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STUDIES FOR SINGLE BUNCH AND MULTI-BUNCH BEAM INSTABILTIES IN THE DIAMOND-II BOOSTER

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Abstract

To reduce filling times and enable advanced injection schemes, it is desirable for the Diamond-II booster to provide high charge in both single and multi-bunch modes. The single bunch charge will be limited by short range wakefields in the booster, and long-range wakefields limit the charge for the multi-bunch trains. Due to the relatively low 100 MeV injection energy into the booster, the injected beam is susceptible to instabilities due to the very weak synchrotron radiation damping. In this paper, we present the simulation results carried out to estimate the single and multi-bunch charge thresholds in the Diamond-II booster including short and long range wakefields, RF cavity HOMs, and with physical apertures applied. Simulations results will also be presented that demonstrate the extracted multi-bunch charge could be increased by installing a transverse multi-bunch feedback (TMBF).

INTRODUCTION

For Diamond-II [1], an upgrade of the Diamond storage ring, a new booster [2, 3] has been designed with a beam emittance of 17 nm.rad and a bunch length of 38 ps at the extraction energy of 3.5 GeV. The lower emittance is essential to accomplish off-axis beam accumulation into the storage ring with reduced dynamic aperture. Shorter bunch length will ensure a suitable matching with the storage ring RF bucket so that the energy spread of the injected beam during synchrotron oscillations remains small. The major Diamond-II booster parameters are given in Table 1, more lattice details can be found in [1-3]. To ease the filling times and enable advanced injection schemes into the Diamond-II storage ring, it is desirable for the Diamond-II booster to provide high charge in both single and multi-bunch modes of operation. The booster should be capable of accelerating high charge single and multi-bunch trains from the injection energy of 100 MeV to the extraction energy of 3.5 GeV without degradation of the equilibrium parameters. The deviation in equilibrium parameters and the extracted bunch charge will be limited by beam instabilities due to the wakefields arising from various engineering components in the booster.

Earlier studies for the single bunch instabilities [4] including resistive wall (RW), geometric wakefields and RF cavity HOMs showed that there is a small and acceptable change in the equilibrium parameters at extraction. However, the single bunch charge is limited to ~1.5 nC. Maximum losses take place at the low energy regime of the beam energy ramp. The reason for this is twofold. Firstly, a large beam centroid and emittance growth is caused by the wakefields and secondly there is only very weak synchrotron radiation (SR) damping at the lower energy.

Studies were previously carried out [4] using only the linear ILMATRIX element in *elegant* [5]. The effect of chromaticity on the extracted bunch charge was studied, and it was found that a small positive chromaticity helps to increase the threshold.

Table 1: Main Parameters of Diamond-II Booster

Parameters	**At 100 MeV**	**At 3.5 GeV**
Circumference	163.85 m	
Tunes [Q_x / Q_y]	12.41 / 5.38	
Chromaticity [ξ_x / ξ_y]	+1 / +1	
Mom. compact. factor	5.65e-3	
Damping times [H, V, L]	[156, 173, 91] s	[3.7, 4.0, 2.1] ms
Energy loss/turn	0.63 eV	947.5 keV
Nat. emittance	14.1 pm.rad	17.3 nm.rad
Nat. energy spread	2.45e-5	8.6e-4
Nat. bunch length	0.55 ps	38 ps
RF Voltage	200 kV	2 MV
Energy acceptance	2.8 %	0.93 %
RF frequency	499.51 MHz	

In this paper, the studies have been extended to include amplitude dependent tune shift (ADTS) terms, as these can suppress the beam instability to some extent due to Landau damping. An updated impedance model of the booster components [6] has been used to estimate the extracted bunch charge, including wakefields generated for the flanges, TMBF striplines and with TiN coating on the booster kicker ferrite. We will present the simulation results for single and multi-bunch charge thresholds including both short range and long range wakefields. The feasibility of including transverse feedback to enhance the extracted charge will also be presented.

BOOSTER RAMP PROFILES AND IMPEDANCE MODEL

The beam energy and RF voltage ramp profiles of the Diamond-II booster are similar to the ones used in the existing Diamond booster. The beam energy is increased

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from 100 MeV to 3.5 GeV, compared to 3 GeV in the existing booster, with a biased sinusoidal waveform at 5 Hz repetition rate. To accept the beam at the injection energy with a large energy spread, the RF voltage is set to 200 kV. This provides a sufficient energy acceptance of 2.8%. The voltage is kept constant up to 1.93 GeV and then increases with the fourth power of energy up to 2 MV at extraction.

The engineering design of the major components in the Diamond-II booster have been completed [6]. Details of the potential wakefield sources in the booster are described here. There are two types of round stainless steel vacuum vessel with apertures having radius 18.3 mm (in the injection/extraction sections) and 11.5 mm (in the arc sections). In each arc section there is one ceramic break of 10 mm length with inner radius 11.5 mm to terminate the eddy currents generated by the fast-cycling magnetic fields. There are four in-vacuum ferrite kickers, one for beam injection and three for beam extraction. The RW impedances of these components have been calculated using the *ImpedanceWake2D* code [7]. It was found that ferrite loaded injection/extraction kickers contribute significantly to the RW impedance. To reduce the impedance to a lower amplitude, it was therefore proposed to apply a thin titanium nitride (TiN) coating directly on the ferrite blocks in the kicker magnets. Simulations were performed for both single bunch and multi-bunch charge thresholds to decide on the optimum coating thickness. The coating should be reasonably thin to limit the field attenuation and phase delay following the short rise/fall time of <100 ns.

Sources of geometric impedance are BPMs, screens, tapers, flanges, striplines etc. and their impedances have been simulated using *CST Studio* Suite [8] for a 0.5 mm Gaussian drive bunch. A complete description of the updated impedance database for the Diamond-II booster can be found in [6].

SINGLE BUNCH CHARGE THRESHOLD

To estimate the extracted bunch charge after the ramp, we use the *elegant* multiparticle tracking simulation code [5]. For these studies, an initial beam from the exit of the linac at 100 MeV is taken. This is then tracked through the linac-to-booster transport line to the booster injection point. The associated RMS beam emittances, bunch length and energy spread are 240 nm.rad, 20 ps and 0.5 %, respectively. The total or lumped impedance is calculated by adding the contributions of all impedance sources weighted with local beta function. The lumped impedance is normalized with the beta function at the point of insertion in the lattice. In the simulation, cavity HOMs, SR effects and ADTS terms are all included. The ADTS for the Diamond-II booster at chromaticity [1,1] are:

$$\left(\frac{dQ_x}{dJ_x},\frac{dQ_{x(y)}}{dJ_{y(x)}},\frac{dQ_y}{dJ_y}\right) = (372.5, 75.3, -42.8)\ m^{-1}.$$

The simulation results for the single bunch charge thresholds including all cavity HOMs, geometric wakes and short range RW impedance with a 100 nm thick TiN coating on the kicker ferrites are shown in Fig. 1. It can be observed that for kickers with bare ferrite, the extracted bunch charge is limited to ~1 nC for small positive values of the corrected chromaticity. The kicker magnet ferrites are more exposed to the beam in the vertical plane compared to horizontal, and as a result there is a more severe effect on the beam stability in that direction. It results in a blow up of the vertical emittance in the low energy region of the ramp. For the case with a TiN coating thickness of 100 nm or more, the threshold increases to >1.5 nC. The TiN reduces the impedance, and this results in a reduced severity on the single bunch stability and hence an increase in the extracted bunch charge.

The simulations indicate that to reach the highest extracted single bunch charge, the TiN coating thickness must be >100 nm and the operating chromaticity should be a low positive value, consistent with previous results [4].

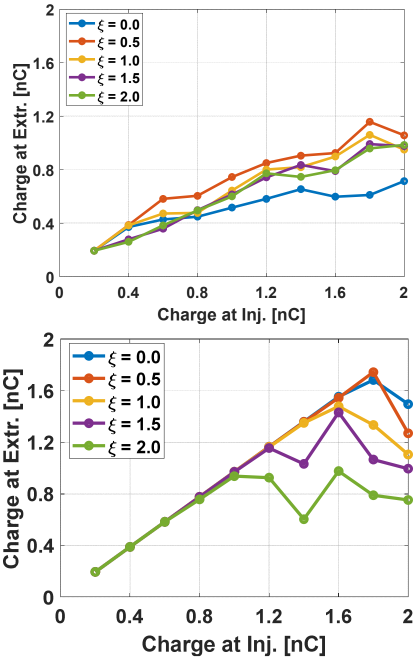

Figure 1: Extracted single bunch charge vs charge at injection in the Diamond-II booster with updated impedance data including kickers with bare ferrite (top) and with TiN coating of 100 nm (bottom) at various chromaticities.

MULTI-BUNCH CHARGE THRESHOLD

The studies have been extended to estimate the extracted charge in multi-bunch operation of the booster. In the booster, a beam train of up to 180 bunches (out of 273 RF buckets) can be extracted for injection into the Diamond-II storage ring. The maximum number of bunches is limited by the rise and fall times of 100 ns for the injection and extraction kickers in the booster.

The long range RW wakefields of the vacuum chamber components and kickers have been generated using the *ImedanceWake2D* code [7]. The kickers with bare ferrite and with TiN coating thickness of 100 nm have been simulated. The long range wakefields are again normalized with the local beta functions, and the cavity HOMs have also been included in the *elegant* simulation.

In simulation, a beam distribution at 100 MeV with a train of 180 bunches has been generated with 10,000 particles per bunch. Gaussian distributions are assumed with RMS beam emittances of 240 nm.rad in both planes, an RMS bunch length of 6 ps (corresponding to the s-band frequency of the linac) and an RMS energy spread of 0.5 %. The beam tracking was performed in *elegant* including ADTS terms and physical apertures. The simulation results are given in Fig. 2. The charged threshold is > 5nC for the case of kickers with bare ferrite and is ~ 5 nC for the case where the kicker ferrites are coated with 100 nm TiN coating.

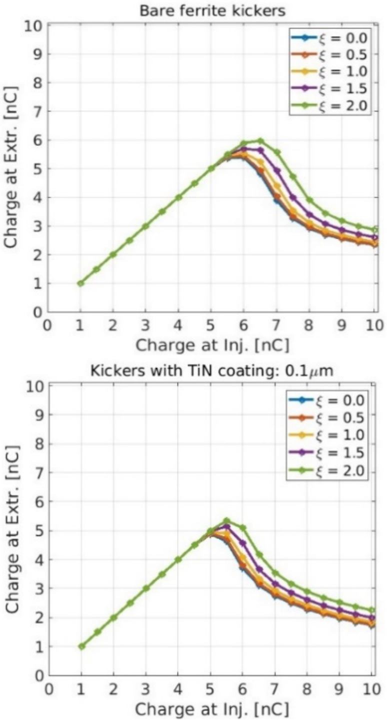

Figure 2: Extracted charge vs charge at injection for the cases of kickers with bare ferrite and with TiN coating of 100 nm for corrected chromaticity in the range 0-2. In the simulation, all long range wakefields and cavity HOMs have been included.

ADDITION OF TRANSVERSE FEEDBACK SYSTEM

We have also carried out simulations to see how the thresholds change after adding a transverse feedback system. As shown in Fig. 3, the single bunch charge threshold increases to ~1 nC for the case of kickers with bare ferrite for all chromaticities, and >1.7 nC for kickers coated with 100 nm TiN coating and low chromaticity. In the multibunch mode, the charge threshold increases to >10 nC for all chromaticities, as shown in Fig. 4.

CONCLUSIONS

Based on the updated impedance model for the Diamond-II booster, *elegant* tracking simulations have been carried out to study the charge variation during the beam energy ramp. It was found that single bunch charges of ~1.5 nC can be achieved with small positive chromaticity. This is much higher than the value required for top-up operation in the Diamond-II storage ring (0.1-0.2 nC per shot). For multibunch operation, the charge at extraction is predicted to be >5 nC. This could be increased to >10 nC by adding a TMBF system to the booster.

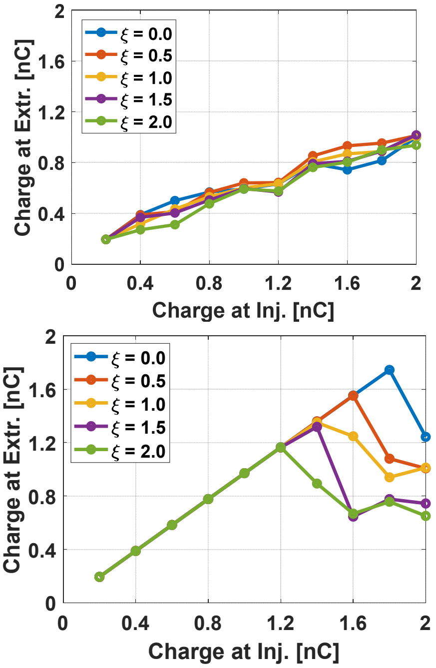

Figure 3: Similar to Fig. 1, with transverse feedback.

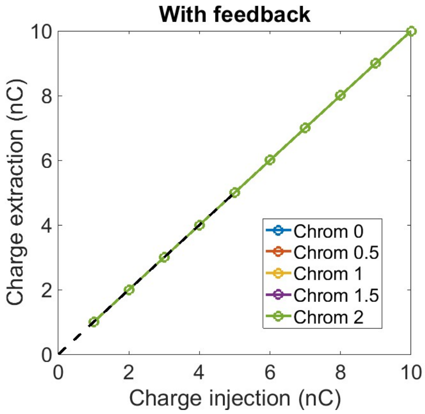

Figure 4: Extracted charge vs charge at injection with 100nm TiN coating thickness with transverse feedback for corrected chromaticity in the range 0-2.

The SR damping effect during energy ramping and Landau damping due to ADTS help to suppress the effect of instabilities.

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