COMMISSIONING AND FIRST MEASUREMENTS ON THE CTF3 CHICANE

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Abstract

The transfer line between the linac and the first recombination ring (Delay Loop) of the CTF3 project has been installed at CERN in spring-summer 2004. In the transfer line a magnetic chicane is used to tune the length of the bunches coming from the linac in order to minimize the Coherent Synchrotron Radiation contribution to the beam energy spread in the recombination system. The first measurements of the beam parameters at several linac and stretcher settings are described. We report the compression curve as a function of the optical parameter R_{56} representing the dependence of the longitudinal position of a particle on its energy, obtained by measuring the bunch length with a 3 GHz RF deflector.

INTRODUCTION

The Compact Linear Collider (CLIC) project is a multi-TeV electron-positron collider for particle physics based on the two-beam acceleration concept; a high-intensity drive beam powers the main beam of a high-frequency (30 GHz) linear accelerator with a gradient of 150 MV/m, by means of transfer structure sections.

The aim of the CLIC Test Facility (CTF3) is to make exhaustive tests of the main CLIC parameters [1]. An international collaboration participates to the construction of the machine and the LNF contributes to the realization of a large part of the recombination system, consisting of two rings which will multiply the bunch frequency and peak current by a factor of ten. In particular the INFN Frascati laboratories responsibility is to design and realize the first of the two rings of the bunch train compression system, the Delay Loop (DL), and the transfer line that connects the Linac to the DL including a magnetic chicane used to vary the bunch length (see Fig. 1).

CTF3 is under construction in the LEP preinjector complex building at CERN. It uses where possible the existing magnets, power supplies, equipments and ancillary system. In summer 2004 the chicane and the transfer line have been installed and aligned in the tunnel; the vacuum chamber connected and tested together with the diagnostics devices [2]. In autumn 2004 the commissioning of this part of the machine started and a full set of measurements on the electron beam characteristics has been performed. The beam transverse emittances have been measured with the quadrupole scan method monitoring the beam sizes on a carbon OTR screen. The bunch length with different optical function configurations in the magnetic chicane has been measured using a 3GHz radio-frequency deflector.

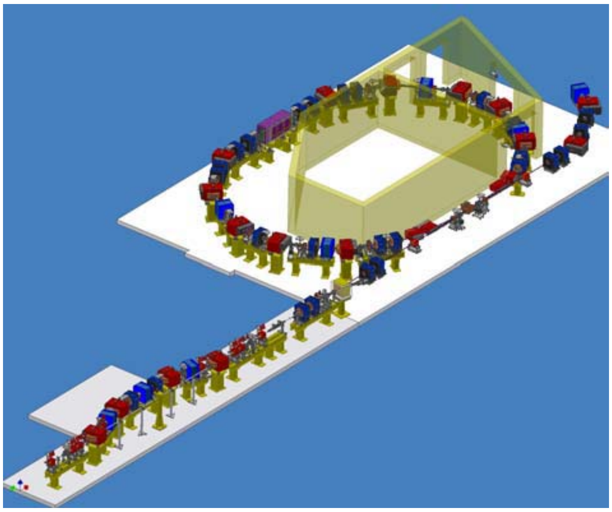

Figure 1: Layout of the Transfer line and Delay Loop.

TRANSFER LINE COMMISSIONING

The transfer lines elements have been tested before the commissioning. In particular the vacuum chamber were baked-out in the Frascati Laboratories and shipped in light nitrogen overpressure. After installation the achieved vacuum was better than $8*10^{-9}$ Torr in all the chambers without any heating. The tests of the magnets power supplies, the beam position monitor (BPM) electronics and the magnets polarity control have been completed before starting the operation shifts.

The commissioning of the transfer line, including the magnetic stretcher-compressor chicane, has been performed in eight weeks of operation starting from October 2004, sharing the time with the power extraction system (PETS) experiment [3] that use a dedicated line connected, through a dog-leg, at the low energy linac section.

The first beam has been transported up to the spectrometer through the chicane by-pass after matching the optical function at the linac exit with two triplets placed at the chicane end. The chicane has been used the first time with the quadrupoles off, obtaining a good measurement of the beam energy, of the dispersion function and of the BPM calibration. The trajectory has been reconstructed with the beam position monitor system resulting well centered with no corrector magnets on. After the first check the beam has been transported with different configurations of the optics that permit, by varying the quadrupoles currents, to change the bunch length in a very wide range at the chicane exit. The full transport efficiencies for the different optical configura-

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tions have been monitored summing the calibrated signals of the beam position monitors.

MEASUREMENTS

Measurements on beam characteristics have been done with different sets of conditions. We summarize here the most representative, which corresponds to the beam parameters listed in Table I.

Table I: Beam parameters used in the measurements

Charge per bunch	1.3 nC
Bunch length at linac exit	6 ps
Beam energy	100 MeV
Energy spread	1.2 %
Number of bunches in the train	600
Bunch train duration	200 ns
Average current	3.8 A

Energy and Energy Spread Measurements

Energy and energy spread along the bunch train, as well as individual bunches, have been measured with the spectrometer at the line end and with the beam position monitors in the dispersive regions. During the measurements the energy of the bunches along the train must be constant; an efficient control system of the klystron phase permits to square the RF pulses that power the accelerator sections.

Emittance Measurements

The horizontal and vertical emittances have been measured with the quadrupole scan method, observing the the beam transverse dimensions on a carbon OTR screen as the current in an upstream quadrupole was varied. The produced OTR radiation has been collected by a large aperture optics in a CCD camera.

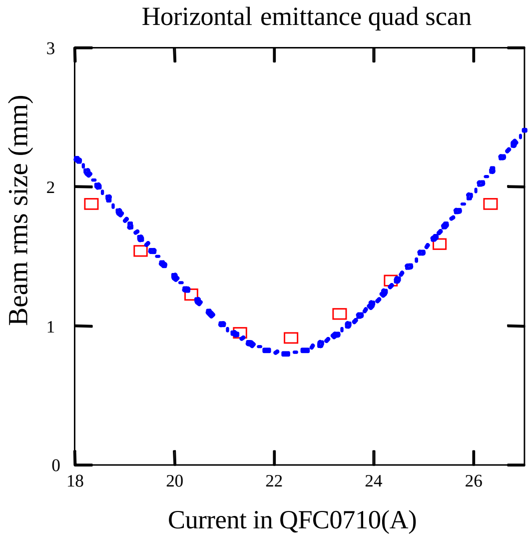

Figure 2: Horizontal beam size vs. quadrupole current.

The image has been stored and processed by a frame grabber and integrated in the control system.

The values of the horizontal and vertical emittances measured are 112 and 103 mm*mrad respectively, in good agreement with the expected 100 mm*mrad value. An example of the measurement performed at the linac end is shown in Fig. 2.

Bunch Length Measurements

The power extraction efficiency from the drive beam calls for precise control of the bunch spacing and of the beam emittance along the whole frequency multiplication system. The emittances, both transverse and longitudinal, are affected by the collective effects depending on bunch length and energy spread. The chicane between the Linac and the DL has been designed with a wide range of R_{56} tunability, where, being D the dispersion function and ρ the constant bending radius in the dipoles

$$R_{56} = \frac{1}{\rho}\int_{dipoles} D(s)\,ds$$

is the first order transfer matrix element relating the particle position along the bunch with its energy deviation $\Delta p/p$:

$$ct = (ct)_o + R_{56}\frac{\Delta p}{p} + T_{566}\left(\frac{\Delta p}{p}\right)^2 + \ldots$$

and T_{566} is the corresponding second order transfer matrix term depending on the chromaticity of the line. The tunability range is large essentially for diagnostic purposes. The chicane with quadrupoles off has $R_{56} = 0.46$ m and very small T_{566}. By increasing the horizontal focusing, R_{56} goes to negative values and $|T_{566}|$ together with the other 2nd order terms increases and the beam distribution becomes non-gaussian.

A 3GHz RF deflector [4], placed after the chicane, has been used for the bunch length measurements. The head and the tail of each bunch, passing through the deflector cavities at field zero crossing point, are deflected vertically and in opposite direction; the longitudinal distribution is converted into vertical distribution on an OTR screen intercepting the beam and measured via an optical system and CCD camera.

An accurate image analysis permits to reduce the errors due to the background coming from the CCD and the OTR screen.

We obtained a calibration for the measurement by relating the displacement of the beam distribution centroid in pixels with the phase of the RF wave. The calibration result is a ratio of pixels per degrees valid for a certain value of the RF power and a certain distance of the screen from the deflector.

We have chosen to calculate the RMS value of the beam to characterize its width rather than the standard deviation obtained by a gaussian fit of the profile, because in most cases the beam profile was not gaussian at all and the fit was not congruent with the profile. In case of gaussian beam the RMS and the fit give the same results. However the disadvantage of taking the RMS value is the weight of the tails in the calculation, so that a very accurate filter is needed to make a precise selection of the beam. We used IACO, a Labview and Matlab based software, that applies a filter on a digital image. The filter subtracts the background found by a statistical treatment of the image and then via an iterative algorithm removes the isolated x-ray produced spikes. At the end of every interaction the program compares the value of parameters such as sigma and centroid, stopping when their changes are negligible (less than ½ pixel).

For each measurement we took many images; the program averages over all the values of the parameters coming from different images inside the same directory (measurement), giving out the average centroid and sigma (x and y) for each directory, and respective errors.

The transverse distribution of the bunch at the OTR screen position is the convolution between the deflected longitudinal profile and the vertical dimension of the bunch at the same position (σ_y). To achieve good resolution the vertical dispersion induced by the RF deflector has been chosen bigger than σ_y. For each measurement at different R_{56} the spot size without deflection has been stored in order to normalize the measure.

The bunch length is determined by measuring the vertical distribution size.

The beam has been accelerated on crest along the linac, except on the last section where 30% off crest on the negative side gives a correlation in longitudinal phase space.

The value of the chicane R_{56} has been varied from 0.45 to -0.2 m. According to the ELEGANT code simulations, the maximum expected compression corresponds to R_{56} = 0.2m (see Fig. 3), and this has been confirmed by the measurements with a very good agreement.

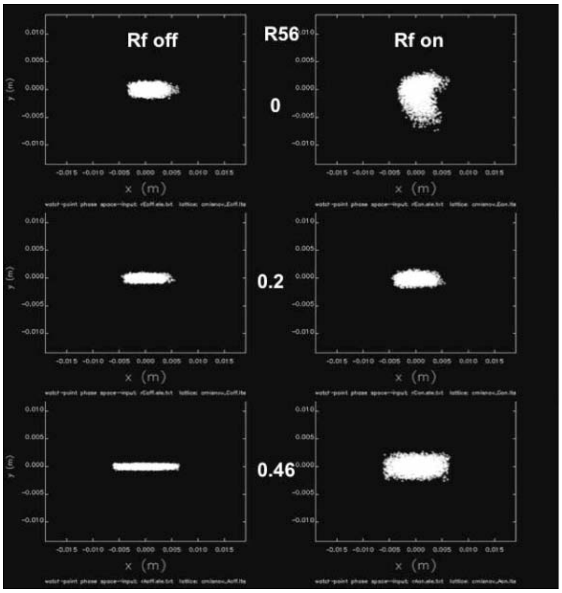

Figure 3: Simulated beam transverse distributions for three different values of R_{56}.

The minimum bunch length is less than 0.5 mm. The comparison between the simulated transverse distributions on the screen and the measured ones (Fig. 4) shows also a very good agreement, sign of good modelling of the whole system (Fig. 5).

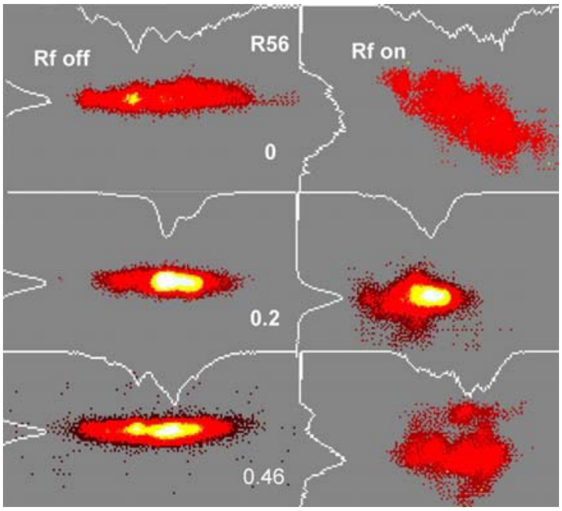

Figure 4: Beam transverse distributions on the OTR for the same conditions of Figure 3.

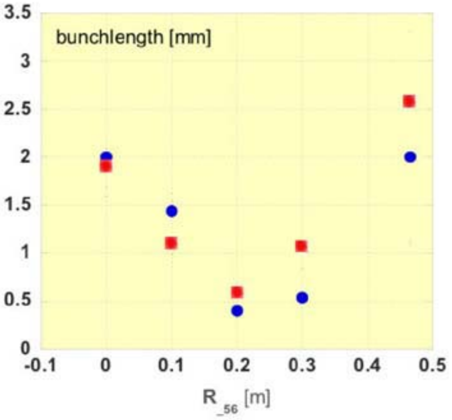

Figure 5: Bunch length vs R_{56} factor: dot measured, squares simulated.

CONCLUSIONS

Installation and commissioning of CTF3 transfer line between linac and Delay Loop has been completed. The first set of measurements of the beam characteristics such as emittance, bunch length tunability with R_{56} and transfer efficiency are in good agreement with the expected values.

REFERENCES

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