Effect of Strain Gage Blocks on Normal Sextupole Moment in DSA321 and DSA323

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Introduction. In a previous note, the effect of the pressure gage blocks contained in the strain gage pack on cold measurements of the dipole field in 50 mm aperture SSC model dipole DSA321 was reported.[1] It appeared that the gage block magnetization was already tending toward saturation at transport currents below 400 A, and that the perturbation in the dipole field brought about by the eventual magnetization would be close to 40 Gauss at high currents (> 1 kA.)

In this note we examine the effect at 5 kA transport current of the gage block on the normal sextupole harmonic b2[2], using longitudinal scan data from DSA321 and DSA323, the first two 50 mm model dipoles to be cold tested. We also look at the gage block perturbation of b2 as a function of current using sawtooth ramp measurements of b2 on and off the gage pack.

All of the data used in this memo were taken at Lab 2 using Probe 11, a Morgan Coil device with 18" active length, read out with the Lab 2 magnetometer. The measurements were taken by Mike Lamm, Tariq Jaffery and the Lab 2 staff, and the initial data reduction was performed by Tariq Jaffery and Carol Diebold.

Figures 1a and 1b show the positions of the strain gage collar packs in DSA321 and DSA323. In DSA323 the pack was deliberately moved further off-center to facilitate exclusion of the gage block effect in harmonics measurements, and this is now the standard position for the gage pack in further 50 mm aperture model dipole magnets.

[1] M. Wake, "Magnetization Effect of Pressure Gage Block," TS-SSC 91-024, January 31, 1991.

[2] In this memo, b2 is always given in prime units at 1cm. That is, b2 is the normal sextupole field strength divided by the dipole field strength at 1cm radius, multiplied by 10,000.

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Longitudinal Scans. Longitudinal scans ("z-scans") were performed on DSA321 and DSA323. These scans had the goal of measuring harmonics up through the 10-pole as a function of axial position along the magnet . Data were taken with the center of Probe 11 at magnet center and at 2 inch intervals on either side of magnet center out to ±24 inches (twenty five positions in total.) At each position, 30 measurements were made. At magnet center, 70 measurements were made.

The z-scan data were taken at 4.2 K. First, the magnet was ramped to quench at 16 A/sec. Next the magnet was ramped to 6.5 kA at 12 A/sec, and held at 6.5 kA for 2 minutes. The magnet was then ramped down to 110 A at -12 A/sec and held there for 2 minutes. Finally, the magnet was brought up to 5.0 kA at 6 A/sec.

Figures 2a and 2b show the z-scan data for DSA321 and DSA323 b2. All points beyond 12 inches (.30 meters) on either side, part of Probe 11 is outside the yoked/collared region of the magnet. Only the points lying within the dotted lines in the figures will be considered further.

Figures 3a and 3b show the z-scan data for the two magnets, confined to the z positions for which Probe 11 lies completely within the yoked/collared length of the magnet.

For magnet DSA321 (Figure 3a), the points at -8, -6, -4, -2, 0, and 2 inches include the full strain gage pack. That is, the full length (6 inches) of the strain gage collar pack is covered by part of the 18 inch active length of Probe 11. The points at -12 and -10 inches contain part of the gage pack, as do the points at 4, 6, and 8 inches. Only the points at 10 and 12 inches have Probe 11 completely in the yoked/collared region and away from the strain gage pack.

It is seen that b2 is less positive for points affected by the gage pack than for points away from the gage pack.[3] The magnitude of the effect is about 0.8 prime units at 1cm, although there is clearly some variation in b2 as the gage pack is traversed.

For magnet DSA323 (Figure 3b), in which the strain gage pack was shifted toward the lead end, a larger subset of z-scan points are unaffected by the strain gage pack. In particular, the points at -4, -6, -8, -10, and -12 inches should be unaffected by strain gage block effects. For the points at -2, 0, and 2 inches, Probe 11 covers part of the strain gage pack. For the 4, 6, 8, 10, and 12 inch points, Probe 11 covers the entire strain gage pack. Here, the 2 inch point is unexpectedly high, but the same qualitative effect as in DSA321 is seen; b2 is about 0.6 units less positive in the strain gage pack region as away from it.

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[3]Of course, the gage block magnitization introduces a non-two dimensional effect, so that it is not strictly correct to say that points for which Probe 11 does not cover any part of the strain gage pack are totally unaffected by the gage block magnitization.

Current Dependence of b2 Shift. Figure 4 shows b2 on and off the gage pack for magnet DSA323 as a function of current for transport currents above 1 kA. These data were taken with Probe 11 at -9 and 9 inches respectively. These data were taken at 4.2 K employing a "sawtooth ramp" at 16 A/sec from 0 A to a peak current of Iquench - 200 A and back down to 0 A. The black arrow-heads indicate the part of each scan corresponding to the up-ramp.

At both z positions, the usual effect of superconductor magnetization is seen, in that b2 is less positive on the up-ramp than on the down-ramp. The irregularities in the shape of b2 above 4 kA are due to saturation of various parts of the iron yoke.

Figure 5a shows the difference between b2 on and off the gage pack as a function of current, for transport currents above 1 kA[4]. Two sets of points are shown in the figure. One set corresponds to the field on the up-ramp, the other to the down-ramp field. It is seen that the shift in b2 at a given transport current is about the same on the up-ramp as on the down-ramp.

Should the shift in b2 be constant with current? (In other words, should the shape of the b2 loop be the same on as off the gage pack?) This question can be addressed with a simple model as follows.

If the gage blocks had *only* an associated dipole field B0_g, then b2 would shift by approximately -b2*(B0_g / B0), where b2 and B0 are the sextupole moment and dipole field away from the gage pack. Since the dipole field contributed by the gage pack is of the order of 40 Gauss at high current, the change in b2 due to this field will be a few parts in one thousand, which is a small compared to the observed effect of ~0.25 - 1.1 units.

On the other hand, if the gage block had *only* an associated sextupole field of magnitude B2_g at 1 cm, then b2 would shift by 10,000 * (B2_g / B0), that is, the gage pack would simply add its inherent b2 to the already present b2 of the magnet.

Figure 5b shows the b2 shift on the up-ramp plotted with a prediction using -1.6 Gauss for B2_g.[5] Clearly a small constant sextupole field due to strain gage block magnitization could account for the most of the observed shape of the shift in b2. On the down-ramp, the shape will be the same except for the shift in the value of B0 relative to the up-ramp value at a given transport current, which for magnet DSA323 is only about .9%.

Finally, is the change in b2 due to the strain gage pack consistent from magnet to magnet? Figure 6 shows b2 for DSA321 with Probe 11 centered at magnet center, and the data from DSA323 with Probe 11 covering the entire strain gage pack are superimposed. The shapes of the two loops are seen tobe nearly identical.

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[4]There is one caveat pertaining to this plot. The currents at which data were recorded for the on- and off-gage pack traces were not exactly the same. Corresponding points in the two scans were used for the subtraction.

[5]As far as I know, no one has ever tried to model the fields produced by the gage blocks. Several hours of sketching magnetic field lines did not lead to a definitive motivation for a particular sign for the sextupole field.

Conclusion. The effect of the strain gage pressure blocks on the normal sextupole moments of two 50 mm aperture magnets, DSA321 and DSA323 has been examined.

While in magnet DSA321 the strain gage collar pack was not optimally placed for these studies, an effect can be seen, with b2 at the gage pack about 0.8 units less positive than the intrinsic b2 of the magnet at 5 kA transport current.. The effect is much clearer in the data from DSA323, in which the gage pack was purposely moved further from magnet center. Here, b2 at the gage pack is 0.6 units less positive.

Current loop data on and off the gage pack show that above 1 kA transport current, the shift in b2 is not constant with transport current, but is more or less the same on the up ramp as on the down ramp. This is consistent with a small constant negative sextupole field (amplitude 1.6 Gauss at 1 cm) from the pressure blocks of the strain gage pack.

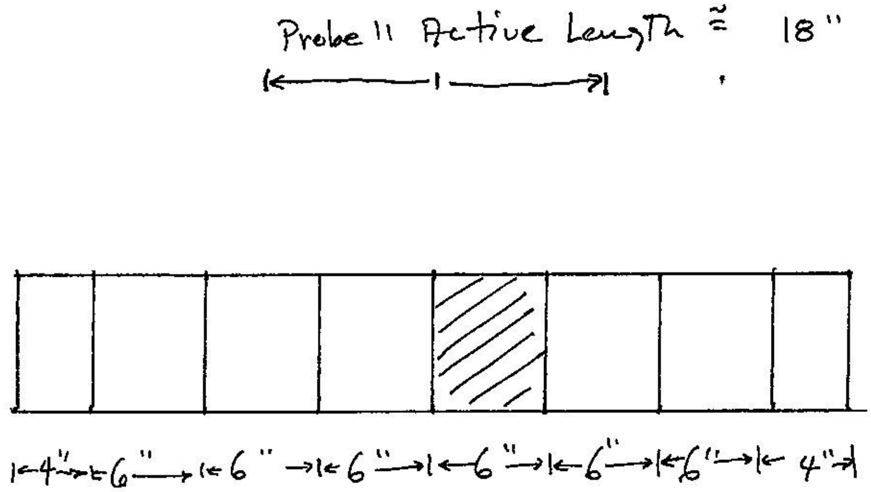

Figure 1a. DSA321 Gage Pack Position

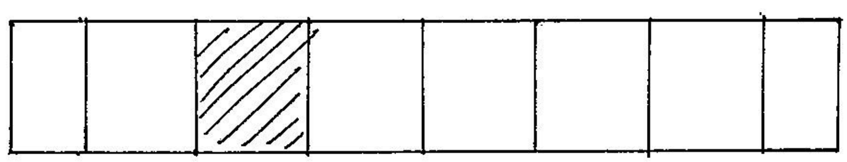

Figure 1b. DSA323 Gage Pack Position

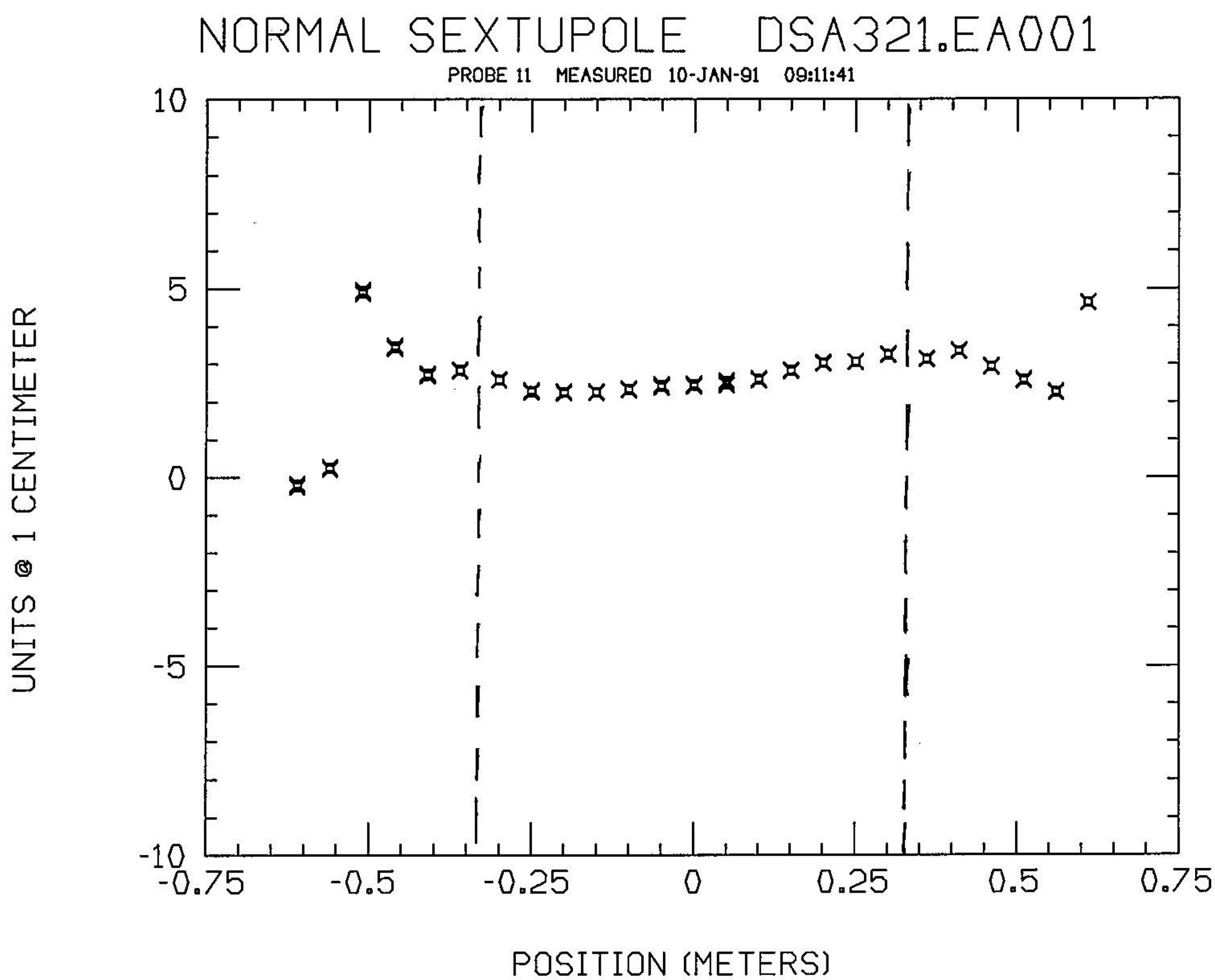
NORMAL SEXTUPOLE DSA321.EA001
PROBE 11 MEASURED 10-JAN-91 09:11:41
10
5
0
-5
-10
-0.75
-0.5
-0.25
0
0.25
0.5
0.75
UNITS @ 1 CENTIMETER
POSITION (METERS)

Figure 2a

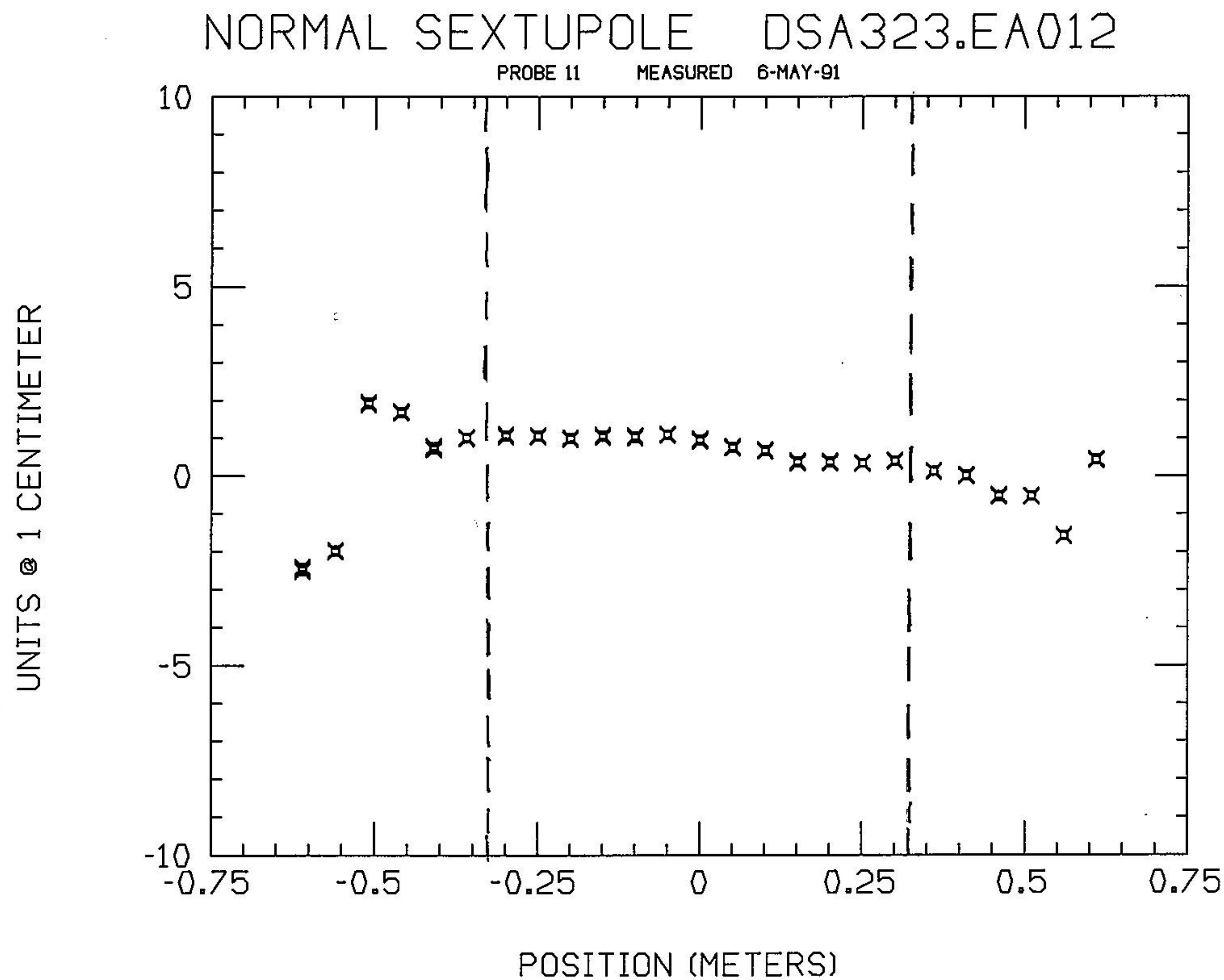
NORMAL SEXTUPOLE DSA323.EA012
PROBE 11 MEASURED 6-MAY-91
UNITS @ 1 CENTIMETER
POSITION (METERS)
10
5
0
-5
-10
-0.75
-0.5
-0.25
0
0.25
0.5
0.75

Figure 2b

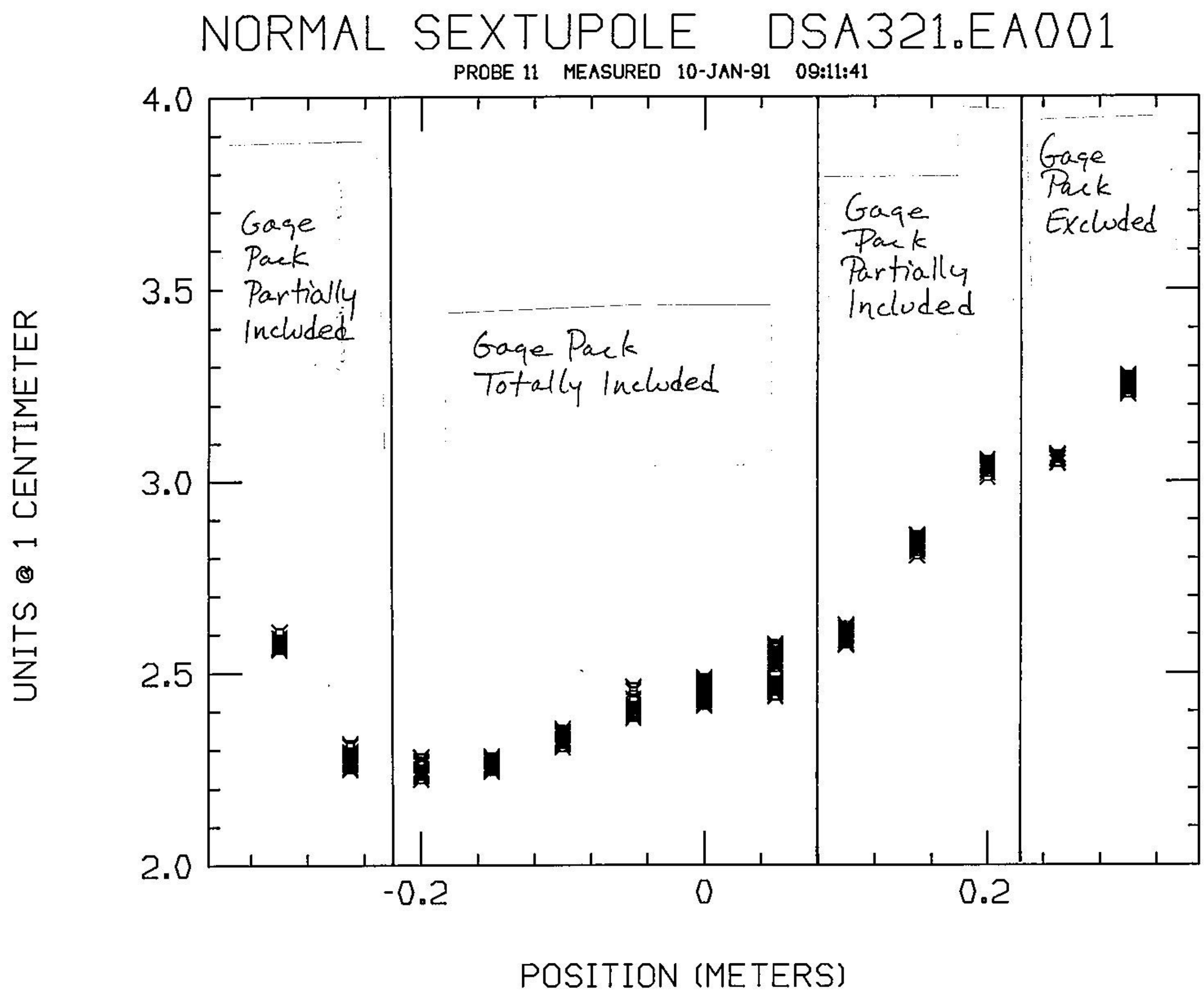
NORMAL SEXTUPOLE DSA321.EA001
PROBE 11 MEASURED 10-JAN-91 09:11:41
4.0
3.5
3.0
2.5
2.0
UNITS @ 1 CENTIMETER
-0.2
0
0.2
POSITION (METERS)
Gage Pack Partially Included
Gage Pack Totally Included
Gage Pack Partially Included
Gage Pack Excluded

Figure 3a

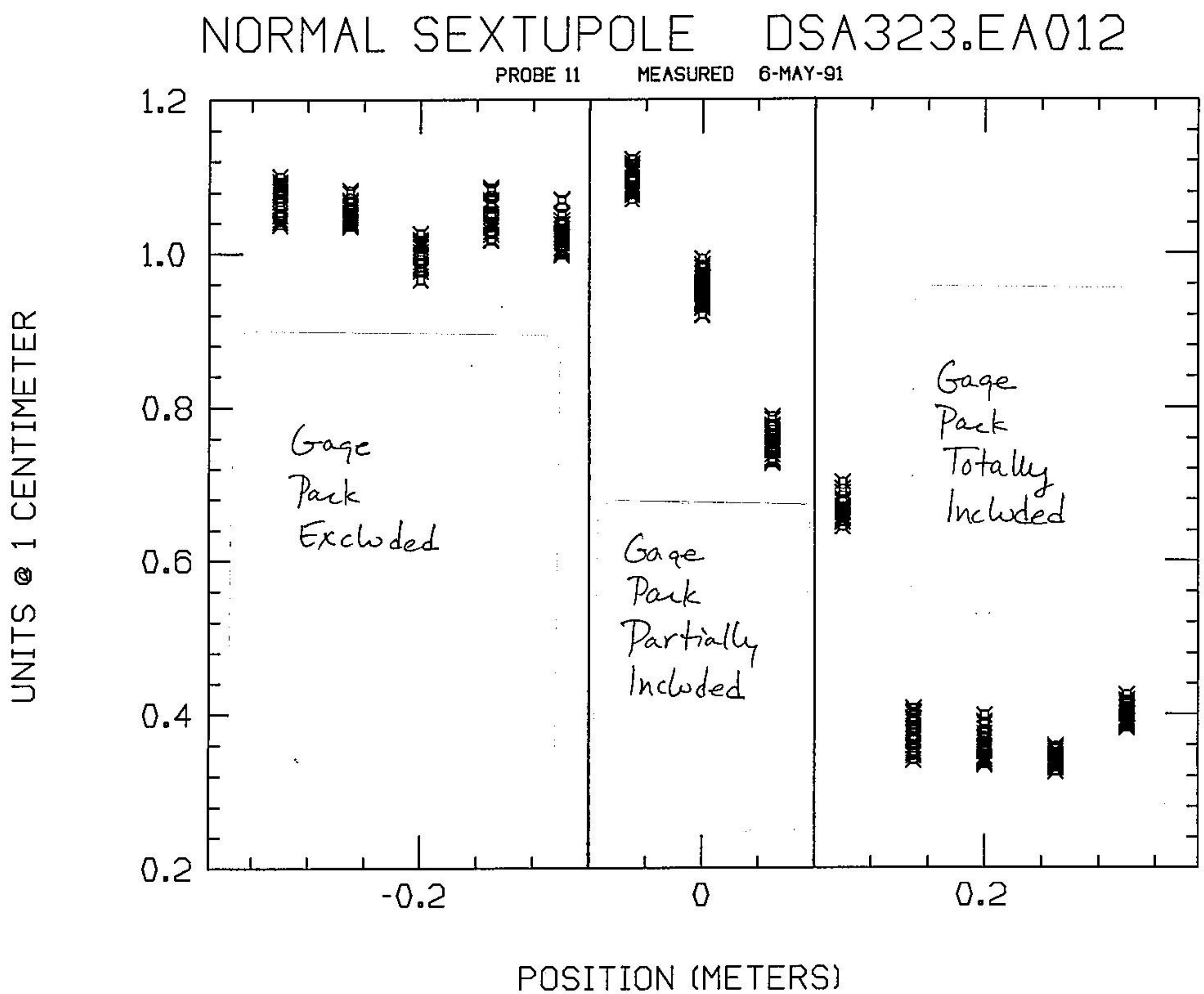
NORMAL SEXTUPOLE DSA323.EA012
PROBE 11 MEASURED 6-MAY-91
UNITS @ 1 CENTIMETER
1.2
1.0
0.8
0.6
0.4
0.2
-0.2
0
0.2
POSITION (METERS)
Gage Pack Excluded
Gage Pack Partially Included
Gage Pack Totally Included

Figure 3b

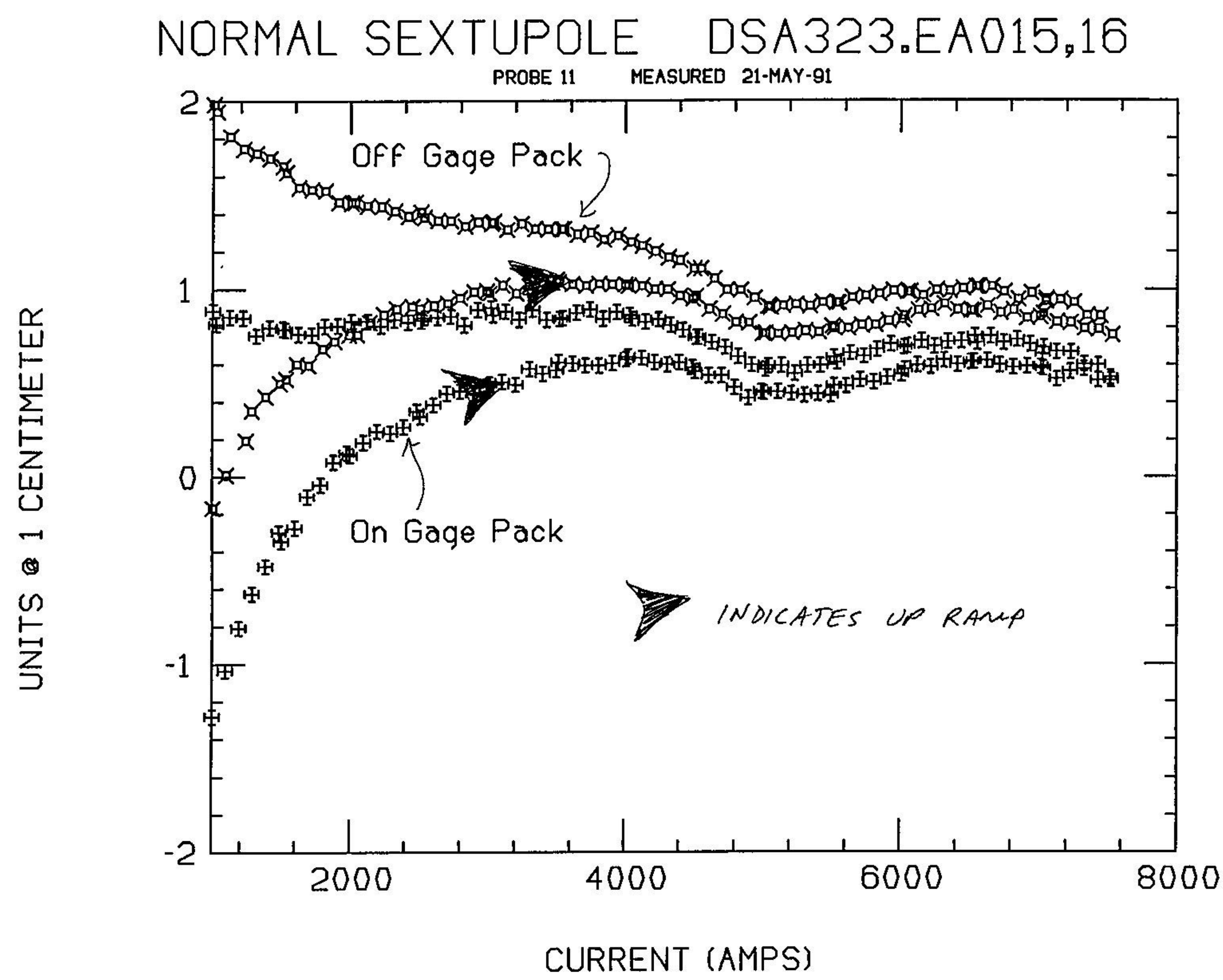
NORMAL SEXTUPOLE DSA323.EA015,16
PROBE 11 MEASURED 21-MAY-91
Off Gage Pack
On Gage Pack
INDICATES UP RAMP
UNITS @ 1 CENTIMETER
CURRENT (AMPS)
2
1
0
-1
-2
2000
4000
6000
8000

Figure 4

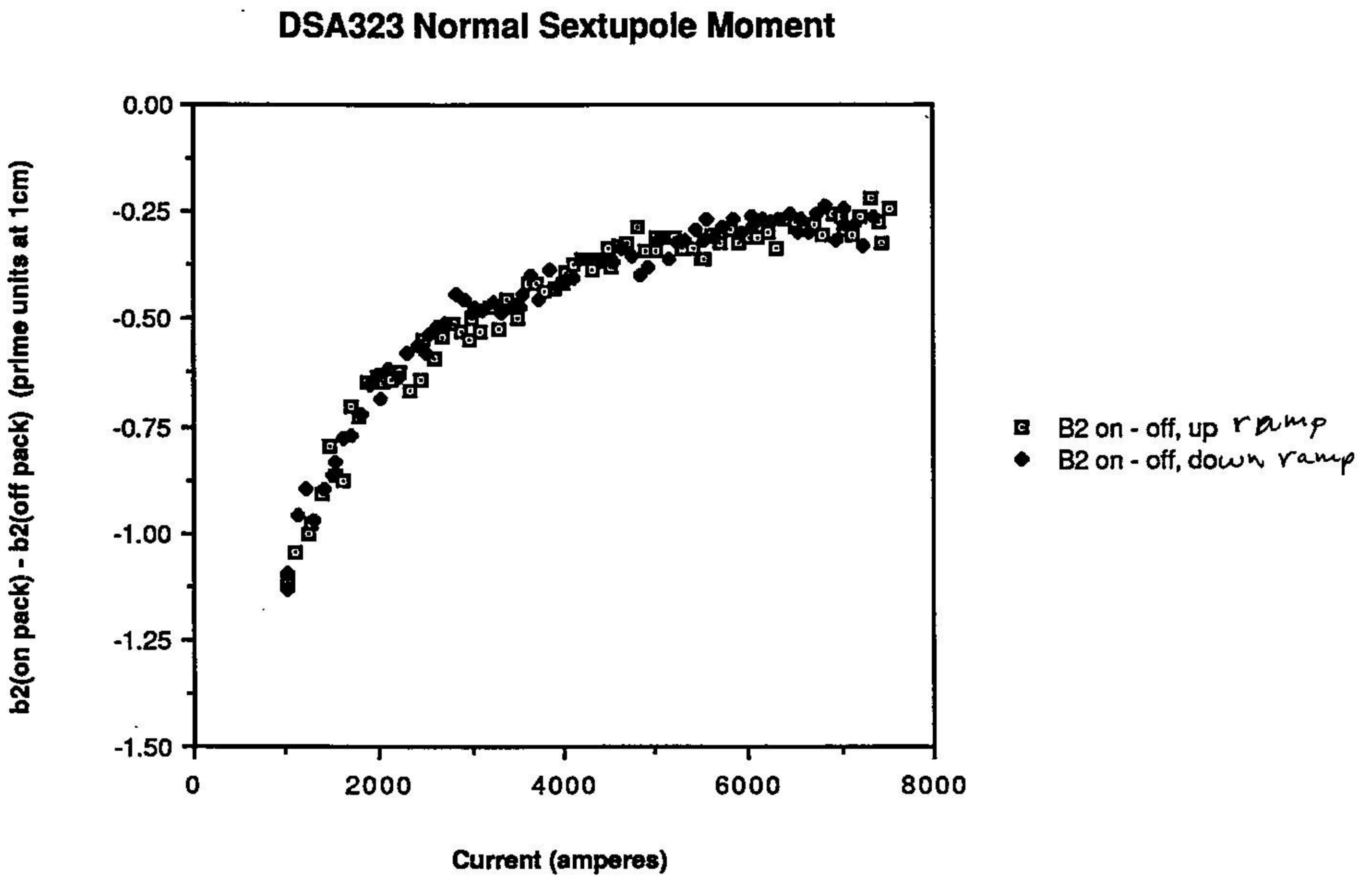
DSA323 Normal Sextupole Moment
b2(on pack) - b2(off pack) (prime units at 1cm)
0.00
-0.25
-0.50
-0.75
-1.00
-1.25
-1.50
0
2000
4000
6000
8000
Current (amperes)
B2 on - off, up ramp
B2 on - off, down ramp

Figure 5a

DSA323 Normal Sextupole Moment

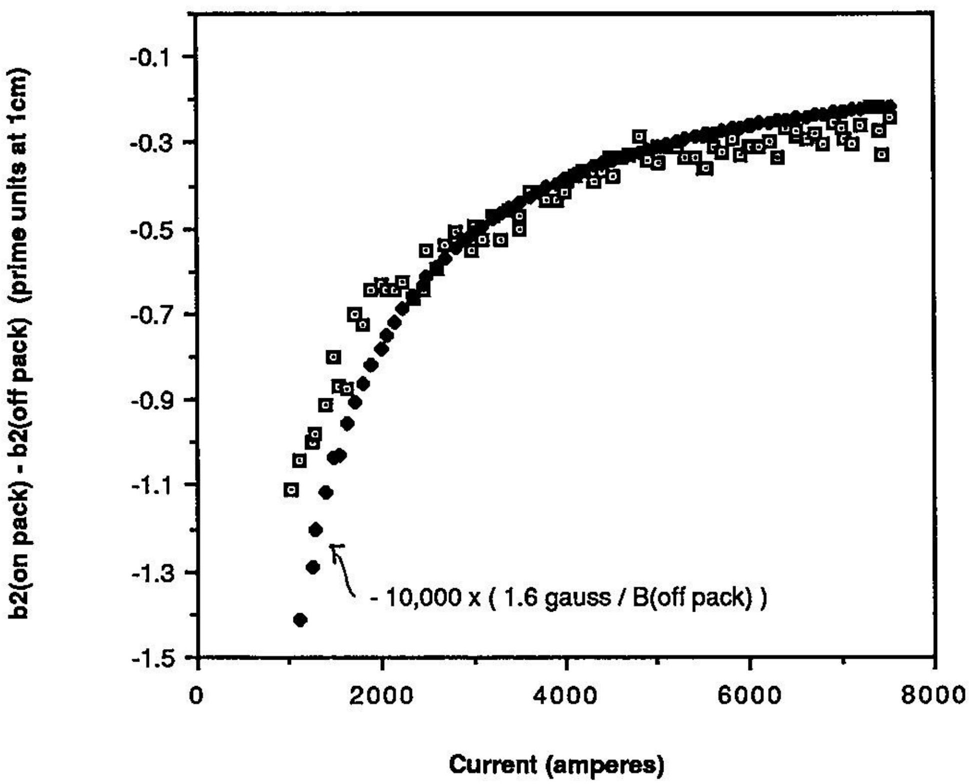

Figure 56

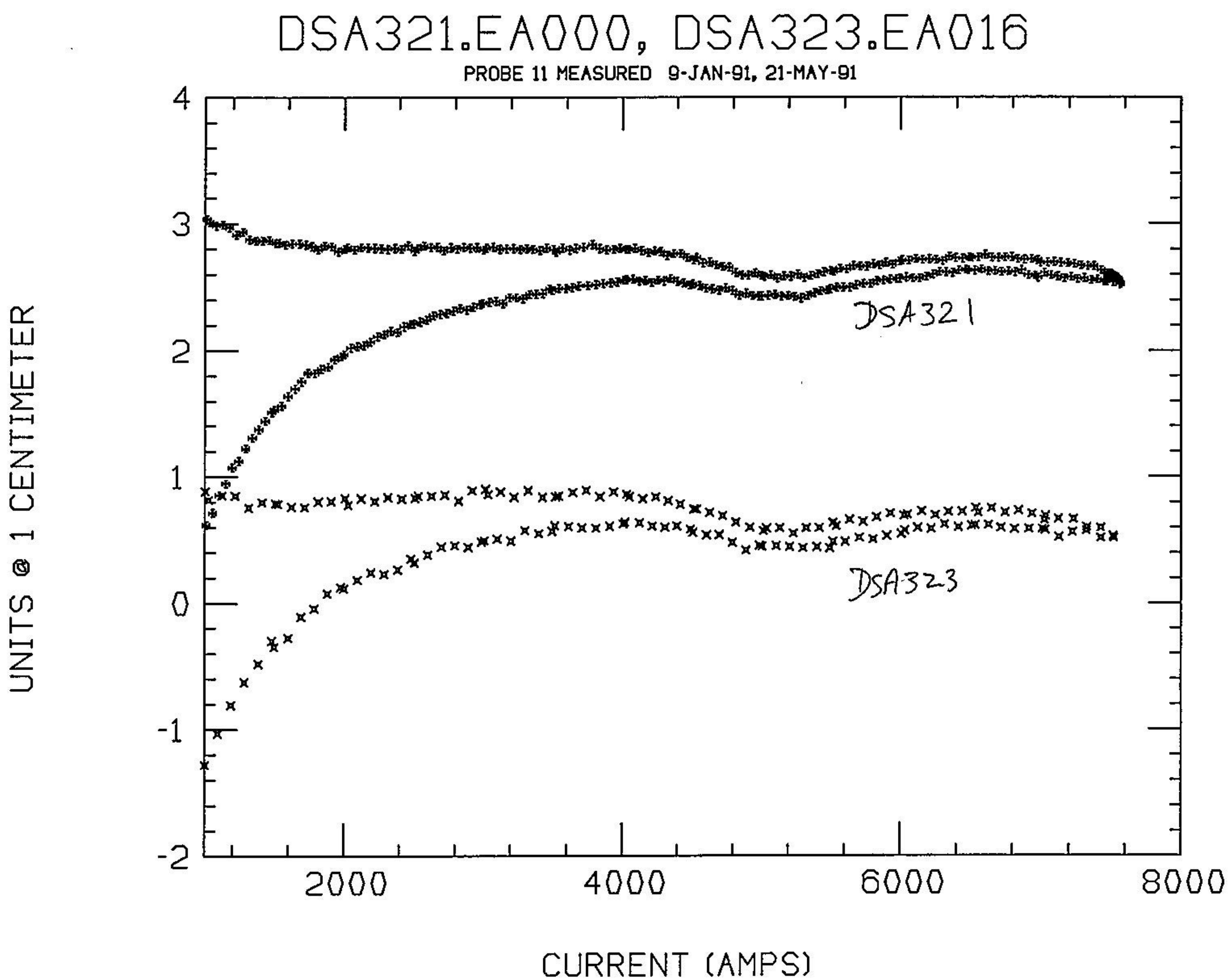
DSA321.EA000, DSA323.EA016
PROBE 11 MEASURED 9-JAN-91, 21-MAY-91
UNITS @ 1 CENTIMETER
4
3
2
1
0
-1
-2
2000
4000
6000
8000
CURRENT (AMPS)
DSA321
DSA323

Figure 6