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**CORRELATION OF SUPERCONDUCTOR STRAND, CABLE, AND DIPOLE
CRITICAL CURRENTS IN ISABELLE MAGNETS,*** M.J. Tannenbaum,
M. Garber, W.B. Sampson, Brookhaven National Laboratory — A
calibration between vendor critical current data for 0.0268"
diameter superconductor strand supplied to Fermilab, and the
BNL 10^{-12} Qcm critical current specification is presented.
Vendor critical current data for over 400 Fermilab type bil-
lets are shown, both as supplied by the Vendor and converted
to BNL units. Predictions of cable critical current are made
using the sum of the critical currents of the 23 strands,
where all strands from the same half billet are assigned the
same critical current. The measured cable critical current
shows excellent correlation to the predicted value and is
approximately 14 ± 2 percent below it. ISABELLE full length
dipoles reach the conductor critical current limit, essential-
ly without training. Magnet performance is predictable from
the measured critical current of a short sample of cable to
within 2%.

*
Work performed under the auspices of the U.S. Department of
Energy.

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CORRELATION OF SUPERCONDUCTOR STRAND, CABLE, AND DIPOLE CRITICAL CURRENTS IN ISABELLE MAGNETS

M.J. Tannenbaum, M. Garber, and W.B. Sampson

I. Fermilab Experience Compared to BNL Expectations

An outline of the steps involved in cable production from billet to strand to cable is shown in Figures 0A and B.

Fermilab has provided us with the manufacturer's current certifications at 5.0 Tesla 4.2°K for a representative strand from each half billet for 120 half billets labelled 163-1 through 222-2 from MCA and 282 billets numbered 02 through 348 from IGC. Also, as part of their proposal to us IGC submitted data to us on 82 strands from 41 billets numbered in the range 301 to 350.

All this data has been entered into the data base. For MCA, separate entries are retained for each half billet, but for IGC the two samples per billet are averaged. A histogram of all the data is shown in Figure 1. The data are tabulated in Figures 2 and 3. The means and standard deviations of the distributions are nearly identical but the MCA distribution is more skew, having a longer tail at low currents. Based on this information, a requirement of a 240 ampere minimum for the material seemed eminently reasonable since only 4.2% of the MCA conductor and 1.4% of the IGC was below this value.

According to the Fermilab strand Spec. 1610-ES-54654 and engineering note EN-740904-1 (written by none other than B. Strauss, now of MCA) the short sample critical current is defined at an effective resistivity of 10^{-12} Ω cm. If the sample quenches at a lower effective resistivity, then the quench current is used. Through the cooperation of Bob Rensbottom and Al McInturff of FNAL, and Bruce Zeitlin and Kanithi Hemachalam of IGC, a cross comparison was made between BNL's measurement of 10^{-12} Ω cm critical current as specified by Meyer Garber and Bill Sampson in TN 349 and the data given by the strand manufacturers to Fermilab. Seven wire samples were provided to us by IGC. MCA wire samples were provided by Fermilab as part of our cable procurement. Figure 4 shows a comparison between the same sample measured at IGC, BNL and FNAL. Agreement between BNL and IGC is excellent. Four of the FNAL measurements agree but two are high by ~ 10%.

At the time when these measurements were performed, a comparison between our own measurements and those sent by IGC to Fermilab revealed that the numbers in IGC's strand certification to FNAL were about 12% higher than the 10^{-12} Ω cm measurements. In a telephone check to IGC, they freely admitted that their certification to Fermilab was at an effective resistivity of 1.3×10^{-11} Ω cm, which explains the difference. They subsequently put this information in their written proposal to us (from which Figure 4 is taken) and suggested that we change the minimum current specification accordingly if we wanted to use our 10^{-12} Ω cm critical current definition. The reason for their request becomes clear if we normalize their billet data to our 1×10^{-12} Ω cm definition by multiplying by a factor of 0.892 as determined from Figure 4. The conversion factor for MCA is 0.875 as determined from the data in Figure 5.

The average conversion factors are used for all billets. For both manufacturers the actual conversion factor on a billet varies from the average with a $\sim 3\%$ RMS spread.

The manufacturer's billet data converted to the BNL current definition are shown in Figure 6 and tabulated in Figures 7 & 8. The data for both manufacturers are now nearly indistinguishable. They can be characterized by a mean current of 244 amperes, with a standard deviation of 16 amperes (or 6.5%) about the mean. While it is pleasing to see such consistency among the manufacturers, the distressing part is that 40% of the conductor would fail the 240 ampere minimum current according to our definition. Instructions from Bob Palmer were to specify Fermilab's actual material, so ISABELLE Spec. 89 was revised (Rev. A, March 3, 1982) to require 220 amperes minimum current and a length weighed average current over four billets of at least 240 amperes. This was meant to reflect the data of Figure 6. For both manufacturers, about 5% of the billets in Figure 6 fall below 220 amperes and would be rejected.

A more common method of displaying manufacturer's yield curves is to use probability paper. The critical currents corresponding to the percentiles of the integrated distribution are plotted. The trick of probability paper is that the probability scale is linear in standard deviations (for a Gaussian) so that a pure Gaussian distribution will be a straight line. As shown in Figure 10, the IGC distribution is Gaussian from the 5 to 98 percentile while the MCA has a tail at low currents and is truncated at higher currents.

Another question to ask with this data is whether there was improvement or consistency over the production. The manufacturer's billet data in BNL units are plotted in Figures 11 and 12 against billet number. The IGC data (Fig. 11) shows all the unacceptable billets at the beginning of production and then reasonable consistency over 300 billet numbers. Unfortunately, the MCA data (Fig. 12) show poorer billets in the latter part of their production. We shall soon be in a position to evaluate this information with our own strand. However, it has been enlightening to be able to analyze, as a warm-up, data from Fermilab on superconductor corresponding to 425 full length ISABELLE dipoles.

As a closing remark to this section, we can hazard a very educated guess on the discrepancy in short sample currents between Fermilab and BNL. BNL defines the critical current at an effective resistivity of 1.0×10^{-12} Ωcm over the full strand diameter with the full gauge length of 50 cm subjected to a perpendicular component of magnetic field within $1/2\%$ of the 5.0 Tesla specified value. In the Fermilab sample holder used for both strand and cable, the sample is held in a 3" diameter semi-circle in the plane of the magnetic field of the solenoid. Thus only 6 to 9% of the sample is subjected to a perpendicular component of magnetic field within $1/2$ to 1% of the specified value. If the effective resistivity is calculated using the full semi-circular length of conductor between the voltage taps, an error of a factor of 11 to 16 in effective resistivity results. This is consistent with IGC's statement that the effective resistivity in the FNAL sample holder is 1.3×10^{-11} Ωcm rather than 10^{-12} .

II. Comparison Of BNL Cable Short Sample Measurement With Billet Data And Cable Maps Supplied By Outside Vendors

For each cable supplied by NEEWC, a map of the strands is provided as shown in Figure 13. Thus the start of C0020IN consists of 20 strands of S-347 and 3 strands of S-328 while the end of C0020IN (and thus the start of C0021IN) consists of only 4 strands of S-347 and 19 strands of S-328. Koldwelds, made when spools of strand are changed, are indicated by an x. These maps have been entered into the data base. In addition, the billet critical currents provided by the manufacturer (Fig. 14) have also been entered. Penny Baggett has written a program to sum the manufacturer's billet currents (corrected to BNL units) for the 23 individual superconductor strands for each segment of cable between Koldwelds. In this way a map of the critical current variation over the entire cable can be obtained. This is shown in Figure 15 for a typical cable, C0021IN, in which the computed critical current varies from 6017 amps at the start of the cable to 6154 amps at the end. From the production point of view, the worst cable we have received is C0020IN (Fig. 16) whose computed critical current varies from 5467 amps at the start to 6017 amps at the end. Of course from the R&D point, this is the most interesting cable.

The 10' short sample of cable whose critical current is measured by Meyer Garber is always taken from the start of the reel. The start of a finished insulated reel of cable is the same as the start indicated on Figure 13 because the cable is wound on a reel after cabling and then rewound in the course of insulating. I have compared Meyer's measured short sample current to the computed value from the front end of the cable maps. This is tabulated in Figure 17, and a plot of measured versus computed current is shown in Figure 18. A clear correlation is observed in Figure 18, however it is more instructive to study the tabulated data (Figure 17).

Concentrating on cables C0009IN through C0024IN (9I thru 24I in the table), the mean I_{c2} short sample current is 5039 amps and the variation about the mean is 4.3% RMS. The ratio of the measured short sample (I_{c2}) to the computed short sample current averages 0.866 with a variation of 2.6% RMS. The reduction in variance indicates a correlation between the computed and measured short sample critical currents. (The level of significance of this correlation is left as an exercise for the reader.) The problem is made more difficult by the high quality of the cables. The ratio of the minimum to maximum critical currents of each cable is tabulated (Figure 17). The average variation over a cable is only 3%. The largest predicted short sample variation is from the start of cable 20 to the end of cable 20 (which is identical to the start of cable 21). The measured data nicely track this. Also, a plot of I_{c2}/I_{ss} start on probability paper (Figure 19) shows an impressively good Gaussian distribution in agreement with the fitted parameters.

With the data illustrated above, it would appear that we now have the possibility to predict the short sample critical current of each foot of each cable to a precision of 2.6% RMS. Two questions arise: Is it worth it? and can we do it any better? For the R&D phase it is probably worth it because

the magnets are stable in quench current to a reproducibility more like 0.1% RMS. For the production phase, I would expect that the cables could be made considerably more reproducible than at present. The manufacturer's billet data in Figure 6 indicate a mean current of 244 amperes and a 6.5% RMS spread. If we had enough billets to make cable with 23 random samples from this distribution, I would expect an average cable I_{c2} of 4860 amperes, with a spread about the average of 1.4% RMS. Of course if we carefully matched strands, we could reduce the spread still further. The present cables have a larger spread because they are made with strand from only 2 to 5 billets. Also, as shown in Figure 20 for cable 17, individual cable segments may contain strand from only a single billet.

There is also plenty of room for improvement of the calculated short sample current. The present example used manufacturer's data on critical current for two representative strand short samples for each billet. As shown in Figures 4 and 5 the correlation of our own measurements of 1×10^{-12} Qcm critical current to the manufacturer's FNAL definition strand current was only good to 2.7% RMS, the same precision as our correlation to the cables! In this light, the correlation to the predicted cable short sample is really impressive and we would expect to do much better when we used our own directly measured values for the strand critical current.

The other aspect is how well the two selected strands represent the critical current of the 210,000 feet of strand in a billet. The only direct evidence we presently have on this subject comes from our measurement of the individual strands making up cable 17. Cable 17 was heavily studied because it had an 8% lower short sample current than the previous 7 cables made with IGC strand. It was also noteworthy (Fig. 20) because all the strand at the start of this cable came from billet 332-I. The samples of strand from each spool, routinely supplied to us by NEEWC, were tracked down and measured. The results are shown in Figure 21. The reason for the A,B... nomenclature is that the manufacturer's spools of up to 30,000 feet of strand are cut down to spools of length 7000 to 8000 feet by NEEWC. I have averaged the data from the individual spools. The maximum variation over a spool is 2.0% RMS. However it is clear that the critical current variation over this billet is 6.2% RMS which is roughly the same as that given in Figure 6 for IGC's entire billet production. It turns out that by accident I know that the IGC current certifications for this billet (Fig. 14) come from reels 1 and 7. Thus the data for this billet are consistent with reels 1 thru 10 (131,000 feet) having 250 ampere critical current and reels 13-24 having 225 ampere critical current. I don't think that it pays to do more work on this particular billet. However we should make careful measurements of short sample variations over the length of a billet when we get our own material.

III. Relationship Between Cable Short Sample Current And Magnet Performance -- Is There Any?

In order to relate the cable short sample measurement at 5.0 Tesla and 4.22°K to the magnet performance, one needs to know the variation of critical current with magnetic field and temperature, and the magnet transfer function. For LM5 & LM6, the transfer function seems to have stabilized (E. Willen, MTG 94) and I use the parameterization

$$\tau = \frac{B(I)}{I} = 1.3732 (1 - 0.065 [I - 4.000])$$

which seems to be adequate for $2.5 < I < 4.0$ kA. (My units are Tesla and kiloamperes.)

The critical current variation with temperature and magnetic field is not adequately mapped for the 6 Tesla 3.0° Kelvin regime we are working in. The best data comes from TN 238, Figure 3, for the old, braided, conductor (Fig. 22). Note that this figure also appears in TN 320, Figure 13. I had previously noted (TN 238) that any constant transfer function gives a load line short sample current behavior versus temperature which remarkably linear and extrapolates to zero at between 9.5 and 9.6°K. This is shown on Figure 22 for $\tau = 1.50, 1.40$, and 1.25 . Note that this does not depend on the assumption $BI = K(T)$, or any other assumption since it is obtained directly from the measured data. Thus if a magnet is at short sample at one temperature, its behavior at another is predicted by a straight line passing through 9.6°K for a constant τ . However, since our τ varies, I do the extrapolation using the local τ . Also the conductor behavior for fields above 5 Tesla and temperatures below 4.2°K is not available. Hence I propose that the data of Fig. 22 be remeasured for a typical 4900-5000 amp cable at fields from 0 to 6 T and temperatures from 10°K to as low as possible.

For all the cables measured (Fig. 23) there is typically a 1 to 2% loss in $B \times I$ at 5.5 T compared to $B \times I$ at 5.0 T. I thus compute the magnet short sample as follows using I_c at 2×10^{-12} Qcm 5.0 T and a peak field enhancement of 1.02.

$$I_{LL} = \sqrt{\frac{0.98 \times 5.0 \times I_{c2}}{\tau(I_{LL}) \times 1.02}}$$

I use the weaker cable of the inner coil for the computations. For LM6 this is 14I, 5.260 kA and for LM5, 18I, 4.749 kA. I start with $\tau(4$ kA) and iterate:

$$I^{0.4.2K} = 1.8704 \sqrt{I_{c2}} \quad I^{0.4.5K} = \frac{9.6 - 4.5}{9.6 - 4.2} I^{0.4.2K}$$

	LM6 5.260 = I_{c2} (kA)		LM5 4.740 = I_{c2} (kA)	
I^* 4.2K	4.290		4.072	
I 4.2K	4.331	5.82 Tesla	4.082	5.58 Tesla
I^* 4.5K	4.067		3.860	
I 4.5K	4.076	5.57 Tesla	3.842	5.33 Tesla

The results are plotted in Figure 23 compared to the magnet performance as drawn by Per Dahl. At 4.5°K, the prediction for LM5 is 1.8% too low but for LM6 it is right on. It is rewarding that the magnet with higher current cable performs better. However the 1.8% discrepancy for LM5 is larger than I would have liked. More data would help sort this out. It is also interesting to note that at 3.8°K, LM5 performance agrees with the extrapolation from 4.5°K but LM6 falls below it, even after considerable training.

IV. Conclusion

The cable conductor electrical properties are now understood to a precision of roughly 2% RMS. If we obtain vendor performance equal to the FNAL history once our own strand pipeline is filled, then it would be possible to obtain cable with an average I_c (at 2.0×10^{-12} Ω cm resistivity, 5.0 Tesla and 4.22°K) of 4860 amperes, and a 1.4% RMS spread about the average. Furthermore, magnet current limitation due to superconductor critical current should be predictable at the 1/2% level.

**STEPS IN THE PRODUCTION OF
MULTIFILAMENTARY SUPERCONDUCTING WIRE**

FINAL SPEC - MINIMUM CURRENT

AS 4014-20

10 8 6 4 2 0 100 200 300 400 500 600 700 800 900 1000

1000

1000

1000

1000

30%

20%

10%

170 180 190 200 210 220 230 240 250 260 270 280 290 300 310 320 330 340

Ic FROM MFR, FINAL SPEC

P. 1

MFR 120 mA
 278 mA
 280 mA
 280 mA

250 mA
 250 mA
 250 mA
 250 mA

STRAND'S CRITICAL CURRENT FOR MNF - I

IC CRITICAL CURRENT (AMPS), BY MANUFACTURER

STATISTICS.....

MAX CNT	202.000	MAXIMUM	324.000
MINIMUM	214.000	MEAN	275.054
STD DEV	10.030	SKENNESS	0.059
KURTOSIS	0.270	VARIANCE	325.075
STD ERR	1.074	C.V. PCT	6.555
95 C.I.	272.950	TO	277.159
MODE	275.000	MEDIAN	275.147

VALID OBSERVATIONS	202
MISSING OBSERVATIONS	0
REJECTED OBSERVATIONS	0

STRAND'S CRITICAL CURRENT FOR MNF - I

IC CRITICAL CURRENT (AMPS), BY MANUFACTURER

LOWER LIMIT	UPPER LIMIT	ABSOLUTE FREQUENCY	RELATIVE FREQUENCY (PERCENT)	CUMULATIVE REL FREQ (PERCENT)
210.00	220.00	2.00	0.71	0.71
230.00	240.00	2.00	0.71	1.42
240.00	250.00	15.00	5.32	6.74
250.00	260.00	34.00	12.06	18.79
260.00	270.00	53.00	18.79	37.59
270.00	280.00	60.00	24.11	61.70
280.00	290.00	52.00	18.44	80.14
290.00	300.00	26.00	9.22	89.36
300.00	310.00	20.00	7.09	96.45
310.00	320.00	7.00	2.40	98.84
320.00	330.00	3.00	1.06	100.00
TOTAL		202.00	100.00	100.00

STRAND'S CRITICAL CURRENT FOR MHF - M

IC CRITICAL CURRENT (AMPS), BY MANUFACTURER

STATISTICS.....

MIN CUT	120.000	MAXIMUM	312.500
MINIMUM	216.256	MEAN	270.106
STD DEV	10.213	SKELNESS	-0.769
KURTOSIS	1.235	VARIANCE	331.695
STD ERR	1.663	C.V. PCT	6.547
.95 C.I.	274.094	TO	201.470
MODE	275.000	MEDIAN	279.667

VALID OBSERVATIONS	120
MISSING OBSERVATIONS	0
REJECTED OBSERVATIONS	0

STRAND'S CRITICAL CURRENT FOR MHF - M

IC CRITICAL CURRENT (AMPS), BY MANUFACTURER

LOWER LIMIT	UPPER LIMIT	ABSOLUTE FREQUENCY	RELATIVE FREQUENCY (PERCENT)	CUMULATIVE REL FREQ (PERCENT)
210.00	220.00	1.00	0.03	0.03
220.00	230.00	2.00	1.67	2.50
230.00	240.00	2.00	1.67	4.17
240.00	250.00	2.00	1.67	5.03
250.00	260.00	6.00	5.00	10.03
260.00	270.00	10.00	15.00	25.03
270.00	280.00	30.00	25.00	50.03
280.00	290.00	27.00	22.50	73.33
290.00	300.00	16.00	13.33	86.67
300.00	310.00	15.00	12.50	99.17
310.00	320.00	1.00	0.03	100.00
TOTAL		120.00	100.00	100.00

CRITICAL CURRENT DATA
FROM LONG AND SHORT SAMPLE TESTS
CONDUCTED AT BNL, IGC AND FNAL

SENSITIVITY	$2 \times 10^{-12} \Omega \text{cm}$			$1 \times 10^{-12} \Omega \text{cm}$		$1.3 \times 10^{-11} \Omega \text{cm}$
PLACE OF TEST	BNL	IGC	FNAL	BNL	IGC	IGC
SAMPLE LENGTH	LONG	LONG	SHORT	LONG	LONG	SHORT
SAMPLE NO.						
327-01	244	244	260	237	235	275
327-11	273	275	275	266	268	302
329-15	270	269	275	253	262	290
335-05	283	280	280	276	272	302
337-29	243	244	275	235	234	270
339-13	308	298	305	302	292	325

~~BNL~~ $\frac{\text{BNL}}{\text{FNAL}}$ 0.862
 0.881
 0.907
 0.914
 0.870
~~0.929~~ 0.920

 0.892 10.024

M.C.A
WIRE TEST RESULTS

10-12-81
E. SPERRY

PALMER CABLE

SAMPLE	I _C AMPS	I _Q AMPS	V _Q MV	(^{BNL} / _{MCA})	(^{BNL} / _{MCA})
S 179-1-M BNL 002	248	310	3000	301	.824
S 180-2-1-M BNL 003	235	295	800	269	.874
S 187-1-10-M BNL 3	255	333	4500	281	.904
S 192-2-M BNL 002	252	309	1150	282	.894
S 189-2-5-M	240	310	2700	278	.863
S 174-1-4A-M	228	281	1000	See above	
S 175-2-17-M	245	300	5000	274	.894
S 177-1-9-M	241	287	700	272	.886
S 176-2-4A-M	242	295	1100	276	.877
S 190-1-5A-M	244	290	1230	267	.914
S 174-1-4B-M	226	282	3800	265	.853
S 187-1-8-M	249	292	750	See above	
S 180-2-1A-M	235	286	4300	See above	
S 174-1-4C-M	222	281	1750	See above	
S 179-1-4-M	247	301	3800	See above	
S 190-2-12-M	243	297	3500	283	.859
S 188-1-11-M	240	290	710	276	.870
S 173-1-1-M	225	278	1320	261	.862

WIRE FROM
CABLE I-3

182 255 1240

↑
this doesn't
make sense

241.2 ± rms 8.7

0.875
2.0.024

OHL 1 E-12 CRITICAL CURRENT FOR IMF = 1

STATISTICS.....

EXT. CNT	202.000	MAXIMUM	269.000
HIGHEST	190.000	MEAN	243.340
STD. DEV	16.000	SKEWNESS	0.050
CORRECTS	0.270	VARIANCE	250.650
STD. ERR	6.950	C.V. PCT	6.555
95 C.I.	243.471	TO	247.225
MODE	245.000	MEDIAN	244.072

SOLID OBSERVATIONS	262
MISSING OBSERVATIONS	0
EXCLUDED OBSERVATIONS	0

OHL 1 E-12 CRITICAL CURRENT FOR IMF = 1

SC

LOWER LIMIT	UPPER LIMIT	ABSOLUTE FREQUENCY	RELATIVE FREQUENCY (PERCENT)	CUMULATIVE REL FREQ (PERCENT)
190.00	200.00	2.00	0.71	0.71
210.00	220.00	11.00	3.90	4.61
220.00	230.00	35.00	12.41	17.02
230.00	240.00	55.00	19.50	36.52
240.00	250.00	70.00	27.66	64.10
250.00	260.00	51.00	10.89	02.27
260.00	270.00	33.00	11.70	93.97
270.00	280.00	11.00	3.90	97.87
280.00	290.00	6.00	2.13	100.00
	TOTAL	202.00	100.00	100.00

Polynomial Equations
and
Polynomial Functions

- Tac
- Net

Method

S/C STRAND'S CRITICAL CURRENT VS. DILLET NUMBER FOR MNF = 1

S/C STRAND'S CRITICAL CURRENT VS. BILLET NUMBER FOR MHF = H

BROOKHAVEN NATIONAL LABORATORY
CABLE DATA SHEET

CØØ2Ø·IN

ENL Reel No. _____ Vendor Reel No. 18-3020 Date 2/3/82
ENL P.O. No. BNL-556841-15A Vendor Order No. 4216
Width .307 Thickness .0525 x .0465

Strand Manufacturer T6C Insulation NEEUC

Strand No. 3493 Feet _____

- 1 S-347-10A-I 1618' x S-328-2C-I
- 2 S-347-17-I
- 3 S-347-15-I 3127' x S-328-10-I
- 4 S-347-17A-I
- 5 S-328-1-I
- 6 S-347-16-I 2859' x S-328-5-I
- 7 S-347-18-I 2056' x S-328-3A-I
- 8 S-328-10-I
- 9 S-347-24-I 2915' x S-328-6-I
- 10 S-347-21-I 3068' x S-328-8-I
- 11 S-347-80-I 355' x S-328-15-I
- 12 S-347-13-I
- 13 S-347-20-I 3264' x S-328-10A-I
- 14 S-347-22-I 1088' x S-328-2-I
- 15 S-347-10-I 1056' x S-328-10-I
- 16 S-347-19-I 1830' x S-328-3-I
- 17 S-347-9-I 1103' x S-328-2A-I
- 18 S-347-13A-I 3119' x S-328-9-I
- 19 S-347-19A-I 2410' x S-328-4-I 983' x S-328-100-I
- 20 S-328-1A-I
- 21 S-347-108-I 2972' x S-328-7-I
- 22 S-347-20A-I
- 23 S-347-12-I 1327' x S-328-2C-I

Vendor's Remarks: (x) Donated by Kudwilt at NEEUC. Cable has all Submittal wires.

Short Sample Test Data

Tested By _____ Date _____

	<u>5.0T</u>	<u>5.5T</u>	<u>6.0T</u>
I _q (A)	_____	_____	_____
I _c (A)	_____	_____	_____
Series No.	_____	_____	_____
Holder No.	_____	_____	_____

I Reg

I Reg

 1.3410-11
 IC
 1.3410-11

✓ 205 I					273.
? 214 I	285	279			282
✓ 255 I					279 279.
✓ 262 I					278.
ADD TO 262.					
301 I	318	300	318	300	309
325 I	280	303	293 ✓	303 ✓	298
327 I			270	300	285
328 I	300	300	300	300	300
332 I	288	275			281
336 I			278	280	279
338 I	248	260			254
343 I			320	312	316
344 I	255	275	255	275	265
345 I	270	268			269
346 I	265	263			264
347 I	270	252			261.5 266
348 I	285	276	285	276	280.

SUM OF 23 STRAND CRITICAL CURRENTS IN CABLE SEGMENTS

0001

SUM OF 23 STRAND CRITICAL CURRENTS IN CABLE SEGMENTS

0020

Run No.	2nd Run	3rd Run	4th Run	5th Run	6th Run	7th Run	8th Run	9th Run
4M	2424	4935	5362	.920				
5M	3615	4930	5532	.891				
6M	3239	4770	5532	.862				

9I	2375	5270	6107	0.863	5940	6107	5940	0.972
10I	3444	5235	6023	0.869	6107	6107	5942	0.973
11I	3435	5190	5957	0.871	6022	6056	5957	0.984
12I	3438	5255	6022	0.873	5939	6040	5939	0.983
13I	3451	5250	5928	0.886	5875	5928	5875	0.991
4M6 14I	3493	5260	5880	0.895	5843	5891	5836	0.991
15I 15I								
16I	3492	5155	5806	0.888	5775	5806	5775	0.995
17I	3490	4825 ⁺	5775 ⁺⁺	0.835	5543	5775	5543	0.960
4M5 18I	3482	4740	5543	0.855	5364	5543	5364	0.967
19I	3493	4705	5364	0.877	5467	5467	5364	0.981
20I	3493	4705	5467	0.861	6017	6017	5467	0.908
21I	3493	5060	6017	0.840	6154	6154	6017	0.977
22I	3502	5051	6154	0.821	5785	6154	5785	0.940
23I	3489	4945	5785	0.855	5473	5785	5467	0.945
24I	3499	4945	5473	0.903	5710	5710	5473	0.958
AVERAGE		5039		0.866				0.968
RMS		214		0.023				0.023
RMS %		4.3%		2.6%				

6809

261A

218A

7.11 MAR 65

6412

5500

4500

4000

5000

WAVELENGTH (microns)

5500

5000

4500

4000

3500

3000

2500

2000

1500

1000

500

0

BROOKHAVEN NATIONAL LABORATORY

CABLE DATA SHEET

BNL Reel No. _____ Vendor Reel No. B-3017 Date 1/27/62BNL P.O. No. BNL-556841-13A Vendor Order No. 4216Width .307 Thickness .0525 x .0465Strand Manufacturer IGC Insulation NEEWCStrand No. 3490 Feet _____

1 S-332-21-I

2 S-332-17-I 1998' S-347-6A-I

3 S-332-10A-I 625' S-332-27-I

4 S-332-9-I 1557' S-347-6-I

5 S-332-8B-I 1135' S-347-2A-I

6 S-332-13A-I 837' S-332-27A-I

7 S-332-23D-I 2434' S-347-6B-I

8 S-332-23-I

9 S-332-20-I

10 S-332-9B-I 3106' S-347-8B-I

11 S-332-24-I 2531' S-347-7-I 905' S-347-8D-I

12 S-332-21B-I

13 S-332-10B-I 179' S-332-25-I 2587' S-347-8A-I

14 S-332-8-I 1115' S-347-2-I

15 S-332-23C-I

16 S-332-13-I 881' S-347-1-I

17 S-332-8A-I 1143' S-347-3-I

18 S-332-23A-I

19 S-332-19-I 348' S-332-26-I 2260' S-347-5-I

20 S-332-9A-I 1458' S-347-5-I 1050' S-347-6C-I

21 S-332-21A-I

22 S-332-13B-I 1369' S-347-4-I 1813' S-347-8C-I

23 S-332-23B-I

Vendor's Remarks (X) Denotes keld weld at NEEWC. Cable has all
Stabvite wires.

Short Sample Test Data

Tested By _____ Date _____

5.0T

5.5T

6.0T

I_q (A)I_c (A)

Series No.

Holder No.

Torque

CABLE 17

S-352-	TOTAL LENGTH OF SPOOL FEET	I _Q	I _{C1}	I _{C2}	V _Q	n	AVERAGE ON SPOOL	
8		317	259	266	4000	26.6		
8A	18,763	307	266	272	650	31.0	262	3.5
8B		316	262	269	5000	29.5		
9		307	253	259	3000	27.2		
9A	23,173	305	260	266	800	28.8	256	3.6
9B		309	255	261	3700	28.5		
10A	22,968	303	242	249	3000	24.0	244	2.1
10B		308	245	252	4000	24.5		
13		306	232	240	5500	20.3		
13A	21,760	292	235	242	850	21.4	231	4.0
13B		306	227	235	7200	20.5		
17	4,563	294	229	237	2300	20.7	229	
19	2,863	296	232	240	2400	20.8	232	
20	8,279	299	219	228	3500	18.2	219	
21		305	224	232	5200	19.5		
21A	22,649	293	224	232	2300	19.9	224	0.6
21B		305	225	233	7500	19.9		
23		300	223	231	3500	19.0		
23A		296	226	234	2500	19.4		
23B	29,276	311	229	237	7500	19.8	227	4.5
23C		295	222	231	2500	19.3		
23D		302	233	241	2500	20.5		
27	2,744	294	221	227	4500	19.2	221	
							2345	14.7
TOTAL		6971	5443	5616				6.2%
AVE.		303.1	236.7	244.2		22.5		

ND. TOTAL LENGTH SPOOLS 1 THRU 7 = 65,714 FEET.