AC Measurements of Booster Corrector Magnets with a Fixed-Coil Array

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Fermilab

IMMW15

23-Aug-07

Outline:

Measurement requirements

Design

Fabrication

DAQ

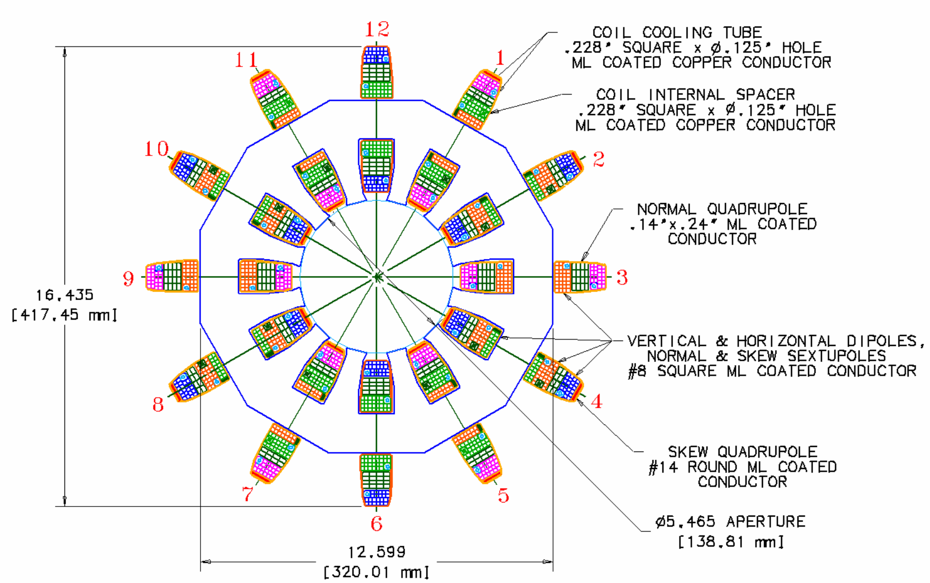
Software

Measurements

What's next

Requirements

Booster Corrector Magnet



Corrector Type	Maximum Integral Field at Full Current	Maximum Integral Field Slew Rate
Horizontal Dipole	0.015 T-m	3.5 T-m/s
Vertical Dipole	0.015 T-m	3.5 T-m/s
Normal Quad	0.16 T	160 T/s
Skew Quad	0.008 T	0.8 T/s
Normal Sextupole	1.41 T/m	2279 T/m/s
Skew Sextupole	1.41 T/m	2279 T/m/s

Small fields, high ramp rates

Booster cycling at a rate of 15Hz.

Transition region where elements change from full positive to full negative field in 1 millisecond.

Sampling rates of at least 10kHz through at least the first allowed harmonic of each element (i.e. 18-pole for sextupole magnet).

→ To achieve the high time-resolution, a simultaneously sampled fixed-coil array was developed for production measurements.

Also AC measurement with slowly rotating coil was pursued (G. Velev)

Fixed-Coil Array

- Limitations – large number of channels→ complexity, cost, fabrication of coils.

- Advantages – measure field snapshots at daq sample rate (what we really want to do)

- Use bucking:
  - Ease dynamic range requirements (can add amplification on weak residual harmonics signals)
  - Ease coil placement requirements (false harmonics from feed-up reduced by factor of bucking ratio)

→ PC boards – low cost, accuracy, bucking, can produce large number

Design

Mechanically, magnet length is 425 mm. However, since the magnet has a large, 138 mm, aperture, the end field extends considerably beyond the physical length of the magnet assembly. → want probe length ~1.3m

PC boards were prototyped in 0.56m lengths

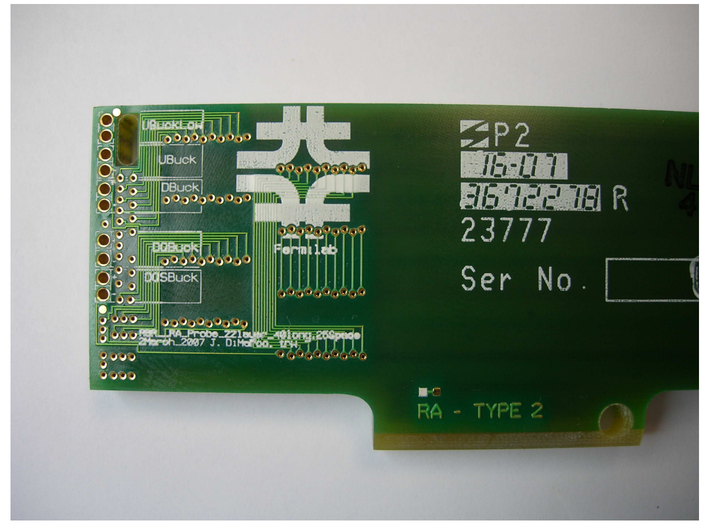
Tried :

- Radially-Bucked Tangential (RBT) design – proof of principle (density/sensitivity limited by size of 'via' holes')
- Two-ended Radially-Bucked Radial (RBR) design – higher density/sensitivity (but couldn't find affordable 1.3 m)
- One-ended RBR (thought was to use two 0.56m probes butted end-to-end to achieve long integration length – doubles daq or makes operations hard (measure half at a time))

Ended up renewing search for (at least) 1m circuit board probe fabrication as best option to length issue

Two manufacturers worked with us: cost was substantially different (factor 2)

Sanmina produced boards at about $400/ea.



Thanks to:

Tom Wesson
John Green
Craig Drennan

For design and procurement of the boards!

9 turns per loop
0.15mm/0.1mm space/trace
1m (40”) length

1.44 km (0.9 miles) of wire traces on each of the 32 boards

Fabrication

15Mar07 → order for probes goes out to Sanmina (promising 7-day turn-around)

03Apr07 → after some delays (manufacturer had problem with 'scoring' and had to reorder material) first partial shipment arrives: 9 boards – but 8 have shorts, only 1 is "good" (manufacturer had not done final inspection). Problem appears to be in core (layers) alignment.

11Apr07 → discussions, etc have taken place – manufacturer to try again.

21Apr07 → Sanmina ships 47 boards

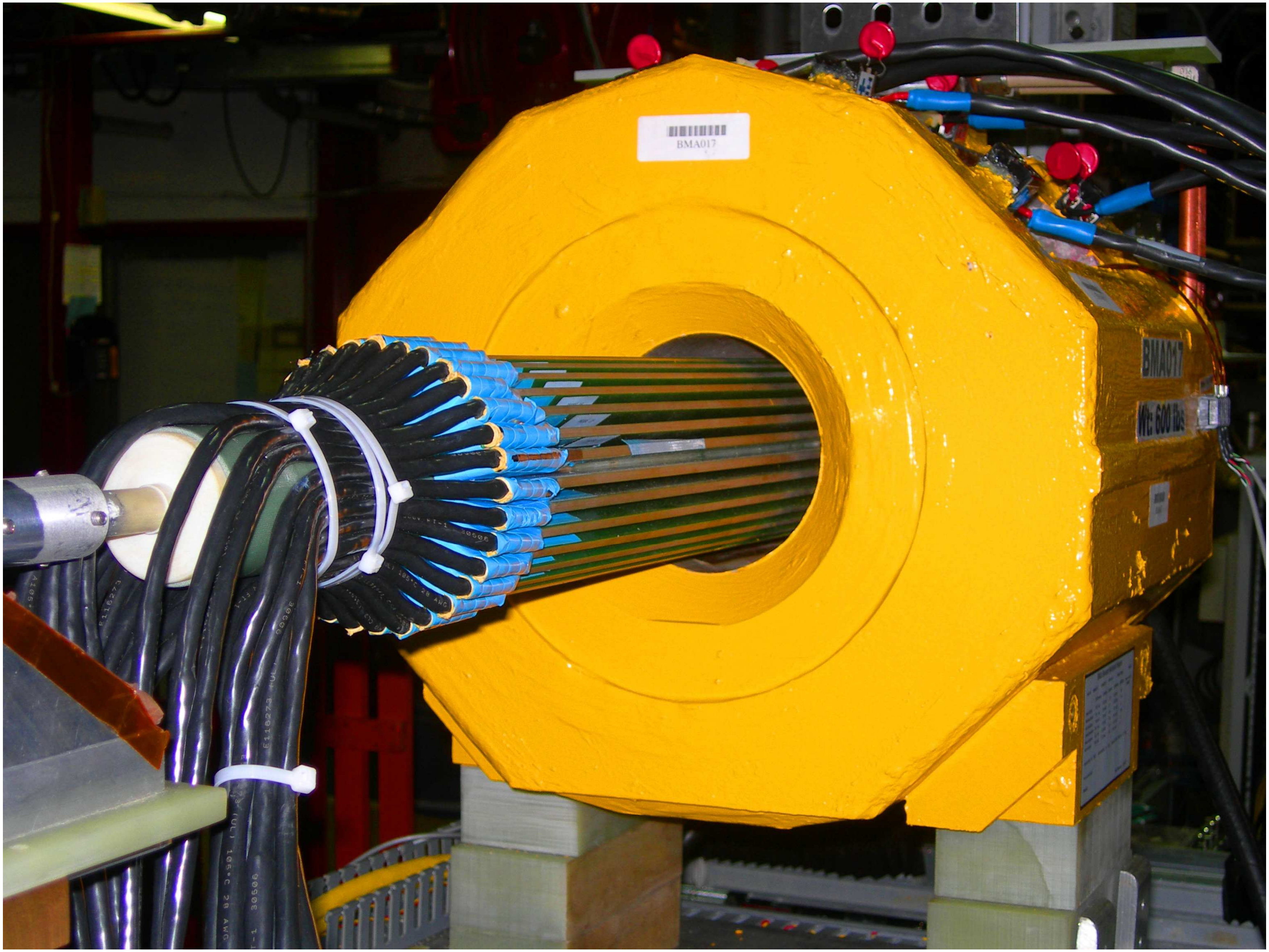
11May → boards have been wired with connectors

22May07 → boards finished mounting on cylindrical form

mid-June → test-stand opportunity for fixed-coil tests – minor wiring problems downstream from probe to DAQ. Also check DAQ software algorithms (drift correction, etc.).

20July07 → after couple of weeks of test/development of software for analysis of data and taking data – probe consider 'commissioned' for qualifying magnets


Kimwipes


BMA017
BMA017

DAQ

Each probe has 5 pairs of signals (UBuck_low, UBuck_high, DBuck, DQBuck, DQSBuck). 32 boards → 160 channels

Only monitor 32 channels (harmonics) + 8 (strength) + 8 (currents).

Switch between Bucked signals depending on magnet

Probe resistance are high: 1.2kOhm UBH to 14.4kOhm for DQSB. Need buffer amplifiers.

Signal conditioning requires low noise and low drift amplifiers.

ADC channels must be synchronized well

The dynamic range must be >=20 Bits of alias free passband to at least 10kHz.

Use NI PXI-4472 dynamic signal acquisition module. 100kHz, 24-bit. DAQ cost appx. $5k/8 channels + crate space, etc.

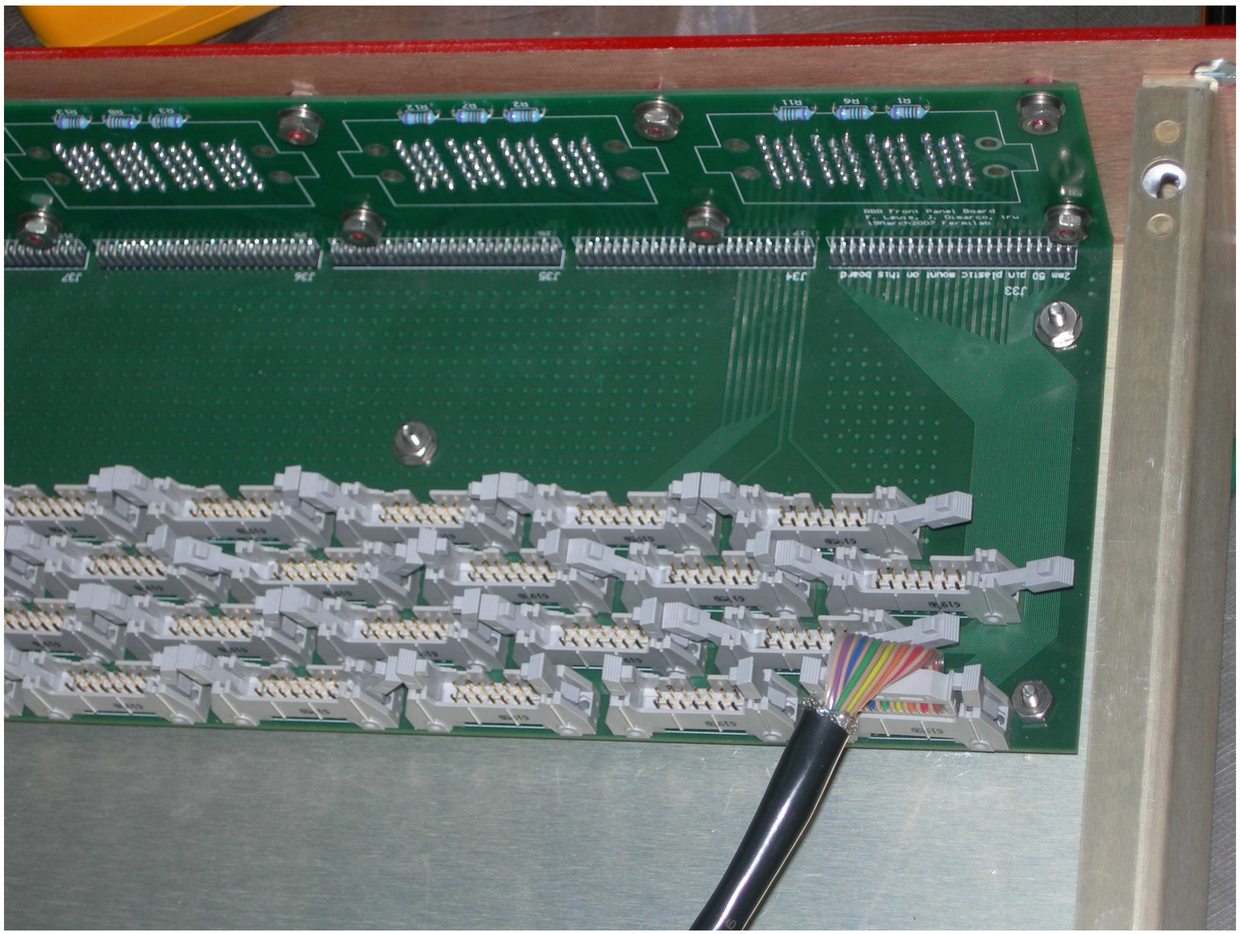
Install in a temperature controlled rack to minimize amplifier drift.

Wiring

Wire directly to probe with twisted-pair ribbon cable – 5 channels from one probe on each connector

Wire DAQ modules for 32 channels harmonics, 8 strength

All switching complexity left for interface box



Software

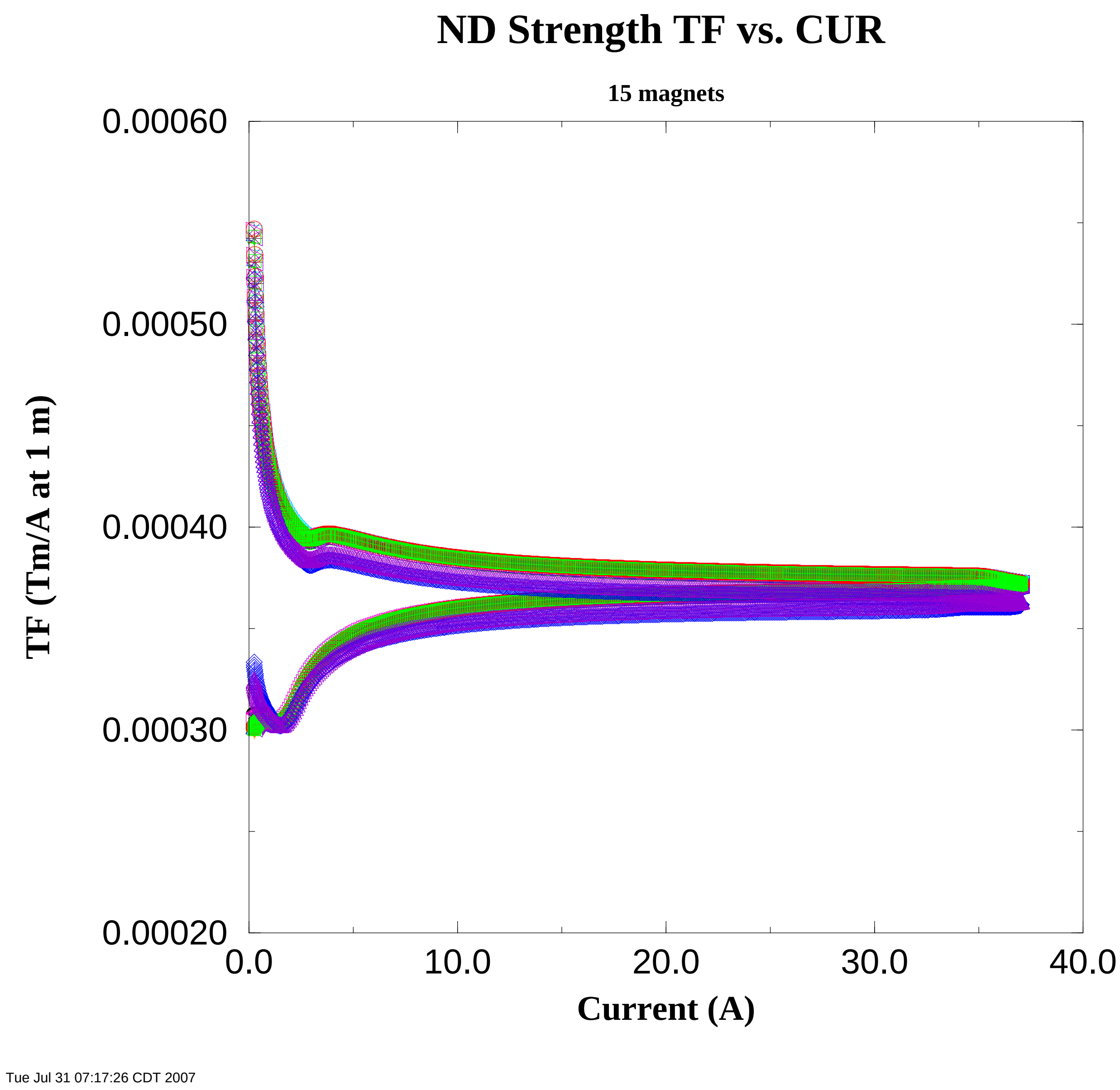
Labview acquisition software – acquire 100 cycles of data synchronized to ramp profile drive. Takes about 6 seconds.

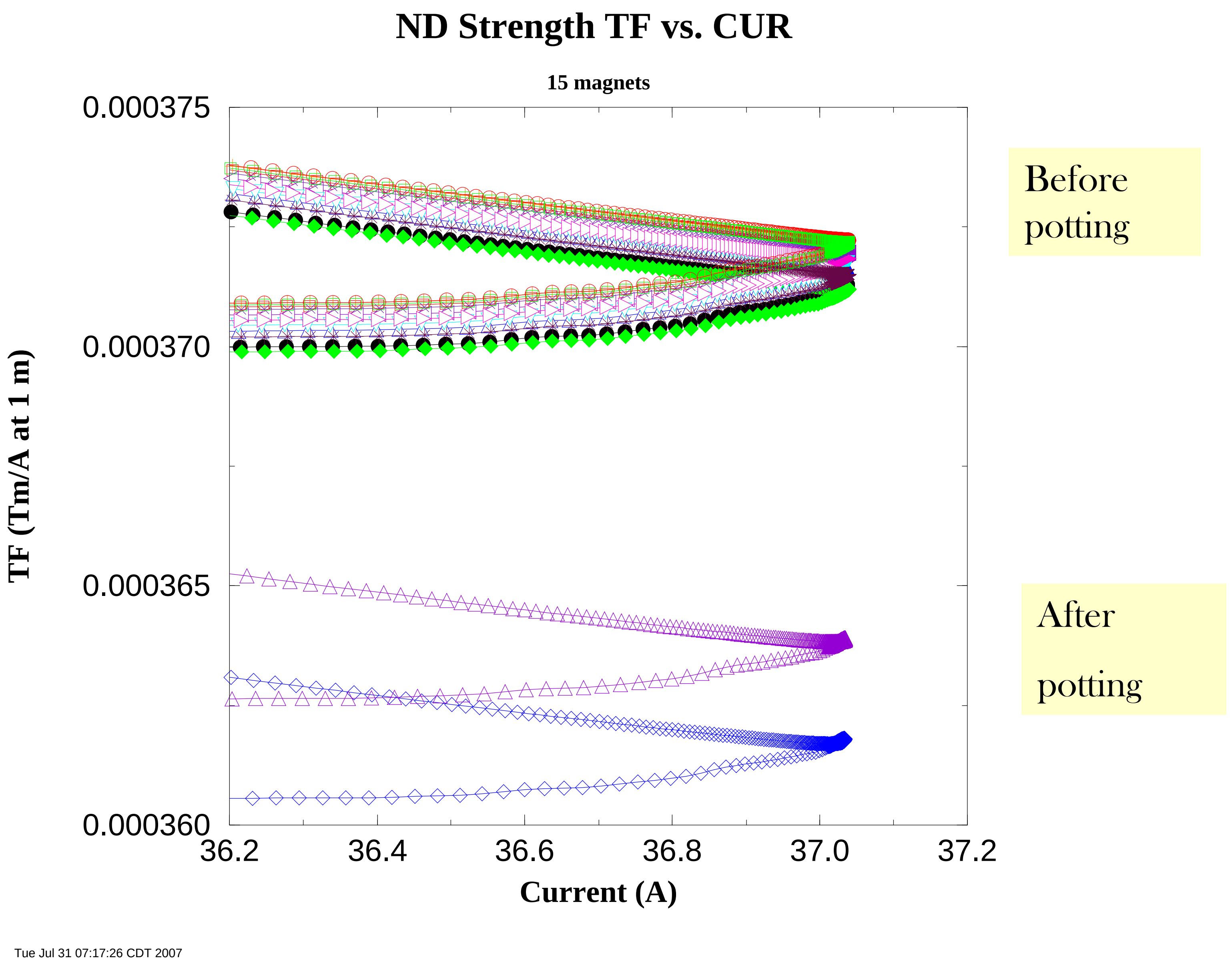
Correct for drifts, average, package data.

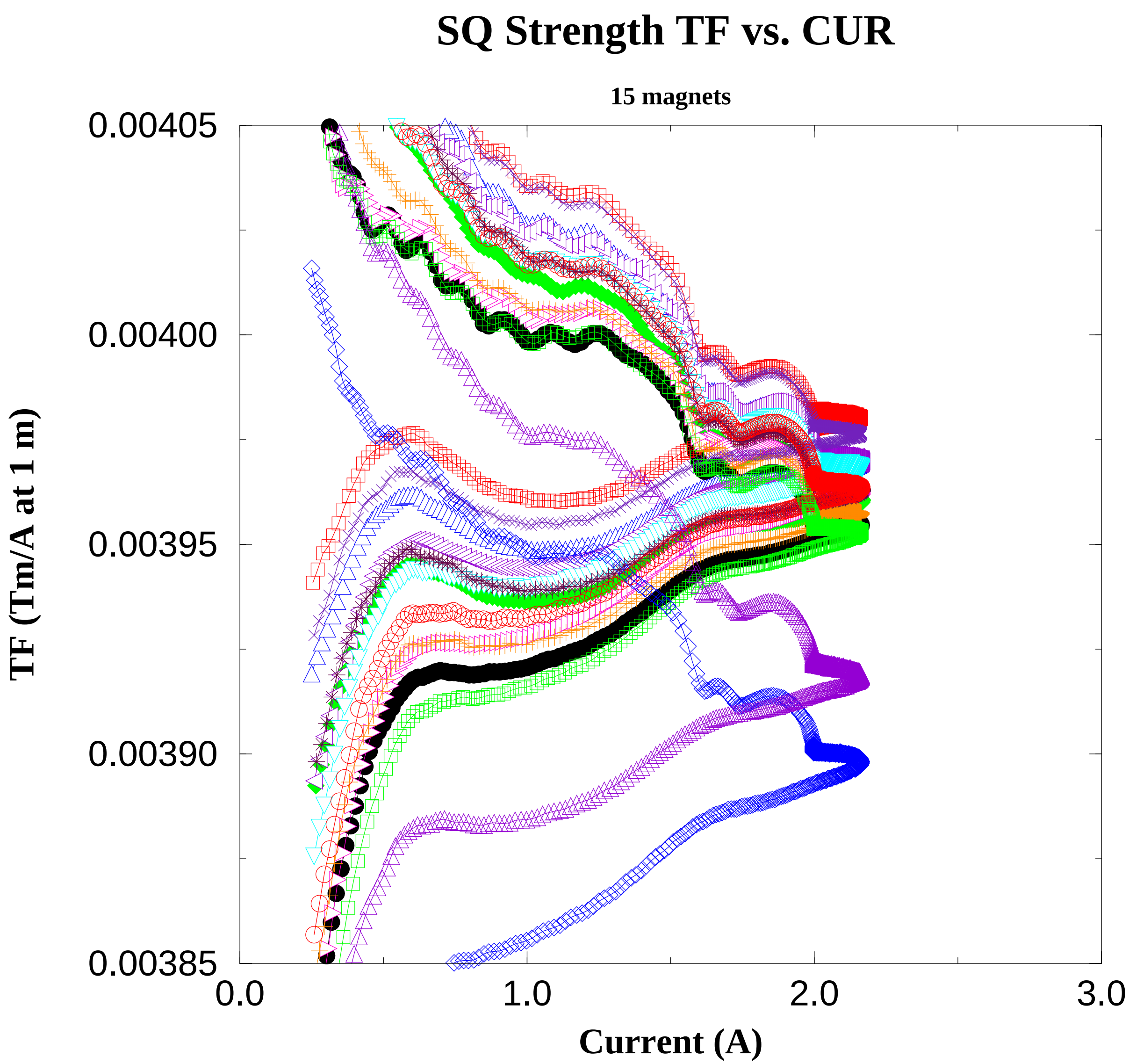
Analysis of data with EMS harmonics software (standard software).

Working on feed to data portal (Webdat)

Measurements

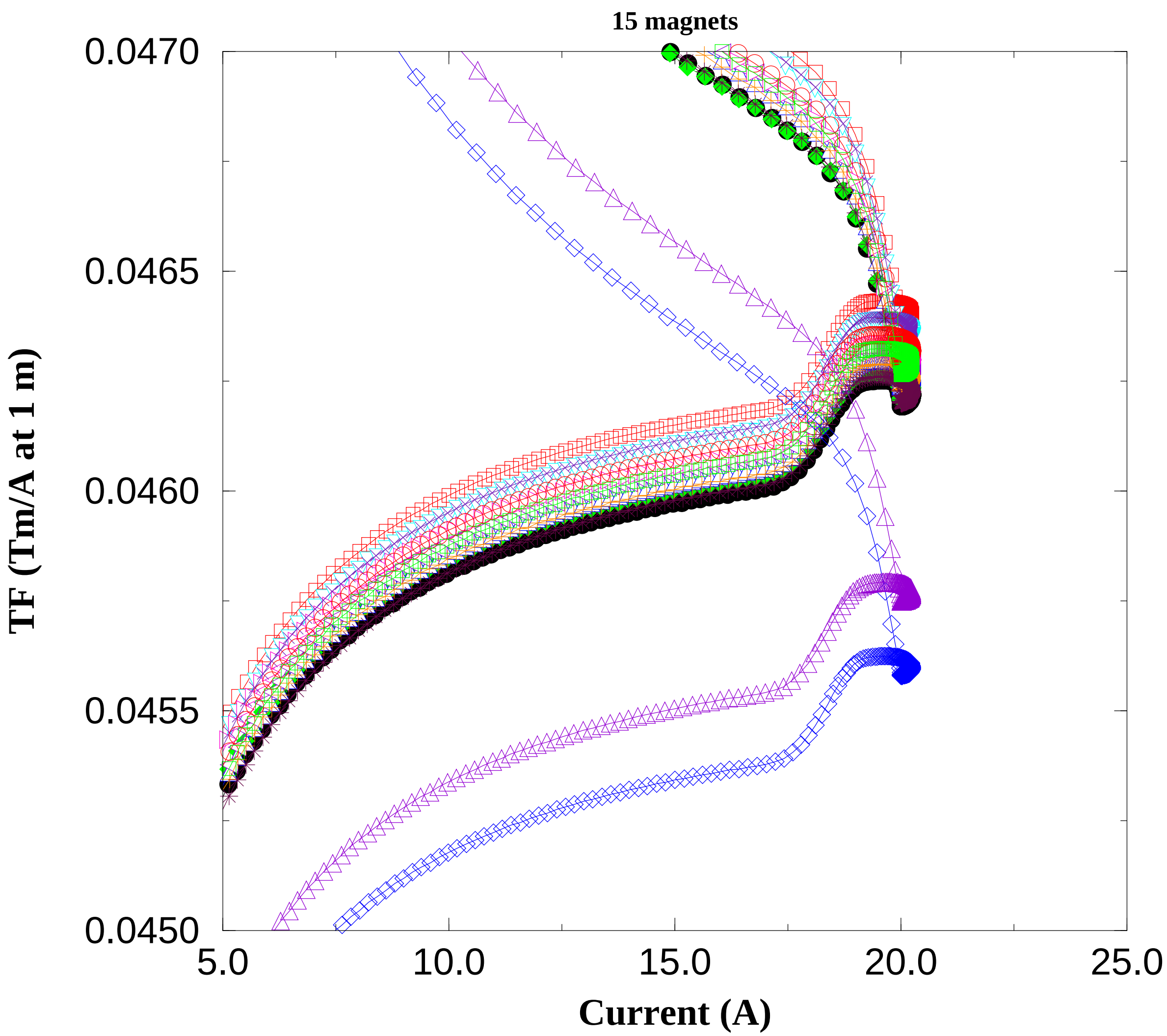



ND Strength TF vs. CUR
15 magnets
TF (Tm/A at 1 m)
0.000375
0.000370
0.000365
0.000360
36.2
36.4
36.6
36.8
37.0
37.2
Current (A)
Before potting
After potting
Tue Jul 31 07:17:26 CDT 2007



Tue Jul 31 09:17:38 CDT 2007

NS Strength TF vs. CUR



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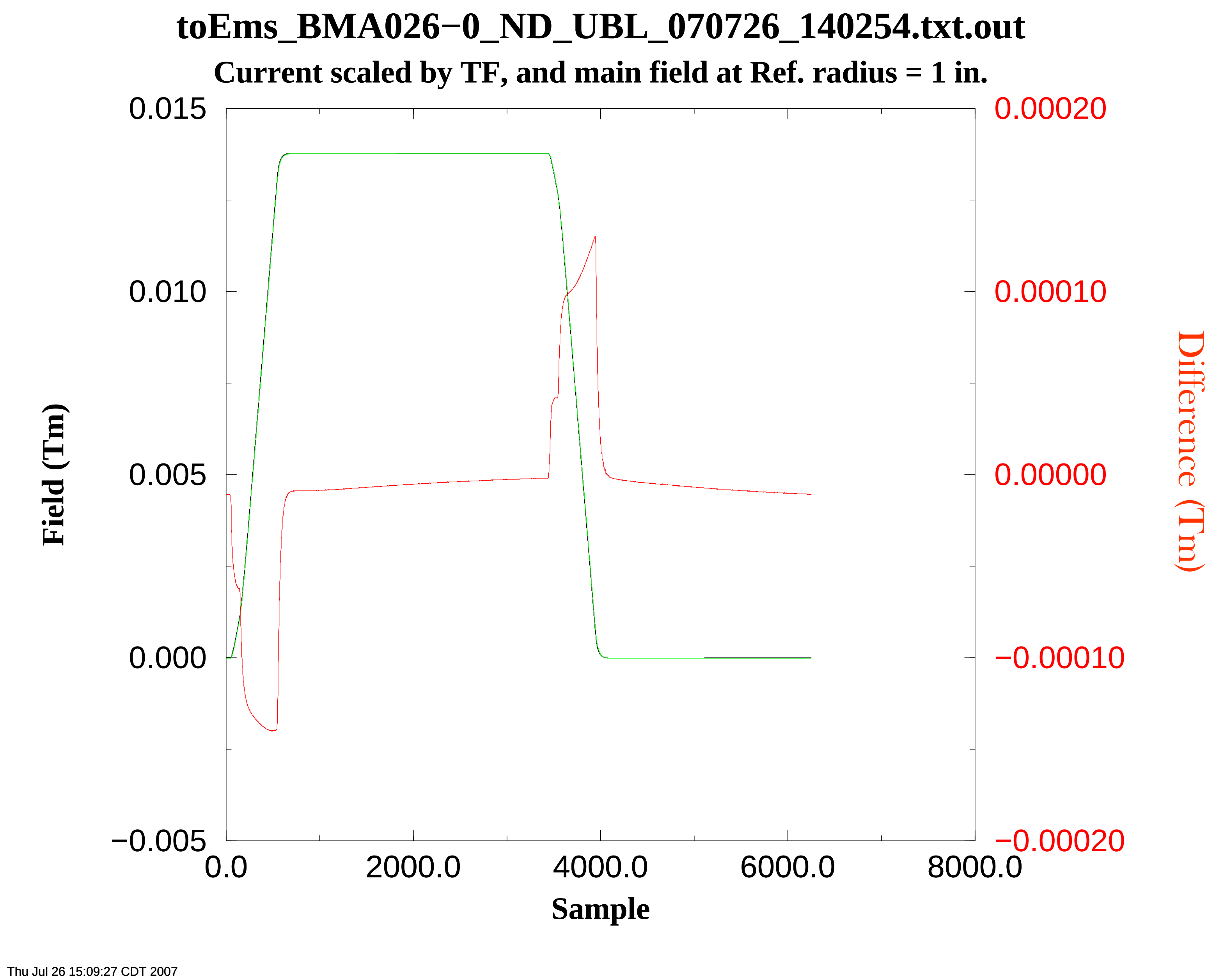
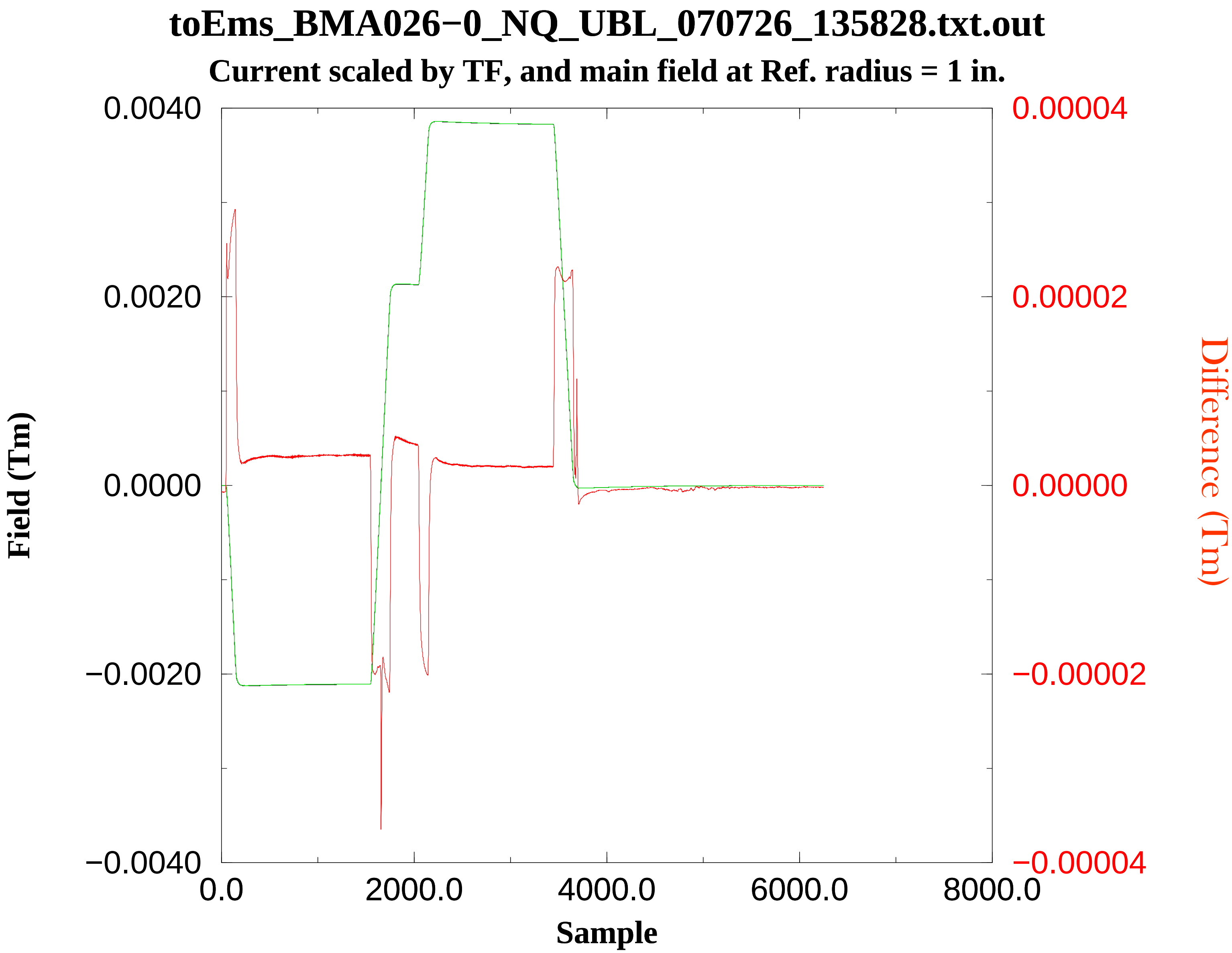

toEms_BMA026−0_ND_UBL_070726_140254.txt.out
Current scaled by TF, and main field at Ref. radius = 1 in.
Field (Tm)
Difference (Tm)
Sample
0.015
0.010
0.005
0.000
−0.005
0.00020
0.00010
0.00000
−0.00010
−0.00020
0.0
2000.0
4000.0
6000.0
8000.0
Thu Jul 26 15:09:27 CDT 2007



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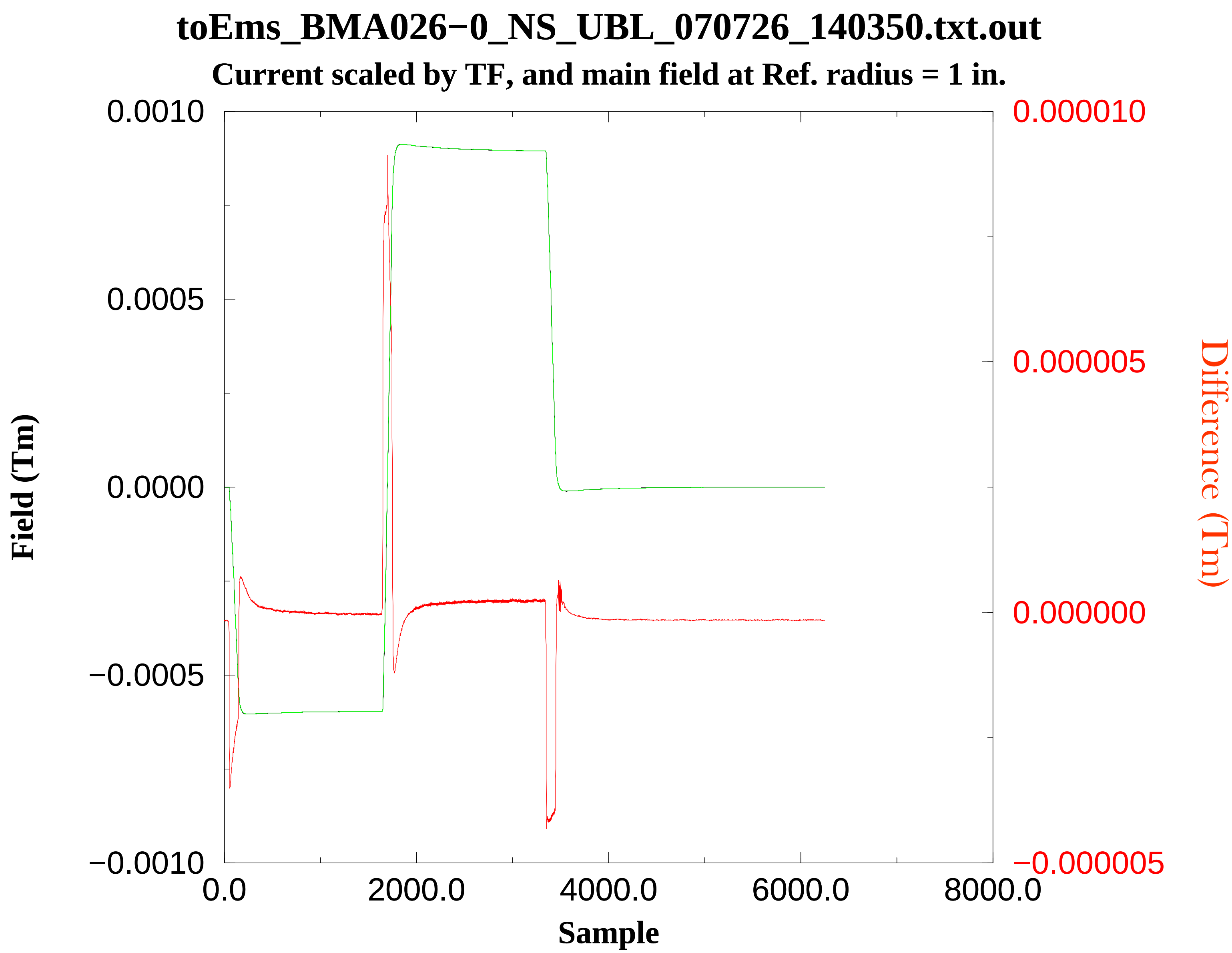

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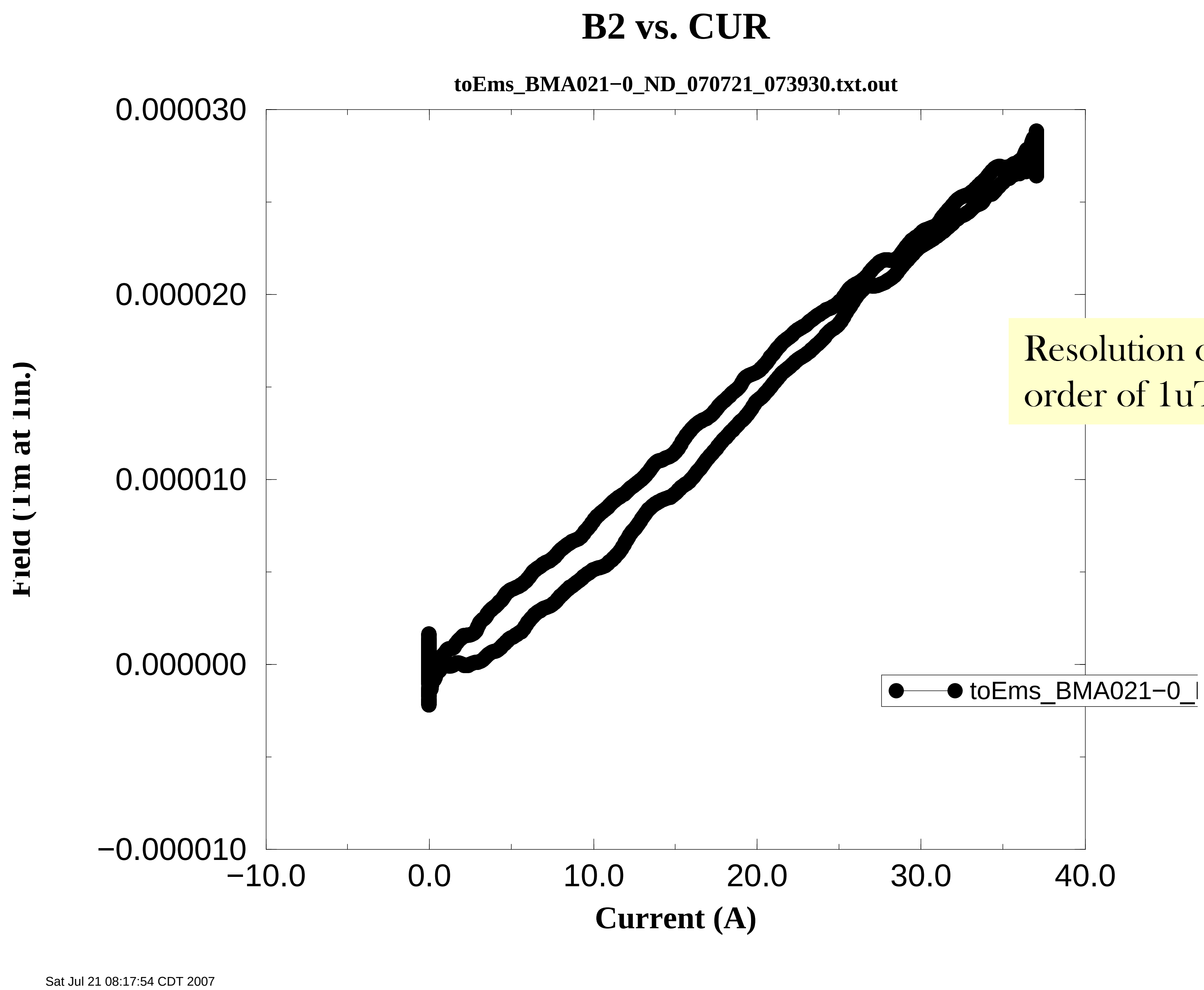
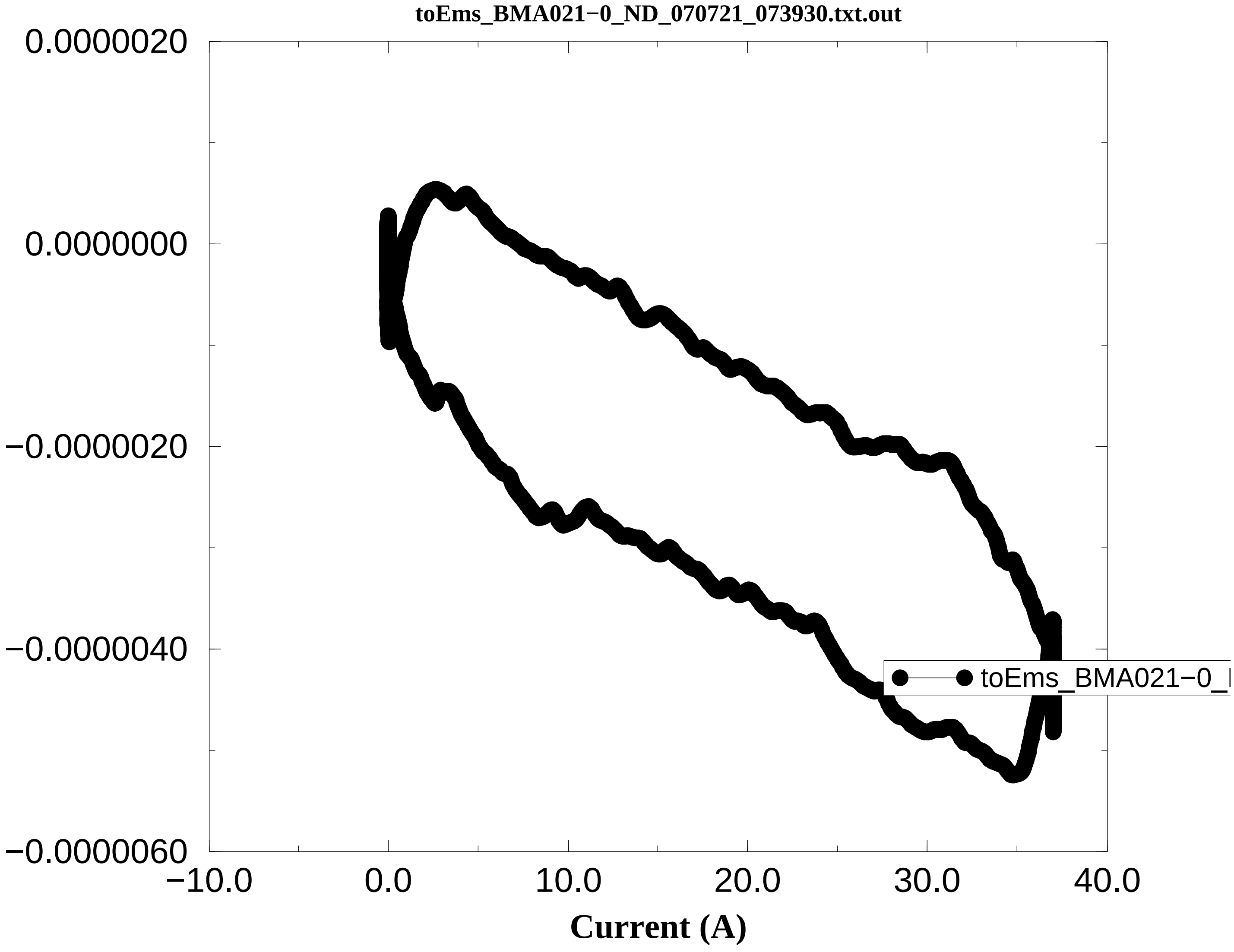
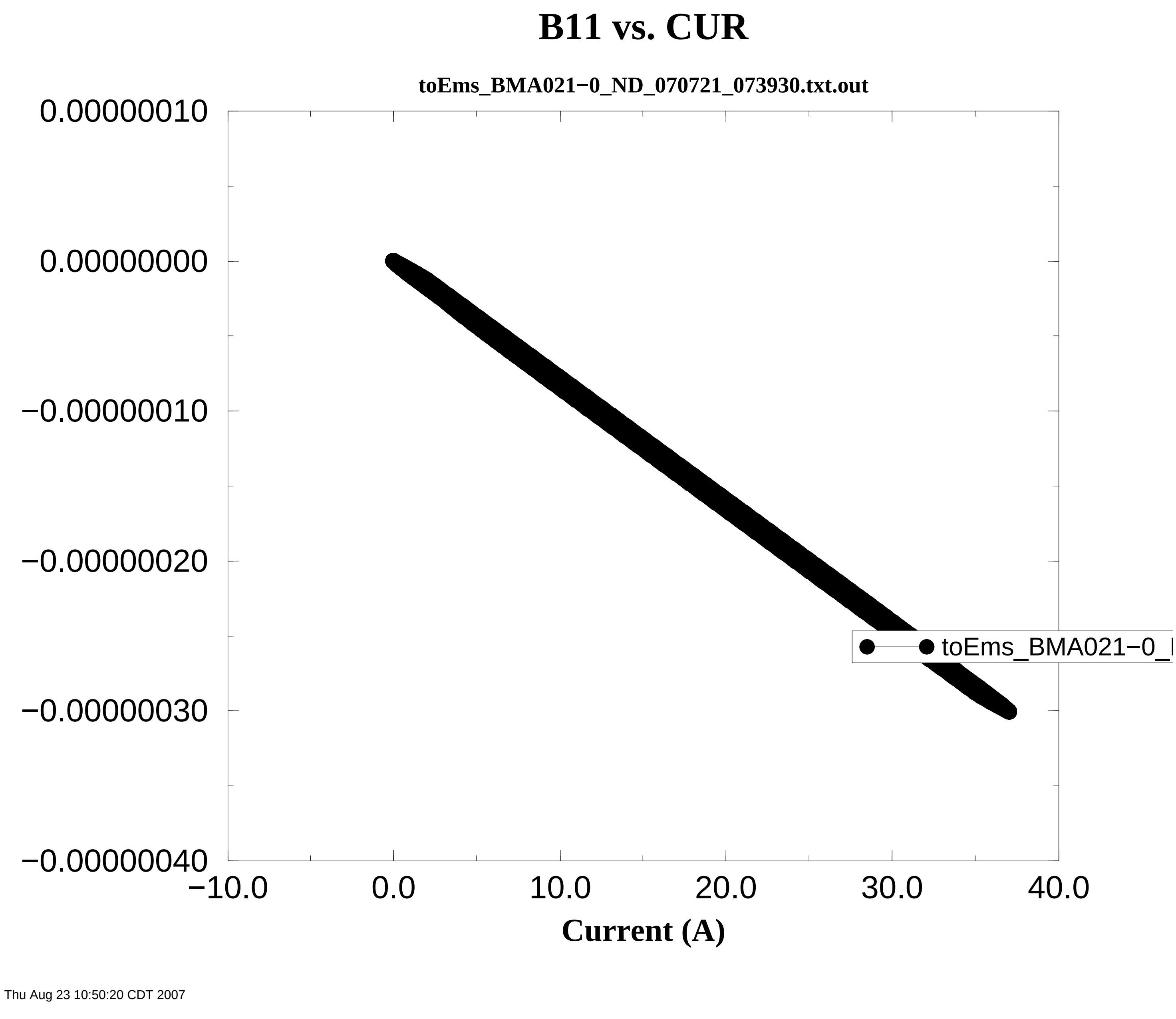


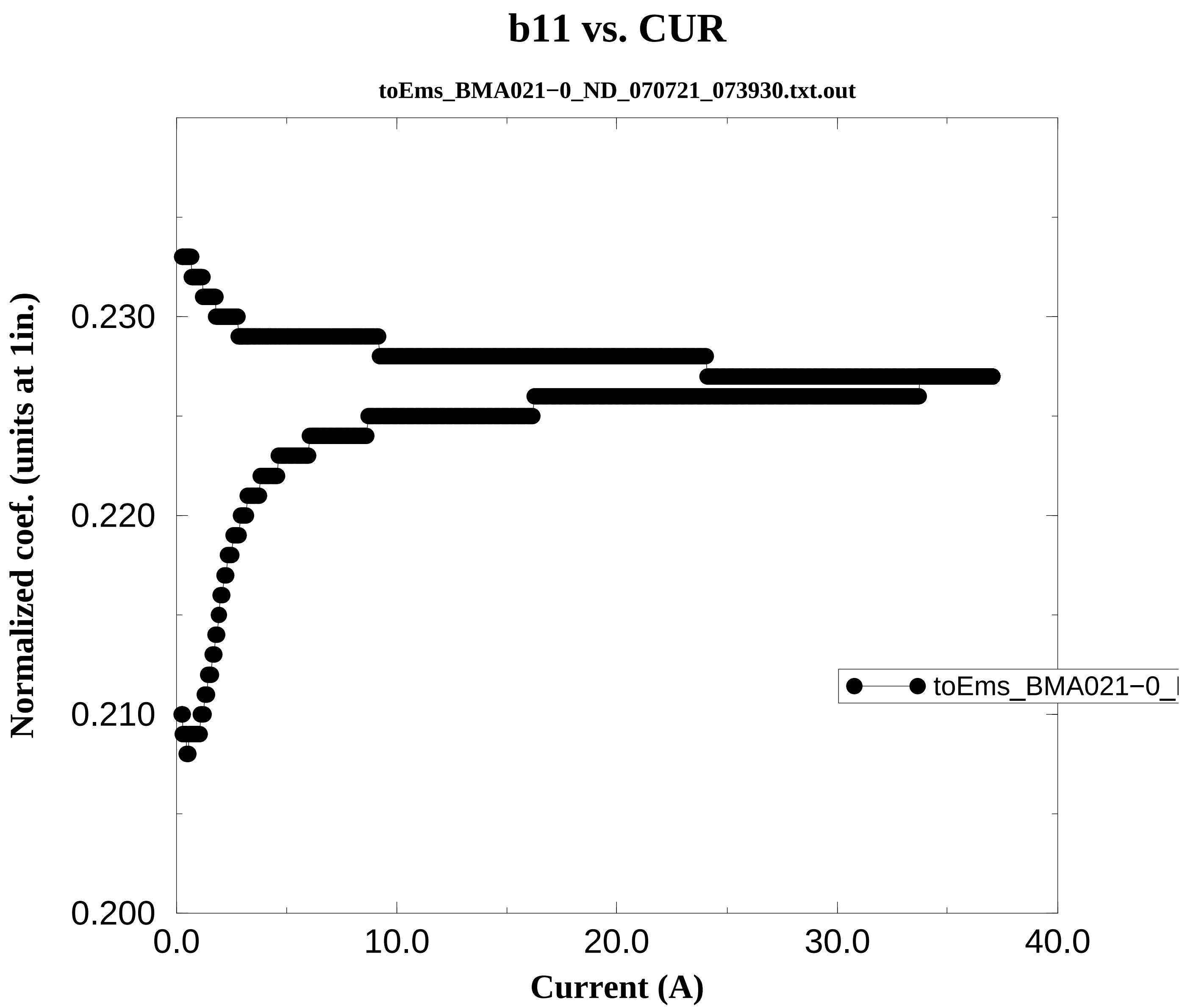
Resolution on the order of 1uT

B3 vs. CUR



Sat Jul 21 08:17:43 CDT 2007


B11 vs. CUR
toEms_BMA021−0_ND_070721_073930.txt.out
0.00000010
0.00000000
−0.00000010
−0.00000020
−0.00000030
−0.00000040
−10.0
0.0
10.0
20.0
30.0
40.0
Current (A)
toEms_BMA021−0_
Thu Aug 23 10:50:20 CDT 2007



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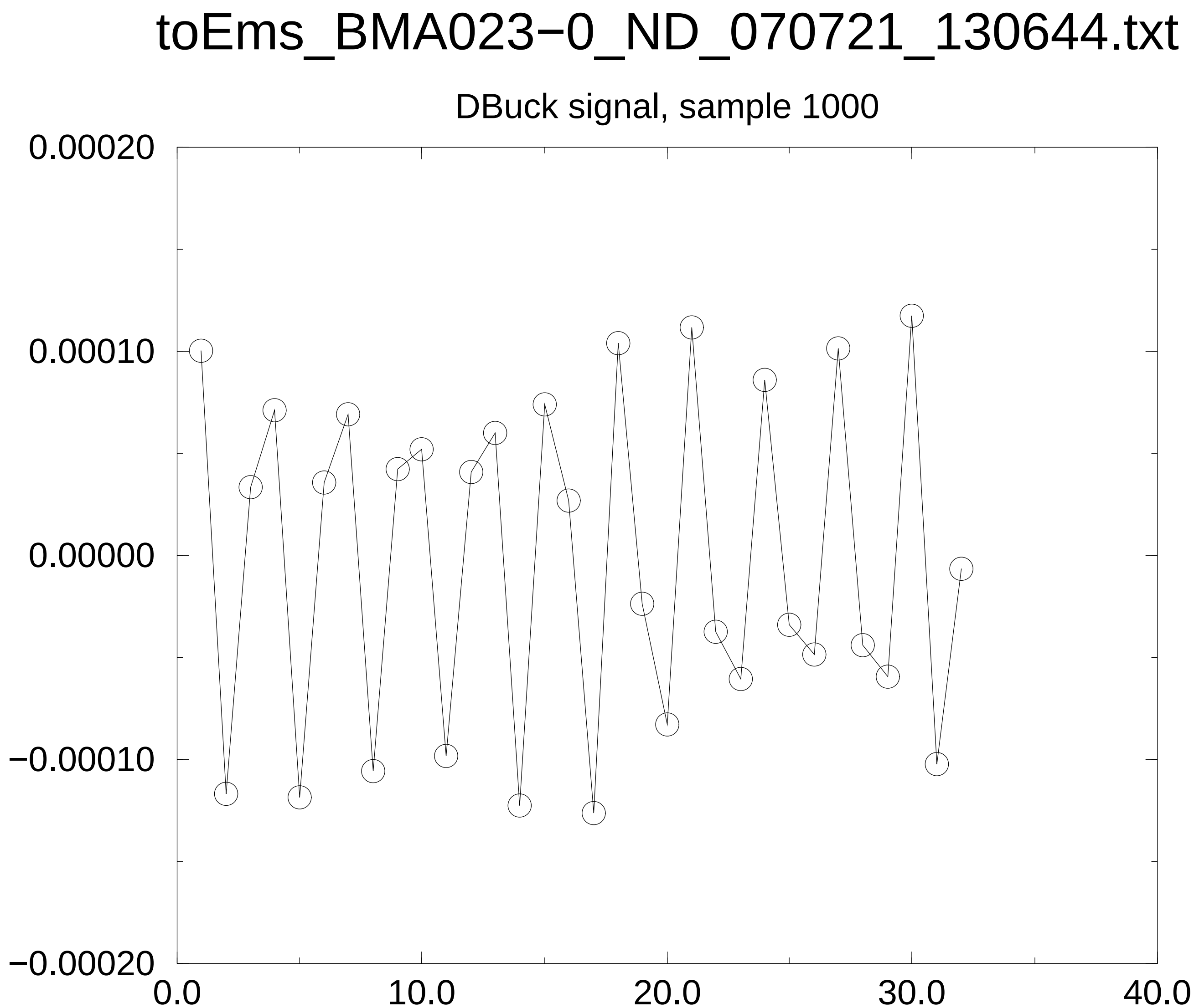
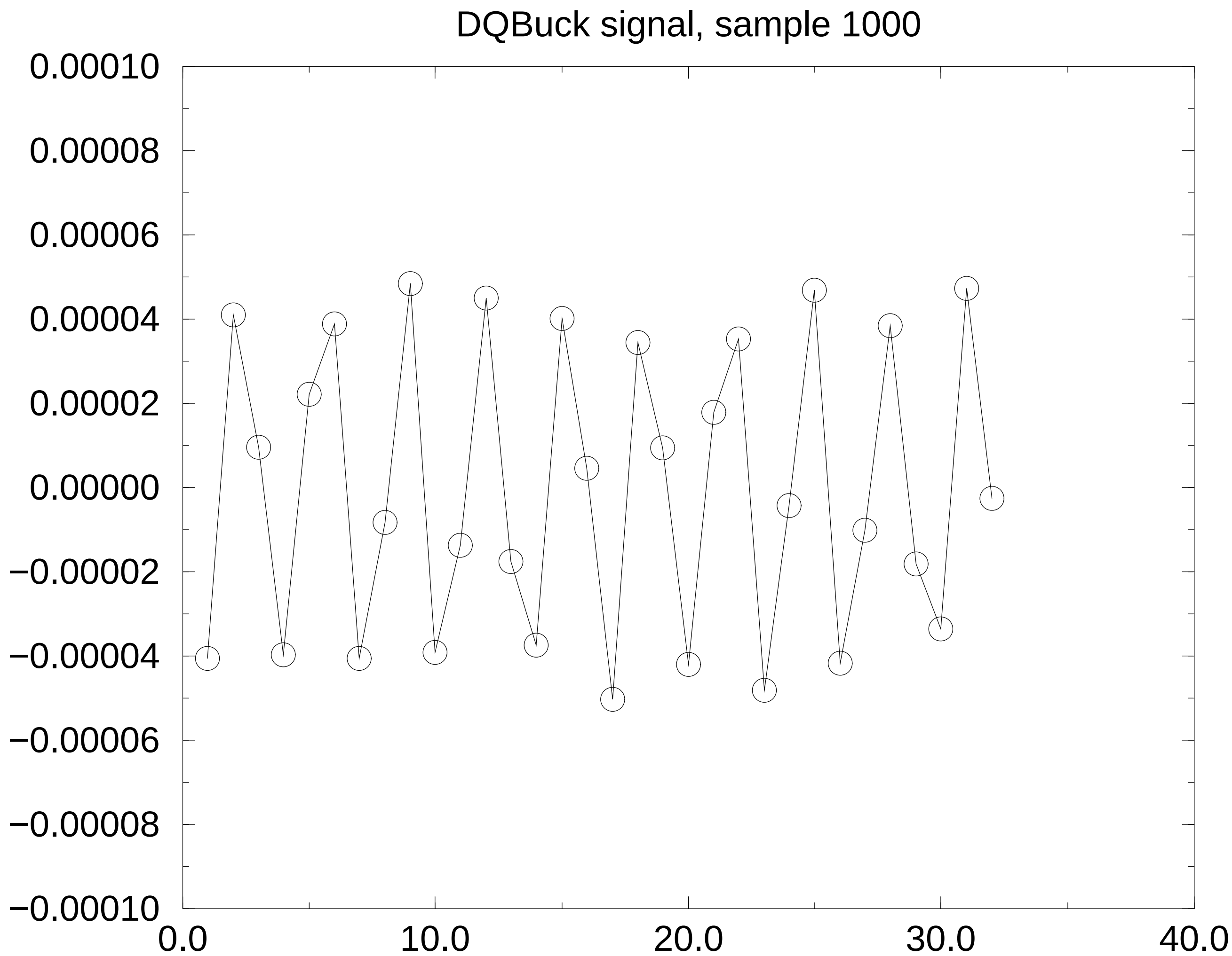
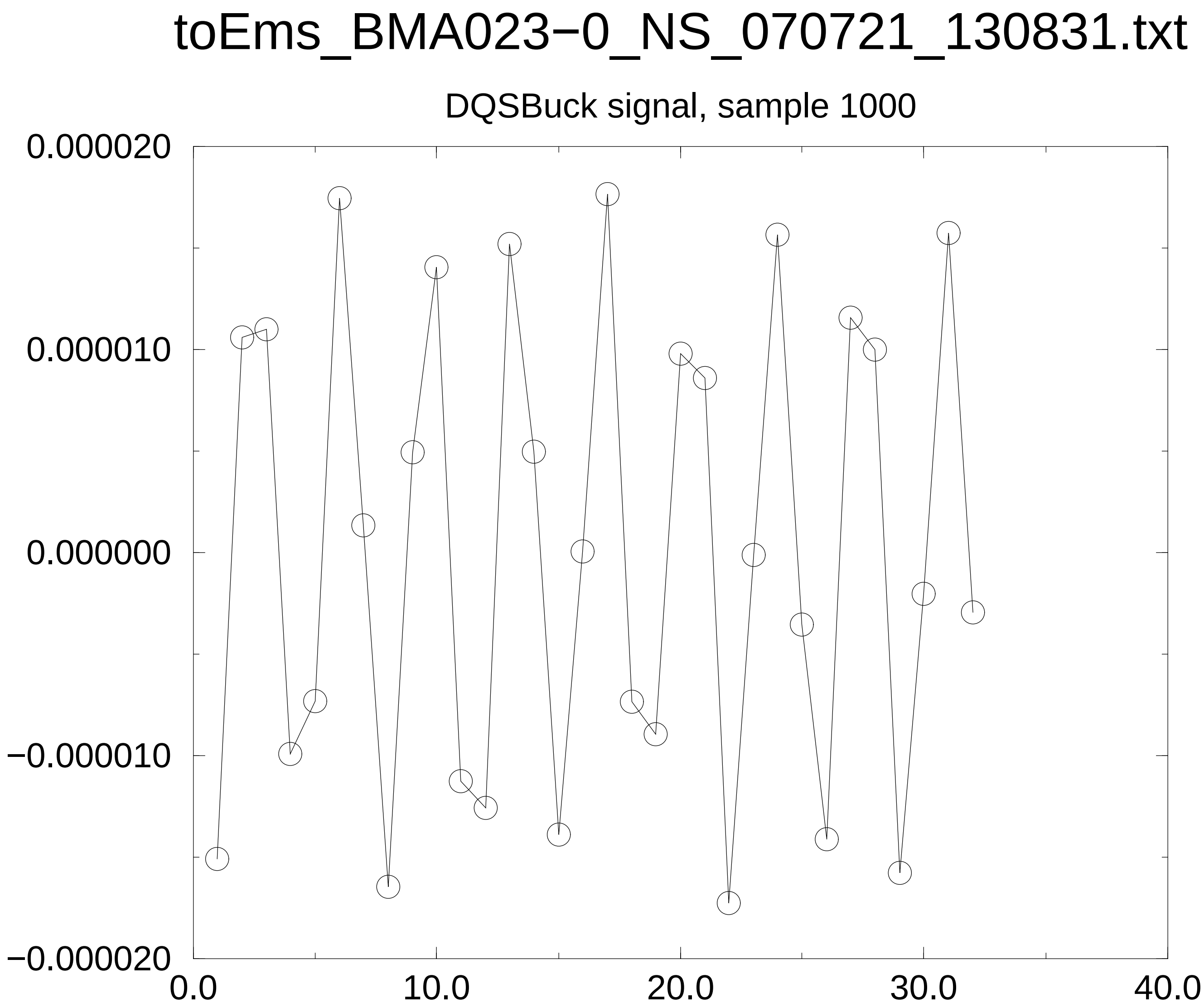
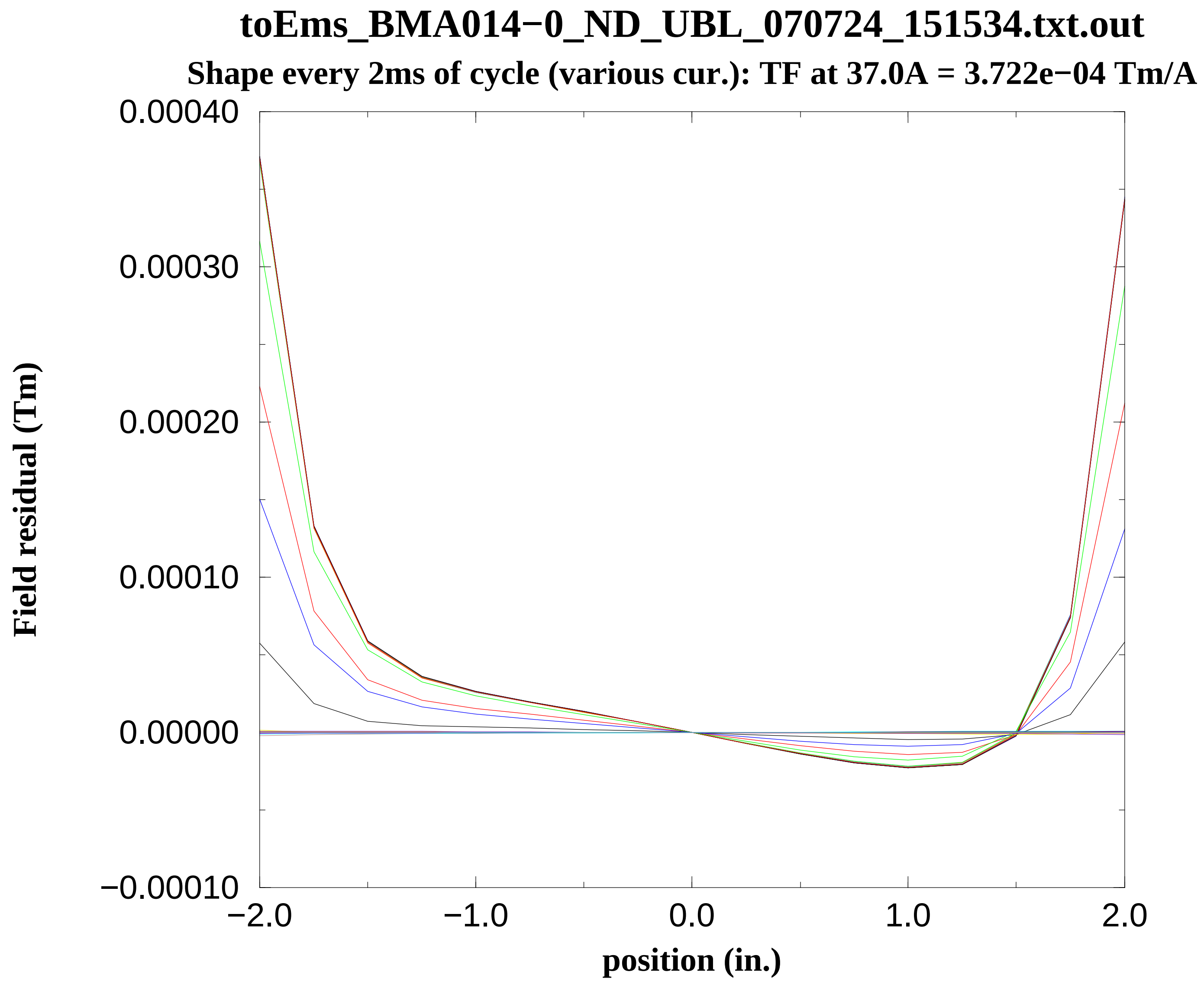


toEms_BMA023−0_ND_070721_130644.txt
DBuck signal, sample 1000
0.00020
0.00010
0.00000
−0.00010
−0.00020
0.0
10.0
20.0
30.0
40.0

toEms_BMA023−0_NQ_070721_130207.txt




toEms_BMA023−0_NS_070721_130831.txt
DQSBuck signal, sample 1000
0.000020
0.000010
0.000000
−0.000010
−0.000020
0.0
10.0
20.0
30.0
40.0



Tue Jul 24 15:59:47 CDT 2007

What's next

With having to qualify magnets for production, have not had time to go through and understand data/system carefully – still need to do that.

In particular need to understand calibrations of harmonics values (e.g. does variation in individual probes create some false harmonics). Have taken data with the probe rotated to several angles for this calibration.

Need to understand if 'hysteresis' shapes seen in some multipoles are from the magnet or related to the probe (some sort of coupling effect).

Final transformations for centering, angle based on normal quad, dipole applied.

Data should be uploaded automatically to data portal.

Quality checks incorporated into operator interface.