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Booster Technical Note No. 190 (Addendum)

Booster dipole production

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U.S. Department of Energy

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DISCLAIMER

BOOSTER DIPOLE PRODUCTION MEASUREMENTS

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May 20, 1994

The note describing the Booster dipole measurements was published in 1991 without a data sheet. This addendum is being published to add the data sheet.

In addition, the table of systematic and random errors in the original note was wrong. The error data were originally in centimeters and were converted to meters in an attempt to use a standard set of units. Unfortunately, the conversion went the wrong direction and the error was not noticed because of the unfamiliar units - the errors given are appropriate for an accelerator with a good field aperture of several hundred meters instead of several centimeters! (The systematic b_3 and a_3 tolerance values had an additional factor-of-10 typographical error.) The corrected table is included here, using both units.

	Systematic Errors (meters)			Random Errors (meters)		
	Tolerance	Measured 2600 A	Measured 5000 A	Tolerance	Measured 2600 A	Measured 5000 A
B_0				1.5E-04	1.5E-04	3.0E-04
b_1				2.0E-03	9.1E-04	8.6E-04
b_2	1.0E+00	-2.4E-01	-6.4E-01	5.0E-02	8.9E-03	8.3E-03
b_3	1.5E+01	2.1E-01	5.3E-01	7.0E+00	1.4E-01	1.3E-01
b_4	1.0E+02	-9.8E+00	-8.7E+01	1.0E+02	1.1E+00	1.1E+00
b_5	3.0E+03	5.5E+01	1.2E+02	1.0E+03	5.9E+01	5.4E+01
b_6	1.0E+04	-2.4E+01	-9.1E+03	5.0E+04	5.6E+02	4.9E+02
a_0				1.5E-04	4.9E-05	5.4E-05
a_1	1.0E-03	2.4E-04	6.0E-04	2.0E-03	4.0E-04	4.8E-04
a_2	1.0E+00	-7.5E-04	-1.4E-04	5.0E-02	4.2E-03	5.6E-03
a_3	1.5E+01	1.1E-01	1.5E-01	7.0E+00	7.9E-02	9.4E-02
a_4	1.0E+02	1.4E-01	4.7E-01	1.0E+02	8.8E-01	7.8E-01
a_5	3.0E+03	-2.2E+01	-5.3E+00	1.0E+03	2.1E+01	1.9E+01
a_6	1.0E+04	8.7E+01	-6.1E+01	5.0E+04	3.2E+02	3.2E+02

Table 2a. Systematic and random errors (rms), in units of m^{-n}. The *systematic error* is the average over all the magnets, and the *random error* is the standard deviation of the same set. The errors for B_0 have been estimated as described in the text.

	Systematic Errors (cm)			Random Errors (cm)		
	Tolerance	Measured 2600 A	Measured 5000 A	Tolerance	Measured 2600 A	Measured 5000 A
B_0				1.5E-04	1.5E-04	3.0E-04
b_1				2.0E-05	9.1E-06	8.6E-06
b_2	1.0E-04	-2.4E-05	-6.4E-05	5.0E-06	8.9E-07	8.3E-07
b_3	1.5E-05	2.1E-07	5.3E-07	7.0E-06	1.4E-07	1.3E-07
b_4	1.0E-06	-9.8E-08	-8.7E-07	1.0E-06	1.1E-08	1.1E-08
b_5	3.0E-07	5.5E-09	1.2E-08	1.0E-07	5.9E-09	5.4E-09
b_6	1.0E-08	-2.4E-11	-9.1E-09	5.0E-08	5.6E-10	4.9E-10
a_0				1.5E-04	4.9E-05	5.4E-05
a_1	1.0E-05	2.4E-06	6.0E-06	2.0E-05	4.0E-06	4.8E-06
a_2	1.0E-04	-7.5E-08	-1.4E-08	5.0E-06	4.2E-07	5.6E-07
a_3	1.5E-05	1.1E-07	1.5E-07	7.0E-06	7.9E-08	9.4E-08
a_4	1.0E-06	1.4E-09	4.7E-09	1.0E-06	8.8E-09	7.8E-09
a_5	3.0E-07	-2.2E-09	-5.3E-10	1.0E-07	2.1E-09	1.9E-09
a_6	1.0E-08	8.7E-11	-6.1E-11	5.0E-08	3.2E-10	3.2E-10

Table 2b. Systematic and random errors (rms), in units of cm^{-n}. The *systematic error* is the average over all the magnets, and the *random error* is the standard deviation of the same set. The errors for B_0 have been estimated as described in the text.

PARAMETER SHEET FOR BOOSTER MAIN DIPOLE
Date: 11/6/92

Prototype Name	BMD (Booster Main Dipole)
Magnet Class	Dipole
Number of Magnets	36 plus 3

MECHANICAL					
CORE					
Lamination Length (arc)	91.238	in			
Tolerance	0.010	in			
Lamination Length (chord)	91.130	in			
Overall Length					
Aperture Shape	Rectangular				
Gap Height	3.250	in	82.55	mm	
Pole Width	10.000	in	254.00	mm	
Core Height	23.75	in	603.25	mm	
Core Width	30.00	in	762.00	mm	
Wedge Angle of Magnet	9.656	degree			
Weight of Dipole	16765	lb			
Weight of Dipole and Base	20465	lb			
LAMINATIONS					
Material	M45 Si Steel, 24 Ga.				
Coating	C4				
Coating Thickness					
Overall Thickness					
END MODULE BLOCK					
Number per Magnet	2				
Laminations (approx)	176				
Weight before wedging	858.1	lb			
Tolerance	0.5	lb			
CENTER MODULE BLOCK					
Number per Magnet	7				
Laminations (approx)	356				
Weight before wedging	1726.4	lb			
Tolerance	0.5	lb			
VACUUM PIPE					
Material	Iconel 625				hch
Height - Outside	2.752	in	69.9	mm	hch
Width - Outside	6.496	in	165	mm	hch
Wall Thickness	0.079	in	2	mm	hch
Tolerance Specified	0.002	in	0.04	mm	hch
Tolerance Measured - 95%	0.002	in	0.05	mm	hch
Half Height - Inside	1.299	in	33.0	mm	hch
Half Width - Inside	3.169	in	80.5	mm	hch
Resitivity			1.29E-06	Ohm-cm	hch
Tol. Specified			2.0E-08	Ohm-cm	hch
Tol. Measured - 80%			2.0E-08	Ohm-cm	hch

MAIN COIL					
COIL					
Turns per Pole	8				
Poles per Magnet	2				
Resistance per Magnet	0.0007453	Ohm			
Inductance per Magnet - DC	0.00280	H			
Inductance per Magnet - 1 kHz	0.00185	H			
CONDUCTOR					
Material	OFHC Copper				
Shape	Rectangular				
Width	0.965	in	24.51	mm	
Height	2.000	in	50.80	mm	
Cooling Hole Dia.	0.437	in	11.10	mm	
Area	1.771	in^2	1143	mm^2	
Length per Pole	1803	in	45796	mm	
Length per Magnet	3606	in	91592	mm	
INSULATION					
Material	Epoxy-Fiberglas				
Thickness, turn-turn	0.04	in	1.0	mm	
Thickness, ground	0.14	in	3.6	mm	
Tolerance					
Ground Test	12500	V			
Impulse Test					
COOLING					
Circuits per Magnet	2				
Flow Rate per Magnet	6.1 ?	GPM			
Input Pressure					
Temp Rise @ Ramp to Imax					
CURRENT					
I-max (PS Limit)	5700	A			
Current Density @ Imax	3218	A / in^2	4.99	A / mm^2	
DC Power @ Imax	24215	W			
Stored Energy @ Imax	45486	J			

BUMP COIL					
COIL					
Turns per Pole	1				
Poles per Magnet	2				
Resistance per Magnet		Ohm			
Inductance per Magnet - DC		H			
Inductance per Magnet - 1 kHz		H			
CONDUCTOR					
Material	OFHC Copper				
Shape	Rectangular				
Width	3.000	in	76.20	mm	
Height	0.094	in	2.39	mm	
Cooling Hole Dia.	none	in	0.00	mm	
Area	0.282	in^2	182	mm^2	
Length per Pole	217.8	in	5532	mm	
Length per Magnet	435.6	in	11064	mm	
INSULATION					
Material	Epoxy-Fiberglas				
Thickness, turn-turn		in		mm	
Thickness, ground		in		mm	
Tolerance					
Ground Test		V			
Impulse Test					
COOLING					
Circuits per Magnet	none				
Flow Rate per Magnet					
Input Pressure					
Temp Rise @ Ramp to Imax					
CURRENT					
I-max (PS Limit)		A			
Current Density @ Imax		A / in^2	0.00	A / mm^2	
DC Power @ Imax		W			
Stored Energy @ Imax		J			

EDDY CURRENT COILS (5 circuits per magnet)					
COIL					
Turns per Pole	1				
Poles per Magnet	2				
Resistance per Magnet		Ohm			
Inductance per Magnet - DC		H			
Inductance per Magnet - 1 kHz		H			
CONDUCTOR					
Material	Copper				
Shape	#12 Wire				
Width		in		mm	
Height		in		mm	
Cooling Hole Dia.	none	in		mm	
Area		in^2		mm^2	
Length per Pole	219	in	5563	mm	
Length per Magnet	438	in	11125	mm	
INSULATION					
Material					
Thickness, turn-turn		in		mm	
Thickness, ground		in		mm	
Tolerance					
Ground Test		V			
Impulse Test					
USAGE OF COILS					
Eddy Current Corr. Driver	2	Coils			
Monitor	1	Coil			
Spare	2	Coils			
CURRENT					
I-max (PS Limit)		A			
Current Density @ Imax		A / in^2		A / mm^2	
DC Power @ Imax		W			
Stored Energy @ Imax		J			

MAGNETIC PROPERTIES (MAIN COIL)			
EXCITATION CURVE		Unit	Ref
B * L-eff @ I=0	0.0018755	T-m	ret
B * L-eff / I @ I=200	0.0005921	T-m / A	ret
B * L-eff / I @ I=600	0.0005887	T-m / A	ret
B * L-eff / I @ I=2600	0.0005881	T-m / A	ret
B * L-eff / I @ I=5000	0.0005666	T-m / A	ret
B * L-eff / I @ I=5700		T-m / A	
Saturation, 5000/2600	3.65%		
B @ I=0	0.0007620	T	ret
B / I @ I=200	0.0002445	T / A	ret
B / I @ I=600	0.0002431	T / A	ret
B / I @ I=2600	0.0002430	T / A	ret
B / I @ I=5000	0.0002366	T / A	ret
B / I @ I=5700		T / A	
Saturation, 5000/2600	2.66%		
L-eff @ I=0	2.4613	m	ret
L-eff @ I=200	2.4214	m	ret
L-eff @ I=600	2.4216	m	ret
L-eff @ I=2600	2.4200	m	ret
L-eff @ I=5000	2.3952	m	ret

SYSTEMATIC ERRORS					
	LIMITS	MEASURED		UNITS	REF
		@ 2600A	@5000A		
Bn / B0, n = 1				cm^{-1}	ar,ret
Bn / B0, n = 2	1.0E-04	-2.4E-05	-6.4E-05	cm^{-2}	ar,ret
Bn / B0, n = 3	1.5E-05	2.1E-07	5.3E-07	cm^{-3}	ar,ret
Bn / B0, n = 4	1.0E-06	-9.8E-08	-8.7E-07	cm^{-4}	ar,ret
Bn / B0, n = 5	3.0E-07	5.5E-09	1.2E-08	cm^{-5}	ar,ret
Bn / B0, n = 6	1.0E-08	-2.4E-11	-9.1E-09	cm^{-6}	ar,ret
An / B0, n = 1	1.0E-05	2.4E-06	6.0E-06	cm^{-1}	ar,ret
An / B0, n = 2	1.0E-04	-7.5E-08	-1.4E-08	cm^{-2}	ar,ret
An / B0, n = 3	1.5E-05	1.1E-07	1.5E-07	cm^{-3}	ar,ret
An / B0, n = 4	1.0E-06	1.4E-09	4.7E-09	cm^{-4}	ar,ret
An / B0, n = 5	3.0E-07	-2.3E-09	-5.3E-10	cm^{-5}	ar,ret
An / B0, n = 6	1.0E-08	8.7E-11	-6.1E-11	cm^{-6}	ar,ret
RANDOM ERRORS					
	LIMITS	MEASURED			
		@ 2600A	@5000A		
B0	1.5E-04	1.5E-04	3.0E-04		
Bn / B0, n = 1	2.0E-05	9.1E-06	8.6E-06	cm^{-1}	ar,ret
Bn / B0, n = 2	5.0E-06	8.9E-07	8.3E-07	cm^{-2}	ar,ret
Bn / B0, n = 3	7.0E-06	1.4E-07	1.3E-07	cm^{-3}	ar,ret
Bn / B0, n = 4	1.0E-06	1.1E-08	1.1E-08	cm^{-4}	ar,ret
Bn / B0, n = 5	1.0E-07	5.9E-09	5.4E-09	cm^{-5}	ar,ret
Bn / B0, n = 6	5.0E-08	5.6E-10	4.9E-10	cm^{-6}	ar,ret
An / B0, n = 0	1.5E-04	4.9E-05	5.4E-05		
An / B0, n = 1	2.0E-05	4.0E-06	4.8E-06	cm^{-1}	ar,ret
An / B0, n = 2	5.0E-06	4.2E-07	5.6E-07	cm^{-2}	ar,ret
An / B0, n = 3	7.0E-06	7.9E-08	9.4E-08	cm^{-3}	ar,ret
An / B0, n = 4	1.0E-06	8.8E-09	7.8E-09	cm^{-4}	ar,ret
An / B0, n = 5	1.0E-07	2.1E-09	1.9E-09	cm^{-5}	ar,ret
An / B0, n = 6	5.0E-08	3.2E-10	3.2E-10	cm^{-6}	ar,ret

REFERENCES

hch: H. C. Hseuh
ar: A. Rugierro
as: A. Soukas
ret: R. Thern