HOM DAMPED NC PASSIVE HARMONIC CAVITIES AT BESSY*

W. Anders, P. Kuske, BESSY, Berlin, Germany

Abstract

HOM damped normal conducting passive harmonic cavities are developed and installed at the BESSY II storage ring. The mechanical and electrical parameters and the operation modes are described. The operational parameters are presented, showing good agreement of bunch lengthening, synchrotron frequency shift and increase of Touschek lifetime. Measured data of the transient shift of the synchronous phase driven by the harmonic cavities are presented. Due to the HOM dampers no coupled bunch modes of the beam are driven by the harmonic cavity.

INTRODUCTION

BESSY II is a high brilliance 3rd generation synchrotron light source running with electrons at 1.7 GeV. Typical lifetime at a current of 250 mA is in the order of 6-8 hours, depending on the settings of the insertion devices and the vacuum conditions. The lifetime is mostly dominated by the Touschek scattering driven by the small bunch volume. Small transversal beam dimensions are desired, but Touschek scattering can be reduced also by increasing the bunch length without influence on the measurements of the synchrotron light users.

Basic Ideas:

The bunch length is proportional to the square root of the gradient of the rf voltage at the position of bunch. By adding a harmonic voltage of the rf voltage, the gradient can be changed (Fig.1).

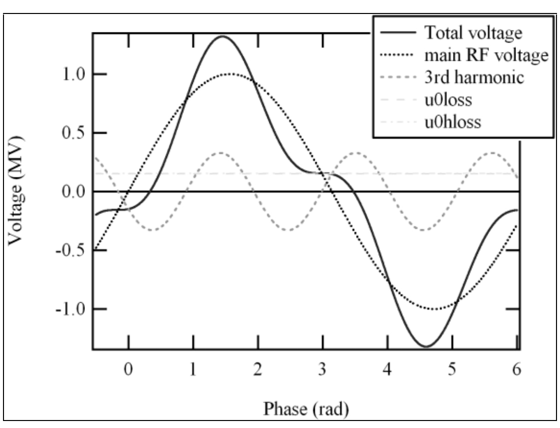

Figure 1. Plot of the voltages in the 500 MHz main cavities and in the 1.5 GHz cavities, summing up a zero slope to the beam at the synchronous phase.

When using a passive cavity at a harmonic frequency of the main rf (3rd harmonic at BESSY) the beam induces the voltage in the harmonic cavity having no accelerating fields at the position of the bunch. By tuning the resonance of the harmonic cavity little above or below the harmonic of the main rf, the phase of the harmonic voltage is changed ±90° resulting in decreasing (resonance above harmonic) or increasing gradient of the sum voltage leading to bunch lengthening or bunch shortening. The voltage in the passive harmonic cavity depends on the beam current (beam spectrum) and can be controlled by the resonance of the harmonic cavity using a plunger for tuning.

Harmonic Cavities with uneven Bunch Filling

With harmonic cavities the gradient of the rf can be made flat at the position of the bunch and lifetime increase up to a factor of 3 can be calculated [1] assuming even bunch filling. First tests with harmonic cavities at BESSY [2] and ALS showed much lower values. This is now well understood. When running the storage ring with an asymmetric filling the voltage of harmonic cavities increases while electron bunches are passing and decreases in the gaps of the filling. This results in varying gradient of the synchronous phase during a revolution. Taking this in account, the achievable gain in lifetime reduces. The parameters are calculated in a tracking code [3] and are in quite good agreement with the measurements.

Landau Damping with Harmonic Cavity

The gradient in synchronous phase gives a decoupling of the bunches and can be used for supressing coupled bunch modes [4]. At the BESSY storage ring all cavities are equipped with HOM dampers. Therefor no coupled bunch modes have to be supressed.

PARAMETERS OF THE HARMONIC CAVITIY

Mechanical Parameters

Figure 2 HOM damped cavity body

The harmonic cavity is a further development of the non damped cavities [2]. The cavity has a pillbox shape and three wave guides with cut off 1.85 GHz (Fig.2). The beam tube diameter is 60 mm and the total length is 200 mm. The cavity body is made from HC copper with inter-

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nal cooling channels. The typical water flow is 15 l/min. The copper plated stainless steel wave guides are half size wave guides at the corner of the body expanding to full size at the flanges with vacuum ferrite [5] for higher order mode damping. Because of space requirements the waveguides are bent to one side of the cavity. There are two plungers for tuning (only one necessary) and two diagnostic loops to do S_{12} measurements with beam for adjusting the resonance in respect to the beam harmonics .

Electrical Parameters

The main parameters of the cavity are given in table 1:

Parameter	Value	Unit
fundamental frequency	1,499	MHz
R/Q	62	Ohm
Q_o	13,900	
R_{eff}	860	k Ohm
typical operation voltage	60	kV/cavity
length of cavity	20	cm
number of installed cavities	4	

Table 1: Electrical Parameters of Cavity (measurements)

The cavity was cross checked by a mafia calculation to adjust the cut off of the wave guides. For reasons of symmetry only two wave guides were calculated. A prototype cavity was built and the length of the wave guides and the exact diameter of the body evaluated. The shunt impedance of the cavity was measured by bead pull measurement. The Q value and the higher harmonic modes were investigated by S_{12} measurements with a

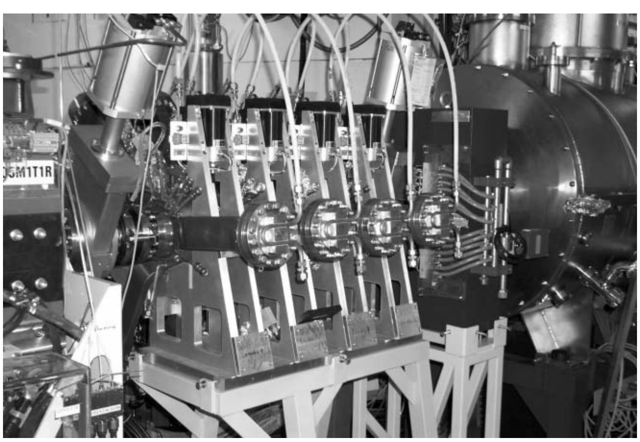

Figure3: Four harmonic Cavities installed at BESSY II

network analyser and cross checked by measurements with beam in single bunch mode. The Q value of the most powerfull TM011 is about Q=150. The TE111 mode has a moderate high Q=1,000 HOM near the cut off of the wave guides, but shunt impedance is low and the beam is not excited by this mode.

OPERATING MODES

The harmonic cavities are controlled by the EPICS control system. The operator can choose between four operation modes. The harmonic number h of the 3rd harmonic of the main rf is h=1200.

1. *Parking Position:* In this mode the plunger drive to a fixed position so that the resonance of the cavities is in the middle of two revolution harmonics, for example on harmonic number h=1195.5
2. *Set Mode:* Set mode is dedicated to machine studies. Both plungers can be driven to positions given by sliders on the control system.
3. *Lengthening Mode:* Lengthening mode is the standard mode in user operation. The resonance is tuned for decreasing the gradient of the total rf voltage for lengthening the bunch and increasing the lifetime of the beam. One plunger is on fixed position while the other is controlled by a voltage loop. The loop is programmed as a slow PI-loop on the EPICS control system. To avoid the cavity going to resonance and inducing very high voltages, the range of the position of the plunger to drive is limited to about 250 kHz to 750 kHz above 3rd harmonic of main rf corresponding to harmonic number h=1200.2 to h=1200.6. By limiting the range of the resonance, at low currents the desired voltage can not be achieved. This is no problem, because touschek scattering is reduced by low currents as well and lifetime is high enough.
4. *Shortening Mode:* This operation mode is a voltage loop similar to the lengthening mode, but the resonance of the harmonic cavities is set to values below the 3rd harmonic of the main rf to harmonic numbers of h=1199.4 to h=1199.9 giving a bunch shortening.

OPERATIONAL RESULTS

Four harmonic cavities are installed in the BESSY II storage ring (figure 2) and operated normally in bunch lengthening mode. The operational voltage per cavity of 55-60 kV means a sum voltage of 230 kV while the sum voltage of the accelerating 500 MHz rf cavities is 1.3 MV. Lifetime and bunch length were measured (figure 4) using a Hamamatsu C5680 streak camera. harmonic voltage decreases at currents lower than 150 mA due to the tuning limit of the plungers controlled by the voltage loop. The increase of the bunch length is measured as σ=15.6 ps going to σ=20.5 ps (30%). The synchrotron frequency shift fit to those data. The increase of toushek lifetime is 30% as well and in agreement with the increase of bunch length. Considering a gas scattering lifetime of 25 h at the time the measurements are done the total increase of lifetime is 20%. There is no heating of the beam by HOM´s driven by the harmonic cavities. The TE111 mode can be seen on the beam spectrum but due to its low shunt impedance there is no influence on beam stabilty.
Bunch shortening has been demonstrated in machine shifts in low alpha optic for generating coherent radiation with very short bunches.

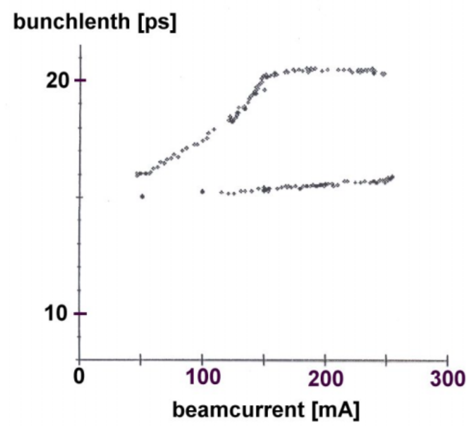

Figure 4: Bunch length with harmonic cavities at 225 kV (lengthening mode) and lower 30 kV (parking position). Main rf voltage is 1.3 MV. For beam currents lower than 150 mA the harmonic voltage decreases due to the tuning limit.

BESSY II is an electron storage ring. For ion clearing not all the 400 buckets of the ring are filled but a bunch train of 360 bunches and a ion clearing gap of 80 ns is used. The asymmetric filling produce a modulation of the harmonic voltage resulting in a change of the synchrounous phase of the bunches in respect of the position of the bunch (figure 5). The phase detector of the longitudinal feed back has a detection range of 30° phase, so the clearing gap has to be kept short.

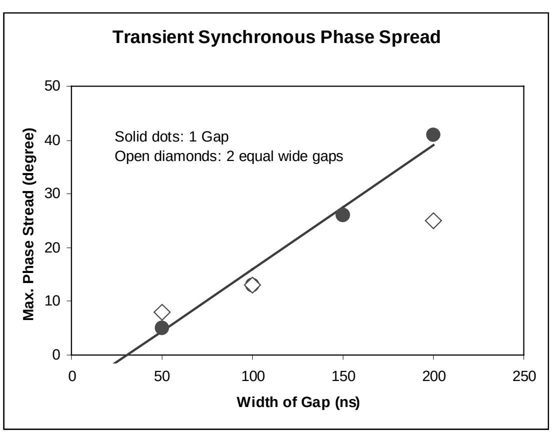

Figure 5: Transient phase shift of synchronous phase of the bunches due to influence of harmonic cavities at BESSY II. Total harmonic voltage is 225 kV, voltage of the fundamental rf cavities is 1.3 MV. Solid dots are measurements with one bunch train and one gap, open diamonds are measured using two symmetrical bunch trains and two gaps

Outlook

The voltage in the harmonic cavities is still below the optimum voltage. The harmonic voltage is limited by the power capacity of the cavities and the installation length in the storage ring. To achieve a higher voltage and having lower phase transients a super conducting harmonic cavity is ordered at ACCEL company and will be delivered this year. The SC cavity is a passive 1.5 GHz scaled version of the cornell type CESAR cavity. The design voltage is up to 500 kV and the length of the cryostat is 80 cm flange to flange. This is the same length as the four normal conducting cavities so that the cavities can be replaced on the same installation place of the storage ring.

Conclusion

Four passive 3^{rd} harmonic HOM damped cavities are installed and operated without problems in the BESSY II storage ring resulting in a lifetime improvement of overall 20% in normal user operation of the storage ring.

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