SSC MAGNET ERRORS -- A SHORT SUMMARY

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The magnetic errors anticipated in the four basic magnet designs under consideration for the SSC have been assessed by the Magnetic Errors Working Group(Ref. 1) of the SSC Aperture Task Force. The four magnet designs are:

(1) Design A of the SSC Reference Designs Study (RDS), a cosine-theta type in a two-in-one configuration, 4-cm inner-coil inside diameter, cold iron with collar (Ref. 2).

(2) Design B of the RDS, a cosine-theta type in a one-in-one configuration, 5-cm coil I.D., "no" iron (Ref. 3).

(3) Design C of the RDS, a superferric cold-iron type in a two-in-one configuration with a 2.5x4 cm rectangular aperture (Ref. 4).

(4) Design D, a cosine-theta type, collared, cold iron, one-in-one configuration, initially with 4-cm I.D. (Ref. 5); however, a 5-cm-I.D. version also is under consideration, although a detailed design has not been made.

The systematic magnetic errors anticipated for the several designs due to geometric and persistent current effects are summarized in Table 1 and Figure 1. The errors are expressed in terms of the multipole expansion coefficients a_n, b_n, defined by the customary magnetic field expansion:

$$B_x - iB_y = B_0 \sum_{n=0} (a_n - ib_n)(x+iy)^n / R_R^n$$

where B_0 is the magnitude of the dipole field (in the y-direction); R_R is

the reference radius (1 cm here); 2(n+1) is the number of magnetic poles; the a_n are the skew coefficents; and the b_n are the normal (having dipole symmetry) coefficients.

The multipole strengths predicted from geometric effects are expected to be accurate within 0.5×10^{-4} (at 1 cm), based on experience at Fermilab, Brookhaven, and LBL with Tevatron, CBA, and various SSC models. The zero sextupole and decapole strengths in Design C derive from the use of three separate excitation currents. The multipole strengths calculated for persistent currents in the superconducting filaments (6) are expected to be accurate within about 30Δ.

The rms variation of the multipole strengths due to random geometric errors, to variations in temperature and critical-current density in the superconducting material, and to random errors in the sextupole and decapole correctors are summarized in Table 2 and Figure 2. The random geometric variations predicted for the cosine-theta magnets are based on data from the Tevatron and CBA dipoles, as fitted and extrapolated by the models of Fisk (7), Herrera (8), and Meuser (9). The rms variations projected for the quadrupole coefficients (a_1 and b_1) for designs A and D have been reduced from the extrapolated values because of the assumption of centering the coils within the iron yokes so as to minimize the quadrupole strengths. (This centering procedure is not possible with designs B and C.) The random "geometric" variations predicted for the superferric design are based partly on variations observed in the first six model magnets and partly on analytic estimates (including permeability variations) made by the Texas Accelerator Center (10). An independent study of the magnetic errors in the superferric design has been initiated at LBL. The rms variation in the multipole strengths due

to persistent currents is taken as 0.10 of the systematic persistent-current effect, based on variations observed in the persistent-current sextupole strengths observed in the Tevatron dipoles (sigma of 9Δ) (Ref. 11) and on variations expected from a sawtooth temperature variation in the cryogenic system with an amplitude of 0.25 degree Kelvin (12). The variation due to mechanical errors in the sextupole and decapole corrector windings assumes a random 0.1 mm error in centering and a random angular error of 6 milliradians (13).

References:

(1) Members: H.E. Fisk (Chairman), W.S. Gilbert, W.V. Hassenzahl, R.B. Meuser, J.M. Peterson, S. Pissanetzky, C.E. Taylor, P.J. Wanderer, W.A. Wenzel.

(2) Coil Configuration C-5, BNL SSC Tech Note 19.

(3) FNAL design OPTI 824

(4) S. Pissanetzky and W. Schmidt, Design of the Dipole Magnet for the "C" Version of the SSC for 20 TeV Twin-Beam Proton Accelerator," 1985 National Accelerator Conference, Vancouver, B.C., to be published.

(5) Design D originally had the C-5 design in a one-in-one configuration, as described in BNL SSC Tech. Note 23, Feb. 1985. To obtain a smaller 18-pole coefficient, the design was modified to configuration PK-15 (BNL).

(6) M.A. Green, "Fields Generated within the SSC Magnets due to Persistent Currents in the Superconductor," Workshop on Accelerator Physics Issues for an SSC, M. Tigner (Ed.), pp. 126-131, Ann Arbor, Mich., 1983.

(7) H.E. Fisk, et al, "SSC Magnetic Field Quality Considerations," 1984 Summer Study on the Design and Utilization of the SSC, Snowmass, Colorado, p. 329.

(8) J. Herrera et al, "Random Errors in the Magnetic Field Coefficients of Superconducting Magnets," 1985 National Accelerator Conference, Vancouver, B.C., to be published.

(9) R.B. Meuser, "Effect of Manufacturing Errors on Field Quality of Dipole Magnets for the SSC," 1985 National Accelerator Conference, Vancouver, B.C., to be published.

(10) S. Pissanetzky and W. MacKay, private communications.

(11) R. Hanft, private communication, Feb. 1985.

(12) W.V. Hassenzahl, private communication, Feb. 1985.

(13) J.M. Peterson, private communication.

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Table 1.
Systematic Multipoles in SSC Magnets
b_1 = normal quadrupole coefficient, etc.
units: 10^{-4} at 1 cm
Data of 7/30/85

	b_1	b_2	b_4	b_6	b_8	b_{10}	b_{12}
Design A[a]							
geometry, Inj.	0	-.9	0	.2	.8	0	-
geometry, 20 Tev	-.4	-.2	0	.2	.8	0	-
persistent, 5μ, Inj.	0	-4.7	.30	.07	-	-	-
persistent, 9μ, Inj.	0	-7.5	.67	.13	-	-	-
Design B[b]							
geometry, Inj. & 20 TeV	0	.07	-.07	.09	-.14	.014	-
persistent, 5μ, Inj.	0	-3.6	.08	0	-	-	-
persistent, 9μ Inj.	0	-5.6	.24	0	-	-	-
Design C							
geometry, Inj.[c]	0	0	0	.5	.1	-	-
geometry, 20 TeV[c]	0	0	0	1.5	.2	-	-
persistent, 20μ, Inj.[d]	0	1.3[g]	-	-	-	-	-
remanent H, Inj.[d]	0	1.1[g]	-	-	-	-	-
Design D(4 cm)[e]							
geom, Inj.	0	-0.05	-.16	-.03	.15	.19	-.05
geom, 20 TeV	0	2.	-.16	-.03	.15	.19	-.05
persistent, 5μ, Inj.	0	-4.7	.30	.07	-	-	-
persistent, 9μ, Inj.	0	-7.5	.67	.13	-	-	-
Design D(5 cm)							
geom, Inj.[f]	0	-.037	-.086	-.012	.044	.041	-.0079
geom, 20 TeV[f]	0	1.47	-.086	-.012	.044	.041	-.0079
persistent, 5μ, Inj.	0	-2.9	.10	.03	-	-	-
persistent, 9μ, Inj.	0	-4.7	0.23	.07	-	-	-

a. Coil configuration C-5, 2-in-1
BNL SSC Tech. Note 19
b. Coil configuration OPTI 824 (FNAL)
c. Data on superferric design WF3CMS (TAC)
d. Data on superferric design NF2C (TAC)
e. Coil configuration PK-15, (BNL)
f. Scaled from D(4 cm)
g. Can be canceled by current adjustment

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Table 2.
RMS MULTIPOLE VARIATIONS
PROJECTED FOR SSC MAGNET DESIGNS
a_n, b_n = skew, normal coefficient of 2(n+1)-pole
Units are 10^{-4} at 1 cm
Data of 7/30/85

Multipole Coef	Design A and D(4 cm)					Design B				
	σ_{geom}	σ_{Pers} 5μ	σ_{Pers} 9μ	σ_{Tot} 5μ	σ_{Tot} 9μ	σ_{geom}	σ_{Pers} 5μ	σ_{Pers} 9μ	σ_{Tot} 5μ	σ_{Tot} 9μ
a_0	5.9	-	-	-	-	5.6	-	-	-	-
b_0	3.0	-	-	-	-	2.8	-	-	-	-
a_1	0.70	.09	.15	.71	.72	3.6	.07	.11	3.6	3.6
b_1	0.70	.09	.15	.71	.72	1.75	.07	.11	1.75	1.75
a_2	0.61	.09	.14	.62	.63	0.59	.05	.08	.59	.60
b_2	2.01	.47	.75	2.06	2.15	1.94	.36	.56	1.97	2.02
a_3	0.69	0	0	.69	.69	0.60	0	0	.60	.60
b_3	0.35	0	0	.35	.35	0.30	0	0	.30	.30
a_4	0.14	0	0	.14	.14	0.11	0	0	.11	.11
b_4	0.59	.03	.07	.59	.59	0.46	.01	.02	.46	.46
a_5	0.16	0	0	.16	.16	0.11	0	0	.11	.11
b_5	.059	0	0	.059	.059	0.042	0	0	.042	.042
a_6	.034	0	0	.034	.034	.022	0	0	.022	.022
b_6	.075	.01	.01	.076	.076	.048	0	0	.048	.048
a_7	.030	0	0	.030	.030	.017	0	0	.017	.017
b_7	.016	0	0	.016	.016	.0091	0	0	.0091	.0091
a_8	.0064	0	0	.0064	.0064	.0033	0	0	.0033	.0033
b_8	.021	0	0	.021	.021	.011	0	0	.011	.011
a_9	.0056	0	0	.0056	.0056	.0026	0	0	.0026	.0026
b_9	.0030	0	0	.0030	.0030	.0014	0	0	.0014	.0014
a_{10}	.0012	0	0	.0012	.0012	.00050	0	0	.00050	.0005
b_{10}	.0071	0	0	.0071	.0071	.0030	0	0	.0030	.0030

$\sigma_{pers}(b_{2,4,6}) = 0.10\, b_{2,4,6}$ = rms variation of persistent-current multipole coef. due to variations in critical current density and temperature at injection.

$\sigma_{pers}(a_1, b_1, a_2)$ are due to random sextupole-correction-coil errors.

$\sigma^2_{tot} = \sigma^2_{pers} + \sigma^2_{geom}$(at injection).

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Table 2. RMS Multipole Variations (continued)
Units are 10^{-4} at 1 cm
Data of 7/30/85

Multipole Coef	Design C					Design D (5 cm)				
	σ_{geom}*	σ_{Pers} 9μ	σ_{Pers} 20μ	σ_{Tot} 9μ	σ_{Tot} 20μ	σ_{geom}	σ_{Pers} 5μ	σ_{Pers} 9μ	σ_{Tot} 5μ	σ_{Tot} 9μ
a_0	-	-	-			5.5	-	-	-	-
b_0	-	-	-			2.8	-	-	-	-
a_1	3.1	.01	.03	3.1	3.1	0.56	.06	.09	.56	.57
b_1	1.2	.01	.03	1.2	1.2	0.56	.06	.09	.56	.57
a_2	1.1	.01	.03	1.1	1.1	0.41	.04	.07	.41	.42
b_2	1.	.06	.13	1.	1.	1.4	.29	.47	1.4	1.5
a_3	1.3	0	0	1.3	1.3	0.40	0	0	.40	.40
b_3	0.8	0	0	.8	.8	0.20	0	0	.20	.20
a_4	0.8	0	0	.8	.8	.07	0	0	.07	.07
b_4	0.4	0	0	.4	.4	.29	.01	.02	.29	.29
a_5	0.7	0	0	.7	.7	.069	0	0	.069	.069
b_5	0.4	0	0	.4	.4	.025	0	0	.025	.025
a_6	0.7	0	0	.7	.7	.012	0	0	.012	.012
b_6	0.5	0	0	.5	.5	.028	0	.01	.028	.028
a_7						.0094	0	0	.0094	.0094
b_7						.0050	0	0	.0050	.0050
a_8						.0017	0	0	.0017	.0017
b_8						.0057	0	.0057	.0057	
a_9						.0013	0	0	.0013	.0013
b_9						.00069	0	0	.00069	.00069
a_{10}						.00024	0	0	.00024	.00024
b_{10}						.0014	0	0	.0014	.0014

* Based partly on measured variations among the first six model magnets (types NF2C, WF2C, and WF3CMS) and partly on estimated random construction errors. From S. Pissanetzky and W. MacKay, private communications.

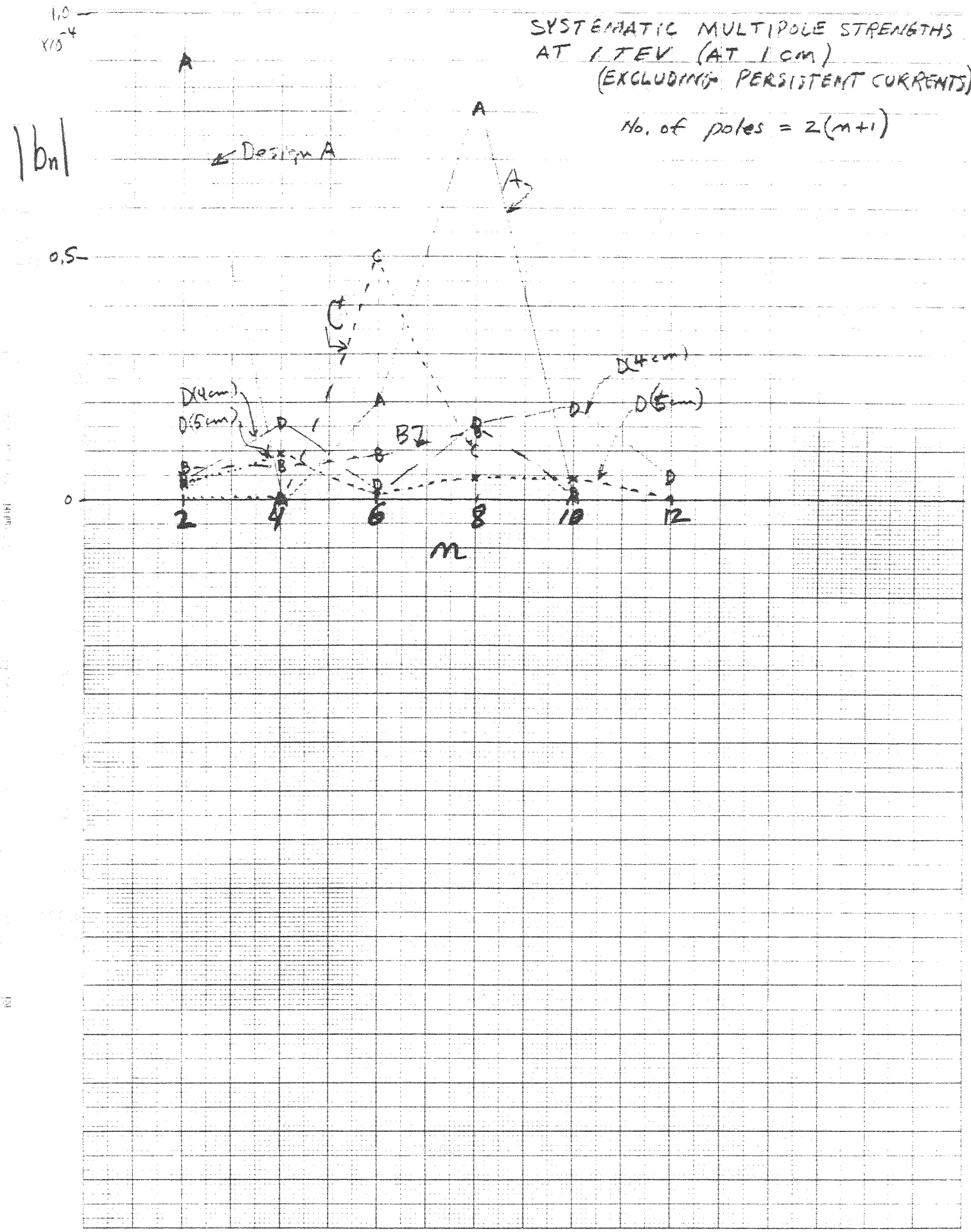
SYSTEMATIC MULTIPOLE STRENGTHS
AT 1 TEV (AT 1 cm)
(EXCLUDING PERSISTENT CURRENTS)
No. of poles = 2(n+1)
|bn|
1.0 x10^-4
0.5
0
Design A
A
C
D(4cm)
D(5cm)
B
2
4
6
8
10
12
n

FIG. 1

RMS VARIATION OF MULTIPOLE STRENGTHS (AT 1CM)
DUE TO GEOMETRIC AND PERMEABILITY VARIATIONS

No. of poles = 2(m+1)

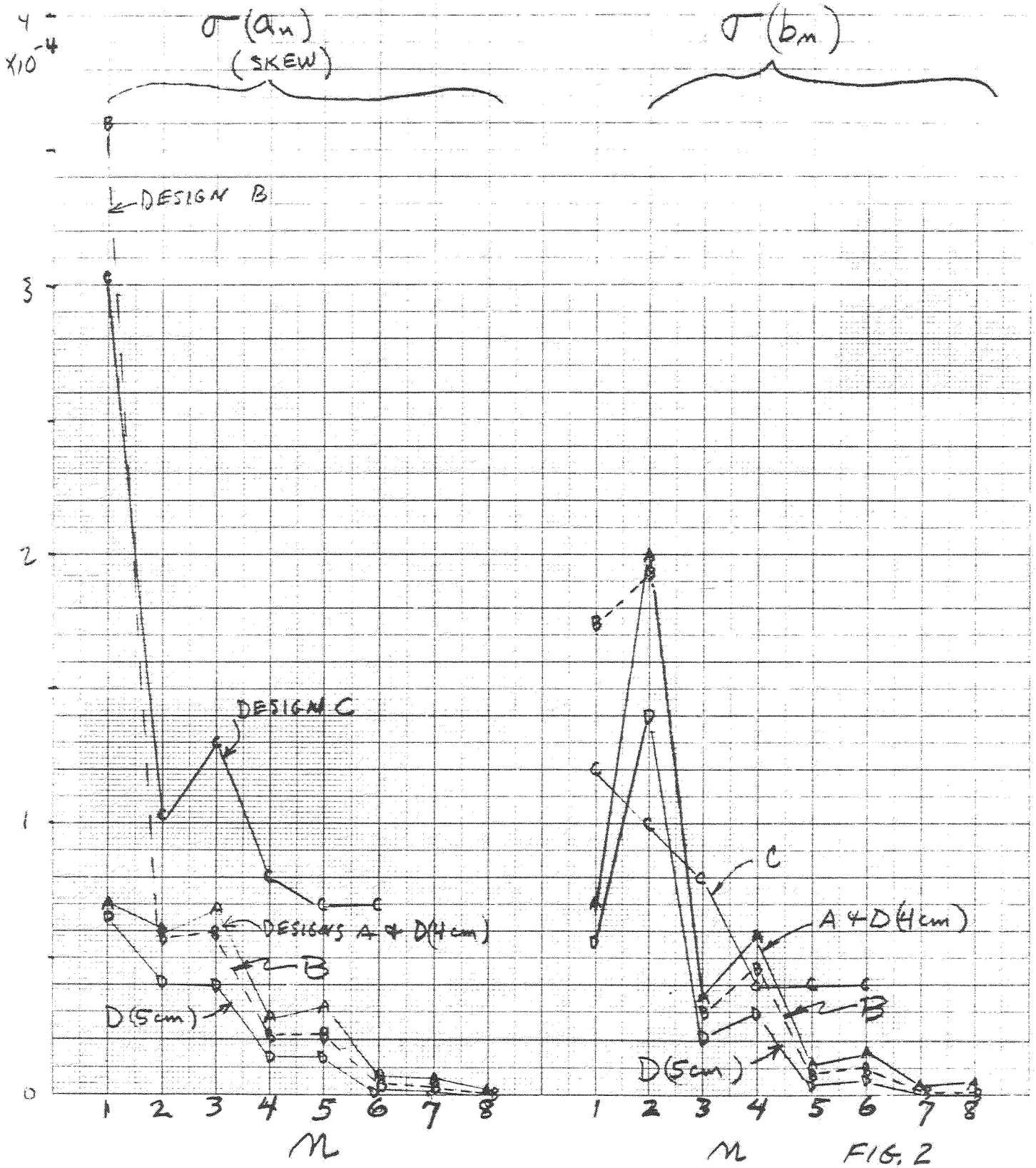

FIG. 2