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PULSED CORRECTORS FOR THE BEAM VERTICAL STABILITY DURING INJECTION IN CESR*

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Abstract

Beam motion during injections could be a serious problem to x-ray users and jeopardize their experiments. In the Cornell Electron Storage Ring (CESR) the particles are injected with pulsed elements such as pulsed bumpers and septum which cause transient motion of the stored beam. By analyzing the turn-by-turn position data of the stored beam acquired during injection, we identify the source of beam motion in different time scales. A new corrector coil is then designed to compensate the beam motion with 0.15 msec duration pulse at a 60 Hz repetition rate in the vertical plane. In addition to the new corrector we also use existing magnet coils to correct 60 Hz kicks and DC offsets. Although, during the last summer maintenance period the 60 Hz source was identified and suppressed by an order of magnitude, this corrector is still in use to minimize the injection transient. The waveforms, used to drive the correctors, are determined based on the beam turn-by-turn coordinates and orbit kick analyses using the 110 CESR Beam Position Monitors data. In this paper we discuss the requirements and parameters of the new corrector, as well as the correction technique, which is proven to be effective.

INTRODUCTION

Cornell Electron Storage Ring (CESR) [1] originally was built as an electron-positron collider operating at a center-of-mass energy in the range of 3.5-12 GeV. Currently CESR operates as a high-intensity, high-energy light source, namely Cornell High Energy Synchrotron Source (CHESS).

The stability requirements, for positron beams in the vertical plane are that the centroid position drifts less than 3 µm over all time scales, and the beam trajectory simultaneously varies by less than 1 µrad; in the horizontal direction the requirements are 60 µm and 5 µrad. These are defined by the 10% stability requirement standard used at many light sources.

The positron beam is accelerated in the Synchrotron up to 6 GeV and injected into the CESR ring through a transfer line with the typical repetition rate of 60 Hz.

During the injection in CESR the beam motion is significantly larger, which has different sources particularly pulsed bumps, and a pulsed septum, designed for matching the CESR orbit with incoming (from Synchrotron) beam trajectory. One of the challenges is to have stable conditions during the injection.

The corrector, discussed in this paper is designed to address the vertical instability during the injection coming from the pulsed septum. We'll discuss the beam turn by turn data analysis results, the requirements to the corrector, its design, and the final correction results.

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INJECTION BEAM DATA ANALYSIS AND THE CORRECTOR REQUIREMENTS

Locating a Vertical Instability Source During CESR Injection:

For the beam coordinate measurements CESR Beam Position Monitors (BPM) [2] are used. The CESR ring is equipped with 110 BPMs, their four-electrode design allows measurements of both the horizontal and vertical coordinates with 10 µm single-turn precision. The BPM system data acquisition (DAQ) allows accumulation of data for up to 300k turns from each BPM. However, for the injection kick analysis typically 16k turns are recorded, which cover injection 2 full cycles - one 60 Hz cycle corresponds to 6507 turns, since CESR revolution frequency is 390.14 kHz.

To analyze the orbits and locate the vertical beam instability sources, BPM turn-by-turn (TBT) data are recorded with different conditions. The instability was observed with beam data, when the pulsed septum (only) is triggered. Thus the subsystem causing the instability is identified. However, to confirm the kick location, as well as obtain the kick angle as a function of turn number (actually time) for the further corrections, vertical orbit kick analysis is performed.

The orbit distortion due to localized kicks can be described by the following formula [3]

$$f(s) = \sum_{i=1}^{N} \theta_i \frac{\sqrt{\beta(s)\beta(s_i)}}{2sin(\pi Q)} cos(|\phi(s) - \phi(s_i)| - \pi Q), \quad (1)$$

where $f(s)$ is the closed orbit function for N kicks, i is the index of kicks, θ_i is the beam deflection angle by the i-th kick, $\beta(s)$ and $\beta(s_i)$ are the ring lattice beta functions at location s and at the kick location s_i, the CESR betatron tunes are 16.556 and 12.636 for horizontal and vertical planes respectively, $\phi(s)$ and $\phi(s_i)$ are the lattice betatron phase advances at locations s and at the location of the kicker s_i.

The ROOT data analysis framework [4] and the Minuit minimization package [5] are used for the analysis. The analysis technique is described in details in [6] and [3].

The orbit fits show (see Figure 1) that the vertical beam instability, due to the pulsed septum, consists of a vertical pulse-kick (from septum itself), and a 60Hz unipolar AC kick (from a nearby equipment). The 60 Hz noise was first cancelled (Figure 1, red line) by generating an opposite kicks using a corrector located about 1.5 m downstream, where the twiss parameters are not significantly different.

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Later the equipment making the 60 Hz noise was identified and relocated so that the noise is suppressed by an order of magnitude. However, the remaining fast kick pulse could not be cancelled using the same corrector.

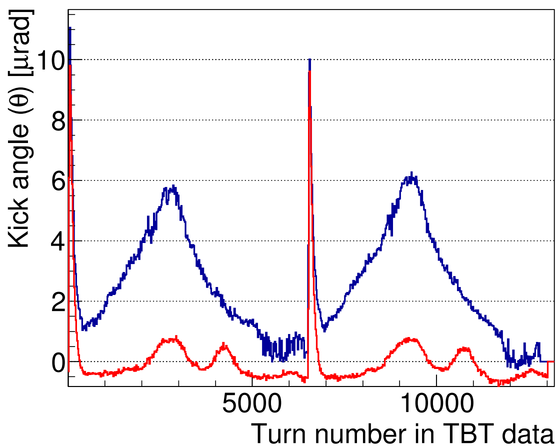

Figure 1: The figure shows the kick angle dependence (coming from the pulsed septum location) as a function of turn number. The blue line corresponds to noise including fast pulse and 60Hz unipolar kicks, while the red distribution corresponds to data recorded after 60Hz noise is addressed. The pulse amplitude depends on CESR orbit, twiss parameters, and the septum HV. The pulse width RMS is 55.5 (±5.1) turns. The interval between two pulses is 6507 turns, one cycle of 60 Hz.

Requirements to the Corrector for the Pulse-kick, and its Design:

Figure 1 shows that the maximum pulse-kick angle is about 10 μrad at the pulsed septum location. The peak value mostly depends on the CESR orbit, the pulsed septum high voltage, and the twiss parameters. Analyzing orbits from standard CESR operations yields a peak that varies from 6 to 10 μrad. For 6 GeV positron beam, 10 μrad kick angle corresponds to 200 Gs·cm magnetic field integral. 10 μrad pulse peak is the typical maximum we observe with the TBT beam data analysis; this is one of the key requirements to the corrector. Another requirement is the pulse width - the corrector must be fast enough to provide the kick pulse with RMS of 60 turns, or 150 μsec. Due to the limited space in the CESR ring around the pulsed septum, the corrector is installed more downstream, at a location with exactly 3π vertical phase advance difference, where the beta function is a factor of 4 lower compared to the pulsed septum location. This difference doubles the pulsed corrector field integral requirement (to 400 Gs·cm).

The Opera3D [7] magnetic field simulation package is used to model the potential options for the pulsed corrector. Air- and steel-cored models were considered. However, to keep the corrector coil production and its installation procedure simple, air-cored coils were chosen.

With 8 turns per coil, the model parameters (magnetic field, current, inductance) meet the requirements. The model image of the coils is shown in the top graph of Figure 2. The bottom graph in Figure 2 shows the horizontal field profile for 100 Amp·turns total current. The horizontal magnetic field integral is calculated 445 Gs·cm. Worth mentioning that 100 Amp·turns current is not the limit(the actual coils are tested for up to 120 Amp·turns current). After testing a prototype, the model calculations are confirmed, and the coils are installed in the CESR ring.

As a fast power supply, an audio amplifier-like board is used, which provides AC wave-forms only. The board gets its input voltage from a wave-form generator, and the generator's input is defined in a text file by the data analysis codes (once only).

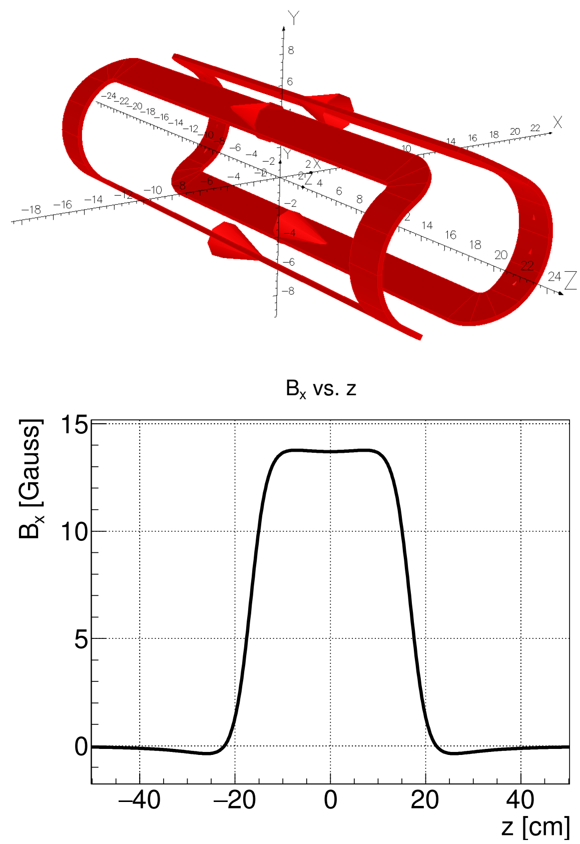

Figure 2: (top) Air-cored pulsed corrector coil geometry. The arrows show the current direction. (bottom) Horizontal magnetic field profile at 100Amp·turns total current, the field integral is 445 Gs·cm.

The Corrector Performance, and the Results:

TBT beam data with the powered coils are recorded and analyzed to check the performance of the corrector coils. Figure 3 shows the pulsed corrector kick angle as a function of turn number. The input wave is tuned and timed-in for cancellation of the septum vertical pulse. The first pass of the corrections are obtained and applied based on TBT kick angle fits, then a fine tuning is applied based on the vertical

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coordinates TBT distributions from BPMs located upstream of the insertion device (ID) straight sections.

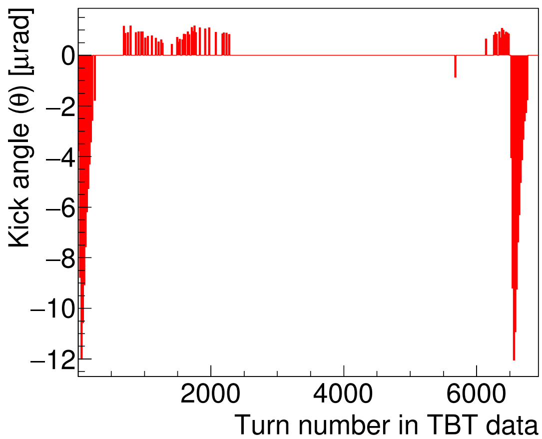

Figure 3: The figure shows the kick angle, coming from pulsed corrector location, vs turn number. Data are recorded with the pulsed corrector turned on. The kick pulse standard deviation corresponds to about 58.0 (±4.7) turns. 6507 turns interval between two kick pulses corresponds to one injection cycle with 60 Hz repetition rate.

Figure 4 shows the beam TBT vertical coordinates as a function of turn number. The blue line corresponds to the TBT position data recorded with the pulsed septum only triggered without correctors, the green line is from TBT data with both the septum and corrections triggered, and the red line corresponds to data with the 60 Hz cancellation only, before relocating the 60 Hz noise source away from the beam. The overall vertical coordinate RMS went down from 10.4 µm to 2.0 µm. However, one can see that the pulse is not completely cancelled, the remaining "spike" is due to the limited time resolution of the waveform generator, which is 33 µsec for 60 Hz frequency waves.

After a successful implementation of such a setup, another similar amplifier board was designed and built with an additional feature - to amplify not only AC signals, but also DC offsets. Currently this board replaces the power supply of the corrector that previously was used for the 60Hz cancellation.

CONCLUSION

For the injection beam vertical stability, TBT data analysis is performed and the vertical orbit kick sources are located. The noise consists of unipolar sinusoidal 60 Hz and a fast pulse with RMS about 60 turn. The correction requirements are estimated, and correction coils, and its power components are designed, build, tested, and installed on the CESR ring. This corrector is operating for 12-20 µrad kicks cancellation with the pulse width of about 60 turns, or 150 µsec.

The 60Hz AC noise is cancelled first using similar coils existed before and installed right downstream the pulsed septum, and then the noise source was moved far from the CESR beam. Currently this corrector is also equipped with a fast performing power source, and cancels the remaining 60 Hz unipolar noise which is suppressed by a factor of 10. In the near future we plan to apply the corrections using this one only, since it is close to the kick location and does not depend on CESR beam optics degradation during weeks of operations.

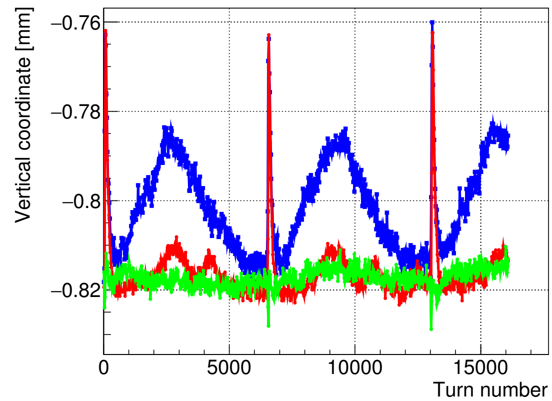

Figure 4: Beam position TBT coordinates as a function of turn number (blue) before and (green) after cancellation of the noise coming from the pulsed septum. Red line represents the data with 60 Hz cancellation using the old setup, before upgrading to the faster setup. The coordinate RMS values are 10.4 µm, 7.1 µm and 2.0 µm for blue, red and green graphs respectively.

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