DEFLECTING MODE OPTIMIZATION FOR A HIGH ENERGY BEAM DIAGNOSTIC TOOL

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Abstract

Travelling wave and standing wave deflectors are well known RF devices that nowadays are used in particle accelerators as a beam diagnostic tool. They will also be implemented in the FERMI@Elettra project, a soft X-ray fourth-generation light source under development at the ELETTRA laboratory, and used to completely characterize the beam phase space by means of measurements of bunch length and transverse slices emittance. In particular, one deflector will be placed at low energy (250 MeV) and another at high energy (1.2 GeV), just before the FEL process starts. In this note we collect our experience and simulation on this last device, making a comparison between the most relevant options we have considered to satisfy our RF and space constraints. Basic cell design is discussed for both the travelling and standing wave choice. In particular, three different modes, the 2/3π, 5/6π and the quasi π, are analyzed for the travelling wave option while an 11 cells design in π mode is proposed for the standing wave case. For both cases sensitivity analysis and other relevant RF parameters are given.

INTRODUCTION

The use of the deflecting cavity in the FERMI@ELETTRA Project is represented in figure 1; the beam is stretched and forced to collide with an optical transition radiation (OTR) screen that converts the beam signal into an optical signal suitable for digitizing [1]. One deflector will be placed at low energy (250 MeV) and another at high energy (1.2 GeV), just before the FEL process starts. We have already completed a complete RF and mechanical design of a 5 cells π-mode standing wave deflector for the low energy case [2]. For the high energy deflector we have analyzed four structures which we present in this work. The main constraints of the RF device are listed in table 1. In order to reach the minimum peak transverse voltage, V_t, required with the maximum available RF power P_{RF}, we have optimized the deflecting mode considering both standing wave and travelling wave structures. Other important constraints are the filling time which must be less than the RF pulse t_{RF}, and the total length L_{tot} which must be less than $2m$. The working frequency, f_{RF}, is tuned to that of the FERMI linac.

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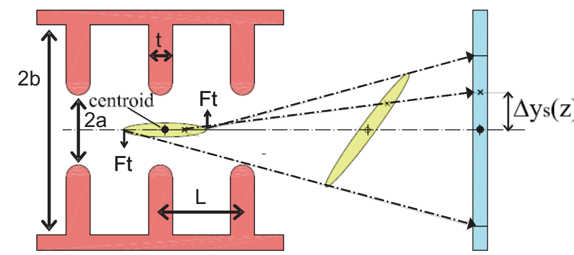

Figure 1: Deflection of the electron bunch: the centroid remains on axis while at the end of the bunch the transverse force F_t has opposite directions.

Table 1: High Energy Deflector main constraints: f_{RF} is the working frequency, V_t is the integrated deflecting voltage, P_{RF} is the maximum available power, t_f is the filling time and L_{tot} is the space available.

f_{RF}	2.998GHz
V_t	20MV
P_{RF}	15MW
t_f	$\leq 3\mu s$
L_{tot}	$\leq 2m$

BASIC CELL DESIGN

The basic cell design has been performed using the HFSS electromagnetic code [3]. The cell parameters for every choice are the cell length L, the iris radius a, the cell maximum internal radius b and the iris thickness t (figure 1). For every configuration L has been chosen in order to achieve the synchronism condition between the electromagnetic field and the electrons travelling at the speed of the light c. The iris radius and the thickness radius has to be $a = 12.5mm$ and $t = 8mm$ for each option. The maximum internal radius b has been varied with the code to tune the cell to the working frequency. In this paper we discuss the 2/3π, 5/6π and the quasi π modes for the travelling wave option and an 11 cells design for the standing wave case. The dispersion diagram of the four structures that we have considered is plotted in figure 2.

TRAVELLING WAVE DEFLECTOR

In a travelling wave structure the deflecting voltage is given by:

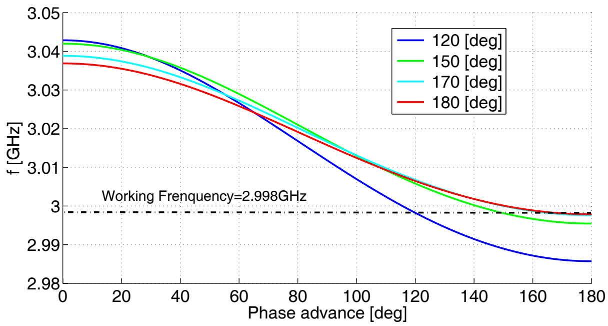

Figure 2: Dispersion diagram of the four choices considered; each basic cell has been tuned to the working frequency $f_{RF} = 2.998GHz$.

$$V_t = \sqrt{2\,\alpha\,l}\left(\frac{1-e^{-\alpha l}}{\alpha\,l}\right)\sqrt{P_{RF}\,r_t\,l} \qquad (1)$$

where α is the field attenuation constant, r_t is the shunt impedance and l is the deflector length. Differentiating equation 1 with respect to αl we find that the maximum deflecting efficiency is obtained for $(\alpha\,l)_{opt} = 1.26$ as for the travelling wave accelerating structure. Despite this, we can not increase the deflector length l as we have a space constraint L_{tot}. Since the group velocity v_g is related to the attenuation by $\alpha = \frac{\pi f}{Q v_g}$ where Q is the quality factor, we can optimize the deflecting mode and so approach the ideal deflector efficiency by reducing v_g. But we must respect the t_{RF} constraint taking in account for the travelling wave structure the filling time is given by $t_f = \frac{l}{v_g}$.

$\frac{2}{3}\pi$ *Mode Option*

We report the geometrical and RF parameters for the $\frac{2}{3}\pi$ solution in table 2; we have placed $\beta_g = \frac{v_g}{c}$ where c is the speed of the light.

Table 2: RF Parameters for the $\frac{2}{3}\pi$ Deflecting Mode

L	33.33 $[mm]$		Q	13536
b	59.33 $[mm]$		R_t	29.9 $[M\Omega]$
a	12.5 $[mm]$		R_t/Q	2.21 $[K\Omega]$
t	8 $[mm]$		α	0.147 $[1/m]$
l	2.04 $[m]$		β_g	0.0157

We need 61 cells in order to achieve $20MV$ with this option, so a deflector length of $l = 2.04m$.

$\frac{5}{6}\pi$ *Mode*

The geometrical and RF parameters for the $\frac{5}{6}\pi$ solution are reported in table 3; with this option we need 42 cells and a deflector length of $1.75m$ to achieve $20MV$.

Table 3: RF Parameters for the $\frac{5}{6}\pi$ Deflecting Mode

L	41.66 $[mm]$		Q	15851
b	59.52 $[mm]$		R_t	29.4 $[M\Omega]$
a	12.5 $[mm]$		R_t/Q	1.86 $[K\Omega]$
t	8 $[mm]$		α	0.222 $[1/m]$
l	1.75 $[m]$		β_g	0.00890

Quasi π *Mode*

The $\frac{17}{18}\pi$ solution is the slowest mode we have considered; the geometrical and RF parameters for the are reported in table 4.

Table 4: Rf Parameters for the $\frac{17}{18}\pi$ Deflecting Mode

L	47.22 $[mm]$		Q	17197
b	59.66 $[mm]$		R_t	26.6 $[M\Omega]$
a	12.5 $[mm]$		R_t/Q	1.55 $[K\Omega]$
t	8 $[mm]$		α	0.594 $[1/m]$
l	1.37 $[m]$		β_g	0.00308

With this solution we need 29 cells and $l = 1.37m$ to satisfy our constraint on V_t.

Mode Efficiency Comparison

We can define the mode efficiency E_ϕ as:

$$E_\phi = \frac{V_t(\alpha l)_\phi}{V_t(\alpha l)_{opt}} \qquad (2)$$

where $\phi = \frac{2}{3}\pi, \frac{5}{6}\pi, \frac{17}{18}\pi$. E_ϕ is represented in figure 3 and it is listed in table 5 with t_{RF} and $(\alpha l)_\phi$. The slowest mode $\frac{17}{18}\pi$ has the best efficiency, very near to the maximum theoretical deflector efficiency achievable; it would need $l = 2.12m$ to reach the maximum efficiency. We can see from table 5 that all modes satisfy the t_F constraint.

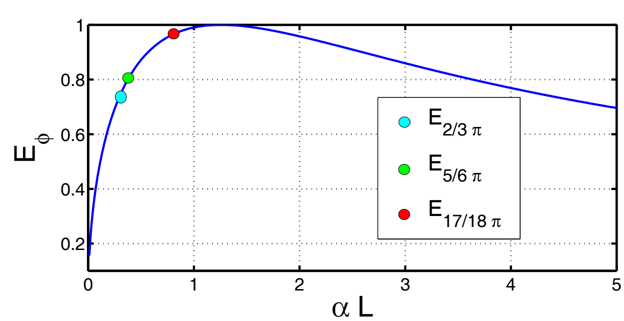

Figure 3: Efficiency of the three travelling modes presented; the blue line is the theoretical deflecting voltage normalized.

Table 5: t_F and efficiency parameters for the travelling wave mode simulated.

	$t_F[\mu s]$	$(\alpha l)_\phi$	E_ϕ
$\frac{2}{3}\pi$	0.43	0.30	0.74
$\frac{5}{6}\pi$	0.66	0.39	0.81
$\frac{17}{18}\pi$	1.48	0.81	0.97

STANDING WAVE DEFLECTOR

The deflecting voltage for a standing wave structures is defined by:

$$V_t = \sqrt{2P_{RF}R_t} \quad (3)$$

For an n-cell structure we have:

$$V_t = \frac{1}{k}\int_0^{nL} \frac{\partial E_z}{\partial y}\bigg|_{z=0} e^{jkz}dz \quad (4)$$

where $k = \frac{2\pi f_{RF}}{c}$. We have planned to use two standing wave deflectors dividing the total $P_{RF} = 15MW$ in two branches of $7.5MW$ and then we have evaluated how many cells we need to satisfy our constraint on V_t. Table 6 lists the basic cell dimension, the cell number and the main RF parameters of the standing wave structures which we have considered.

Table 6: RF Parameters for the Standing Wave π Deflecting Mode

L	$50.00\ [mm]$
b	$59.73\ [mm]$
a	$12.5\ [mm]$
t	$8\ [mm]$
Q	17837

Cells	$R_t\ [M\Omega]$	$V_t[Mv]$
5	3.28	7.01
7	4.59	8.3
9	5.91	9.41
11	7.22	10.4

We can see that two structures of 11 cells placed in series can sustain a deflecting voltage of $20MV$. In this case we have verified that the frequency separation of nearest mode excited is $\Delta f = 2.4MHz$. The filling time for the standing wave device is given by $t_f = 3\tau = 2.82\mu s$ where $\tau = 2\frac{Q_L}{\omega}$ and Q_L is loaded quality factor. In our case we obtain critical coupling and hence $Q = \frac{Q_L}{2}$.

SENSITIVITIES

We have reported the sensitivities obtained analyzing the basic cell for every option in table 7; the external and the iris radius are the most sensitive parameters. We have also verified that the 11 cells standing wave configuration does not loose efficiency when one perturbs the maximum internal radius by up to of $15\mu m$.

ELECTRIC PEAK FIELDS

In table 8 we report the peak fields of the structures examined. We observe that the peak electric field increases for slower modes in the travelling wave case; also for the standing wave structure the maximum electric field peak is acceptable.

Table 7: Sensitivity for the $\frac{2}{3}\pi$, $\frac{5}{6}\pi$, $\frac{17}{18}\pi$ Travelling Wave Mode and the π Standing Wave Mode

	$\frac{2}{3}\pi$ Mode $[\frac{MHz}{mm}]$	$\frac{5}{6}\pi$ Mode $[\frac{MHz}{mm}]$	$\frac{17}{18}\pi$ Mode $[\frac{MHz}{mm}]$	π Mode $[\frac{MHz}{mm}]$
a	-16.4	-15.4	-14.4	-13.8
b	-48.6	-48.4	-48.0	-48.3
L	2.6	1.7	1.4	1.27
t	-2.4	-0.97	-0.55	-0.41

Table 8: Electric Peak Fields of the Deflecting Structures Examined

Mode	$P_{RF}[MW]$	$\lvert E\rvert[MV/m]$
$\frac{2}{3}\pi$	15	23
$\frac{5}{6}\pi$	15	32
$\frac{17}{18}\pi$	15	54
π (11 cells)	7.5	47

CONCLUSION

In this work we presented all the options we have considered in order to satisfy the constraints of the FERMI@ELETTRA project high energy deflector. In the travelling wave options we have analyzed the $\frac{2}{3}\pi$, the $\frac{5}{6}\pi$ and the quasi π mode. Reducing the group velocity we have almost reached the optimization, keeping satisfied the constraint on the filling time. We have also considered a standing wave structure working in π mode. That last option is very interesting because it minimizes the length constraints; for this reason a prototype is under construction at Sincrotrone Trietse S.C.p.A.

REFERENCES

[1] P. Emma, J. Frisch, P. Krejcik, *A transverse RF deflecting structure for bunch length and phase diagnostic*, Proceedings of PAC 2001, Chicago, USA, 2001

[2] P. Craievich et al., *FERMI Low Energy Transverse RF Cavity*, Proceedings of EPAC 2008, Genova, Italy, 2008.

[3] `http://www.ansoft.com/products/hf/hfss/`.