TOP-OFF MODE OF OPERATIONS: SETTING LIMITS ON THE EXTRACTED BEAM ENERGY BY CONSTRAINING CURRENTS OF MULTIPLE BOOSTER DIPOLE POWER SUPPLIES

T. Shaftan*, BNL, Upton, Long Island, New York, U.S.A.

Abstract

In preparation for the top-off mode of the NSLS-II operations we have studied impact of errors in the dipole power supply current on the extracted beam energy, which has to be interlocked so to satisfy the safety requirements. The NSLS-II booster dipole power supplies are combined into 3 independent PS circuits, which adds complexity in setting the limits of the extracted beam energy.

INTRODUCTION

During top-off mode of injection user beamline shutters are open and there is a risk of the injected beam propagating along the user beamlines and causing hazardous radiation dose in the occupied areas on the facility experimental floor. To mitigate this risk a number of interlocks are to be established that constrain accelerator power supply (PS) currents and exclude the possibility of any beam trajectory to end up outside of the accelerator enclosure under various fault conditions of the storage ring and injector magnets or their PS. Extensive tracking studies took place at NSLS-II to establish guidelines in setting interlocks on the machine parameters and PS currents [1].

One of the critical beam parameters that require interlock is the injected beam energy. The standard approach in constraining the beam energy in modern light sources is in setting limits on the booster dipole current PS. This constraint, together with the requirement of the RF frequency be constant, warrants that the beam energy will stay within the desired window during the beam extraction from the booster prior to injection into the storage ring.

This constraint is straightforward in the case of a single PS feeding all of the dipoles in the machine. To reduce requirements on the dipole PS power we divided all sixty combined-function dipole of two types in the NSLS-II booster synchrotron [2] into three independent PS circuits. In this case the relation between PS current windows in multiple PS feeding several dipole families and the beam energy at extraction requires an analysis. What are the PS current windows on different PS to ensure a given window of the electron beam energy at extraction? Do we have to interlock all PS currents or can we constrain only few of them? This paper presents a study of the problems above in the context of the NSLS-II booster.

ESTIMATES AND BOOSTER PARAMETERS

Here we consider a booster synchrotron at the extraction energy. We write an expression for the change in the orbit circumference induced by dipole field errors:

$$\Delta C = \frac{1}{B\rho}\oint D_x \Delta B_{err}\, ds, \quad (1)$$

where D_x is the dispersion and ΔB_{err} is the dipole field error as functions of the coordinate along the machine.
Under the condition that the RF frequency is constant the change in circumference above corresponds to the following change in the beam energy:

$$\frac{\Delta p}{p} = -\frac{1}{\alpha}\frac{\Delta C}{C}, \quad (2)$$

where α is the momentum compaction.
Substituting (1) into (2) we get the energy change as:

$$\frac{\Delta p}{p} \approx -\frac{1}{\alpha \cdot C \cdot B\rho}\sum_i \Delta B^i_{err} \int_{dipoles_i} D_x\, ds, \quad (3)$$

where the sum goes over *i* dipole families. We note that in the combined-function magnet lattice the power supply error induces changes not only in the dipole but in quadrupole and sextupole components of the magnet field. Dispersion and the momentum compaction change depending on the magnitude of the field error.

In the following table we list the essential NSLS-II booster parameters.

Table 1: NSLS-II Booster Parameters

Parameter	Unit	Value
Extraction energy	GeV	3
Circumference	m	158.4
Momentum compaction		8.8E-3
RF frequency	MHz	499.68
RF acceptance	%	0.65

Sixty booster dipoles are split into three dipole PS circuits: one PS (200V, 860A max) feeds 28 BF focusing dipoles and each of the other two PS (730V, 740A max) feeds 16 BD defocusing dipoles located in two opposite halves of the machine.

*shaftan@bnl.gov

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PARTICLE TRACKING AND COMPARISON WITH ESTIMATES

We set-up a booster model in Elegant [3]. In the model we assumed a systematic field error in a single family of dipoles. We tracked a particle scanning the energy range of ±2% and repeating these scans for the range of the relative field error within ±3%. The following plot shows relative change in the particle's energy for a given magnet family field error.

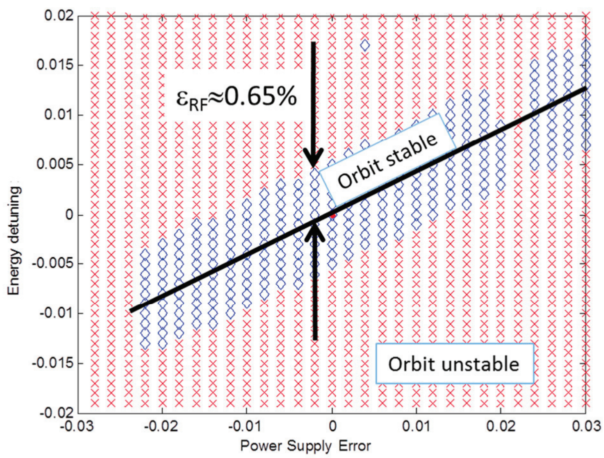

Figure 1: Particle energy deviation in relation to systematic field error in a magnet family.

Black line on the Fig. 1 above corresponds to the energy deviation given by the expression (3). In this calculation we were taking into account actual momentum compaction and dispersion for the lattice at any given value of the field error.

Red crosses show regions where the particle is outside of the machine energy acceptance; therefore it does not survive through the tracking. The width of the blue "stable" region matches the booster energy acceptance at extraction.

This calculation established confidence in the adopted booster model. The next step is to assume different combinations of the field errors in all three dipole families and calculate the corresponding energy deviation.

RESULTS FOR FIELD ERRORS IN ALL DIPOLE FAMILIES

Next we set-up tracking scans for the booster lattice with different amounts of relative field errors in all three dipole families. We track particles with energy deviation within ±3% window, imposing "interlock" of ±1% on BF and BD1 circuits for a certain fixed error in the BD2 circuit. Then we repeated these scans for ten different values of BD2 error thus covering the whole range of ±1% for all 3 circuits. A subset of the results of this tracking is shown in Fig. 2.

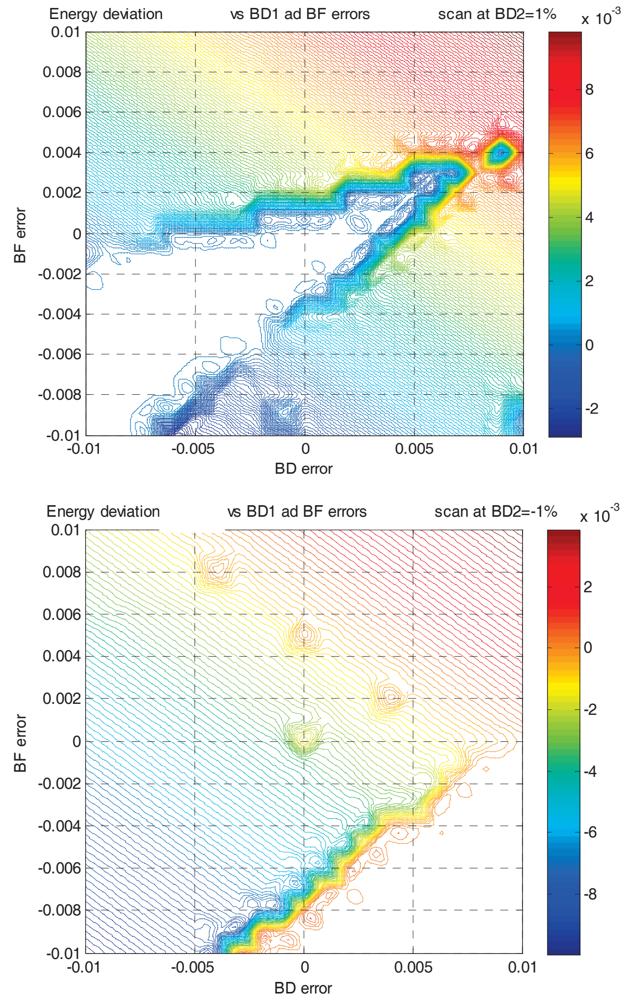

Figure 2: Plots of energy deviation (colour bar on the right) for any combination of errors in BF and BD1 circuits. Upper plot corresponds to the error of +1% in BD2 current, lower plot is for -1% in the BD2 current.

White regions in the plots above show that there exist no stable orbits or focusing solutions for the given set of errors in all three circuits. Red and blue colours mark positive and negative energy deviation with respect to the situation without errors at all.

For these two examples of +1% and -1% current windows in all three magnet circuits the energy deviation is constrained within 0.8% and 1% windows correspondingly.

We carried out similar scans with only two PS circuits "interlocked" within ±1% of the relative field error and found that the energy deviation may exceed required 1% window.

CONCLUDING REMARKS

As a part of the ongoing safety tracking studies we carried out calculations of interlock limits on the booster dipole PS. The NSLS-II booster lattice includes two different families of combined-function dipoles fed by three different power supplies. We conclude that all three

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PS currents must be interlocked to ±1% of the value at extraction so to fulfil the requirement of the extracted beam energy staying within ±1%. Interlocking only two out of three PS, even in expense of tighter interlock limits, still dos not disable beam energy deviations outside of the required window.

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