CTF3 COMPRESSOR SYSTEM

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Abstract

In the CTF3 complex the Linac pulse train, 1.4 µs long, is squeezed to a 140 ns train with a peak current 10 times higher (35A) by means of the bunch interlacing technique. The compressor system consists of two rings; the first (Delay Loop) multiplies the Linac bunch frequency by a factor 2, the second (Combiner Ring) by another factor 5. The lattices of the rings and transfer lines allow fine tuning of the trajectory and bunch length. The beam impedance budget is minimized to avoid energy spread growth. The layout of the rings and the intermediate transfer lines are shown. Design of special components of the rings and measurements on the prototypes are presented.

1 INTRODUCTION

CTF3 [1] is the first test for the production of RF power at 30 GHz at the nominal CLIC parameters: power of ~ 250 MW/m corresponding to an accelerating voltage of ~ 150 MV/m are the design goals. The compression system of the drive beam is the subject of this paper.

The main challenge from the beam dynamics point of view is the manipulation of the high current/low energy beam: the energy ranges between 150 and 300 MeV (factor 8–4 below CLIC), for a bunch charge of 2.3÷1 nC (factor 1÷2.3 below CLIC). The compression system consists of a Delay Loop (DL) [2], in which the current is multiplied by a factor 2, a Combiner Ring (CR) [3] which adds a factor 5, and the Transfer Lines (TL) [4] in between the Linac, the rings and the power extraction system. Fig. 1 shows the layout of the system and in Table 1 the main parameters of the rings are listed.

Table 1: CR and DL parameters

	DL	CR
Length [m]	42	84
Energy [MeV]	150-300	150-300
Emittance [µrad]	0.34-0.17	0.34-0.17
Bunch length (rms) [mm]	0.5-2.0	0.5-2.0
Charge/Bunch [nC]	2.3-0.5	2.3-0.5
Isochronicity: $\|R_{56}\|$	< 0.02m	<0.02 m
Total Δp/p	5 %	5 %
Path Length Tuning [mm]	± 5 mm	± 5 mm
Max. Beta H/V [m]	10.5/14.0	11.1/11.1
Max. Dispersion [m]	1.3	0.72
Phase Advance H/V	3.96/1.38	7.23/4.14
Chromaticity H/V	-6/-8	-12.0/-8.8

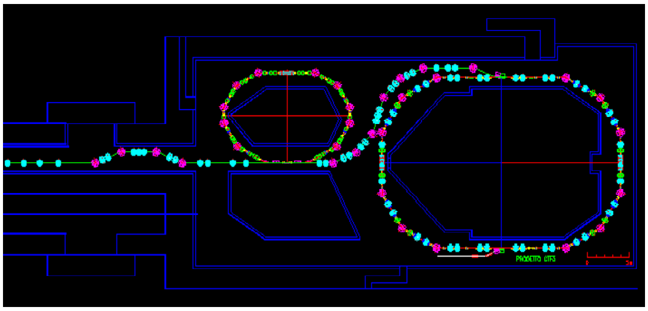

Figure 1: Compressor system layout

2 BEAM DYNAMICS

Energy losses and energy spread are of a great concern for the frequency multiplication system since they can affect strongly the efficiency of the RF power production. The energy losses give rise to relative phase errors between bunches through non-perfect ring isochronicity, which result in deterioration of the timing both among individual bunches and merging trains. The energy spread, in turn, leads to bunch lengthening and phase space distortion.

2.1 Frequency structure preservation

The power production efficiency depends on the final longitudinal beam structure at 15 GHz. Since the path followed by every bunch of each group of 10 is different, knobs to tune the path length and special care in minimizing the effects of both collective and single particle dynamics on the beam are needed.

Path length tuning devices (3-poles wigglers) are inserted in both the DL and the CR, assuring path length tunability within few mm. Adjustments with the Linac frequency on the whole train of bunches are also foreseen.

2.2 First-order beam dynamics

The bunch energy spread is affected by wake fields and by the Coherent Synchrotron Radiation (CSR). These collective effects depend on the bunch charge density and therefore on the bunch length. The latter is related to the R_{56} term of the first order transfer matrix through the energy spread and by the T_{5j6} (j=1,…6) terms of the 2nd order transfer matrix through all the 6 coordinates.

Requirements concerning bunch length variation, necessary to cope with CSR, ask for isochronicity in the rings and tunable R_{56} in the TL where all the bunches pass once. The last feature (R_{56} = ± 16 cm) is obtained by inserting a first stretcher/compressor section just after the Linac and a second one before the power extraction system.

Single particle effects can be controlled by a smooth linear optics, which makes the non-linear corrections less demanding. In the DL and in the CR fine-tuning of R_{56} by few mm is obtained by flexible optics. In the DL the isochronicity and achromaticity condition is fulfilled in each half ring, while in the CR in each quarter of the ring. The injection/extraction regions and the wigglers are placed in dispersion free sections. In the CR the optimum working point for minimum beam loading is foreseen [5].

2.3 Second-order beam dynamics

An energy acceptance of ± 2.5% is a strong requirement, especially considering that the isochronicity condition is obtained with strong horizontal focusing which makes more critical the 2^{nd} order correction.

Second order terms relate transverse and longitudinal phase planes. In absence of sextupoles the longitudinal particle position in the bunch after going through the DL or the CR depends on the energy spread by the 2^{nd} order term of the transport matrix, T_{566}. The minimization of this term by one sextupole family does not assure the isochronicity, since the relationship between transverse and longitudinal coordinates by the other T matrix terms produces emittance filamentation, which in turn, induces longitudinal emittance degradation. These terms are relevant for the DL and CR optics due to the small bending radius of curvature, to the high quadrupole gradients imposed by the isochronicity condition and are also influenced by the sextupoles. The contemporaneous correction of the more harming terms by three sextupole families in each isochronous section preserves the nominal beam parameters [2].

3 IMPEDANCE BUDGET AND PROTOTYPES

The experience acquired during the construction of high current colliders, like PEP II, KEKB and DAΦNE, can be successfully applied to reduce the coupling impedance of the vacuum chamber components, minimizing wake fields and CSR effects, the main sources of energy loss and energy spread [6].

The Combiner Ring impedance budget has been estimated. It has been shown that the CSR and the conventional wake fields give almost equal contributions to the energy spread and losses, which can be kept within the design limits, even for those bunches passing 5 times along the ring.

The energy spread due to CSR is $\Delta E = \pm 0.9$ MeV, or $\Delta E/E \sim \pm 0.5\%$ for a 2 mm long bunch. It is not reasonable to have bunches shorter than 2 mm in the CR since the energy spread grows rapidly with the bunch length (faster than $\sim \sigma^{-4/3}$). The energy spread for a 1 mm long bunch would exceed the acceptable value of $\Delta E/E = \pm 1\%$.

The electromagnetic design of each component of the vacuum chamber requires an accurate study aimed at reducing the impedance contribution.

The 2 RF deflectors and the 36 BPMs give the dominant contribution both to the energy spread and to the energy losses. The wake fields created by these components last longer than the distance between bunches in the trains and an additional study of the multibunch and multiturn effects is still necessary.

In the following we describe the main components of the vacuum chamber, evaluate their contribution to the impedance budget and estimate the RF energy loss and spread for the 2 mm long bunch with a charge of 2.33 nC.

3.1 RF deflectors

A pair of RF deflectors has been designed and almost completely constructed. The design procedure and the mechanical fabrication techniques are reported in ref. [7,8]. The beam dynamics in the combiner ring with the RF deflectors and, in particular, the effects of the beam loading have been carefully investigated [5].

The 2 RF deflectors give a contribution to the energy spread of 230 keV and to the energy loss of 150 keV.

3.2 Beam Position Monitor

A prototype of the Beam Position Monitor (BPM) has been built. The pickup is a transformer excited by the beam with 4 secondary windings surrounding a ferrite core placed in correspondence of a vacuum chamber ceramic gap. The beam current acts as a primary winding that drives magnetic flux in the core, inducing a voltage signal in each secondary winding with the amplitude depending on the beam position.

The pickup is designed to work in the lower end of the beam frequency spectrum, precisely in the 0.4÷100 MHz range, to reproduce only the envelope of the combiner ring bunch trains both in single and in multi-turn operation mode with 0.1 mm resolution. This sensitivity and dynamic range allow measurements with 1% of the nominal beam current.

Measurements based on the coaxial wire method have been performed in order to estimate the transfer impedance of the device, i.e. the complex ratio of the voltage induced by the beam at the external termination to the beam current (see Fig.2).

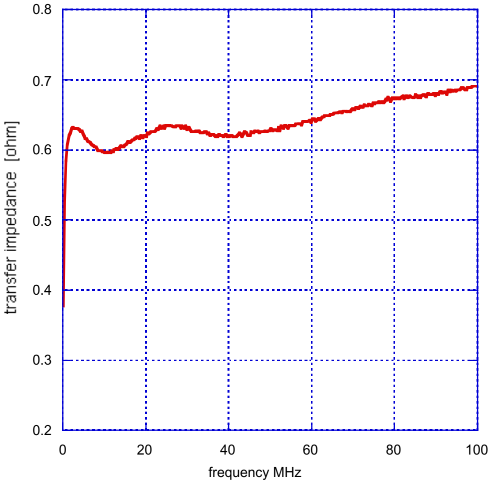

Figure 2: Transfer impedance of BPM

The overall BPM contribution to the energy spread is 330 keV. This value has been estimated from the impedance measured on similar BPMs developed at CERN. Some modification to reduce the coupling impedance is under study.

3.3 Extraction kicker

The extraction kicker has been designed with HFSS e.m. code and a first prototype has been built. A shunt impedance of 60 kΩ has been measured.

In the kicker the bunch looses 18 keV and accumulates 34 keV of energy spread after 5 turns in the CR. This contribution is negligible with respect to the previous ones.

3.4 Vacuum chamber

In the present CR vacuum chamber design the vertical dimension is kept almost constant and the number of horizontal cross section variations is reduced. Tapers are foreseen only at the arc ends, where the injection/extraction sections and the wiggler sections begin. Such a uniformity of the vacuum chamber cross section provides good vacuum conductance and allows avoiding valves.

A vacuum chamber section with a rectangular profile and with rectangular flanges has been realized. Special vacuum gaskets have been developed in order to avoid the RF contact in the junctions.

The contribution of the resistive walls can be small if the vacuum chamber is made of aluminium. The estimated losses in this case are about 12 keV, while the spread does not exceed 36 keV.

3.5 Vacuum pumps

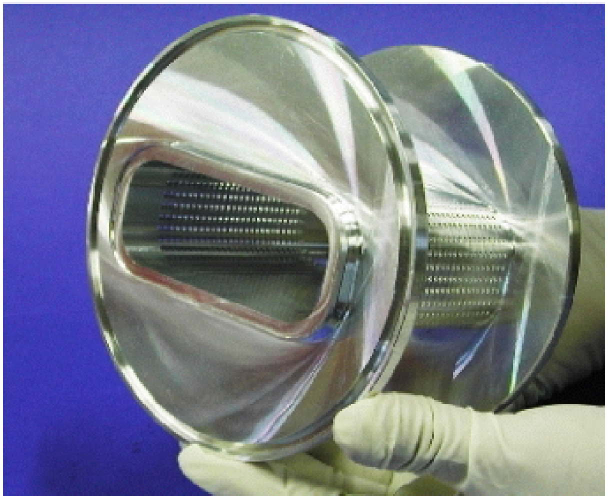

Figure 3: Vacuum pump connection

Vacuum pump connections have been realized with shielded pumping slots. The screen is composed by long grooves with hidden holes having a diameter smaller than the bunch longitudinal size. The measured conductance of a prototype section 8 cm long is 60 l/s. The section is shown in Fig. 3 before welding.

3.6 Bellows

A bellows with the RF shielding has been developed with sliding contacts having the same inner shape of the vacuum chamber. The RF shield is finger type with a minimum number of slots. Appropiate design of spring-finger assures the necessary force to maintain good electrical contact.

The inductive impedance of hidden pumping slots, sliding contact bellows, RF screened flanges are expected to be negligible.

4 CONCLUSIONS

The optics of the CTF3 compressor system has been designed with great care for first and second order beam dynamic.

A detailed analysis of the Combiner Ring vacuum chamber impedance has been done. The guidelines for the vacuum chamber design have been fixed and will be also used to design the Delay Loop and Transfer Line vacuum chamber, even though these systems are less demanding from the impedance point of view.

Prototypes of special components such as Beam Position Monitor, RF Deflectors, vacuum ports and bellows have been built and characterized.

5 REFERENCES

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