COMPARISON OF RF DEFLECTING STRUCTURES FOR FUTURE BEAM PHASE SPACE STUDIES AT PITZ*

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Abstract

A detailed characterization of the longitudinal and transverse phase space of the electron beam provided by the Photo Injector Test Facility at DESY in Zeuthen (PITZ) is required to optimize the photo injectors for Free-Electron Laser (FEL) applications. By means of the RF deflector the transverse slice emittance and the longitudinal phase space can be analysed. In this paper we compare two standing wave and one travelling wave deflecting cavities. We present comparisons of beam dynamic simulations of the measurements with these cavities and the prospect layout of the diagnostics for the beam phase analysis.

INTRODUCTION

The main research goal of PITZ is the development of electron sources with minimized transverse emittance [1]. The current setup at PITZ permits us to measure transverse emittance averaged along a bunch using the Emittance Measurement System (EMSY) [2].

At PITZ2 the application of an RF deflector is planned. The deflector position is about 9 m from the gun. The next 3.5 m of a space is taken by a tomography module. At about 15.5 m a spectrometer based on a dipole magnet is positioned. The RF deflector in the combination with the tomography module gives a possibility to analyse the transverse emittance of a longitudinal slice. Using a dispersive arm the longitudinal beam phase space can be completely reconstructed.

In Fig. 1 the idea of the RF deflector is illustrated: the RF deflector voltage is zero for the longitudinal centre of the bunch and gives a linear transverse deflection to the rest of the bunch. The maximum displacement of the edge slice Y_B can be estimated by the expression

$$Y_b = \frac{\pi \cdot f_{RF} \cdot L \cdot L_B \cdot V_\perp}{c \cdot E / e}, \qquad (1)$$

where f_{RF} is the frequency of the deflecting voltage, $V_\perp$ is the peak transverse voltage, L – drift space after the deflector, and E is the beam energy in eV units [3].

The resolution length L_{res} can be estimated as the bunch length L_B divided by the number of slices N_{slices} which we can resolve at the screen and the number of the slices is Y_B divided to transverse beam size σ_B.

$$L_{res} = \frac{L_B}{N_{slices}} = \frac{L_B \cdot \sigma_B}{Y_B} = \frac{\sigma_B \cdot c \cdot E / e}{\pi \cdot f_{RF} \cdot L \cdot V_\perp} \qquad (2)$$

Because of the limited size of the screen (Y_B) to improve the resolution length we have to minimize the beam transverse size (σ_B). That is done by a matching section in the tomography module.

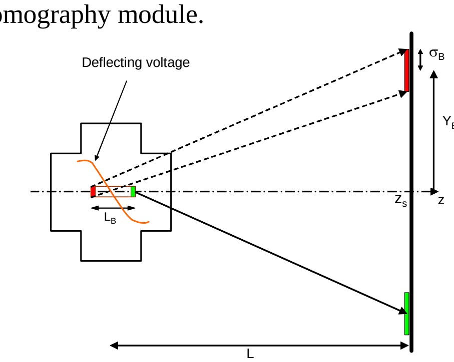
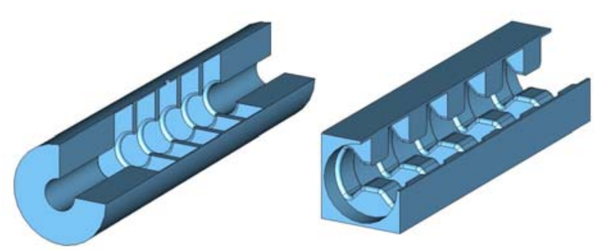


Figure 1: The principal of the RF deflector work.

RF DEFLECTORS

For PITZ2 diagnostics we have reviewed three kinds RF deflectors. Two of them are standing wave resonators and one is a travelling wave cavity. We analyzed electron beam parameters after passing the cavity and compared the results for the different deflectors.

We have chosen the well known cavity which is a disk loaded waveguide [3]. It has five cylindrical cells, see Fig.2a. We scaled it to the frequency of 1.3 GHz. This cavity operates at TM11 mode. Another standing wave cavity is a new one designed by V. Paramonov. The shape of the structure is shown in Fig.2b. It operates at TE11 mode having frequency of 1.3 GHz. More details about this cavity are given in [4].



a) b)

Figure 2: General view of “classical” cavity (a) and “Paramonov” cavity (b)

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The third cavity is based on LOLA-IV - transverse deflecting cavity [5], Fig.3. We have adapted it for our beam: scaled it from 2.856 GHZ to 1.3 GHZ and changed the length from 3.6 m to 0.7 m. It has 9 cells and two additional cells for a coupler and a load.

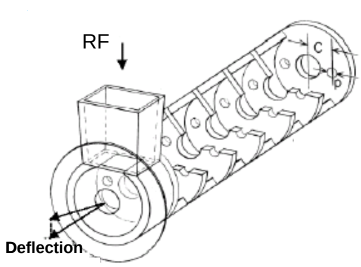

Figure 3: Travelling wave cavity based on LOLA-IV

In the Table 1 we compare the deflector's parameters for two operations regimes. First – to analyse the longitudinal phase space at a distance of about 6 m from the deflector in the dispersive arm. Second – to observe the beam at the screens in the tomography module at a distance of 2–4.2 m from the deflector. In the table Q denotes unloaded quality factor, "Field build up" is the time which field needs to reach about 99% of it's maximum value [5].

Table 1: Deflector's parameters

	Classic cavity		"Paramonov" cavity		Travelling wave cavity	
Frequency GHz	1.3	1.3	1.3	1.3	1.3	1.3
Distance, m	2-4.2	6	2-4.2	6	2-4.2	6
$V_{\perp}$, MV	up to 1.8	0.6	up to 1.8	0.6	up to 1.8	0.6
Q	21000	21000	15000	15000	19000	19000
P_{RF}, MW	up to 1	0.12	up to 0.17	0.02	up to 9.1	1.01
Field build up, μs	~20	~20	~20	~20	~0.2	~0.2

BEAM DYNAMICS

Beam dynamics simulations have been performed for comparing the cavities presented above. For our simulations we use a beam with the parameters corresponding to PITZ2: energy 32 MeV, emittance about 1 mm mrad. The bunches (up to 800) are grouped in a trains which repeats at frequency up to 10 Hz. The beam is passing through the deflector and is observed at the points of screens positions in the tomography module and in the dispersive section after the dipole. The transverse beam size on the screens in the tomography module is about 0.12 mm (RMS).

For correct longitudinal phase space measurements in the dispersive arm we have to minimize distortion of the longitudinal momentum distribution during passing the deflector. We compared the longitudinal momentum distribution on the dispersive arm screen for the different deflectors. In Fig.4 momentum distributions for the three types of the deflectors are compared with the initial momentum distribution (before deflector). One can not see any large difference between these three cases. The estimated resolution of the method is about 25 keV/c. This value we can roughly resolve from the presented distributions. The rise or fall edge in the initial momentum distribution is about a few keV. They are transformed to the edges with the width of about 25 keV.

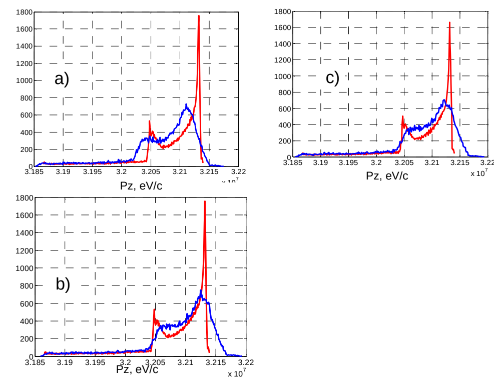

Figure 4: Longitudinal momentum distribution. Red line corresponds to the initial distribution (before deflector). Blue line is the distribution for the beam passed through a) "classic" cavity, b) "Paramonov" cavity, c) traveling wave cavity.

The transverse slice emittance measurements require high similarity of the initial longitudinal charge distribution to the transverse charge distribution (along deflecting direction) after deflector. This requires a linear dependence of the deflecting voltage to the position inside the bunch. This requirement is provided by a quite large RF wave length (230 mm) in the cavities in comparison with the bunch length (8 mm). Beside of that the cavity has to generate a minimum distortion in the transverse direction (perpendicular to the deflected direction). This is necessary for correct emittance measurements. In Fig.5 we compare the longitudinal charge distribution of the initial beam and transverse charge distribution for the beam passed through the deflecting cavity at a distance 4.21 m from the deflector. We add a special gap (0.15 mm) in the initial distribution in our simulations. This helps us to estimate the resolution length by observing the gap in the transverse distribution of the deflected bunch. One can see that all cavities provide transverse bunch charge profile (which corresponds to the deflected direction) similar to the initial longitudinal charge profile. Because of the 100 % modulation in the final distribution we can estimate that the resolution length for these measurements is about the gap width (0.15 mm).

The transverse momentum distributions (perpendicular to the deflection direction) practically are not changed in the deflector. The transverse beam emittance before and after the deflector is changed from 0.96 π mm mrad to 1.02 π mm mrad. So, the simulations show minimal influence from the deflectors to transverse beam parameters (perpendicular to the deflection direction).

DIAGNOSTIC COMPLEX FOR THE PHASE SPACE ANALISYS

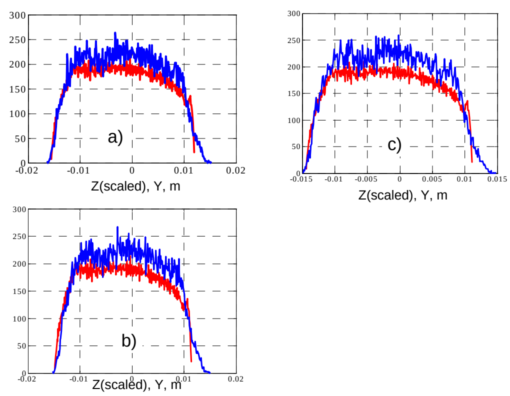

Figure 6: Charge distributions. Red line corresponds to the initial longitudinal distribution (before deflector). Blue line is the transverse distribution in the deflected direction for the beam passed through a) "classic" cavity, b) "Paramonov" cavity, c) traveling wave cavity.

The layout of the prospect system for slice emittance measurements is shown in Fig.7. It contains a deflecting cavity, a tomography module and a dispersive section. The beam is matched by quadrupoles on the entrance of the tomography section so that α and β functions are periodically repeated from screen to screen [6]. This

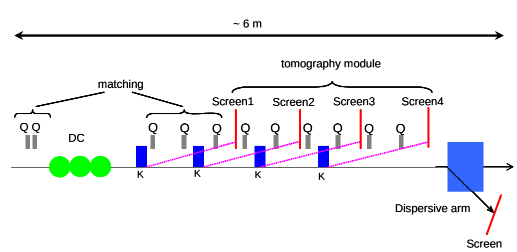

Figure 7: Prospect diagnostic for longitudinal slice emittance measurements.
Q – quadruple; K – kicker; DC – deflecting cavity

permits us to analyse the beam more easily. The bunch deflected in the RF cavity in vertical direction is deflected by a kicker in horizontal direction to the screens. The screens are located off axis. The kicker pulse duration is less than 100 ns with rise(fall) time about 10 ns. This allows to observe the deflected bunches only. The few bunches which are distorted in the deflecting cavity by a rising or falling RF field don't hit the screens and are lost in the beam line. All other bunches are passing through the tomography module and accepted at the beam dump.

The value of the resolution length (0.15 mm) is estimated in the previous paragraph for the last screen (number 4). If we keep the RF power in the deflector the resolution length for other screens will be worse. This follows from the Eq. 2. The distance from the deflector to the first screen is 1.95 m (4.21 m to the fourth screen) and according to the Eq. 2 we have the resolution length at the first screen of about 0.35 mm (about 25 slices). This number of slices is high enough for a detailed analysis of the bunch at PITZ2.

The diagnostic of the longitudinal beam phase space is based on the dipole magnet. Downstream the tomography module we plan to set the dipole magnet. The distance between the deflector and the screen in the dispersive arm is about 6 m. Bunches are deflected by a dipole magnet and are analysed on the screen. During the dispersive arm operation the magnets in the tomography module will be off.

THE DISSCUSION OF THE RESULTS

All presented cavities can be used for the beam phase space analysis. We have considered their advantages and disadvantages. The main differences are between standing wave and travelling wave cavities. The first one request less RF power (see Table 2) and is easy in control. But the travelling wave cavity gives us a possibility to analyse a single bunch in a bunch train. We plan to work with the beam bunch repetition frequency up to 9 MHz (period ~0.11 µs). Because of a short filling time in travelling wave cavity (0.2 µs) we can "take" a single bunch, direct it to a screen and distort 1-2 other pulses in the train only. This possibility is important for the analysis of the beam parameters fluctuation in the train from bunch to bunch. Also we can make the beam monitoring during tuning the beam. We decided to use the travelling wave cavity in combination with the tomography module for the possibility to analyse single bunches.

CONCLUSION

The deflectors reviewed in this paper satisfy the requirements for the beam diagnostic at PITZ2. We consider to use the travelling wave deflecting cavity due to its additional possibility to analyse single bunches in a bunch train. We expect the possibility to measure longitudinal slice transverse emittance with ~25 slices in the tomography module. For longitudinal phase space measurements in the dispersive arm we estimate the resolution as ~25 keV/c.

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