AN RF DEFLECTOR DESIGN FOR 6D PHASE SPACE CHARACTERIZATION OF THE *SPARC* BEAM *

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Abstract

The characterization of the longitudinal and transverse phase space of the beam provided by the *SPARC* photoinjector is a crucial point to establish the performance quality of the photoinjector itself. By means of an RF deflector and a dispersive system, the six dimensional beam phase space can be analysed. A five-cell SW aluminum prototype of the *SPARC* RF deflector has been realized and tested. We report in this paper the design issues together with the RF measurement results. The simulation results of the 6D phase space reconstruction of the *SPARC* beam are also presented.

INTRODUCTION

The characterization of the longitudinal and transverse phase space of the beam at the exit of the third LINAC section, (E ≅ 150MeV), is a tool to verify and tune the photoinjector performance. With a RF deflector it is possible to measure the bunch length and, together with a dispersive system, the longitudinal beam phase space can be reconstructed [1]. A schematic layout of the measurement is reported in Fig. 1. The effect of the RF deflector is null in the longitudinal center of the bunch and gives a linear transverse deflection to the bunch itself. If we consider the beam distribution and a drift space of length L after the deflector, the transverse kick results in a transverse displacement of the centroid of the bunch slice. The displacement is proportional to the slice longitudinal offset L_B, and RF voltage according to the expression:

$$x_B = \frac{\pi f_{RF} L L_B V_\perp}{cE/e} \qquad (1)$$

where $V_\perp$ is the peak transverse voltage, and E/e is the beam energy in eV units.

Equation (1) shows that the longitudinal bunch distribution can be obtained by measuring the transverse bunch distribution at the position z_s. To measure the bunch length with a proper accuracy, the "displacement" x_B has to be greater than the rms transverse beam size σ_x. The resolution length L_{res} can be defined, therefore, as the relative slice longitudinal position that gives, on the screen, an x_B equal to σ_x. From Eq. (1) we can calculate the transverse voltage $V_\perp$ necessary to achieve the desired resolution:

$$V_\perp = \frac{\sigma_x cE/e}{\pi f_{RF} L L_{res}} \qquad (2)$$

A voltage $V_\perp$= 1.0 MV has been chosen for the RF deflector, obtaining a resolution of ≈ 2 %. The complete longitudinal phase space measurement can be obtained adding the effect of a dispersive system. In this scenario, the bunch is vertically deflected by the RF deflector and horizontally by a magnetic dipole. The dispersion properties of the dipole allow characterizing the energy distribution of the bunch and the total longitudinal phase space can be displayed on the screen. The transverse phase space characterization is obtained measuring the beam slice emittance in both the transverse planes with the quadrupole scan technique.

SIMULATION RESULTS

A 150k particle beam obtained from PARMELA [2] simulation at the end of the linac section has been tracked with the ELEGANT code [3] along the SPARC transfer lines.

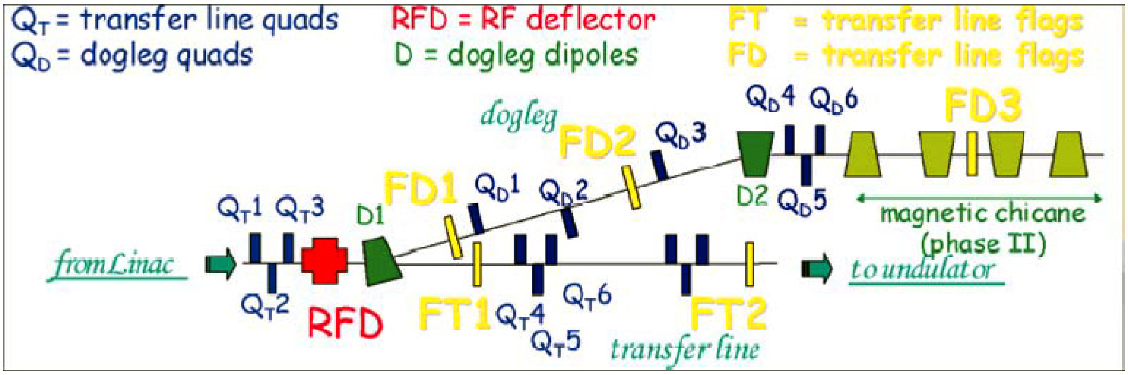

Figure 1: SPARC measurement layout for high energy beam characterization

The images of the beam obtained at the screen location, FT2, are shown in Fig. 2 with the RF voltage OFF and ON, respectively.

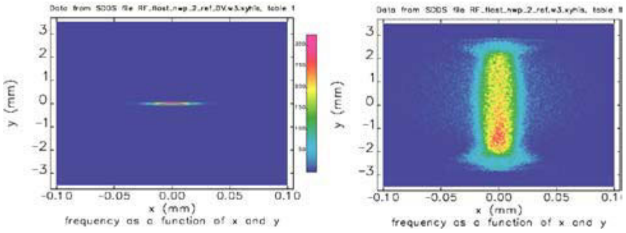

Figure 2: Bunch transverse distribution at the FT2 location with the RF deflector voltage OFF (left) and ON (right) respectively.

The results of the data analysis are shown in Fig. 3 where the vertical projected and the longitudinal distributions of the bunch are displayed.

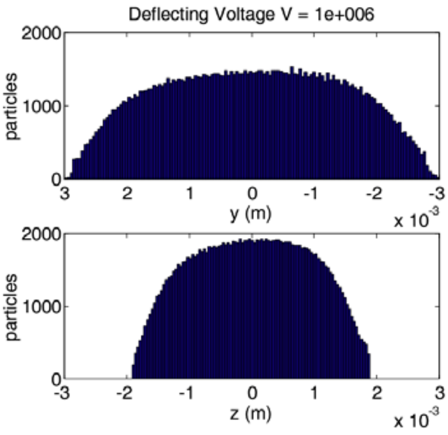

Figure 3: Above: the longitudinal bunch distribution as projected by the RF deflector on the vertical coordinate of the screen FT2; below: the particle distribution vs. time.

The value of σ_z, as obtained by applying Eq. (1), and by the longitudinal analysis of the raw data from ELEGANT tracking agree with an error less than 1%. The images collected on the dogleg at the screen located in FD2 show the reconstruction of the longitudinal phase space as shown in Fig. 4 where the time-energy $(z, \delta p/p)$ distribution is replicated in the transverse plane (y,x).

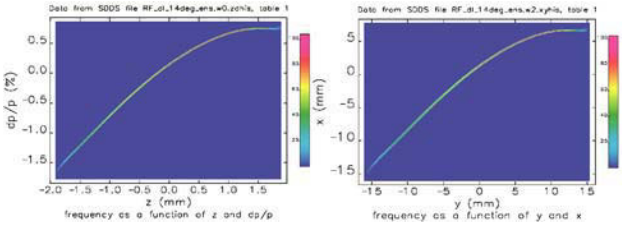

Figure 4: Above: Longitudinal phase space distribution of the SPARC beam . Below: Beam transverse distribution at the FD2 screen location as obtained tracking the beam through the SPARC dogleg with the RF deflector ON.

The "reconstructed" rms energy spread value is in very good agreement with the real one, and the same holds for the slice analysis. To measure the beam slice emittance in the horizontal plane the RF deflector is used to scan the beam rms size at the screen locations FT2.

In Fig. 5 the beam horizontal slice emittance is given for the simulated measurement: (left figure),on the right the result of the temporal analysis of the raw data is reported.

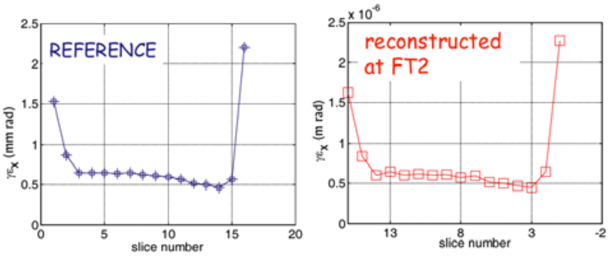

Figure 5: Reconstructed horizontal beam slice emittance (in mm-mrad) as a function of slice number with the beam size scanning at FT2. The left curve is the horizontal emittance as calculated by slicing the beam output file (tracked with Elegant) along the temporal coordinate, the right curve is the result of the simulated quadrupole scan at the screen location.

RF DEFLECTOR DESIGN

The simplest and more efficient multi-cell deflecting structure that can be used to deflect the bunch is a standing wave structure operating in the π -MODE. The choice of the number of cells has been done according to the following considerations:

a) the available transverse deflecting voltage for a given input power;
b) the available space in the SPARC transfer line;
c) the mode separation with different number of cells to avoid problems of mode overlapping;
d) the maximum acceptable surface peak electric field to avoid problems related to high field intensities, discharges and so on.

A 5-cell deflecting structure fulfils all of the stated requirements. In fact, it allows operating with a very low input power ($P_{RF} \leq 2$MW) obtaining contemporary low peak surface electric field and resolution length up to $\approx 25 \mu m$. These characteristics permit measurement of the longitudinal beam profile with good accuracy, even considering the possibility of longitudinal compression factors of up to 20. Moreover the operation at low input power allows simplifying the power line design.

The 2D profile of the 5-cell RF deflector has been studied using the MAFIA 2D code. The simulated 5-cell profile is reported in Fig. 6 with the final dimensions and parameters shown in Table 1. The radius of the cells connected to the beam pipe tube in this design has been changed in order to achieve a field flatness of 3%. The on-axis magnetic field profile in the structure is plotted in Fig. 7.

Table 1: Final dimensions and parameters of the 5-cell deflecting structure.

Dimension [mm]	*a*	20.00
	b2=b3	59.97
	b1	60.67
	t	9.50
	d	52.48
Param.	Frequency [GHz]	2.85699
	Q	16800
	$R_\perp$ [$M\Omega$]	2.47

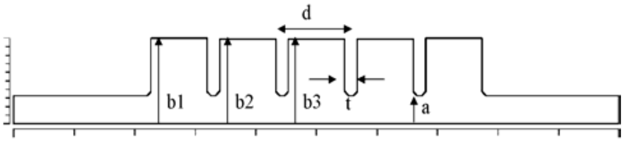

Figure 6: 5-cells deflecting cavity simulated by MAFIA2D.

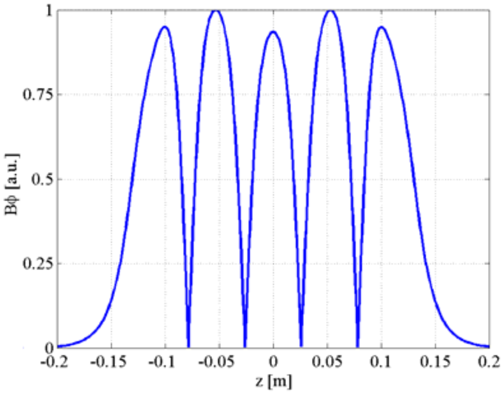

Figure 7: Absolute value of the magnetic field for the 5-cells cavity obtained by MAFIA 2D simulations.

The coupler design has been chosen to adapt a rectangular waveguide; more details about the design procedure can be found in [1].

PROTOTYPE MEASUREMENT RESULTS

A full-scale aluminum prototype, see Fig. 8, has been constructed to make field measurements and to implement tuning procedures. Bead-pull measurements have been done to measure the field flatness in the cavity [4]. Different perturbing objects have been used to measure the H-E field components. The tuning procedure that we have implemented is based on the study of field and frequency sensitivities with respect to the 5-tuners and is widely discussed in [5]. The reflection coefficient at the input coupler port is plotted in Fig. 9. The comparison between the measured quantities and the simulated ones is reported in Table 2. The external quality factor should be slightly increased by adjusting, experimentally, the window coupler dimensions.

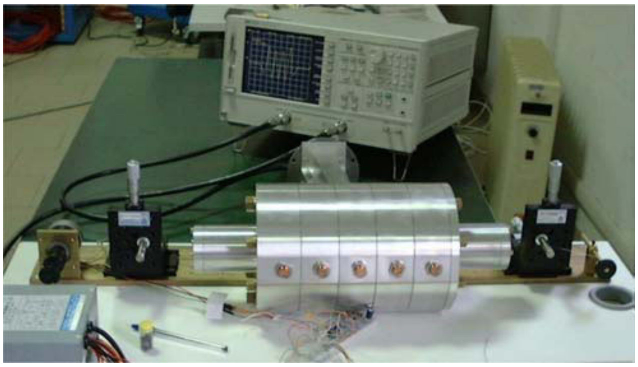

Figure 8: Deflector aluminum prototype and measurement setup.

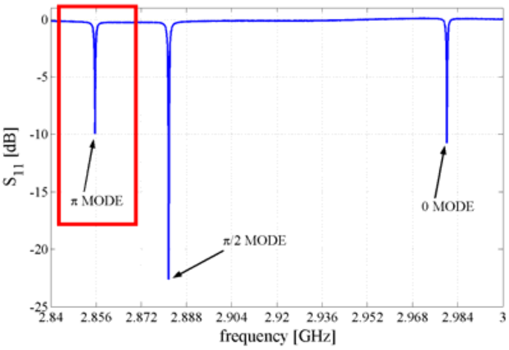

Figure 9: Measured reflection coefficient at the input coupler port.

Table 2: compare between the measured quantities and the simulated ones

	Q_0	Q_{EXT}	R_T/Q
Simulations	13200	16800	147
Measurements	6600	12900	149

CONCLUSIONS

A five-cell SW aluminum prototype of the SPARC RF deflector has been realized and test results are in agreement with the design predictions. The SPARC diagnostic layout has been presented together with the measurement simulation and the results of the 6D phase space reconstruction show the feasibility of a complete characterization of the longitudinal and transverse phase space of the beam provided by the SPARC photoinjector.

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