

MODELING LONGITUDINAL DYNAMICS IN THE FERMILAB BOOSTER SYNCHROTRON

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Abstract

The PIP-II project will replace the existing 400 MeV linac with a new, CW-capable, 800 MeV superconducting one. With respect to current operations, a 50% increase in beam intensity in the rapid cycling Booster synchrotron is expected. Booster batches are combined in the Recycler ring; this process limits the allowed longitudinal emittance of the extracted Booster beam. To suppress eddy currents, the Booster has no beam pipe; magnets are evacuated, exposing the beam to core laminations and this has a substantial impact on the longitudinal impedance. Noticeable longitudinal emittance growth is already observed at transition crossing. Operation at higher intensity will likely necessitate mitigation measures. We describe systematic efforts to construct a predictive model for current operating conditions. A longitudinal only code including a laminated wall impedance model, space charge effects, and feedback loops is developed. Parameter validation is performed using detailed measurements of relevant beam, rf and control parameters. An attempt is made to benchmark the code at operationally favorable machine settings.

INTRODUCTION

Proton Improvement Plan-II [1] (PIP-II) is Fermilab's plan for delivering higher intensity proton beams in support of intensity frontier physics and provide a flexible platform for further enhancements of its accelerator complex. The centerpiece is a new 800-MeV superconducting linear accelerator (SCL) which will supply beam to the Booster synchrotron, replacing the existing warm 400 MeV linac. The increased energy will reduce the space charge tune shift in this machine by 30%, and allow for an increase in intensity on the order of 50%. It is assumed that this can be realized while keeping beam losses at the present level. Concretely, this implies not only that uncontrolled losses in the Booster itself need to remain at the current level (0.5 kW) but also that the longitudinal emittance at ejection should not be degraded beyond its current value (0.1 eV-s, 100%). The limit is set by the slip-stacking scheme employed in the downstream machine (Recycler). Simulations are needed to help assess to what extent this objective can be attained.

BOOSTER SYNCHROTRON

The Booster synchrotron is a 15 Hz rapid cycling machine. Its combined function bending magnets are powered by a resonant circuit that produces a sinusoidal field ramp. Twenty rf stations (originally 16) deliver a maximum 1.2 MV total ring voltage. The linac (H^-) beam is accumulated during

multiple turns (10 to 18), adiabatically captured and accelerated to 8 GeV. Transition takes place at ($\gamma_{tr} = 5.45$). A distinctive feature of the machine is that the bending magnets do not have a conventional vacuum chamber. To circumvent issues with eddy currents that arise with a conventional chamber, the volume between the magnet poles is evacuated and the beam is directly exposed to the pole laminations. While this configuration is cost-effective, it also results in unusually large reactive and resistive contributions to the ring impedance. The Booster is currently operated without a formal γ_{tr} jump system. A system using dedicated pulsed quadrupoles was installed in the late 1980's but was later decommissioned due to problems with orbit steering and envelope perturbations.

Wall Impedance

Clearly, credible simulations demand a reasonable model of the magnet wall impedance. Over the years, a succession of increasingly refined analytical models were devised. The magnet impedance was also measured in 1986 and in 2001 using a wire technique to simulate the beam [2]. We settled on an analytical expression for rectangular symmetry obtained a few years ago by Burov and Lebedev and independently by Macridin. The details are too cumbersome to reproduce here; the interested reader can consult the references [3, 4]. With careful adjustment of geometric parameters and experimentally obtained information about high-frequency dependence of the lamination material permeability, satisfactory agreement with wire measurements is obtained. Even though it assumes an idealized periodic geometry, the analytical expression provides an impedance model that (1) is consistent with causality and (2) reflects the essential physics. Figure 1 shows the relative contri-

Figure 1: Machine impedance at transition. The total imaginary component is dominated by space charge.

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