MEASUREMENTS OF FIELD DECAY AND SNAPBACK EFFECT ON TEVATRON DIPOLE AND QUADRUPOLE MAGNETS *

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Abstract

Since the beginning of 2002 an intensive measurement program has been performed at the Fermilab Magnet Test Facility (MTF) to understand dynamic effects in Tevatron magnets. Based on the results of this program a new correction algorithm was proposed to compensate for the decay of the sextupole field during the dwell at injection and for the subsequent field "snapback" during the first few seconds of the energy ramp. Beam studies showed that the new correction algorithm works better than the original one, and improves the Tevatron efficiency by at least 3%. The beam studies also indicated insufficient correction during the first 6s of the injection plateau where an unexpected discrepancy of 0.15 sextupole units of extra drift was observed. This paper reports on the most recent measurements of the Tevatron dipoles field at the beginning of the injection plateau. Results on the field decay and snapback in the Tevatron quadrupoles are also presented.

INTRODUCTION

Field errors from persistent currents play a significant role in the complex operation of modern superconducting accelerators due to their large amplitude and time dependence. For example the effects from normal sextupole (b_2) field errors, observed during the injection plateau at the early stage of the Tevatron operation, were unacceptable and corresponding time dependent corrections were invented [1].

For the ongoing Run II, the Tevatron normal sextupole compensation during injection went through several stages of improvement. Recently a new set of sextupole corrections was obtained from a systematic series of magnetic measurements performed at MTF. A new algorithm to control the Tevatron normal sextupole (b_2) during injection was put in place. The result from magnetic measurements was distilled into five proposals for optimization of the Tevatron operation as follows: 1) remove the precycle(s) after the end of a successful store; 2) use a constant duration for the back-porch (the current profiles, back-porch, flattop and injection porch definitions used in our measurements are described in detail in ref.[2]); 3) use only one precycle with an increased length of ~60 min. if the store ended abnormally; 4) adopt the gaussian form (3) from ref. [2] for the snap-back compensation and 5) use the logarithmic form

$$\Delta b_2 = b_{2,1} \cdot \log(\frac{t+t_s}{t_s}). \quad (1)$$

for the decay correction during the injection plateau defined in [2]. These proposals allowed a reduction in the number of parameters in the correction algorithms during injection and they increased the reproducibility between accelerator stores.

As a result of implementation of the proposal the Tevatron luminosity was increased by at least 3%. In details these proposals were discussed in the papers [2,3] presented at EPAC 2004.

This paper is a follow-up to previous publications [2,4] presented at PAC2003 and EPAC2004 conferences. The first part of the paper presents our measurements on the Tevatron dipoles with very short injection plateaus typically smaller than 30 s. In the second part of the paper results on the field decay in the Tevatron quadrupoles are also summarized.

SEXTUPOLE FIELD DECAY IN TEVATRON DIPOLES AFTER A SHORT INJECTION PORCH

The b_2 corrections were tested and optimized using beam based studies. A beam study was performed with a very short injection porch (~6s) to measure the chromaticity on the Tevatron ramp in a situation where the injection porch drift and snapback are minimal [5]. These measurements indicated a discrepancy on the level of 0.13-0.20 units (the field multipoles are reported at 25.4 mm reference radius) between the average Tevatron b_2 component and the correction algorithm described by equation (1) (see Fig.2 in ref. [5]). The discrepancy vanishes approximately after the first 60 second of the beginning of the injection plateau.

The 6s injection porch condition was not explored in the previous magnet test campaign, in which the shortest injection porch duration was set to 60s. A new systematic series of measurements with short duration injection porches (6, 12, 20 and 30s) were carried out. Furthermore, a ramp profile was executed which was as close as possible to the Tevatron beam study profile, where the discrepancy was observed (10 s flattop, 6 s back-porch and 6 injection porch). Four Tevatron dipoles (TB0834, TC0604, TC1130, TB1136) from the spares-pool were measured.

A typical b_2 hysteresis loop from the Tevatron beam-type study profile with 6s injection porch is shown in Fig. 1. A standard procedure, described in ref. [2,4], is used
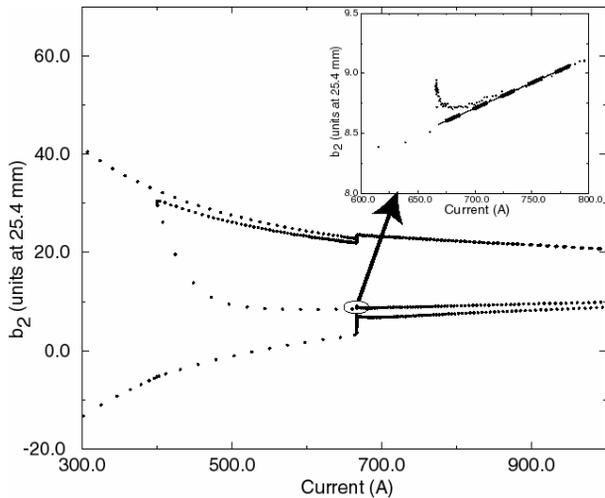
Figure 1: Typical b_2 hysteresis loop with short injection porch. The upper insert shows the snap-back after 6 s of injection porch and the line approximation of the loop in the snap-back's region

to decouple the decay and snapback from the underlying loop. In short, the b_2 values were linearly parametrized as a function of the current in the region of 0.7-0.78 kA, extrapolated to the injection plateau at 0.66 kA and subtracted from the sextupole loop at 0. 66 kA (the upper insert in Fig.1). An unexpected fast decay of approximately 0.2 units and accompanying snapback is observed. In general the logarithmic form (1) can be used to estimate the drift amplitude Δb_2 after 6s on the injection porch. For the time constant t_s=170s, determined from beam measurements with a flattop longer than 60 min and 5 min back-porch conditions, formula (1) predicts 0.017 units which is ~10 times smaller than the observed effect.

To achieve direct comparison with (1) we performed measurements with current profiles which corresponds to t_s=170 s and with a short duration of the injection porch (6, 12, 20 and 30 s). Fig. 2 shows the snapback curves for the magnet TC0604. Similar decay amplitudes and snapback times were obtained for magnet TB0834. The results are consistent with the observation a fast decay in first 6s with amplitude of approximately 0.2 units, alike to what was observed in the Tevatron beam measurements.

The third measured magnet, TC1130, showed a large deviation from the pattern. The decay and snapback for this magnet is presented in the insert of Fig. 2. One observes that the decay amplitude for this magnet is much larger, on the order of 1 unit. One hypothesis is that TC1130 was produced from a different cable batch than the other two magnets. A fourth magnet, TB1136 close in production time to TC1130, was examined. It performed like the first two magnets with decay amplitude of 0.25 units after first 6 s of the injection porch.

The decay processes were occurring for relatively short period of time, which initially pointed to a direction of a possible connection to the ramp eddy currents in these magnets. Two of the dipoles (TC0604 and TC1130) were extensively tested for eddy currents, measuring the hysteresis loop width dependence on different ramp rates.
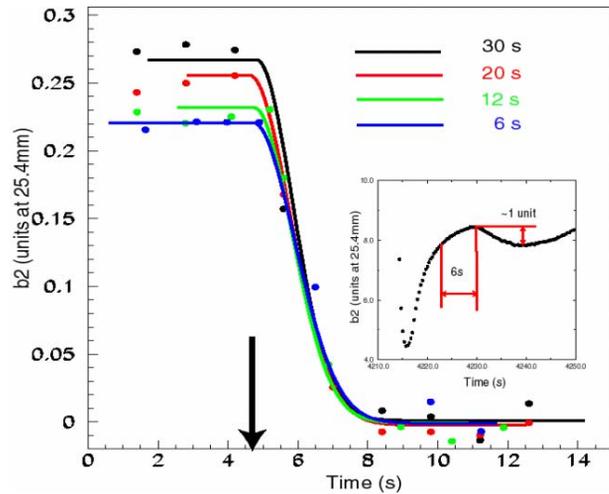
Figure 2: Snapback of the sextupole component in TC0604 for a plateau at injection of 6,12,20 and 30 s for 60 min flattop and 5 min back-porch. A fast decay of approximately 0.2 units is observed after first 6 s. The arrow shows the beginning of the snapback. The insert shows the decay and snapback for TC1130 in case of 6 s injection porch

It was found that a change in the current ramp rate from 10 to 80A/s resulted an increase of the b_2 hysteresis loop width by 0.1±0.05 units in TC0605 and by 3.6±0.06 in TC1130. The preliminary conclusion is that eddy currents can be considered a possible source for the observed fast decay in the magnets. Additional testing is needed to confirm or reject this hypothesis.

In case of the Tevatron operation at injection an additional constant value of b_2=0.13 units was adjusted to normal sextupole correction algorithm for the first 6s as described in [5].

FIELD DECAY AT INJECTION PORCH IN TEVATRON QUADRUPOLES

The results reported in ref. [2,4] and in the first part of this paper address the decay and snapback in Tevatron dipoles. The next major component of the Tevatron ring is the qudrupole magnets.

The Tevatron correction scheme includes magnetic corrector elements up to the octupole component of the fields. Therefore we have investigated decay and snapback in the main field, and possible dynamic effects in the sextupole and octupole components in Tevatron quadrupole magnets. In addition, to create a consistent picture, a result on dodecapole decay and snapback is also presented.

Four Tevatron qudrupoles from the spares pool, n9921f, tq214f, tq245f and tq103f were measured cold. All have the same coil design but differ in length: the tq-type is a standard 66 inches qudrupole magnet while n9921f has a length of 99 inches.

Fig.3 shows the result for the typical decay in the main quadrupole field for magnet n9921f after a 30 min injection porch. The average decay amplitude of
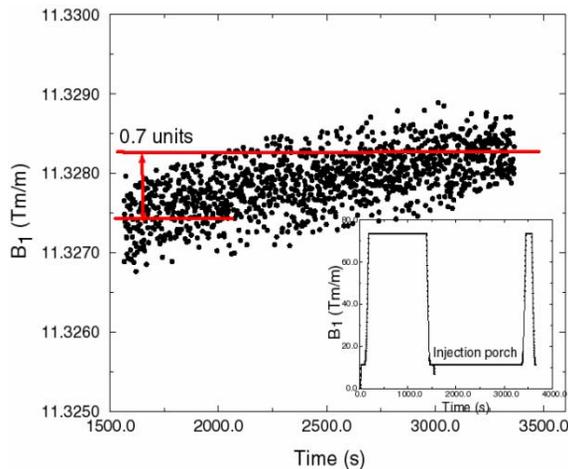
Figure 3: A main field for the Tevatron quadrupole N9921F after 30 min injection porch. The insert shows the main field dependence versus time for this measurement. A decay of 0.7 units was observed

Table 1: The decay amplitude in units for the quadrupole main field, normal sextupole and normal dodecapole for the four measured Tevatron quadrupoles after 20 min flattop, 1 min back-porch and 30 min injection porch.

Quad	Main Field (units)	b_2 (units)	b_5 (units)
n9921f	0.7±0.2	< 0.1	0.33±0.09
tq214f	0.9±0.3	0.21±0.07	0.31±0.08
tq245f	0.7±0.2	0.13±0.10	0.25±0.09
tq103f	0.4±0.2	<0.1	0.46±0.11
Average	0.67±0.1	~0.1±0.10	0.34±0.07

0.67±0.10 units (Table 1) is somewhat smaller than that observed in the dipoles which we found to be on the order of 1 unit (preliminary result). This may generate a deviation in the optimal ratio of the integrated quadrupole to dipole fields and be a source of tune drift instability in Tevatron operation.

Table 1 summarizes the decay amplitudes for the quadrupole main field, and the normal sextupole and normal dodecapole components. A small effect was found in the normal sextupole in tq214f, but the overall value is consistent with zero. Furthermore no evidence was found for the decay in the octopole field as it was expected.

The normal dodecapole shows an expected decay with average amplitude of 0.34±0.07 units (Table 1). The average snapback time, accordingly Eqn. (3) from ref. [2], was found to be 5.2±0.4 s. The result is consistent with the mean value of 5.1 s obtained from Tevatron dipoles [2].

For one of the quadrupoles, tq245f, a measurement with a 60 min flattop, 5 min of back-porch and short duration (~20 s) injection porch was executed. The analysis revealed small b_5 decay on the level of approximately 0.13 units. Additional testing is needed to create a consistent picture of possible fast decay in Tevatron quadrupoles.

CONCLUSION

For the first time a fast decay and accompanying snapback was observed in the sextupole field component in the Tevatron dipoles. The measurements showed that an average decay of 0.25 units occurs after the first 6 s of the injection porch. This decay is not described with the long-term parametrization (Eqn. 1) typically used for the b_2 operational corrections. Furthermore there is a hint that this fast decay may depend on the eddy current effect in the cable. The results from these measurements may be useful for the future operation of the LHC, where the

injection porch is expected to be relatively short and accurate dynamic corrections are critical to the beam stability.

The main field, b_2/a_2, b_3/a_3 and b_6 possible decay and snap-back effects at injection were studied on four Tevatron quadrupoles. No decay (consistent with zero decay amplitude) was found in the low order unallowed normal and skew harmonics. In addition, it was confirmed that the dynamic effects in quadrupoles are consistent with those observed in the Tevatron dipoles.

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