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

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Abstract

The performance of Fermilab's Tevatron accelerator, currently in its Run II stage, is degraded by beam loss and emittance dilution during ramping from injection to collision energy. This could be related in part to insufficient compensation of dynamic effects such as the decay of the magnetic field in the dipoles during the dwell at injection and the following so-called snapback during the first few seconds of the energy ramp. The two effects are closely related and depend on the powering history of the magnets. Dynamic effects, which were originally discovered at the Tevatron [1], were investigated on Tevatron magnets in various past measurement campaigns in the 1980s and later in 1996 [2]. This paper reports on the most recent measurements performed on an additional set of Tevatron magnets.

1 INTRODUCTION

At injection energy the sextupole field errors from persistent currents can be significant due to their large amplitude and time dependence. It was found that their change during injection is unacceptable for the Tevatron operation and corresponding corrections were developed (for example see ref. [1][3]).

The Run II Tevatron corrections were obtained from 1996 magnetic measurements [2] and are later optimized using beam based measurements. However up to 10% beam losses at injection and at the beginning of the acceleration is still observed in the Tevatron.

A systematic series of measurements for an additional optimization of the existing correction algorithm was carried out. In this paper we present the first results from measurements of b_2 decay and snapback on four Tevatron dipoles (TC1220, TB0834, TC0483, TB0269) which have been extensively tested at the Fermilab Magnet Test Facility.

2 MAGNETIC MEASUREMENTS

2.1 Measurement system

Magnetic measurements were performed using a horizontal drive rotating coil system. A 1.8 m long drive shaft is used to transfer the rotation to the probe in the body of the magnet. The shaft and the probe are supported by bearings inside the warm bore.

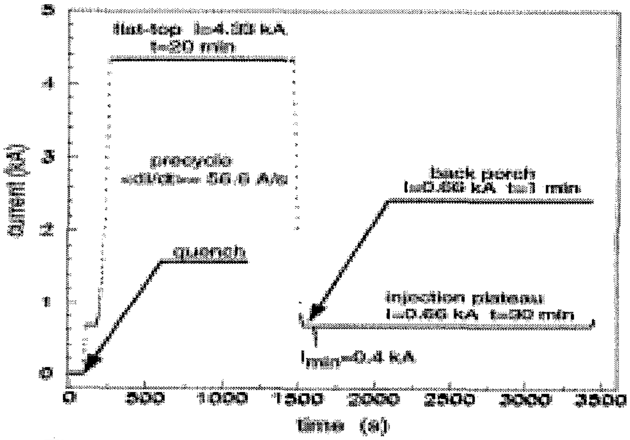

Figure 1: Current cycle for standard decay and snap-back measurements.

The probe in use, a 81.7 cm long coil with a 19.6 mm nominal radius, has a tangential winding for measurement of higher order harmonics as well as specific dipole and quadrupole windings for measurement of the lowest order components of the field.

The DAQ system is a slightly modified version of the setup being used for the LHC magnet measurements. Coil winding voltages are read out by Metrolab PDIs. The PDIs were configured first to read and store data in the internal buffers (active time) and next to transfer them to the VME computer (passive time). This regime was selected for its long term reliability independently of the low duty factor of 50%. More details on the readout system are reported elsewhere [4].

To achieve good sensitivity on the rapidly changing dynamic effects in the magnets, like a snap-back which typically occurs within an interval of 5-10 s in the case of the Tevatron, the shaft rotational speed was set to 5 Hz. To decrease the effect of the mechanical vibration and to increase the signal to noise ratio we used an analog bucking technique providing a cancellation of the main dipole field term with a simple addition of signals from the tangential and dipole coils.

2.2 Current cycle

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. Its parameters are: a 20 min. flat-top (FT) at 4.3 kA (980 GeV beam energy), a 1 min. back porch (BP) duration and a 30 min. injection plateau (IP). Additionally we varied the duration of FT (1,10, 20 and 60 min., in some cases up to 12h), the duration of the BP (1,10 and 30 min.), the duration of IP (30, 60 and 120 min.), as well as number of the flattops (NF) (1,2,3 and 6) and the

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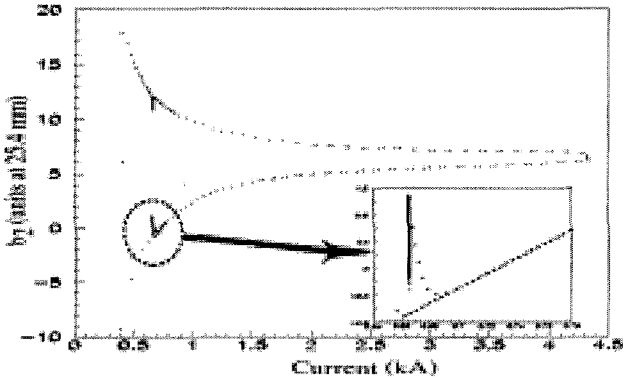

Figure 2: Hysteresis loop of the sextupole component. The insert shows the snap-back and the line approximation of the loop at the snap-back's region

maximum flat-top current (3.5, 4.0 and 4.3 kA). The variation of the last parameter has no direct impact on Run II Tevatron operation since the maximum current is held constant at 4.3 kA

3 FIELD DECAY AT INJECTION PORCH

The typical b_2 hysteresis loop from the nominal measurement is shown in Fig. 2. In the Tevatron operational scheme its sextupole correctors have to be controlled in such a way that they compensate for decay and snap-back of the b_2 harmonic at injection time. Therefore we need to extract only the effect of the dynamic processes. To subtract the underling sextupole loop underling we linearly parametrized b_2 as a function of the current in the region of 0.7-0.78 kA and extrapolated its value to the injection plateau at 0.66 kA (see the insert in fig.2).

Two different functional forms have been used in the past to model decay processes in superconducting accelerator magnets. The behavior of Tevatron and HERA magnets could be modeled as a logarithmic decay [3],[5]

$$\Delta b_2 = b_{2,0} + b_{2,1} \cdot \log(t / t_0). \tag{1}$$

The behavior of RHIC magnets was parametrized by two superimposed exponentially decaying terms [6]

$$\Delta b_2 = b_{2,0} + b_{2,1} \cdot e^{-t/t_1} + b_{2,2} \cdot e^{-t/t_2}. \tag{2}$$

In our case we used a logarithmic function to parametrize the b_2 decay. Fig. 3 shows the b_2 decay for different durations of FT. It was found that t_0 is close to 1 s as in the HERA magnets thus $t_0 = 1$ s was fixed in out fits. To describe the interval below 100 s we slightly modify the logarithmic form (1) adding a time offset parameter t_s

$$\Delta b_2 = b_{2,0} + b_{2,1} \cdot \log(t + t_s). \tag{3}$$

The parameters $b_{2,0}$, $b_{2,1}$ and t_s were fitted with different functional forms, either polynomial or exponential or superposition of both, depending on the duration of IP, BP and FT. These one dimensional functions are the first step towards a new multiparameter correction form for the Tevatron b_2 correction at injection.

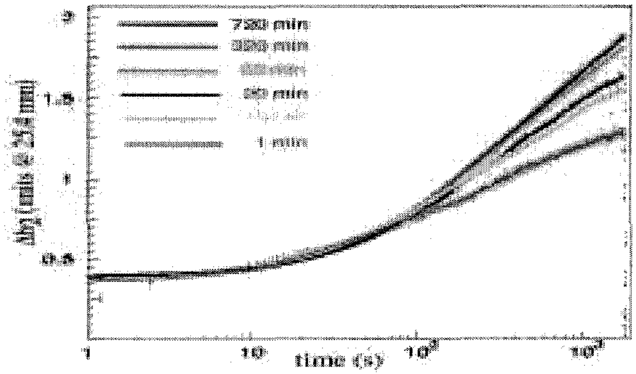

Figure 3: Decay of the sextupole component for a plateau at injection of 30 min. and different duration of the flat-top. After one hour duration of flat-top, the b_2 decay shows similar behavior

We also tried to model the b_2 decay with a double exponential form according to (2). In two of the four measured magnets the fit returned a very large time constant of order of 10^6. In the other two magnets the double exponential form (2) performed slightly better than (3). The attempt to find the best parametrization for the decay part was not conclusive and will be continued in the future experiments. In addition we are trying to understand if there is a reason for the different parametrization behavior (for example, different cable characteristics).

4 MEASUREMENTS OF THE SNAPBACK

At the Tevatron the snap-back compensation is done according to

$$\Delta b_2 = b_{2,0} \cdot (1 - t^2 / t_0^2)^2, \tag{4}$$

where $b_{2,0}$ is the initial amplitude and t_0 is the snap-back time [2]. Although the polynomial form (4) was found in general to work for snap-back compensation, we determined that a gaussian form

$$\Delta b_2 = b_{2,0} \cdot \exp(-t^2 / t_0^2), \tag{5}$$

describes our measurements with a high probability (χ^2/ndf ~1). Some of the snap-back fits are shown in Fig. 3. The time scale is set to zero when the acceleration ramp is started and the snap-back is initiated. Note that t_0 has a different meaning in formulae (4) and (5): in the first case it is the value where the functional form is zeroed, in the second case, it is the standard width of the gaussian distribution.

We parametrized the snap-back amplitude $b_{2,0}$ and time t_0 as a function of the duration of the current cycle intervals (IP, BP, FT). An exponential dependence according to

$$b_{2,0}, t_0 = p_1 \cdot \exp(-t / p_2) + p_3 \tag{6}$$

where t is the duration in minutes of the varied cycle interval is proposed. Fig.4 shows a parametrization of $b_{2,0}$ and t_0 for different duration of the flat-top. The dashed line represents the average fit to the four measured

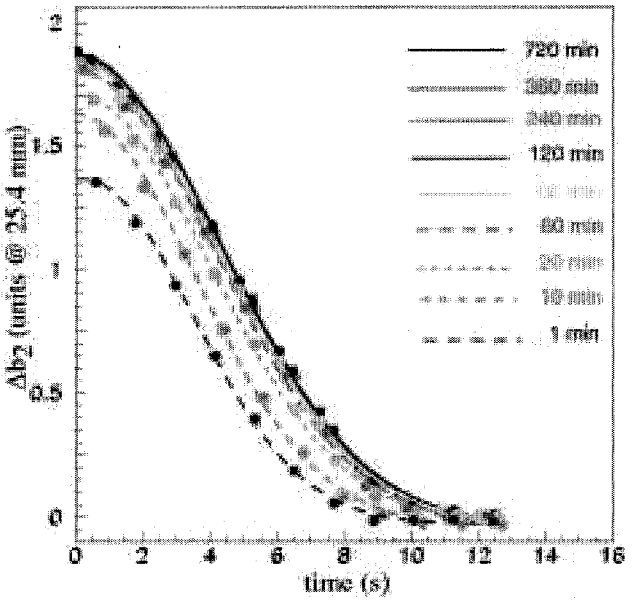

Figure 3: Snapback of the sextupole component for a plateau at injection of 30 min. and different duration of the flat-top. The dashed lines represent the snap-back for short flat-top durations.

magnets.

Table 1 summarizes the fit output for the p_1-p_3 parameters. When we vary NF the data are fit to a constant. This is because the fit returns a negligible slope in case of linear approximation. In addition one can observe that after 60 min. of FT the snap-back amplitude and time are practically independent of its duration (see fig. 3 and fig 4).

These two results are important for the optimization of the Tevatron operation. In fact one can propose to remove the precycle after the end of a successful store and to start the injection directly after ending a collision. On the other hand if the store is ended abnormally, for example by a quench, data suggest that the number of precycles may be reduced from 6 to 3 or either 2.

The effect of the BP duration shows opposite tendency comparing to the FT duration. The snap-back amplitude and time decrease exponentially with the BP duration and converge to Δb_2=0.8 units and t_0=3.54 s at large values of the BP durations (Table 1, BP column).

Table 1: Results from the fits describing $b_{2,0}$ and t_0 with the exponential form (6). The parameters represent the average fit from the sample of four measured magnets.

Par	IP	BP	FT	NF
Snap-back amplitude				
P_1	-0.7±0.1	0.78±0.1	-0.5±0.1	0
P_2	52.±5.1	7.1±0.5	7.9±0.2	0
P_3	2.0±0.2	0.8±0.1	0.2±0.1	1.5±0.2
Snap-back time				
P_1	-1.1±0.2	2.1±0.1	-2.6±0.6	0
P_2	66.±28.	5.91±0.7	0.9±0.2	0
P_3	6.4±0.1	3.54±0.1	5.2±0.1	5.3±0.2

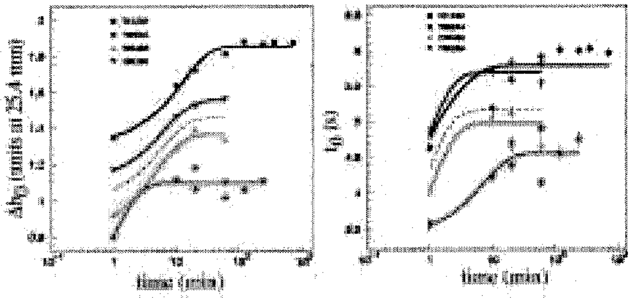

Figure 4: The snap-back amplitude and time parametrized with (6) as a function of the flat-top duration time. The dashed line represents the average fit for the sample of four magnets.

6 CONCLUSIONS AND PLANS

The sextupole decay and snap-back effects at Tevatron injection ware studied on four Tevatron dipoles. It was confirmed that the durations of IP, BP and FT have a major impact on the b_2 decay amplitude and snap-back time. Other possible variations of the current cycle, like the number of flattops and the maximum flat-top current were found to have small or no impact on the dynamic processes at injection.

A new type of the snap-back parametrization was proposed. Is was found that gaussian distribution, instead of polynomial form (4), fits better the magnet data.

The data shows that b_2 decay amplitude and the snap-back time reach saturation after 60 min. FT. This result supports the proposal of removing the precycle after the end of successful stores.

A set of functions describing the sextupole decay and snap-back are obtained. These functions are the first step towards a new multidimensional correction form for the Tevatron operation at injection.

We are planning to extend the measurements to more dipoles and to refine them in order to develop a detailed set of measurements in the relevant parameter space for Tevatron operation.

6 REFERENCES

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