Compensating for injection slewing with Booster corrector magnets in the Project X era

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Abstract

It has been proposed to inject a 1 GeV ion beam into the existing Fermilab Booster as a first step toward Fermilab Project X. Because such a beam would have a lower current than the existing linac, the slewing of the magnetic fields in the Booster magnets over the required injection time becomes an issue, and it's been suggested that we could compensate for this with the new Booster corrector system. We show that the corrector system should comfortably be able to compensate for the change in the total integrated field, but that slew rate limitations set a minimum injection current of 2.2 mA, in order to have the capacity to load 10^{13} protons into the Booster.

1 Introduction

The Fermilab Booster is a rapid cycling synchrotron, which cycles between the minimum and maximum energy in a 15 Hz offset sine wave. While the extrema this sine wave may be changed, there is currently no way to change the shape. In particular, there is no way to create an injection or extraction flat top with the existing combined function lattice magnets. Thus, the integrated field changes during the injection, as illustrated in Fig. 1.

This is not a problem for the present linac, which has a high enough current to fill the Booster in less than 30 μsec. On the other hand, the proposed 1 GeV linac for project X will only have about a 1 mA maximum current, so it will take on the order of 1 msec to fill the Booster, and on that time scale, the integrated field will change on the order of 1% - well outside the momentum acceptance of the Booster.

One solution would be to vary the energy of the linac to track the changing effective injection energy of the Booster, but this is a significant design complication. Alternatively, it has been suggested that we can use the new Booster corrector system to compensate for the increasing B field.

2 Required field strength

Tab. 1 shows the parameters of the Booster during the Project X era, where integrated field is calculated using

$$\oint B\dot{d}l = 2\pi \frac{p}{e} \tag{1}$$

We can then express the time dependence of the integrated field near the minimum as

$$\Delta(BL) \equiv (BL) - (BL)_{\rm min} = \frac{1}{2}\left((BL)_{\rm max} - (BL)_{\rm min}\right)(1 - \cos 2\pi f t) \tag{2}$$

and the slew rate as

$$\frac{\Delta(BL)}{dt} = \pi f \left((BL)_{\rm max} - (BL)_{\rm min}\right) \sin 2\pi f t \tag{3}$$

It is this time dependence which must be compensated with the new correctors. Fig. 2 shows the integrated dipole field and slew rate *per corrector*. These can be compared to the Booster corrector system specifications and parameters [1], as summarized in Table 2. In the case of the total integrated field, we can assume that the lattice magnets will be set to the middle of the range and we will operated the correctors in a bipolar manner. The effective limit would then be twice what is in the table. We of course assume that the injection window is symmetric about the field minimum.

We see that in terms of total dipole field, we should be alright for injections of 2 or even 3 ms, provided no large closed orbit corrections are required at injection. The limit comes from the slew rate. If we take 5 T-m/s as the working limit with the existing system, we have a window of ± 287 μsec, for a total injection time of 718 μsec. If we want to have the capacity to inject up to 10^{13} protons, this sets a minimum average current of 2.2 mA.

References

[1] E.Prebys, J.Lackey, D.Harding, and C.Drennan, "Specification for the Booster Corrector Magnets and Power Supplies", FNAL-BEAMS-DOC-1881, http://beamdocs.fnal.gov/ (2006)

[2] W.Pellico, *private communication*

Table 1: Booster parameters in Project X era

Parameter	Symbol	Value
Kinetic Energy at Injection	$K_{\min}$	1.0 GeV
Kinetic Energy at Extraction	$K_{\max}$	8.0 GeV
Momentum at Injection	$p_{\min}$	1.69 GeV/c
Momentum at Extraction	$p_{\max}$	8.89 GeV/c
$\oint B\dot{d}l$ at Injection	$(BL)_{\min}$	35.5 T-m
$\oint B\dot{d}l$ at Extraction	$(BL)_{\max}$	186.1 T-m
Frequency	f	15 Hz

Table 2: Corrector dipole specification and relevant parameters

Parameter	Value	Comment
Max. Dipole Field	.015 T-m	
Transfer Function	2710 A/T-m	measured value
Inductance	13 mH	measured value
Bulk Supply Limit	200 V [2]	
Maximum slew rate	5.7 T-m/s	calculated from above parameters

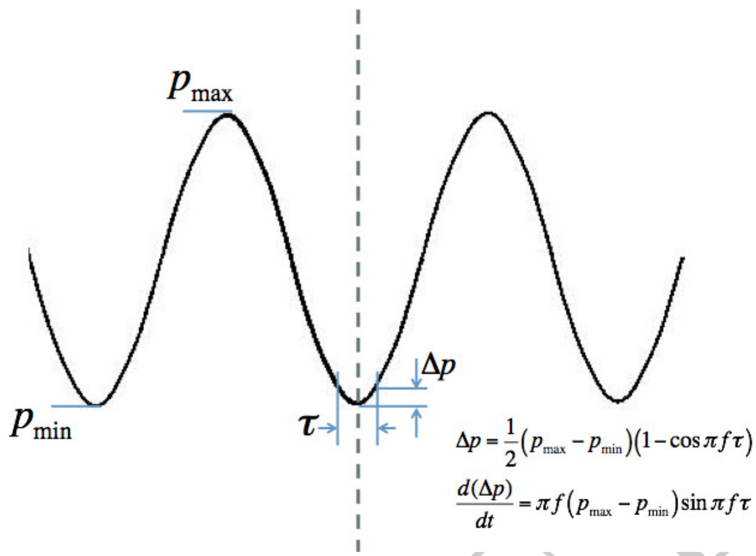

Figure 1: Waveform representing the beam momentum and magnetic field in the Fermilab Booster.

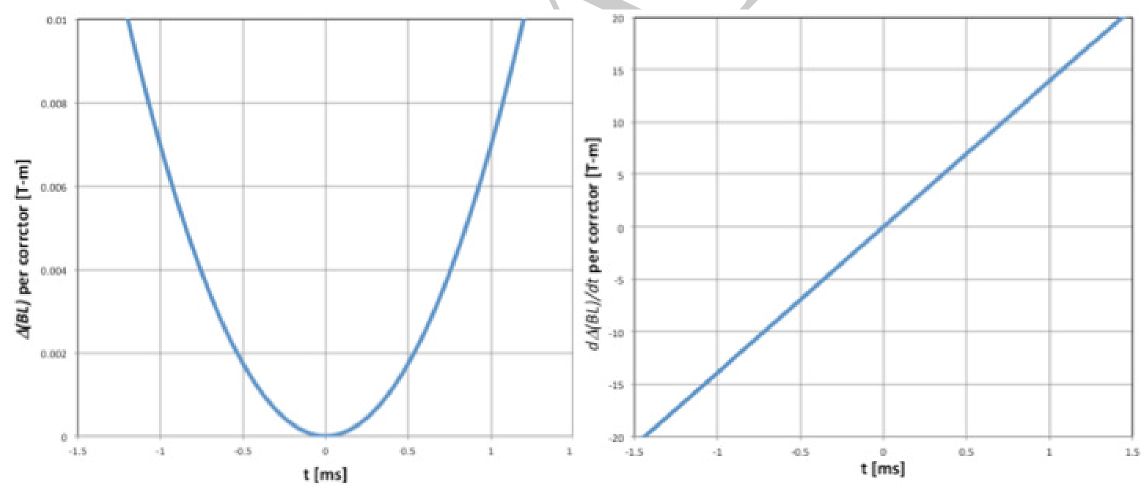

Figure 2: Required corrector fields and slew rate to compensate for changing magnetic field. This is obtained by taking the total integrated field of the lattice magnets and dividing by the number of correctors (48).