

EUROFEL-Report-2005-DS1-013

EUROPEAN FEL Design Study



Deliverable N°: D1.15

Deliverable Title: Design of an RF Deflector for SPARC

Task: DS-1

Author: David Alesini, INFN

Contract N°: 011935

**Project funded by the European Community
under the “Structuring the European Research Area” Specific Programme
Research Infrastructures action**

DESIGN OF AN RF DEFLECTOR FOR SPARC

Contact person: David.Alesini@Inf.infn.it

INTRODUCTION

The SPARC RF deflector has been designed to completely characterize the six dimensional beam phase space at the end of the SPARC photoinjector [1]. It is a five cells resonant structure operating on the π -mode at 2.856 GHz. The design has been done using 2D and 3D electromagnetic codes like MAFIA and HFSS.

RF DEFLECTOR DESIGN PROCEDURE

The required transverse deflecting voltage $V_T=1$ MV [1,2] can be, in principle, achieved by either travelling wave (TW) or standing wave (SW) structures. In our case the choice between the two solutions is related to the maximum available input power (2 MW as shown in later), space (about 0.4 m) and RF pulse length ($\approx 5 \mu s$). After a careful comparison between the two structures [1,2] it has been, finally, proposed to adopt a 5 cells SW structure operating on the π -mode. This structure allows reaching a maximum transverse deflecting voltage of more than 3 MV with low peak surface electric field. Moreover, since the power to feed the cavity can be split out from the SPARC RF gun klystron waveguide by a 10 dB directional coupler, the circulator and the directional coupler itself preserve the klystron and the RF gun from the cavity reflected power.

2D Design

The 2D geometry is sketched in Fig. 1. The inner radius (a) has been chosen equal to the SPARC beam pipe radius (20 mm), the cell length (d) equal to $c/2f_{RF}$ (with c speed of light) to synchronize the bunch passage to the π -mode deflecting field, and the external radii (b_1, b_2, b_3) have been tuned to set up the resonant frequency at 2.856 GHz by using the electromagnetic (e.m.) codes MAFIA [3] and HFSS [4]. The iris thickness (t) has been chosen at a reasonable value of 9.5 mm, considering that it is not a critical dimension in term of power dissipation, frequency sensitivities and deflection efficiency. The final dimensions, parameters and frequency sensitivities, are reported in Table 1 assuming copper material.

The 5-cell deflecting structure fulfils all of the requirements for the SPARC case . In fact, it allows

operating with a very low input power $P_{RF} \leq 2MW$ obtaining contemporary low peak surface electric field and resolution length of the order of $12 \mu m$. These parameters permit the measurement of the longitudinal beam profile with good accuracy, even considering the possibility of longitudinal compression factors up to 20. Moreover the operation at low input power ($P_{RF} \leq 2MW$) allows to simplify the power line design as discussed later.

Table 1: 5-cells structure dimensions, parameters and sensitivities.

Dimensions [mm]		Parameters	HFSS	Sensitivities $kHz / \mu m$	
b_0	60.04	f_{res} [GHz]	2.856	$\partial f_{res} / \partial b_0$	-9.6
b_1	59.93	Q_0	16540	$\partial f_{res} / \partial b_1$	-10.5
b_2	60.72	R_T [$M\Omega$]	2.44	$\partial f_{res} / \partial b_2$	-8.1
a	20.00	R_T/Q [$M\Omega$]	148		
t	9.5	E_{peak} / \sqrt{P} [$V / mW^{-1/2}$]	$3.33 \cdot 10^4$		
d	52.48				

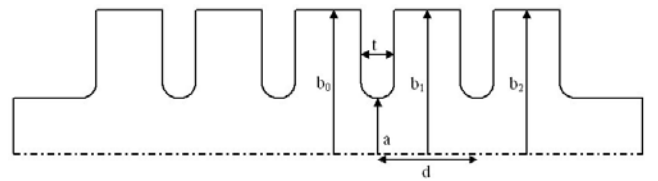


Fig. 1: 2D profile of the 5-cells SPARC deflecting structure.

3D Design

The 3D simulations of the deflecting structure have been performed using HFSS and have been oriented to:

- 1) design the input coupler;
- 2) design the tuning system;
- 3) design the system to split the frequency of the 90 deg tilted polarity with respect to the working one.

The coupler has been inserted in the central cell in order not to excite the $4/5 \pi$ mode that has the

frequency nearest to the π mode and no field in the central cell itself. To reduce the coupler window dimensions and, therefore, the perturbation to the deflecting field on the central cell, the smaller dimension (34mm) of the standard S-band waveguide has been tapered to the dimension of 16 mm. The HFSS simulated structure is plotted in Fig. 2. We have simulated one quarter of the deflector with the proper boundary conditions. The dimensions of the coupler window (w) and of the central cell radius (b_0) have been tuned in order to obtain a coupling coefficient $\beta = 1$, a resonant frequency of the whole system equal to 2.856 GHz and to preserve a good B field flatness. The plot of the transverse B and E field on axis is shown in Fig. 3 while the reflection coefficient at the input port is shown in Fig. 4.

A complete analysis has been performed in order to calculate the frequency separation between the working deflecting mode and the other modes. It is important to distinguish between the four deflecting TM_{110} -like modes with the same polarity of the working one and those related to the 90 deg tilted polarity. Concerning the first category, the nearest $4\pi/5$ mode at 2.860 GHz is (in principle) not excited by the coupler and it can, therefore, perturb only marginally the deflecting field. The nearest mode with the same polarity that can be excited by the coupler is the $3\pi/5$ mode whose frequency is about +20 MHz away from the working one. To prevent the excitation of the modes with the 90 deg tilted polarity, two longitudinal rods (of radius $r=1.5$ mm) crossing off-axis the cells have been inserted, as shown in Fig. 5. The resonance frequencies of such modes are shifted far enough from the operating mode frequency (even if, in principle, they are not excited by the central coupler). The calculated frequency shift given by the rods is about +50 MHz while the working mode is practically unperturbed.

Finally, for the tuning system, we have proposed to use cylindrical tuner of $r=5$ mm that gives a sensitivity of about 500 kHz/mm on the resonant frequency of each cell. The possible machining errors can be therefore compensated by a penetration of the tuners of few mm.

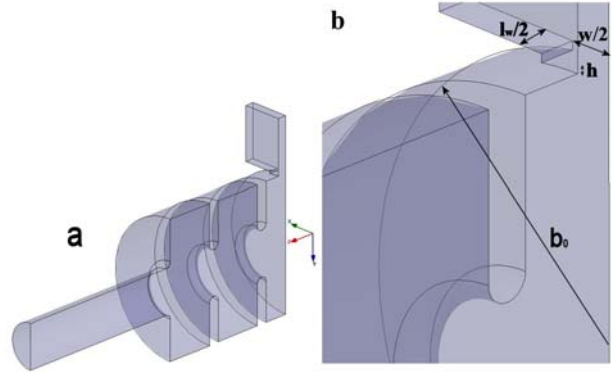


Fig. 2: 3D HFSS simulated structure with coupler.

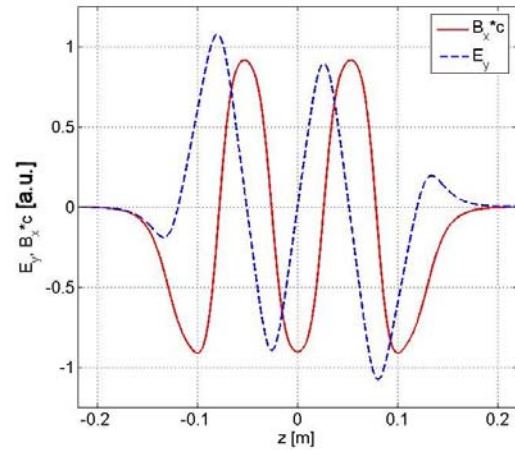


Fig. 3: Transverse B and E field of the 5-cells deflecting cavity.

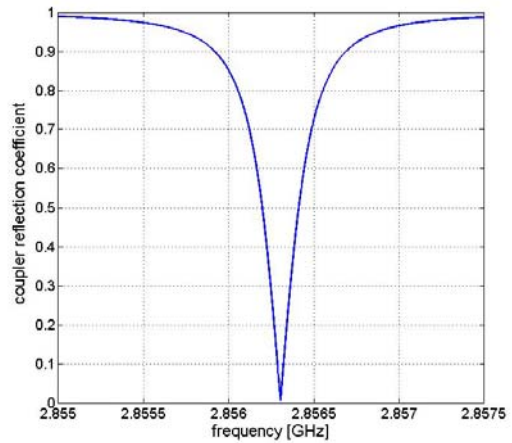


Fig. 4: Reflection coefficient at the input port obtained with HFSS.

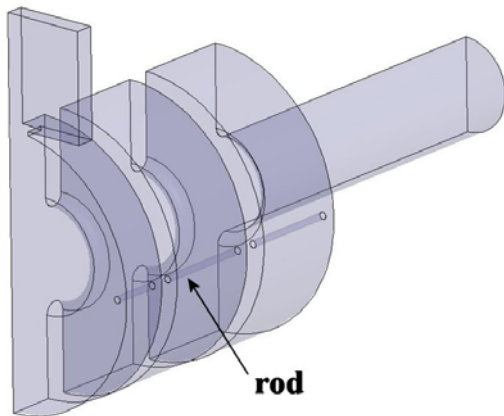


Fig. 5: Longitudinal rods to split the 90 deg tilted polarity.

transverse phase space characterization at SPARC”, to be submitted to NIM.

[3] www.cst.de.

[4] www.ansoft.com.

Power feeding system

The 2 MW input power needed to feed the structure can be split out from the first klystron waveguide feed with a 10 dB directional coupler, as illustrated in Fig. 6. The circulator and the directional coupler assure that every reflected power from the deflector does not interact with the power feeding the RF gun. Moreover the high power switch is included to allow the deflecting field to be completely turned off.

Because of the reduced power needed for the structure it is possible to simply employ a waveguide system with air-fill, thus reducing the costs of the entire power feed system.

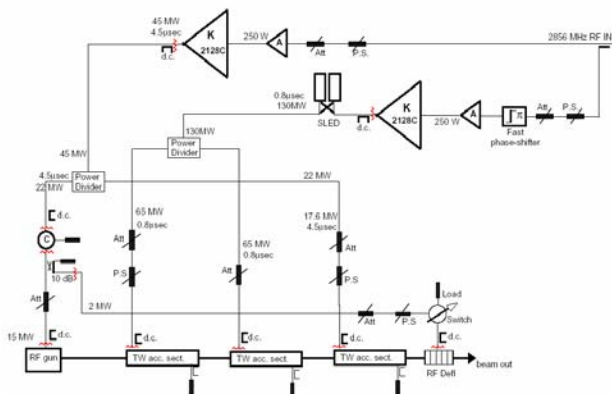


Fig. 6: Sketch of the RF deflector power feed system.

REFERENCES

- [1] D. Alesini and C. Vaccarezza, “Longitudinal and transverse phase space characterization at SPARC”, SPARC note, 2003.
- [2] D. Alesini, et al., “RF Deflector design and measurements for the longitudinal and