

COMMISSIONING OF THE BOOSTER SYNCHROTRON FOR THE DIAMOND LIGHT SOURCE

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Abstract

The Diamond booster synchrotron has been in construction through 2005 and its various subsystems were installed and commissioned independently such as magnets, power converters, vacuum system, RF, cabling cooling and safety systems. Since December 2005 the booster has been brought up to specification as the subsystems and utilities became available and has performed excellently as an injector for the initial trials of the Diamond storage ring in May 2006.

INTRODUCTION

The Diamond injector train consists of a 100 MeV Linac and a 3 GeV Booster with a nominal repetition rate of 5 Hz. The booster has a FODO lattice with missing dipoles and a circumference of 158.4m. It utilises a single kicker for an on-axis injection scheme. For extraction a pre-septum, septum and fast kicker are used to extract 3GeV beam into the booster to storage ring transfer line (BTS).

FACILITIES AND PROCUREMENT

The Diamond booster is housed in a separate vault with the injector linac in another vault adjacent to it. The vault allows independent booster operation and testing of most of the injector when the storage ring is delivering beam, at least until top up mode is utilised.

The early vault availability allowed installation of many of the basic services (water, cabling, ventilation etc) to commence early in the program.

While Diamond considered a complete booster purchase package (so called turn-key solution) this plan was dropped due to lack of competitive bidders and a desire to have control over the machine design. The final method of procurement was 'by major subsystem and self integration'. Essentially this meant Diamond designed the lattice, produced procurement drawings and specifications of essential components which were sent out to competitive tender as designs completed.

This led to the following procurement decisions:

- The linac - procured from Accel Instruments
- Booster girder assemblies [1] – procured from Danfysik as fully assembled magnets and vacuum systems on pre-aligned girders ready for direct installation in the Booster vault.
- The booster RF cavity – procured from Accel
- The booster rf amplifier – procured from Thales
- Power converters primarily the booster dipole and quadrupole supplies [2] - from OCEM.

- Injection and extraction pulsed elements were procured from Danfysik as a pulser/magnet combination, with DLS taking over the charger and control interface[3].

The linac [4] is the subject of another paper in these proceedings and is not discussed further here.

Depending on individual contract details Diamond staff took over or assisted in the installation and pre-commissioning of all equipment by moving in equipment, performing survey and alignment and providing the controlled environments necessary for testing of equipment producing radiation. It was also a first opportunity for Diamond staff to familiarise themselves with equipment to operate and maintain it.

Essentially Diamond performed the integration tasks of getting all the subsystems working together and under Diamonds computer control system so that beam commissioning could commence.

BEAM COMMISSIONING

Beam commissioning went forward in several phases as essential pieces of hardware were available. The beam testing was performed in the following steps;

1. Booster operation in DC mode at a fixed 100 MeV equivalent current in the booster dipoles.
2. Booster operation at 5 Hz ramping to a maximum energy of 700 MeV, including extraction and injection to the storage ring at this energy.
3. Full specification operation ramping from 100 MeV to 3 GeV at 5 Hz .

The implementation of these steps were complex but essentially driven by two things, firstly the availability of the booster dipole supply (1st week of January '06) and secondly the lack of availability of the on-site demineralised cooling systems and the eventual necessity to hire individual cooling systems to facilitate further testing.

The first step with booster operation at a fixed energy of 100 MeV allowed testing of the Linac to Booster transfer line (LTB), the basic magnetic lattice performance and of course the injection system.

The second step was actually performed with no water cooling in the booster magnets (dipoles and quadrupoles) after a careful assessment of the maximum safe current they could be operated at. This allowed ramping and extraction tests up to 700 MeV. A small temporary cooling system was installed for the rf Cavity and amplifier.

The third step involved commissioning of a further temporary cooling system for the booster magnets. This meant that the booster magnets could be ramped to 3 GeV equivalent field and final system testing commence.

Table 1 summarises the important booster parameters.

Table 1: Key booster specifications

Injection energy	100 MeV
Extraction energy	3 GeV
Circumference	158.4 m
Repetition rate	5 Hz (max)
Harmonic number	264
Rf Frequency	500 MHz
Cavity voltage	1.1 MV
n dipoles	36
n quadrupoles	44 in two families
n Sextupoles	28 in two families
n correctors (independent)	44 h & v
Design current	3 mA
modes	Single bunch, long bunch
Design emittance	150 nm.rad
Nom.working point ($v_x v_y$)	7.16, 4.11

Commissioning results

The first stage of testing commenced in the early part of December. With sextupoles off a first turn then many turns were achieved at 100 MeV. The first turn required no correctors to be energised. Some limited energisation of the RF system at very low voltages lead to bunching of the beam. This was an encouraging step that led to some confidence that the next phase, ramping would be relatively easy to achieve.

The second stage of commissioning took a little more time as with biased ac sine waveforms there was more setting up to carry out in aligning timing relative to the injection pulse and ensuring these waveforms tracked each other. These waveforms were independently timed to track using either difference signals or dividing each quadrupole signal into the dipole and comparing with the theoretical prediction of the difference to actual, then ‘degree’ of tracking adjusted. Also a very good measure of correct tracking was beam survival up the 100 ms ramp to the 100ms point even though survival beyond 100ms (the extraction point) is of no operational value.

Diagnostics from BPMs via Libera boxes were available and greatly assisted in tracking early turns including the first and dynamic tracking during each ramp cycle. During these 700 MeV tests it was possible to measure tune through the ramp to extraction.

Stage 3 commissioning (to 3 GeV) repeated and built upon the experience of the stage 2 testing and within a

few days 3 GeV beam became available, giving a clear indication of the need to perform limited beam cleaning of the booster to reduce photodesorption effects.

Injection

Injection into the booster is via a short injection septum magnet and a fast injection kicker [3]. Initial injection studies made during stage 1 under non-ramping conditions demonstrated the effectiveness of the injection process. Once a first turn was achieved it was possible to improve injection efficiency and reduce losses during the first few turns. At stage 2 this process was repeated leading to an injection efficiency > 80%, for stage 3 **then** is some optimisation left to carry out.

RF system

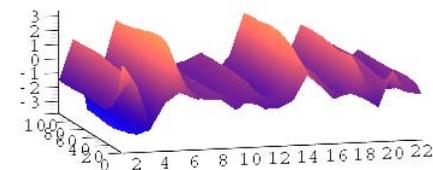
During stages 1 and 2 the booster RF system was maintained at a DC level at very low cavity volts as this was all that was necessary to ramp 2 mA to 700 MeV. All that was necessary was to phase the cavity correctly.

At stage 3 the RF system was set up with a ramping function from a bias level at injection. While complex ramps could have been programmed a simple triangular ramp was more than sufficient with 30 kW at 3 GeV. The performance of the RF system is described more fully in [5].

Closed orbit during ramping

Even though it is possible it has not yet been thought necessary to dynamically correct the orbit by ramping the h and v correctors with defined waveforms. Essentially a once off correction is made on the injection orbit and the correctors left at these settings during the ramp. As can be seen from Figure 1 both the horizontal and vertical orbits distortions are small (+/- 3mm H and +3 /-2 V)

Booster Closed Orbit :BN:WFSX



Booster Closed Orbit :BN:WFSY

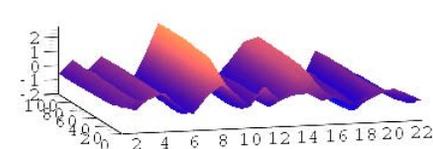


Figure 1: Booster ramp orbit, horizontal scale: BPM number around circumference, Vertical scale: orbit deviation mms and depth scale: time in 0-100ms range. Upper trace horizontal, Lower trace vertical.

Tune tracking during ramping

Using the function available for the BPMs [6] the tunes can be tracked dynamically during the ramping process across all of the turns up to 100ms where extraction takes place. To enhance the tune signal after injection oscillations have started to damp a set of striplines is

utilised with a ramped white noise signal increasing the level of drive as the beam energy increases. There is a deviation in the early part of the horizontal tune which during stage 2 700 MeV testing was corrected by small (less than 1% adjustments) to the pre-programmed ramp of the quadrupoles as this was necessary for charge survival. After the dipole power supply control loops were tuned for maximum current performance for stage 3 (3 GeV) testing it was no longer necessary to take out these small oscillations so the quadrupole ramp correction has been removed.

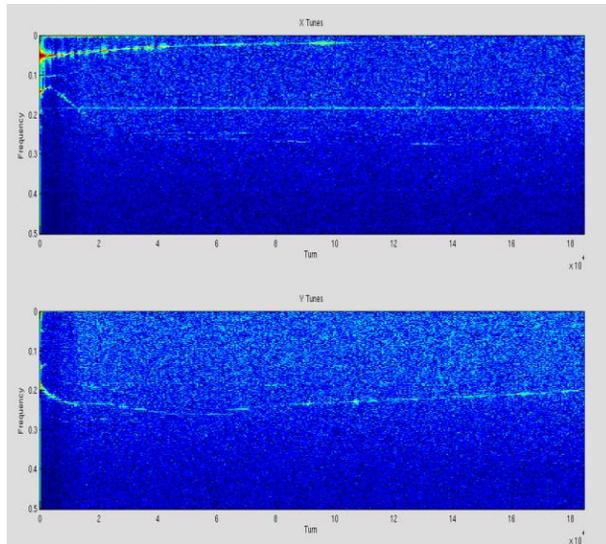


Figure 2: Horizontal and vertical tune during ramping on a turn by turn basis. (the line at 0.18 is an artefact and can be ignored)

Booster current

Using the Booster DCCT the injected and ramped current can be monitored during the ramp process. Figure 3 shows a typical beam being ramped to 3 GeV. Note how the process continues over 100ms (the extraction point) as the beam was not extracted in this example.

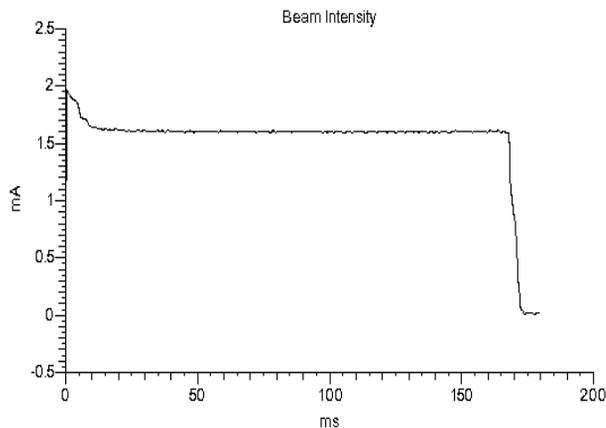


Figure 3: Ramping to 3GeV over the top of the extraction point at 100mS.

Extraction to the BTS

For the stage 2 testing (700 MeV) extraction was trialled and surprisingly simple to extract cleanly into the BTS with very high efficiency >90% for a 200ns test beam, set up using diagnostic screens. Stage 3 testing (3GeV) reconfirmed this and identical performance is seen at 3GeV when beam extracted into the BTS.

SUMMARY

Diamond's injector train of linac, LTB, booster and BTS has been successfully commissioned to its design parameters over the last 7 months. It has been used to provide first injected beam into the Diamond storage ring to commence initial beam commissioning of the storage ring at 700 MeV. The booster is now operating at 3 GeV ready for the commencement of the final beam commissioning of the Diamond Storage ring planned for September 2006 onwards.

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