Fermilab

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SUBJECT: Warm-cold harmonics comparison in ASST magnets

I have made a set of plots comparing harmonics measured on the collared coil[1], on the complete magnet before cold test[2], at 4.3 K and 2 T[3], and after cold test[4]. The collared coil harmonics are measured as looking from the lead end, while the yoked magnet harmonics are measured as looking from the non-lead end. This causes a reversal of sign for all even skew and odd normal harmonics. I have chosen to reverse the signs on the yoked magnet data, so all harmonics are given here as viewed from the lead end.

Figure 1 compares the harmonics of the collared coil with those at 2 T at 4.3 K. The closed circles represent the normal and the open circles the skew multipoles. This comparison is important since field quality problems found before the magnet is fully assembled will be easier to fix. The allowed multipoles are expected to change substantially between these two cases, both because of the magnetic effects of the iron and because of changes in the ovality of the coils due to the mechanical interaction of the yoke and collars. A correlation should exist, however it may be with a slope not equal to 1 and with a non-zero intercept. As seen in Figure 1a, the allowed multipoles are significantly larger in the collared coil state than in the complete magnet at 4.3 K. (The dotted line has unit slope and zero intercept and is present only to guide the eye.) The lack of correlation in the case of b2 is notable. A reasonable correlation exists for b4 and b6, while the magnet-to-magnet variation in b8 is very small.

The correlation between collared coil and complete magnet harmonics is expected to be better for the unallowed than the allowed multipoles, since the iron should add little to them either by magnetic or mechanical interaction. Since the iron contributes more strongly to the dipole field than higher multipoles, the harmonics should be a bit smaller in the complete magnet. A naive estimate can be made by assuming that the iron contributes only to the dipole field and not at all to the unallowed multipole fields. In this case the unallowed harmonics in the complete magnet should be about 0.8 (the ratio of transfer functions) or that in the collared coil. The odd harmoics (Figure 1b) and a2 (Figure 1a) follow roughly this behavior, but the higher even skew harmonics do not. All a4 are greater than zero in the collared coil state, but the average is compatible with zero in the complete magnet. The correlation for a6 has a clear non-zero intercept, and all values of a8 are of opposite sign. The cause of this poor correlation for the higher even skew multipoles is not known, but it may indicate a problem with the measurements.

Figure 2 compares the harmonics in complete magnets at room temperature and 0.1 T with those at 4.3 K and 2 T. Again, shifts in the allowed terms are expected due to changes in the ovality of the coil resulting from the difference in thermal contraction of the collars and the yoke. (The intent of the design was to put the conductors at their design location at liquid helium temperatures.) The sextupole b2 appears to decrease by about 0.7 unit with cooldown, but about half of this is due to the effect of persistent currents at 2 T. The decapole b4 decreases by 0.05-0.1 unit; correction for persistent currents would increase this effect by about 0.02 unit. The 14-pole b6 increases on the average by about 0.005 unit, while there is no apparent change in b8.

Within the scatter of the data there is no systematic change in any of the unallowed multipoles, as expected. (At first glance it appears that the scatter is consistent with the measurement error of the room temperature data[5].) Possible exceptions are one point each in a1 and a3. These both come from DCA313. Comparison among the four data sets suggests that the warm measurements before cold test are in error, although there is no known cause of this problem[5].

The warm data before and after cold test are compared in Figure 3. Except for b4 all harmonics return, within the scatter of the data, to their original values after two cold test cycles. (The outlying point in each of the a1 and a3 plots are DCA313, noted above.) For b2, the scatter in the data is smaller here than in the warm-cold comparison, suggesting that much of the scatter in b2 in Figure 2a represents real magnet-to-magnet variability in either the persistent current contribution or in warm-cold geometry changes. For the unallowed multipoles the scatter in Figure 3 is somewhat larger than in Figure 2, since the measurement error is smaller on the cold data.

The apparent shift in b4 following cold test is somewhat puzzling. Taken at face value it implies that there has been a net geometric change, presumably a small shift of the conductors within the collars. What sort of movement could affect only b4 without changing any of the other allowed harmonics is not known.

REFERENCES

[1] S. Delchamps, data files
FNAL::PRJ$ROOT:[TS_SSC_PRJ.HARMONICS.MOLE.DCA31*]COLLAR.TOP

[2] J. DiMarco, data file SSCVX1::USER3:[DIMARCO.TEMPDATA]WARM_BEF.MPOLE

[3] J. DiMarco, data file SSCVX1::USER3:[DIMARCO.TEMPDATA]COLD.MPOLE

[4] J. DiMarco, data file SSCVX1::USER3:[DIMARCO.TEMPDATA]WARM_AFT.MPOLE

[5] J. DiMarco, private communication.

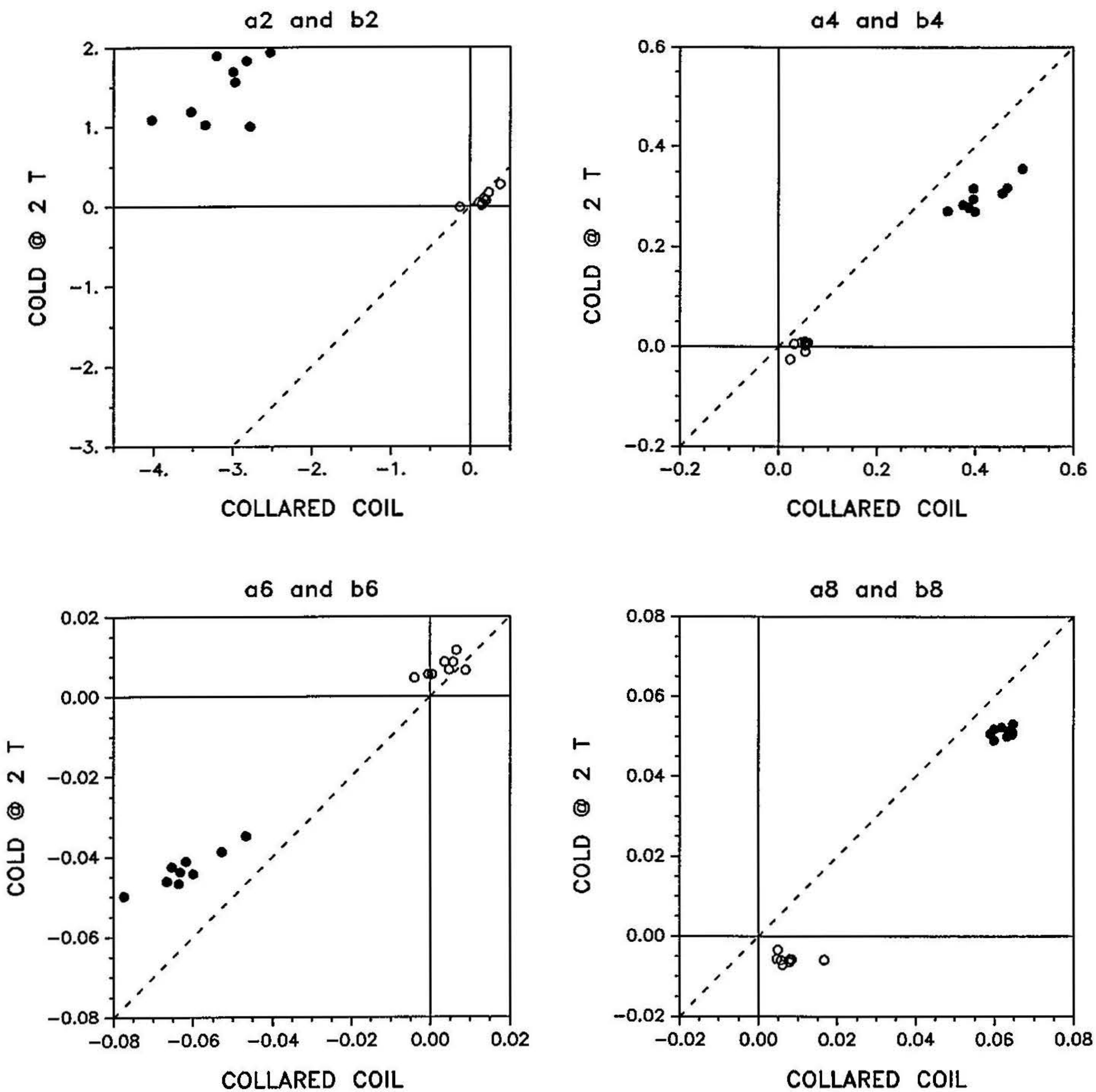

a2 and b2
COLD @ 2 T
COLLARED COIL
2.
1.
0.
−1.
−2.
−3.
−4.
−3.
−2.
−1.
0.
a4 and b4
0.6
0.4
0.2
0.0
−0.2
0.2
0.4
0.6
a6 and b6
0.02
0.00
−0.02
−0.04
−0.06
−0.08
−0.06
−0.04
−0.02
0.00
0.02
a8 and b8
0.08
0.06
0.04
0.02
0.00
−0.02
0.00
0.02
0.04
0.06
0.08

Figure 1a

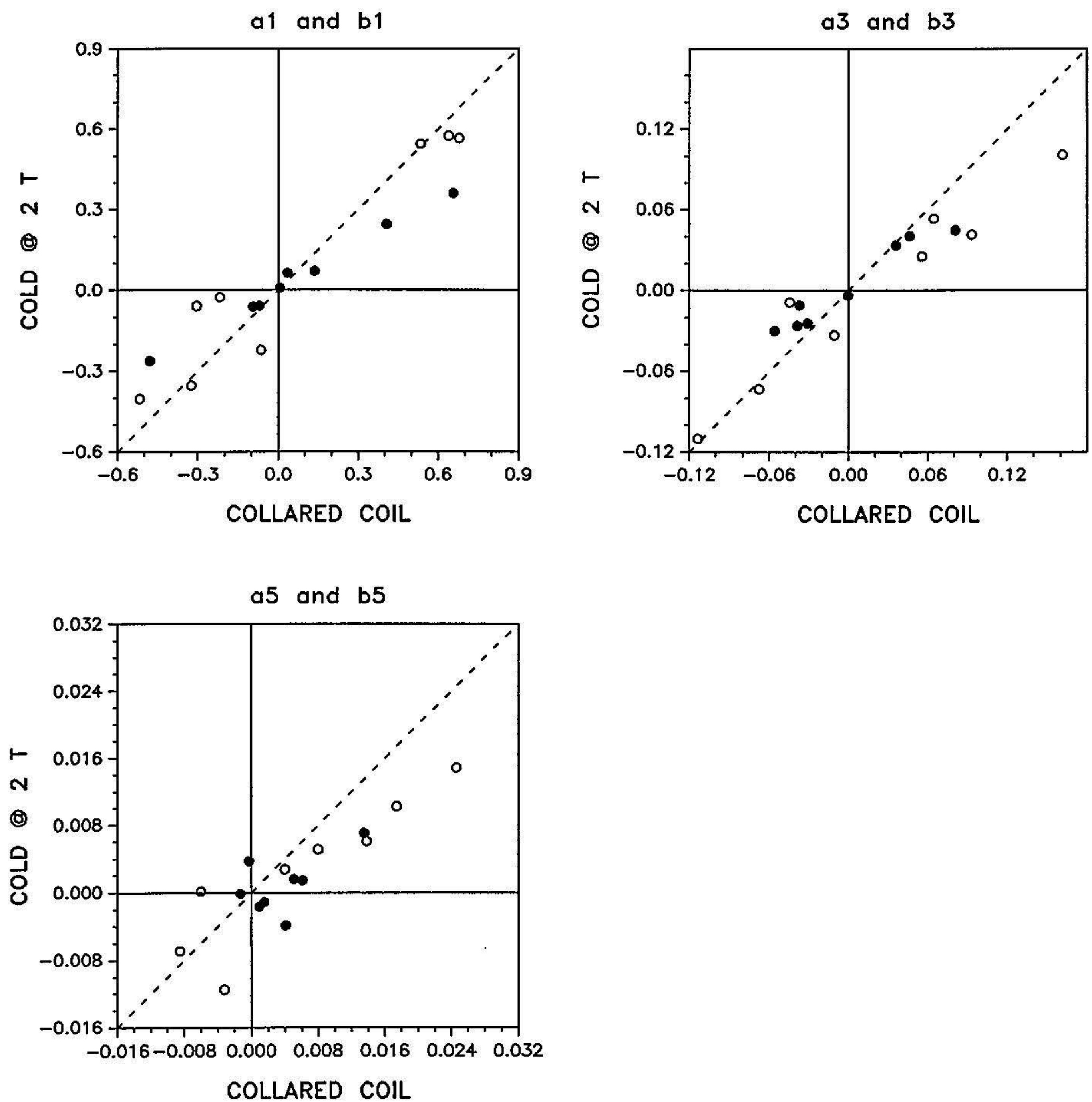
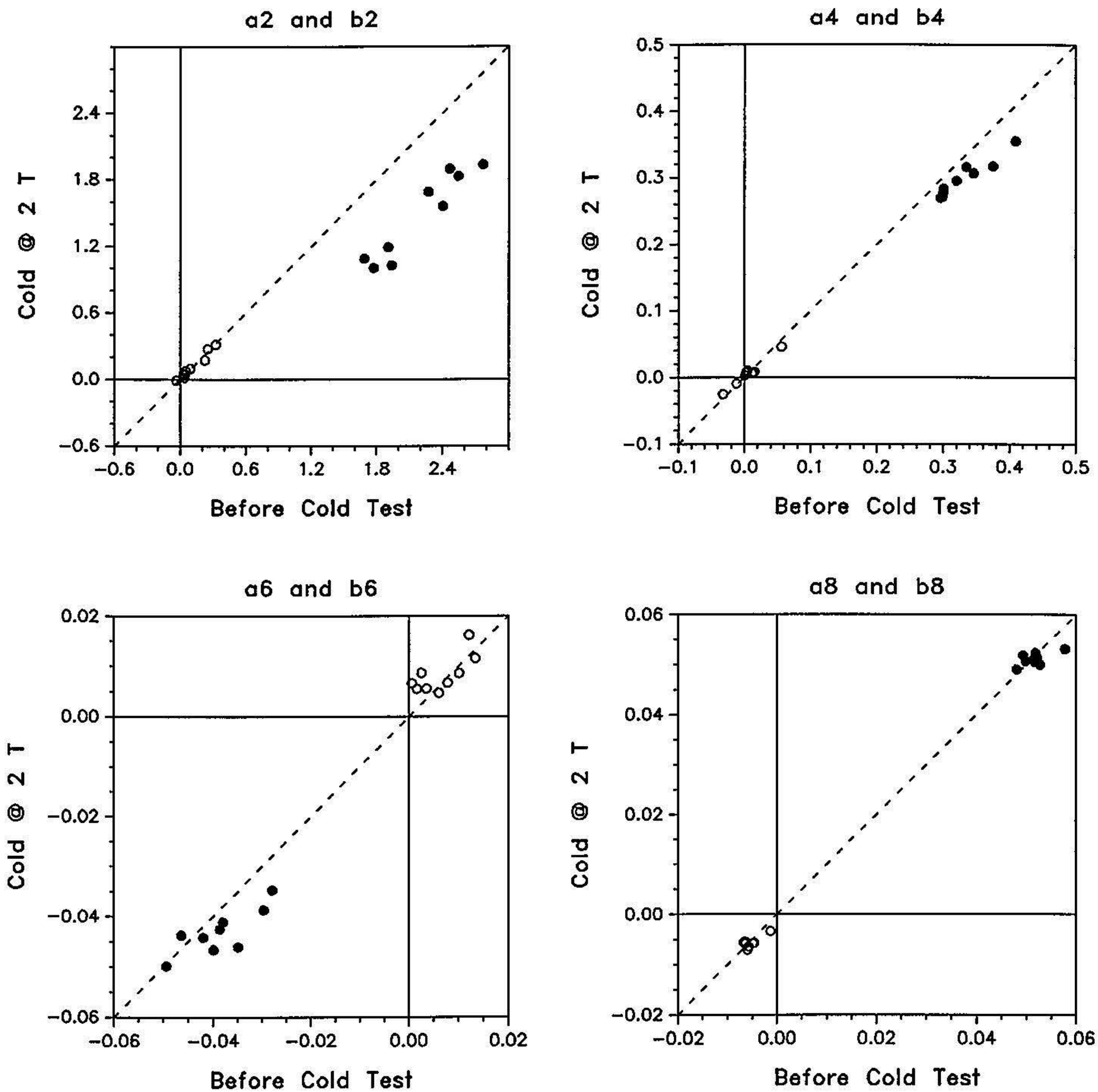


Figure 1 b



a2 and b2
Cold @ 2 T
Before Cold Test
2.4
1.8
1.2
0.6
0.0
−0.6
−0.6
0.0
0.6
1.2
1.8
2.4
a4 and b4
Cold @ 2 T
Before Cold Test
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
−0.1
0.0
0.1
0.2
0.3
0.4
0.5
a6 and b6
Cold @ 2 T
Before Cold Test
0.02
0.00
−0.02
−0.04
−0.06
−0.06
−0.04
−0.02
0.00
0.02
a8 and b8
Cold @ 2 T
Before Cold Test
0.06
0.04
0.02
0.00
−0.02
−0.02
0.00
0.02
0.04
0.06

Figure 2a

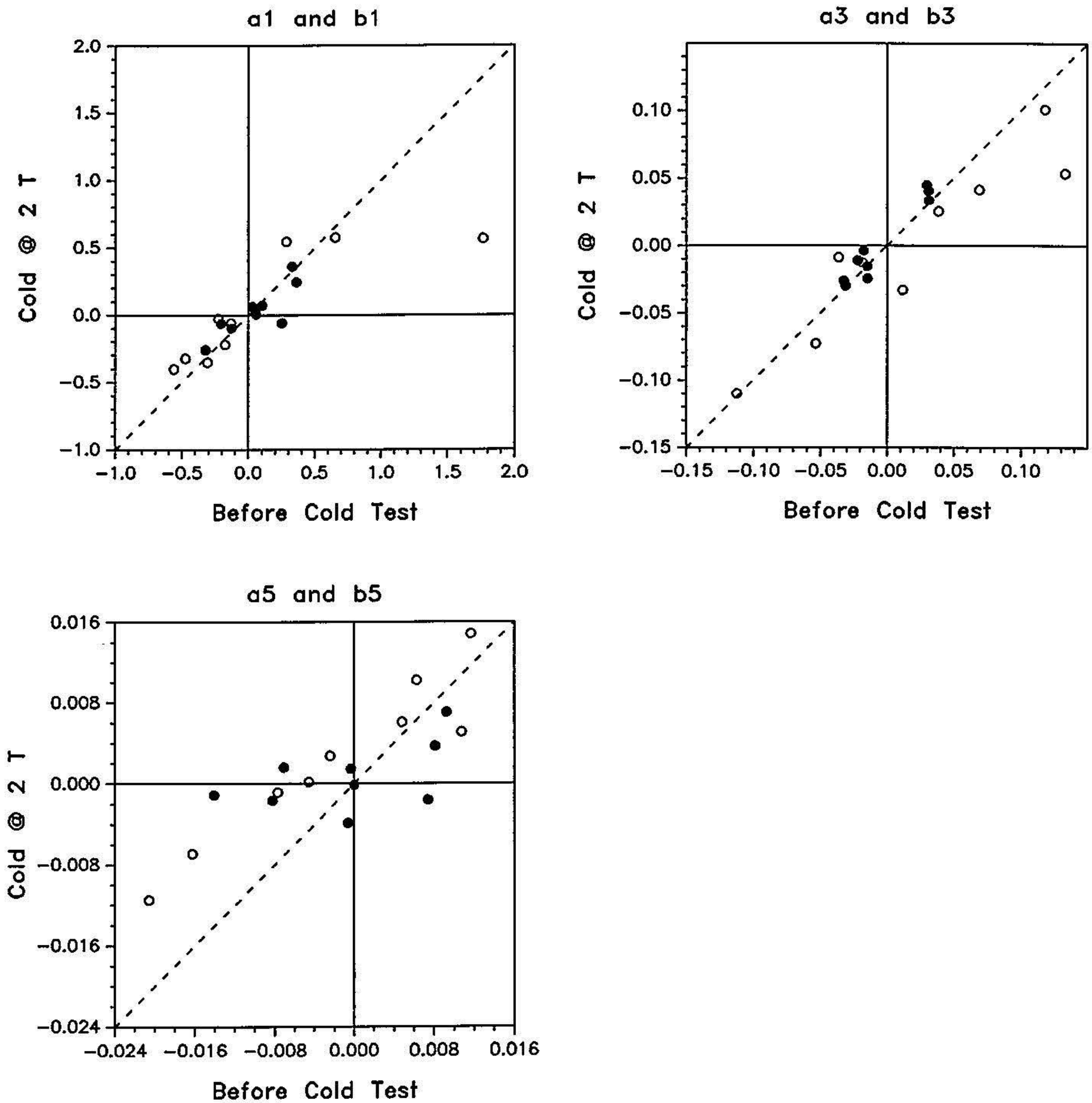

a1 and b1
Cold @ 2 T
Before Cold Test
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0
a3 and b3
Cold @ 2 T
Before Cold Test
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.15
−0.10
−0.05
0.00
0.05
0.10
a5 and b5
Cold @ 2 T
Before Cold Test
0.016
0.008
0.000
−0.008
−0.016
−0.024
−0.024
−0.016
−0.008
0.000
0.008
0.016

Figure 2b

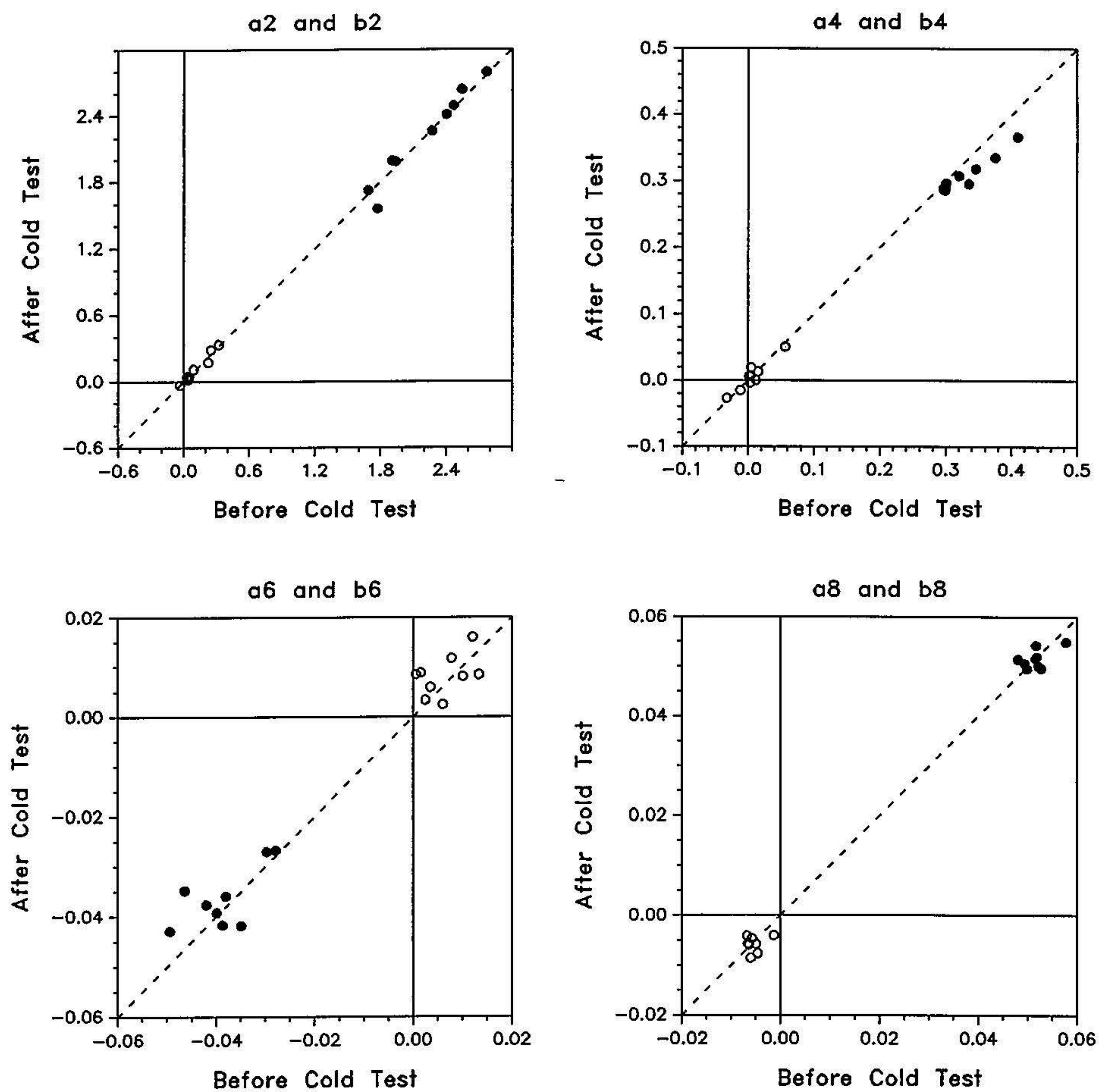
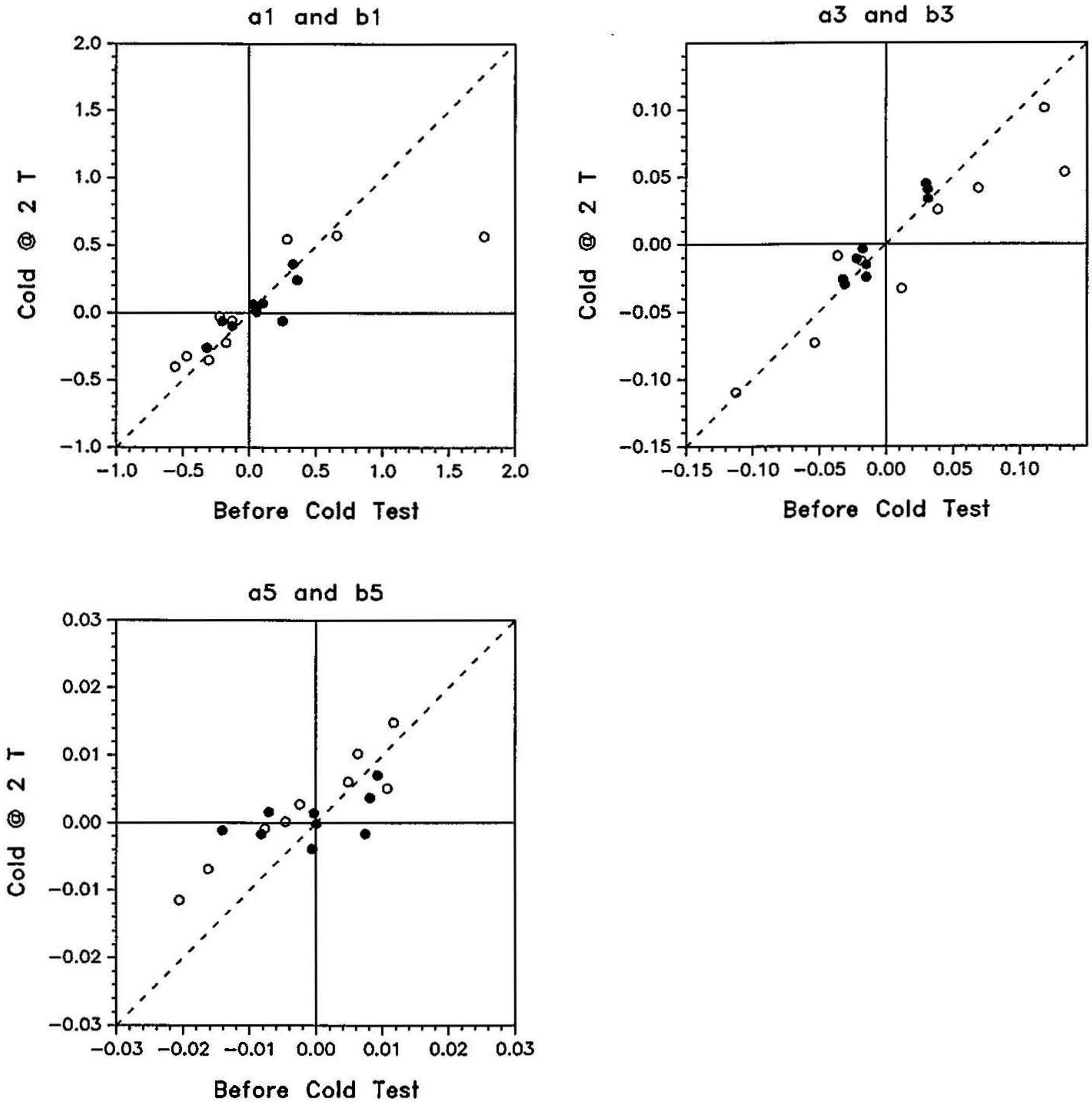

a2 and b2
After Cold Test
Before Cold Test
-0.6
0.0
0.6
1.2
1.8
2.4
a4 and b4
After Cold Test
Before Cold Test
-0.1
0.0
0.1
0.2
0.3
0.4
0.5
a6 and b6
After Cold Test
Before Cold Test
-0.06
-0.04
-0.02
0.00
0.02
a8 and b8
After Cold Test
Before Cold Test
-0.02
0.00
0.02
0.04
0.06

Figure 3a



a1 and b1
Cold @ 2 T
Before Cold Test
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
0.5
1.0
1.5
2.0
a3 and b3
Cold @ 2 T
Before Cold Test
0.10
0.05
0.00
−0.05
−0.10
−0.15
a5 and b5
Cold @ 2 T
Before Cold Test
0.03
0.02
0.01
0.00
−0.01
−0.02
−0.03

Figure 3b