# COMMISSIONING OF THE BOOSTER INJECTOR SYNCHROTRON FOR THE HIGS FACILITY AT DUKE UNIVERSITY*

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*Abstract*

A booster synchrotron (Duke booster) has been built and recently commissioned at Duke University Free Electron Laser Laboratory (DFELL) as part of the High Intensity Gamma-ray Source (HIGS) facility upgrade. HIGS is collaboration between the DFELL and Triangle Universities Nuclear Laboratory (TUNL). The booster provides top-off injection into the Duke FEL storage ring in the energy range of 0.24 - 1.2 GeV. When operating the Duke storage ring to produce high energy Compton gamma ray beams above 20 MeV, continuous electron beam loss occurs. The lost electrons are replenished by the booster injector operating in the top-off mode. The presentt operational injection and extraction rate of the machine allows us to routinely replenish up to $5 \cdot 10^8$ electrons per second. The compactness of the booster posed a challenge for its development and commissioning. The booster has been successfully commissioned in 2006. This paper reports experience of commissioning and initial operation of the booster.

## DUKE BOOSTER PARAMETERS

The Duke booster is a compact 31.9 m circumference synchrotron with race-track shape [1,2,3]. Figure 1 shows the Duke booster enclosed in a radiation shielding vault. The booster is currently operates in either single bunch or two bunch mode. It has also been commissioned with a long electron pulse from the injection linac into all 19 buckets. The present operational parameters of the booster are listed in Table 1.

The injection beam energy from the linac is 0.24 – 0.27 GeV. The injection and extraction is vertical using horizontal Lamberson injection and extraction septum magnets. A local orbit bump symmetrical for injection and extraction allows us to use a single injection and single extraction kicker. The extraction energy of the booster varies from 0.24 to 1.2 GeV. The booster and the storage ring are fully synchronized for the extraction. The RF frequency of the booster may be tuned independently or be phase-locked to the master oscillator of the main ring [4]. The odd ratio of the harmonic numbers of the booster and ring, 19/64, provides for extraction of any individual electron bunch from the booster into any selected RF bucket of the storage ring. The short pulse of extraction kicker supports the extraction of individual bunches without disturbing others.

The lattice, design and injection features of the booster are described in detail in [5,6,7].

Figure 1: Duke University HIGS facility booster

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Table 1: Booster parameters

| | Single bunch | Two bunches |
|---|---|---|
| Maximum beam energy [GeV] | 1.2 | |
| Injection energy [GeV] | 0.24-0.27 | |
| Stored beam current [mA] | 1.5-2 | 2-4 |
| Circumference [m] | 31.902 | |
| Bending radius [m] | 2.273 | |
| RF frequency [MHz] | 178.55 | |
| Harmonic number | 19 | |
| Nominal operation cycle [sec] | 1.4-1.6 | 2.3-2.5 |
| Energy rise time [sec] | 0.59–0.61 | |
| Maximum $\beta_x$/ $\beta_y$/ $\eta_x$ [m] | 27.2/9.9/1.65 | |
| Betatron tunes $Q_x$/$Q_y$ | 2.375/ 0.425 | |
| Momentum compaction factor | 0.158 | |
| Natural chromaticity $C_x$/$C_y$ | -1.7/ -3.7 | |
| At injection energy $E$=0.24 GeV: | | |
| Energy acceptance | 1.5 - 2% | |
| Damping times $\tau_{x,y}$/ $\tau_s$ [mS] | 195 / 385 | |
| At maximum energy $E$=1.2 GeV: | | |
| Beam emittance $\varepsilon_x$, $\varepsilon_y$ [nm·rad] | ~440/ 6 | |
| Damping times $\tau_{x,y}$/ $\tau_s$ [mS] | 3.16 / 1.60 | |
| Energy loss per turn [KeV] | 80.7 | |
| Energy spread $\sigma_E/E$ | $6.8\cdot10^{-4}$ | |

## DIAGNOSTIC AND CONTROL SYSTEMS

Beam diagnostics for the booster and injection lines have been selected with a premium on ease of use and operation [8]. Twelve insertable screens of DFELL design (two in the Linac to Booster line (LTB), five in the booster ring, and five in the Booster to Ring (BTR) line) and three ceramic breaks (in the LBT, booster, and BTR) are designed into the vacuum system. The booster ceramic break hosts a Bergoz Modular Parametric Current Transformer (MPCT). LTB and BTR breaks provide a space for the Bergoz Integrating Current Transformers (ICT) at the entrance and exit of the booster. Nine sets of BPM button modules from Bergoz are installed around the booster. In the linac we have two Faraday cup charge monitors, one at the beginning of the linac (E≈35 MeV) and another at the end of it (E=240-275 MeV). Faraday cups, ICT's, and MPCT are sufficiently sensitive to monitor efficiency of injection and extraction with the typical amount of beam charge of 0.15-0.3 nC per pulse.

All ramping booster power supply channels are controlled by VME based waveform generators triggered from the timing system [16]. The control interface [9,10,11,12] allows the filling of any bunch in the booster extracting it into any specified bunch pattern in the storage ring. The injection/extraction can be performed in a single shot, continuous, or top-off mode. Typical booster cycle for one bunch per cycle operation is shown in Figure 2. The control system provides tunable delays at injection and extraction to allow sufficient damping time for the beams in the booster and in the storage ring.

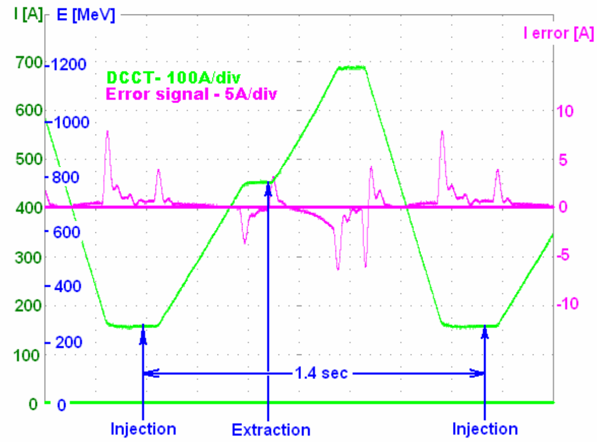


Figure 2: Booster operation cycle for one bunch mode.

## BOOSTER COMMISSIONING

The booster commissioning started in June 2006. Initially we used photo-injection driven by Continuum Minilite-II Nd:YaG laser at third harmonic (λ=355nm). The laser produced a pulse of ~6 nS wide with less then 1 nS jitter. With this laser we stored the first beam in the booster on July 27, 2006. The initial stored beam currents were as low tens to hundreds of microamperes. Further progress in the booster commissioning was associated with the commissioning and/or debugging of the following key systems:

- BMP orbit monitoring system;
- PMT based low beam current tune measurement system;
- Main booster ramping power supply;
- Energy ramping control system.

BPM's were found out to be reasonably sensitive at ~50 μA of beam current, which allowed the required orbit correction. The BPM were calibrated based upon the measured machine dispersion function.

We developed a PMT based system capable of measurement of betatron tunes with a beam current as low as 5-10 μA [13,14]. That allowed us to continue commissioning of the booster even after the failure of driving Minilite-II laser, using a multi bunch mode with very low currents (~10-15 μA per bunch). Currently we use a nitrogen laser (λ=337nm) with less than 1 ns pulse width and ~1nS jitter. The power per pulse is ~300 μJ.

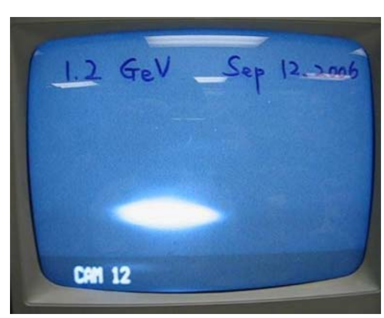


Figure 3: Synchrotron radiation image of the beam first ramped to 1.15 GeV.

 

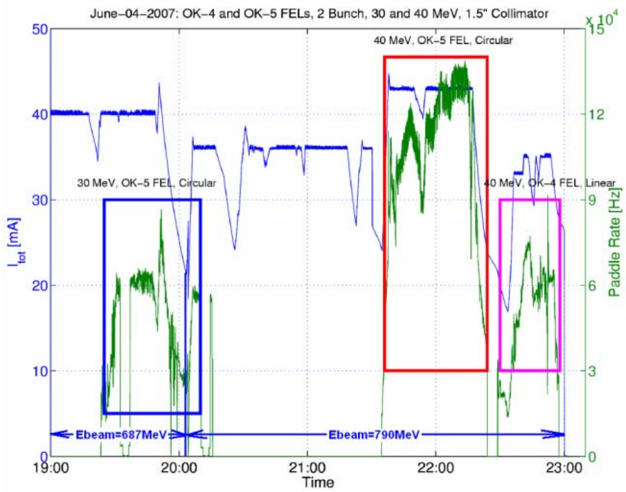


Figure 4: The first experience of the HIGS top-off operation in the electron loss mode gamma production with electron beam energies E=687 and 790 MeV.

The dipoles and quads of the booster are driven by a single main power supply unit (PSU) [5,15]. The PSU was optimized so as to provide a fast ramp very closely following the control voltage (see Figure 2). The secondary/trim power supplies [16] did not need any effort to match their timing with the ramping of the primary PSU. After correction of tunes and chromaticities we successfully commissioned the energy ramping in the booster up to the maximum design energy of 1.2 GeV (Figure 3). All the needed lattice corrections, as well as compensation of the extraction septum leakage fields [17], were implemented at low control level. The latter compensation was vital to commission the extraction from the booster to the storage ring [6].

Currently the booster is an operational machine providing top-off operations for the Duke FEL storage ring. Figure 4 demonstrates the first experience of the HIGS facility top-off operation for the gamma production in the electron loss mode.

## CONCLUSION

The Duke booster synchrotron has been successfully commissioned with all major hardware and control system functioning as designed. The operation with extraction energies higher then 0.8 GeV still needs some further tuning which will be performed as required.

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