MEASUREMENT OF THE TUNE VERSUS BEAM INTENSITY AT THE SYNCHROTRON LIGHT SOURCE PETRA III

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

Abstract

At DESY the PETRA storage ring has been converted into a synchrotron radiation facility, called PETRA III. The commissioning with beam started in April 2009. The betatron tune versus beam intensity was measured for different configurations of the wiggler magnets which are installed in PETRA III to achieve the small emittance of 1 nm. These measurements are compared with predictions from the impedance model. The measured tune shift is well within the impedance budget and the design single bunch intensities of up-to 2.5 mA have been stored in PETRA III. The predicted vertical tune shift is about 30 % smaller than the measured one.

PETRA III

PETRA was built in 1976 as an electron - positron collider and was operated from 1978 to 1986 in this mode. From 1988 to 2007 PETRA was used as a preaccelerator for the HERA lepton hadron collider ring at DESY. After the end of the HERA collider physics program in June 2007 the PETRA ring was converted into a dedicated 3rd generation synchrotron radiation facility, called PETRA III [1]. The main design parameters are summarized in Table 1. The commissioning with beam started in April 2009, see Ref. [2].

Table 1: PETRA III design parameters

Parameter	PETRA III	
Energy / GeV	6	
Circumference /m	2306	
Emittance (horz. / vert.) /nm	1 / 0.01	
Bunch length / mm	12	
Total current / mA	100	
Number of bunches	960	40
Bunch population / 10^{10}	0.25	12
Bunch separation / ns	8	192

The octant between the halls North-East and East of the PETRA ring was completely redesigned to provide space for 14 insertion devices in nine double bend achromat (DBA) cells. The location of the new experimental hall is shown in Fig. 1. In the long straight sections West and North damping wigglers have been installed. Also a new vacuum system was installed in the seven "old" octants during the conversion of PETRA into a synchrotron radiation facility.

#rainer.wanzenberg@desy.de

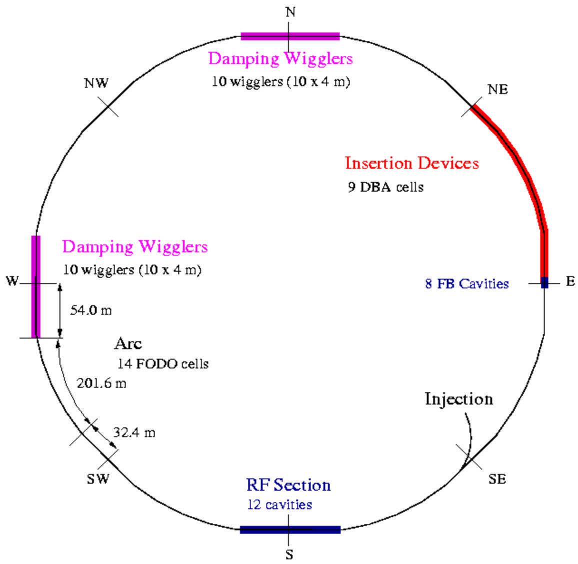

Figure 1: Layout of PETRA III.

The positron or electron beam interacts with its vacuum chamber surroundings via electromagnetic fields. These wake fields in turn act back on the beam and can lead to instabilities, which limit either the achievable current per bunch or the total current or even both. Multi-bunch instabilities are mainly caused by Higher Order Modes (HOMs) in the rf-cavities. Transverse and longitudinal feedback systems [1, 2] are used to avoid these coupled bunch instabilities. This report focused mainly on Transverse Mode Coupling Instabilities (TMCI) which can limit the single bunch current [3]. In the next section the impedance model in terms of kick parameters is presented, which are compared with measured betatron tune shifts for different single bunch intensities.

IMPEDANCE MODEL

The total impedance of PETRA III depends on the RF cavities, undulator chambers (7mm gap), bellows, beam position monitors, kickers, pump ports, the finite resistivity of the chamber and many other objects [3, 4]. In a collaboration of DESY, the University of Darmstadt, the Otto-von-Guericke University of Magdeburg, CANDLE (Yerevan University, Armenia), and the Budker Institut, BINP (Novosibirks, Russia) an impedance model of PETRA III has been built which includes more than 25 objects. The details of the numerical calculations and analytical estimates of the wakefields can be found in Ref. [4, 5, 6, 7, 8].

Wakefields, Kick Parameters

The interaction of the beam with its vacuum chamber surroundings via electromagnetic fields can be characterized with a wake potential. The impedance is the Fourier transform of the point charge wake potential. The wake potential of a bunch is the convolution of the point charge wake potential with the line charge density $\lambda(s)$ of the bunch. We will express the impedance of PETRA III in terms of the so-called loss and kick parameters, which are defined via the wake potential and the normalized beam line charge density. The loss parameter $k_{\parallel}$, and the kick parameter $k_{\perp}$ are defined as [9]:

$$k_{\parallel} = \int ds \;\; W_{\parallel}(s) \;\; \lambda(s) \tag{1}$$

$$k_{\perp} = \int ds \;\; W_{\perp}(s) \;\; \lambda(s) . \tag{2}$$

The total kick parameter of all elements is a weighted sum of the individual kick parameters and the beta functions of each component:

$$k_{\perp \mathrm{total}} = \frac{1}{\langle \beta \rangle} \sum_{n} \beta_n \; k_{\perp n} \; , \tag{3}$$

where $\langle\beta\rangle = 20$ m is the reference beta-function. The values of the total kick parameter for the horizontal and the vertical plane are summarized in Tab. 2. The results are based on a detailed analysis of the wakefields for more than 25 different elements [4, 5, 6, 7, 8].

Table 2: The total kick parameters of PETRA III

	Parameter	**Impedance Model**
Horizontal	$k_{\perp\mathrm{total}}$	750 V/pC/m
Vertical	$k_{\perp\mathrm{total}}$	2610 V/pC/m

Predicted Tune Shift

The instability threshold for transverse mode coupling instabilities can be estimated from the tune shifts of the lowest order transverse beam modes [3, 9] using the total kick parameters:

$$\Delta Q_{\beta} = \frac{I_B \; T_0}{4\pi \, E / e} \; \langle \beta \rangle k_{\perp \mathrm{total}} \; , \tag{4}$$

where I_B is the single bunch current, E is the beam energy, T_0 = 7.685 µs is the revolution time and $\langle\beta\rangle$ is the reference beta-function. Assuming that a total tune shift of $\Delta Q_{\beta}/Q_s$ = 0.5 is acceptable (Q_s = 0.049 is the synchrotron tune), one obtains a limit for the total kick parameter of 4800 V/pC/m, which is the transverse impedance budget. The impedance budget and the total kick parameters of the impedance model can be translated into expected betatron frequency shifts $\Delta f_{\beta} = f_0 \, \Delta Q_{\beta}$, ($f_0 = 1/T_0$ = 130 kHz) which are summarized in Tab. 3.

Table 3: Betatron frequency shifts

	Horz. Tune shift $\Delta f_x/\Delta I$	**Vert. Tune shift** $\Delta f_y/\Delta I$
Impedance Model	-0.2 kHz/mA	-0.7 kHz/mA
Impedance Budget	-1.28 kHz/mA	

MEASUREMENTS

The betatron tune shift versus single beam intensity has been measured several times during the commissioning phase of PETRA III. In Fig. 2 and Fig. 3 the results from Aug. 14, 2009 are show. By that date all wigglers were installed and the bunch length was expected to have the nominal values which was also assumed for the calculations.

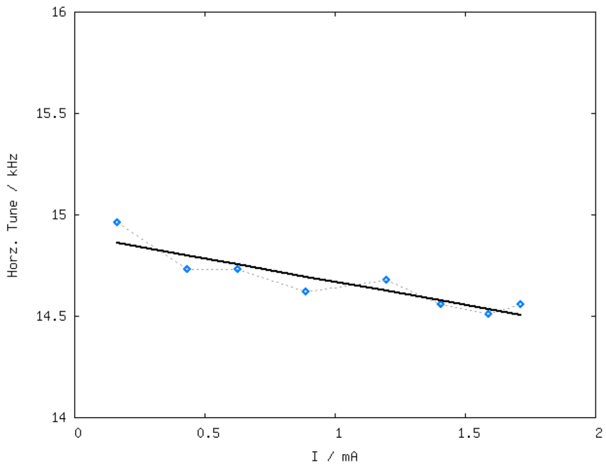

Figure 2: Horiz. tune shift versus intensity.

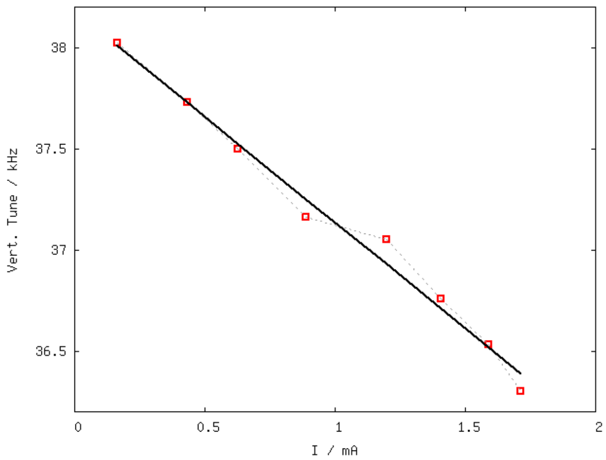

Figure 3: Vert. tune shift versus intensity.

The diamonds mark the measured betatron frequencies in Fig. 2 and 3 while the dark line is a least square fit through the data which was used to determine the tune shift versus intensity. The tune data were obtained from the tune spectrum which was obtained from the transverse multibunch feedback system. The tune shift versus intensity has also been measured before all wigglers were installed and the rms bunch length was shorter. All measurements are summarized in Tab. 4. The large vertical tune shift from the measurement without wigglers (June 6, 2009) has not been understood. The rf-voltage was only 10 MV during that measurement while all the other measurements in 2009 where done with an rf-voltage of 15 MV. The theoretical bunch length with no wigglers and an rf voltage of 10 MV is 10 mm, which is somewhat smaller than the design bunch length of 12 mm but cannot explain the much larger vertical tune shift.

The impedance of PETRA III is increased about a factor of two in the horizontal plane and a factor of 2.5 in the vertical plane compared with PETRA II, i.e. when PETRA was still operated as a preaccelerator for HERA.

Table 4: Measured betatron frequency shifts

	Horz. Tune shift $\Delta f_x/\Delta I$/kHz/mA	**Vert. Tune shift** $\Delta f_y/\Delta I$/ kHz/mA
Aug. 14, 2009, 20 wigglers	-0.228	-1.046
July 24, 2009, 12 wigglers	-0.295	-1.03
July 15, 2009 6 wiggler	-0.129	-0.91
June 6, 2009, No wigglers	-0.23	-1.73
June 30, 2006 PETRA II	-0.1	-0.4

CONCLUSION

The predicted horizontal betatron tune shift (see Tab. 3) is 13 % smaller than the measured betatron tune shift (Aug. 14, 2009) and the predicted vertical betatron tune shift is 33 % smaller than the measured betatron tune shift, which may still be regarded as reasonable agreement between theory and measurements. The measured tune shift (with all wigglers installed) is well within the impedance budget of -1.28 kHz/mA. On Aug. 18, 2009 the design single bunch current of 2.5 mA was archived in a store with one bunch, see Fig. 4.

Figure 4: PETRA III beam current on Aug. 18, 2009.

ACKNOWLEDMENT

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REFERENCES

[1] PETRA III: A low Emittance Synchrotron Radiation Source”, Technical Design Report, DESY 2004-035

[2] K. Balewski, “Commissioning of PETRA III”, IPAC 2010, these proceedings

[3] K. Balewski, R. Wanzenberg, “Beam Current Limitations in the Synchrotron Light Source PETRA III”, 9th European Particle Accelerator Conference, EPAC04,5 to 9 July, 2004 Lucerne

[4] K. Balewski, R. Wanzenberg, O. Zagorodnova “The Impedance Model of PETRA III”, ICFA Beam Dynamics Newsletter No. 45, April 2008

[5] E. Gjonaj, T. Lau, T. Weiland, R. Wanzenberg, “Computation of Short Range Wake Fields with PBCI”, ICFA Beam Dynamics Newsletter No. 45, April 2008

[6] A.K. Bandyopadhyay, A. Joestingmeier, A.S. Omar, R. Wanzenberg, “Wake Computations for Selected Components of PETRA III”, ICFA Beam Dynamics Newsletter No. 45, April 2008

[6] M. Ivanyan, E. Laziev, V. Tsakanov, A. Vardanyan, A. Tsakanian, R. Wanzenberg, “PETRA III Storage Ring Resistive Wall Impedance”. ICFA Beam Dynamics Newsletter No. 45, April 2008

[8] V. Smaluk, R. Wanzenberg, “Geometrical Impedance of the PETRA III Damping Wiggler Section”, ICFA Beam Dynamics Newsletter No. 45, April 2008

[9] T. Weiland, R. Wanzenberg: “Wakefields and Impedances”, in M. Dienes, M. Month, S. Turner (Eds.) Proceedings US-CERN School, Hilton Head 1990, Springer-Verlag, Berlin