Proceedings of 2005 Particle Accelerator Conference, Knoxville, Tennessee

VERY SHORT BUNCHES IN MIT-BATES SOUTH HALL RING

D. Cheever, W. Franklin, W. Graves, M. Farkhondeh, E. Ihloff, J. Van der Laan, C. Tschalar,
D. Wang, D.F. Wang, F. Wang, T. Zwart, MIT-Bates, Middleton, MA 01949, USA
B. Podobedov, BNL/NSLS, Upton, NY 11973, USA

Abstract

The ultra-short bunch is the key for producing strong terahertz coherent synchrotron radiation (CSR) and some other applications. A study is being conducted at MIT-Bates South Hall Ring to get 1 mm or shorter electron bunch length. A set of low momentum compaction lattice configurations have been designed. In first beam experiment in 2004, two of these configurations were successfully commissioned in which the momentum compaction was reduced by two orders of magnitude. About 1 mm rms bunch length was measured with a streak camera. It has been demonstrated that this storage ring machine has a great degree of flexibility and potential as an ideal test bed for various advanced beam physics studies.

INTRODUCTION

The primary motivation of making very short bunches at MIT-Bates South Hall Ring is to explore the possibility of coherent synchrotron radiation in terahertz regime. Recent development of electron accelerator-based sources has demonstrated the generation of high power broadband THz radiation via CSR[1][2]. Beam experiments were carried out to significantly shorten the electron bunch length for CSR production in several storage ring light sources, including BESSY-II at Berlin, Germany, New-Subaru at Hyogo, Japan, etc. [3][4][5]

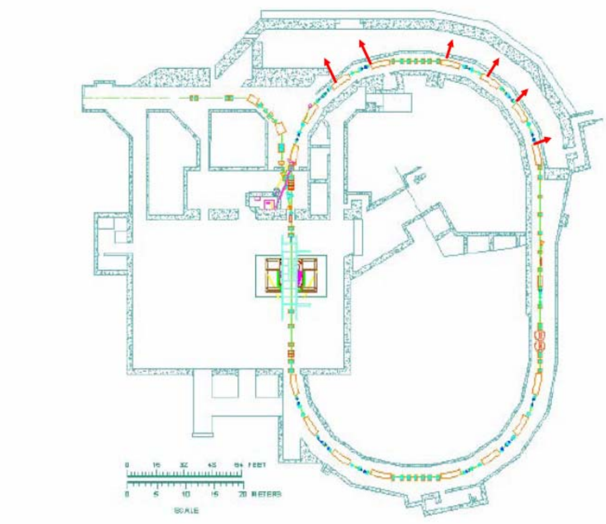

Figure 1: MIT South Hall Ring plan view.

The potential scientific significance of electron ring-based THz sources has led to proposals to explore CSR in existing storage rings as well proposals for new facilities.

MIT South Hall Ring is an electron storage ring with a circumference of 190m. The operating energy ranges from 0.4 to 1.0 GeV with 200-300 mA average current in nuclear physics runs. Figure 1 shows that the facility has ample space for numerous synchrotron radiation experiments. The lab's operation for nuclear physics experiments will end in summer 2005. This could provide great opportunities for other scientific research [6]. For example, SHR could produce very high average power for THz spectroscopy and imaging. It could also address the needs for high-field study with the addition of a stacking cavity and laser slicing technology and ultrafast time-domain experiments for different beam-lines/users in a dedicated, ultra-stable CSR operation mode.

This study is to explore the potential of SHR ring in electron beam manipulations, primarily short bunch operations. On the single particle dynamics front, a series of beam optics are studied to have small momentum compactions. For collective effects there are also some issues to be addressed.

SOUTH HALL RING

From point of view of beam physics and machine operation the characteristics of MIT-Bates SHR may be summarized as follows:

- Low- and medium-energy range, from 0.4 to 1.0 GeV (could be expanded with minor modifications if needed)
- Long (190m) circumference compared to others in similar energy regime
- Uniquely high frequency (2.856 GHz) RF system, a natural advantage to make short bunches
- A large number of quadrupole power supplies, showing flexibility in lattice matching and tuning

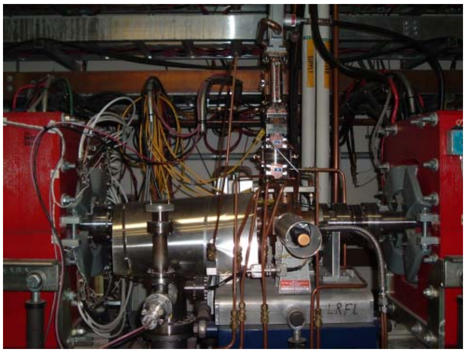

Figure 2: Unique 2856 MHz RF cavity in ring.

- Very long straight sections (> 30 m each). Functions of Arcs and straights can then be separated (e.g., injections, tuning, matching of momentum compaction/emittance).

LOW MOMENTUM COMPACTION OPTICS

At low intensity the electron bunch length is determined by

$$\sigma_l = \sqrt{\frac{2\pi\alpha h c^2}{\omega_{rf}^2 \cos\phi_s}\frac{E}{eV_{rf}}}\,\sigma_E$$

For the first beam experiment at SHR ring the energy was the same as in nuclear physics runs (850 MeV) to avoid complexities due to major changes in operation conditions. The RF parameters and natural energy spread are pretty much fixed. The only parameter one can vary is the momentum compaction.

The low momentum lattice configurations for SHR are remarkably different from nuclear physics ones except in injection straight. Since the bending angles of ring dipoles are relatively large (22.5 degrees) it is impossible to get small momentum compaction by minimizing the dispersion functions inside the dipoles. Instead one needs to match dispersions with opposite signs in different dipole and cancel mostly their contributions to the momentum compactions. Figure 3 shows a typical optics with small alpha value. Comparison of LMC (low momentum compaction) optics and nuclear physics (NP) is shown in Table 1.

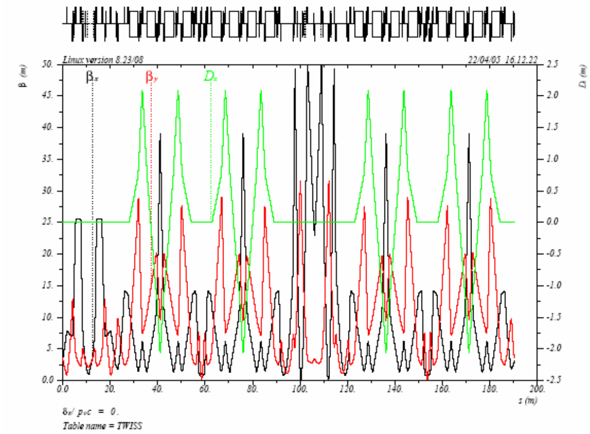

Figure 3: Lattice of LMC optics.

Table 1: momentum compactions of different optics

Lattice	Synch. Integrals			α
	I2	I3	I4	
NP	6.8e-2	7.4e-2	-5.1e-3	2.91e-02
LMC-3	6.8e-2	7.4e-2	-3.6e-4	2.04e-03
LMC-4	6.8e-2	7.4e-2	-5.3e-5	3.05e-04
LMC-5	6.8e-2	7.4e-2	-3.8e-6	2.16e-05

A close look at TWSS parameters in arc can be found in Figure 4. The maximum/minimum dispersions in arc are about +2 meters and -2 meters. The natural emittance is about 40 nm.rad.

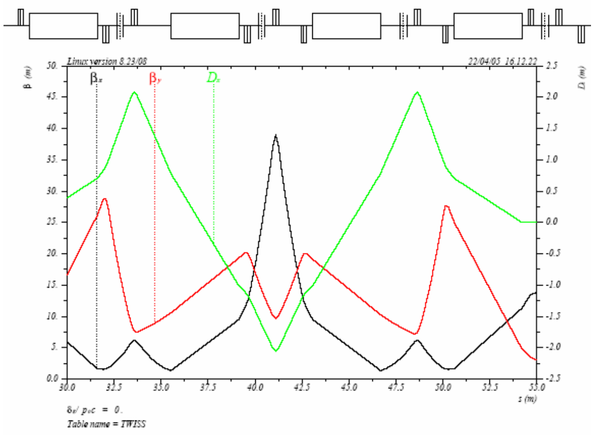

Figure 4: Lattice functions in a dispersive section.

Table 2: Synchrotron tunes and bunch lengths

Lattice	ν_s	f_s (kHz)	σ_l(mm)	σ_l(ps)
NP	0.034	54.0	~6	~20
LMC-3	0.0097	15.2	1.5	5.1
LMC-4	0.0037	5.78	0.6	2.0
LMC-5	0.0010	1.57	0.2	0.53

Thanks to the high frequency of RF system, MIT-SHR is capable of reaching very short bunch length with relatively moderate momentum compactions.

FIRST BEAM EXPERIMENT

In December 2004 the first beam commissioning of LMC optics was performed. The LMC3 worked after a few shifts of tuning as LMC optics has completely different parameters from NP one that has been in operation for many years. The LMC4 was then achieved quite quickly.

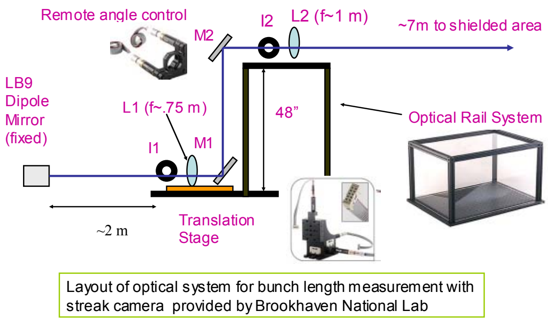

Figure 5: Setup of bunch length measurement.

0-7803-8859-3/05/$20.00 ©2005 IEEE

The measurements of synchrotron tunes and bunch length with streak camera agree each other quite well. Figure 5 shows the layout of the optical system of bunch length measurement with the streak camera. The measured rms bunch length with LMC4 is about 3.6 ps or 1.1 mm with highest possible RF voltage. (See Figure 6) The dependence of bunch length on different RF voltages and momentum compaction was studied (Fig. 8). Bunch lengthening with beam intensity was clearly seen although this was not the emphasis of the test run. The average beam currents ranged from 0.1 mA to 5mA(LMC4), 20 mA(LMC3).

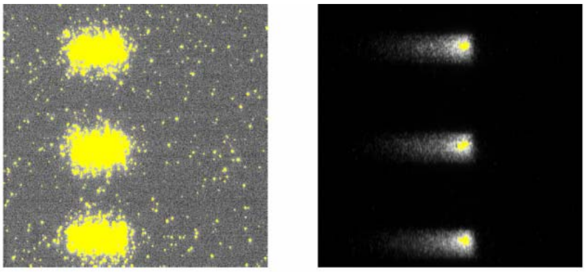

Figure 6: Bunch length reduction with small momentum compaction, left: ~20 ps for nuclear physics optics, right: 3.6 ps for low momentum compaction optics.

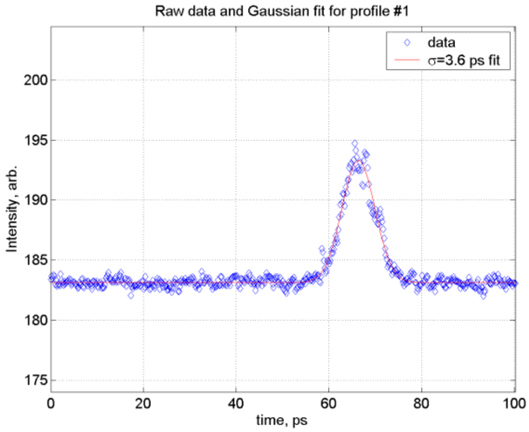

Figure 7: Fitting of measured data, LMC4, 3.6 ps rms length.

SENSITIVITY OF OPTICS

The LMC5 was tested shortly after a serious power failure. The measured beam parameters appeared to be far from the predictions. This fact brings up another issue of sensitivity of optics to small power supply errors. (The higher order term is considered still small in this case. Other intensity related instabilities[7][8] can also be excluded at this time.) We then develop an alternative optics based on the old low momentum compaction lattice. The overall level of dispersion function was somehow lower than LMC3-5 optics, hence the sensitivities of α on the errors of quadrupole field gradients. See Table 3. The trade-off is that the chromaticities of this optics are much higher. This optics LMC5A, together with improved LMC4,5 will be test in accelerator physics run in summer 2005.

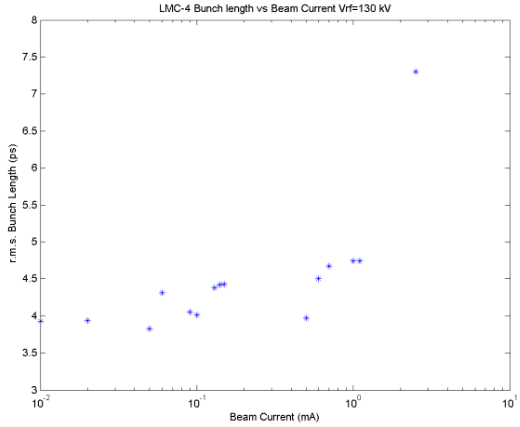

Figure 8: Bunch length vs. current (LMC4 optics).

Table 3: Sensitivities of α on optical errors

Optics	**LMC-5A**	**LMC-4.5**
Original α	5.5e-5	8e-5
k errors	+/- 1e-3	+/1 1e-3
Quad in arc	α (e-5)	α (e-5)
KQF	1.7/7.8	9.4/6.0
KQD	4.8/4.6	-5.0/20
KQF2	4.5/5.0	not in use
KQD1	4.8/4.6	9.0/6.0
KQF1	3.2/6.2	2.0/13.0

ACKNOWLEDGEMENTS

We'd like to thank R. Milner, S. Steadman of MIT, L. Carr, J. Murphy of BNL, J. Bird of LBNL for helpful discussions. We also want to thank all operations personnel for their outstanding efforts to make beam experiments successful.

REFERENCES

[1] M. Abo-Bakr, *et al.*, Phys. Rev. Lett. **88**, 254801 (2002).
[2] G. L. Carr, e*t al*., Nature 420 (2002) 153-156.
[3] M. Abo-Bakr, *et al.*, PAC03 p.3023 (2003).
[4] Y. Shoji, S. Hashimoto, A. Ando, AIP Conf. Proc. 705:57-60, 2004.
[5] J. B. Murphy, ICFA Beam Dynamics Newsletter No.35, p.20-27 (2004).
[6] M. S. Sherwin, *et al., edit,* DOE-NSF-NIH workshop report, Feb. 12-14, 2004, p.105-108.
[7] G. Stupakov and S. Heifets, Phys. Rev. ST Accel. Beams, Vol. 5, 054402 (2002).
[8] K. Bane, S. Krinsky & J.B. Murphy, AIP 367, p.191-198, 1996.
[9] F. Wang, MIT-Bates AP-Note 001, 2001.