Fermilab

TS-SSC 91-120
June 10, 1991

To: J. Butteris, S. Delchamps, W. Kinney, M. Lamm, J. Strait, C. Hess

From: K. Coulter

Subj: Notes on Tangential Probes: Calculations for Probe 14 at Lab 2.

Probe 14 is the new 25cm probe under construction in Lab 2. There are a tangential, a belly band, and 2 dipole windings, D1 and D2, as well as an auxiliary tangential winding.

The pertinent probe geometry parameters are listed on page 1. The calculations follow from references [1], [2] and [3]. Page 2 shows the bucking factor when using only the belly band. Page 3 shows the bucking factors when using only D1 and D2 (no belly band). Pages 4.0 - 4.2 show the equations and bucking factors when using D1 and D2 to make corrections to bucking with the belly band. Since this correction is required only in the event of probe imperfections, these factors will have to be determined from measurements using the probe.

Page 5 reiterates the definitions of C_n S_n F_n and γ_n from reference [3]. Page 6 is a table of F_n's for no bucking, belly band bucking, and D1 and D2 bucking, for multipole number n, where D=0 is the dipole. These results are from the FORTRAN program TANGENTIAL.

Figure 1 shows the probe sensitivity factor, F_n, for probe 14 as a function of multipole number n, where n=0 is the dipole. The results for both the unbucked and bucked tangential winding (using the belly band) are similar to the example calculation in reference [3]. The magnitude is lower by approximately a factor of 5 since the length of probe 14 is about 1/5 the probe length used in the example calculation. Figure 2 shows F_n vs multipole for the unbucked tangential winding and for the bucked tangential winding using D1 and D2 for bucking instead of the belly band.

Tables 1, 2 and 3 list the output from the program TANGENTIAL that was used to make the figures. I have also written in the bucking factors computed in program TANGENTIAL for comparison with the values calculated on pages 2 and 3.

References

[1] J. Strait, Notes on Tangential Probes: Basic Equations, TS-SSC 90-082, 11/9/90.

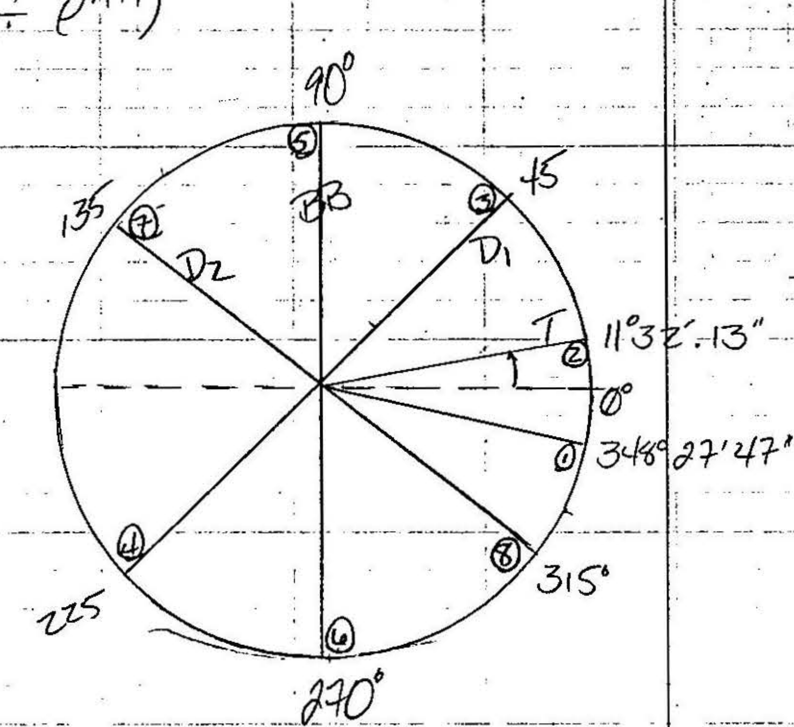
[2] J. Strait, Notes on Tangential Probes: Basic Equations II, TS-SSC 90-092, 11/27/90.

[3] J. Strait, Notes on Tangential Probes: Example Calculations, TS-SSC 90-093, 11/29/90.

cc: S. Gourlay
T. Jaffery
W. Koska

1. calculate d's
2. calculate F_n's $(\div \ell^{n+1})$

Probe 14



	i	ϕ_i	N_i	f_i	l_i (cm)	r_i (cm)
T	1	348.463	20	+1	24.30	1.242
T	2	11.537	20	−1	24.30	1.242
D_1	3	45°	1	$-d_3$	25.0 (9.442)	1.242 (.499)
D_1	4	225°	1	$+d_3$	25.0	1.242
BB	5	90°	4	$-d_5$	24.32	1.242
BB	6	270°	4	$+d_5$	24.32	1.242
D_2	7	135°	1	$-d_7$	24.68	1.242
D_2	8	315°	1	$+d_7$	24.68	1.242

Belly Band bucking only (no D_1 & D_2)

$$C_0 = N_1 l_1 r_1 \left[\cos \varphi_1 - \cos \varphi_2\right] + N_5 l_5 r_5 d_5 \left[\cos \varphi_5 - \cos \varphi_6\right] \equiv \emptyset$$

$$A + B d_5 = \emptyset$$

$$S_0 = N_1 l_1 r_1 \left[\sin \varphi_1 - \sin \varphi_2\right] + N_5 l_5 r_5 d_5 \left[\sin \varphi_5 - \sin \varphi_6\right]$$

$$C + D d_5 = \emptyset$$

$$d_5 = \frac{A - C}{D - B}$$

$$= \frac{N_1 l_1 r_1 \left[C_{12} - S_{12}\right]}{N_5 l_5 r_5 \left[S_{56} - C_{56}\right]}$$

$$\frac{20(24.30)\left[\emptyset - -0.4\right]}{4(24.32)\left[2 - \emptyset\right]}$$

$$d_5 = .99918$$

for bucking with belly band alone

D_1 & D_2 bucking (no belly band)

from Jim's paper 11/9/90

$$d_3 = \frac{N_1\, l_1\, r_1\, (C_{12} S_{78} - S_{12} C_{78})}{N_3\, l_3\, r_3\, (C_{78} S_{34} - S_{78} C_{34})}$$

$$\frac{20(24.30)\left[\emptyset - (-0.4)(-1.414)\right]}{1\,(25.0)\left[\underbrace{(-1.414)(1.414)}_{-2} - \underbrace{(1.414)(1.414)}_{2}\right]}$$

$$\boxed{d_3 = -2.7488}$$

$$d_7 = \frac{N_1\, l_1\, r_1\, (C_{12} S_{34} - S_{12} C_{34})}{N_7\, l_7\, r_7\, (C_{78} S_{34} - S_{78} C_{34})}$$

$$\frac{20\,(24.30)\left[\emptyset - (-0.4)(1.414)\right]}{1\,(24.68)\left[-2 - 2\right]}$$

$$\boxed{d_7 = -2.7845}$$

for bucking using D_1 & D_2 only
(no belly band)

Belly Band Bucking w/ D_1 & D_2 for correction

$$C_0 = N_1 l_1 r_1 [\cos\varphi_1 - \cos\varphi_2] + N_3 l_3 r_3 [\cos\varphi_3 - \cos\varphi_4] d_3 + N_5 l_5 r_5 [\cos\varphi_5 - \cos\varphi_6] d_5 + N_7 l_7 r_7 [\cos\varphi_7 - \cos\varphi_8] d_7$$

$$= A + B d_3 + C d_5 + D d_7$$

$$S_0 = N_1 l_1 r_1 [\sin\varphi_1 - \sin\varphi_2] + N_3 l_3 r_3 [\sin\varphi_3 - \sin\varphi_4] d_3 + N_5 l_5 r_5 [\sin\varphi_5 - \sin\varphi_6] d_5 + N_7 l_7 r_7 [\sin\varphi_7 - \sin\varphi_8] d_7$$

$$= E + F d_3 + G d_5 + H d_7$$

Choose $d_5 = 1.0$ (belly band) from pg 2 since D_1 & D_2 are used only to correct for geometric imperfections in probe

$$A + B d_3 + C + D d_7 \equiv \emptyset$$

$$E + F d_3 + G + H d_7 \equiv \emptyset$$

$$(A+C) + Bd_3 + Dd_7 = \emptyset$$

$$(E+G) + Fd_3 + Hd_7 = \emptyset$$

$$\left((A+C)H - (E+G)D\right) + (BH - DF)d_3 = \emptyset$$

$$d_3 = \frac{(A+C)H - (E+G)D}{DF - BH}$$

$$\left((A+C)F - (E+G)B\right) + (DF - BH) = \emptyset$$

$$d_7 = \frac{(A+C)F - (E+G)B}{DF - BH}$$

$$d_3 = \frac{(N_1 l_1 r_1 C_{12} + N_5 l_5 r_5 C_{56})\cancel{N_7}\cancel{l_7}\cancel{r_7} S_{78} - (N_1 l_1 r_1 S_{12} + N_5 l_5 r_5 S_{56})\cancel{N_7}\cancel{l_7}\cancel{r_7} C_{78}}{\cancel{N_7}\cancel{l_7}\cancel{r_7} C_{78} N_3 l_3 r_3 S_{34} - N_3 l_3 r_3 C_{34} \cancel{N_7}\cancel{l_7}\cancel{r_7} S_{78}}$$

$$d_3 = \frac{N_1 l_1 r_1 (C_{12} S_{78} - S_{12} C_{78}) + N_5 l_5 r_5 (C_{56} S_{78} - S_{56} C_{78})}{N_3 l_3 r_3 (C_{78} S_{34} - S_{78} C_{34})}$$

$$d_7 = \frac{(N_1 l_1 r_1 C_{12} + N_5 l_5 r_5 C_{56})\cancel{N_3}\cancel{l_3}\cancel{r_3} S_{34} - (N_1 l_1 r_1 S_{12} + N_5 l_5 r_5 S_{56})\cancel{N_3}\cancel{l_3}\cancel{r_3} C_{34}}{N_7 l_7 r_7 C_{78} \cancel{N_3}\cancel{l_3}\cancel{r_3} S_{34} - \cancel{N_3}\cancel{l_3}\cancel{r_3} C_{34} N_7 l_7 r_7 S_{78}}$$

$$d_7 = \frac{N_1 l_1 r_1 (C_{12} S_{34} - S_{12} C_{34}) + N_5 l_5 r_5 (C_{56} S_{34} - S_{56} C_{34})}{N_7 l_7 r_7 (C_{78} S_{34} - C_{34} S_{78})}$$

$$d_3 = \frac{20(24.30)\left[\emptyset - (-0.4)(-1.414)\right] + \overset{.22624}{4(24.32)\left[\emptyset - (2)(-1.414)\right]}}{(1)(25.\emptyset)\left[\underbrace{(-1.414)(1.414)}_{-2} - \underbrace{(1.414)(1.414)}_{2}\right]}$$

$$d_3 = -.00226$$

$$d_7 = \frac{20(24.30)\left[\emptyset - (-0.4)(1.414)\right] + 4(24.32)\left[\emptyset - (2)(1.414)\right]}{(1)(24.68)\left[\underset{(-2)}{(-1.414)(1.414)} - \underset{(2)}{(1.414)(1.414)}\right]}$$

$$d_7 = .00229$$

$$C_n = \sum_{j=1}^{8} f_j N_j l_j \frac{r_j^{\bar{n}}}{\rho^{\bar{n}}} \cos \bar{n} \varphi_j$$

$$S_n = \sum_{j=1}^{8} f_j N_j l_j \frac{r_j^{\bar{n}}}{\rho^{\bar{n}}} \sin \bar{n} \varphi_j$$

$$F_n = \sqrt{C_n^2 + S_n^2} \qquad \gamma_n = \tan^{-1}\left(\frac{S_n}{C_n}\right)$$

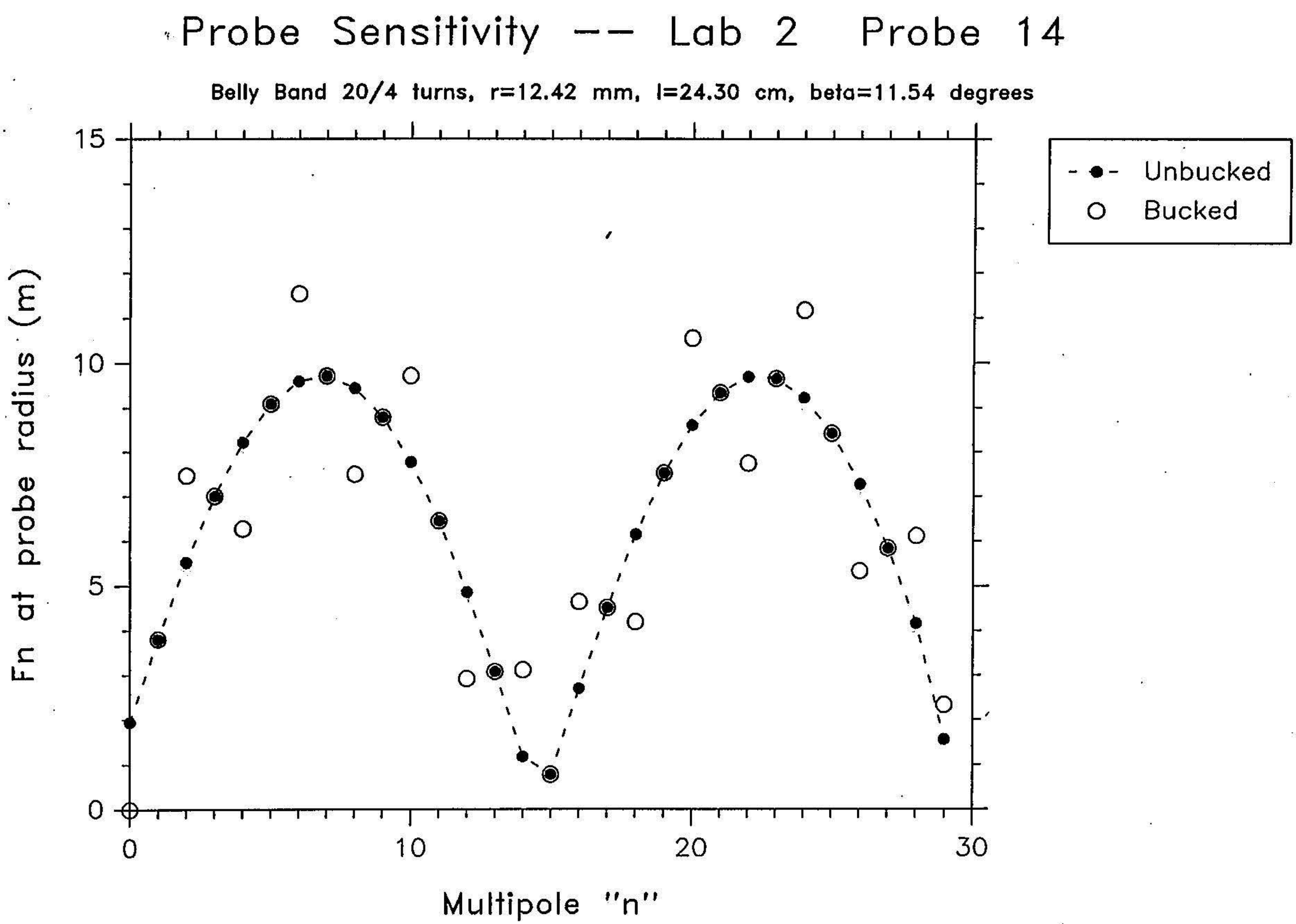
given Fourier amplit A_n and phase δ_n,

$$h_n = \frac{\bar{n} A_n}{B_0 \rho F_n} \qquad \alpha_n = \delta_n - \gamma_n - \bar{n}\varphi + \pi$$

are the multipole amplitude & phase

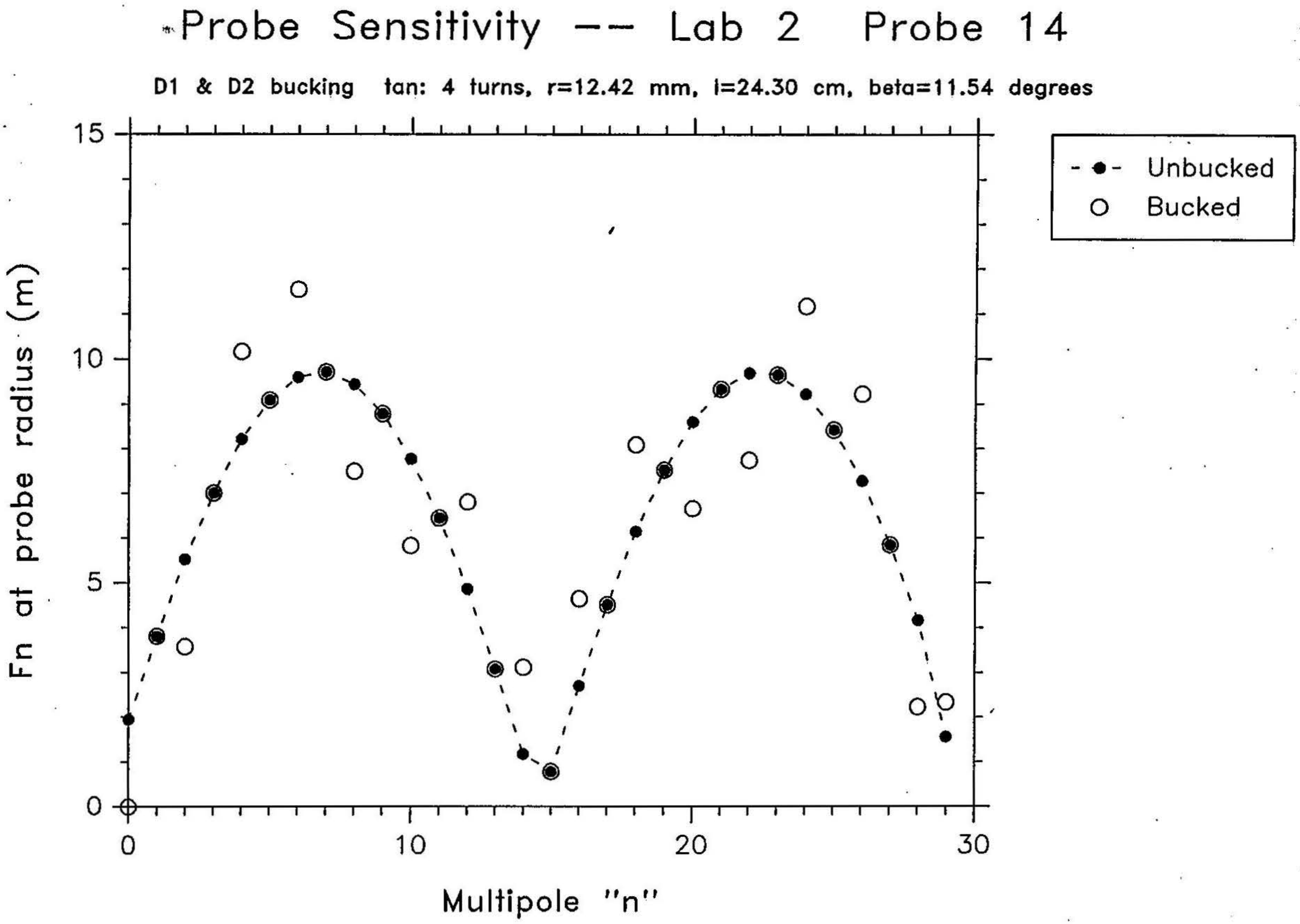
r_n

N	Unbucked tangential	Bellyband Bucking	D1 + D2 bucking
0	1.944	4.E-17	6.E-17
1	3.809	3.809	3.809
2	5.521	7.465	3.577
3	7.009	7.009	7.009
4	8.215	6.271	10.16
5	9.088	9.088	9.088
6	9.594	11.54	11.54
7	9.712	9.712	9.712
8	9.438	7.494	7.494
9	8.783	8.783	8.783
10	7.772	9.716	5.828
11	6.448	6.448	6.448
12	4.863	2.919	6.807
13	3.081	3.081	3.081
14	1.175	3.119	3.119
15	.7782	.7782	.7782
16	2.700	4.644	4.644
17	4.513	4.513	4.513
18	6.144	4.200	8.088
19	7.526	7.526	7.526
20	8.604	10.55	6.660



Probe Sensitivity -- Lab 2 Probe 14
Belly Band 20/4 turns, r=12.42 mm, l=24.30 cm, beta=11.54 degrees
Unbucked
Bucked
Fn at probe radius (m)
Multipole "n"
0
5
10
15
0
10
20
30

Figure 1



Probe Sensitivity -- Lab 2 Probe 14
D1 & D2 bucking tan: 4 turns, r=12.42 mm, l=24.30 cm, beta=11.54 degrees
Unbucked
Bucked
Fn at probe radius (m)
Multipole "n"
0
5
10
15
0
10
20
30

Figure 2

tangential only — no bucking

N	NBAR	C	S	F(M**(N+2))	GAMMA	FORLITZ	F00.39IN.
0.	1.	0.3286E-09	-.1944E+01	0.2415E-01	-90.00	0.1944E+01	0.2415E+01
1.	2.	0.1288E-08	-.3809E+01	0.5877E-03	-90.00	0.3809E+01	0.5877E+01
2.	3.	0.2799E-08	-.5521E+01	0.1058E-04	-90.00	0.5521E+01	0.1058E+02
3.	4.	0.4739E-08	-.7009E+01	0.1668E-06	-90.00	0.7009E+01	0.1668E+02
4.	5.	0.6942E-08	-.8215E+01	0.2428E-08	-90.00	0.8215E+01	0.2428E+02
5.	6.	0.9216E-08	-.9088E+01	0.3337E-10	-90.00	0.9088E+01	0.3337E+02
6.	7.	0.1135E-07	-.9594E+01	0.4375E-12	-90.00	0.9594E+01	0.4375E+02
7.	8.	0.1313E-07	-.9712E+01	0.5501E-14	-90.00	0.9712E+01	0.5501E+02
8.	9.	0.1436E-07	-.9438E+01	0.6640E-16	-90.00	0.9438E+01	0.6640E+02
9.	10.	0.1484E-07	-.8783E+01	0.7675E-18	-90.00	0.8783E+01	0.7675E+02
10.	11.	0.1445E-07	-.7772E+01	0.8436E-20	-90.00	0.7772E+01	0.8436E+02
11.	12.	0.1308E-07	-.6448E+01	0.8692E-22	-90.00	0.6448E+01	0.8692E+02
12.	13.	0.1068E-07	-.4863E+01	0.8142E-24	-90.00	0.4863E+01	0.8142E+02
13.	14.	0.7291E-08	-.3081E+01	0.6408E-26	-90.00	0.3081E+01	0.6408E+02
14.	15.	0.2980E-08	-.1175E+01	0.3036E-28	-90.00	0.1175E+01	0.3036E+02
15.	16.	-.2104E-08	0.7782E+00	0.2497E-30	90.00	0.7782E+00	0.2497E+02
16.	17.	-.7758E-08	0.2700E+01	0.1076E-31	90.00	0.2700E+01	0.1076E+03
17.	18.	-.1373E-07	0.4513E+01	0.2234E-33	90.00	0.4513E+01	0.2234E+03
18.	19.	-.1973E-07	0.6144E+01	0.3777E-35	90.00	0.6144E+01	0.3777E+03
19.	20.	-.2544E-07	0.7526E+01	0.5747E-37	90.00	0.7526E+01	0.5747E+03
20.	21.	-.3054E-07	0.8604E+01	0.0000E+00	90.00	0.8604E+01	0.8161E+03
21.	22.	-.3471E-07	0.9335E+01	0.0000E+00	90.00	0.9335E+01	0.1100E+04
22.	23.	-.3766E-07	0.9688E+01	0.0000E+00	90.00	0.9688E+01	0.1418E+04
23.	24.	-.3914E-07	0.9650E+01	0.0000E+00	90.00	0.9650E+01	0.1754E+04
24.	25.	-.3896E-07	0.9222E+01	0.0000E+00	90.00	0.9222E+01	0.2082E+04
25.	26.	-.3700E-07	0.8421E+01	0.0000E+00	90.00	0.8421E+01	0.2361E+04
26.	27.	-.3322E-07	0.7280E+01	0.0000E+00	90.00	0.7280E+01	0.2535E+04
27.	28.	-.2766E-07	0.5845E+01	0.0000E+00	90.00	0.5845E+01	0.2528E+04
28.	29.	-.2045E-07	0.4173E+01	0.0000E+00	90.00	0.4173E+01	0.2242E+04
29.	30.	-.1183E-07	0.2333E+01	0.0000E+00	90.00	0.2333E+01	0.1557E+04

Table 1

Bucking w/ belly band

N	NBAR	C	S	F(M**(N+2))	GAMMA	FORLITZ	F00.39IN.
0.	1.	-.3866E-16	0.2776E-16	0.5911E-18	144.33	0.4759E-16	0.5912E-16
1.	2.	0.1288E-08	-.3809E+01	0.5877E-03	-90.00	0.3809E+01	0.5877E+01
2.	3.	0.3785E-08	-.7465E+01	0.1430E-04	-90.00	0.7465E+01	0.1430E+02
3.	4.	0.4739E-08	-.7009E+01	0.1668E-06	-90.00	0.7009E+01	0.1668E+02
4.	5.	0.5299E-08	-.6271E+01	0.1854E-08	-90.00	0.6271E+01	0.1854E+02
5.	6.	0.9216E-08	-.9088E+01	0.3337E-10	-90.00	0.9088E+01	0.3337E+02
6.	7.	0.1365E-07	-.1154E+02	0.5262E-12	-90.00	0.1154E+02	0.5262E+02
7.	8.	0.1313E-07	-.9712E+01	0.5501E-14	-90.00	0.9712E+01	0.5501E+02
8.	9.	0.1140E-07	-.7494E+01	0.5272E-16	-90.00	0.7494E+01	0.5272E+02
9.	10.	0.1484E-07	-.8783E+01	0.7675E-18	-90.00	0.8783E+01	0.7675E+02
10.	11.	0.1806E-07	-.9716E+01	0.1055E-19	-90.00	0.9716E+01	0.1055E+03
11.	12.	0.1308E-07	-.6448E+01	0.8692E-22	-90.00	0.6448E+01	0.8692E+02
12.	13.	0.6413E-08	-.2919E+01	0.4887E-24	-90.00	0.2919E+01	0.4887E+02
13.	14.	0.7291E-08	-.3081E+01	0.6408E-26	-90.00	0.3081E+01	0.6408E+02
14.	15.	0.7908E-08	-.3119E+01	0.8058E-28	-90.00	0.3119E+01	0.8058E+02
15.	16.	-.2104E-08	0.7782E+00	0.2497E-30	90.00	0.7782E+00	0.2497E+02
16.	17.	-.1334E-07	0.4644E+01	0.1851E-31	90.00	0.4644E+01	0.1851E+03
17.	18.	-.1373E-07	0.4513E+01	0.2234E-33	90.00	0.4513E+01	0.2234E+03
18.	19.	-.1349E-07	0.4200E+01	0.2582E-35	90.00	0.4200E+01	0.2582E+03
19.	20.	-.2544E-07	0.7526E+01	0.5747E-37	90.00	0.7526E+01	0.5747E+03
20.	21.	-.3744E-07	0.1055E+02	0.0000E+00	90.00	0.1055E+02	0.1000E+04
21.	22.	-.3471E-07	0.9335E+01	0.0000E+00	90.00	0.9335E+01	0.1100E+04
22.	23.	-.3010E-07	0.7744E+01	0.0000E+00	90.00	0.7744E+01	0.1133E+04
23.	24.	-.3914E-07	0.9650E+01	0.0000E+00	90.00	0.9650E+01	0.1754E+04
24.	25.	-.4718E-07	0.1117E+02	0.0000E+00	90.00	0.1117E+02	0.2520E+04
25.	26.	-.3700E-07	0.8421E+01	0.0000E+00	90.00	0.8421E+01	0.2361E+04
26.	27.	-.2435E-07	0.5336E+01	0.0000E+00	90.00	0.5336E+01	0.1858E+04
27.	28.	-.2766E-07	0.5845E+01	0.0000E+00	90.00	0.5845E+01	0.2528E+04
28.	29.	-.2998E-07	0.6117E+01	0.0000E+00	90.00	0.6117E+01	0.3286E+04
29.	30.	-.1183E-07	0.2333E+01	0.0000E+00	90.00	0.2333E+01	0.1557E+04

10g Tangential: $\theta_3 = \emptyset.9993$

Table 2

Ducking w/ D1 & D2

N	NBAR	C	S	F(M**(N+2))	GAMMA	FORLITZ	F00.39IN.
0.	1.	-.4857E-16	0.3469E-16	0.7414E-18	144.46	0.5969E-16	0.7414E-16
1.	2.	0.1288E-08	-.3809E+01	0.5877E-03	-90.00	0.3809E+01	0.5877E+01
2.	3.	0.1814E-08	-.3577E+01	0.6854E-05	-90.00	0.3577E+01	0.6854E+01
3.	4.	0.4739E-08	-.7009E+01	0.1668E-06	-90.00	0.7009E+01	0.1668E+02
4.	5.	0.8584E-08	-.1016E+02	0.3003E-08	-90.00	0.1016E+02	0.3003E+02
5.	6.	0.9216E-08	-.9088E+01	0.3337E-10	-90.00	0.9088E+01	0.3337E+02
6.	7.	0.1365E-07	-.1154E+02	0.5262E-12	-90.00	0.1154E+02	0.5262E+02
7.	8.	0.1313E-07	-.9712E+01	0.5501E-14	-90.00	0.9712E+01	0.5501E+02
8.	9.	0.1140E-07	-.7494E+01	0.5272E-16	-90.00	0.7494E+01	0.5272E+02
9.	10.	0.1484E-07	-.8783E+01	0.7675E-18	-90.00	0.8783E+01	0.7675E+02
10.	11.	0.1084E-07	-.5828E+01	0.6326E-20	-90.00	0.5828E+01	0.6326E+02
11.	12.	0.1308E-07	-.6448E+01	0.8692E-22	-90.00	0.6448E+01	0.8692E+02
12.	13.	0.1496E-07	-.6807E+01	0.1140E-23	-90.00	0.6807E+01	0.1140E+03
13.	14.	0.7291E-08	-.3081E+01	0.6408E-26	-90.00	0.3081E+01	0.6408E+02
14.	15.	0.7908E-08	-.3119E+01	0.8058E-28	-90.00	0.3119E+01	0.8058E+02
15.	16.	-.2104E-08	0.7782E+00	0.2497E-30	90.00	0.7782E+00	0.2497E+02
16.	17.	-.1334E-07	0.4644E+01	0.1851E-31	90.00	0.4644E+01	0.1851E+03
17.	18.	-.1373E-07	0.4513E+01	0.2234E-33	90.00	0.4513E+01	0.2234E+03
18.	19.	-.2597E-07	0.8088E+01	0.4972E-35	90.00	0.8088E+01	0.4972E+03
19.	20.	-.2544E-07	0.7526E+01	0.5747E-37	90.00	0.7526E+01	0.5747E+03
20.	21.	-.2364E-07	0.6660E+01	0.0000E+00	90.00	0.6660E+01	0.6317E+03
21.	22.	-.3471E-07	0.9335E+01	0.0000E+00	90.00	0.9335E+01	0.1100E+04
22.	23.	-.3010E-07	0.7744E+01	0.0000E+00	90.00	0.7744E+01	0.1133E+04
23.	24.	-.3914E-07	0.9650E+01	0.0000E+00	90.00	0.9650E+01	0.1754E+04
24.	25.	-.4718E-07	0.1117E+02	0.0000E+00	90.00	0.1117E+02	0.2520E+04
25.	26.	-.3700E-07	0.8421E+01	0.0000E+00	90.00	0.8421E+01	0.2361E+04
26.	27.	-.4209E-07	0.9224E+01	0.0000E+00	90.00	0.9224E+01	0.3212E+04
27.	28.	-.2766E-07	0.5845E+01	0.0000E+00	90.00	0.5845E+01	0.2528E+04
28.	29.	-.1093E-07	0.2229E+01	0.0000E+00	90.00	0.2229E+01	0.1198E+04
29.	30.	-.1183E-07	0.2333E+01	0.0000E+00	90.00	0.2333E+01	0.1557E+04

F_i

$d_3 = 2.7494$

$d_7 = 2.7848$

Table 3