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ANL EXPERIMENTAL PROGRAM FOR PULSED SUPERCONDUCTING COILS*

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Summary

Argonne National Laboratory (ANL) had recognized the clear advantage of a superconducting ohmic-heating (OH) coil and started an aggressive development program in FY 1977. The main objectives for FY 1977 are to develop cryostable basic cable configurations with reasonably low ac losses, to develop 12 kA cryostable cable, using it to design and build a 1.5 MJ pulsed coil, and to develop a rather inexpensive large fiberglass reinforced helium cryostat for the 1.5 MJ pulsed coil. The principal objective in building the 1.5 MJ ac coil is to demonstrate ac cryostability of a large coil ranging from 2 T/s up to 12 T/s. Another objective in the pulsed coil program is to determine the feasibility of parallel coil operation in order to avoid excessive voltage and current requirements and to minimize the number of turns for the equilibrium field (EF) coils, should the EF coils be connected in parallel with the OH coils. A two-coil section model using the 11 kA cable will be built and tested.

Introduction

The conceptual design studies of tokamak experimental power reactors undertaken at Argonne and elsewhere over the last three years have identified the need for large-volume pulsed superconducting magnet systems to contain and drive the plasmas in these ignition devices. Because of the large stored energy of the tokamak magnet coils, they must be cryogenically stable, but they must also tolerate rapid cycling.

At Argonne, considerable progress has been made to identify critical elements of tokamak coil design and required technology development. In July of 1975, a program plan was suggested[1] which would develop the technology required to assure successful operation of the pulsed coils and efficient and inexpensive energy storage and transfer systems when needed for future tokamak reactors.

Scope and Objectives

A set of superconducting ohmic heating coils (OHC) is the selected design for the ANL/GA TNS OH-Coil system[2] and, in all likelihood, future tokamak reactor systems. The selection is based on the results of critical evaluations of the Argonne EPR design studies[3] of the past two years (FY 1975 and FY 1976) and based on the results of the on-going GA/ANL TNS OH-coil conceptual design studies.

The main ojectives for FY 1977 are to develop cryostable basic cable configurations with reasonably low ac losses, to develop 11 kA cryostable cable, to design and build a 1.5 MJ prototype pulsed superconducting OHC, and to develop a rather inexpensive large fiberglass reinforced helium cryostat for the 1.5 MJ pulsed coil. All of these efforts are important steps to the advancement in the state-of-the-art of pulsed superconducting magnet technology. The principal objective in building the 1.5 MJ ac coil is to demonstrate ac cryostability of a large coil with the dB/dt ranging from 2 T/s up to 12 T/s.

Another important objective in the FY 1977 pulsed coil program is to determine the feasibility of parallel coil operation. The present ANL/GA TNS OHC design, for which ANL has prime responsibility, considers parallel operation in order to avoid inducing equilibrium field (EF) coil currents during OHC pulsing. The studies so far have indicated that parallel operation of multiple OHC sections appear feasible and perhaps advantageous.[4] This means that OHC can be divided into many parallel paths and thus the OHC can be charged with a relatively low voltage and high current. A two-coil section model using the 12 kA cable will be built and tested in the next few months.

Present Results

Basic Cable Development Program

The cable configuration giving the best compromise between stability and ac losses is illustrated in Fig. 1. The six pure copper wires are soldered to the superconducting composite forming an essential current sharing subgroup. A thin coating of organic varnish is brushed on the surface of each of the three subgroups in the basic cable. The varnish coatings serve to reduce the eddy current losses among the subgroups. The coating is thin enough, however, that limited current sharing among subgroups will be allowed. The criterion chosen for cryostability is such that both minimum propagating current and recovery current are greater than critical current. The basic cable is rated at 405 A at 5 T.

Small Testing Coils

To study the ac losses and the magnet current sharing, three small testing coils[5] were wound using three different basic cables. The ac losses are measured both by a calorimeter method and by an electrical method. To study the current sharing of small coils, a potentiometer is used to balance the inductive voltage of the testing coils. The specifications and the results of these testings were presented in reference 5.

Development of Large Fiberglass Reinforced Plastic Dewars

For superconducting OHC, stainless steel helium cryostat will have excessive ac losses. Therefore, a nonmetallic cryostat with low helium permeation must be developed. As a first step, a plastic cryostat is developed for a 1.5 MJ pulsed coil. The plastic cryostat, as shown in Fig. 2, consists of two tanks with 100 layers of superinsulation between. The superinsulation is slit to reduce the eddy current heating, as shown in Fig. 3. The inner tank has an I.D. of 91.4 cm, a depth of 152.4 cm, and a wall thickness of 0.95 cm; while the outer tank has an I.D. of 107 cm, a depth of 156.5 cm, and a wall thickness of 1.27 cm. Both tanks are made of fiberglass reinforced Hetron 31 polyester with 35% glass component.

The cryostat was filled with liquid nitrogen without superinsulations. Afterwards, many patch-like small cracks were found on the inner surface of the inner tank. Therefore, the inner tank was reinforced by about 1 cm thick wet-wound fiberglass epoxy.

As shown in Fig. 2, the cryostat cover is a 6.3 cm thick micarta plate. A 30 cm thick styrofoam cut to fit the inner diameter of the inner tank is attached to the micarta cover for radiation shield.

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With 100 layers of superinsulation, the cryostat was filled with an 80 cm deep liquid helium. The steady state heat leak measured was about 0.85 W. A 10^{-7} Torr vacuum was achieved with cryopumping. Helium permeation was not detectable over a period of 48 hours.

On-Going Program

1.5 MJ Coil Fabrications

The 1.5 MJ successful construction will be the most important milestone of the FY 1977 ANL pulsed coil program. The design of the coil and fabrication of G-10 coil form are completed. The magnet characteristics are tabulated in Table 1. The coil cross section is shown in Fig. 4.

The operational current is 11 kA. The design of the cable is shown in Fig. 1. Fabrication of a 600 m long cable will be completed in November 1977. Five-hundred thirty-one meters of cable will be used to wind the 1.5 MJ pulsed coil. The remaining 69 m will be used to wind two 20-turn pancakes for parallel operation tests which are described in the following section.

In addition to the demonstration that the 1.5 MJ OHC is cryostable, another important goal of building the coil is to energize and deenergize the magnet over a wide range of dB/dt. Furthermore, to study the conductor motion and its frictional heating of high current cable, pressure transducer and unbalanced voltage method will be used to measure the conductor motion and the energy release due to the frictional heating.

The power supply, as shown in Fig. 5, planned for charging the 1.5 MJ coil is a 7 MW ignitron-type power supply with 700 V and 11 kA peak ratings.

Parallel Operation of Sectional Coil

The feasibility of parallel operation will be demonstrated in two 20-turn pancake coils. The two pancake coils will be tested within the field bore of the 1.5 MJ coil.

FY 1978 Program Goals

The objectives of FY 1978 are to study the parallel operation of pulsed coils, to develop a 50 kA cryostable cable, to build a small test coil with the 50 kA cable, and to perform a preliminary engineering design of a 100 MJ model coil.

100 MJ Demonstration Coil

The ultimate goal of the ANL Pulsed Coil Program is to design, build, and test a demonstration-size, 100 MJ pulsed superconducting coil. The coil would be tested with a 100 MVA motor-generator-flywheel set and energy conversion system available at ANL.

Schedule and Costs

With approximately \$3 M funding over a five-year period, the ANL Pulsed Coil Program could be ready to start the fabrication aspects of TNS superconducting OHC by FY 1982. Details are presented in Table 2.

Table 1. Magnet Characteristics of 1.5 MJ Prototype Superconducting OHC

Central Field	4.3 T
Peak Field	4.7 T
Operational Current	11 kA
Inductance	24.9 mH
Stored Energy	1.5 MJ
Coil I.D.	41.6 cm
Coil O.D.	86.4 cm
Axial Length	58.1 cm
No. of Layers	18
No. of Turns/Layer	15
Total No. of Turns	270
Layer-to-Layer Spacing	4.76 mm
Conductor Current Density	5760 A/cm^2
Cryostable Recovery Heat Flux	0.35 W/cm^2
Average Current Density	2274 A/cm^2
AC Losses	3.7 kW at 8 T/s
Max. Radial Magnetic Pressure	12 ksi
Max. Axial Magnetic Pressure	4 ksi

References

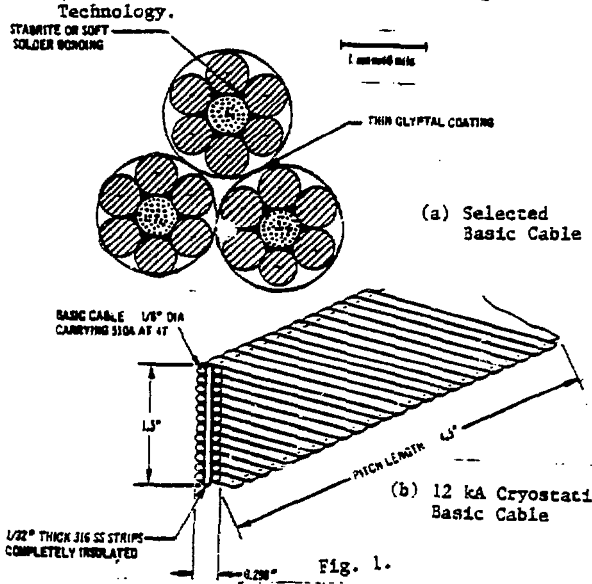
1. R. L. Kustom and J. R. Purcell, *Proposal for a Research and Development Program on a Pulsed Superconducting Coil System for a Tokamak Experimental Power Reactor (TEPR)*, Argonne National Laboratory, Argonne, IL (July 1975).

2. *TNS Scoping Studies, Interim Status Report*, Argonne National Laboratory Report ANL/FPP/77-2 or General Atomic Company, San Diego, CA Report GA-A14412 (May 1977).

3. Weston M. Stacey, Jr. et al., *A Revised Design for the Tokamak Experimental Power Reactor*, Argonne National Laboratory Report ANL/FPP/TM-77 (March 1977).

4. S.-T. Wang, R. E. Fuja, S.-H. Kim, R. L. Kustom, W. F. Praeg, K. Thompson, and L. R. Turner, *TNS Superconducting Ohmic-Heating System*, Paper U-11, this symposium.

5. S.-T. Wang, S.-H. Kim, W. F. Praeg, and C. I. Krieger, *A 1.5 MJ Cryostatic Stable Superconducting Ohmic-Heating Coil*, to be published in Proc. of Sixth International Conference on Magnet Technology.



(a) Selected Basic Cable

(b) 12 kA Cryostatic Basic Cable

Fig. 1.

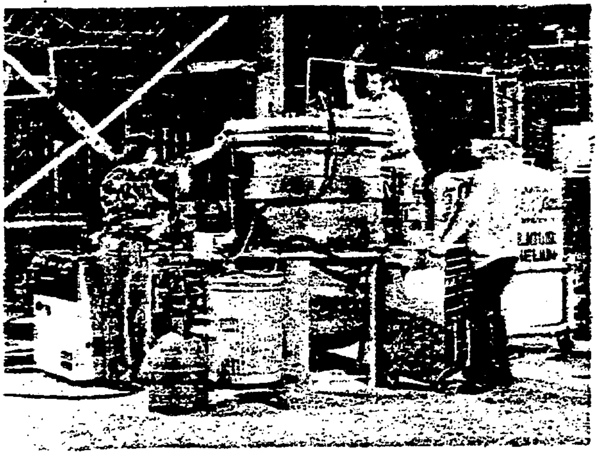


Fig. 2. Plastic Helium Cryostat

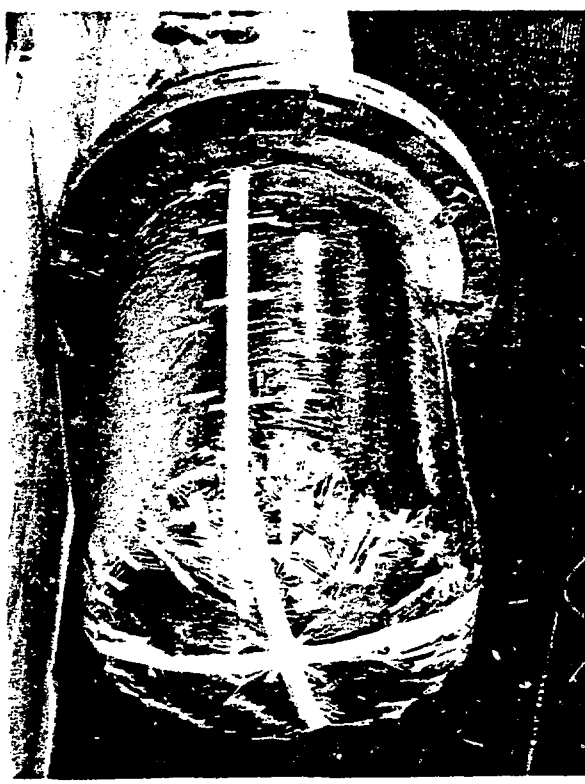


Fig. 3. 100 Layers Super-insulation on the Inner Tank

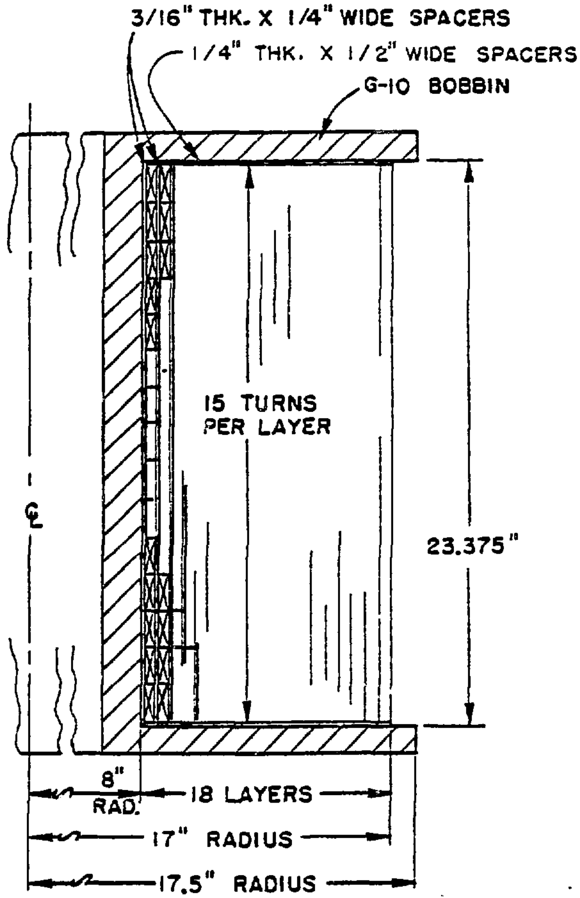


Fig. 4. 1.5 MJ Coil Cross Section

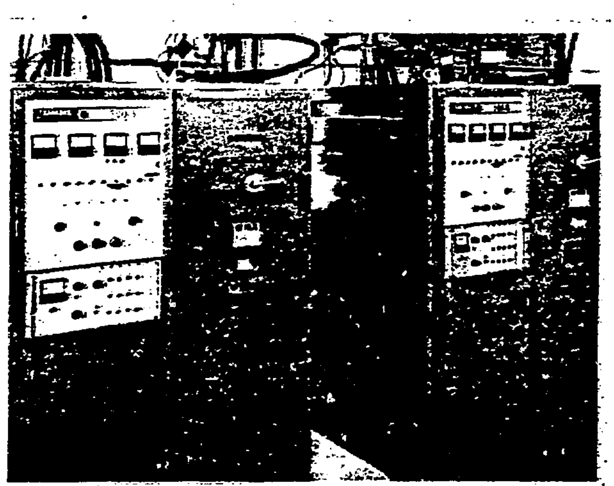


Fig. 5. 7 MW Power Supply

Table 2. ANL PULSED COIL PROGRAM

(In Thousands of Dollars)

Tasks	FY 1977	FY 1978	FY 1979	FY 1980	FY 1981
1. High Current Cable Development	$34	$105	$ 105	$ 105	$105
A. Basic Cable Study	4	5	5	5	5
B. 12 kA Cable Study	30	-	-	-	-
C. 50 kA Cable Study	-	100	-	-	-
D. 100 kA Cable Study	-	-	100	-	-
E. TNS OHC Cable Study	-	-	-	100	100
2. Cryostability Study of Pulsed Magnet	-	10	55	55	25
A. Heat Transfer and Cooling System	-	-	25	25	-
B. Mechanical Perturbation	-	5	25	25	25
C. AC Losses Study	-	5	5	5	-
3. Plastic Cryostat Development	5	10	50	125	50
A. 36 in. Diam. x 60 in. Deep Dewar	5	-	-	-	-
B. 100 MJ Coil Cryostat Development	-	10	25	75	-
C. TNS OHC Cryostat Development	-	-	25	50	50
4. Build Model Coil	27	10	800	1075	200
A. 1.5 MJ	22	-	-	-	-
B. Parallel Operation Coils	5	10	25	75	-
C. 100 MJ Design and Engineering	-	-	25	50	50
Construction	-	-	650	850	50
Test	-	-	-	100	100
5. TNS Superconducting OHC Design	-	50	75	100	100
A. Conceptual Design	-	50	-	-	-
B. Detail Design	-	-	75	100	100
6. 100 MVA Power Supply Conversion	-	-	100	100	100
TOTAL FUNDING REQUIRED	$66	$185	$1085	$1435	$580