COMPRESSED ELECTRON BUNCHES FOR THz GENERATION - OPERATING BESSY II IN A DEDICATED LOW ALPHA MODE*

J. Feikes, K. Holldack, P. Kuske, G. Wüstefeld, BESSY, Berlin, Germany

Abstract

For the first time an electron storage ring has been operated during regular user shifts in a dedicated 'low alpha' mode, where electron bunches are shortened by a factor of 5 for coherent THz radiation experiments. Operation experiences are presented.

INTRODUCTION

BESSY II is presently the only electron storage ring worldwide which can generate stable, broadband coherent THz radiation (CSR) [1]. This radiation is up to 10^7 more powerful than the incoherent radiation. There are two machine modi where enhanced THz radiation is produced. One mode is the regular user optics, where no changes of the optics are required only the beam current has to be at least 4 mA per bunch. This is realized in the regular single bunch user shifts, where bunch currents up to 20 mA are accumulated. Above the 4 mA threshold the bunch becomes unstable and powerful bursts of CSR are emitted [2] in a more or less irregular temporal manner. In the multi bunch shift at 250 mA the single bunch current is less than 0.7 mA, below the bursting threshold.

The second mode is a dedicated 'low alpha' machine optics which was offered for the first time in a one week shift to user experiment. In this case the bunches are longitudinally compressed and, depending on the beam current, stable CSR below and bursting CSR above an α dependent threshold current is emitted. The 'low alpha' bursting mode is, in comparison to the bursting mode of the single bunch user optics, much more stable and well suited for experimental applications [3]. Experiments were performed on THz near field imaging [4] and THz spectroskopy [5], see also [6]. There was also interest from users in short x-ray pulses. In the zero current limit the bunches are as short as 3.5 ps. Recently, the optics was further refined to produce even sub-ps electron bunches [7].

THE MACHINE OPTICS

A special optics, the so called 'low alpha' optics is set up for the purpose of bunch shortening. This optics is a simplified 16-fold version of the regular BESSY II user optics of 8-fold symmetry, as shown in Fig. 1. In the 'low alpha' mode the 'momentum compaction factor', α, of the machine is reduced, where α is defined as the relative increase of the electron orbit, dL/L_0, with deviating electron

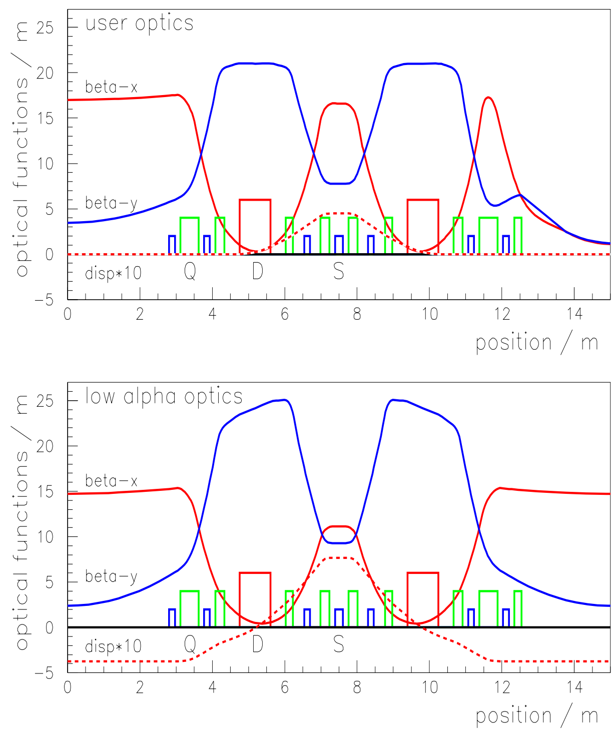

Figure 1: Optical functions of user (upper part) and low alpha optics (lower part) of one out of 16 ring cells. Dipoles, quadrupoles and sextupoles are indicated by D, Q and S respectively.

momenta, dp/p_0:

$$dL/L_0 = \alpha \; dp/p_0.$$

By an appropriate detuning of the quadrupoles α can be varied at fixed transverse working point, starting with $7.3 \cdot 10^{-4}$ of the regular user optics down to $7.3 \cdot 10^{-6}$ and less.

In parallel with the reduction of α, the bunch length is lowered, following a $\sqrt{\alpha}$ dependency at lower bunch currents. Also the longitudinal synchrotron frequency, detected by a strip line, is reduced in proportion to $\sqrt{\alpha}$, which gives us instant information on the bunch length.

This optics requires carefully tuned sextupole corrections to control the transverse chromaticity and specially the longitudinal chromaticity. The setting of the sextupoles

* Work supported by the Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie and by the Land Berlin.

Table 1: Parameters of the Low Alpha Optics

bunch fill pattern	**buckets filled**	**buckets empty**
multi bunch (MB)	200	200
single bunch (SB)	1	399
SB and MB current	**bunch length**	**life time**
0.25 mA 50 mA	7.5 ps rms	8 h
0.10 mA 20 mA	5.5 ps rms	20 h
0.025 mA 5 mA	3.5 ps rms	40 h
optics parameter	**regular user optics**	**low alpha optics**
nat. emittance	6 nmrad	30 nmrad
transv. tunes		
Q_x / Q_y	17.82 / 6.72	14.71 / 6.22
nat. chromaticity		
ξ_x / ξ_y	-53 / -27	-35 / -27
long. tune Q_s	0.0060	0.0014

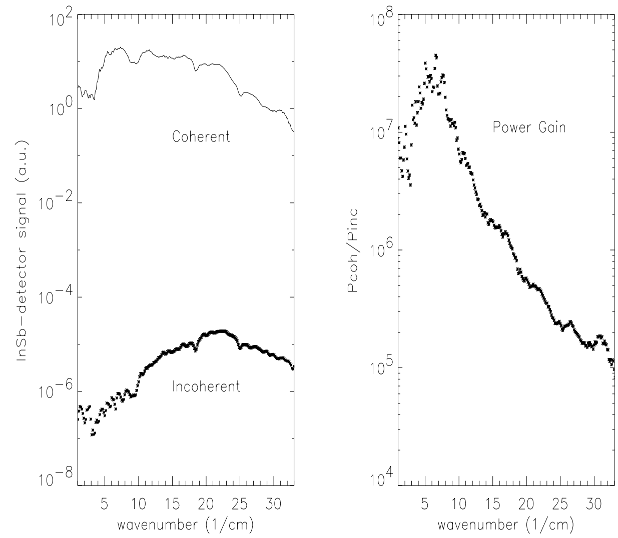

Figure 2: Emitted THz power at 20 mA in the low alpha optics. The left figure part shows raw data of the coherent and incoherent THz power measurements with an InSb-detector. The right figure part shows the ratio of these two intensities, yielding a power gain of more than 10^7 achieved by the coherent emission process.

where optimized by applying sextupole strength scans [8]. The goal was to increase the life time of the stored beam. It was found, that the life time close at its optimum value was extremely sensitive to the setting of sextupole family S1 (at position 7.5 m in Fig.1.), which mostly acts on the horizontal chromaticity. A relative current change of 0.001 leads to lifetime changes of more than a factor two. We finally choose a sextupole strength, which leads to a beam life time of 10 h and a current limit of 40 mA. We expect that the nonlinear part of alpha (the longitudinal chromaticity) depends very sensitively on the horizontal chromaticity and that the longitudinal chromaticity defines the size of the stable rf-bucket. The unstable fix point, which limits the bucket size, is located at $\alpha(dp/p_0) = 0$ and one wants to push this to large momentum values.

For the production of coherent radiation the length of the electron bunches have to be compressed to become comparable to the wavelength of the emitted THz radiation, which is then superimposed coherently and becomes extremely powerful.

For the BESSY 'low alpha' user shift a value of $\alpha = 3.5 \cdot 10^{-5}$ was chosen, where the zero current bunch rms-length is about 1 mm, five times shorter than the bunch length in the regular user optics. This value of α is balanced between less stable operation with a further reduced bunch length and a more reliable operation of the machine. With this α value it is possible to inject and accumulate at a good rate - no detuning of the optics for the injection process is necessary. A smaller α value leads to a more sensitive machine and less stable beam orbits, typically thermally dependent orbit shifts.

A specially adapted, automatic orbit correction procedure was developed [9], where the rf-correction was excluded. The present rf bit-resolution of 1 Hz at 500 MHz rf-frequency is insufficiently fine in case of the small α orbit corrections and leads to steplike orbit changes of up to 40 micrometers. With the smoothly running orbit correction it is possible to operate insertion devices with variable gaps. Hence, other users, who are not interested in this special machine mode are not excluded. Strong insertions like the superconducting wave length shifters and wigglers with small gaps were not operated since the distortion of the beam optics would be too large.

The THz experiments are not sensitive to small orbit changes, but to a possible related detuning of alpha. The THz signal was significantly affected by helical insertion devices if the polarization was changed. This is performed by a longitudinal shift of the magnetic rows and leads to a change of the horizontal focussing. This in turn affects the dispersion function and the low alpha setting, leading to α-changes of up to 20%. The power of the emitted THz radiation is dependent on α and sensitively reacts to the horizontal tune change. However, keeping the horizontal tune fixed does reset the α value. A tune feed forward will be developed to control this [10]. We expect, that the THz intensity will be stable with this correction.

EXPERIMENTAL SET-UP

THz experiments where performed at one of the IRIS [11] beam ports. The THz radiation was analyzed by means of a Martin-Puplett far infrared spectrometer and the intensity modulation by a liquid helium cooled InSb detector followed by a lock-in amplifier at an lock-in frequency of 1.25 MHz, the bunch revolution frequency.

The time constant of the detector is faster than the revolution time of the electrons in the storage ring of 800 ns. A beam fill pattern of 200 bunches out of 400 possible buckets was chosen to have an optimum signal modulation.

The initial beam was 40 mA providing a sufficiently strong THz signal. From earlier measurements it was shown, that the corresponding single bunch current of 0.25 mA is far above the bursting threshold, which is α-dependent and during this optics tuning lies at about 0.08mA. It was also shown that the bursting in the low alpha multibunch mode does not deteriorate the quality of the spectra taken in the step scan mode [3]. This mode could be very well used for near field imaging. The intensity recorded by the detector is the result of 200 bursting bunches, leading to a better average of the power, compared, for example, to the bursting, single bunch mode in the user optics.

CONCLUSION

The low alpha week for user operation proved that this optics mode is running very reliable with good beam stability and lifetime. It is not limited to special machine shifts of experts only. It can be offered as a regular, dedicated user shift and is well handled by the machine operators. For November 2004 a second, one week shift is foreseen. Since recently, a second port for THz experiments is in operation [12].

ACKNOWLEDGEMENT

There are many BESSY collegues involed in this work, supporting us during many shifts of machine tests and developpments. We express our gratitude to them for this excellent support.

REFERENCES

[1] M. Abo-Bakr et al., Phys. Rev. Lett. 88, 254801 (2002). M. Abo-Bakr et al., Phys. Rev. Lett. 90, 094801 (2003).

[2] J. M. Byrd et al., Phys. Rev. Lett. 89, 224801 (2002).

[3] K. Holldack et al., 'Coherent Synchrotron Radiation Experiments at BESSY II', PAC'03, Portland (USA), p. 839, May 2003.

[4] U. Schade et al, 'THz near-field imaging employing synchrotron radiation', App. Phys. Lett. Vol. 84, Issue 8, p. 1422, (2004).

[5] H.-W. Hübers et al, 'THz Spectroscopy of excited acceptor states in p-type Germanium', BESSY 2003 annual report, 2004, and to be published.

[6] E.J. Singley, et al., 'Measuring the Josephson plasma resonance in Bi2Sr2CaCu2O8 using intense coherent THz synchrotron radiation', Phys. Rev. B 69, 092512 (2004).

[7] J. Feikes et al, 'Sub-Pico Second Electron Bunches in the BESSY Storage Ring', EPAC'04, Luzern (Switzerland), July 2004.

[8] J. Feikes et al., 'Beam Lifetime Optimisation of BESSY II by Systematically Adjusting the Harmonic Sextupoles', EPAC'02, Paris (France), p. 775, June 2002.

[9] Roland Müller, BESSY, priv. comunication.

[10] J. Bahrdt et al., 'Insertion Devices', BESSY 2003 annual report, 2004.

[11] U. Schade et al., Rev. Sci. Instrum. 73(3), 1568 (2002)

[12] K. Holldack et al., 'THz Diagnostics for the Femtosecond X-ray Source at BESSY', EPAC'04, Luzern (Switzerland), July 2004.