BROOKHAVEN NATIONAL LABORATORY

MAGNET DIVISION NOTES

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Title: Critical Currents of Heat Treated RHIC Wires

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Introduction

Heat treatments at relatively low temperatures and short times are used in molding magnet coils and sometimes to anneal wire prior to cabling. As the usual treatments produce small changes in the superconducting critical currents, measurements were made at higher temperatures and for longer times in order to make clear the trends in degradation and limits which should not be exceeded.

Experimental Procedure

A length of RHIC wire was cut into 24 3 ft. samples. In the tables which follow these are listed in the order in which they were cut. Five samples served as controls. The others were heated in argon at 10^{-5} mm Hg for the times and temperatures indicated in the tables. The heat up and cool down times were about 10 minutes. The effect of this is small except for the "1/3 hr" points which would shift slightly; no correction for this has been made, however.

Standard short sample tests were made for each wire sample: critical current, Ic, quench current, Iq, n-value of the superconducting transition, room temperature resistance, R295, and residual resistance ratio, RRR. From the resistance the copper-to-superconductor ratio, C/S, was calculated. Definitions and details of the experimental methods are given in the references.

Results

Results are given in three tables of measured and calculated quantities and in four graphs which show the isothermal and isochronous behavior of the critical current for fields of 5T and 7T.

Table 1 - Resistance Data. The values of R295, RRR, and C/S are essentially constant for the control samples. It can be seen that relatively mild heat treatments produce high RRR values in these wires; e.g., 225°C for 20 minutes raises RRR above 200. In the first three groups of wires, i.e., those at 150, 225, and 300°C, the resistance changes from 753 ohms to 737 ohms, the latter being nearly the ideal resistivity of the copper matrix at 295 K. The calculated C/S values for these three groups of wires are a little higher than for the controls (average value for the heated wires, 2.244 vs 2.218 for the controls). This indicates an error in the formula for calculating C/S, which is insignificant for practical purposes, however. On the other hand, the variation in the last group of wires, at 350°C, is real: R295 increases and C/S decreases. Since RRR also increases, presumably part of the copper matrix becomes poisoned by diffusion of some impurity element.

Table 2 - Critical Currents at 5T. The critical currents of the first two groups of wires, 150 and 225°C, are approximately constant and are higher than the average of the

control wires by about 2%. (The listed Jc's are about 3% higher as they are calculated using the calculated C/S values.) As the RRR values are greater than 165 in all cases it appears that this increase occurs entirely in the early stages of the heat treatment. For the higher temperatures, 300 and 350°C, serious degradation of critical current occurs after times of the order of a few minutes. Two interesting facts are associated with this degradation. First, the n-values increase; thus none of the decrease in critical current is due to change in shape of the transition curve. Second, the ratio of quench current to critical current does not vary much among all samples. The average values for the various groups were 1.080, 1.078, 1.076, 1.057, and 1.068, respectively, for the control, 150, 225, 300, and 350°C groups. This ratio is not sensitive to the copper matrix resistivity, therefore.

Table 3 - Critical Currents at 7T. The behavior is similar to that at 5T except that some degradation occurs at 225°C for the longer times. The quench current/critical current ratios are all about 1.10. An additional quantity listed in this table is the ratio Ic(5T)/Ic(6T) which increases significantly as the degradation increases.

Figures - Ic (4.22K)

1. Isochronous behavior, 5T
2. Isochronous behavior, 7T
3. Isothermal behavior, 5T
4. Isothermal behavior, 7T

Acknowledgements:

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References:

1. W. B. Sampson, "Procedures for Measuring the Electrical Properties of Superconductors for Accelerator Magnets", Proceedings of the ICFA Workshop on Superconducting Magnets and Cryogenics, Brookhaven National Laboratory, Publication No. 52006, pp. 153-156, 1986.

2. M. Garber and W. B. Sampson, "Test Methods for Short Sample Critical Current Determination of Twisted Multifilamentary Superconducting Wire", SSC Technical Note SSC-MD-89, Brookhaven National Laboratory, January 1985 (unpublished).

3. M. Garber and W. B. Sampson, "Test Method for Normal State Resistance of NBTi Superconducting Wire", SSC Technical Note SSC-MD-88, Brookhaven National Laboratory, January 1985 (unpublished).

TABLE 1 RESISTANCE DATA (B=0)

#	TEMP(°C)	TIME(HRS)	R295(Ω/cm)	RRR	C/S
1	CONTROL		752	47	2.23
2	150	1	741	165	2.22
3	"	3	736	237	2.26
4	"	10	738	205	2.24
5	"	30	737	223	2.25
6	CONTROL		753	46	2.22
7	225	1/3	737	230	2.25
8	"	1	738	254	2.24
9	"	3	738	231	2.24
10	"	10	738	246	2.24
11	"	30	737	263	2.25
12	CONTROL		753	47	2.161
13	300	1/3	737	254	2.25
14	"	1	737	254	2.24
15	"	3	737	263	2.24
16	"	10	737	263	2.25
17	"	30	737	283	2.25
18	CONTROL		753	48	2.21
19	350	1/3	736	263	2.26
20	"	1	737	273	2.24
21	"	3	738	273	2.23
22	"	10	744	286	2.18
23	"	30	750	289	2.12
24	CONTROL		753	47	2.21

TABLE 2 CRITICAL CURRENT DATA AT 5T, 4.22K

#	TEMP (°C)	TIME (HRS)	I_c (AMPS)	I_Q (AMPS)	n-VALUE	J_c (A/mm²)
1	CONTROL		278	299	42	2730
2	150	1	284	307	41	2780
3	"	3	282	304	41	2800
4	"	10	285	307	41	2810
5	"	30	285	307	39	2820
6	CONTROL		277	300	40	2720
7	225	1/3	282	305	36	2790
8	"	1	281	302	41	2770
9	"	3	285	306	42	2810
10	"	10	284	305	43	2800
11	"	30	284	305	42	2810
12	CONTROL		279	299	43	2730
13	300	1/3	279	295	41	2760
14	"	1	276	295	45	2720
15	"	3	266	282	46	2620
16	"	10	250	260	48	2470
17	"	30	218	230	45	2160
18	CONTROL		278	301	42	2720
19	350	1/3	261	276	44	2590
20	"	1	234	251	46	2310
21	"	3	215	229	47	2110
22	"	10	163	174	48	1580
23	"	30	132	142	52	1250
24	CONTROL		275	299	41	2690

TABLE 3 CRITICAL CURRENT DATA AT 7T, 4.22K

#	TEMP (°C)	TIME (HRS)	I_c (AMPS)	I_Q (AMPS)	n-VALUE	J_c (A/mm²)	$I_c(5T)/I_c(6T)$
1	CONTROL		164	183	35	1610	1.26
2	150	1	167	185	34	1630	1.26
3	"	3	162	178	37	1610	1.27
4	"	10	168	184	36	1660	1.26
5	"	30	167	184	36	1650	1.26
6	CONTROL		164	184	34	1610	1.26
7	225	1/3	166	183	34	1640	1.26
8	"	1	159	175	38	1570	1.28
9	"	3	164	180	37	1620	1.27
10	"	10	161	177	37	1590	1.28
11	"	30	158	175	38	1560	1.29
12	CONTROL		165	183	37	1610	1.26
13	300	1/3	159	182	38	1570	1.27
14	"	1	153	167	40	1510	1.29
15	"	3	143	156	42	1410	1.30
16	"	10	131	140	40	1300	1.31
17	"	30	110	118	40	1090	1.33
18	CONTROL		164	183	36	1600	1.26
19	350	1/3	143	155	40	1420	1.29
20	"	1	124	136	41	1220	1.31
21	"	3	112	123	41	1100	1.32
22	"	10	80.3	90	43	780	1.34
23	"	30	61.6	69	43	580	1.36
24	CONTROL		162	182	36	1580	1.26

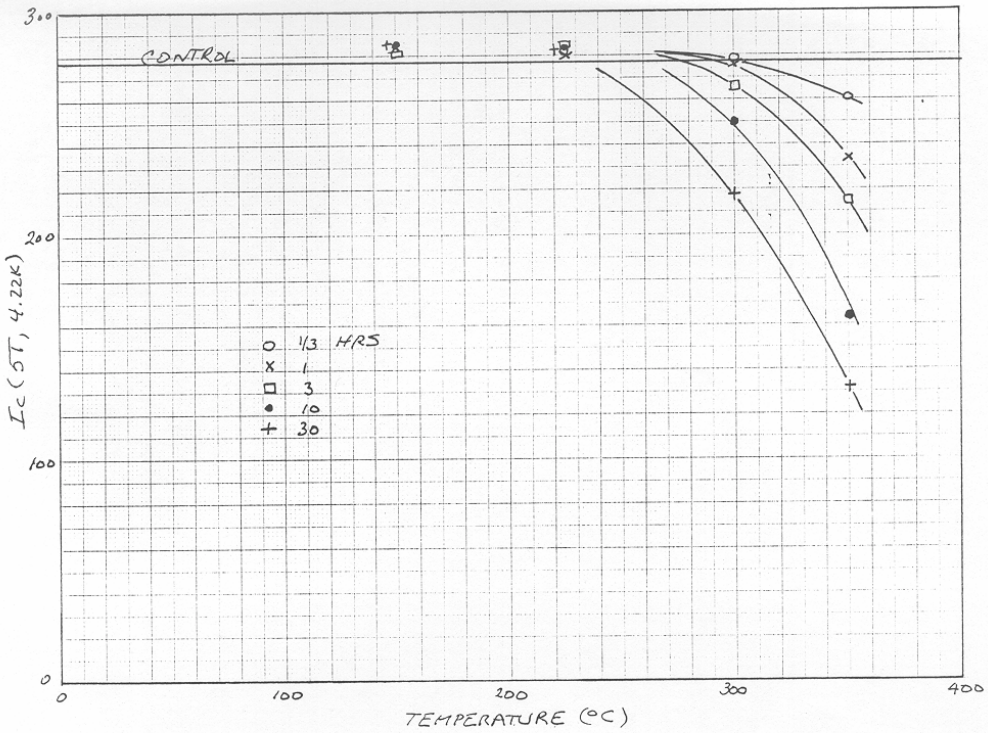

CONTROL
1/3 HRS
1
3
10
30
Ic (5T, 4.22K)
300
200
100
0
0
100
200
300
400
TEMPERATURE (°C)

Fig. 1

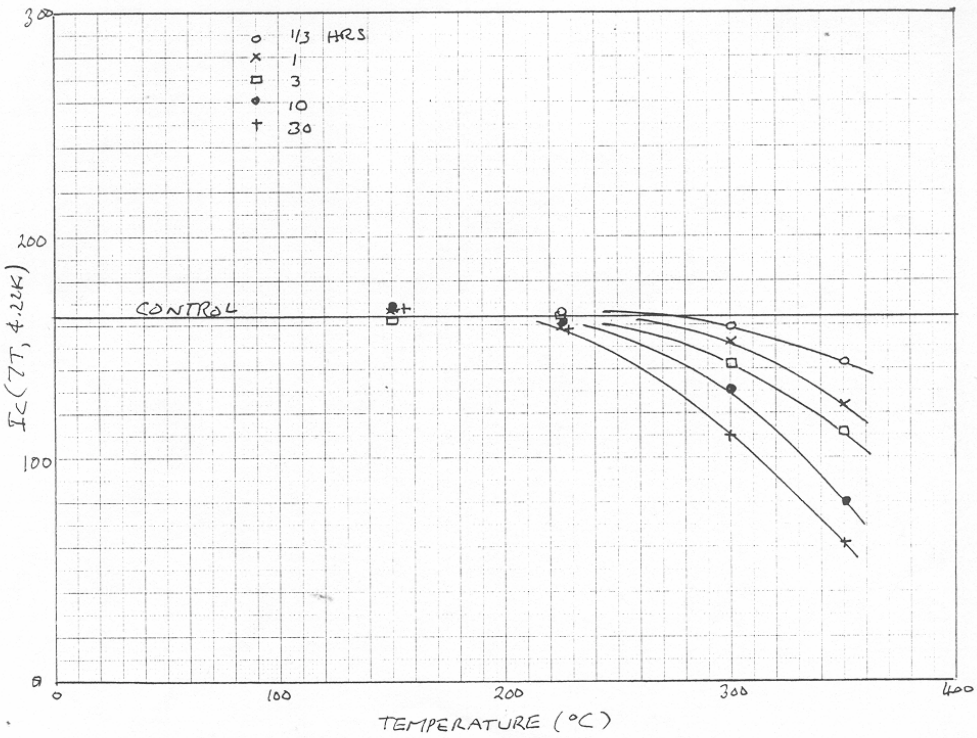

1/3 HRS
1
3
10
30
CONTROL
Ic (7T, 4.22K)
300
200
100
0
0
100
200
300
400
TEMPERATURE (°C)

Fig. 2

Fig. 3

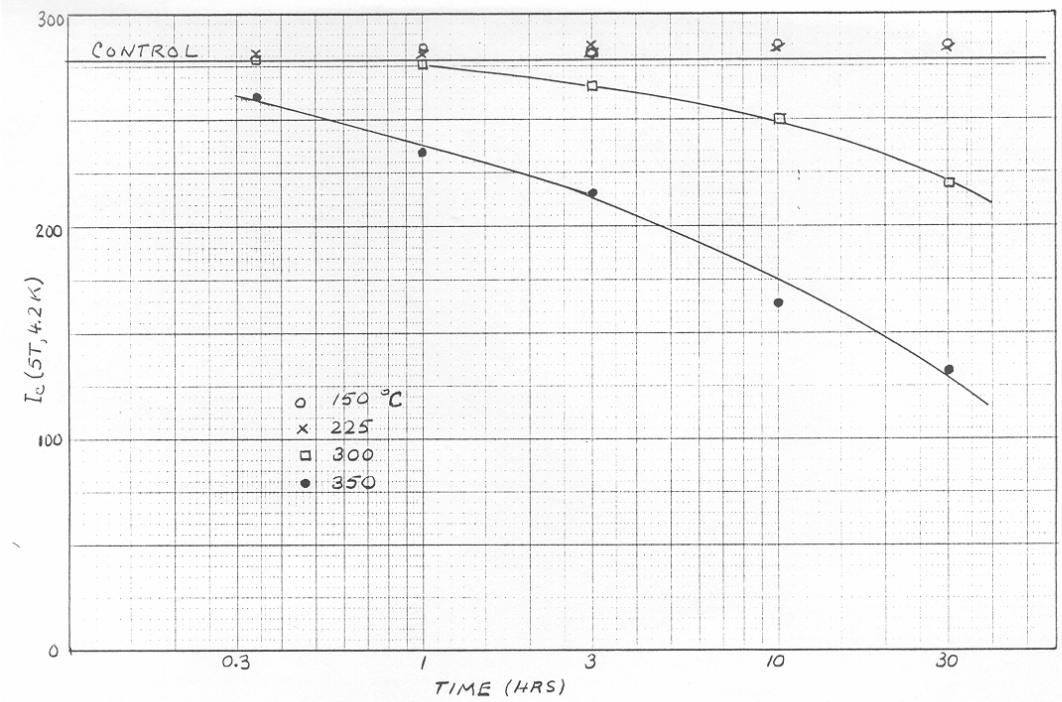
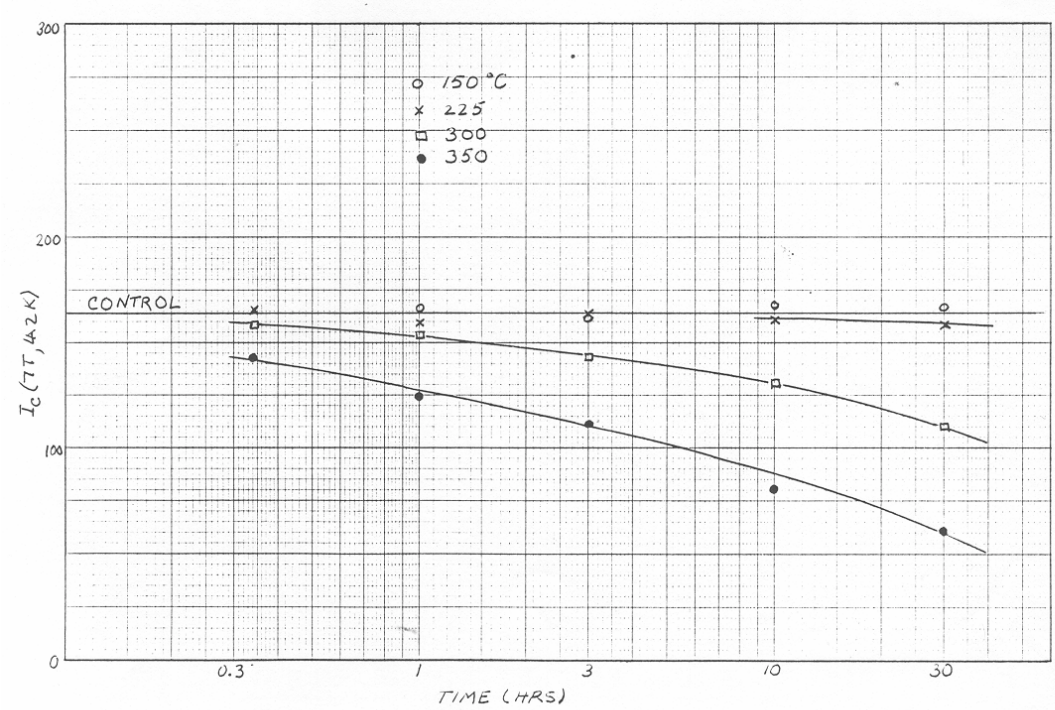

300
200
100
0
CONTROL
I_c (5T, 4.2 K)
o 150 °C
× 225
□ 300
● 350
0.3
1
3
10
30
TIME (HRS)

Fig. 4


300
200
100
0
CONTROL
I_c (7T, 4.2 K)
o 150 °C
× 225
□ 300
● 350
0.3
1
3
10
30
TIME (HRS)