A LONGITUDINAL KICKER CAVITY FOR A BUNCH-BY-BUNCH FEEDBACK SYSTEM AT ELSA*

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Abstract

At the Electron Stretcher Facility ELSA [1] of Bonn University, a longitudinal bunch-by-bunch feedback system is currently being installed in order to damp multibunch instabilities and to enable a future intensity upgrade of up to 200 mA. As a main component, a longitudinal kicker cavity was developed and manufactured. The kicker requires a bandwidth of 250 MHz taking into account the bunch spacing of 2 ns at ELSA. Existing designs used at other facilities were optimized in view of the considerably larger bunch lenght at ELSA. The choice of 1.125 GHz as a center frequency is a result of these considerations. With the resulting low quality factor, the design had to be optimized in order to maximize the shunt impedance. The longitudinal feedback is succesfully working with the prototype installed in the stretcher ring. The design and detailed simulations of the geometry are discussed and laboratory measurements are presented.

INTRODUCTION

In a storage ring with many circulating bunches, multibunch instabilities (MBIs) limit beam quality and the storable beam current. These instabilities can be caused by the excitation of higher order modes of the accelerating cavities and wakefield generated by discontinuities of the vacuum chamber. Longitudinal MBIs are characterized by different modes of the coherent synchrotron oscillation, which are define by the phase relation of adjacent bunches and appear in the beam spectrum as upper and lower synchrotron sidebands of the revolution harmonics. Therefore, all MBIs are located in the frequency range of $f_{\mathrm{RF}}/2$ above and below f_{RF} and its harmonics [2].

Within the framework of a planned intensity upgrade, a longitudinal feedback system was installed at the ELSA stretcher ring [3]. A longitudinal feedback system detects the phase displacement of every bunch and computes a correction signal that can be applied on each bunch via a broadband longitudinal kicker cavity.

REQUIREMENTS FOR THE KICKER

To be able to damp all MBIs, the minimum bandwidth of the kicker cavity must be $f_{\mathrm{RF}}/2$, thus the center frequency f_{cent} of the cavity should be chosen as $(p \pm 1/4) \cdot f_{\mathrm{RF}}$ with an integer p [4]. However, the large bunch length of $2 \cdot \sigma \approx 6\,\mathrm{cm}$ in the ELSA stretcher ring limitates the choice of f_{cent}. To accelerate all particles of a bunch in the same direction

$$\frac{\lambda_{\mathrm{cent}}}{2} - 2 \cdot \sigma > \text{accelerating gap of the cavity}$$

must be valid, where λ_{cent} ist the wavelength of the resonance frequency. These considerations and the ELSA RF of 500 MHz yield to a f_{cent} of 1.125 GHz and a required bandwidth of 250 MHz, which corresponds to a loaded quality factor of $Q_{\mathrm{L}} = 4.5$.

General Layout

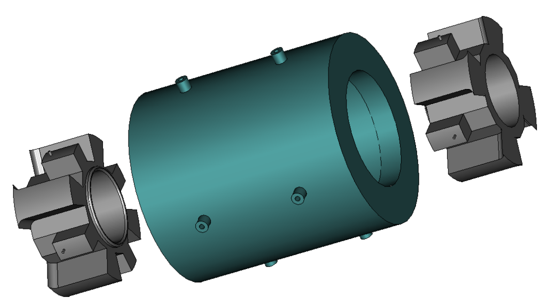

Figure 1: An exploded view of the kicker cavity.

The design of the kicker is shown in Figure 1 and is based mainly upon several design developments at other accelerators like PLS [5]. To fi the geometry to the requirements, simulations were carried out with *CST MICROWAVE STUDIO®*.

At first a pillbox cavity providing the required longitudinal electric fiel via its fundamental TM_{010} mode was designed.

To reliably damp all MBIs, it is further necessary to maximize the shunt impedance keeping the required bandwidth and center frequency. The radius of the beam pipes was chosen to 50 mm, due to the beam width at the position of the kicker and effective suppression of the higher order modes of the kicker.

To obtain the low Q-factor, four input and four output ports including a ridge waveguide geometry was chosen. To couple the RF signal into the kicker, a coax-waveguide transition with an impedance of 50 Ω was optimized regarding low reflection by using simulations with the *CST® Transient Solver*.

Finally, nose cones were introduced at the resonator-beam pipe transition, to get a higher effective electric fiel of the TM_{010} mode.

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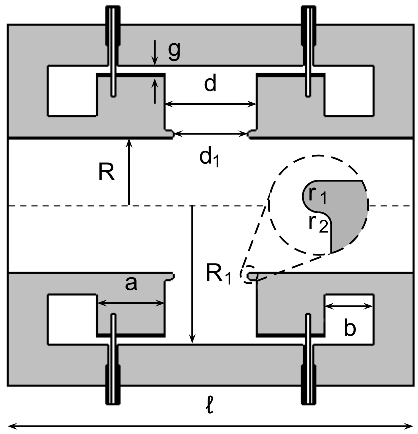

Figure 2: The geometry of the kicker cavity.

Table 1: Geometric parameters of the kicker cavity

Parameter	Value / mm
cavity length ℓ	300
beam pipe radius R	50
pillbox cavity radius R_1	103
cavity gap d	68
gap g	6.5
gap between nose cones d_1	54
ridge lenght a	50
$\lambda/4$-termination length b	36
nose cone radius r_1	2.5
nose cone radius r_2	2.0

With the aid of the simulations the shunt impedance could be maximized by enlarging the surface, and a high coupling of the resonator to external loads was assured.

The fina geometry is shown in Figure 2, the parameters can be found in Table 1.

MEASUREMENTS

After the kicker cavity was manufactured in-house, measurements were carried out to check the performance of the cavity and the results were compared with those obtained by simulations.

Reflection Coefficient

Scattering parameters of the cavity were measured. For this purpose, the four input ports are connected to a Vector Network Analyzer (VNA) (Rohde&Schwarz ZVC) via a broadband four-way power splitter (Microlab D4-55FN) and four cables of identical length, while the four output ports are matched with 50 Ω.

The measurement of the reflectio coefficien S_{11} is shown in Figure 3, where the measurement is compared to the simulated curve derived using the *CST® Transient Solver*. From these resonance curves, the center frequency f_{cent}, the bandwidth f_{BW} and so the Q-factor as well as the coupling coefficien κ can be extracted. These values as well as the design specification can be found in Table 2. The shift of the curve to higher frequencies was expected

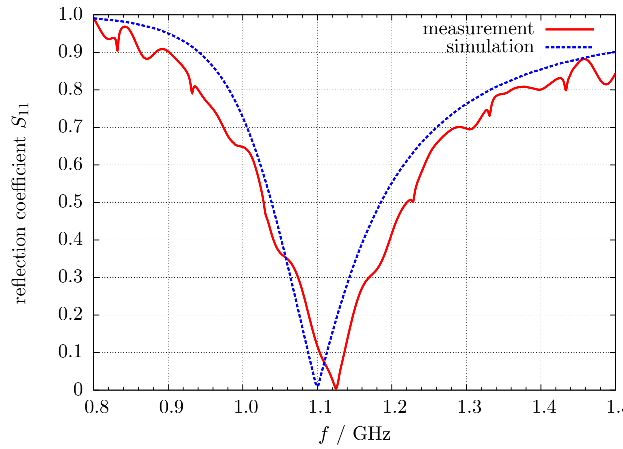

Figure 3: Comparison of the simulated and the measured reflectio coefficien S_{11}.

Table 2: Comparison of the measured parameters with the design values and the simulated ones.

Parameter	Specified	Simulated	Measured
f_{cent} / GHZ	1.125	1.100	1.125 ± 0.001
f_{BW} / GHz	0.250	0.260	0.302 ± 0.022
Q_{L}	4.5	4.22	3.7 ± 0.2
κ	1.00	1.02	1.01 ± 0.01

since a prototype of the kicker had been fabricated before to check how the kicker corresponded to the simulation. That is why the geometry of the new kicker was changed slightly to counteract the deviation mentioned above and to hit the required design specifications The origin of the frequency shift is still unknown.

Furthermore, the measured curve shows several dips not attributable to the kicker geometry. These are probably caused by standing waves of specifi frequencies that can form in the measurement setup (splitter and cables).

Electric Field

The longitudinal electric fiel distribution of the TM_{010} mode was measured by a bead ball perturbation method [6]. Therefor, the shifted resonance frequency caused by an iron ball with a diameter of 10 mm was measured at the cavity axis at different positions each 5 mm. The measurement setup is shown in Figure 4.

All four input ports were connected to the VNA via the power splitter, the output ports were terminated with 50 Ω. The VNA measures the resonant frequency in dependence of the position z of the ball which is adjusted by a stepping motor controlled by a computer.

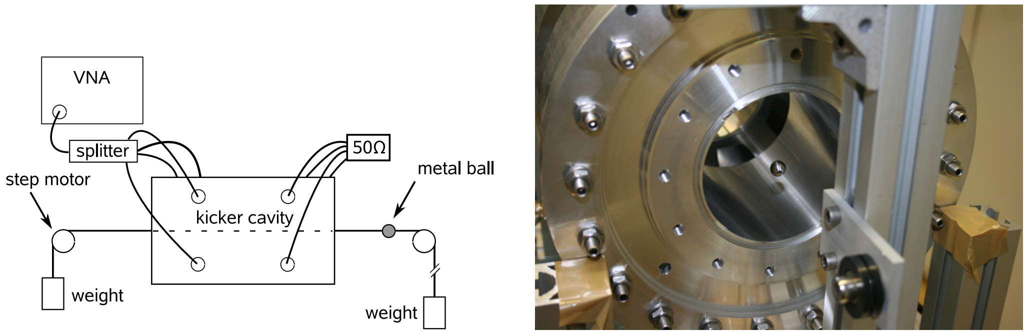

Figure 4: The experimental setup for measuring the electric fiel along the cavity axis using the bead ball perturbation method.

From the resulting data which was gained by averageing over approximately thirty measurement cylces, the unperturbed frequency f_0 and the perturbed frequency $f(z)$ can be extracted via fittin a gaussian shape. The longitudinal electric fiel on the axis normalized to the dissipated power $P_{\rm diss}$ in the cavity walls can be calculated as

$$\frac{|\vec{E}_0(z)|}{\sqrt{P_{\rm diss}}} = \sqrt{\frac{(f_0^2 - f(z)^2)\, Q_0}{2\,\pi\,\alpha_{\rm ball}\, f(z)^2\, f_0}} \ ,$$

where $Q_0 = (1+\kappa)\cdot Q_{\rm L}$ is the quality factor, $\alpha_{\rm ball} = 3/2 \cdot \varepsilon_0 \cdot V_{\rm ball}$ the bead ball constant [7] with the vacuum permittivity ε_0 and the bead ball volume $V_{\rm ball}$. In Figure 5, the simulated and the measured electric

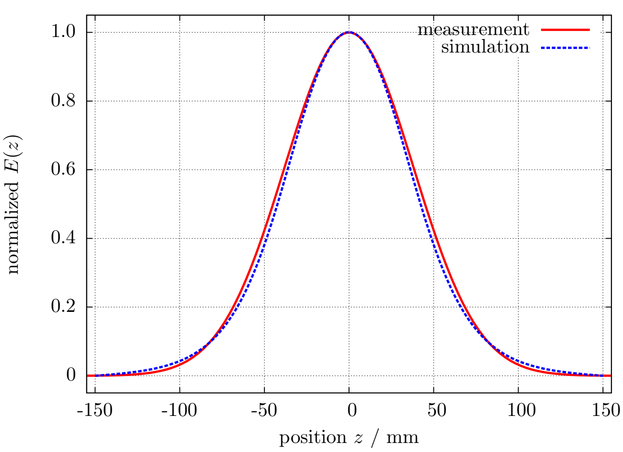

Figure 5: Comparison of the electric fiel on the cavity axis as a function of the longitudinal position z.

field normalized to the maximum value are shown. The measured fiel distribution agrees well with that of the simulation.

Shunt Impedance

Using the measured longitudinal electric fiel $E_0(z)$ and taking into account the oscillation of the electric RF fiel during the passage of the highly relativistic electrons through the cavity, the shunt impedance $R_{\rm S}$ can be calculated via the effective voltage normalized to $P_{\rm diss}$

$$\frac{U_{\rm eff}}{\sqrt{P_{\rm diss}}} = \int_{-\ell/2}^{\ell/2} \frac{|\vec{E}_0(z)|}{\sqrt{P_{\rm diss}}} \cos\left(\frac{2\,\pi\, f_0\, z}{c}\right) \mathrm{d}z \ ,$$

where ℓ is the lenght of the cavity:

$$R_{\rm S} = \frac{1}{2}\left(\frac{U_{\rm eff}}{\sqrt{P_{\rm diss}}}\right)^2 \ .$$

The shunt impedance determined by using the measured data is $(355 \pm 28)\ \Omega$.

CONCLUSION

With the simulations carried out, the required bandwidth, the coupling factor and the center frequency could be obtained with the fabricated kickers. The shunt impedance was maximized. A further increasement is not possible due to the beampipe radius, the required center frequency and loaded Q-factor.

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