

AD-A047 177

WESTINGHOUSE RESEARCH AND DEVELOPMENT CENTER PITTSBU--ETC F/G 9/3  
THEORY AND DESIGN OF ELECTRICAL ROTATING MACHINERY.(U)  
NOV 77 W J CARR

N00014-72-C-0432  
NL

UNCLASSIFIED

[of]

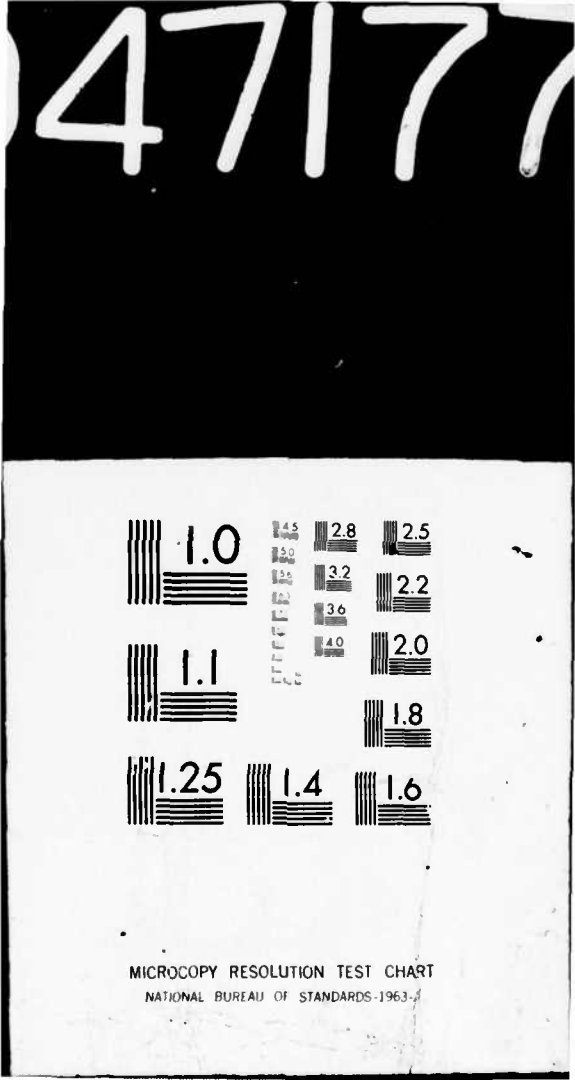
AD  
A047177



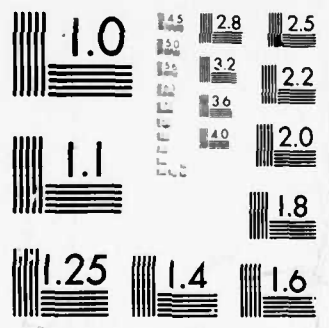
END  
DATE  
FILMED

1 - 78

DDC



47177



MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

AD A U 4 7 1 7 7

THEORY AND DESIGN OF ELECTRICAL  
ROTATING MACHINERY

12  
B.S.

Annual Report for Period  
Ending October 31, 1977

Submitted to  
Office of Naval Research  
in November 1977

Principal Investigator:  
W. J. Carr, Jr.

Sponsored by:  
Power Program ONR Contract No. N00014-72-C-0432

Identification NR097-385/12-5-72 (473)

DDC  
RECEIVED  
NOV 28 1977  
F

Approved for public release; distribution unlimited.  
Reproduction in whole or in part is permitted for any  
purpose of the United States Government.

AD No. \_\_\_\_\_  
DDC FILE COPY



Westinghouse R&D Center  
1310 Beulah Road  
Pittsburgh, Pennsylvania 15235

THEORY AND DESIGN OF ELECTRICAL  
ROTATING MACHINERY

Annual Report for Period  
Ending October 31, 1977

Submitted to  
Office of Naval Research  
in November 1977

Principal Investigator:  
W. J. Carr, Jr.

Sponsored by:  
Power Program ONR Contract No. N00014-72-C-0432

Identification NR097-385/12-5-72 (473)

Approved for public release; distribution unlimited.  
Reproduction in whole or in part is permitted for any  
purpose of the United States Government.



Westinghouse R&D Center  
1310 Beulah Road  
Pittsburgh, Pennsylvania 15235

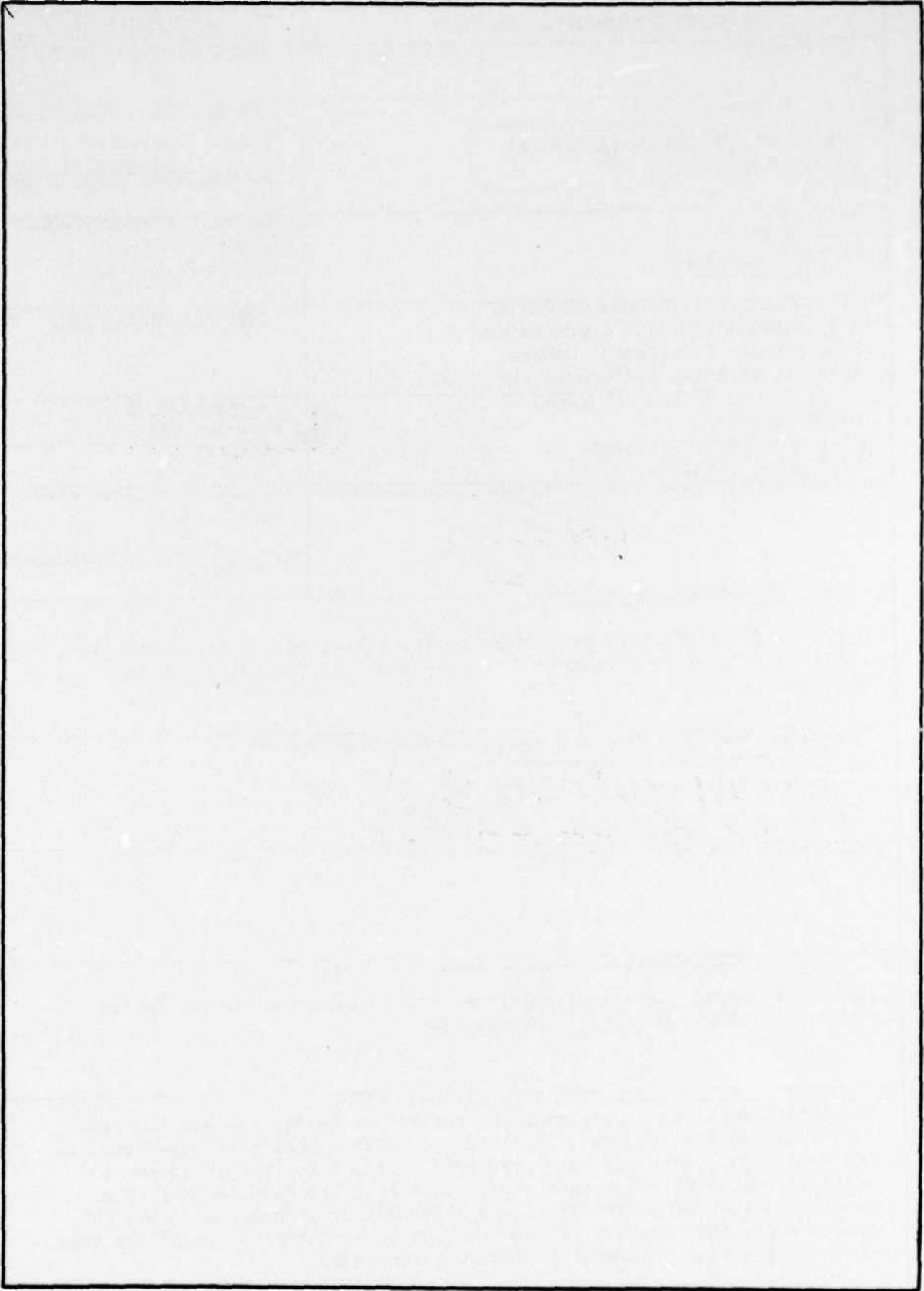
REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) <b>THEORY AND DESIGN OF ELECTRICAL ROTATING MACHINERY.</b>		5. TYPE OF REPORT & PERIOD COVERED Annual - November 1, 1976 to October 31, 1977
7. AUTHOR(s) <b>W. J. Carr, Jr.</b>		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS Westinghouse Electric Corporation Research and Development Center 1310 Beulah Road, Pittsburgh, PA 15235		8. CONTRACT OR GRANT NUMBER(s) <b>15</b> /N00014-72-C-0432 ✓
11. CONTROLLING OFFICE NAME AND ADDRESS Power Program Office of Naval Research Arlington, Virginia 22217		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) <b>12 21p.</b>		12. REPORT DATE <b>11</b> November 1977
		13. NUMBER OF PAGES
		14. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release, distribution unlimited. Reproduction in whole or in part is permitted for any purpose of the United States Government.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) <b>9 Annual rept. no. 5, 1 Nov 76 - 31 Oct 77,</b>		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Motors, Electric, Rotating, Superconducting, Superconductors, Losses, Hysteresis, Eddy Currents, Machines, AC		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The objective of this program is to contribute toward new and improved rotating machines for Naval applications, with emphasis on superconducting machinery. Work has been performed on the theory of ac losses in multifilament superconductors and experiments were made to check the theory. A list of publications and abstracts of scientific papers published under the contract is given. Some work on the design of the iron circuit of a normal homopolar motor was concluded.		

376 625

LB

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)



Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

ACCESSION No.	White Section <input checked="" type="checkbox"/>	Part Section <input type="checkbox"/>	<input type="checkbox"/>
RIS			
DOC			
UNANNOUNCED JUSTIFICATION			
BY	DISTRIBUTION/AVAILABILITY CODES		
DATE	AVAIL. INFO. OR SPECIAL		
	A		

TABLE OF CONTENTS

	<u>Page</u>
1.0 REPORTING PERIOD . . . . .	1
2.0 OBJECTIVES . . . . .	2
2.1 General . . . . .	2
2.2 Specific . . . . .	2
3.0 SUMMARY . . . . .	3
4.0 STUDIES OF AC LOSSES . . . . .	4
5.0 STUDIES ON HOMOPOLAR MOTORS . . . . .	6
6.0 PUBLICATIONS DURING THE PAST YEAR . . . . .	7
6.1 Longitudinal and Transverse Field Losses in Multifila- ment Superconductors . . . . .	7
6.2 Longitudinal Field Losses in Multifilament Supercon- ductors over a Range of Frequencies . . . . .	7
6.3 Alternating Field Losses in Filamentary Superconductor Carrying DC Transport Current . . . . .	8
6.4 Magnetic Circuit Design for a Homopolar Motor . . . . .	8
7.0 COMPLETE LIST OF PUBLICATIONS UNDER THE CONTRACT . . . . .	9
7.1 AC Loss in a Twisted Filamentary Superconducting Wire .	10
7.2 AC Loss in a Twisted Filamentary Superconducting Wire II . . . . .	10
7.3 Theory of Alternating Field Losses in Cylindrical Twisted Multifilamentary Superconductors . . . . .	10
7.4 Electromagnetic Theory for Filamentary Superconduc- tors . . . . .	10
7.5 Conductivity, Permeability and Dielectric Constant in a Multifilament Superconductor . . . . .	11
7.6 Alternating Field Loss in a Multifilament Supercon- ducting Wire for Weak AC Fields Superposed on a Constant Bias . . . . .	11

	<u>Page</u>
7.7 Loss Behavior in Twisted Filamentary Superconductors . . . . .	11
7.8 Possibility for an All-Superconducting Synchronous Motor or Generator . . . . .	12
7.9 Design Theory for a Fully Superconducting Synchronous Motor or Generator . . . . .	12
7.10 Eddy Current Losses in Twisted Multifilamentary Superconductors . . . . .	12
7.11 A Low-Speed Direct Current Superconducting Heteropolar Motor . . . . .	12
7.12 Hysteresis Loss in a Multifilament Superconductor . . . . .	13
7.13 Parallel Field Losses in Twisted Multifilament Superconductors . . . . .	13
7.14 Longitudinal and Transverse Field Losses in Multifilament Superconductors . . . . .	14
7.15 Longitudinal Field Losses in Multifilament Superconductors over a Range of Frequencies . . . . .	14
7.16 Alternating Field Losses in Filamentary Superconductor Carrying DC Transport Current . . . . .	15
7.17 Magnetic Circuit Design for a Homopolar Motor . . . . .	15
8.0 PROGRAM PERSONNEL . . . . .	16
9.0 DISTRIBUTION LIST . . . . .	17

1.0 REPORTING PERIOD

This is the fifth annual technical report and covers the work from November 1, 1976 to October 31, 1977.

## 2.0 OBJECTIVES

### 2.1 General

The objectives of the program are to contribute toward new and improved rotating machines for Naval applications, particularly in the area of superconducting machinery.

### 2.2 Specific

A specific objective was to study the ac loss which occurs in multifilament superconductors, with the object of providing the information needed for the design of stable low-loss conductors for use in rotating machines.

A smaller part of the program was used to investigate normal homopolar motors.

### 3.0 SUMMARY

This annual report is in the nature of a status report of unfinished tasks and a summary of technical publications made during the past year and during the life of the contract. Completed tasks have all been published, or are scheduled for publication in the scientific literature, and therefore are not discussed at length in this report. Abstracts of the work, and the Journal of Publications are listed at the end.

Approximately 90% of the funding on this program was spent in the study of ac losses in multifilament superconductors. This is a basic research program to study losses, with the primary objective of the program being an understanding of the various loss mechanisms, and the development of methods for accurately calculating losses under various conditions of possible interest in regard to superconducting rotating machines.

Although it is obvious from a study of the recent literature on ac losses that some problems still remain to be solved, even in the relatively simple cases of transverse and longitudinal fields in the absence of transport current, for the most part these losses are now understood. In particular considerable progress has been made under this contract in understanding longitudinal field losses during the past year. In addition some progress was made on the combined effects of transport current and applied magnetic fields. However, the latter is a large area of unfurnished work and demands the most attention in the future.

The work done on this project which was not directly connected with ac losses was connected with the theory of homopolar machines containing an iron path for the flux. A method for shaping the iron path was developed, which eliminates the necessity for a compensating winding to prevent circumferential saturation of the iron.

#### 4.0 STUDIES OF AC LOSSES

Interest in ac loss theory and the need for more accurate calculations from the standpoint of superconducting machinery design arises in two ways: (1) where the ac loss is small and the interest is in the proper amount of cooling needed to remove the heat and (2) where the ac losses are large and form the primary design limitation. AC loss due to ripples in a dc magnetic field and loss due to slow switching of the field usually produce no problem if they are well understood and predictable, so that adequate cooling can be provided for, and a proper conductor design can be selected. The question here is reliability at minimum cost. To obtain this information entirely from the construction and testing of experimental machines would require too long a time period and would be very expensive.

The second category is connected with the possibility of using superconductors in a primarily ac field, and future hopes for revolutionary machine design. The rate of recent progress in conductor design, and in the understanding of the various loss mechanisms which dictate a given design, indicate the likelihood that superconductors can be developed for fully ac applications. The attainment of this goal would open the possibility of new designs and new types of superconducting machinery.

The work which has been done under this contract, to date, has been mainly concerned with understanding the loss mechanisms due to a transverse or a longitudinal applied magnetic field in the absence of transport current in the conductor. The results may be used for the case where the transport current is small, but not for the case where a transport current that is an appreciable fraction of the critical current is flowing in the conductor. A reasonably good understanding of these losses has now been obtained, and for the most part measurements which have been made agree rather closely with the calculations. During the past year

some loss measurements have been reported in the literature which purport to disagree with the theory. Some of these findings are simply the result of not properly applying the theory to the special conditions which exist. Other cases, however, seem to require a close look, to see if some modification in the theory is required. In the case of longitudinal field losses the general theory has been completed only during the past year and not enough measurements are yet available to check the calculations.

Obviously before the theory is complete, an understanding of the effect of transport current on the loss must be developed. An attack on this problem was started during the past year but the work is far from complete. The particular aspect which was investigated was the effect of a dc transport current on the transverse field losses. The results were reported at the CEC-ICMC Conference in Boulder, Colorado.

## 5.0 STUDIES ON HOMOPOLAR MOTORS

In a conventional homopolar motor or generator with an iron circuit for the magnetic flux, problems arise due to saturation of the iron in the circumferential direction, which decreases the useful flux across the air gap. This problem is generally solved by the use of a compensating winding. However the compensating winding adds to the copper loss and increases the effective air gap. A magnetic circuit design using optimized circumferential air gaps in the iron has been designed which avoids the necessity of a compensating winding. This work will be reported on at the next winter meeting of the IEEE Power Engineering Society.

## 6.0 PUBLICATIONS DURING THE PAST YEAR

1. W. J. Carr, Jr., "Longitudinal and Transverse Field Losses in Multifilament Superconductors," IEEE Transactions on Magnetics, Vol. MAG-13, 192 (1977).

Abstract: A review is given of the method of calculating losses in a composite twisted multifilament superconductor based on the anisotropic continuum model, and a summary of results are shown for the loss as a function of frequency due to longitudinal and transverse applied fields. In both cases three frequency ranges may be distinguished in which (1) the magnetic field in the superconductor is just the applied field, (2) the field produced by internal currents becomes important, and (3) skin effect develops in the eddy currents, which flow transverse to the filaments. In addition to these losses in the body of the superconductor (characterized by a vanishing component of electric field parallel to the filament axes), the losses in the current saturated boundary layer is described. Some discussion is also given on the use of ac field losses in calculating the "ramped" field case.

2. W. J. Carr, Jr., "Longitudinal Field Losses in Multifilament Superconductors over a Range of Frequencies," J. Appl. Phys., 2022 (1977).

Abstract: The power loss in a twisted multifilament superconductor due to a time-dependent longitudinal magnetic field is calculated as a function of frequency. The longitudinal field is assumed to have a sinusoidal dependence on both space and time, alternately changing direction along the conductor over a length  $\ell$ . The eddy current loss, as a function of frequency, initially is approximately proportional to  $\ell^2$  and rises as the square of the frequency, until it reaches a plateau which tends to be frequency independent and inversely proportional to  $\ell^2$ . After a further increase with frequency, the skin effect region is reached

with frequency to the one-half power dependence. The current-density distribution in the conductor is calculated, and it is shown that for large  $\ell$  the entire cross section of the conductor can become current saturated if the amplitude of the ac field is greater than  $L\lambda j_c$  where  $L$  is the twist length,  $j_c$  is the critical current density, and  $\lambda$  is the fraction of superconductor.

3. W. J. Carr, Jr., J. H. Murphy, and G. R. Wagner, "Alternating Field Losses in Filamentary Superconductor Carrying DC Transport Current," To appear in the Proceedings of the CEC-ICMC Meeting in Boulder, CO 1977.

Abstract: Alternating field losses in multifilament superconductors have been calculated previously only for special limiting cases, i.e., for the case of full field penetration of the filaments, or for the case of no transport current. From these limiting values interpolation formulas are given here for the full range of alternating field and dc transport current, assuming only that the frequency is below the critical frequencies for internal field effects, and that saturation effects in the outer filaments may be neglected. The results are compared with some measurements.

4. W. J. Carr, Jr., "Magnetic Circuit Design for a Homopolar Motor," Westinghouse Research Report 76-9C30-MACON-P2. Submitted to the Winter Meeting IEEE Power Engineering Society in New York, January 1978.

Abstract: The use of iron to enhance the flux density in a homopolar machine is limited by the presence of a large circumferential field which tends to saturate the iron in the wrong direction. It is shown that the use of an iron structure with optimized circumferential gaps can overcome this difficulty, and in many cases eliminate the necessity of a compensating current.

## 7.0 COMPLETE LIST OF PUBLICATIONS UNDER THE CONTRACT

1. W. J. Carr, Jr., "AC Loss in a Twisted Filamentary Superconducting Wire," *Journal of Applied Physics*, 45:929 (1974).

Abstract: Calculations are made for the ac losses in a twisted filamentary superconductor by assuming a continuum model with anisotropic conductivity. The Maxwell equations are solved for a long wire of radius  $R_0$  and twist length  $L$ . In terms of the classical skin depth  $\delta$ , appropriate for the conductivity perpendicular to the filaments, the losses are calculated for an applied magnetic field transverse to the wire axis in the case of (1) a uniform field ( $\sqrt{2} R_0/\delta \ll 1$ ,  $L/2\pi\delta \ll 1$ ), (2) shielding from surface currents ( $\sqrt{2} R_0/\delta \ll 1$ ,  $L/2\pi\delta \gg 1$ ), and (3) skin effect ( $\sqrt{2} R_0/\delta \gg 1$ ). Losses are also calculated for the case of a transport current in no applied field. The model can be used in more general cases and has the virtue of giving precise results with a minimum of auxiliary postulates.

2. W. J. Carr, Jr., "AC Loss in a Twisted Filamentary Superconducting Wire II," *Journal of Applied Physics*, 45:935 (1974).

Abstract: Hysteresis losses in a twisted filamentary superconducting wire are calculated for various cases corresponding to complete penetration of the magnetic field into the wire, shielding of the field by the supercurrents, and shielding due to eddy currents. In general, the wire may be divided into two regions: an outer saturated layer which tends to behave at the higher frequencies like a solid superconductor, and the interior where the average parallel electric field vanishes and the wire behaves like a collection of individual filaments.

3. J. H. Murphy, M. S. Walker, and W. J. Carr, Jr., "Theory of Alternating Field Losses in Cylindrical Twisted Multifilamentary Superconductors," Intermag Conf. Proc., IEEE Trans. Mag., 10:868 (1974).

Abstract: The theory of sinusoidal alternating field losses in a cylindrical multifilamentary superconducting wire is discussed. Hysteresis loss expressions are presented for the individual filament losses in the interior of the wire when these filaments are completely penetrated, and for the loss occurring in an outer current-saturated layer of the wire. The loss expressions presented were determined assuming a continuum model with anisotropic conductivity for the superconductor. The case of a permeability different from unity, applicable for weak fields, is discussed.

4. W. J. Carr, Jr., "Electromagnetic Theory for Filamentary Superconductors," Physical Review B, 11:1547 (1975).

Abstract: It is shown that a multifilament superconductor, made up of a bundle of twisted filaments embedded in a normal matrix, can be treated as a new state of matter with anisotropic electrical and magnetic properties. Macroscopic electromagnetic field vectors, which satisfy Maxwell's equations, are defined in terms of averages over the "microscopic" fields. However, the sources for the field, i.e., the current and charge densities and the magnetization and polarization, differ in some respects from those for ordinary matter. In particular, since the elementary magnetic dipole moments are distributed along lines rather than located at fixed points, the definition of the magnetization transverse to the filaments differs by a factor of 2 from that for ordinary matter, and the definition of the macroscopic current density is also slightly modified. Constitutive relationships among the field vectors in terms of permeabilities, dielectric constants, and conductivities are examined in the limits of strong and weak fields.

5. W. J. Carr, Jr., "Conductivity, Permeability and Dielectric Constant in a Multifilament Superconductor," *Journal of Applied Physics*, 46:4043 (1975).

Abstract: Results are given for the permeability, conductivity, and dielectric constant of a multifilament superconductor, treated as an anisotropic state of matter. The calculations are made for the limiting cases of strong and weak ac magnetic fields compared with the field required for complete penetration of the filaments. General expressions are given for the ac power loss.

6. W. J. Carr, Jr., M. S. Walker, and J. H. Murphy, "Alternating Field Loss in a Multifilament Superconducting Wire for Weak AC Fields Superposed on a Constant Bias," *Journal of Applied Physics*, 46:4048 (1975).

Abstract: Expressions are given for the alternating field loss in a twisted filamentary superconductor as a function of frequency and magnetic field, for the case of small ac applied fields which do not completely penetrate the filaments. The ac field is superimposed on a fixed bias field. In this limit the effective diamagnetism of the filament leads to a permeability less than unity for the composite. Expressions are presented for both the hysteresis and the eddy current loss.

7. M. S. Walker, W. J. Carr, Jr., and J. H. Murphy, "Loss Behavior in Twisted Filamentary Superconductors," *IEEE Trans. on Magnetics*, MAG-11, 1475 (1975).

Abstract: A careful comparison between theory and experiment is made for the transverse alternating field eddy current losses in three twisted mixed-matrix filamentary superconductors of the composition  $3\text{CuNi}:3\text{Cu}:1\text{NbTi}$ . The measurements were made over a wide frequency range, up to  $10^6$  Hz. Good agreement is obtained.

8. W. J. Carr, Jr., "Possibility for an All-Superconducting Synchronous Motor or Generator," Westinghouse Research Report 73-9J2-MACON-R1.

Abstract: Possibilities for a motor or generator with superconducting armature and field winding are discussed, and the ac losses that would be expected in the armature winding are calculated.

9. W. J. Carr, Jr., "Design Theory for a Fully Superconducting Synchronous Motor or Generator," Westinghouse Research Report 73-9J2-MACON-R2.

Abstract: Theory is developed for a superconducting synchronous motor or generator having both the field and the armature windings superconducting. An approximate design is given for a four-pole 30 MW operating at 180 rpm.

10. J. H. Murphy and W. J. Carr, Jr., "Eddy Current Losses in Twisted Multifilamentary Superconductors," Westinghouse Research Report 73-9J2-MACON-R3.

Abstract: Calculations are made for the eddy current losses in a multifilament superconductor having a copper sheath.

11. L. N. Wedman, "A Low Speed Direct Current Superconducting Heteropolar Motor," Report EM4562.

Abstract: Important progress in assessing the limits of ratings for new concept electrical machines for ship propulsion applications has been achieved. The superconducting heteropolar motor has been identified as the most promising machine concept for slow-speed, high-power use. Maximum utilization of the drum homopolar machine is limited by transmission line current ratings, and may be greatly improved if an in-line drive is required, thus allowing the use of the homopolar torque converter. The magnetic disc homopolar motor with water cooling appears to be the preferred concept for low-speed homopolar motor applications. Technical progress in the conceptual configuration of the superconducting

heteropolar machine is presented, together with a report on progress on the solution of commutation problems in such machines.

12. W. J. Carr, Jr., M. S. Walker, D. W. Deis, and J. H. Murphy, "Hysteresis Loss in a Multifilament Superconductor," *Advances in Cryogenic Engineering*, 22, 428 (1977).

Abstract: Theory of hysteresis loss in a multifilament superconductor is reviewed and measurements are presented for a mixed-matrix NbTi conductor. The measurements were made calorimetrically as a function of frequency and transverse ac magnetic field, for a 50 kOe dc bias field, and also with no bias. Both a linear ac field dependence and a cubic field dependence were observed, corresponding to the case of complete penetration of the filaments, and partial penetration. Comparison of experiment with calculation was made by evaluating the critical current density from the measurements and the loss expression, and comparing this value with a direct measurement of  $j_c$  from transport current. Good agreement was obtained.

13. W. J. Carr, Jr., "Parallel Field Losses in Twisted Multifilament Superconductors," *Sixth Symposium on Engineering Problems of Fusion Research*, IEEE Pub. No. 75CH1097-5-NPS (1975), p. 152.

Abstract: In some applications of multifilament superconducting wire an appreciable component of a time dependent magnetic field exists along the twisted filaments, and across the matrix, and loss and stability problems are introduced. It has been suggested by various authors that these effects can be minimized by periodically introducing reverse twist in the wire. A calculation is given for the eddy current loss that can be expected for such a conductor. The calculation also applies for the case where the twist is uniform but the direction of the magnetic field reverses along the length of the conductor.

14. W. J. Carr, Jr., "Longitudinal and Transverse Field Losses in Multifilament Superconductors," IEEE Transactions on Magnetics, Vol. MAG-13, 192 (1977).

Abstract: A review is given of the method of calculating losses in a composite twisted multifilament superconductor based on the anisotropic continuum model, and a summary of results are shown for the loss as a function of frequency due to longitudinal and transverse applied fields. In both cases three frequency ranges may be distinguished in which (1) the magnetic field in the superconductor is just the applied field, (2) the field produced by internal currents becomes important, and (3) skin effect develops in the eddy currents, which flow transverse to the filaments. In addition to these losses in the body of the superconductor (characterized by a vanishing component of electric field parallel to the filament axes), the losses in the current saturated boundary layer is described. Some discussion is also given on the use of ac field losses in calculating the "ramped" field case.

15. W. J. Carr, Jr., "Longitudinal Field Losses in Multifilament Superconductors over a Range of Frequencies," J. Appl. Phys., 2022 (1977).

Abstract: The power loss in a twisted multifilament superconductor due to a time-dependent longitudinal magnetic field is calculated as a function of frequency. The longitudinal field is assumed to have a sinusoidal dependence on both space and time, alternating changing direction along the conductor over a length  $\ell$ . The eddy current loss, as a function of frequency, initially is approximately proportional to  $\ell^2$  and rises as the square of the frequency, until it reaches a plateau which tends to be frequency independent and inversely proportional to  $\ell^2$ . After a further increase with frequency, the skin effect region is reached with frequency to the one-half power dependence. The current-density distribution in the conductor is calculated, and it is shown that for large  $\ell$  the entire cross section of the conductor can become current saturated if the amplitude of the ac field is greater than  $L\lambda j_c$  where  $L$  is the twist length,  $j_c$  is the critical current density, and  $\lambda$  is the fraction of superconductor.

16. W. J. Carr, Jr., J. H. Murphy, and G. R. Wagner, "Alternating Field Losses in Filamentary Superconductor Carrying DC Transport Current," To appear in the Proceedings of the CEC-ICMC Meeting in Boulder, CO 1977.

Abstract: Alternating field losses in multifilament superconductors have been calculated previously only for special limiting cases, i.e., for the case of full field penetration of the filaments, or for the case of no transport current. From these limiting values interpolation formulas are given here for the full range of alternating field and dc transport current, assuming only that the frequency is below the critical frequencies for internal field effects, and that saturation effects in the outer filaments may be neglected. The results are compared with some measurements.

17. W. J. Carr, Jr., "Magnetic Circuit Design for a Homopolar Motor," Westinghouse Research Report 76-9C30-MACON-P2. Submitted to the Winter Meeting IEEE Power Engineering Society in New York, January 1978.

Abstract: The use of iron to enhance the flux density in a homopolar machine is limited by the presence of a large circumferential field which tends to saturate the iron in the wrong direction. It is shown that the use of an iron structure with optimized circumferential gaps can overcome this difficulty, and in many cases eliminate the necessity of a compensating current.

## 8.0 PROGRAM PERSONNEL

The personnel who have contributed to this program are as follows:

W. J. Carr, Jr. - Consultant in Magnetism and Superconductivity

J. H. Murphy - Engineer, Cryogenics

G. R. Wagner - Physicist, Cryogenics.

Consultation has been provided by other members of the Machinery and Cryogenics Groups.

9.0 DISTRIBUTION LIST

	<u>Number of Copies</u>
Office of Naval Research 800 North Quincy Street Arlington, VA 22217	
Attention: Mr. K. Ellingsworth	3
Mr. E. Edelsack	1
Commanding Officer	1
Office of Naval Research Branch Office Box 39, FPO New York 09510	
Director	
U. S. Naval Research Laboratory Washington, DC 20390	
Attention: Technical Information Division	6
Dr. R. A. Hein	1
Dr. E. H. Takken	1
Defense Documentation Center	12
Cameron Station Alexandria, VA 22314	
Commander	
Naval Ships Systems Command Department of the Navy Washington, DC 20360	
Attention: Mr. A. Chaikin	1
Mr. J. C. Grigg	1
Commander	
Naval Ship Engineering Center Center Building Prince Georges Center Hyattsville, MD 20782	
Attention: Mr. D. Schmucker	2

	<u>Number of Copies</u>
<b>Commander</b> Naval Ship R&D Laboratory Annapolis, MD 21402	
Attention: Dr. H. Boroson	1
Dr. E. Quandt	1
Dr. W. J. Levedahl	1
Mr. H. O. Stevens	1
Mr. T. J. Doyle	1
<b>Headquarters</b> Naval Material Command Department of the Navy Washington, DC 20360	
Attention: Mr. R. V. Vittucci	1
<b>Office of the Chief of Naval            Operations</b> Washington, DC 20350	
Attention: Mr. H. Cheng	1
Dr. R. Burns	1
<b>Office of the Assistant Secretary            of the Navy (R&amp;D)</b> Pentagon, Room 4E741 Washington, DC 20350	
Attention: Mr. J. Probus	1
<b>Naval Undersea Research and            Development Center</b> San Diego, CA 92132	
Attention: Dr. T. G. Lang	1
<b>Advanced Research Projects Agency</b> 1400 Wilson Boulevard Arlington, VA 22209	
Attention: Dr. E. C. Van Reuth	1
<b>Massachusetts Institute of Technology</b> Cryogenic Engineering Laboratory Cambridge, MA 02139	
Attention: Professor Joseph Smith	1

Number  
of Copies

General Electric Company  
P. O. Box 43  
Schenectady, NY 12301

Attention: Mr. G. R. Fox	1
Dr. J. A. Mirabal	1
Dr. M. J. Jefferies	1
Mr. B. D. Hatch	1

National Bureau of Standards  
U. S. Department of Commerce  
Boulder, CO 80302

Attention: Mr. R. H. Kropschot	1
--------------------------------	---

University of Colorado  
Electrical Engineering  
Boulder, CO 80302

Attention: Professor J. Fuller	1
--------------------------------	---

U. S. Atomic Energy Commission  
Applied Technology Division  
Germantown, MD 20545

Attention: Dr. G. Johnson	1
---------------------------	---

Garrett Corporation  
Cafritz Building  
1625 "I" Street, N.W.  
Washington, DC 20006

1

Arthur D. Little, Inc.  
Acorn Park  
Cambridge, MA 02140

1

Air Research Manufacturing Company  
9851-9951 Sepulveda Boulevard  
Los Angeles, CA 90009

1

J. Thomas Broach - STSFA-EA  
U. S. Army Mobility Equipment  
Research and Development Center  
Fort Belvoir, VA 22060

1

Number  
of Copies

C. O., USAMERDC  
Electrotech Department  
Electrical Equipment Division  
Fort Belvoir, VA 22060

Attention: STSFB-EA (Dr. W. D. Lee)

1

Mr. Charles E. Oberly  
AFAPL/POD-1  
Wright-Patterson AFB, OH 45433

1

LME