FERMI LOW-ENERGY TRANSVERSE RF DEFLECTOR CAVITY

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Abstract

FERMI@Elettra is a soft X-ray fourth generation light source under development at the ELETTRA laboratory. The single bunch beam is produced by a photo-injector, then accelerated up to 1.2 GeV by a linear accelerator, and finally transported to the undulators, where the free electron lasing occurs. In order to completely characterize the beam phase space by means of measurements of the bunch length and of the transverse slice emittance two deflecting cavities will be positioned at two points in the linac. One will be placed at 1.2 GeV (high energy), just before the FEL process starts; the second at 250 MeV (low energy), after the first bunch compressor (BC1). In this note we describe the low-energy bunch deflection, which allows the efficiency of the first bunch compressor to be measured. Furthermore the RF design and electromagnetic simulations are presented, with a complete evaluation of the wakefields inside the structure.

INTRODUCTION

Complete characterization of the beam phase space by means of measurements of the bunch length and of the transverse slice emittance are important tasks for the FERMI FEL project [1]. Deflecting cavities, such as iris loaded wave guide or multi cell standing wave structures, are a powerful tool to reach this aim. Two deflecting cavities will be positioned at two points in the linac: one at 1.2 GeV (high energy), just before the FEL process starts; the second at 250 MeV (low energy), after the first bunch compressor (BC1). Figure 1 shows the linac layout where the transverse deflecting structures are indicated with RF DEFL1 and RF DEFL2. In this note we describe the low-energy bunch deflection following the work done for the high-energy RF deflector [2]. The deflector following BC1 will operate in a vertical deflecting mode to allow measurements of the horizontal slice emittance and bunch length. This will allow the efficiency of the first compression to be estimated. The deflector will be followed by a multi screen emittance measurement station and the quadrupole magnets in-between the OTR screens will be separated by $\pi/4$ phase advance. The screen at a phase advance of $117deg$ with respect to the RF deflector will be used for the bunch length measurements. The worst phase advance on the screens is at $200deg$ downstream of the deflector. The vertical β-functions at the deflector and screens positions are $12m$ and $5m$, respectively. Deflecting cavities, such as iris loaded wave guide or multi cell standing wave structures, are a powerful tool to reach this aim. In particular the deflector at low energy will work at a maximum beam energy of 250 MeV and with an S-band RF frequency of $2998MHz$ (the operating frequency of the linac). Table 1 contains the beam parameters for the Medium Length Bunch option (MLB) [1]. These have been used for the calculations in the following sections.

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Table 1: Beam parameters for Medium Length Bunch (MLB) option.

Beam Parameter		Unit
Total Charge	0.8	nC
Bunch Length (RMS)	210	μm
Total Normalized Emittance	2.0	μm
Max Beam Energy	250	MeV

BUNCH LENGTH MEASUREMENTS

If the finite transverse emittance of the bunch is taken into account, then the RMS beam size at the screen after the deflection can be estimated by the quadratic summation of the RMS non-deflected particle transverse size distribution and of the RMS beam size in the pencil beam approximation estimated by following [3] and references therein:

$$\begin{aligned}\sigma_{y,S,\epsilon} &= \sqrt{\sigma_{y,0}^2 + \sigma_{y,s}^2} \\ &= \sqrt{\frac{\epsilon_N \beta_S}{\gamma} + \left[\frac{eV_\perp}{E}\sigma_z\left(\frac{\omega_{RF}}{c}\cos\varphi_{RF}\right)R_{34}\right]^2} \qquad (1)\end{aligned}$$

Figure 2 shows the calculated beam size as a function of $V_\perp$ according to eq. 1. The observations at the OTR screens satisfy the requirements for both the worse beam optics ($200deg$) and the better beam optics ($117deg$). Finite emittance contribute to the increase of the beam size measured at the screen and Eq. 1 shows that if $V_\perp$ is sufficiently large the relative error due to finite emittance can be reduce, i.e. a relative error less than 3% requires a deflecting voltage $V_\perp \geq 1.6MV$.

Maximum Peak Voltage Specification

The measurement of the transverse slice emittance requires short portions of the bunch length to be resolved at the screen after the bunch is deflected. Assuming a uniform longitudinal charge distribution, the slice length at the

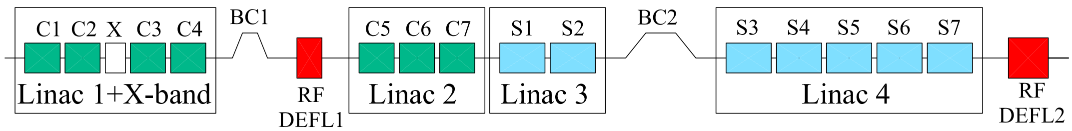

Figure 1: Sketch of the FERMI linac layout with the positions of the RF deflectors.

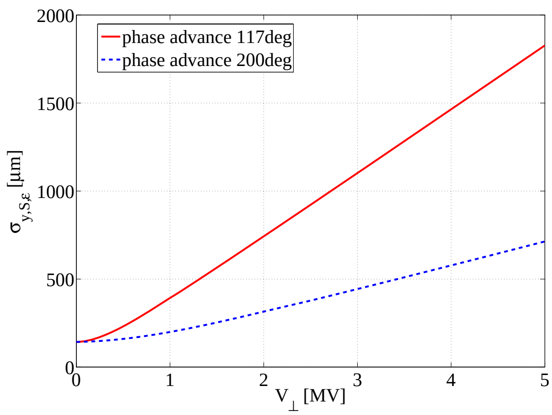

Figure 2: The calculated beam size at the OTR screens as a function of the deflector peak voltage $V_\perp$. Solid and dashed lines represent the beam size as calculated at the best and least effective screen locations.

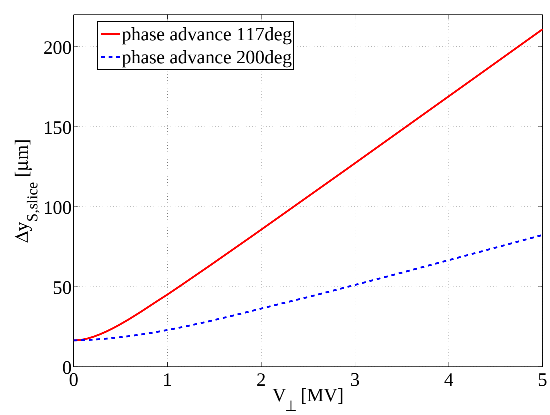

Figure 3: Slice length at the OTR screens as a function of the deflecting voltage $V_\perp$ considering a division of the bunch into 30 longitudinal slices.

screen is given by:

$$\Delta y_{S,slice} = \frac{\sqrt{12}\sigma_{y,S,\epsilon}}{30} \tag{2}$$

Figure 3 shows the slice length at the OTR screens as a function of deflecting voltage $V_\perp$ considering a division into 30 slices of the whole bunch. As seen in [3] assuming $10\mu m$ RMS resolution of the screen then a contrast of 70% allows the detection of the $40\mu m$ slice length. Going back to figure 3, in the approximation of the uniform bunch current distribution, a minimum peak voltage of $2.3MV$ is required in the worse optical condition for the bunch vertical deflection.

RF DEFLECTOR SPECIFICATIONS

The RF design and the choice between different options was done taking into account the following constraints:

- the minimum peak voltage $V_\perp \geq 2.3MV$;
- the working RF frequency $f_{RF} = 2998MHz$;
- RF pulse length $t_{RF} \leq 3\mu s$;
- the maximum available RF power $P_{RF} = 5MW$;

The minimum peak voltage $V_\perp = 2.3MV$ can be achieved by both traveling wave (TW) or standing wave (SW) structure. We have chosen to scale the deflecting SW structure developed for the SPARC project [4] to the FERMI operating frequency. Such a choice allows us reaching better resolution and flexibility. This could become important if one contemplates use of an even shorter bunch as in the single bunch compressor scheme which was proposed as a possible option for FERMI@Elettra [5].

RF DEFLECTOR DESIGN

The deflector is a SW structure composed of 5-cells operating on the π-mode. Table 2 lists the main RF parameters of the deflector such as the quality factor Q, the transverse shunt impedance $R_\perp = V_\perp^2/2P_{RF}$, the filling factor t_f when the coupling coefficient $\beta = 1$, and the nearest mode frequency separation Δf. L is the total length of the RF structure. The deflector geometric parameters are plotted in figure 4. They are the iris radius a, the iris thickness t, period L_{cell}, the coupling cell radius R_1 and the side radius R_2, R_3, the rectangular coupling window dimension x_w, y_w.

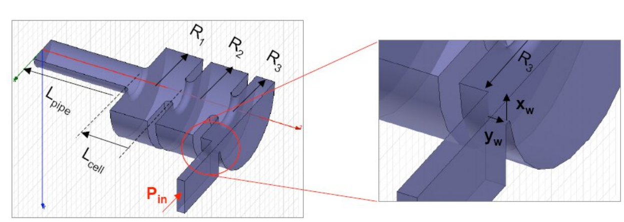

Figure 4: Schematic view of the standing wave deflector [6].

The proposed RF structure is about $0.5m$ long and satisfies all the RF constraints.

Table 2: Main RF and structure parameters of the transverse deflector.

L_{cell}	$50.00\ [mm]$	f_{RF}	$2.998\ [GHz]$
R_1	$58.25\ [mm]$	Q	15600
R_2	$57.60\ [mm]$	$R_\perp$	$2.4\ [M\Omega]$
R_3	$57.45\ [mm]$	P_{diss}	$150\ [W]$
a	$18\ [mm]$	τ	$0.8\ [\mu s]$
y_w	$8\ [mm]$	$V_\perp @5[MW]$	$4.9\ [MV]$
x_w	$19.5\ [mm]$		
t	$9.5[mm]$		

WAKEFIELDS EVALUATION

A special procedure has been used in order to find the longitudinal and transverse wake functions, as reported in [7]. Numerical results obtained with the ABCI code [8] have been fitted with exponential functions taken as perturbations to the well-know diffraction regime wake functions [9], namely ($0 < z \leq 3.5mm$):

$$w_{||}(z) = 0.36[e^{-21.03z^{0.499}} + e^{21.03z^{0.56}}]\frac{Z_0 c}{\sqrt{2}\pi^2 a}\sqrt{\frac{1}{z}} \quad (3)$$

and

$$w_\perp(z) = 0.37[0.85e^{-66\ z} + e^z]\frac{2^{3/2} Z_0 c}{\pi^2 a^3}\sqrt{z} \quad (4)$$

Figure 5 shows the longitudinal (top) and transverse (bottom) wake potentials as obtained using the parametrized wake functions in eqs. 3, 4 and as computed with ABCI. There is a very good agreement between the "analytical" and numerical results.

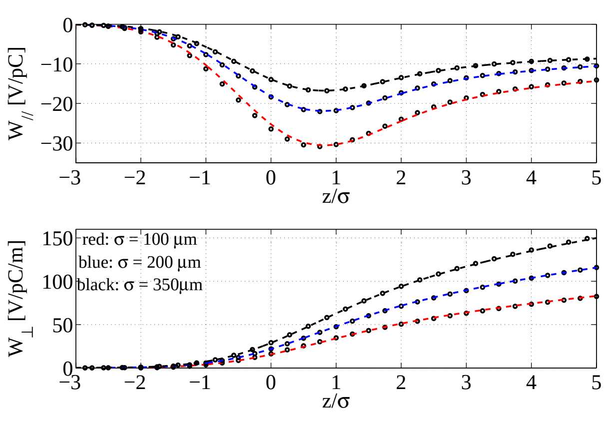

Figure 5: Longitudinal (top) and transverse (bottom) wake potentials for Gaussian bunches as obtained using the parameterized wake functions (eqs. 3, 4) (dashed lines)and as computed with ABCI (black circles).

In order to estimate the effects due to the wakefields on the electron beam we have considered a bunch with $\sigma = 200\mu m$ and calculated the loss factor $k_{||}$ and the kick factor $k_\perp$. The results are the following: $k_{||} = 15.5keV/nC$ and $k_\perp \approx 0.1\mu rad/nC/mm$ at $250MeV$. Thus, the passive influence of the low-energy deflector on the electron beam can be neglected.

CONCLUSION

In this paper the study of the electron bunch deflection at around $250MeV$ for the measurement of the bunch length and of the transverse slice emittance is performed. As a conclusion, a peak voltage of $2.3MV$ for the RF deflector is completely satisfactory for the bunch length measurement. The same specification allows for a resolution of 30 slices over the MLB with an intensity contrast of about 70%. A complete RF design has also been performed, taking also in account of the wakefields effects. The wakefield estimations have shown that the passive influence of the low-energy deflector on the electron beam can be neglected.

ACKNOWLEDGMENT

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