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Critical Current of an LMI Cable

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1. Summary

HERA dipole cables consist of 24 strands of diameter 0.83 mm with Cu/SC = 1.8. The critical current specification is 8000A, not self-field corrected, at applied field 5.5T and T = 4.6K. There is a sizable effect due to the field produced by the conductors themselves. The specification value corresponds to a true I_c of about 8650A. In this note we will refer throughout to cable I_c's which are self-field corrected, for T = 4.6K, B = 5.5T. Wire self-field corrections are smaller and more complicated and are not made customarily. J_c values are quoted for 4.22K and 5.0T, for ease of comparison with other conductors. The measurements are actually made at temperatures between 4.35 and 4.45K and converted to 4.6K. The calculation has been checked by raising the He bath pressure and making the measurement at 4.6K.

LMI asked us to measure a specially prepared cable as well as the strands of which it was made. Recently their cables have been somewhat lower in critical current than those made by BBC. A recent group of LMI's with relatively high I_c's, 9600 ± 100A, gave the impression that they had solved their problems. However, a group having I_c's of 9100 ± 100A then followed. Examination of some of these cables showed evidence of filament damage. As a result, LMI paid special attention to mandrel control and strand tension during cabling. A short length of carefully made cable was sent to us for evaluation. The 24 strands were left attached at the point of cabling so that we could remove and measure these also. Finally, the cable was uncabled and the separated strands were measured.

Our conclusion is that this cable has low degradation and therefore the cabling parameters are under control. But it also has low critical current because the wire J_c is low to begin with. LMI have made high J_c wires in the past, and if they can be combined with the latest cabling improvements a respectable product should result.

2. Wires Used to Make the Cables

Table 1 lists the results for the 24 strands that were used to make the cable. The mean value of the critical current is

$$I_c = 441 \pm 11 \text{ A} \quad (T = 4.22K,\ B = 5.5T)$$

$$n = 18.5 \pm 1.7$$

The cable value correspond to this current, converted to 4.6K, is

$$I_{cable} = 24 \times 441 \times .861 = 9114A.$$

The critical current density was calculated assuming Cu/SC = 1.8 (there is some uncertainty in the value determined from resistance because of the Staybrite layer).

The mean values of J_c at 5.5 and 6.5T, 4.22K are 2279 and 1772 A/mm^2, respectively. The estimated value at 5T is

$$J_c(5T) = 2530 \text{ A/mm}^2.$$

Figure 1 is a histogram of the critical currents at 6.5T and shows a spread of almost 10%. Figure 2 is a scatter plot of I_c vs. n-value and shows that the I_c variation is probably due in large part to variations in filament cross-section (sausaging). The wire n-values are somewhat low and this may be the cause of the low J_c values. Scatter plots of I_c vs. Cu/SC ratio or vs. normal state resistance did not show such correlation. As Fig. 3 shows, the control of Cu/SC or resistance is good, the variation being about 2%.

3. Cable Results

Table 2 gives the measurement and calculation results for this cable. I_a (5.5T) exceeds the 8000A specification, but it is 600 or 700A less than a typical BBC value.

The degradation is

$$1 - \frac{8930}{9114} = 2\%$$

As is customary, no self-field correction has been applied to the wire data; hence, the true degradation is somewhat larger.

4. Wires From the Taken Apart Cable

Two wires broke during uncabling and were not measured. Results for the remaining 22 are listed in Table 3.

Mean values at 4.22K are:

$$I_c(5.5T) = 424 \pm 14 \text{ A}$$
$$I_c(6.5T) = 332 \pm 10 \text{ A}$$

The mean n-value is 17 at both fields. The estimated cable current at 4.6K is

$$24 \times I_{wire} = 24 \times 424 \times .861 = 8760 \text{ A. (4.6K, 5.5T)}$$

The wires from the cable are degraded in regions corresponding to bending at the edges, but much of the wire has little distortion. We would expect this current to lie between 9114 and 8930 A. That it is lower is probably due to the fact that the wire value is not self-field corrected.

Comparison of the wire results before and after cabling gives a value of 4% for the true degradation.

5. Conclusion

The performance of the cable showed a small amount of degradation. The critical current at 5.5T, 4.6K was 9114A. This corresponds to an I_a value in excess of the DESY Spec. But, in order to get currents comparable with the BBC values of around 10000 A the starting wire critical current density would have to be increased to

$$2530 \times (10000/9114) = 2775 \text{ A/mm}^2 \text{ (5T, 4.22K)}.$$

There is evidence, Figure 2 above, that J_c can be improved by better filament geometry - i.e., reduction of cross-section variation.

TABLE 1.

S. C. Wire Test — Date: 1-11-88 — (2)

RAW DATA for 24 wires in SPECIAL CONTROL CABLE

Manufacturer: LMI

Description: Dia. (in.) .0329 — Fil. dia. (μm) — Nominal C/S 1.8 — No. Fils.

Comments: J_c calculated assuming dia. = .0327" & C/S = 1.8 — These values may be off due to Shyorite

Sample	B	I_c	I_q	n	J_c*	R(295)	RRR	C/S_R
	kG	A	A		A/mm	μΩ/cm		
192-1	55	447	>500	19	2311	488.3	123	1.79
	65	344	419	19	1779			
192-2	55	443	>500	17	2290	486.9	125	1.86
	65	347	421	19	1792			
192-3	55	439	>500	15	2269	489.4	122	1.73
	65	345	419	18	1783			
192-4	55	440	>500	18	2272	486.2	126	1.76
	65	345	419	19	1780			
196-5	55	427	>500	15	2204	485.4	127	1.77
	65	340	413	19	1755			
196-6	55	427	>500	18	2205	486.8	126	1.76
	65	337	415	17	1742			
196-7	55	437	>500	20	2258	483.3	129	1.79
	65	334	408	17	1726			
196-8	55	427	>500	18	2209	487.1	122	1.76
	65	330	412	16	1706			

S. C. Wire Test — Date: 1-14-88 — (3)

Manufacturer: LMI

Description: Dia. (in.) .0329 — Fil. dia. (μm) — Nominal C/S 1.8 — No. Fils.

Comments: dia. without sulfur used (.0327) — length of sample 61.5 cm

Sample	B	I_c	I_q	n	J_c*	R(295)	RRR	C/S_R
	kG	A	A		A/mm	μΩ/cm		
205-9	55	428	>500	17	2214	486.3	127	1.76
	65	333	411	18	1722			
205-10	55	435	>500	19	2249	484.1	129	1.79
	65	336	406	18	1735			
205-11	55	430	>500	19	2221	485.8	132	1.77
	65	331	404	18	1709			
205-12	55	432	>500	18	2231	485.0	130	1.78
	65	332	399	17	1713			
207-13	55	457	>500	18	2360	485.9	127	1.77
	65	356	416	21	1841			
207-14	55	466	>500	21	2406	488.2	124	1.74
	65	358	420	21	1852			
207-15	55	461	>500	22	2380	483.8	124	1.79
	65	358	419	22	1849			
207-16	55	443	>500	16	2289	494.3	130	1.68
	65	341	427	16	1764			

S. C. Wire Test — Date: 1-15-88 — (4)

Manufacturer: LMI

Description: Dia. (in.) .0329 — Fil. dia. (μm) — Nominal C/S 1.8 — No. Fils.

Comments: dia. of .0327 used (+/- milder) — Sample length 61.5 cm

Sample	B	I_c	I_q	n	J_c*	R(295)	RRR	C/S_R
	kG	A	A		A/mm	μΩ/cm		
205-17	55	435	>500	19	2247	482.2	129	1.81
	65	340	411	19	1756			
205-18	55	436	>500	18	2253	481.8	131	1.81
	65	342	416	19	1769			
205-19	55	433	>500	19	2238	481.8	131	1.81
	65	337	409	19	1743			
205-20	55	445	>500	21	2299	483.6	128	1.79
	65	344	413	20	1780			
192-21	55	445	>500	19	2298	489.8	122	1.73
	65	344	413	19	1777			
196-22	55	446	>500	19	2305	485.9	128	1.77
	65	347	418	18	1794			
207-23	55	455	>500	20	2350	485.6	118	1.71
	65	357	421	22	1843			
207-24	55	450	>500	19	2326	485.0	118	1.78
	65	353	418	20	1822			

TABLE 2.

Cable: LMI Special

B	T	It	Iq	n	-- Measured
50	4.399	9956	11058	17	
55	4.404	8964	10269	18	
59	4.372	8183	8969	17	

R295= 21.1 RRR= 75

B	Ic	Ia	-- Calculated T=4.6K
50	10030	9200	
55	8930	8190	
60	7840	7170	

TABLE 3.

S. C. Wire Test

Date: 1-22-88 p.1/3

Manufacturer: LMI

Description: Dia. (in.) .0329" Fil. dia. (μm)
Nominal C/S 1.8 No. Fils.

Comments: 22 wires from LMI special cable (2 broke).
I_q & R_{295} were not recorded.

Sample	B	I_c	I_q	n	J_c	R(295)	RRR	C/S_R
	kG	A	A		A/mm	μΩ/cm		
1	55	426		19				
	65	333		16				
2	55	397		15				
	65	311		15				
3	55	435		15				
	65	343		20				
4	55	432		20				
	65	340		16				
5	55	423		15				
	65	330		16				
6	55	420		14				
	65	329		16				
7	55	422		22				
	65	331		18				
8	55	448		21				
	65	348		20				

S. C. Wire Test

Date: 1-22-88 p.2/3

Manufacturer: LMI

Description: Dia. (in.) Fil. dia. (μm)
Nominal C/S No. Fils.

Comments: 22 wires from cable, cont'd.

Sample	B	I_c	I_q	n	J_c	R(295)	RRR	C/S_R
	kG	A	A		A/mm	μΩ/cm		
9	55	431		20				
	65	335		17				
10	55	408		16				
	65	322		17				
11	55	442		19				
	65	338		16				
12	55	417		16				
	65	327		17				
13	55	414		16				
	65	326		18				
14	55	454		20				
	65	349		16				
15	55	426		16				
	65	332		17				
16	55	442		17				
	65	346		19				

S. C. Wire Test

Date: 1-22-88 p.3/3

Manufacturer: LMI

Description: Dia. (in.) Fil. dia. (μm)
Nominal C/S No. Fils.

Comments: 22 wires from cable, cont'd.

Sample	B	I_c	I_q	n	J_c	R(295)	RRR	C/S_R
	kG	A	A		A/mm	μΩ/cm		
17	55	417		16				
	65	328		17				
18	55	414		17				
	65	323		16				
19	55	426		17				
	65	333		17				
20	55	419		17				
	65	327		16				
21	55	402		14				
	65	315		15				
22	55	415		16				
	65	326		18				

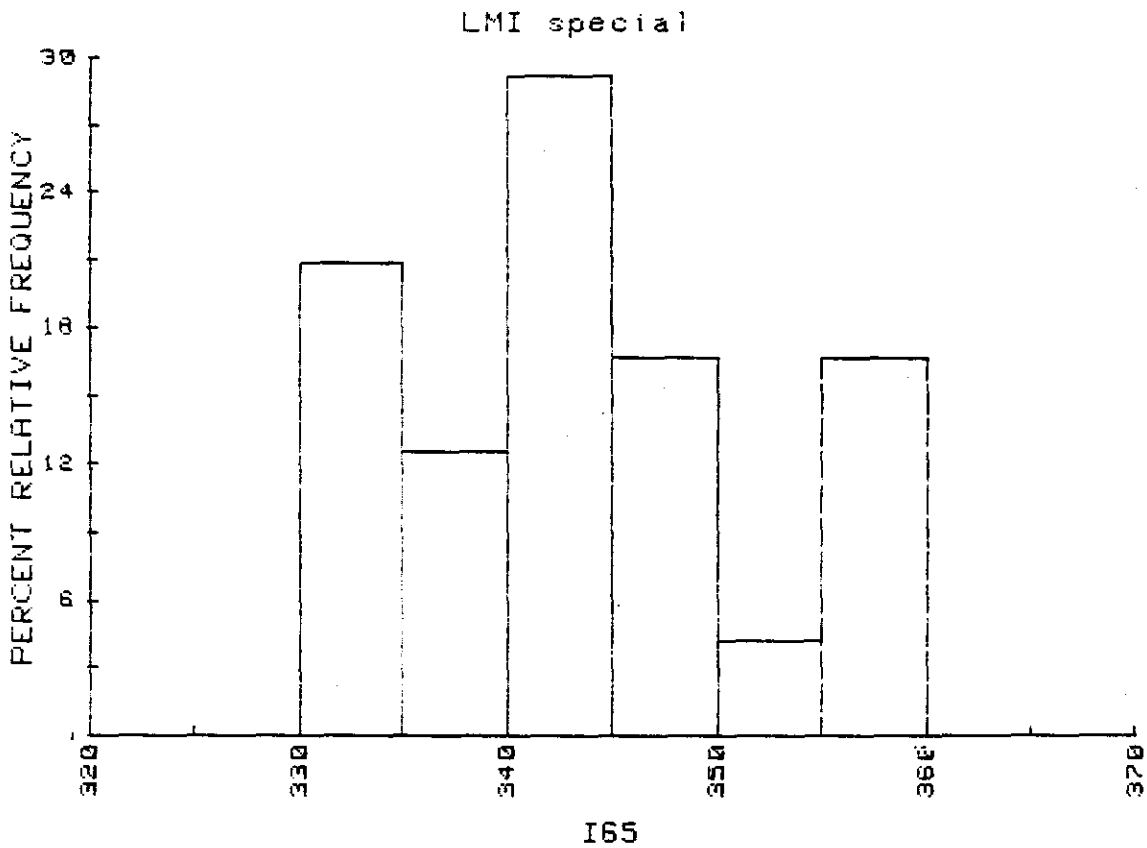
LMI special
PERCENT RELATIVE FREQUENCY
30
24
18
12
6
320
330
340
350
360
370
I65

FIGURE 1.

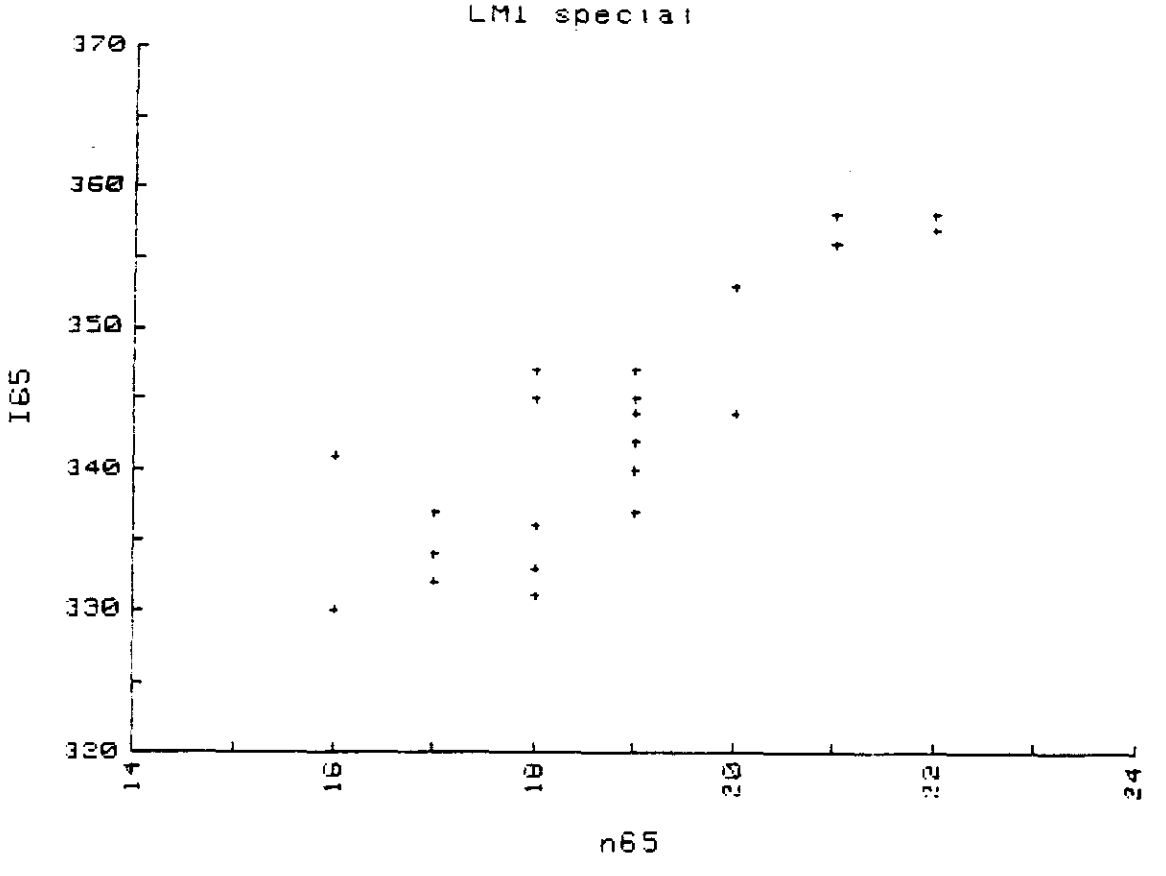

FIGURE 2.

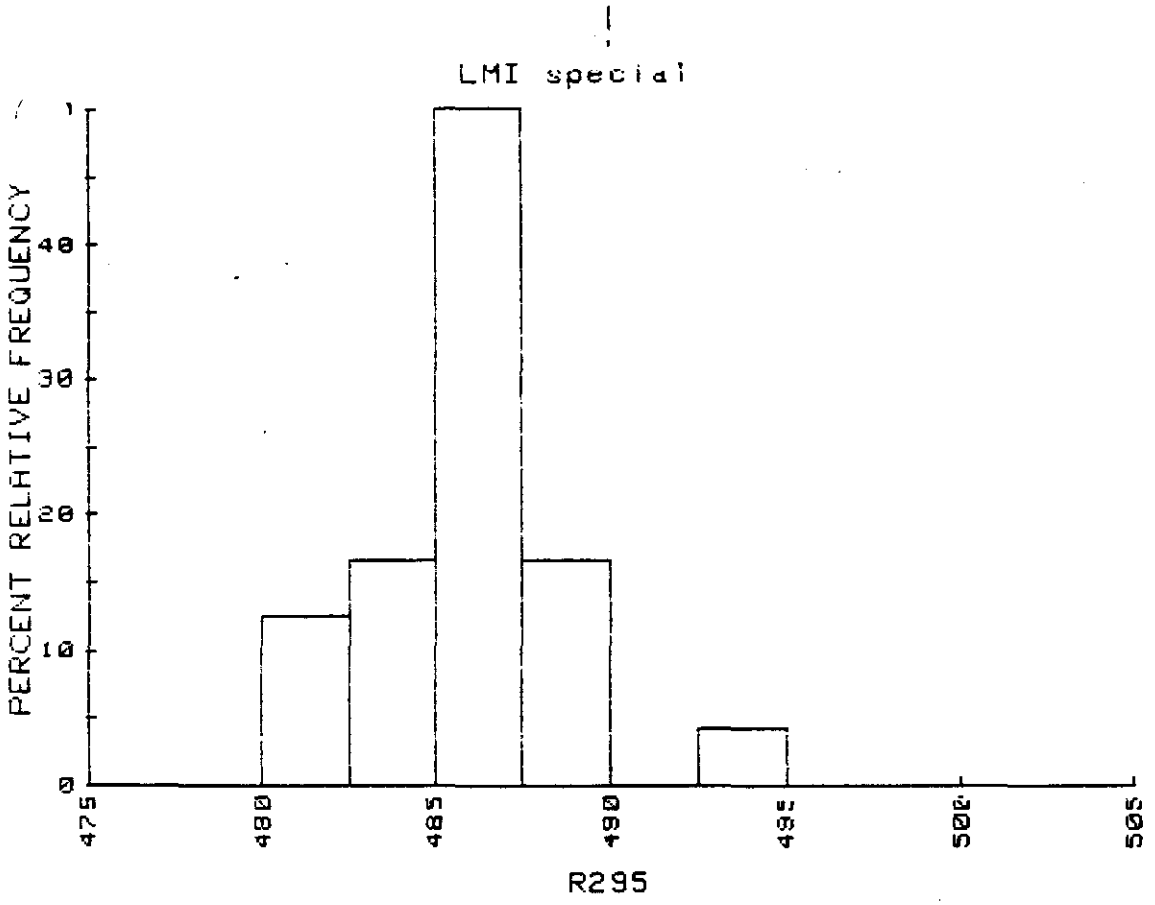
LMI special
PERCENT RELATIVE FREQUENCY
40
30
20
10
0
475
480
485
490
495
500
505
R295

FIGURE 3.