

BEAM LOADING COMPENSATION REQUIREMENT FOR MULTIBATCH COALESCING IN FERMILAB MAIN INJECTOR

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Abstract

Fermilab collider Run IIa requires 36 proton bunches with intensities 270E9ppb and 36 antiproton bunches with intensities 40-70E9ppb[1]. Currently the proton bunches are produced by coalescing 5-7 53MHz bunches into one 53MHz bunch and repeating this process a total of 36 times. It is necessary to coalesce each group of 5-7 bunches (called a ‘batch’) on independent cycles mainly because of beam loading. The beam loading requirements that would allow us to coalesce 4 proton batches at a time are presented.

1 INTRODUCTION

For the Run IIa operation, Main injector has to extract 1-4 proton batches every cycle. Each batch consists of 5 bunches which are concentrated into one bunch with a coalescing process. The intensity of the final proton bunch is 270E9ppb. During the coalescing, the 53MHz RF voltage is reduced to 0-30kV, therefore the beam loading effects are large.

We have already implemented the RF feedback system with a gain of 20dB[2]. In this paper, we will present beam loading measurement results, simulation results and discuss how much the Q-value must be reduced to avoid the beam loading effects for Run IIa.

2 RF CAVITY IN MAIN INJECTOR

Four kinds of cavities are used for Main Injector operation. The Main Injector radius is 528.3m, and so the revolution frequency is 90kHz.

We are mainly using the 53MHz RF cavities for acceleration, which have an harmonic number of 588. There are 18 stations and they are separated into two groups of 9 stations. By individually changing the voltage of each group of stations, the total amplitude of the RF voltage may be adjusted.

To extract the proton and antiproton beam at 2.5MHz to the Tevatron, five 2.5MHz RF cavities are used and operated for coalescing.

We also have a 106MHz and a 5MHz cavity, higher harmonic cavities for the 53MHz and 2.5MHz systems, respectively.

Thus, the beam goes through many cavities and may be affected by their impedance. The 53MHz cavity has a large shunt impedance, and the fundamental frequency of the beam is 53MHz, therefore the major beam loading effect on the beam should be due to these 53MHz cavities. In this paper, we will consider about beam loading effects caused by the 53MHz RF cavities only.

3 MEASUREMENT OF THE BEAM LOADING EFFECTS

During the coalescing, we first reduce the 53 MHz RF voltage from 1.1MV to 30kV. After a quarter of a synchrotron period at 30kV, the 53 MHz RF voltage is reduced close to zero by paraphasing each group of stations by 90 degrees, with each group moving oppositely in phase. Then the bunches rotate 60 kV bucket of the 2.5MHz RF.

We estimated the beam loading effects for the case of 4 batches, with each batch consisting of 5 bunches. The total intensity was taken to be 0.18E12.

If we assume that the bunch length is short, the induced voltage is can be written in equation (1)[3].

$$V_{bl}(n) = \frac{q\omega_{rf}R}{Q} e^{-n\pi/Q} \quad (1)$$

where q is the charge per bunch, R is the shunt impedance of the RF cavity, ω_{rf} is the resonant angular frequency, Q is the Q-value of the cavity and n is the bunch spacing given in number of buckets.

Since there are 18 RF stations in the Main Injector, the total induced voltage is $V_{bl}(total) = 18 \times V_{bl}$. The R/Q is 100 for each station, and the Q-value is 500 when RF feedback is on. The calculation results of the total induced voltage and phase shift which is compared with the 30kV of applied RF voltage in Fig. 1.

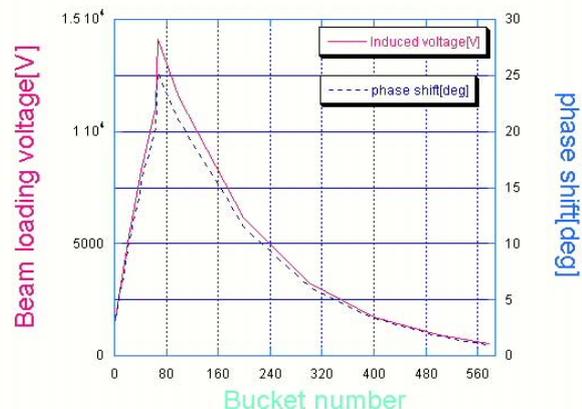


Figure 1: The calculation results of the total induced voltage and phase shift which is compared with 30kV of applied RF voltage

We have measured these effects by using a phase detector and gap voltage monitor. Based on the calculation, we expected to measure a voltage of about 15kV and a phase shift of 25deg. When the bunches are in a 30kV bucket of the 53MHz system, it was not easy to determine the induce voltage from the gap monitor, because the induce voltage should be almost same as the RF voltage. On the other hand, since the voltage of the 53MHz RF is zero when bunches are captured by 2.5MHz RF voltage, we can't compare this phase with the phase of 53 MHz RF voltage.

Figure 2 and 3 show the phase detector signal when the 53MHz RF voltage was 30kV, and the gap voltage monitor signal when the 53MHz RF voltage was 0V.

Figure 2 shows a maximum phase shift of 23.5 degrees which agrees with the calculation results. We also estimated the Q-value using the decay rate, and found it was 480. From Fig. 3, the maximum gap voltage is 8.2kV.

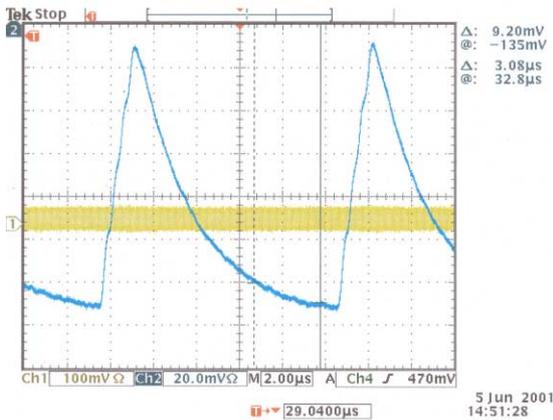


Figure 2: RF gap voltage phase shift detected by phase detector (189 degrees/volt). Scale of the voltage is 20mV/div and time is 2.0µsec/div

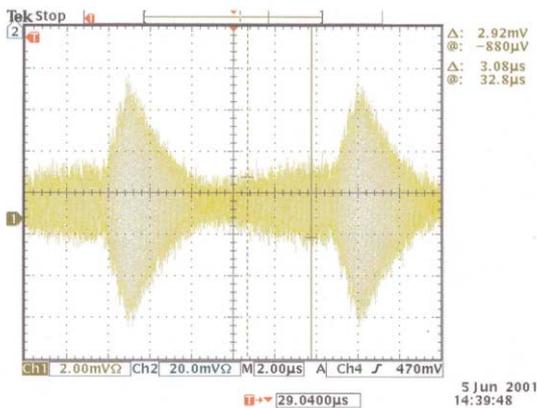


Figure 3: RF gap voltage (1.2kV/1mV). Scale of the voltage is 2mV/div and the time is 2.0µsec/div

4 BEAM MEASUREMENT AND SIMULATION

We also measured the bunch shape during the coalescing to know how the beam loading affects to the beam. These are Mt. range plots for the cases of low intensity (0.12×10^{12} ppp) and high intensity (0.42×10^{12} ppp) are shown in Fig. 4 and 5, respectively.

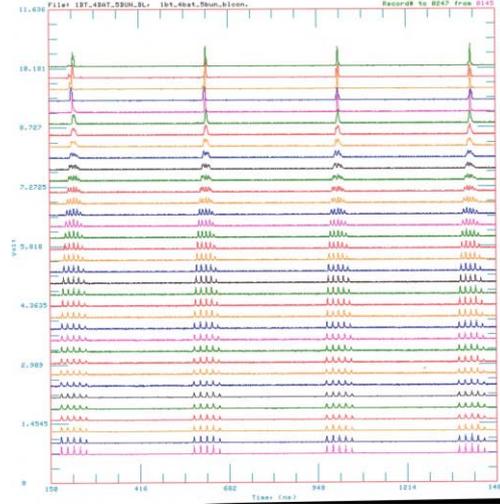


Figure 4: Measurement results in the case of the intensity is 0.12×10^{12} particles per pulse.

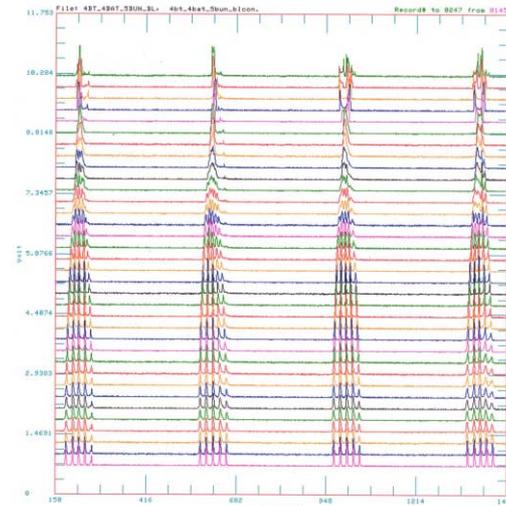


Figure 5: Measurement results in the case of the intensity is 0.42×10^{12} particles per pulse.

Multi particle ESME[4] simulations were carried out with beam loading effects and having the same intensities as the measurements. Figure 6 and 7 show mountain range plots obtained by simulation. In the low intensity case, there is no emittance growth after coalescing. On the other hand, in high intensity case, we can see emittance growth clearly in the both the measurement and in the simulation results. The simulation results are in good agreement with the measurement results.

CAPTURE WITH 1MV
every 200 turns, from turn 200

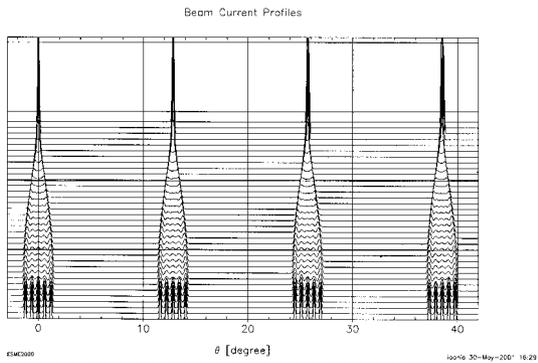


Figure 6: Simulation results with the intensity of $0.12 \cdot 10^{12}$ particles per pulse and $Q=500$.

CAPTURE WITH 1MV
every 200 turns, from turn 200

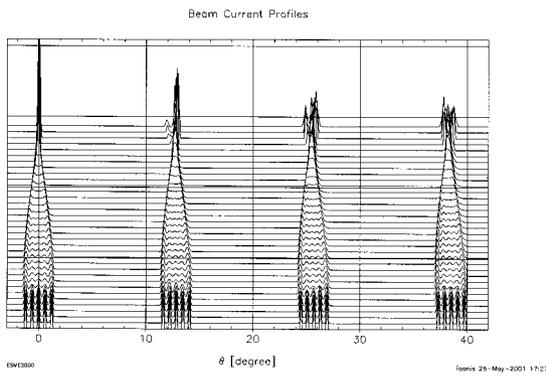


Figure 7: Simulation results with the intensity of $0.42 \cdot 10^{12}$ particles per pulse and $Q=500$.

5 SIMULATION FOR THE RUN IIA GOAL

In near future, proton bunch with $270E9$ particles will be required for Run II operation. There is also requirement to coalesce 4 proton batches on the same machine cycle at this high intensity. Thus, the intensity will be 4 times higher than for the case which we presented in section 3. Therefore the beam loading compensation is a most important issue for Main Injector requirement.

In order to optimize the feed back gain, the multi particle simulation was carried out with required beam parameters, and the results are shown in Fig. 8 and 9. According to the results, the gain of the feedback must be 4 times larger for Run II operation. We have already stated development of the feed ford system to compensate the beam loading effects, and the Q value is supported to be around 25.

CAPTURE WITH 1MV
every 200 turns, from turn 200

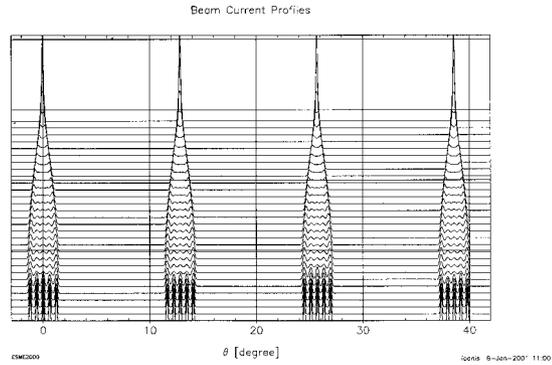


Figure 8: Simulation results with the intensity of $1.2 \cdot 10^{12}$ particles per pulse and $Q=25$.

4 BATCHES 5 BUNCHES
TURN 0
0.000E+00 SEC

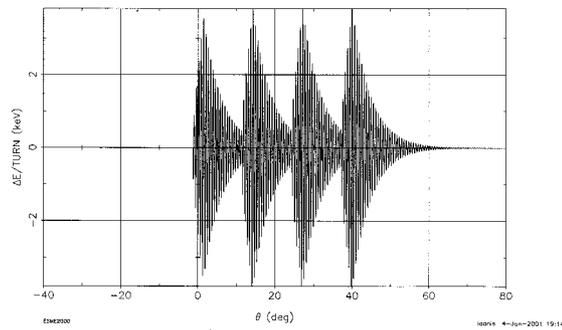


Figure 9: The beam loading voltage obtained by the simulation with the intensity of $1.2 \cdot 10^{12}$ particles per pulse.

6 CONCLUSION

The beam loading effects for the case of 4 proton batches was measured, calculated, and simulated with the intensity of around $180Eppb$. For the collider Run Iia operation, which has a required intensity $270E9ppb$ protons, the Q value is supposed to be around 25.

7 REFERENCES

- [1] K. Koba et al, "Status of the Fermilab Main Injector", these proceedings.
- [2] J.Dey and J.Steimel, "Improving the linearity of ferrite loaded cavities using feedback", these proceedings
- [3] J. Marriner, "Main Injector beam loading in the 2.5MHz system", not published.
- [4] J. MacLachlan, "Users Guide to ESME", 2000.