LONGITUDINAL PHASE SPACE CHARACTERIZATION OF THE CTF3 BEAM WITH THE RF DEFLECTOR

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Abstract

The characterization of the longitudinal phase space of the CTF3 beam is an important item for tuning all machine parameters and increase the 30 GHz RF power production. By means of an RF deflector and a dispersive system the longitudinal phase space can be completely characterized. In this paper we present the simulation of the measurement and the mechanical layout of the full system.

INTRODUCTION

The recombination process in the CLIC test facility CTF3 has been already successfully tested in the Preliminary Phase [1]. Bunch length and energy spread of the beam should be carefully controlled before and during the recombination process to optimise the power generation at 30 GHz. Different bunch profile measurements have already been done during the commissioning of the full-loaded LINAC. In this paper we study the possibility to adopt a different method based on the use of RF deflectors [2] to completely characterize the longitudinal phase space of the CTF3 beam. The proposal is to do this measure at the end of the Drive Beam injector after the chicane using the travelling wave RF deflectors (RFD) already constructed for the Combiner Ring (CR) [3]. The nominal beam parameters after the chicane are reported in Table 1. In par. 1 we discuss the layout of the overall system looking at the main key parameters. In par. 2 we briefly discuss the perturbation induced on the beam by the RFD and, finally, in par. 3 we illustrate the optics parameters and the simulation results of this measure.

Table 1: CTF3 beam parameters after the chicane

Beam Energy E [MeV]	150
Bunch length σ_z [mm]	1-3
Bunch spacing [cm]	20
Number of bunches	2100
Energy spread $\Delta E / E$	0.8%
Beam emittance ε [mm mrad]	~ 0.4
Bunch charge [nC]	2.33

LAYOUT AND MAIN KEY PARAMETERS

The layout of the beam line after the chicane is reported in Fig. 1. The measurement is illustrated in Fig. 2: the head and the tail of each bunch are deflected vertically and with opposite sign by the RFD (whose main parameters are reported in Table 2). The bunch length can be determined by measuring the vertical distribution of the bunch at the OTR1 position while the whole longitudinal phase space can be reconstructed by measuring the transverse distribution on the OTR2 position after the dipole. The transverse image of each bunch at the OTR positions can be digitalized by a gated camera.

Table 2: RFD main parameters

Frequency (f_{RFD})	2.99855 [GHz]
Iris internal radius (a)	21.43 [mm]
Number of active cells	10
Phase advance per cell	$2\pi/3$
Deflector length	33 [cm]
Filling time	47 [ns]
r_s/Q	1425 Ω/m
Transv. Defl. Voltage	2 MV @ P_{RFIN}=10 MW

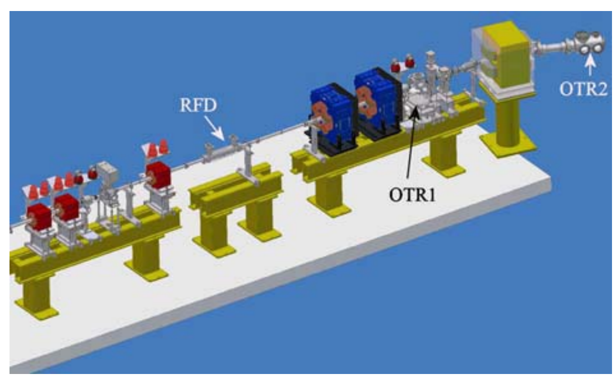

Fig. 1: Layout of the CTF3 beam line for measurements with RFD.

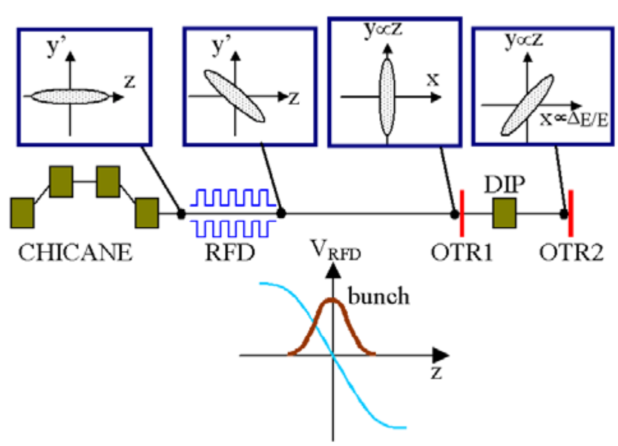

Fig. 2: Sketch of the bunch length and longitudinal phase space measurements with RFD.

Let us consider first the bunch length measurement. The transverse distribution of the bunch at the OTR1 position is the convolution between the deflected longitudinal profile and the vertical dimensions of the bunch at the same positions (σ_y). In order to measure the bunch length with a certain resolution, the vertical displacement induced by the deflector should be bigger than σ_y. The resolution length (L_{res}) can be defined as the bunch length that give, on OTR1, a vertical spot exactly equal to σ_y. It is easy to find that:

$$L_{res} \cong \frac{2c(E/e)\sqrt{\varepsilon}}{\omega_{RFD}\sqrt{\beta_{y\_defl}}\sin(\Delta\Phi)V_T} \qquad (1)$$

where β_{y_defl} is the vertical β-function at the deflector position and $\Delta\Phi$ is the phase advance between the deflector and the OTR1 position. Moreover the transverse dimension of the beam at the deflector position should be much less than the RFD irises diameter (a), that is:

$$\beta_{y\_defl} << \frac{(2a)^2}{\varepsilon} \cong 4600 \qquad (2)$$

The resolution length is plotted in Fig 3 as a function of β_{y_defl} and for different RFD input powers assuming $\Delta\Phi = 90°$.

Concerning the energy spread distribution on OTR2 we can define the energy spread resolution as the minimum energy spread that give a transverse spot exactly equal to the horizontal dimension σ_x, that is:

$$\left.\frac{\Delta p}{p}\right|_{res} = \frac{\sqrt{\varepsilon\beta_{x\_defl}}}{D_{OTR2}} \qquad (3)$$

where D_{OTR2} is the dispersion function on OTR2.

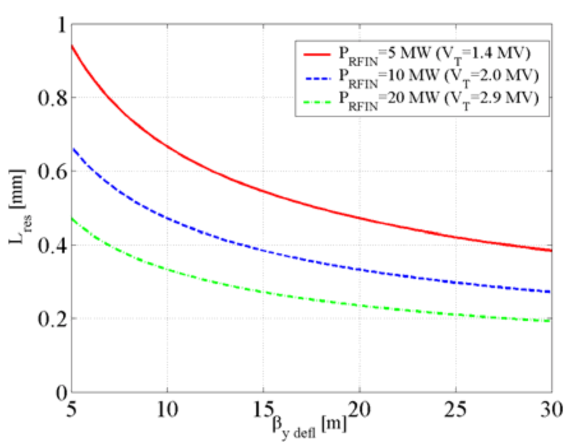

Fig. 3: Resolution length as a function of β_{y_defl} and for different RFD input powers assuming $\Delta\Phi = 90°$.

EFFECTS OF THE BEAM LOADING IN THE RFD

The effect of RFD on transverse beam dynamics is mainly due to the out-of-phase wake generated by the beam off-axis passage. The analysis of this wake field and the related effects in the CR dynamics is widely discussed in [4]. Here it is important to investigate the impact on transverse dynamics to establish the beam alignment requirements in the RFD itself. Since the wake is a 90°-out-of-phase wake and the bunches are spaced by $2T_{RFD}$ the transverse wake has a zero crossing in the center of each bunch and has a longitudinal slope different from zero over the bunch length. This transverse slope can perturb the main deflecting field and, therefore, the bunch length measurement. In Fig. 4 the ratio between the wake field slope and the main RF field slope is plotted as a function of the bunch number and for different beam displacement. In the plot only the first 150 bunches are reported since after ≈ 70 bunches the steady state regime is reached (the deflector filling time is 47 ns). From this plot it is possible to conclude that an alignment precision of $\pm 3mm$ give a perturbation of about 3%.

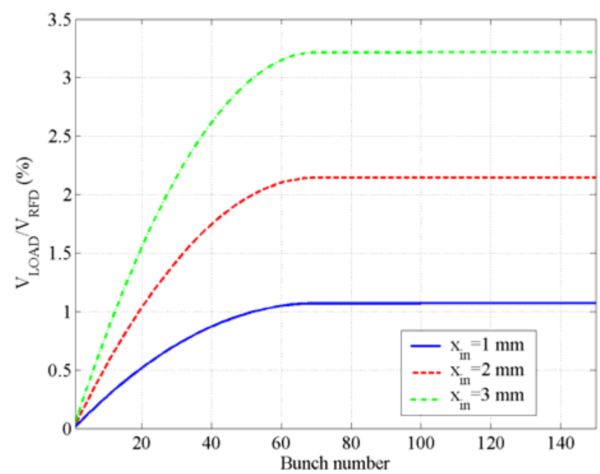

Fig. 4: Ratio between the wake field slope and the main RF field slope as a function of the bunch number and for different off-axis (P_{RFIN}=10MW).

EXAMPLE OF MEASUREMENT SETUP

The chicane and the injection line to the Delay Loop is tunable in term of R_{56} between $\pm 40cm$. This means that the longitudinal phase space at the deflector position can be varied in a wide range supposing compression, stretching or isochronicity conditions. In the nominal configuration the chicane and the side quadrupoles triplets are symmetric with respect to the chicane center. For the measurement this symmetry condition can be relaxed and the quadrupole set points between the chicane and the diagnostics can be changed for optimising the measurement resolution for any R_{56} configuration.

As example the optical functions reported in Fig. 5 are referred to the case of a chicane set with R_{56}=30 cm. The longitudinal and transverse planes at different points of the beam line obtained by the ELEGANT code [5] are reported in Fig. 6 (CSR effect is not included in the simulations). In this case it has been considered an uncorrelated σ_z of 1 mm at the entrance of the chicane and V_T=2MV. The chicane set give a correlation between energy and longitudinal position so that $\sigma_z = 3mm$ at the RFD position. In the considered case L_{res}=0.3 mm at the OTR1 position and L_{res}=0.5mm at the OTR2 position while the energy spread resolution is $\Delta p / p|_{res} = 0.1\%$. By simply scaling the plots in the transverse phase space xy it is possible to measure the bunch length and energy spread distribution with the resolution previously discussed.

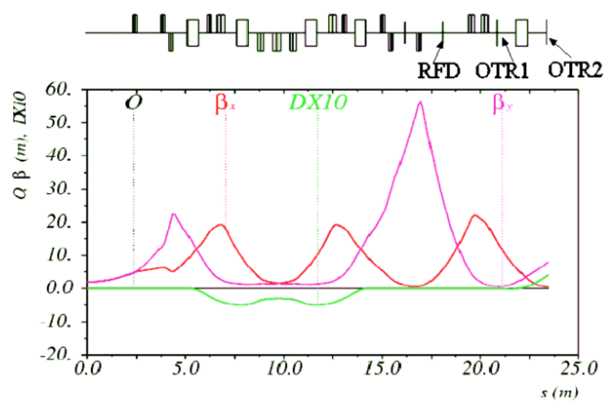

Fig. 5: Example of optical functions for measurements with the RFD.

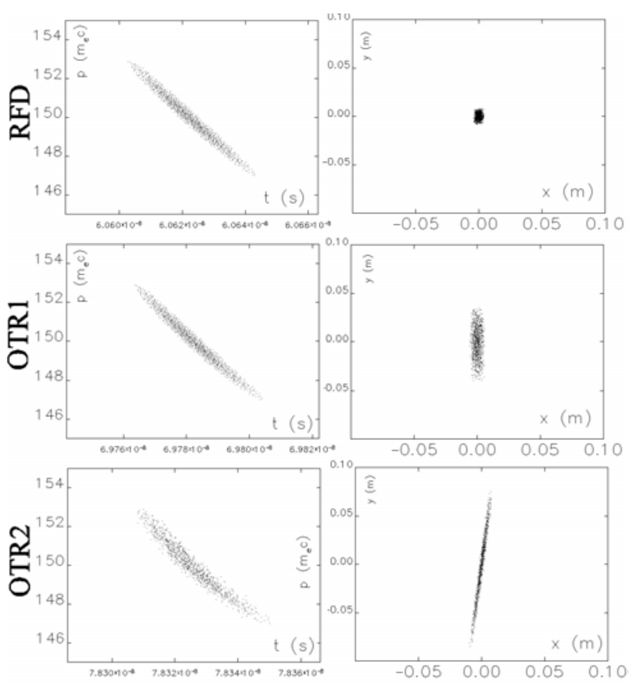

Fig. 6: Longitudinal phase space and transverse plane distribution along the beam line in case of measurements with RFD (obtained by ELEGANT).

Finally, in Fig. 7 it is plotted what we expect in term of transverse plane distribution at the OTR2 position with the RFD on/off.

It is important to remark that, with this method, it is possible to completely characterize the longitudinal phase space of bunches after the chicane with a good resolution. We expect, therefore, to measure the effects of the Coherent Synchrotron Radiation in case of high charge and strong compression factors in the chicane as head-tails energy spread growth and so on.

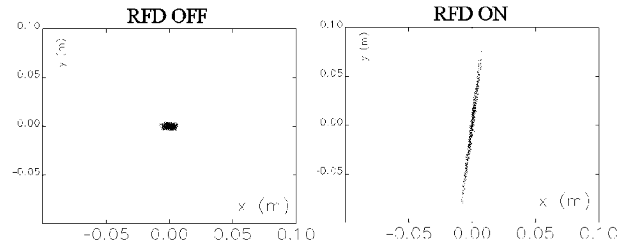

Fig. 7: Transverse plane distribution at the OTR2 position with the RFD on/off (obtained by ELEGANT).

CONCLUSIONS

In the paper we have studied the possibility to measure the bunch length and the longitudinal phase space of the CTF3 injector by using an RF deflector. We have proposed to use the travelling wave RF deflectors already constructed for the Combiner Ring. The main key parameters that allow increasing the resolution of the measure have been introduced. We have also discussed the perturbation induced on the beam dynamics by the RF deflector and we have concluded that a beam alignment precision of $\pm 3mm$ in the deflector gives a perturbation of about 3% in the measure. For any different chicane configuration it is possible to find an optical solution that optimise the measurement resolution in term of bunch length and energy spread. An example of optical functions and measurement simulation results has been, finally, shown.

REFERENCES

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