**Letter Report for the Superconducting
Magnet Development Program**

September 1, 1975—December 1, 1975

MASTER

OAK RIDGE NATIONAL LABORATORY

OPERATED BY UNION CARBIDE CORPORATION FOR THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

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LETTER REPORT FOR THE SUPERCONDUCTING
MAGNET DEVELOPMENT PROGRAM

September 1, 1975 - December 1, 1975

Engineering Sciences Department
Thermonuclear Division

FEBRUARY 1976

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OAK RIDGE NATIONAL LABORATORY
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TABLE OF CONTENTS

I. Introduction	1
II. Program Objectives	1
III. Implementation of the Program	1
IV. Program Staff as of 1 December 1975	1
V. Subprogram Reports	2
VI. List of Major Purchases	7
VII. List of New Proposals under Consideration	7
VIII. Visitors	8
IX. Staff Trips	8
X. Reports and Papers	10
XI. Talks	11
Appendix	11

Letter Report for the Superconducting
Magnet Development Program, No. 5

Period Ending 1 December 1975

H. M. Long, Program Manager
R. W. Derby, Assistant Program Manager
M. S. Lubell, Assistant Program Manager
J. K. Lovin, Program Monitor

I. INTRODUCTION

During this reporting period, the Sixth Symposium on Engineering Problems of Fusion Research was held in San Diego. We contributed 21 papers directly, and 7 other papers were given by groups under subcontract to the Superconducting Magnet Development Program (SCMDP). These papers will be available soon in an IEEE publication of the conference proceedings. A list of the papers is included in Section X.

Other meetings of significance for the program, which were held at Oak Ridge, were the summer workshop on an Experimental Power Reactor (EPR), the ad hoc committee on EPR superconducting magnet systems, the Fusion Power Coordinating Committee (FPCC), and the SCMD program panel review.

The Oak Ridge EPR Reference Design (published as ORNL-TM-5042) was presented at the Summer Workshop, and thorough discussions held with the two other EPR design teams, representing Argonne National Laboratory and General Atomic. The major difference in design approach to emerge from the meeting was the employment of Nb₃Sn by Oak Ridge in the high field region of the toroidal field coils.

The ad hoc committee reviewed the various designs, and their major consensus was that the high field option should be maintained without compromising the successful development of NbTi coils operating to a maximum field of 8 T.

A comprehensive review of our program was presented to the FPCC. Discussions concerning changes in the program were held with the panel review members. Our present thinking is outlined in the next section.

The following acronyms are used in this report:

CT - Compact Torus
ECT - Eccentric Coil Test
EPR - Experimental Power Reactor
LCP - Large Coil Project
LVDT - Linear Variable Differential Transformer
OH - Ohmic Heating
SCMDP - Superconducting Magnet Development Program
SCR - Silicon Control Rectifier
SMFTL - Superconducting Magnetic Fabrication and Testing Laboratory

II. PROGRAM OBJECTIVES

Our program plan was published as ORNL-TM-5109, but we anticipate making continual changes in it as developments proceed both in the work at ORNL and externally. Aspects of our present thinking which will require changes and revisions in some sections of the plan are summarized as follows:

- (1) Proceed with as many small scale experiments as possible, focusing primarily on conductor stability and cooling experiments involving

- (2) relevant and prototype conductor for the EPR. Fabricate (primarily in industry) large coils relevant for the EPR and proceed to a test and demonstration in a large toroidal simulation. The coils are expected to be noncircular with a 3 to 4 m horizontal bore. The test facility design is still under study, but it will be either a compact torus or a cluster test as described in the previous quarterly report and the annual report.
- (3) All magnets will employ cryostatically stabilized conductor.
- (4) Following the large coil demonstration, we expect to proceed directly to a prototype EPR coil, which will most likely be the first coil of a production set up.
- (5) In all of this work the primary emphasis will be on NbTi conductor, but Nb₃Sn will be kept as an option and will be investigated, unless some experimental information should rule it unacceptable for the EPR project.

III. IMPLEMENTATION OF THE PROGRAM

There were no new additions to the staff during this period. A listing of the program staff is given in Section IV.

The new offices in Building 9204-1 were finished and are now occupied by the remainder of our staff. Construction continued on the laboratories, and it is anticipated that they will be ready for occupancy during the next quarter.

IV. PROGRAM STAFF AS OF 1 DECEMBER 1975

Scientific (Monthly)

J. K. Ballou	J. K. Lovin
R. L. Brown	M. S. Lubell
R. W. Derby	J. W. Lue
G. W. Donaldson	J. N. Luton
L. Dresner	J. R. Miller
J. F. Ellis	J. W. Pearce
W. A. Fietz	R. E. Schwall
K. J. Froelich	S. S. Shen
W. H. Gray	J. E. Simpkins
C. G. Lawson	P. L. Walstrom
C. J. Long	H. T. Yeh
H. M. Long	

Technical (Weekly)

L. Alley	J. P. Rudd
C. M. Fitzpatrick	W. H. Wagner
E. C. Moore	

Consultants*

J. E. Akin	N. E. Johnson
R. Dineen	A. R. Moazed
W. F. Gauster	H. Pih

Engineering Personnel*

E. L. Allred	R. E. Hill
W. C. Anderson	R. O. Hussung
E. H. Bryant	T. J. Huxford
P. B. Burn	J. R. Johnson
W. D. Cain	J. P. Kois
T. J. Colson	E. F. Marguerat
R. I. Deaderick	J. R. Moore
J. S. Foreman	W.C.T. Stoddart
G. S. Henderson	D. F. Woodring

* Employed only on a part time basis.

V. SUBPROGRAM REPORTS

A. Systems Design

Personnel: H. M. Long*, R. W. Derby, J. K. Lovin,
M. S. Lubell, J. W. Lue

This subprogram serves to coordinate the overall program, by providing the general management and administrative activities, and the necessary liaison among the subprograms and with other related programs.

Program Monitor. Several revisions were made to the budget plan and projected allocation of funds. This was necessary because of the delay in obtaining the additional funds required to fully support the SCMDP plan. Routine checks were made of expenditures to insure that only proper charges were made to the program.

Systems Design. This task was accomplished with the support of personnel from other subprograms. During this reporting period we participated in the completion of the Oak Ridge Tokamak Experimental Power Reactor Study Reference Design. Some work was done during this period on refining the chapter on Electromagnetic Systems. The refrigeration system requirements, and the energy storage and switching were also revised. The reference design was published in November 1975 as ORNL-TM-5042.

Work was done on the formulation of additional areas in the magnetics system requiring review in the continuing EPR design. These areas include, for example, superconducting cable design, voltage and current limitation of the pulse field coils, the stress analysis model, alternative energy storage and transfer scheme for the pulse field coils, and the effect of flow options on the refrigeration requirements.

A study was made of pulsed field losses in TF coils. Estimates were obtained of ac losses as functions of composite wire size, filament twist pitch, superconductor filament size, and pulse field magnitude. Results show that it is advantageous to use cable conductors with small composite wires because the size of the wires sets the ac loss limit. The existence of a pulse field parallel to the conductor makes it unwise to twist the filament much tighter than 30 times the wire diameter. In addition, it is not necessary to use superconducting filaments much less than 50 μm , since eddy current losses in the stabilizer and structural steel dominate the pulse field loss.

A new circuit concept has been developed for the OH coils energy storage and transfer requirement through the consulting work of E. K. Inall. This scheme uses SCR converters to arrange the six groups of the OH coil system in series for charging and in parallel for energy transfer to and from a homopolar generator. There is no mechanical circuit breaker involved. An additional capacitor is used to make feasible the SCR switching needed in the circuit to match the impedances of the various supplies and coils at different parts of the cycle.

B. Coil Design

Personnel: J. N. Luton*, J. K. Ballou, W. H. Gray,
R. E. Schwall, S. S. Shen

Engineering: P. B. Burn

The short-term objectives of the Coil Design subprogram are to continue design work on the Large Coil Project (LCP), improve our design tools, complete the pulse coil program plan, and conserve financial measures by performing pertinent work for projects outside the SCMDP. Specific accomplishments during this reporting period follow.

PLASS - A Pulsed Loss Code. In the design of the cryogenic system and magnets for the poloidal field system in the EPR, it is important to have as good an estimate as possible for the heat produced in the magnets as a result of the changing magnetic fields. Until recently this estimate was obtained by assuming that the field was constant throughout the coil windings. Each component of the loss was then calculated and multiplied by the appropriate material volume to obtain the total loss. To insure a conservative estimate, the maximum field in the windings was used to determine the field changes used in the calculations. This method tends to overestimate losses, since the field in the windings is not constant. A more accurate method of estimation involves taking into account the spatial variation of the field, and integrating losses over the coil windings. A computer code, PLASS (Pulse Losses in Axisymmetric Superconducting Solenoids) has been written to carry out this improved algorithm.

PLASS calculates the losses in a set of axisymmetric superconducting solenoids due to field changes produced by these coils. Therefore, it is suited to calculations of pulse losses of all poloidal field coils in a tokamak. However, the code will require modification before it can be applied to toroidal field coils. PLASS is a new code and not all of its planned features have been implemented. For example, it will allow only one field-change schedule at present, but it will be updated to a more general form in the near future. It uses the following time schedule: a 2 sec rise time followed by a 96 sec plateau; then a 2 sec fall time and a 100 sec waiting period before the next cycle begins. The losses calculated include superconductor hysteresis, eddy current losses in the stabilizing material, twist losses, and eddy current losses in the metallic structure. The metallic structure is assumed to be limited to hollow conduits that contain the cabled conductor. The support structure is assumed to be nonmetallic.

PLASS was used to analyze the ORNL EPR reference design poloidal system. Results indicate that the total energy released into the cryogenic system had formerly been overestimated by approximately a factor of two. This overestimate will vary with different designs.

Pulse Coil Program Plan. The original and revised SCMD program plans covered principally the toroidal field coil development. It was assumed that the pulse work interspersed in the program combined with the results of other laboratories would be sufficient, or else the pulse coils would be resistive. However, it appears advantageous to propose an expanded pulse coil development program as part of the SCMDP in light of the following: (1) the difference between the technical objectives of existing pulse coil programs

* Program Manager

* Subprogram Manager

and the tokamak EPR pulse coil requirements, (2) the substantial power losses of resistive coils and the difficulties of adapting them for pulse coil service, and (3) the expected synergistic effect of close interaction between the toroidal and pulse coil development efforts. Work to lay out a complete program has been started and is well underway.

Other Tasks. The Compact Torus has been given the less-specific title: Large Coil Test, to indicate other test configurations are also being considered. The effort is concentrated on cryostable designs.

Some features of the preliminary design for the toroidal coil proposed in the EPR reference design are being examined more closely to ensure that "mundane" details such as coolant insertions do not make the design difficult to fabricate.

The staff of the Coil Design Subprogram has never been as large as recommended in the Program Plan, and the continuing shortage of funds has caused a still-further reduction, in the form of work done for (and charged to) outside projects. Thus far work has been done for the Elmo Bumpy Torus, ORMAK Upgrade, and the PLT Beam Line. If possible, any such work undertaken will be at least indirectly beneficial to the SCMDP.

References

1. H. M. Long and M. S. Lubell, ed., Program for Development of Toroidal Superconducting Magnets for Fusion Research, ORNL-TM-5109 (May 1975).

C. Conductor Selection and Test

Personnel: W. A. Fietz*, L. Alley, K. J. Froelich, J. W. Lue, J. R. Miller, J. P. Rudd, R. E. Schwall, S. S. Shen, W. H. Wagner

Metals & Ceramics Division: R. J. Beaver, D. S. Easton, R. E. McDonald, S. Waters

Argonne National Lab.: E. S. Fisher, S. H. Kim

Intermagetics General: C. D. Henning, P. Rackov

Westinghouse: M. S. Walker, G. Wagner

The objective of Subprogram C is to prepare specifications for purchasing conductors and assure adequate sources through quality control. To achieve this objective, it is necessary to define, analyze, and examine the effects of conductor design on the behavior of superconducting tokamak devices. Specific accomplishments during this reporting period follow.

Tensile Properties of MF Nb₃Sn. The first reported measurements of critical current behavior of multifilamentary (MF) Nb₃Sn under tensile loading at 4.2 K were obtained by workers at the Metals & Ceramics Division of ORNL. The tests were performed on monolithic and cabled conductors obtained from commercial sources. Simultaneously, room-temperature bending tests were performed at ORNL's Thermonuclear Division on samples of the same material. The degradation observed was greater at a given strain level than for NbTi, but it seems that Nb₃Sn may be used up to 0.2% strain. Significant differences between cable and monolithic conductors were observed. The cable can be strained 50 to 100% more than the monolithic samples for the same percentage degradation.

In addition, for unknown reasons, the cable recovers most of its lost current capacity when the strain is reduced to zero, while the monolithic conductor is permanently degraded. Preliminary results were reported at the IEEE symposium in San Diego. A paper is in preparation which will be submitted for journal publication.

Testing Apparatus. Apparatus constructed during this period includes the following: (1) A large sample tensile-testing device capable of simultaneously applying transverse compressive loads. This apparatus is similar to that reported at San Diego (Paper B1-1)*, but has the capability of applying 160,000 N (36,000 lbf) tensile loading on samples about 15 cm in length. (2) An apparatus for measuring cryostabilized behavior of superconductors. The conductor will be wound in the form of a bifilar pancake about 25 cm OD which can be oriented at any angle with respect to a 6.0 T background field. The effect of interwinding spacers can be simulated by clamping various covers on the coil. Heaters will be imbedded in the winding so that recovery or non-recovery from a heat pulse can be observed under various conditions of field, current, orientation of cooling channel, and conductor configuration. (3) A device for measuring matrix resistivity ratio at a temperature above the critical temperature. (4) Equipment required for routine measurement of short samples of current in a superconducting magnet. Devices for measuring high temperature critical currents and upper critical field were deferred because of budgetary limitations.

Conductor Stability Measurements. Current measurements of one-dimensional propagation and recovery were made on small samples of superconducting wire and reported at San Diego (Paper D1-12). These measurements allow significant comparison with calculated values and provide a basis for the study of two-dimensional systems in the form of bifilar pancakes. The one-dimensional results have limited application in magnet design, so future emphasis will be on the pancake studies. An apparatus has been designed for the study of stability effects in helical coils, under contract with Westinghouse, and is being reviewed.

AC and Pulse Losses. The measurement of conductor loss in a pulsed field parallel to the current flow was reported in San Diego (Paper B1-11). Further work on this system has been curtailed due to budgetary restrictions. The calorimetric measurement of ac loss as a function of conductor length in a parallel field has been completed. The results were reported at San Diego (Paper B1-13) and a final report from the subcontractor, Westinghouse, is expected soon. A nonmetallic dewar to be used for pulsed coil tests has been received, after completion of additional repairs.

Members of Subprogram C participated in inter-subgroup efforts to define more precisely the goals and approaches in the construction of pulse coils for EPR. A schedule for achieving the construction of pulse coils in coordination with the toroidal field coils has resulted.

Joint Studies. Work by Intermagetics General Corporation and ORNL's Metals & Ceramics Division has been completed; abstracts of the final reports are appended. These studies concentrated mainly on joint design for soldered monolithic conductor joints, although one explosive welding technique was reported.

Impurity Studies. Samples of NbTi conductor doped with various levels of Fe, Al, and Mn were tested for J_c

* Subprogram Manager

* See Section X for complete paper references.

and H_{c2} . This study, documented in a poster session at San Diego, resulted in a number of unanswered questions. Further work in this area is being deferred, pending clarification of the availability of funds.

Cyclic Loading Effects. The first progress report from ANL on the effects of cyclic loading was received; an abstract is appended. In addition to the results reported therein, the workers have reported that the grain structure of copper has a pronounced effect upon its response to cyclic loading, even though the copper was annealed prior to testing. Further investigation of this effect is being carried out.

Conductor Design and Purchase. A study group of four individuals from different subprograms has been formed to produce and analyze conductor designs for SCMDP application. Several designs are being analyzed, and they will be submitted to industry and other interested parties for comment and price quotations. Price quotations have been received for a cryostabilized compacted cable and for aluminum-stabilized NbTi conductor.

D. Radiation Effects on Superconducting Coils

A survey has been initiated on the effects of radiation damage in superconducting magnet components and systems.

E. Coil Protection, Eddy Current Shielding, and Power Supply

Personnel: H. T. Yeh*, G. W. Donaldson,
L. Dresner, E. L. Woods

Computer Sciences Division: S. K. Fischer

Instrumentation and Controls Division:
P. Rubel

Metals and Ceramics: C. V. Dodd

The objectives of Subprogram E are: (1) to solve technical problems in the areas of quenching, protection, eddy current shielding, and power supplies of the fusion EPR superconducting magnets, and (2) to provide input to projects on smaller superconducting magnets to be developed at ORNL prior to EPR.

Thermal Aspects of a Superconducting Coil for a Fusion Reactor. Computer models were used to simulate both localized and extensive thermal excursions in a large superconducting magnet for a fusion reactor. Conditions for the failure of the fusion magnet due to thermal excursion were investigated, and protective designs were evaluated. This work was presented at the symposium at San Diego (Paper D1-13).

Normal Zone Propagation. A program has been written that calculates the propagation velocity of a normal zone in a multifilamentary composite superconductor. The program includes the effects of: (1) current sharing, and (2) temperature variation of the thermal conductivity and specific heat of both the substrate and the superconductor. Results obtained here are in good agreement with experimental data. The work was reported at San Diego (Paper D1-12).

Stability of Force-Cooled Conductors. A program has been written that calculates the temperature-time

history of a uniformly pulse-heated composite conductor cooled by super-critical helium in forced convection. The program determines whether the conductor recovers to the superconducting state, and includes the effects of: (1) current sharing, (2) temperature variation of the specific heat of both the substrate and the superconductor, and (3) temperature variation of the heat transfer coefficient. A related program has been written which performs the same calculation for an initial perturbation that extends over only a limited portion of the conductor.

Model Coil Protection System. A model coil protection system was built, and preliminary test results are satisfactory. The system utilizes hardwired relay logic. Standard hardware is utilized throughout the system and commercially-available equipment is employed for detection and control. Manual override is provided. A new approach to quench detection is used, with the result that the system is operable in an external pulsed magnetic field.

Superconducting Coil Protection. A protection system for superconducting coils was presented at the San Diego symposium (Paper D1-14). The basic system utilizes hardwired relay logic. A second redundant loop is established using digital control. Manual override is utilized as a primary control element for all phases of the coil protection system. Standard hardware is employed throughout the system, and commercially-available equipment is used for detection and control.

The protection system is based on a two-phase construction program. Phase I consists of the development of a reliable hardwired relay control system with a digital loop, utilizing hardware and a microprocessor controller. Phase II involves an expansion of the digital loop to include many heretofore unmonitored coil variables. These newly monitored variables will be utilized to establish early quench detection, and to formulate confirmation techniques of the quench detection mechanism.

Established quench detection methods are discussed in the paper mentioned above, and a new approach to quench detection is presented, in which the circuit is insensitive to external pulsed magnetic fields and the associated induced voltages. Reliability of the coil protection system is discussed with respect to shutdowns of superconducting coil systems. Redundancy and digital system methods are presented as related topics. Several existing coil energy dump systems are presented, together with a proposed dump system which has improved failure and energy dissipation features.

Dump Resistor Design. The stainless-steel welded rod design was finalized, and is recommended in preference to the molten metal or the flame-cut stainless-steel designs, which were previously proposed. Reliability, economy, and flexibility of design helped determine the choice in sizes up to 30 MJ. More economical designs result from the use of the heat-resistant insulation "marinite" instead of the better-known "transite", since "marinite" will provide protection up to higher temperatures. It is now possible to design air-cooled resistors with natural air circulation which have energy densities of hundreds of MJ per m^3 . Forced-air cooling, a hazard in rarely operated protection devices, becomes an asset in regular or periodic applications like the resistor required in the ohmic heating circuit.

A Two-Dimensional Relaxation Program for Systems with Inhomogeneous Permeability. A computer program was developed at ORNL which will solve axially-symmetric

* Subprogram Manager

eddy-current problems, including those with permeable media present. An unusual feature is the combination of coarse and fine lattices, which permits the combination of rapid relaxation of coarse lattices in homogeneous regions and more accurate fine-lattice calculations in the transition regions, where the permeability is varying. The program will be documented in the near future.

Calculation of Eddy Current for Non-Steady Driving Fields Through Time Solution of Integral Equations.

One solution to the eddy-current integral-differential equations is found in the form of a perturbation expansion with separated time-dependence for linear conductors. No reference to field values outside the conductor is required, and a full three-dimensional treatment is maintained. Use of the expansion as an approximation in transient and non-convergent cases will be discussed in a forthcoming report.

The theory has been tested by applying analogous equations in one space dimension to a scalar (heat-flow) problem. The test problem has an exact solution, thus allowing comparison. The one-dimensional analog was run on the IBM 360/91 and plotted for one point in space on the PDP-10 tektronix plotting terminal. The exact solution was also plotted in this way, and agreement was good.

F. Structural Analysis and Material Tests

Personnel: W.C.T. Stoddart*, W. H. Gray,
C. J. Long

Engineering Division: W. D. Cain

Reactor Division: S. E. Bolt

Consultants: J. E. Akin, A. R. Moazed,
H. Pih (Univ. of Tennessee);
C. T. Sun (Univ. of Iowa)

Lockheed: J. A. Mayhall, C. T. Welch

Mechanics Research Inc.: R. L. Dineen,
N. E. Johnson, R. M. Pardue, R. A.
Weed

The purpose of the Structural Analysis and Material Tests Subprogram is to provide the basis for the structural design of reliable and economical superconducting magnets and support structures. The investigations, both analytical and experimental in nature, are coordinated with the overall development program.

Analytical Studies. The STANSOL computer program for the analysis of uniform solenoids has been distributed to other sites, where it is currently in use for DCTR related studies. An extension of the program to include orthotropic material properties was incorporated by Mechanics Research Inc. (MRI), based on theoretical derivations by W. H. Gray. A computer program for the finite-element analysis of discrete solenoids was prepared by J. E. Akin and W. H. Gray. This code extends the methods of analysis readily usable in magnet analysis and allows consideration of non-uniform axial geometry, which was not possible with STANSOL. The development of a technique for the determination of the optimum shape of toroidal field coils free from bending moments and subject to concentrated supports was completed by Lockheed personnel. This technique shows promise in reducing the amount of structural material required for these coils.

* Subprogram Manager

Experimental Studies. Experimental work using photoelastic materials has continued during the last quarter. The area of quantitative disagreement between experimental and finite-element analysis has been resolved. The two methods have been found to be in agreement within the precision limits of the experimental program. An experimental program to establish the behavior of systems using laminated epoxy, fiber glass, and copper has been initiated.

G. Cryogenics and Refrigeration

Personnel: C. G. Lawson*, J. K. Lovin

Engineering Division: J. P. Kois

Computer Sciences Division: K. Rothe

National Magnet Lab.: M. O. Hoenig,
Y. Iwasa, D. B. Montgomery

The environment of the superconducting magnets must be established and maintained at temperatures of 3 to 5 K in the windings. The Cryogenics and Refrigeration Subprogram is established to assure that the heat removal system meets this condition.

Refrigerator Procurement. The specifications for the 3.5 Kelvin Liquid Helium Refrigerator were released to several manufacturers as a request for proposal (RFP). There were two respondents, and these proposals are being reviewed. Both proposals meet the technical requirements in substance. We anticipate making the award in the near future.

National Magnet Laboratory Subcontract: Cryo-stabilized Single-Phase Helium Forced-Cooled Conductors. Superconducting cable samples of 19 fluted-strand cable and 19 triplex-strand cable have been made by standard manufacturing techniques. The conductors will be used for pressure-drop measurements and quench-recovery tests.¹ Fluid pressure-drop calculations have been made that compare the recovery capabilities of a fluted NbTi conductor containing 19 strands with a NbTi triplex conductor containing 19 strands. The triplex strand cable requires about 15% less pressure drop than the fluted strands to recover from the same energy pulse.

A comparison of the Nb₃Sn triplex strand with the NbTi triplex shows that the former requires about 40% of the helium pressure drop needed by the latter to recover from the same energy pulse. This lower pressure drop would occur at a temperature level of about 6 K instead of at 4 K. Thus, the refrigeration pumping power required to recover from a given energy pulse in a triplex strand with Nb₃Sn wire would be about 27% of that required with NbTi wire.

The computer program developed to compute the axial-temperature gradients of the helium and the superconductor², in response to an energy pulse in the conductor, ignored the second derivation axial-conduction term. A new computer program including this term has been developed and is called MIT-AE.

Pumping and Refrigeration Requirements. An analysis was made comparing the pumping power and, therefore, refrigeration power requirements of two flow loop strategies for circulating liquid helium coolant through the magnets and heat exchangers.¹ The first strategy had the pump located at the outlet of the magnet at 3.47 K, with the helium flowing

* Subprogram Manager

through the helium cold bath at the 3 K outlet and then to the magnet and pump. The second strategy had an additional countercurrent exchanger and a 77 K bath. The helium from the magnet left the load at 3.47 K, and flowed through the countercurrent exchanger, the pump and the 77 K bath, then it re-entered the countercurrent exchanger, the 3 K bath and finally the load. The increased current efficiency obtained by operating the pump at 77 K was not sufficient to overcome the pressure drop added by the countercurrent heat exchanger. These calculations and other considerations relating to control of the magnet-cooling system and the refrigerator make the cold pump circulating system the more attractive choice for forced-flow helium cooling systems.

Analytical Modeling. A thermal-analyzer computer code, developed at Lockheed-Huntsville, has been put into operation at ORNL. This code provides the capability to analyze 3-D transient (or steady state) thermal systems having temperature-dependent properties. Comparisons with several other thermal analyzers showed that this code required less computer time than any of the other codes considered. Currently a graphic package is being checked out.

An analytical model was developed to investigate the thermal characteristics of a typical superconductor. This investigation includes determining: (1) the maximum temperature a superconductor can recover from, (2) the effects of conductor slippage, (3) effects of convective film coefficients, and (4) other transient characteristics. In addition, much is being learned about general modeling techniques applicable to superconductors. This information will be used to develop better analytical models for specific superconductors and for localized characteristics.

References

1. M. O. Hoenig, "Cryostabilized Single Phase Helium Cooled, Bundled Conductor for High Field Superconducting Magnets," paper presented at the Sixth Symposium on Engineering Problems of Fusion Research, San Diego, Nov. 1975.
2. M. O. Hoenig, et al., "Single Phase Helium as a Coolant for Superconducting Magnets," paper presented at the International Cryogenics Material Conference, Kingston, Ontario, Canada, July 1975.

H. Coil Fabrication

Personnel: R. L. Brown*, J. F. Ellis,
C. M. Fitzpatrick, K. J. Froelich,
C. J. Long

Engineering Division: E. L. Allred,
P. B. Burn, R. I. Deaderick,
J. F. Foreman, G. S. Henderson,
E. F. Marguerat

Plastics Development: J. R. Day

Electric Shop: H. F. Clayton, J. F. Monday

H&H Industries, Inc.: C. W. Stahl

Subprograms H and I (Subsize and Fullsize Coil Fabrication, respectively) were combined into one subprogram (H) with the title Coil Fabrication. The

goal of this program is to develop technology for fabricating large superconducting magnets, in a reliable and economical manner, for use in thermonuclear reactors. Fabrication facilities should use the best existing technology, but the state-of-the-art should be advanced wherever practical.

Practice Winding Facility. The practice winding facility was designed for coils having diameters up to ~ 4 m. Limited space and handling equipment would prohibit fabricating coils larger than this in our existing facilities. Equipment limitations would likely be the winding table. With adequate supports for carrying additional weight, the existing winding table drive system should pull a total tension of ~ 200 kg on conductors wound on a 6 m bobbin.

The 3 m round bobbin has been mounted on the winding table and appears to be satisfactory for its intended purposes. However, according to an engineering report, some of the problems encountered in the fabrication of this bobbin should be called to the attention of those who may be involved in such designs in the future. It is made of aluminum sheets, welded, formed, and machined. One problem encountered in fabricating a weldment of this size was warpage. This resulted in the lack of stock available for finish machining to size. A second problem resulted from insufficient allowance for machining. This job specified 25.4 mm (1") plate to be welded and then machined to 19.05 mm (3/4") thickness (3.17 mm (1/8") on each side). However, the material would not clean up to the 19.05 mm (3/4") thickness. The fabricator requests an allowance of 9.52 mm (3/8") on a side. In other words the stock should have been 38.1 mm (1-1/2") instead of 25.4 mm (1"). Since it was obvious that all of the dimensions specified for a weldment of this size may not be held, the fabricator should know which ones are really critical. It is well to mark these dimensions on the drawings and request that the fabricator supply certification of inspection. Finally, on this bobbin, the groove for fastening the superconductor wire was mislocated in relation to the bobbin flange in the cleanup machining operation, requiring that the groove be remachined using hand tools -- an expensive operation.

H&H Industries, Inc. of Dayton, Ohio has completed a design of conductor clamps to fit on a permanent winding table they have designed. Since their permanent table will be an expensive long-delivery item, a set of automatic conductor clamps to work on existing equipment will greatly facilitate the winding operation. If funding is available, these clamps will be used on the temporary table now installed. Present methods require manual insertion and removal of "C" clamps for each rotation of the table.

A large aluminum plate has been fabricated for mounting the dereeler, straightener, tension device, and splicer. Unfortunately, assembly of this plate will be delayed because of unavoidable problems in obtaining necessary hardware. Mechanical and electrical equipment for controlling the dereeler, straightener, and tension device are near completion. Practice winding is planned for early 1976.

A larger and improved mechanical and electrical tester, for liquid helium temperatures in a background field, has been constructed. Some testing of superconductor characteristics has been performed and is reported under Subprogram C. Splices will also be tested using this equipment. Twenty-one electron beam butt- and edge-welded conductor splices have been delivered from Sciaky Bros., Chicago. Three spot-welded type splices will not be delivered, because

* Subprogram Manager

tests have shown that the electron beam will not make the necessary penetrations without burning a hole in the conductor. A report on the experimental splicing work by this company has been submitted (an abstract is included in the appendix). Handling and use of explosives in this plant has been investigated with a view to the possible desirability of explosively-welded splices, and no problem is anticipated.

A mold for forming porous plastic insulation sheets is being developed. The first molded sheets had obvious deficiencies requiring mold revisions. These revisions have been made. New insulation sheets using the revised mold have not been made at the present time. Another type of mold for forming a curved plastic ramp and wedge combination has been developed. These parts are used at the end of each layer in conductor test coils, a typical test coil using about 80 of these parts. The production rate for fabricating these parts out of Tefzel is greater than eight per minute. In the past they were made by hand, which was expensive and time consuming. Parts for conductors having different cross sections can be produced with very minor modifications of the mold.

J. Coil Test and Evaluation

Personnel: P. L. Walstrom*, J. F. Ellis,
E. C. Moore, J. W. Pearce, J. P. Rudd,
J. E. Simpkins

Computer Sciences Division: B. A. Clark

The ultimate purpose of the Coil Test Program is to qualify a coil design for use in EPR-size tokamaks. In order to achieve this objective, a phased program for testing coils of large size has been planned.

Test Facility Design. An examination of subsize (i.e. nominally 3 m) coil test configurations was performed with emphasis on cryostabilized test and background coils. The results are summarized in a paper (DI-4) presented at a poster session of the Sixth Symposium on Engineering Problems of Fusion Research at San Diego, California. A modified conceptual design for ECT, using a split cryostabilized background coil, was developed by a team of SCMDP and General Engineering Division personnel. The new design permits testing of significantly larger-diameter test coils. This design was also presented at the San Diego Symposium (DI-1).

Code Development. A graphics package has been added to the noncircular magnetic field code. A version of the code which calculates radial loads has also been produced.

Instrumentation. The coreless LVDT, discussed in the previous quarterly report, is a device for measuring displacements in the presence of high magnetic fields. It was tested in static and pulsed magnetic fields in the magnet laboratory. The LVDT was found to exhibit no measurable sensitivity to B for field ramp rates of 2 T/sec. A small static magnetic field effect (about 1%) was detected, and is apparently the result of an electromechanical vibration. The effect is small enough to allow use of the device as constructed; nevertheless, it was considerably damped by taping the windings and is expected to be eliminated by better mechanical constraint of the windings.

A method for detecting small magnet normalcies discussed previously has been demonstrated experimentally. The method employs a superconducting circuit electrically insulated from, but in good thermal contact with, the magnet conductor. When the magnet conductor goes above the critical temperature of the detector circuit, the detector is driven normal. The resistance of the detector circuit is very nearly proportional to the length of detector circuit which has gone normal.

A semi-automated open-loop generator control system for short sample tests was completed and is in use. The device allows the experimenter to set a field value, and causes the generator to ramp to that level and remain there. The device also shuts off the short sample current when the voltage across the specimen exceeds a preset value. A device which conditions the signal from a function generator to control an SCR power supply was also constructed and is in use.

Final specifications were written for a data acquisition system for coil testing. They were approved and will go out for bid shortly.

VI. LIST OF MAJOR PURCHASES

1. Exact Electronics: Generator
2. Elgar Corp.: AC line regulator
3. Bausch Lomb: Microscope
4. Leeds & Northrop: Voltage motor controller
5. Airco: Nb₃Sn cable
6. Hewlett-Packard Co.: Integrating microvolt meter
7. Burr-Brown Research Corp.: DC converter and components
8. W. C. Dillon and Co.: Digital readout equipment and tension load cell
9. Leeds & Northrop: Strip recorder
10. Standard Engineering Corp.: Data acquisition modules
11. Validyne Engineering Corp.: MCI system
12. Ortec: NIM modules

VII. LIST OF NEW PROPOSALS UNDER CONSIDERATION

1. Intermagnetics General Corporation: Continuation of Development of Joining Methods in Superconductors for the ORNL Coil Development Program
2. Iowa State University: Determination of Effective Module of Superconducting Coil Composites (rejected because of lack of funds)
3. Cryogenic Technology, Inc.: 3.5 K Helium Refrigerator
4. Airco: 3.5 K Helium Refrigerator

* Subprogram Manager

VIII. VISITORS*

September 5 Gregory D. Barthold, Arthur G. Craig, Douglas A. Koop, and Clayton N. Whetstone (Alcoa Laboratories)

September 5 David L. Fenton (Sverdrup-Parcel & Assoc., Inc.)

September 9 Steve Early and Peter Borden (Stanford Univ.)

September 9 Warren G. Pierce (Lakeshore Cryotronics)

September 9 EPR Work Team (Argonne National Lab., General Atomic and ERDA)

September 11 John D. Rogcro (Los Alamos Scientific Lab.)

September 11 Michael S. Walker (Westinghouse)

September 11 Eugene J. Ziurys (ERDA-DCTR)

September 12 W. V. Hassenzahl (Los Alamos Scientific Lab.)

September 15 Vonne Linse and Harry Pattee (Battelle-Columbus Labs.)

September 23 Erik Adam (Airco)

September 24 Eugene J. Ziurys (ERDA-DCTR)

September 30 Roger Hancox (UKAEA, Culham Lab.)

October 3 Ron Sconlon (Lawrence Livermore Lab.)

October 9 Masaki Suenaga (Brookhaven National Lab.)

October 10 Delegation from People's Republic of China

October 20 Carl D. Henning, Peter Rackov, Carl Rosner, and Paul Swartz (Intermagetics General Corp.)

October 20-24 E. R. Small (Australian National Univ., Canberra)

October 22 D. D. Montgomery (MIT National Magnet Lab.)

October 22-24 Michael S. Walker (Westinghouse)

October 27 John Mayhall, Hobson Shirley, George Watson, and C. T. Welch (Lockheed-Huntsville)

October 29-30 John R. Purcell (Argonne National Lab.)

Jack W. Beal, Ronald A. Blanken, Carl D. Henning, James M. Williams, Eugene J. Ziurys (ERDA-DCTR)

* This list does not include discussions with job applicants, nor does it include meetings and discussions with staff members of other ORNL divisions or with staff members of the Thermonuclear Division.

Clyde E. Taylor (Lawrence Livermore Lab.)

John D. Rogers (Los Alamos Scientific Lab.)

R. H. Kropschot (NBS, Boulder)

Joseph File (Princeton Plasma Physics Lab.)

Roger W. Boom (Univ. of Wisconsin)

November 4 Clifford K. Jones (Westinghouse)

November 4-5 Michael S. Walker (Westinghouse)

November 7 David Dew-Hughes and Masaki Suenaga (Brookhaven National Lab.)

November 11 Frank L. Decon (Phelps Dodge Copper Products Company)

November 13-14 A. Knobloch (Max-Planck Institut für Plasmaphysik, München, West Germany)

November 14 D. J. Anthony, A. T. Christensen and G. Thornton (General Electric Co.)

November 24 Yoshio Sawada (Shibaura Electric Co. Ltd., Tokyo)

November 25 Prof. Dr. Becker (Karlsruhe, West Germany)

November 26 J. E. Partridge and S. Skellett (Culham Lab.)

IX. STAFF TRIPS*

R. L. Brown

September 5 H&H Industries, Inc., Dayton, OH

November 17 Convair and General Atomic, San Diego, CA

November 18-21 Sixth Symposium on Engineering Problems of Fusion Research, San Diego, CA

W. D. Cain

November 18-21 Sixth Symposium on Engineering Problems of Fusion Research, San Diego, CA

J. K. Ballou

November 18-21 Sixth Symposium on Engineering Problems of Fusion Research, San Diego, CA

R. W. Derby

September 19 Argonne National Lab., Chicago, IL

October 6 Los Alamos Scientific Lab., Albuquerque, NM

* This listing includes only permanent staff members of the SCMD program and does not include consultants or members of other divisions or external contractors.

October 7	General Atomic, San Diego, CA	October 28-30	SME/ERDA Workshop, O'Hare Holiday Inn, Chicago, IL
October 8	Lawrence Livermore Lab., Livermore, CA	<u>H. M. Long</u>	
October 8	National Bureau of Standards, Boulder, CO	September 5 - October 5	Moscow, Leningrad, USSR Krzhibanovsky Power Institute, Moscow (and other labs)
November 7	National Magnet Lab. and Magnetic Engineering Assoc., Cambridge, MA	October 7-8	Committee Meeting of the Sixth Symposium at San Diego, Denver, CO
November 18-21	Sixth Symposium on Engineering Problems of Fusion Research, San Diego, CA	November 17-21	Sixth Symposium on Engineering Problems of Fusion Research, San Diego, CA
<u>G. W. Donaldson</u>		<u>J. K. Lovin</u>	
October 29	U.S. Dept. of Agriculture, Beltsville, MD	September 15	National Electric Coil Company, Columbus, OH
October 30	U.S. Naval Research Center, Annapolis, MD	September 16	Lewis Research Center, Cleveland, OH
October 31	MIT National Magnet Lab., Cambridge, MA	<u>M. S. Lubell</u>	
November 1	General Electric Research & Development, Schenectady, NY	October 14	Princeton Plasma Physics Lab., Princeton, NJ
November 17	Los Alamos Scientific Lab., Albuquerque, NM	November 18-21	Sixth Symposium on Engineering Problems of Fusion Research, San Diego, CA
November 18-21	Sixth Symposium on Engineering Problems of Fusion Research, San Diego, CA	<u>J. W. Lue</u>	
<u>L. Dresner</u>		November 18-21	Sixth Symposium on Engineering Problems of Fusion Research, San Diego, CA
November 18-21	Sixth Symposium on Engineering Problems of Fusion Research, San Diego, CA	<u>J. N. Luton</u>	
<u>W. A. Fietz</u>		October 17	Univ. of Wisconsin, Madison, WI
October 3	Intl. Conf. on Radiation Effects & Tritium Technology for Fusion Reactors; Gatlinburg, TN	November 17	Convair and General Atomic, San Diego, CA
October 7	Westinghouse Research & Develop- ment, Pittsburgh, PA	November 18-21	Sixth Symposium on Engineering Problems of Fusion Research, San Diego, CA
October 8	Argonne National Lab., Chicago, IL	November 24	Lawrence Livermore Lab., Livermore, CA
<u>K. J. Froelich</u>		<u>J. R. Miller</u>	
November 18-21	Sixth Symposium on Engineering Problems of Fusion Research, San Diego, CA	October 3	Intl. Conf. on Radiation Effects & Tritium Technology for Fusion Reactors, Gatlinburg, TN
<u>W. H. Gray</u>		November 18-21	Sixth Symposium on Engineering Problems of Fusion Research, San Diego, CA
September 19	Argonne National Lab., Chicago, IL	<u>R. E. Schwall</u>	
October 1-2	NASA - Langley Research Center, Hampton, VA	October 3	Intl. Conf. on Radiation Effects & Tritium Technology for Fusion Reactors, Gatlinburg, TN
November 18-21	Sixth Symposium on Engineering Problems of Fusion Research, San Diego, CA	November 18-21	Sixth Symposium on Engineering Problems of Fusion Research, San Diego, CA
<u>G. C. Lawson</u>		November 24	Lawrence Livermore Lab., Livermore, CA
October 29-30	ERDA Headquarters, DCTR Germantown, MD	<u>S. S. Shen</u>	
November 7	National Magnet Lab. and Magnetic Engineering Assoc., Cambridge, MA	November 18-21	Sixth Symposium on Engineering Problems of Fusion Research, San Diego, CA
<u>C. J. Long</u>			
October 22	Combustion Engineering Inc., Chattanooga, TN		

J. E. Simpkins

November 18-21 Sixth Symposium on Engineering Problems of Fusion Research, San Diego, CA

W. C. Stoddart

September 19 Argonne National Lab., Chicago, IL

October 23-24 General Atomic, San Diego, CA

November 18-21 Sixth Symposium on Engineering Problems of Fusion Research, San Diego, CA

H. T. Yeh

November 18-21 Sixth Symposium on Engineering Problems of Fusion Research, San Diego, CA

P. L. Walstrom

October 14 Princeton Plasma Physics Lab., Princeton, NJ

November 18-21 Sixth Symposium on Engineering Problems of Fusion Research, San Diego, CA

X. REPORTS AND PAPERS

E. K. Inall, An Ohmic Heating System Circuit for the ORNL Tokamak EPR Reference Design, ORNL-TM-5200 (October 1975).

M. Roberts, Project Manager, Oak Ridge Tokamak Experimental Power Reactor Study Reference Design, ORNL-TM-5042 (November 1975).

The following papers were presented at the Sixth Symposium on Engineering Problems of Fusion Research, San Diego, California, on November 18-21, 1975 (the paper number is given for each):

B1-1 K. J. Froelich, "An Experiment to Measure the Effects of Biaxial Strain on the Critical Current of NbTi Superconductor"

B1-11 S. S. Shen and J. R. Miller, "Transient Poloidal Field Effects in Twisted Multifilamentary Superconductor for Toroidal Field Windings of Tokamaks"

B1-12 W. J. Carr, Jr. (Westinghouse Research Labs.), "Parallel Field Losses in Twisted Multifilament Superconductors"

B1-13 M. S. Walker, G. R. Wagner, and S. S. Shen, "Losses in Twisted Multifilament Superconductors in Simulated Poloidal (Parallel) Fields"

D1-1 J. K. Ballou, P. B. Burn, J. N. Luton, and E. F. Marguerat, "Eccentric Coil Test (ECT), a Superconducting Magnet Test Facility"

D1-2 J. N. Luton and J. K. Ballou, "The Design of the Metastable Eccentric Coil Test"

D1-3 J. K. Ballou and J. N. Luton, "Optimization of the ECT Background Coils"

D1-4 P. L. Walstrom and T. C. Domm, "Toroidal Magnet Simulation Tests"

D1-5 J. E. Akin, "Finite Element Stress Analysis of High Field Solenoids"

D1-6 N. E. Johnson, W. H. Gray, and R. A. Weed, "Stress Analysis of Non-Homogenous, Transversely Isotropic Superconductor Solenoids"

D1-7 W. D. Cain, "Electromechanical Analyses of Toroidal Field Systems"

D1-8 H. Pih and W. H. Gray, "Photoelastic and Analytical Investigation of Toroidal Magnetic Field Coils"

D1-9 W. A. Fietz, R. E. McDonald, and J. R. Miller, "Preparation and Extrusion of Multifilamentary NbTi Conductor Billets"

D1-10 R. E. Schwall, "The Effect of Commonly Occurring Metallic Impurities on NbTi Superconducting Wire"

D1-11 C. T. Sun and W. H. Gray, "Theoretical and Experimental Characterization of Material Properties of Superconducting Coil Composites"

D1-12 L. Dresner, J. R. Miller, and G. W. Donaldson, "Propagation of Normal Zones in Composite Superconductors"

D1-13 H. T. Yeh, "Thermal Aspects of a Superconducting Coil for Fusion Reactor"

D1-14 E. L. Woods, "Superconducting Coil Protection"

D1-15 R. L. Brown, E. L. Allred, W. C. Anderson, P. B. Burn, R. I. Deaderick, G. M. Henderson, and E. F. Marguerat, "Large Superconducting Coil Fabrication Developments"

E1-2 J. W. Lue, H. A. Peterson, and R. W. Boom (Univ. of Wisc.), "Superconductive Energy Storage for Tokamak Fusion Reactors"

C2-8 R. W. Boom, K. W. Conn, and J. W. Lue (Univ. of Wisc.), "Magnetic Field and Neutron Wall Loading Scaling for Tokamak Reactors"

D2-1 M. O. Hoenig, Y. Iwasa, D. B. Montgomery, and M. J. Leupold (MIT), "Single-Phase Helium as Coolant for Superconducting Magnets"

D2-2 P. M. Rackov, C. D. Henning, and A. Petrovich (IGC), "Superconductor Joining Methods for Large CTR Magnets"

D2-13 J. A. Mayhall (Lockheed Missiles and Space Co., Inc.), "The Determination of Winding Stresses in a Toroidal Field Coil Magnet of Optimum Shape"

B3-5 J. E. Simpkins, "First Wall Coatings"

D3-1 C. T. Welch (Lockheed Missiles and Space Co., Inc.), "Bending-Free Shapes for Toroidal Magnet Field Coils with Concentrated Symmetric Reactions"

D3-12 W. E. Deeds and C. F. Dodd, "Analysis of Induction Phenomena in Thermonuclear Experiments"

A4-12 E. Rapperport, R. D. Hay, and P. G. Marston (Magnet Engineering Associates), "Electrical Insulation in Magnets for Fusion Reactors"

XI. TALKS

- H. M. Long, "Prospects of Toroidal SC Magnet Systems, Application in the US CTR Program," USSR Conference on Technical Applications of Superconductivity, Alushta, USSR, September 16, 1975.
- J. K. Ballou, M. S. Lubell, and W.C.T. Stoddart, EPR Summer Workshop, ORNL, September 9-10, 1975.
- R. W. Derby and M. S. Lubell, Presentation of an Overview of the SCMDP to the FPCC, ORNL, September 23, 1975.
- H. M. Long, Presentation at the SCMDP Review Panel Meeting, ORNL, October 29-30, 1975.
- M. S. Lubell, Review of Magnets and Fusion Reactor Technology, Uranium Enrichment Conference (attendees), ORNL, November 12, 1975.

Twenty-eight papers were presented at the Sixth Symposium on Engineering Problems of Fusion Research, San Diego, Calif., November 18-21, 1975. They are listed in Section X, Reports and Papers.

APPENDIX

Report Abstracts

- P. M. Rackov and C. D. Henning, Superconducting Joining Methods for Large CTR Magnets - Final Report, Intermagnetics General Corporation (Oct. 14, 1975).

Abstract

Various methods and techniques have been investigated for making conductor joints in large superconducting magnets for thermonuclear research. Samples of soldered, explosively-welded and electron beam-welded joints have been prepared by using flat monolithic NbTi superconductor. On the basis of mechanical and electrical tests performed on solders at 4.2 K, strong and ductile solders were selected for subsequent fabrication. Various explosive-welding and electron beam welding-configurations were explored. Electrical resistance of sample joints was measured at 4.2 K and at 7 T, confirming that joint surface resistivities of 10^{-8} ohm cm^2 were in accordance with a current transfer analysis. Tensile tests on joints were carried out at 77 K. Stress and strain distributions in the joints were analytically modeled and results were compared with strain gauge measurements at 77 K. Optimum procedures for incorporating joints in particular locations within the magnet were investigated, as well as assurance methods for the quality of the joint.

- E. S. Fisher, S. H. Kim, and R. W. Siegel, Progress Report on Study of Cyclic Stress Effects on Transport Properties of Superconducting Composite Materials in Liquid Helium: July 15 thru Oct. 15, 1975, Materials Science Division, Argonne National Laboratory (Oct. 27, 1975).

Abstract

Experiments carried out during this 3-month period are similar to those outlined in the previous Progress Report. Data, accumulated prior to this

reporting period, for electrical resistivity changes in OFHC copper were obtained from samples derived from one rod of material, purchased from Utility Brass Company. The latest experiments were carried out with samples of very similar impurity content and residual resistivity ratio (RRR) but supplied by American Metal Climax Corporation (AMAX). The annealed samples were cycled at 0.2% total strain in the exact manner as carried out for the Utility Brass samples, but the increase in ρ_d (defect resistivity) during cycling was significantly smaller. This difference in behavior has been traced to the difference in texture, or preferred orientation of the samples, rather than chemical composition or billet processing. One of the important questions in the design of a complex system of magnets is the possible effect of stress pulses from interacting magnetic fields. In this connection, several series of measurements were made to determine the lowest strain-level at which significant effects on the conductivity of the copper can be expected. No effects have been found at strains of 0.05% to 8,200 consecutive cycles at frequencies in the order of 1 Hz.

The assembling of equipment for monitoring critical current changes with stress cycling in superconducting ribbons is well underway. The split solenoid magnet, with 60 kG capabilities, and the cryostat have arrived from the manufacturers. A 2000 ampere power supply, for the critical current testing of tape samples, is available from the High Energy Physics Division of ANL. The sample holder and loading assembly to be used in conjunction with the 10 1/2 ft high Instron mechanical testing machine is over 50% completed in the ANL machine shop. Plans are to begin assembly by November 1, with preliminary testing of the sample loading scheme during November, 1975.

- A. J. Morehead, Joining of Cu-Clad NbTi Superconductor Ribbon, Progress Report, Metals and Ceramics Division, ORNL (Oct. 7, 1975).

Abstract

An evaluation of 16 candidate solders and 11 fluxes was carried out by performing 45 dip-finishing, wettability tests, and producing 40 sample lap joints. The lap joints were made using a resistance heating device developed for the program. The quality of soldered joints was examined by measuring the wetting angle of each joint produced. The measurements were accomplished by performing radiography on 24 of the joints, and subjecting 12 others to metallography. In addition a peel test was performed on 5 of the joints. A somewhat qualitative ranking of the tested solders and fluxes was obtained.

- L. Damicone, Electron Beam Weld Super Conductive Copper Strips, Final Report, LC-2748, Sciaky Bros., Inc., Chicago, Illinois (Oct. 14, 1975).

Abstract

Electron beam welded splices of monolithic superconductors (NbTi in a copper matrix) were made. Microphotographs indicate that good mechanical seam-type welds are possible using a variety of geometries. All attempts to make tack welds produced vaporized holes in the superconductor rather than puddle, and were therefore unsuccessful. Electrical and mechanical strain testing in suitable environments will be performed by the customer.

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95. D. L. Coffey, American Magnetics Inc., P.O. Box R, Oak Ridge, TN 37830.
96. Dr. D. N. Cornish, Lawrence Livermore Laboratory, P.O. Box 808, Livermore, CA 94550.
97. Joseph E. Darby, Jr., CTR Program, D208, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439.
98. Dr. Ronald W. Fast, Manager, Experimental Facilities, National Accelerator Laboratory, P.O. Box 500, Batavia, IL 60510
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104. Dr. Clifford K. Jones, Manager, Cryogenic Research Laboratory, Westinghouse Electric Corp., R&D Center, Pittsburgh, PA 15235.
105. Edwin E. Kintner, DCTR, ERDA, Washington, DC 20545.
106. Dr. Henry L. Laquer, Los Alamos Scientific Laboratory, P.O. Box 1663, Los Alamos, NM 87544.
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111. Alex Puron, General Atomic Company, P.O. Box 81608, San Diego, CA 92138.
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113. Dr. David J. Rose, Department of Nuclear Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139.
114. Carl H. Rosner, Intermagnetics General Corp., Charles Industrial Park, New Karner Road, Guilderland, NY 12084.
115. Dr. William B. Sampson, Brookhaven National Laboratory, Upton, Long Island, NY 11973.
116. Dr. Yoshio Sawada, Manager, Advanced Engineering Group, Heavy Apparatus Engineering Laboratory, Tokyo Shibaura Electric Co., Ltd., 4, 2-Chrome, Suehiro-cho, Tsurumi-ku, Yokohama, JAPAN.
117. Dr. Weston M. Stacy, Jr., Director, CTR Program, Bldg. 208, W115, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439.
118. Dr. John Stekly, Magnetic Corporation of America, 179 Bear Hill Road, Waltham, MA 02154.
119. Dr. Bruce P. Strauss, Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, IL 60510.
120. Dr. Clyde Taylor, Lawrence Livermore Laboratory, P.O. Box 808, L-384, Livermore, CA 94551.
121. Dr. Robert Thomas, General Atomic Company, P.O. Box 81608, San Diego, CA 92138.

- 122. Dr. J. M. Williams, DCTR, ERDA, Washington, DC 20545.
- 123. Dr. James Wong, Supercon, Inc., 9 Erie Drive, Natick, MA 01760.
- 124. Dr. Herbert H. Woodson, Chairman, Department of Electrical Engineering, The University of Texas at Austin, Austin, TX 78712.
- 125. Dr. Eugene J. Ziurys, DCTR, Washington, DC 20545.