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4/04

Magnetic Measurements on Tevatron Dipoles TB0834 and TC1052 Using CERN Sextupole Hall Probe Array

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This note reports the results of sextupole measurements performed on the Tevatron dipole magnets TB0834 and TC1052 using a system developed at CERN, based on the use of Hall plates to achieve a fast read-out. First measurements with this system were performed on magnets TB0269 and TC1220 (see Fermilab Technical Division notes TD-03-011 and TD-03-027 for further details).

The main motivation for the use of this probe on Tevatron dipoles is a) to obtain more accurate measurements of the b2 snapback thanks to the better time resolution of the Hall probe system, b) to provide an independent check of the measurements performed using rotating coils and c) to gain experience with Hall-probe sensors needed for the development of future magnetic measurement hardware. This work is also in the interest of CERN, because of the plans to use a similar Hall probe sensor for on-line magnetic measurements as diagnostics for the LHC.

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Measurement Program

The standard current cycle for the measurement of decay and snapback in the Tevatron dipoles, together with the nomenclature of the various phases, is shown in Fig. 1. The cycle is based on the typical operation of the accelerator. The magnets are quenched to erase previous history. Nominal injection level is 663 A (corresponding to about 0.66 T) and flat-top level is 4333 A (corresponding to about 4.33 T). The ramp-rate during acceleration and ramp-down is 53 A/s, and a full energy swing (from injection to flat-top) takes about 80 s. Acceleration starts with a parabolic time dependence lasting few seconds before reaching full speed.

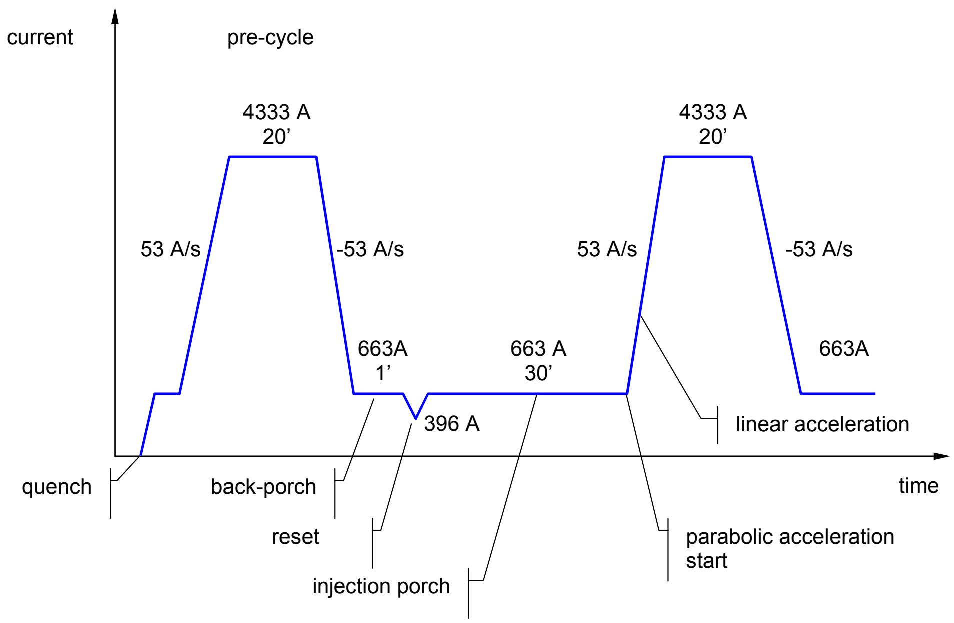

Figure 1: Standard current cycle for the measurement of injection decay and snapback in Tevatron dipoles.

All measurements reported in this note were performed at 4.3 K on TB0834, and at 3.9 K on TC1052. The parameters varied during the measurement campaign were the following:

- flat-top time during the pre-cycle: 1, 10, 20 (standard), 60, 120, 240 and 720 minutes (as part of the so called long flat-top series);
- back-porch time: 1 (standard) and 30 minutes;
- injection-porch time: 30 (standard), 60 and 120 minutes;

The list of all measurements performed on TB0834 and TC1052 can be found at http://www-td.fnal.gov/~velev/tevatron/.

All measurements reported here were performed with the probe placed at approximately 3 m from the end of the warm bore, on the magnet cryogenic return-box side. This location is well inside the body field of the magnet, and the measurements are not affected by end field contributions. Simultaneously magnetic measurements were performed with rotating coils entering the magnet from the feed-box end. Possible interference between the two measurement systems is discussed in TD-03-011. The Hall probe was recalibrated for each measurement, using the rotating coil data, following the procedure described in TD-03-011. The calibration parameters are shown in Appendix A.

Comparison with Rotating Coil

Figures 2 to 5 show an example of the snapback in TB0834 and in TC1052. Both data recorded with the rotating coil and the Hall-probe, after baseline subtraction, are plotted for comparison. Figure 2 and 4 show a good match when the b2 is plotted versus time. The same data presented in Figure 2 (for TB0834) don't show a similar agreement when the snapback is resolved versus B0 (Figure 3). The source of this difference was found to be the following. The B0 associated with the b2 measured by the rotating coil was computed from the current measured at the "same time". The measurement of b2 requires one rotation of the coil, while the current measurement is practically instantaneous. Therefore the acquisition system was set to take the current reading in the middle of the rotation giving a b2 value. Since the difference shown in figure 3 was a systematic effect (present in the analysis of all measurements on TB0834 and the previously tested magnets: TC1220 and TB0269) the procedure was changed for the analysis of TC1052 measurement. In this case the b2 values measured by the rotating coil were associated with the B0 values measured during the same rotation. Figures 5 shows the better match between the two measurements (Hall probe an rotating coil) obtained in this case.

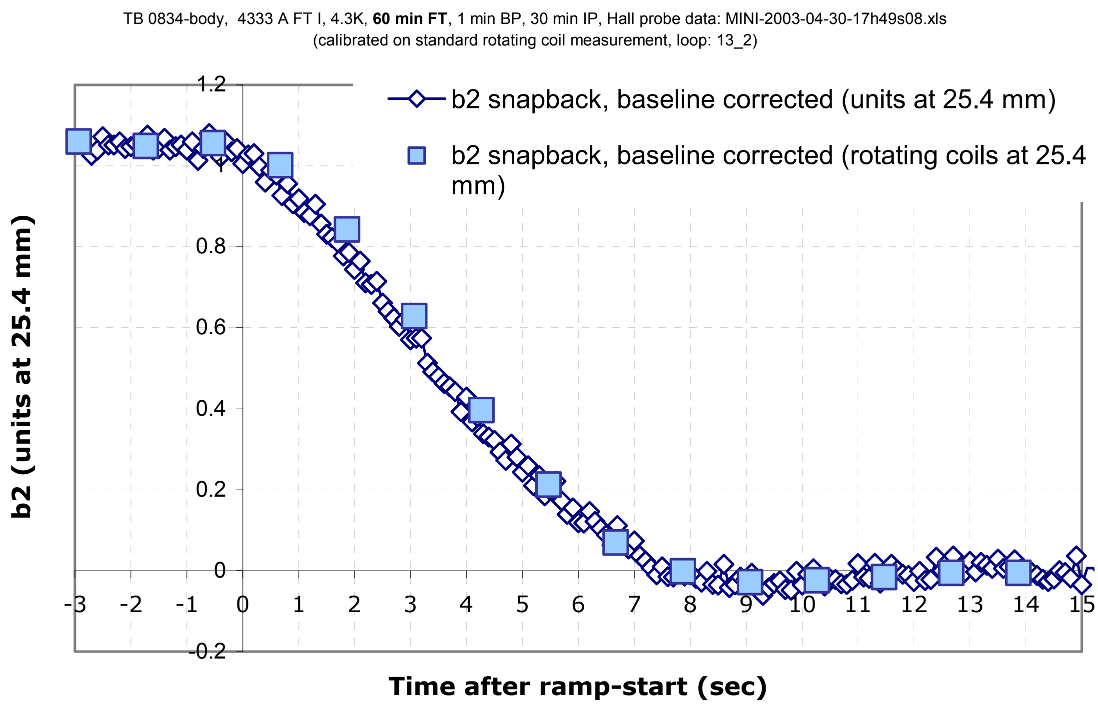

Figure 2: Snapback vs. time in TB0834. Comparison between rotating coil and Hall probe data.

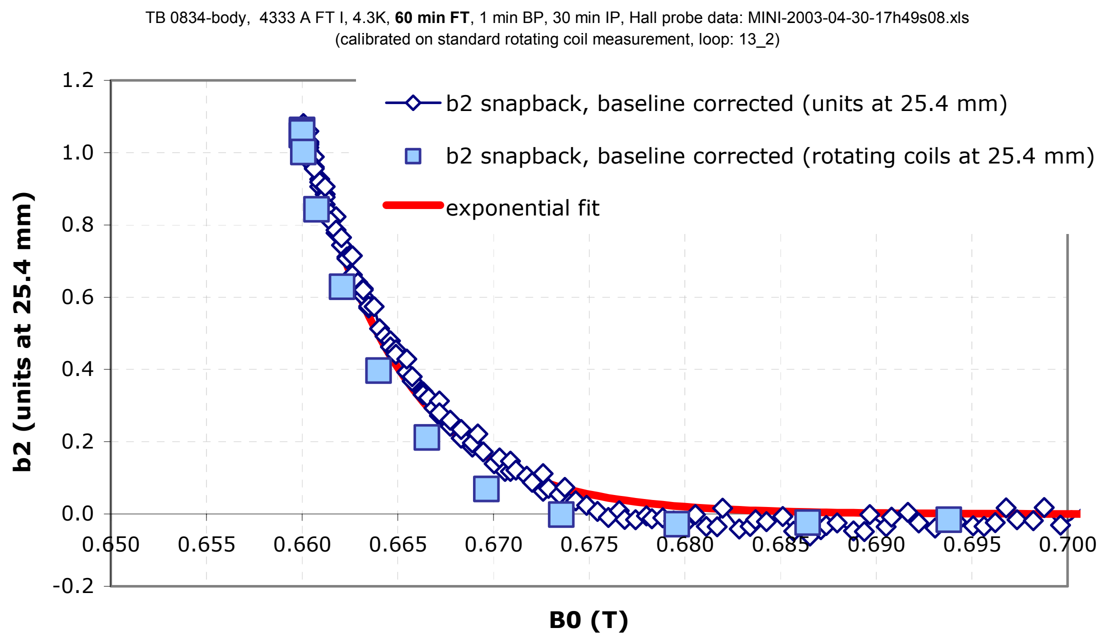

Figure 3: Snapback vs. B0 in TB0834. Comparison between rotating coil and Hall probe data. The B0 values used for the rotating coil were computed from the measurement of the current.

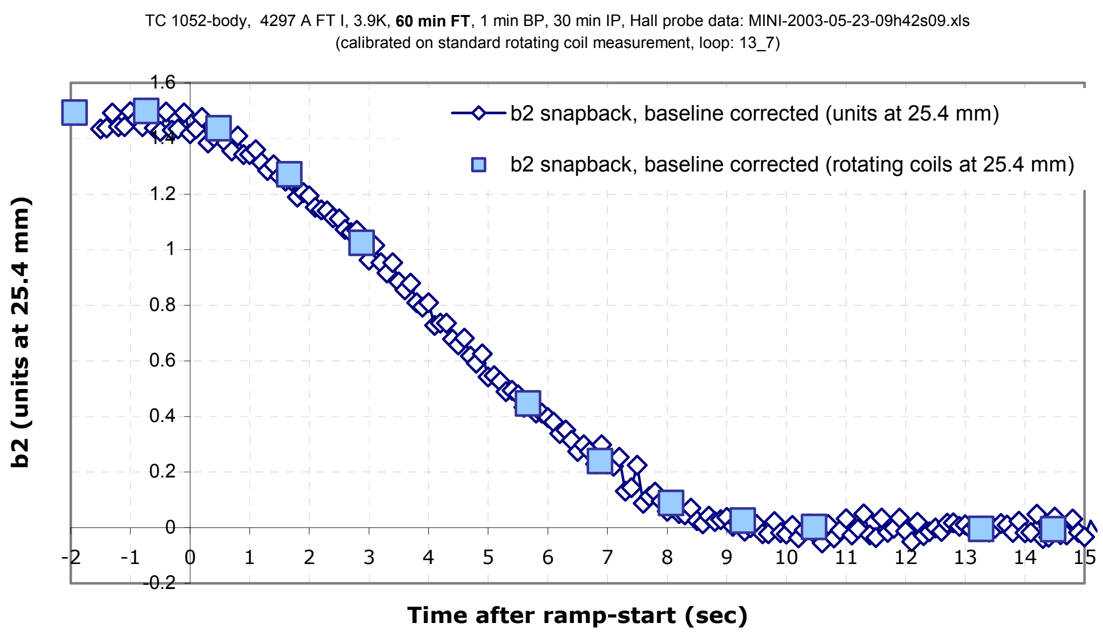

Figure 4: Snapback vs. time in TC1052. Comparison between rotating coil and Hall probe data.

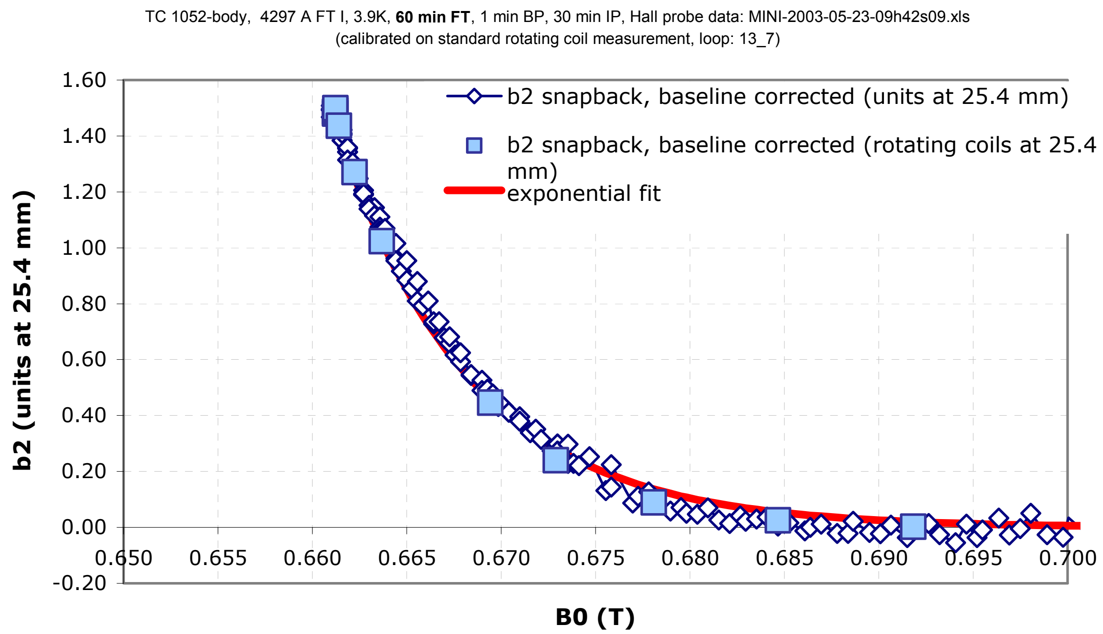

Figure 5: Snapback vs. B0 in TC1052. Comparison between rotating coil and Hall probe data. The B0 values used for the rotating coil were measured together with b2.

Measurement of the Effect of the Flat-top Duration

Figure 6 shows the amplitude of the snapback in TB0834 (measured at 4.3 K) and in TC1052 (measured at 3.9 K) for different pre-cycle flat-top durations (20, 60, 240 and 720 min for TB0834; 1, 10, 20, 60, 720 min for TC1052) followed by 1-min back porch and 30-min injection porch. The measurement of TB0834 after 20 min flat-top is the one that showed the largest difference (0.1 unit) between Hall-probe and rotating coil data (Figure 7).

It can be seen that the saturation of the effect of the flat-top duration occurs below 20 minutes in both magnets.

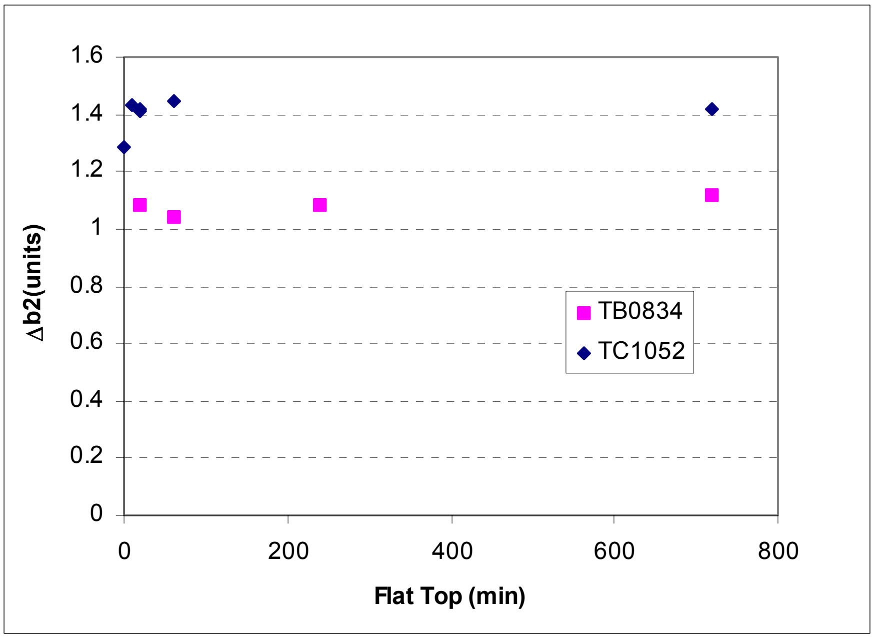

Figure 6: Amplitude of b2 snapback versus pre-cycle flat-top duration in TB0834 (measured at 4.3 K) and TC1052.(3.9 K)

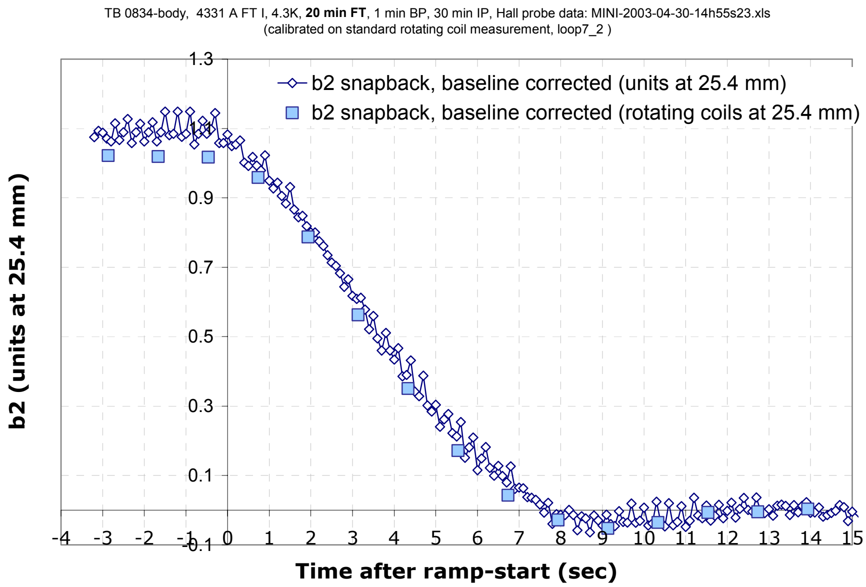

Figure 7 B2 snapback versus time in TB0834 after 20-min flat top, 1-min back-porch and 30-min injection porch.

Measurement of the Effect of the Pre-cycle Back-porch Duration

Figure 8 shows the amplitude of the snapback in TB0834 (measured at 4.3 K) after a 20 min dwell on flat top and 30 min on injection porch for different pre-cycle back-porch durations.

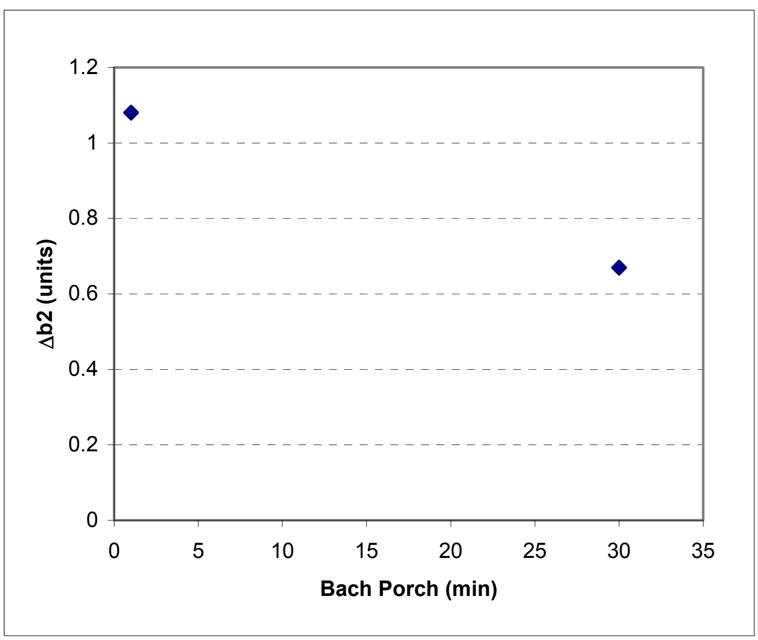

Figure 8: Amplitude of b2 snapback in TB0834 after 20 minutes at flat top and 30 min at injection for different pre-cycle back-porch times (1 and 30 min).

Measurement of the Effect of the Injection Porch Duration

Figure 9 shows the amplitude of the snapback in TB0834 (measured at 4.3 K) and TC1052 (measured at 3.9 K) for different injection-porch durations (30, 60 and 120 min) following a standard pre-cycle (20 min flat-top, 1 min back-porch).

The plot shows the logarithmic dependence of the b2 snapback amplitude from the injection-porch duration.

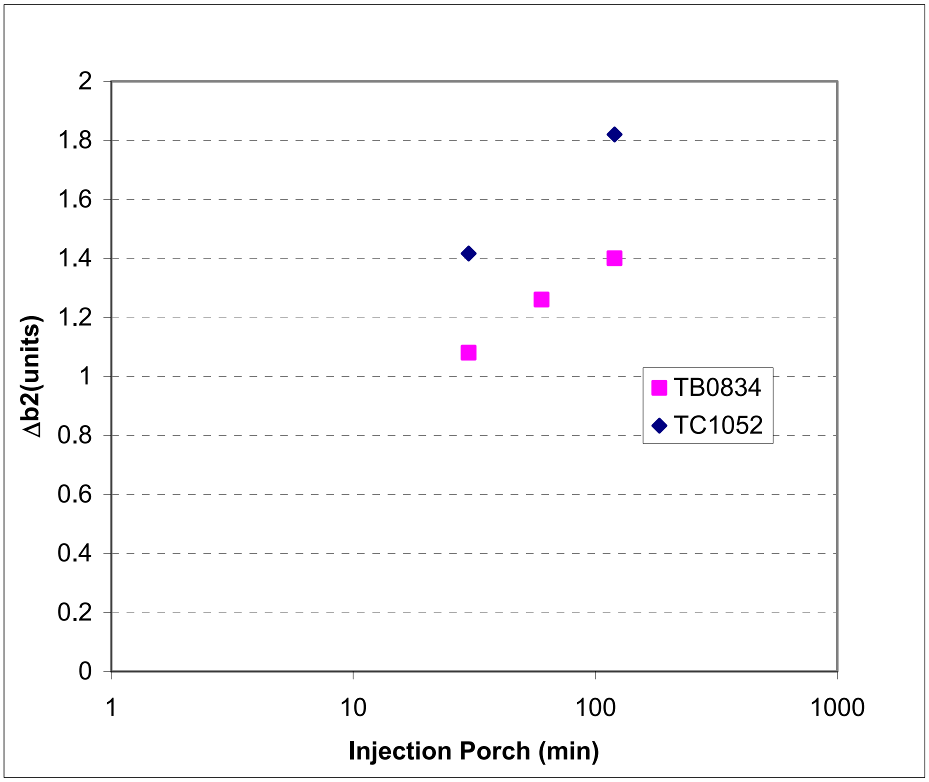

Figure 9: Amplitude of b2 snapback versus injection-porch duration in TB0834 (measured at 4.3 K) and TC1052.(3.9 K) .

Correlation between Drift Amplitude and Dipole Field Change

The snapback data clearly show a correlation between the b2 drift amplitude (the value of b2 at the start of the snapback) and the dipole field change required for completion of the snapback (B0 at end of snapback). The correlation can be measured using the parameters of an exponential curve fitting:

$$b_2^{snap-back}(t) = \Delta b_2 e^{-\frac{B_0(t)-B_{0,injection}}{\Delta B_0}}$$

where $b_2^{snap-back}(t)$ is the sextupole change during snap-back, $B_0(t)$ is the instantaneous value of the dipole field, initially at the injection value $B_{0,injection}$. The snap-back amplitude Δb_2 and the dipole field change ΔB_0 are the two fitting constants.
The correlation for all fitting parameters Δb_2 and ΔB_0 in the exponential is shown in Figure 10 for all Tevatron dipoles tested using the Hall probe up to now .The plot indicates a linear correlation between the two parameters. The coefficient of the linear fit for each magnet is shown in the plot (using the same color of the marks used for that magnet). They are all within a few percent from the average: 0.214 units/mT.

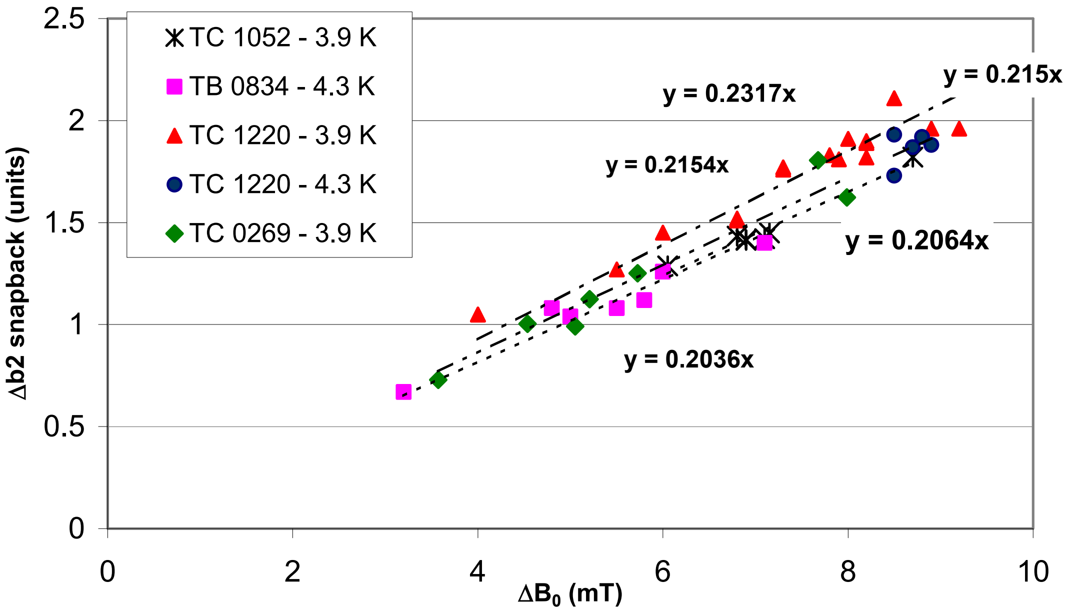

Figure 10. Scatter plot of the snap-back amplitude Δb_2 vs. the dipole field change ΔB_0 for all Tevatron dipoles tested using the Hall probe. The plot indicates a strong correlation between the two parameters.

Conclusions

The CERN Hall-probe array sensor was successfully used for measurements of the b2 snapback in TB0834 and TC1052. The measurements showed good agreement with the rotating coil data (improved by using the B0 measured by the rotating coil instead of computing it from the current value)

The correlation between b2 drift amplitude and the B0 required for completion of the snapback, seen in TB0269 and TC1220, was seen again in these magnets.

Appendix A - Calibration Constants for 2-Ring Sum Voltage

The following plots show the calibration constants found for the 2-ring sum in all the measurements presented in this report. Since a strong variation is expected for different measurement temperatures the calibration parameters used for TB0834 (measured at 4.3 K) and for TC1052 (measured at 3.9 K) are shown in separate figures. A clear correlation can be seen among the thirst three coefficients (offset, bucking and nonlinear). The sensitivity doesn't look so strongly correlated to the others.

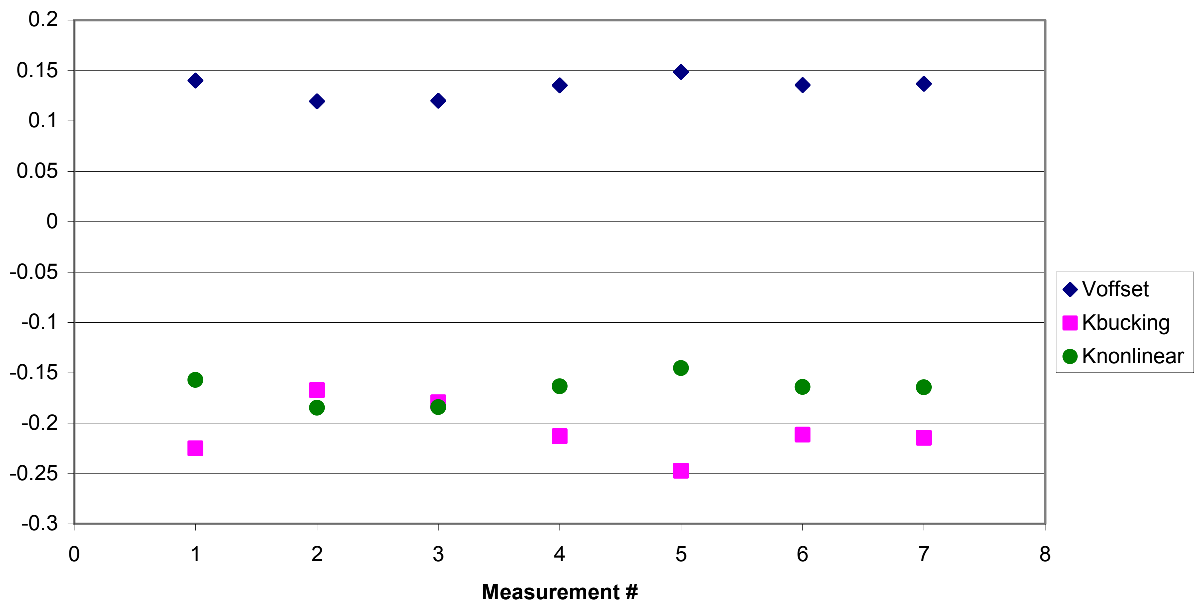

Figure 11: Calibration coefficients used for the 2-ring sum during measurement of TB0834.

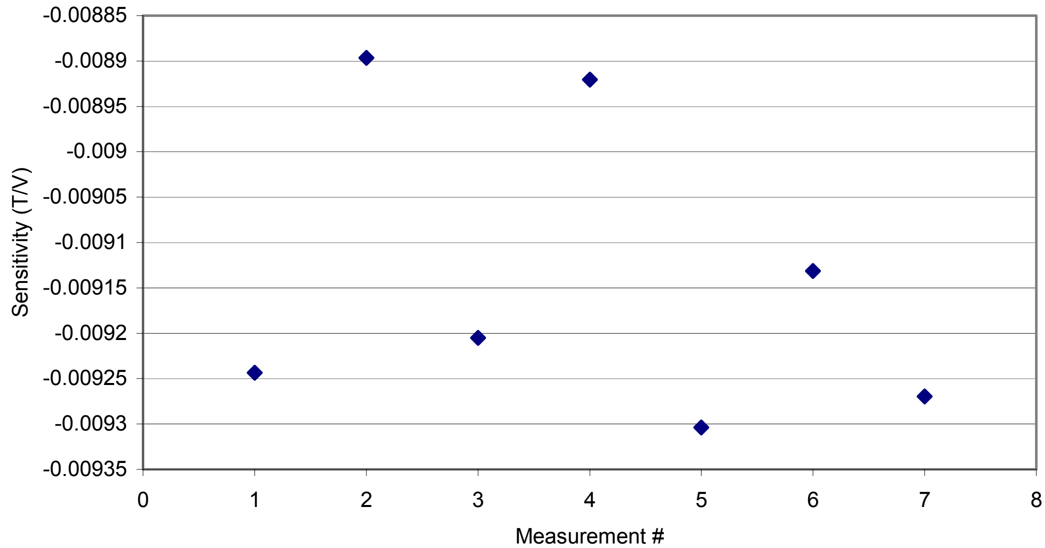

Figure 12: Sensitivity of the 2-ring sum during measurement of TB0834.

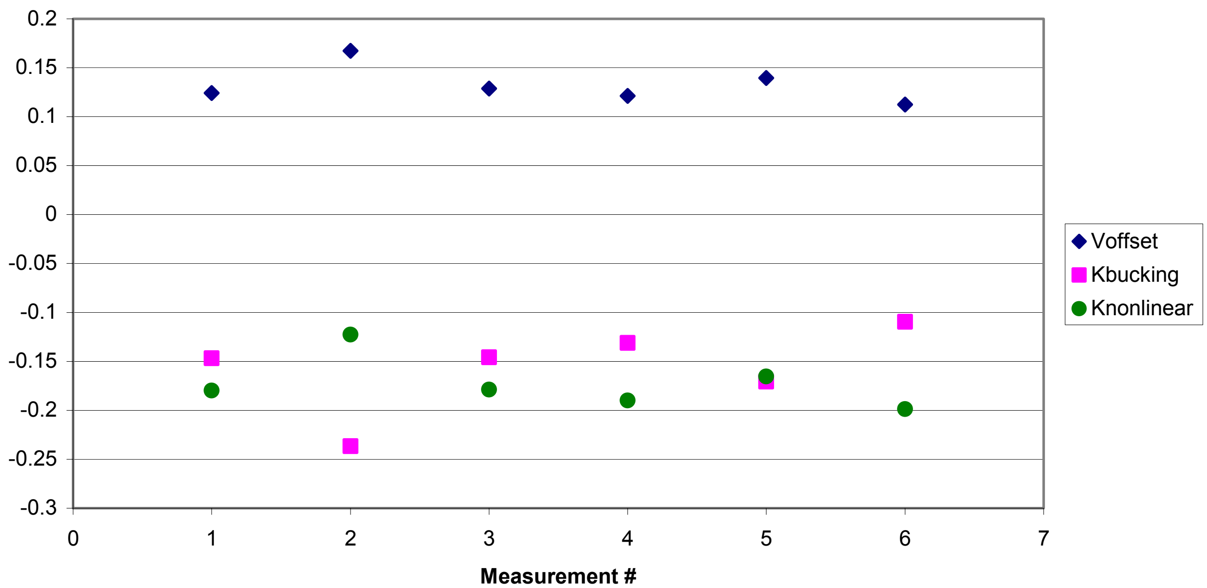

Figure 13: Calibration coefficients used for the 2-ring sum during measurement of TC1052.

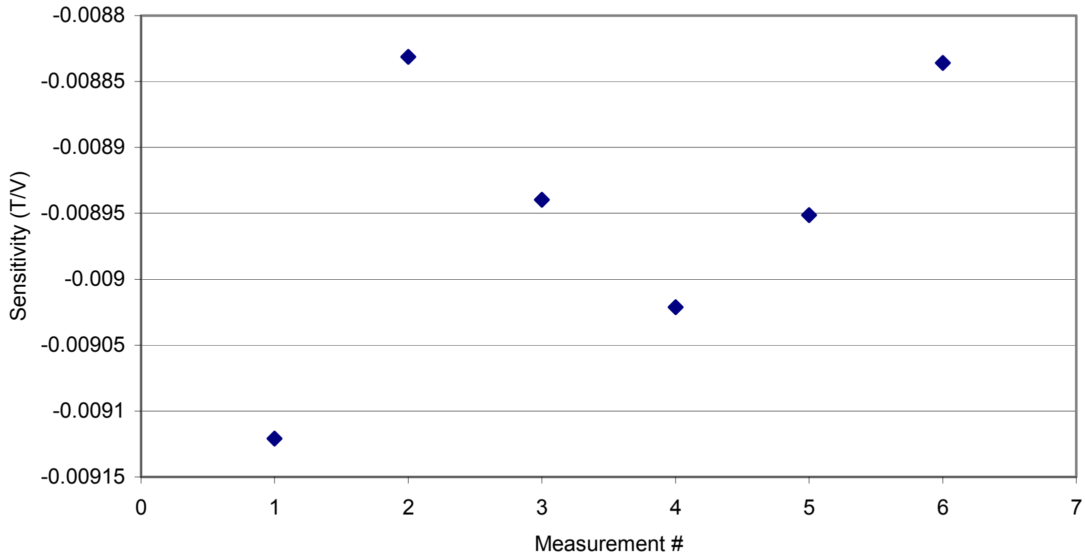

Figure 14: Sensitivity of the 2-ring sum during measurement of TC1052.