Quarterly Progress Report

MIT-12T-Coil Program

For the Period: April 1, 1979–June 30, 1979

DOE Contract No. EG-77-S-02-4 82

Program Objective

The objective of the program is the design, construction and testing of a 1m diameter solenoid using multifilamentary Nb₃Sn Internally Cooled Cabled Superconductor (ICCS). The Coil is to be operated at the High Field Test Facility (HFTF) at the Lawrence Livermore Laboratory (LLL) at a peak field in the superconductor of 12 tesla.

Preliminary Design

A preliminary design of the coil has been completed at MIT. The proposed coil consists of three double pancake subcoils, each separately wound, activated and epoxy potted, using a 40m length of conductor per subcoil. Operating current has been set at 15,700A, sufficient to generate a coil space current density ($J_X$) of 3,100 A/cm². This current density must be contributed by
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the test coil in order to obtain a peak field of 12T at the conductor.

Conductor to be used will have the same sheath dimensions as LCP W (0.818 x 0.818 inch x 0.068 inch wall). A 486 strand (6 x 3') cable with a 40% void fraction and a strand diameter of 0.67mm will be used. Sheath material will that the conductor sheath may be subject to peak stresses of 60,000 to 70,000 psi.

Stability analyses indicate that the conductor should be able to operate under steady state conditions at currents of up to 20,000 A. Operating at the design current level of 15,700 A the conductor should be able to recover from imposed pulsed energy inputs in excess of 300 mJ/cc of wire.

Design Review

A subcontract has been placed with the Large Apparatus Div. of the Westinghouse Electric Corp. (W) to provide a review of the "MIT-12T-Coil Preliminary Design". W will thus provide support in the areas of coil design and thermodynamic, hydraulic, field and stress analyses. Their work is due to be completed by Dec. 15, 1979.

Conductor Development and Winding

Airco has fabricated a 300m long dummy(copper) cable. They have recently added a heavy duty turks head to their tube mill in order to square-off conductor sheathed in Nitronic 40. Encapsulation of the dummy cable, welding, draw-down and square-off of the resultant conductor
will take place in Aug. 1979. The finished conductor will then be used in coil winding tests during Sep. 1979, at the Everson Electric Co. in Allentown, Pa.

**Superconductor Development**

Airco, under subcontract to MIT, has performed heat cycle optimizations on their LCP-W Nb$_3$Sn superconductor. Results performed to date indicate 12T current density enhancement at 750° activation temperatures. Indications are that our objective, a superconductor (non copper) current density in excess of 421 A/mm$^2$ at 12T and 4.2 K could be achieved using the LCP-W superconductor with a 750° firing cycle lasting in excess of 150 hrs. Use of smaller filaments would reduce the length of the firing cycle.

Supercon, also under subcontract to MIT, has made substantial progress testing their copper matrix Nb$_3$Sn superconductor with tubular filaments. Early test results indicate a 22% increase in short sample current density, following warmup to room temperature. These tests also indicate possible current densities of the order of 600A/mm$^2$ with smaller (= 20 μM) filaments. Additional stock billets, incorporating an increase in the Nb:bronze ratio, have been fabricated.

Both superconductor development programs should be completed by Dec. 1, 1979, including stress-strain tests, yet to be formulated. A choice of material and vendor for the MIT-12T-Coil will then have to be made.

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1. Corroborating our own test results on Tin Coil No. 1.
Coil Fabrication and Schedules

The present plan is to fabricate the three (3) sub-coils separately, though in parallel. Dummy winding tests will be performed at Everson Electric. Subcoil fabrication will take place at Westinghouse if this can be arranged contractually, following an MIT final design and the detailing of fabrication procedures by W.

Currently feasible fabrication schedules are:

- Completion of preliminary design review (by W) - - - Dec. 1, '79
- Selection of Superconductor (by MIT) - - - Dec. 1, '79
- Procurement of Superconducting wire - - - Dec. 1, '70 thru Apr. 1, '80
- Cabling and Conductor fabrication completion (by Airco) - - - Jul. 1, '80
- Final coil design (by MIT) by - - - Feb. 1, '80
- Completion of detailed fabrication drawings and procedures (by W) by - - - May 1, '80
- Subcoil winding, activation, insulation and epoxy potting (at W) - - - Jul. 1, '80 thru Nov. 1, '80
- Subcoil instrumentation, assembly of coil, interconnection of Subcoils and preparation for test in HFTF (at MIT) - - - Nov. 1, '80 thru Feb. 1, '81
- Ready for testing at LLL - - - Mar. 1, '81

Work Under Way at MIT in Support of the 12T Program

Test operations at 12T

Two of three available test coils have been subjected to test operation at 12T, using the new 6 inch, warm bore Bitter solenoid 6B at the FBNML*. Superconductor used in both coils tested was Airco's Nb₃Sn "TESPE" conductor with 0.525mm diameter

* Francis Bitter National Magnet Lab.
strands, 14% Sn, 2.8 \mu m filaments and a copper content of 58%. Short sample tests performed by us at the FBNML gave the following current densities at 4.2K:  
\[ J_c(12T) = 321 \frac{A}{mm^2}(\pm 10 \frac{A}{mm^2}) \]  measured at a 20 \mu V sensitivity.  
\[ J_c(11T) = 1.34 J_c(12T) \]  
\[ J_c(10T) = 1.83 J_c(12T) \]  and  
\[ J_c(9T) = 2.41 J_c(12T) \].

Tin Coil 4b is bifilar wound using a 3m length of 6 x 3^3 fully transposed core-less cable, 1.5m of which was located in the high field region of Bitter solenoid 6B. The cable was fabricated with Airco's 0.525mm diameter Nb_3Sn "TESPE" superconductor (specified above). Critical current measurements were obtained at 12, 11 and 10T and represent 97, 89 and 85% of short sample current (resp.). Critical current measurements on a similar coil at 9.5T gave a 77% of short sample current density. Stability tests were performed at 12T as well as lower field levels. At 12T, operating at steady state current levels of 97, 87, 78 and 72% of critical current, maximum (or near maximum) energy input with recovery was found to be 140, 310, 560 and >590 mJ/cm^3 of conductor, respectively.

Tin Coil 1 is bifilar wound using a 3m length of a 19 x 3 cable with a copper content of 41% with 1.05mm diameter strands of Supercon's Nb_3Sn superconductor. This coil has been tested previously at fields of up to 9.4T. It is now scheduled to be tested at 12T in Bitter solenoid 6B during August or September 1979.

2. See report on LCP-W subsize coil test (below).
**Long Conductor Sample Test Coil**, using the TESPE" superconductor has recently been tested in the 12T background field Bitter solenoid 6B. The coil, as reported previously\(^3\) has a 6 x 3\(^2\) configuration and uses the same superconducting strands as Tin Coil 4b. Conductor length is 23m. Following an initial test run at 12T, the coil was examined at room temperature. It was found, that its 304 stainless steel sheath had become porous and the conduit could no longer hold pressure. In addition the sheath was found to be weakly magnetic. Other parts of the coil assembly, made of 304 stainless steel which had been subject to activation at 700\(^\circ\)C were also weakly magnetic. Subsequently the coil was tested again at 12T, with helium pressure at 1 atm. The coil was operated at 12T for a period of several minutes with a steady state current of 1253A without quench. This current level corresponds to 93% of its critical current level, \(I_c(12T)\) which was determined to be 1343A. The \(I_c(12T)\) value also corresponds to 86% of short sample current measurement. No excessive pressures were observed during quench cycles. Further tests are scheduled for July, '79. Metallurgical problems associated with the type 304 stainless steel are being investigated.

**Qualification Tests of Subsize LCP-W Conductor**

A 3m long LCP-W subsize conductor was tested at the FBNML by MIT personnel. Airco's LCP-W 0.69mm

\(^3\) See First Progress Report for period ending 3-15-79.
MF-Nb₃Sn wire was used in a 162 strand (6 x 3²) cable with a 40% void fraction. The square conductor was wound into a bifilar coil. 4 inch long terminations of swaged cable (85% solid) were provided at each end. The coil was wound at MIT, prior to activation at Airco (24 hours at 700°C).

Steady state operations were performed on the test coil at 9.5T, 10,000A (91 to 96% of $I_c(9.5T)$), 4.2K and 3 atm of helium pressure with a pumped helium flow of 14.5cm/s. Length of conductor at or near 9.5T was 1.5m.

Four critical current measurements (between 10,500 and 11,000A) indicated $I_c(9.5T)$ to be 76% of short sample current.

Completion of NbTi D-Coil Tests

Tests have been completed. Pulse coil calibration is in progress.

Test operations demonstrated the following:

(a) Conductor critical current matched its short sample current.

(b) At 7 T, across a 15cm length of coil, the conductor was operated at 88% of its critical current (6,000A) under steady state conditions.

(c) The coil did not quench when its current was ramped from 0 to 5500 A in 250 ms.

(d) When the conductor went normal and the coil underwent quench, current shutdown was accomplished without the
generation of excessive internal helium pressure.

(e) Various stability tests were performed on the test coil using pulse induced transient heating in the conductor strands.

(f) A major feature of this test was the verification that while the motion of cabled wires in the rigidly held conduit generated voltage, pressure, temperature and flow perturbations, it did not cause quench.