FERMILAB-CONF-05-123-AD

BOOSTER 6-GEV STUDY

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Abstract

A wider aperture, which has been obtained along the Booster beam line recently, brings the opportunity to run beams with the intensity higher than ever before. Sooner or later, the available RF accelerating voltage will become a new limit for the beam intensity. Extra accelerating voltages can be achieved either by increasing the RFSUM or by reducing the accelerating rate *via* a slower acceleration, and this motivates the 6-GeV study.

INTRODUCTION

After the lattice distortion caused by the edge focusing of dogleg magnets in extraction sections (long 3 and long 13) is largely removed *via* spacing those magnets out, one expects that a wider aperture will be available for accelerating beams with the higher intensity. Also, since the radiation loss (RL) is largely removed by the collimator, the chance of the RL limiting the maximum beam intensity (MBI) is small. Sooner or later, the RF accelerating voltage (RFSUM) (V_{RF}) at the transition crossing (TC) will become the limit for the MBI.[1] The reason is because the effective accelerating voltage (V_{eff}) is equal to the sum of two parts (V_a and V_L), and it represents the accelerating voltage seen by the beam, as shown by eq.1.

$$V_{eff} = V_a + V_L = V_{RF} \times \sin(\varphi_s). \qquad (1)$$

Here, φ_s is the synchronous phase, which is the phase difference between the waveform of the RFSUM and the centroid of the circulating beam bunch (CB).[2]

V_a is the accelerating voltage required by the rate of the change of the Booster magnetic field (dB/dt) in a cycle, and is independent of the beam intensity. V_L is the beam energy loss caused by the real impedance of the ring, and it increases with the increase of the beam intensity.[3] It is clear that V_{eff} is limited by V_{RF}. The MBI is achieved whenever V_L reaches the difference between V_{RF} and V_a. From the experience of the nominal 8-GeV acceleration, this often happens at the TC when 'V_{RF} -V_a' reaches its minimum while V_L reaches its maximum. This is because dB/dt reaches its peak at the TC, and at the same time the peak current of the CB reaches its maximum as a result of the shortest bunch length.

Either by increasing the RFSUM or by reducing the accelerating rate, the allowable energy loss, which is the difference between V_{RF} and V_a, will be increased, and also the MBI will be increased. There is an upper limit of V_{RF}, which equals the product of the maximum number of RF stations that can be installed in Booster and the output of each station. Another way of increasing 'V_{RF} -V_a' is to reduce V_a *via* a slower acceleration, and it motivates the 6-GeV study.

EXPERIMENTAL RESULTS

All the relevant Booster ramps, which include the magnet ramp, the RF frequency ramp, and the bias ramp, etc., were rescaled to the 6-GeV acceleration. Also, some routine tunings, such as the injection tuning, RF curve tuning, and quad ramp tuning, etc., had been performed before Booster reached a standard running condition.

For the purpose of finding the relationship between the phase jump at the TC and the beam intensity, the synchronous phase detector was used to measure the φ_s right before the TC and right after the TC, and their difference gives the phase jump ($\Delta\varphi_s$). Here, the Linac beam was injected at 0 ms, and the TC gate was set at 20.7 ms. The same measurement was repeated for several extracted beam intensities and also at two different RFSUM curves, RFSUM 1 and RFSUM 2. The results were compared to the data which were taken at the 8-GeV operation.[5]

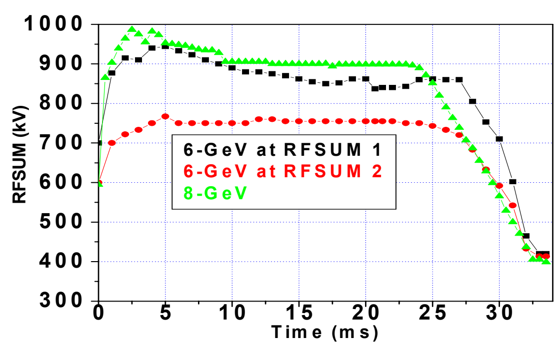

Figure 1(a) RFSUM 1 and RFSUM 2 for the 6-GeV acceleration and RFSUM for the 8-GeV acceleration are shown as the black, red, and green curves respectively.

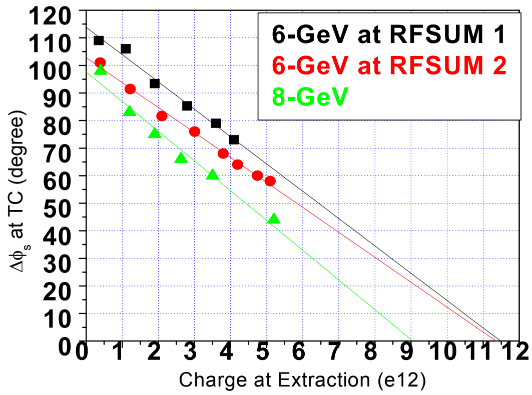

Figure 1(b) $\Delta\varphi_s$ *vs*. the extracted beam intensity at RFSUM 1 and RFSUM 2 for the 6-GeV acceleration, and RFSUM for the 8-GeV acceleration are shown as the black, red, and green points respectively; and their linear-fit results are shown as the black, red, and green lines.

The accelerating voltages (V_a) required by dB/dt for the 6-GeV acceleration and 8-GeV acceleration are shown as the black and red curves in Fig. 2(a) respectively.[2]

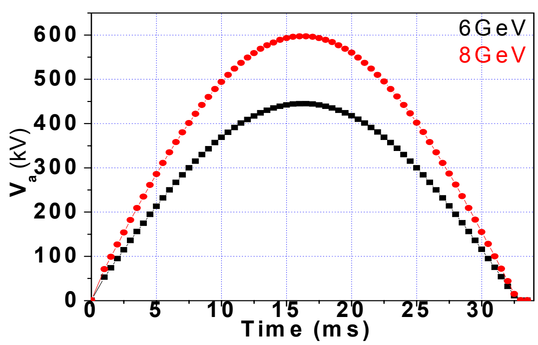

Figure 2(a) the accelerating voltages required by dB/dt for the 6-GeV and 8-GeV accelerations are shown as the black and red curves respectively.

The synchronous phase and RFSUM were measured at extracted beam intensities of 4.1×10^{12} protons (I_1), 3.6×10^{12} protons (I_2), 1.9×10^{12} protons (I_3), 0.35×10^{12} protons (I_0) when Booster was operated at RFSUM 1. The effective accelerating voltages (V_{eff}) per beam turn (BT), were calculated using eq.1. The intensity dependent part (IDP) of the V_{eff}, which is equivalent to the IDP of the V_L, can be estimated from differences between V_{eff} and V_a. Furthermore, by taking the difference (ΔV_{eff}) of the IDP between I_1 and I_0, I_2 and I_0, and I_3 and I_0 separately, the error coming from the offset of signals V_{RF} and φ_s can be minimized, and their differences are shown as the black, red, and green curves in Fig. 2(b) respectively.

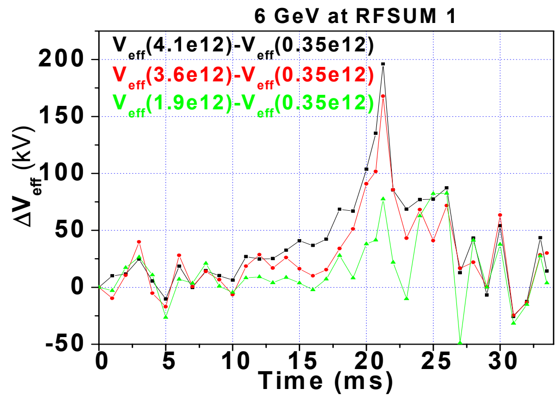

Figure 2(b) the ΔV_{eff} between I_1 and I_0, I_2 and I_0, and I_3 and I_0 are shown as the black, red, and green curves respectively.

The synchronous phase and RFSUM were measured at extracted beam intensities of 4.7×10^{12} protons (I_{1a}), 3.8×10^{12} protons (I_{2a}), 2.1×10^{12} protons (I_{3a}), and 0.39×10^{12} protons (I_{0a}) when Booster was operated at RFSUM 2. The same procedure was applied to obtain ΔV_{eff} between I_{1a} and I_{0a}, I_{2a} and I_{0a}, and I_{3a} and I_{0a} separately, and the results are shown in Fig. 2(c).

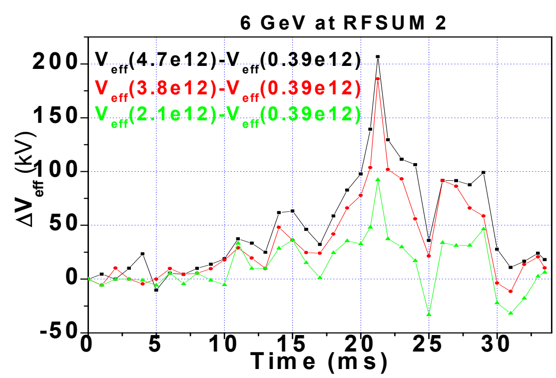

Figure 2(c) the ΔV_{eff} between I_{1a} and I_{0a}, I_{2a} and I_{0a}, and I_{3a} and I_{0a} are shown as the black, red, and green curves respectively.

This is what one expects, since there is an approximately linear relationship between the IDP of V_L and the beam intensity. Unless when the CB gets too short or the shape of the bunch is no longer smooth, high frequency components of the beam current couldn't be neglected any more.

All data were taken under similar conditions with the extracted beam intensity about 5.1×10^{12} protons when Booster was operated at RFSUM 2 of 6 GeV. The method for determining the lower limit of RFSUM is to reduce RFSUM to the value at which the beam loss starts.[6] In the experiment, the RFSUM limit was measured at 3.5 ms, 6.5 ms, 9.5 ms, 12.5 ms, 15.5 ms, 18.5 ms, 21.5 ms, 24.5 ms, and 27.5 ms separately. The RFSUM, the RFSUM limit, the V_{eff}, and the V_a are shown as the black, red, green, and blue curves respectively in Fig. 3(a).

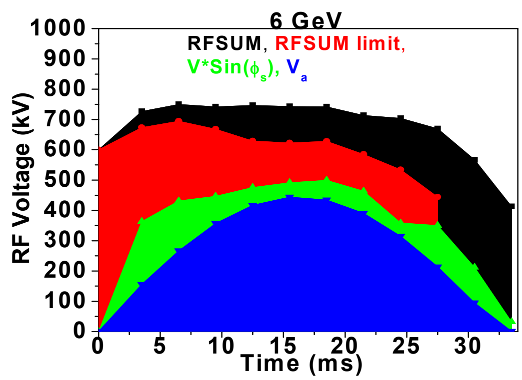

Figure 3(a) RFSUM, the lower limit for RFSUM, the effective accelerating voltage, and the accelerating voltage required by the magnet ramp are shown as the black, red, green, and blue curves respectively. All data were taken under similar conditions at the extracted beam intensity of 5.1×10^{12} protons when Booster was operated at the 6-GeV acceleration.

The data at the 8-GeV operation for the similar beam intensity are shown in Fig. 3(b) for the purpose of comparison.[6]

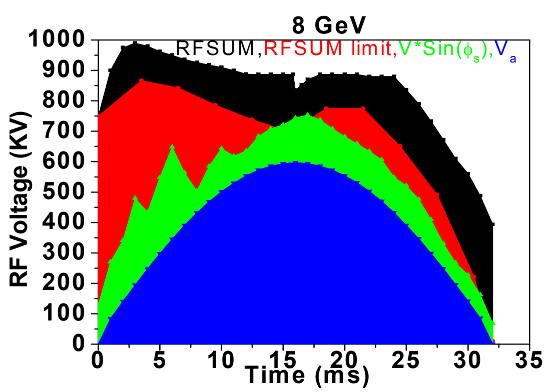

Figure 3(b) the same situation with Fig. 3(a), except the data were taken when Booster was operated at the 8 GeV.

It is clear that in the 6-GeV acceleration, there are more RF voltages available for compensating the beam energy loss, especially for the high intensity beam.

COMMENT

The effective accelerating voltage was reduced at the 6-GeV acceleration since the accelerating rate was reduced in the 6-GeV cycle compared to the 8-GeV cycle. However, the intensity-dependent part of the energy loss, or called the AC component of the energy loss, does not vary significantly from 8-GeV acceleration to 6-GeV acceleration and from one RFSUM curve to another, as shown in Fig. 2(b) and Fig. 2(c). The beam loss and the longitudinal emittance growth at the TC, which are likely caused by the mismatch of the beam in the bucket before and after the TC, could be the intrinsic problem of the Booster RF system, including LLRF and HLRF. This only can be fixed by upgrading the RF system or commissioning the γ_t jump system for the purpose of making the TC faster.[7]

REFERENCES

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