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MEASUREMENTS OF SEXTUPOLE DECAY AND SNAPBACK IN TEVATRON DIPOLE MAGNETS *

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Abstract

To help optimize the performance of the Fermilab Tevatron accelerator in Collider Run II, we have undertaken a systematic study of the drift and subsequent snapback of dipole magnet harmonics. The study has mostly focused on the dynamic behavior of the normal sextupole component, b_2, as measured on a sample of spare Tevatron dipoles at the Fermilab Magnet Test Facility. We measured the dependence of the decay amplitude and the snapback time on Tevatron ramp parameters and magnet operational history. A series of beam studies was also performed [1]. This paper summarizes the magnetic measurement results and concludes with proposals for an optimization of the b_2 correction scheme which is derived from these measurements.

1 INTRODUCTION

In the operation of modern superconducting accelerators, normal sextupole field errors from persistent currents play a significant role due to their large amplitude and time dependence. These effects, first observed in the Tevatron during injection plateau [2], were unacceptable for its operation and corresponding corrections were developed [3].

For the ongoing Run II, the Tevatron normal sextupole compensation during injection was obtained from magnetic measurements performed in 1996 [4] and, at the beginning of the run, it was optimized using beam based studies. However up to 10% beam losses at injection and at the beginning of acceleration which may be connected with problems of the correction algorithm are still observed in the Tevatron [1].

A systematic series of measurements for further optimization of the existing algorithm was carried out. In this paper we present new results from measurements of b_2 decay and snapback on Tevatron dipoles (TB1055, TB0834-remeasured, TB1198, TC0525, TC1052) as well as combined results with measurements previously reported in [5].

In our measurements we used current profiles, which are as close as possible to the real Tevatron operation cycles. The nominal current profile is shown in Fig. 1 (upper insert) or ref.[5]. Its parameters are: a 1 min front porch (FP), a 20 min flat-top (FT) at 4.3 kA (980 GeV beam energy), a 1 min back porch (BP) and a 30 min injection plateau (IP). Additionally, we varied the duration of FT (1, 10, 20 and 60 min, occasionally up to 720 min), of BP (typically 1, 10 and 30 min), of IP (30, 60 and 120 min), as well as number of the flat-tops (NF) (1, 2, 3 and 6) and the maximum flat-top current (3.5, 4.0 and 4.3 kA) (note however that the Run II Tevatron maximum current is held constant at 4.3 kA). Measurements also addressed magnet body-to-end comparison behavior under different current cycles, and b_2 variation inside the magnet body. Details on the readout system are reported elsewhere [5].

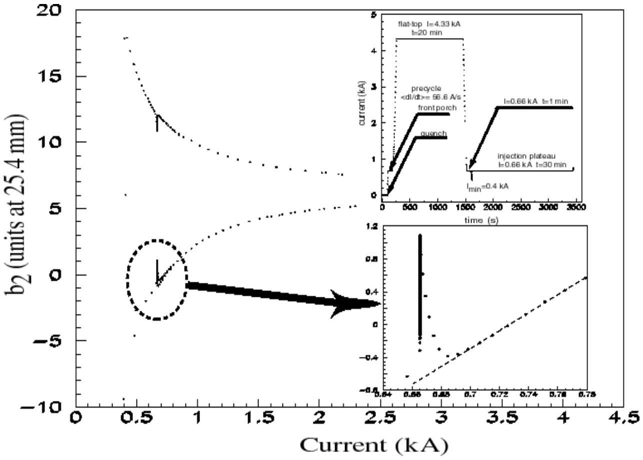

Figure 1: Typical b_2 hysteresis loop. The lower insert shows the snap-back and the line approximation of the loop in the snap-back's region The upper insert shows the current cycle for the standard measurements

2 FIELD DECAY AT INJECTION PORCH

The typical b_2 hysteresis loop from the nominal measurement is shown in Fig. 1. To decouple the decay and snapback from the underlying loop we linearly parametrized b_2 as a function of the current in the region of 0.7-0.78 kA, extrapolated its value to the injection plateau at 0.66 kA and subtracted it from the sextupole loop (see the lower insert in Fig.1).

In a previous paper [5] we exploited the logarithmic form

$$\Delta b_2 = b_{2,0} + b_{2,1} \cdot \log(t + t_s). \quad (1)$$

to model the decay amplitude where t=0 at the beginning of the injection plateau [6]. However the parameter $b_{2,0}$ has no meaning at t=0; thus we recently modified (1) to

$$\Delta b_2 = b'_{2,0} + b_{2,1} \cdot \log(\frac{t+t_s}{t_s}). \quad (2)$$

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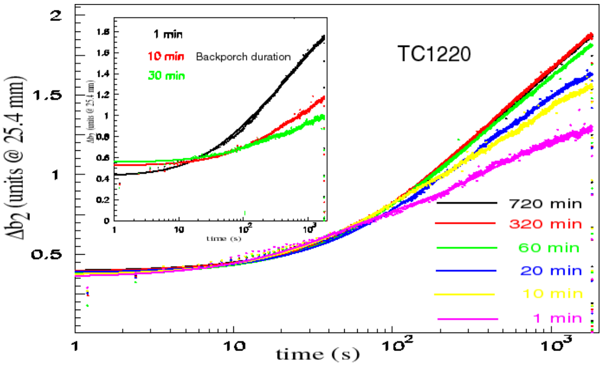

Figure 2: Decay of the sextupole component for a plateau at injection of 30 min and different duration of FT. For FT greater than 1h, the b_2 is independent of the flattop duration. The insert shows the decay for different BP duration

In form (2) after subtraction of the hysteresis loop $b'_{2,0}$ should be close to zero consistent with the expectation from our present understanding of the decay process. The small variation of $b'_{2,0}$ could be an effect of the field pattern averaged over the probe length.

Fig. 2 shows the b_2 decay curves for different FT for magnet TC1220. Similar curves for different BP are shown in the insert. When BP is varied from 1 to 5 min the decay amplitude is reduced by ~45%. The conclusion is that the BP duration gives the dominant contribution to the decay amplitude. A similar result was obtained from earlier measurements [4][5]. We note that in some cases a better parametrization at $t \leq 10$ s is achieved with "two exponential fit" as described in [7].

Fig.3 summarizes the parametrization of the $b_{2,1}$ and t_s as a function of the FT duration. A simple exponential form plus a constant was used to fit the slope and time offset defined in (2). The dotted curve represents the simultaneous fit to all magnet data. The conclusion is that $b_{2,1}$ (left) increases up to FT ~ 60 min and then flattens out. The time offset t_s shows hardly any dependence on FT, the earliest measurements of TB0834 being an exception.

A detailed measurement of the dependence of the decay amplitude on the number of flat-tops was performed. We repeated the first part of the cycle (FP=1,FT=20,BP=1 min) up to six times.

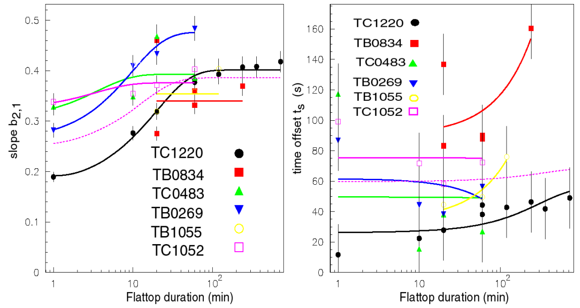

Figure 3: Slope $b_{2,1}$ (left) and time offset t_s (right) for different FT. The dotted line represents the simultaneous fit to all data.

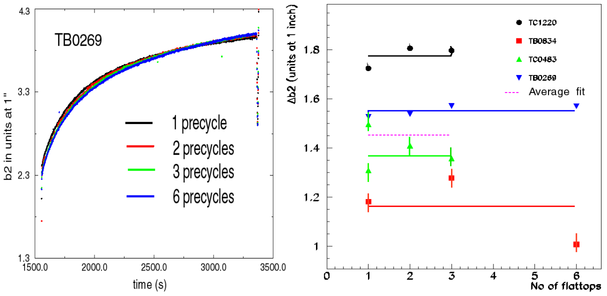

Figure 4: Left: sextupole decay for different NF. Right: decay amplitudes for the four measured Tevatron dipoles as a function of NF. The dotted line represents a constant fit to the data

The result for TB0269 is shown in Fig. 4 (left). Small shifts of the order of 0.08-0.12 units (presumably due to the field pattern) were applied to the decay curves in case of 2,3 and 6 flat-tops. These shifts were calculated from the corresponding hysteresis loops normalized to the region I=0.7-0.8kA. Fig. 4 (right) summarizes the decay amplitude vs number of flat-tops for the four measured magnets. For each magnet the data are fitted by a constant.

Several additional tests were performed to investigate the dependence of the decay amplitude on FP, longitudinal position, including body vs end, and magnet temperature. None of these factors had any significant effect on the normal sextupole decay.

3 MEASUREMENTS OF THE SNAPBACK

A parametrization for the snap-back amplitude

$$\Delta b_2^S = b_{2,0}^S \cdot \exp(-t^2/t_0^2), \qquad (3)$$

was introduced in [5] (see the reference for details) and describes our measurements with a high probability (note, $b^S_{2,0}$ can be estimated as a result of formula (2)).

Some of snap-back fits for different FT (left) and BP (right) are shown in Fig. 5. The time scale is set to zero when the acceleration ramp is started and the snap-back is initiated. One can observe that after 40-60 min of FT the snap-back become independent of the duration. This major conclusion is confirmed from a series of measurements performed on five Tevatron dipoles.

Fig. 6 (top) shows fits of $b^S_{2,0}$ and t_0 with the exponential form

$$b_{2,0}^S, t_0 = p_1 \cdot \exp(-t/p_2) + p_3 \qquad (4)$$

for different FT. The dashed line represents the average fit to the five measured magnets. This result is important for the optimization of the Tevatron operation. In fact one can propose removing the existing pre-cycle(s) after the end of a successful store and to start the injection directly after the store ends.

The snapback amplitude and time decrease exponentially with BP. This tendency is shown in Fig. 6 (bottom) where the $b^S_{2,0}$ and t_0 parametrizations with the exponential form plus a constant for different durations of BP are shown. One can see that the average values of $b^S_{2,0}$

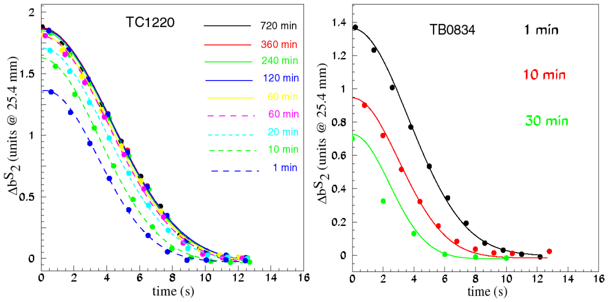

Figure 5: Snapback of the sextupole component for a plateau at injection of 30 min and different FT (left) or BP (right). The dashed lines (left) represent the snap-back for short flat-tops.

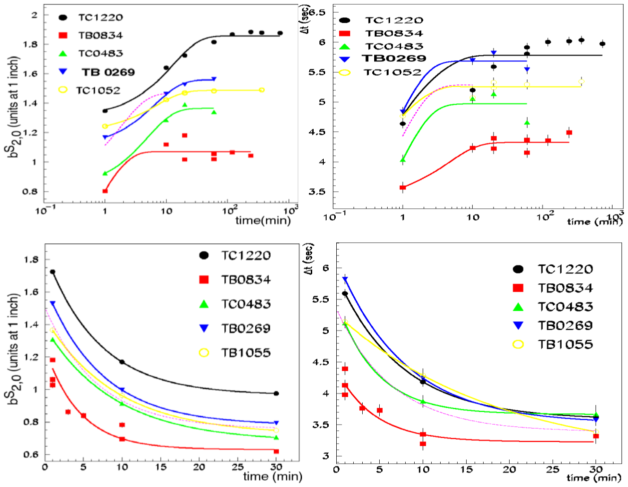

Figure 6: Snap-back amplitude and time parametrized with exponential plus a constant as a function of FT (up) and BP (down) duration time. The dashed line represents the average fit for the sample of five magnets.

and t_0 strongly depend on BP in the first 1 to 10 min. However $b^S_{2,0}$ and t_0 converge to ~0.8 units and ~3.5 s respectively at large values of BP. A possible proposal for an optimization of the Tevatron operation, which prefers short (3-10 min) BP, is to fix the length of the BP plateau. This will decrease the number of parameters accountable for the sextupole component decay and snapback compensation during injection.

Table 1 summarizes the fit output for the p_1-p_3 parameters, defined in (4), in cases of different FP, BP and NF. When we vary NF the data are fit to a constant. The errors are statistical only. The systematic uncertainties are estimated to be on the order of 12%. This estimation comes from the point-to-point variation of the repeated measurements with the same current cycles and magnet temperatures.

4 CONCLUSION

A detailed program of magnetic measurements on the Tevatron dipoles was performed. By this we have gained a clear understanding of which current cycle parameters determined the magnet history have a substantial effect on the dynamic processes of the normal sextupole component during injection and therefore on the machine operation. A large amount of information was analyzed and adequate parametrizations of the decay and snap-back were proposed.

Our result can be distilled into the following proposals for optimization of the Tevatron operation: remove the precycle(s) after the end of a successful store; use a constant duration for the back-porch; use one precycle only but increase its length to 40-45 min after a store is ended abnormally; adopt the gaussian form (3) for the snap-back compensation and use the logarithmic form (2) for the decay correction during the injection plateau. These proposals allow a reduction in the number of parameters in the correction algorithms during injection and increase the reproducibility between accelerator stores. The details of these proposals are discussed in a companion paper [1] presented at this conference.

Table 1: Results from the fits describing $b^S_{2,0}$ and t_0 with the exponential form plus a constant. The parameters represent the average fit from samples of at least four measured magnets.

Par	FT	BP	NF
Snap-back amplitude			
P_1	-0.52±0.11	0.75±0.09	0
P_2	6.40±0.52	6.90±0.23	0
P_3	1.46±0.18	0.75±0.10	1.5±0.2
Snap-back time			
P_1	-2.52±0.16	1.97±0.13	0
P_2	0.81±0.09	6.56±0.22	0
P_3	5.12±0.14	3.38±0.19	5.3±0.2

5 REFERENCES

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