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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

PLASMA FUSION CENTER

Quarterly Progress Report

MASTER

✓ MIT-12T-COIL PROGRAM 77

For Period Ending 30 September 1979

(DOE Contract No. EG-77-S-02-4182)

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Summary

We are reporting on progress made during the quarterly period ending September 30, 1979.

The MIT-12T-Coil Program is one year old. We have completed a preliminary design and have initiated a review of that design by Westinghouse. Superconductor development work is progressing at both Supercon, Inc. and Airco. Airco has also been commissioned to fabricate a 300m length of copper-based conductor, which will be used for winding exercises.

Experiments to evaluate the behavior of Airco and Supercon, Inc.'s Nb₃Sn materials at 12 tesla have been completed.

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Coil Design

As previously reported⁽¹⁾ the MIT Preliminary Design of the coil was completed in June, 1979.

Westinghouse (W) is currently reviewing the MIT Preliminary Design on the basis of the following schedule:

Progress Meeting at MIT on Nov. 6, 1979

Completion of review by Dec. 15, 1979

The coil characteristics are given in Table I (below).

Conductor Winding

Preliminary winding exercises were performed at Everson Electric Company (Allentown, PA) during the week of September 24th. Hollow conductor with an external dimension matching the MIT-12T-Coil was wound satisfactorily onto a 40 cm diameter form, using tooling designed for that purpose. Material used was type 304 stainless steel.

Production of a 300 m length of Nitronic 40 encapsulated conductor at Airco has been delayed. The order is now scheduled for completion in November, 1979. The winding of a complete double pancake, originally scheduled for September at Everson has consequently been rescheduled to December, 1979. The objective of this exercise is the fabrication of one complete double pancake (copper strands), which will subsequently be heat treated. The purpose of this exercise is to determine the degree of stress relief on the cold worked conductor sheath.

(1) See the MIT-12T-Coil Quarterly Progress Report for the period ending June 30, 1979.

Superconductor Development (Nb₃Sn)

Airco heat cycle optimizations continue. They report reproducible short sample current densities in excess of 400 A/mm² (at 12 T and 4.2 K) using activation temperatures somewhat below 750° C, with a firing cycle in excess of 200 hours. Firing cycles in the 750 to 800° C range have a considerably shorter duration but are not as reproducible. Critical current versus critical temperature measurements have been scheduled at the FBNML for October, 1979.

Supercon has fabricated wire from their niobium enriched stock billet. Heat cycle optimizations are in progress.

Our plan is to utilize wire for the 12 T coil from both manufacturers as long as they can meet the MIT-12T-Coil current density requirements. Both development programs should be completed by December 31, 1979.

Plans for Final Design and Coil Fabrication

Final design specifications will be prepared by MIT after completion of the current review. Westinghouse (W) is subsequently expected to prepare detailed manufacturing drawings and most likely fabricate the three subcoils.

A feasible schedule for the MIT-12T-Coil is given in Table II.

Technical Backup at MIT

Work has been initiated in the development of specific hardware for the MIT-12T-Coil. This includes:

- (1) Compression of a full size conductor end into a monolithic, ribbon-shaped electrical connection. This has been achieved using a 162 strand conductor with a "turks head" rolling device,* but needs to be duplicated on the 12T-Coil scale.

*Monolithic Terminations for Multistrand NbTi and Nb₃Sn Cables, by S.J. Waldman and M.O. Hoenig, presented at the 1979 Cryogenic Engineering Conference, Madison, Wisconsin.

(2) Fabrication of hydraulic and diagnostic connections.

(3) Welding techniques for conductor ends.

A stainless steel bellows pump has been fabricated and will shortly be tested.

Scientific Backup - Work underway at MIT in support of the 12 T Program.

Scientific work at 12 T has been completed on all available test coils. A new test coil (Tin Coil 9) is being fabricated in order to evaluate 12 T stability at high current levels for the MIT-12T-Coil, using supercritical helium. A special effort will be made in order to obtain an accurate evaluation of pulsed energy delivered.

Present results have demonstrated that both the Supercon and Airco superconductors provide stable operation when incorporated in "Cable-in-Pipe" configurations.

A comparison has been made between the characteristics of two test coils operating at 9 and 12 tesla (see Table III). Tin Coil 1 was built using Supercon's copper matrix Nb_3Sn wire and has been tested at both 9 and 12 tesla. Tin Coil 4 was built using Airco's bronze matrix Nb_3Sn Superconductor. It has been tested at 12 tesla. The analysis indicates that the average heat flux for the three tests is approximately the same, namely 0.16 W/cm^2 . This would tend to support the theory that recovery of an ICCS from instability is primarily dependent on internal heating and on the enthalpy of helium in the conductor.

Our Long Conductor Sample Test Coil (Tin Coil 8) yielded much useful information.* Due to metallurgical problems using type 304 S.S. however, it was impossible to operate the coil at pressures in excess

*See enclosed paper, "Internally Cooled Nb_3Sn Cable Performance in a Solenoid," by A.G. Montgomery and M.O. Hoëmig, presented at the Cryogenic Engineering Conference, Madison, WI, August, 1979.

of 1.2 atm. A new test coil (Tin Coil 9) is being constructed. It will be built from either the low carbon type 304L stainless steel or Nitronic 40 (21-6-9 alloy).* Both appear to respond well to the stringent requirements of cold work, activation at 700 to 800° C and final cryogenic cycling.

Work on the NbTi Dee Coil has been completed. Results have been reported in literature.**

* Alloy(%)	C(max)	Mn	P(max)	S	Si(max)	Cr	Ni
304	0.08	2(max)	0.20	.15+	1	17-19	8-10
304L	0.03	2(max)	0.045	1 max	1	18-20	8-12
21-6-9	0.08	9	--	--	--	20	6.5

**See enclosed paper, "Experimental Evaluation of a One-Meter-Scale Dee-Shaped Test Coil Fabricated from a 23-Meter Length of Internally Cooled, Cabled Superconductor," by M.O. Hoenig, A.G. Montgomery and S.J. Waldman, presented at the 1979 CED/ICMC Conference, Madison, Wisconsin, August, 1979.

TABLE I

MIT-12T-COIL CHARACTERISTICSGeometry

Coil O.D.	1.0 m
Coil I.D.	0.4 m
Axial Length	0.15 m
Shape	3 double pancakes
Conductor	2 x 2 cm
Corners	0.46 cm (outside radius)
Wall Thickness	0.17 cm
Sheath	Nitronic 40

ETF Operating Characteristics

Coil-Space Current Density	2,000 A/cm ²
Equivalent Current	10,000 A
Peak Field	12 T

HFTF Operating Characteristics

Peak Field with 12 T Coil at Zero Current	9 T
Peak Field with 12 T Coil at 10,000 amp	11 T
Peak Field with 12 T Coil at 15,700 amp	12 T
Coil Space Current Density at 15,700 amp	3,100 A/cm ²
at 10,000 amp	2,000 A/cm ²

Conductor Requirements

Copper (Cu):Noncopper ($\overline{\text{Cu}}$)	
at 40 percent void	1.5:1
at 35 percent void	2:1

Superconductor Requirements

Short Sample Current Density J(12 T, 4.2 K)	410 A/mm ²
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Table II SCHEDULE FOR MIT-12T-COIL - as of 10/19/79

		1979		1980				1981	
		JAS	OND	JFM	AMJ	JAS	OND	JFM	AMJ
Preliminary Design Completion	(MIT)	▲							
Review of Preliminary Design	(W)			△					
Superconductor Development	(Airco)			△					
	(Supercon)			△					
Selection of Superconductor	(MIT)			△					
Dummy Conductor Production	(Airco)		△						
Dummy Conductor & Coil Winding	(MIT@Everson)		▲	△					
Coil Design and Specification	(MIT)			—					
Manufacturing Drawings (Completion)	(W)				△				
Superconductor Manufacture	(SC/Airco)			—					
Subcoil Manufacture	(W)					—			
Superconductor Activation								△	
Coil Assembly & Instrumentation	(MIT)							—	
Coil Ready for Test at LLL									△

Legend: Completion Date -- Proposed -- △
 Completion Date -- Accomplished -- ▲

TABLE III

Stability of Nb₃Sn Conductors

Test Coil	Tin Coil No. 1	Tin Coil No. 1	Tin Coil No. 4b	
Superconductor Manufacturer	Supercon	Supercon	Airco	
<u>Wire Characteristics</u>				
Matrix (type Nb ₃ Sn)	Copper	Copper	Bronze	
Filament diameter	40	40	2.8	μm
Percent tin in bronze			14	%
Percent copper	41	41	58	%
Wire diameter	1.05	1.05	0.525	mm
Activation temperature	750°	750°	700°	C
Activation period	24	24	24	hrs.
Strand insulation	none	none	none	
<u>Cable Characteristics</u>				
Type: Transposed	no	no	yes	
Layered	yes	yes	no	
Configuration	19 x 3	19 x 3	6 x 3 ³	
Percent void	45	45	40	%
<u>Conductor Characteristics</u>				
Material: 304 S.S.	yes	yes	yes	
Shape: round	yes	yes	yes	
O. D.	12.45	12.45	9.40	mm
Wall thickness	0.80	0.89	0.38	mm
<u>Operating Characteristics</u>				
Background field (B)	9	12	12	T
Superconducting current density (max.) [J _Q (Cu) @ B & 4.2 K]	275	93	317	A/mm ²
Operating Current	5840	2511	4324	I
Energy induced (max) with recovery (Q _{imp})	600	500	250	mj/cc (wire)
Pulse period	.019	.019	.019	s
<u>Calculated Results</u>				
Equivalent adiabatic temperature (T _{ad})	25	23	21	K
Current sharing temp. (T _{cs})	8	5.4	5.4	K
Post pulse recovery time	.160	.040	.030	s
Average heat flux during recovery	0.16	0.16	0.16	W/cm ²