5 kW to the centerpost region can easily be accommodated, without bubble evolution, by natural convection within the coil.

In the event of a plasma disruption, the total field change of 0.5 tesla will generate about 7.0 MJ of eddy current heating in the ten TF-coil helium vessels (only a small amount of heat is generated in the cabled conductor). This amount of heat can be absorbed by the 10 m^3 helium volume of each coil without raising its temperature above the 3 K saturation point. Thus the coil will not quench, and the bath operating temperature of 2.5 K can be restored in four hours by the refrigeration capacity required to absorb the neutron heating.

Alternative Superfluid Helium Operation. A bath cooling alternative worthy of serious consideration is employment of superfluid helium. Preliminary investigation of an ETF-like TF-coil, bath cooled with saturated He II at 1.8 K is presented in Ref. 7.

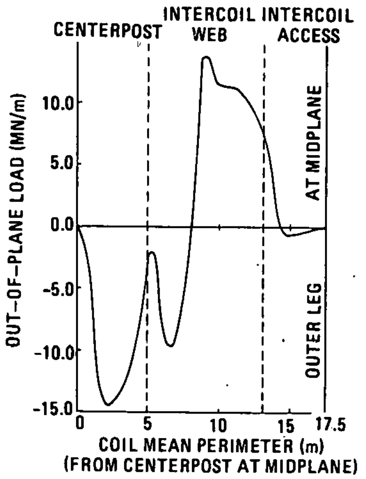

Fig. 7. Out-of-plane load

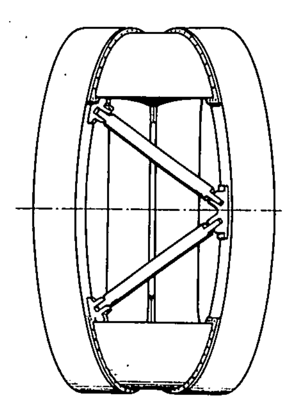

Fig. 8.
Intercoil struts

Out-Of-Plane Loads. The out-of-plane (overturning) loads as a function of perimeter are shown for one coil half in Fig. 7. In the ETF Interim Design this load is borne entirely by the upper and lower intercoil web structure, and by bending in the outer coil legs. However, it appears necessary to connect the upper and lower web supported regions with diagonal intercoil struts (or shear panels) in order to resist the torsional moment between them. Such a strut is shown diagrammatically in Fig. 8.

Quench Protection. A magnet quench analysis for the case of a low liquid level and a normal region starting in the gas space has been performed using the GA developed code QUENCH. This computer program accurately accounts for all the important processes in the cryostat during a magnet quench; liquid level, cryostat pressure, coil temperature, normal region dissipation, energy deposited into the helium bath, current decay, etc. The results (Fig. 9) show that the magnet will not suffer damage, provided intercoil dump resistors are used. The resistive drop of each turn of the quenching coil is almost canceled by its inductive voltage rise (Fig. 10). Thus, the net voltage to ground is controlled by the 0.25 Ω dump resistors.

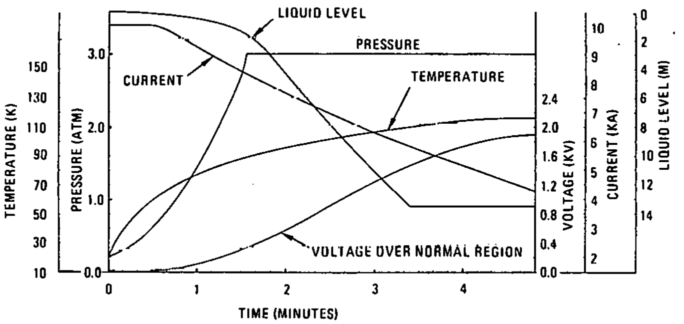

Fig. 9. Coil quench data

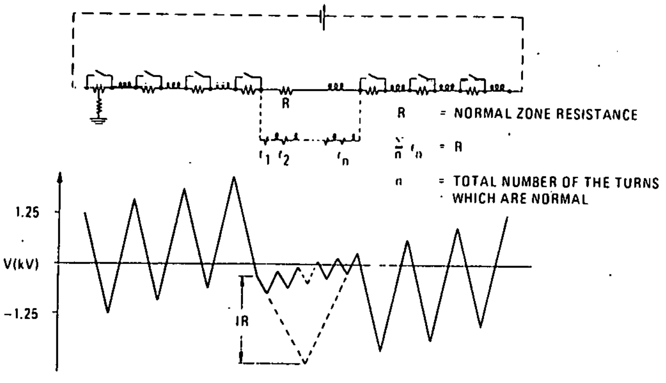

Fig. 10. Distributed quench voltages
(shown for seven coil circuit)

Phase III: 12 Tesla Test Coil

The 12 tesla coil to be tested during FY 82 at the LLNL High Field Test Facility has been designed. The NbTiTa superconductor ordered from Wah-Chang in February 1980 has been received by MCA. Completion of the cabled conductor is now anticipated by February 1981.

Conductor. The 10 kA conductor for the test coil is a three level, unsoldered uninsulated "Rutherford" cable, similar to the high field conductor for the 12 tesla ETF-TF-coil concept described above.

Test Coil. A cross section of the test coil is shown in Fig. 11. The coil is wound onto the "bobbin" weldment of the helium vessel as two double pancakes having 21 turns per layer. After closure, the helium vessel is installed within a vacuum tank. Location and support of the helium vessel is provided by a pattern of insulators, as indicated. Thus the coil can be operated at temperatures down to 1.8 K without excessive heat leak from the surrounding 4.2 K helium bath of the LLNL background field coils.

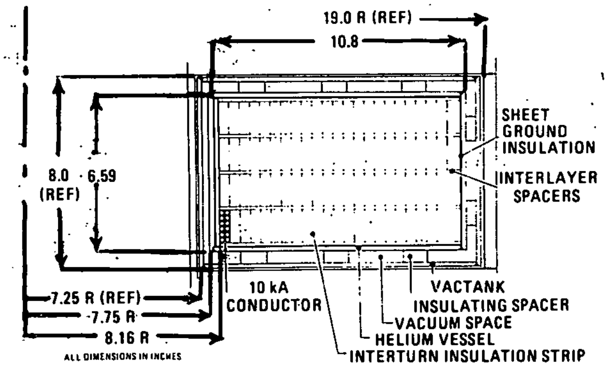

Fig. 11. Test coil: cross section

For the test coil, stainless steel hoop load support is provided by banding around the outer diameter of each coil layer, rather than by distributed support as specified for the ETF TF-coil concept. However, the coolant passage geometry of an actual TF-coil application is simulated by the G-10 interturn strip, and perforated interlayer insulation.

In addition to the current leads, the cryostat neck region includes a J-T valve fill line, a heat exchanger, and a pumping line.

Coil Operation. The basic mode of operation for the test coil will be at a temperature of 2.5 K, subcooled from bath saturation conditions of 3 K and 1/4 atmosphere. Subcooling will be provided by the heat exchanger located within the coil helium vessel neck.

The coil and cryogenic system are designed to also permit operation in the saturated He II regime. This is achieved by pumping the coil down to 12.5 torr and replenishing liquid as required through the heat exchanger/J-T fill line.

Phase IV: Tests Performed at the GA HFTF

A test facility has been established at GA having the capability of generating 10 tesla within the 20 cm bore of its nested solenoid pair. Both background field coils employ NbTi; the 40 cm bore 8 tesla coil, built by MCA, is intrinsically stable, and without internal cooling; the insert coil was "dry" wound by GA using "barber pole" wrapped cable, supported by stainless steel strip wound on its O.D. A vacuum insulated tube can be inserted within the 20 cm bore for testing samples at subatmospheric pressure, and temperatures down to 1.8 K.

With this apparatus, heat pulse/recovery data is being obtained on various cable samples which will augment, and greatly assist interpretation of the FY 82 LLNL HFTF results. Also, a series of saturated superfluid helium tests are being performed to better understand the parameters of this bath cooling option.

Recently, a series of heat pulse/recovery tests have been performed on cabled conductor samples installed within the "cold-finger" insert of this apparatus. Data was obtained for sample environments of 8–10 tesla, and temperatures between 1.8 K and 3 K. Results of these tests are reported in Refs. 8 and 9.

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