Memo

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Re: Status of the study of sextupole compensation during snap-back in collaboration with FNAL

Introduction

In the past six months we have conducted a fruitful collaboration between Fermilab and CERN, devoted at improving the understanding of the sextupole snap-back in superconducting dipoles. Within the scope of the collaboration, originally outlined in a Memorandum of 17/12/2002[1], CERN has provided to FNAL a probe for the measurement of the local sextupole in the Tevatron dipoles under test at the Magnet Test Facility (MTF), and FNAL has conducted several measurement campaigns using the probe, including data evaluation. The magnets tested and analysed to date are TB0269, TB0834 and TC1220.

The main results of the measurements performed so far have shown that once all other known effects are removed (in particular the geometric and persistent current contributions) the sextupole snapback can be fitted by a simple exponential[2]:

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[1] L. Bottura, Collaboration with FNAL on the development of a scaling law for feed-forward of sextupole correction during snap-back, CERN Memorandum of December 17th, 2002

[2] M. Haverkamp, Decay and Snapback in Superconducting Accelerator Magnets, Ph.D. Thesis, University of Twente (NL), October 2003.

$$b_3^{snap-back}(t) = \Delta b_3 e^{-\frac{I(t)-I_{injection}}{\Delta I}} \qquad (1)$$

where $b_3^{snap\text{-}back}(t)$ is the sextupole change during the snap-back, I(t) is the instantaneous value of the current, initially at the injection value $I_{injection}$. The snap-back amplitude Δb_3 and the current change ΔI are the two fitting constants. The quality of the fit is generally better than 0.02 units on the r.m.s. error. This is demonstrated in Fig. 1 for a typical measurement performed on the Tevatron dipole TB0269.

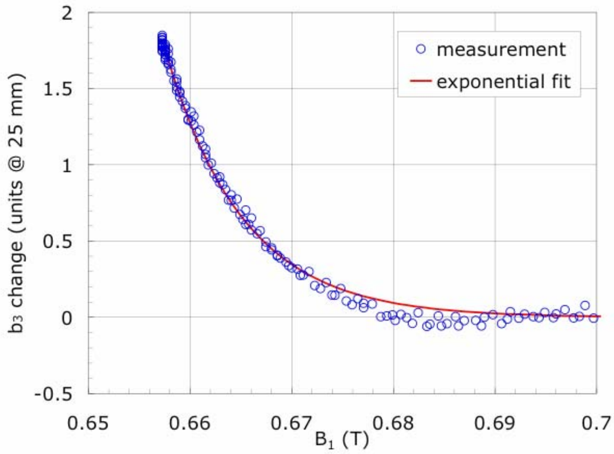

Figure 1. Exponential fit of measured sextupole change during snap-back on the Tevatron dipole TB0269. The current is proportional to the dipole field, with a transfer function of the order of 1 T/kA.

Once the fit parameters Δb_3 and ΔI are known, the current (and hence time) dependence of the sextupole change during snap-back can be accurately described with a simple model amenable of being implemented in a fast control algorithm.

We have also found from the analysis of the data taken on a single magnet for different magnet powering sequences that the fit parameters Δb_3 and ΔI change, in accordance with the fact that the sextupole snap-back is a function of the magnet history. We observed however that the set of fit parameters obtained is strongly correlated, and once represented in a scatter plot Δb_3 vs. ΔI they lie on a straight line, as shown in Fig. 2.

The implication is that only one of the two fit parameters, either Δb_3 or ΔI, is strictly necessary to predict the sextupole change.

Finally, we could observe that the correlation between the fit parameters Δb_3 and ΔI is the same (within the accuracy of the measurement and data analysis) in all magnets tested, shown also in Fig. 2. This fact suggests that the scatter plot representation adopted and the correlation found could provide an *invariant* property of a *magnet* design *family*, independent on the specificities of each magnet instance. This postulate is substantiated by the fact that (a) the magnets tested were not specially selected (e.g. in respect to cable properties) and (b) comparable results are found performing the same measurements and data analysis on the LHC dipoles, as also shown in Fig. 2.

Hence the correlation plot established over a percentage of the total magnet population can be used to characterise the behaviour of the dipoles in the whole accelerator. This could provide a very effective and precise mean to forecast fast sextupole changes during snap-back based on chromaticity measurements during injection, as discussed in the following section.

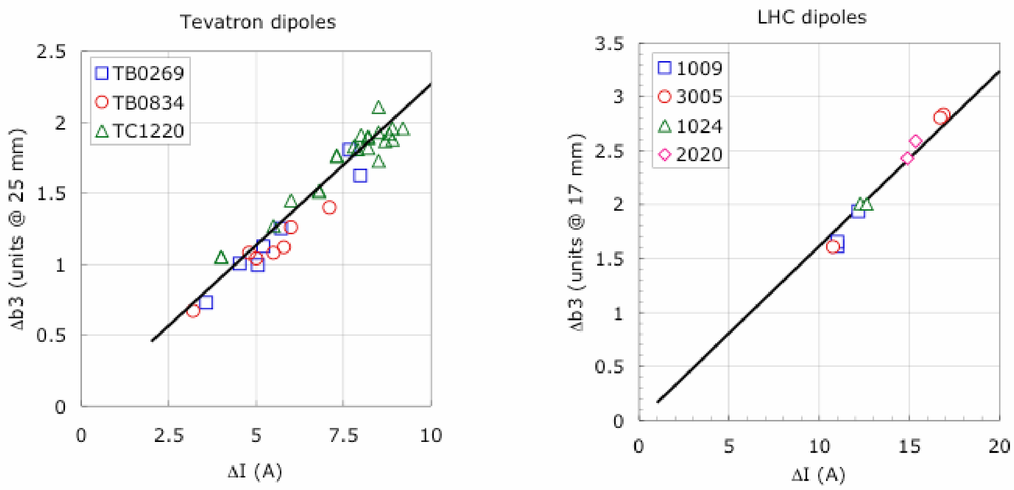

Figure 2. Scatter plot of the fit parameters Δb_3 and ΔI that correspond to sets of different powering cycles in the three Tevatron dipoles tested and analysed to date (left) and four LHC series dipoles (right).

Beam-based sextupole snap-back compensation

The findings reported above indicate that it may be possible to correct the sextupole change during snap-back based solely on beam measurements of the chromaticity. This could be achieved as described schematically in Fig. 3.

Chromaticity would be measured at a few times during the injection porch. These measurements would be converted to sextupole change in the dipoles and used to predict the expected sextupole change during snap-back Δb_3 at an arbitrary ramp-time (on the left in Fig. 3).

A $b_3(t)$ fit formula established during magnetic measurements of the dipoles, or during MD time would be used for this extrapolation. At present, based on magnetic measurement of LHC series dipoles, a double exponential dependence on time appears to be appropriate. As an alternative, a logarithmic function has been found to describe well the behaviour of the Tevatron dipoles.

The expected Δb_3 would then be used to compute the corresponding ΔI through the linear correlation in the Δb_3 vs. ΔI scatter plot (on the right in Fig. 3). In the case of the LHC the correlation would need to be established during series measurements.

Finally, the Δb_3 and ΔI parameters would be used to forecast the sextupole correction during snap-back using the exponential fit of Eq. (1).

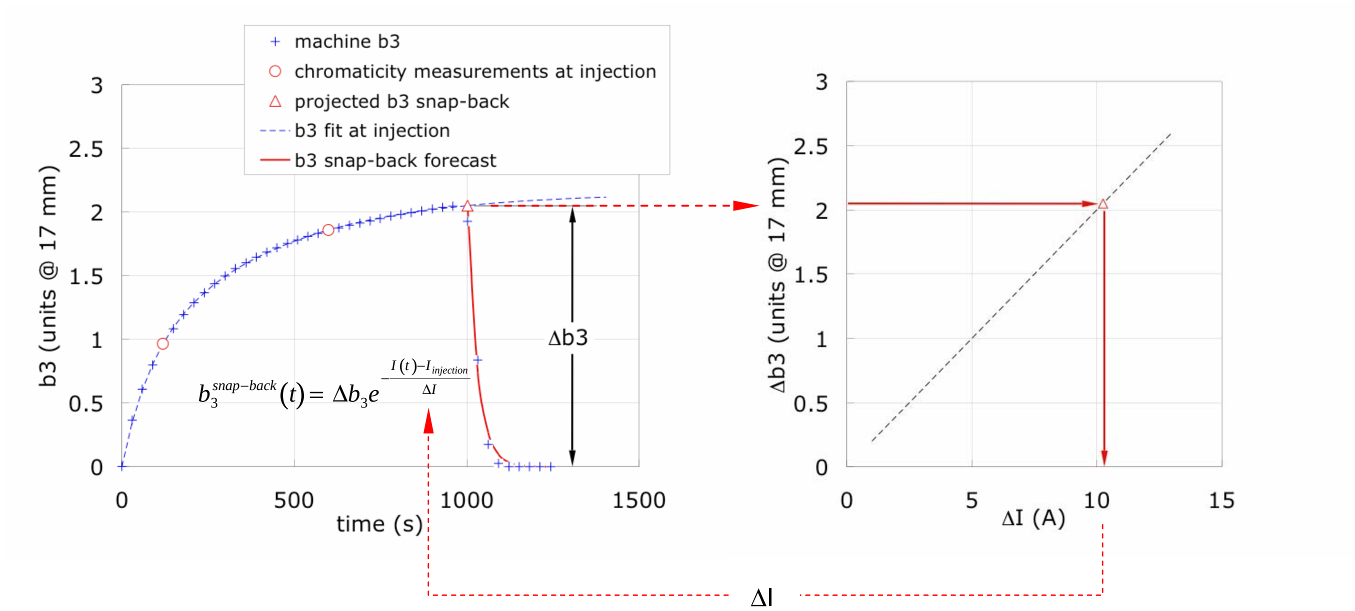

Figure 3. Schematic representation of a beam-based alternative for the correction of the sextupole change in the main bending dipoles during snap-back.

Proposal for a test of the sextupole snap-back compensation

The idea outlined in the previous section is clearly interesting as it is based directly on measured beam properties, and should hence reflect very accurately the integral sextupole changes in the accelerator.

It is flexible, and can be applied for any machine state, with or without conditioning pre-cycle before injection, and arbitrary ramp to injection or injection time.

Also, the required bandwidth of the chromaticity measurement is modest, as it executed only during the injection plateau.

Given the clear potential for flexibility at the LHC, and in line with the idea at the origin of the FNAL-CERN collaboration outline in the cited Memorandum[1], we propose to test the idea discussed in the previous section during MD time at the Tevatron.

The aim of the test would be to assess whether the correction is feasible and determine the accuracy of the procedure. The basis for the forecast of the sextupole correction waveform would be the chromaticity data accumulated so far during Tevatron operation and the correlations established on the Tevatron dipoles tested at the MTF.