OBSERVATION OF INTENSITY DEPENDENT SINGLE BUNCH EFFECTS AT THE SYNCHROTRON LIGHT SOURCE PETRA III

K. Balewski, R. Wanzenberg*, DESY, Hamburg, Germany

Abstract

At DESY the PETRA ring is operated as a synchrotron radiation facility with a very low emittance of 1 nm. Regular user operation has started in summer 2010. A summary of observations and measurements of intensity dependent single bunch effects is presented in this report. The longitudinal impedance of the ring is estimated from the measured bunch length versus beam intensity. The results are compared with predictions from the impedance model. Furthermore measurements of the single bunch intensity limit due to the transverse mode coupling instability (TMCI) are reported. The tune and phase shift around the ring have been measured as a function of the beam intensity. At PETRA III tune spectra have been observed with characteristics which have been observed at other storage rings in connection with electron cloud effects. The present status of the observations of potential electron cloud effects is also discussed.

INTRODUCTION

At DESY user operation has started at the synchrotron light source PETRA III [1] in summer 2010. The very low emittance of 1 nm rad has been achieved with the help of 20 damping wigglers with a length of 4 m each. PETRA III is presently running in a top up operation mode with a total bunch current of up-to 100 mA. Further results from the commissioning with beam, which started in April 2009, are summarized in [2]. PETRA III is operated with *positrons* since PETRA shares the preaccelrator chain with the light source DORIS, which is operated with positrons to avoid problems with ionized dust particles. A summary of the PETRA III design parameters can be found in Table 1 [1].

An impedance model of PETRA III was developed in collaboration with DESY, the University of Darmstadt, the Otto-von-Guericke University of Magdeburg, CANDLE (Yerevan, Armenia) and the Budker Institut BINP (Novosibirks, Russia), see [3]. The loss, gradient loss $k_\parallel(1)$ and kick parameter $k_\perp$ have been used to characterize the impedance of the components in the ring:

$$k_\parallel(1) = \int_{-\infty}^{\infty} ds\ W_\parallel(s)\ \frac{d}{ds}\lambda(s), \qquad (1)$$

$$k_\perp = \int_{-\infty}^{\infty} ds\ W_\perp(s)\ \lambda(s), \qquad (2)$$

where $\lambda(s)$ is the charge density, $W_\parallel(s)$ is the longitudinal, and $W_\perp(s)$ is the transverse wake potential of the Gaussian bunch.

* rainer.wanzenberg@desy.de

Table 1: PETRA III Design Parameters

Parameter	PETRA III	
Energy /GeV	6	
Circumference /m	2304.0	
Harmonic number	3840	
RF frequency /MHz	500	
Total current /mA	100	
Number of bunches	960	40
Bunch Population /10^{10}	0.5	12.0
Emittance (horz. /vert.) /nm	1 / 0.01	
Bunch length /mm	12	
Tune Q_x / Q_y	36.13 / 30.29	
Q_s	0.049	
Momentum compaction /10^{-3}	1.2	

The predictions of the impedance model can be compared with measurements of intensity dependent single bunch effects. At first we present measurements of the bunch length versus bunch intensity from which the longitudinal impedance $Z_\parallel/n$ can be extracted. Then we present an intensity dependent measurement of the betatron phase along the ring which was obtained from an orbit response measurement. This measurement shows were the contributions to the impedance from various components are localized and extends previous measurements of the tune shift versus intensity [4]. Finally we discuss the present status of observations of potential electron cloud effects, which are related to a vertical emittance blow-up for filling schemes with equidistantly spaced bunches with a bunch to bunch spacing of 8 ns and 16 ns, see also [5].

BUNCH LENGTH AND LONGITUDINAL IMPEDANCE

At PETRA III an optical beamline for bunch length diagnostics is installed, which uses the visible synchrotron radiation form a standard dipole . A water cooled Cu mirror extracts the radiation from the beam pipe, and an optical systems guides the radiation to a streak camera, where the bunch length is measured, see Ref. [6]. The measured (rms) bunch length versus the bunch current is shown in Fig. 1 (measurement from Aug 25, 2010)

The effective inductive impedance $Z_\parallel/n$ can be extracted from the measurements using B. Zotter's bunch length σ_z scaling law [7, 8]:

$$\frac{\sigma_z}{\sigma_{z0}} = \left(\frac{\sigma_z}{\sigma_{z0}}\right)^3 - \frac{1}{\sqrt{2}\,\pi}\frac{\alpha_c\, I_B}{{Q_s}^2\, E/e}\,\mathrm{Im}\left(\frac{Z_\parallel}{n}\right)_{\mathrm{eff}}, \qquad (3)$$

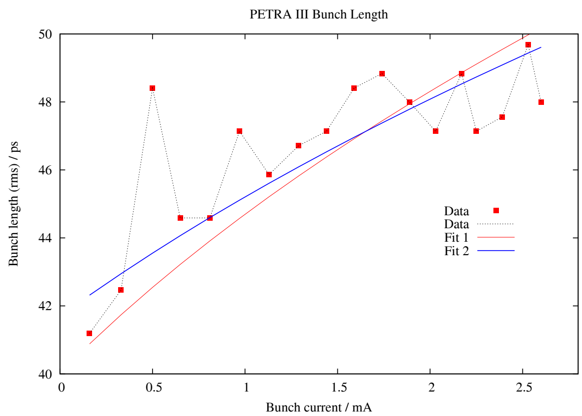

Figure 1: PETRA III bunch length (rms) versus bunch current. The measured data and two fits through the data points are shown.

where σ_{z0} is the zero current bunch length, α_c the momentum compaction factor, Q_s the synchrotron tune, I_B the bunch current and E the beam energy. Setting the zero current bunch length to 12 mm (40 ps) the impedance $Z_{\|}/n = 0.2$ Ohm is obtained from a fit through the data (Fit 1, Fig. 1). An alternative fit gives $Z_{\|}/n = 0.138$ Ohm and a zero bunch length of 12.5 mm (Fit 2, Fig. 1). The fitted values for $Z_{\|}/n$ are close to the value of 0.15 obtained from the impedance model [3], according to:

$$\mathrm{Im}\left(\frac{Z_{||}}{n}\right)_{\mathrm{eff}} = \frac{(2\sqrt{\pi}\,\sigma_z)^3}{c^2\,T_0}\;k_{\|}(1), \qquad (4)$$

which relates the loss parameter $k_{\|}(1)$ to $Z_{\|}/n$ (T_0 is the revolution time).

TUNE SHIFT AND BEAM INTENSITY

Based on the impedance model the betatron tune shift can be estimated from

$$\Delta Q_\beta = \frac{I_B\,T_0}{4\pi\,E/e}\sum_n \beta_n\,k_{\perp\,n}, \qquad (5)$$

where I_B is the single bunch current, E is the beam energy, $T_0 = 7.685\ \mu$m is the revolution time, $k_{\perp\,n}$ is the kick parameter and β_n is the beta-function of component n. A list of the kick parameters are given in Ref. [3]. First measurements of the tune shift versus the single bunch intensity are reported in [4].

In Oct. 2010 the intensity dependent phase advance around the PETRA III ring has been obtained from orbit response measurements (ORM). For the measurements two different filling patterns with 240 and only 10 bunches with a total beam current of about 20 mA have been used. The phase advance around the ring for these ORM have been translated into a frequency shift [9]. The results are shown in Fig. 2 for the horizontal and vertical planes. The position along the ring is measured in meter starting from the center of PETRA III hall South-West (SW). All octants are labeled according to the compass points. All insertion devices are installed in the octant from NE to E. The intensity dependent tune shifts are summarized in Table 2.

Table 2: Betatron Frequency Shifts

	Horz. $\Delta f_x/\Delta I$ /kHz/mA	Vert. $\Delta f_y/\Delta I$ / kHz/mA
Impedance Budget	−1.28	
Impedance Model	−0.2	−0.7
Tune measurement Aug. 14, 2009	−0.228	−1.046
Phase measurement Oct. 21, 2010	−0.17	−1.2

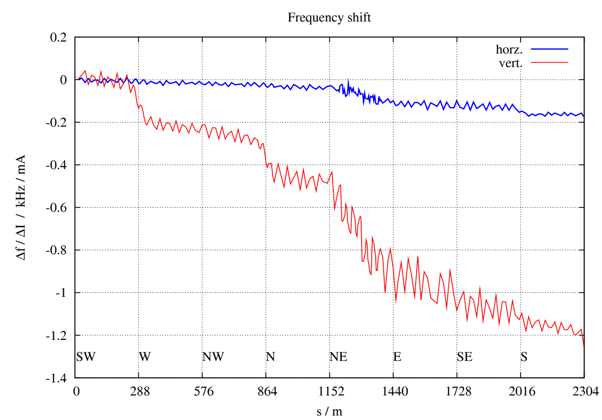

Figure 2: Measured intensity dependent frequency (betatron phase) shift along the PETRA III ring.

The frequency shift in the vertical plane is further analyzed to obtain the contribution to the total frequency shifts from certain areas of the ring. The wiggler section in the West and North and the "new octant" (NE - E) with all insertion devices are clearly visible in Fig. 3. A straight line was fitted through the data of the octant N-NE. A second line parallel to the first one indicates the end of the insertion device section. The vertical frequency shift between the two parallel lines is −0.325 kHz while the prediction from the impedance model was −0.265 kHz. In a similar way the vertical frequency shift for one wiggler section was determined from the data as −0.175 kHz while the predicted value is only −0.095 kHz. The rf section (12 seven cell cavities) is nearly not visible in the measured data which is not understood. The data for the octants E to SE and SE to S seem to be more noisy than the data for the other octants. The measurement of the frequency around the ring showed no unknown impedances and is in general in agreement with the impedance model.

At about zero chromaticity a maximum bunch current of 2.7 mA could be stored which is in agreement with the observed tune shift. Setting the vertical chromaticity to +6.0 and making use of the transverse multibunch feedback system it was possible to store a bunch current of 5.0 mA in PETRA III (measured on Feb 18, 2011). To avoid any damage to the BPM electronics it was not tried to fill bunch

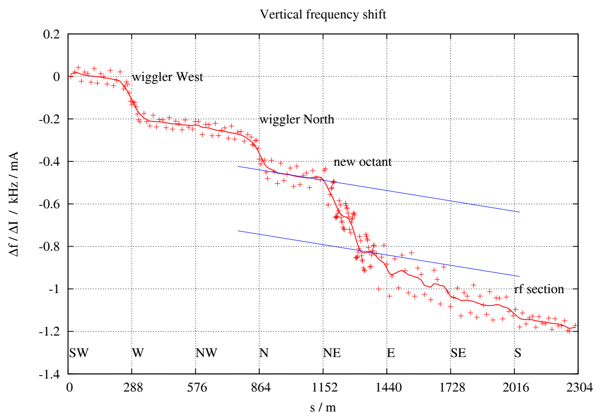

Figure 3: Measured intensity dependent vertical frequency (betatron phase) shift along the PETRA III ring. The crosses indicate the measured data at the beam position monitors. The solid line is a smoothed function through all the data points.

currents above 5.0 mA.

VERTICAL EMITTANCE INCREASE

In May 2010 a vertical emittance increase was first observed when PETRA III was operated with a large number of bunches and a bunch to bunch distance of 8 ns. In connection with the emittance increase tune spectra have been observed with characteristics which have been observed at other storage rings in connection with electron cloud effects [10]. In 2010 two filling schemes with 40x4 bunches (used in May and June) and 60x4 bunches (used in Aug.) were established which showed no emittance increase, see Ref. [5]. Already in 2010 there was an indication that there is a conditioning effect which allows the use of filling schemes with smaller bunch to bunch spacing without vertical emittance growth. In 2011 it was possible to use 240 equidistant bunches with a bunch to bunch spacing of 32 ns for user operation. Studies with a bunch train with 200 bunches and a bunch to bunch distance of 16 ns showed the threshold current for a vertical emittance increase was about 50 mA in May/June 2010 and about 75 mA in 2011. The integrated beam current increased from 133 Ah on May 1, 2010 to 577 Ah on May 1, 2011.

CONCLUSIONS

At PETRA III the measurement of the bunch length versus the single bunch intensity was used to estimate the effective longitudinal impedance $Z_{||}/n$, which is in the range of 0.14 to 0.2 Ohm. The fitted values are close to the predicted values from the impedance model. The rms bunch length at a bunch current of 2.5 mA is about 15 mm.

Previous measurements of the tune shift versus intensity have been complemented by a measurement of the intensity dependent phase advance around ring using orbit response measurements (ORM). These measurements showed no unknown impedances and are in general in agreement with the impedance model.

The design current of 100 mA has been achieved but with a different filling scheme than originally foreseen since a vertical emittance blow-up has been observed for filling schemes with a bunch to bunch spacing of 8 ns and 16 ns. In 2011 is was possible to use a filling scheme with 240 equidistant bunches with a bunch to bunch spacing of 32 ns, which is a clear improvement of the situation from a year ago. The secondary emission yield of the PETRA III vacuum chamber has been studied in detail, see [11].

ACKNOWLEDGMENTS

We would like to thank M. Bieler, J. Keil, A. Kling, G.K. Sahoo who provided valuable data and information for the report. Last but not least we would like to thank M. Lomperski for carefully reading the manuscript.

REFERENCES

[1] Editors: K. Balewski, W. Brefeld, W. Decking, H. Franz, R. Röhlsberger, E. Weckert, "PETRA III: A low Emittance Synchrotron Radiation Source", DESY 2004-035, February 2004.

[2] K. Balewski, "Commissioning of Petra III," Proceedings of 1st International Particle Accelerator Conference: IPAC'10, Kyoto, Japan, 23-28 May 2010.

[3] W. Chou, R. Wanzenberg *eds.*, ICFA Beam Dynamics Newsletter No. 45, April 2008

[4] R. Wanzenberg and K. Balewski, "Measurement Of The Tune Versus Beam Intensity At The Synchrotron Light Source Petra III," Proceedings of 1st International Particle Accelerator Conference: IPAC'10, Kyoto, Japan, 23-28 May 2010.

[5] R. Wanzenberg, "Emittance Growth and Tune Spectra at PETRA III", ECLOUD'10, Cornell University, Ithaca, NY, USA, Oct 8-12, B2010.

[6] H.-Ch. Schröder et al., "Bunch Length Measurements for PETRA III Light Source Storage Ring," Proceedings of 10th European Workshop on Beam Diagnostics and Instrumentation for Particle Accelerators, DIPAC'11, Hamburg, Germany, 16 - 18 May 2011.

[7] B. Zotter, "Potential - Well Bunch Lengthening," CERN-SPS-81-14-DI, CERN, Geneva, May, 1981.

[8] W. J. Corbett *et al.*, "Bunch Length Measurements In Spear3," Proceedings of Particle Accelerator Conference (PAC 07), Albuquerque, New Mexico, 25-29 Jun 2007, pp 4159.

[9] J. Keil, private communication, 2010

[10] K. Cornelis, "The electron cloud instability in the SPS," Mini Workshop on Electron Cloud Simulations for Proton and Positron Beams (ECLOUD'02), Geneva, Switzerland, 15-18 Apr 2002.

[11] R. Cimino et al., "SEY of Al Samples from the Dipole Chamber of PETRA III at DESY", IPAC'11, these proceedings