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Reducing the Emittance Growth during Transition Crossing *via* the rf Manipulation and the γ_T Jump

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Abstract

Usually there is a large longitudinal emittance growth during transition crossing in Booster. The combination of both the rf manipulation and the γ_T jump can reduce the longitudinal emittance growth during transition to a negligible level. So the goal for Booster to be able to deliver 8-GeV proton beams to Main Injector at the intensity of 4.5×10^{12} per batch with ε_L of 0.12 eV·sec and Δp of 18 MeV can be achieved.

Introduction

The maximum beam intensity in Main Injector is limited by the longitudinal emittance (ε_L) and momentum spread (Δp) of the 8-GeV beam before it's transferred from Booster to Main Injector.[1-3] Usually there is a large ε_L growth during transition crossing (TC), so it is important for us to reduce the ε_L growth *via* the rf manipulation, the transition jump, or the combination of both.[4,5]

Since the longitudinal space charge (SC) forces defocus the beam bunch before transition and focus the beam after transition, and also, the synchronous motions are frozen during TC, manipulating the beam in the longitudinal phase space *via* the rf voltage can be implemented.[4] Besides, the existing transition-jump (γ_T) system (TJS) can be used to reduce the deleterious effects of a high intensity beam passing through transition *via* reducing the time that the beam spends near the transition energy.[5,6] One expects that the combination of both the rf manipulation and the γ_T jump would provide a further reduction in the ε_L growth of the beam during TC, and numerical simulations are used to find the answer for this.

Numerical Investigations

ESME simulations are used to search the optimal setting for the combination of both the rf manipulation and the γ_T jump during TC.

Since the RFSUM curve including the rf manipulation during TC already has been optimized for the purpose of minimizing ε_L and Δp of the 8-GeV proton beam,[4] it can be directly used in ESME simulations. Except that the timing of these two rf manipulating pulses, one right before transition and one right after transition, should be adjusted relative to the new transition gate time when the TJS is used. The time relationship between each one of the rf manipulating pulses and the transition gate is fixed no matter what γ_T jump value is used, since the rf manipulation is particularly optimized to reduce the ε_L growth of the beam during TC.[4] Different transition gates should be set for different γ_T jump values according to the Booster γ ramp, as shown in Fig. 1(a),[7] and the result is shown in Fig. 1(b). Five different γ_T jump values ($\Delta\gamma_T$) are used in ESME simulations, and they are 0.0, 0.3, 0.4, 0.5, and 0.6. Measured γ_T waveforms at maximum γ_T jump values of 0.3, 0.4, 0.5, and 0.6, are shown as the black, red, green, and blue curves in Fig. 1(c) respectively, and they are used in ESME simulations.

ESME simulations are done for two different extracted beam intensities of 4.0×10^{12} and 4.5×10^{12} protons, at the configuration of combining both the rf manipulation and the γ_T jump during TC. Five different γ_T jump values, 0.0, 0.3, 0.4, 0.5, and 0.6, are simulated. The longitudinal emittance (ε_L) with 95% of the beam at 8 GeV *vs*. the γ_T jump ($\Delta\gamma_T$) is shown in Fig. 2(a), Δp in rms at the 8-GeV *vs*. $\Delta\gamma_T$ is shown in Fig. 2(b), and the black and red curves in Figs. 2(a) and (b) correspond to extracted beam intensities of 4.0×10^{12} and 4.5×10^{12} protons respectively. Without the rf manipulation at

TC and at the extracted beam intensity of 4.0×10^{12} protons, $\boldsymbol{\varepsilon}_L$ with 95% of the beam and Δp in rms at 8-GeV *vs*. $\Delta\gamma_T$ are shown as the green curve in Figs. 2(a) and (b).

As shown in Fig. 2(a), at the extracted beam intensity of 4.0×10^{12} protons, the minimum $\boldsymbol{\varepsilon}_L$ at 8 GeV is achieved at the configuration of combining both the rf manipulation and the γ_T jump of 0.6 during TC, and it is 0.052 eV·sec. There is a 15.3% ($\approx(0.0614-0.052)/0.0614$)) reduction in $\boldsymbol{\varepsilon}_L$ and a 8.7% ($\approx(3.156-2.88)/3.156$)) reduction in Δp compared to the situation with the γ_T jump only (at the same value of $\Delta\gamma_T$ =0.6); there is a 14.8% ($\approx(0.061-0.052)/0.061$) reduction in $\boldsymbol{\varepsilon}_L$ and a 3.5% ($\approx(2.985-2.88)/2.985$)) reduction in Δp compared to the situation with the rf manipulation only; and there is a 41% ($\approx(0.088-0.052)/0.088$) reduction in $\boldsymbol{\varepsilon}_L$ and a 20% ($\approx(3.58-2.88)/3.58$)) reduction in Δp compared to the situation without both the rf manipulation and the γ_T jump.

Conclusions

Usually there is a large ε_L growth during TC at the normal operation (without both the rf manipulation and the γ_T jump). For a Gaussian distribution, $\boldsymbol{\varepsilon}_L$ is six time EPSILON. At the extracted beam intensity of 4.0×10^{12} protons, EPSILON *vs*. time is shown in Fig. 3(a), and $\boldsymbol{\varepsilon}_L$ is nearly doubled after TC. However, the combination of both the rf manipulation and the γ_T jump during TC can reduce the $\boldsymbol{\varepsilon}_L$ growth to about 4% ($\approx(0.052-0.05)/0.052$), as shown in Fig. 3(b). Comparing situations with and without both the rf manipulation and the γ_T jump, there is a 41% reduction in $\boldsymbol{\varepsilon}_L$ and a 20% reduction in Δp.

With the combination of both the rf manipulation and the γ_T jump, at the extracted beam intensity of 4.0×10^{12} protons, $\boldsymbol{\varepsilon}_L$ of 0.052 eV·sec with 95% of the beam and Δp in rms of 2.88 MeV at 8-GeV can be achieved; at the extracted beam intensity of 4.5×10^{12} protons, $\boldsymbol{\varepsilon}_L$ of 0.055 eV·sec and Δp of 2.92 MeV at 8-GeV can also be achieved. There is only a 6% increase in $\boldsymbol{\varepsilon}_L$ from the extracted beam intensity of 4.0×10^{12} protons to 4.5×10^{12} protons, provide that the TJS setting should be readjusted for each beam intensity.

References:

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[2] K. Koba and J. Steimel, "SLIP STACKING", FERMILAB-CONF-02-205.

[3] X. Yang, etc., "Reducing the Momentum Spread of the 8-GeV proton Beam *via* the Bunch Rotation in Booster", FERMILAB-FN-0769-AD, submitted.

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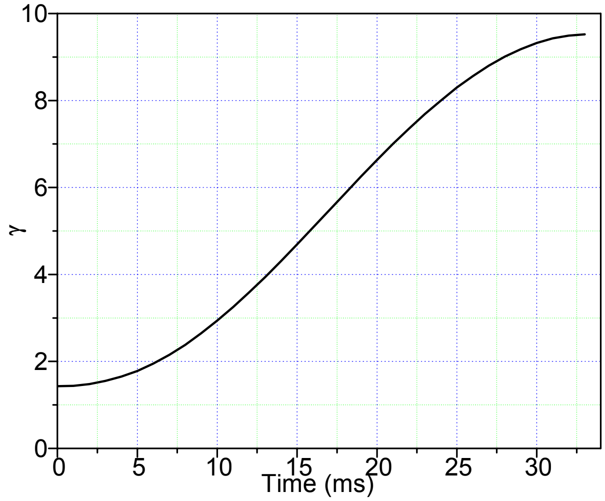
[5] W. Merz, etc., "Transition Jump System for the Fermilab Booster", FERMILAB-TM-1473.

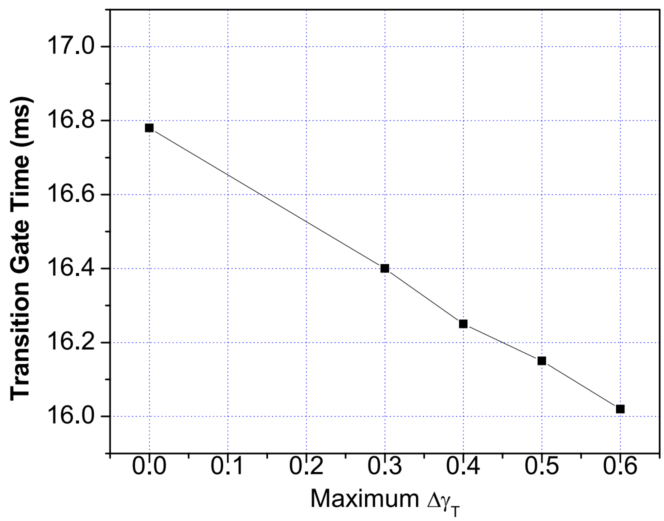
[6] X. Yang, etc., "Study Report of the Booster Transition Jump System", FERMILAB-TM-2287-AD.

[7] X. Yang, etc., "Booster 6-GeV Study", FERMILAB-TM-2283-AD.



10
8
6
4
2
0
γ
0
5
10
15
20
25
30
Time (ms)

Fig. 1(a)



17.0
16.8
16.6
16.4
16.2
16.0
Transition Gate Time (ms)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Maximum Δγ_T

Fig. 1(b)

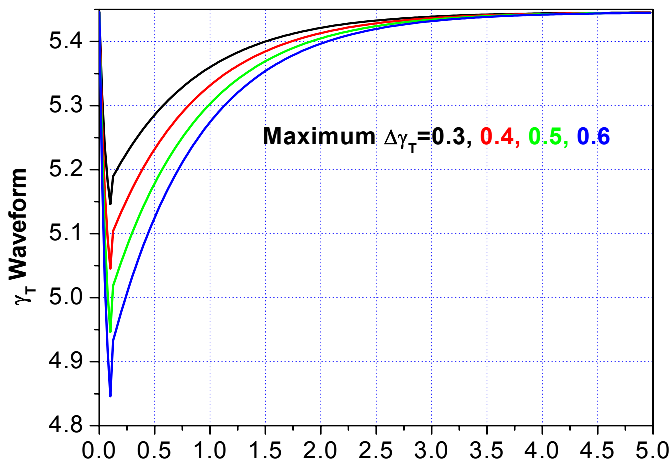


Fig. 1(c)

Fig. 1(a) the Lorentz relativistic factor (γ) *vs*. the time in a Booster cycle.

Fig. 1(b) the transition gate time *vs*. the γ_T jump value ($\Delta\gamma_T$).

Fig. 1(c) γ_T waveforms at maximum γ_T jump values of 0.3, 0.4, 0.5, and 0.6, are shown as the black, red, green, and blue curves respectively.

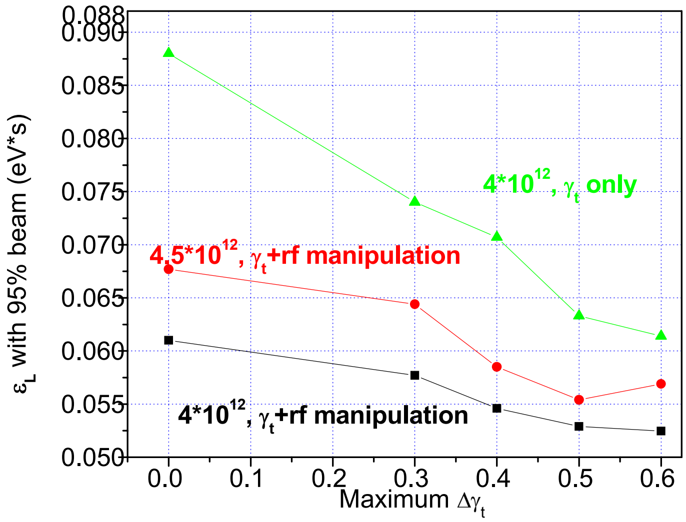


Fig. 2(a)

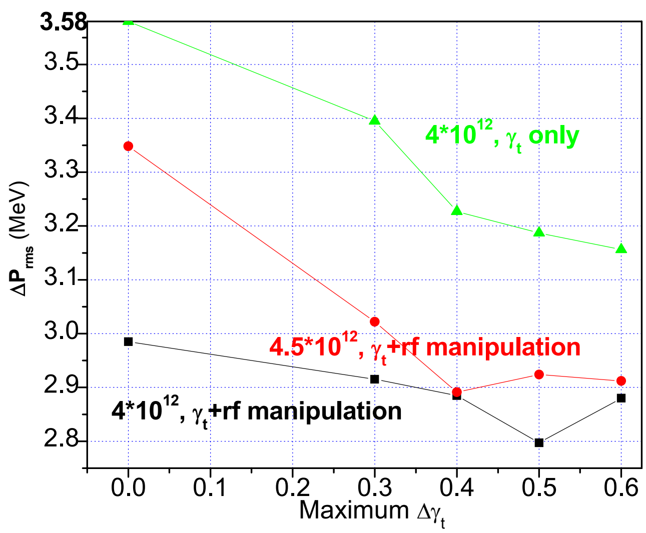


Fig. 2(b)

The black and red curves in Figs. 2(a) and (b) correspond to extracted beam intensities of 4.0×10^{12} and 4.5×10^{12} protons respectively at the configuration of combining both the rf manipulation and the γ_T jump during TC, and the green curve in Figs. 2(a) and (b) is at the extracted beam intensity of 4.0×10^{12} protons and without the rf manipulation at TC.

Fig. 2(a) $\boldsymbol{\varepsilon}_L$ with 95% of the beam at 8 GeV *vs*. $\Delta\gamma_T$.

Fig. 2(b) Δp in rms at the 8-GeV *vs*. $\Delta\gamma_T$.

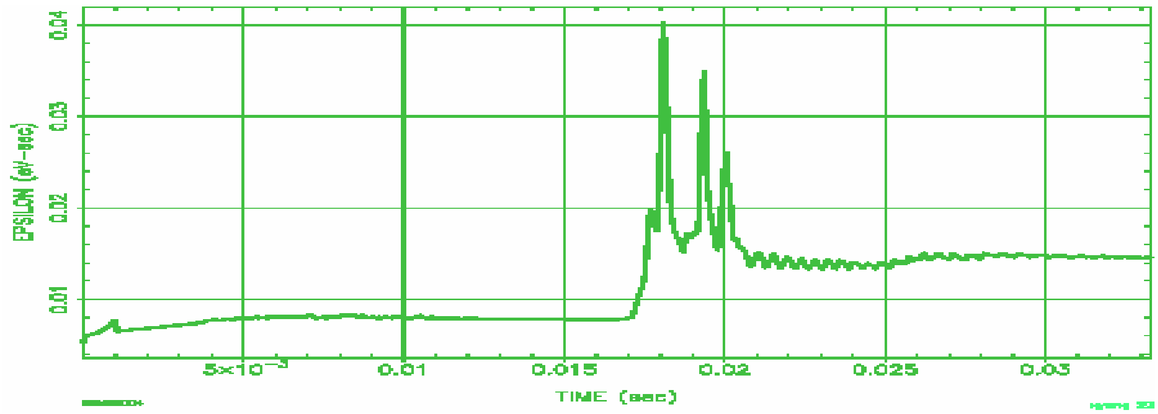


Fig. 3(a)

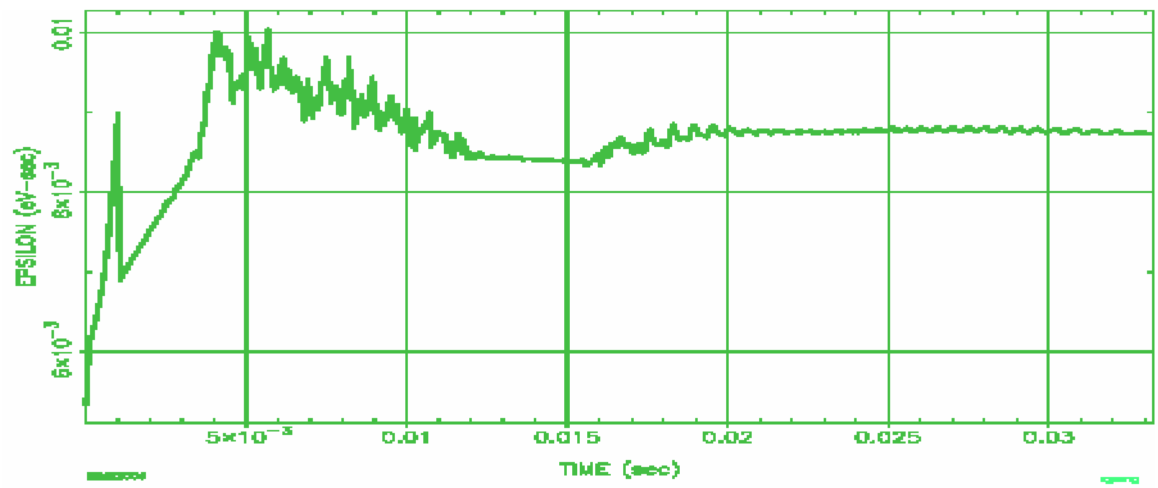


Fig. 3(b)

Fig. 3(a) without both the rf manipulation and the γ_T jump, at the extracted beam intensity of 4.0×10^{12} protons, EPSILON *vs*. time.

Fig. 3(b) with the combination of both the rf manipulation and the γ_T jump during TC, at the extracted beam intensity of 4.0×10^{12} protons, EPSILON *vs*. time.