THE DAMPED C-BAND RF STRUCTURES FOR THE EUROPEAN ELI-NP PROPOSAL

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Abstract

The gamma beam system of the European ELI-NP proposal foresees the use of a multi-bunch train colliding with a high intensity recirculated laser pulse. The linac energy booster is composed of 12 travelling wave C-Band structures, 1.8 m long with a field phase advance per cell of 2π/3 and a repetition rate of 100 Hz. Because of the multi-bunch operation, the structures have been designed with a damping of the HOM dipoles modes in order to avoid beam break-up (BBU). In the paper we discuss the design criteria of the structures also illustrating the effectiveness of the damping in the control of the BBU. Prototype activity is finally illustrated.

INTRODUCTION

In the context of the ELI-NP Research Infrastructure, to be built at Magurele (Bucharest, Romania) an advanced Source of Gamma-ray photons is planned, capable to produce beams of mono-chromatic and high spectral density gamma photons. A European proposal is under preparation for the Compton gamma-ray Source of ELI-NP [1]. The photons will be generated by Compton back-scattering in the collision between a high quality electron beam and a high power laser. The machine is expected to achieve an energy of the gamma photons tunable between 1 and 20 MeV with a narrow bandwidth (0.3%) and a high spectral density (10^4 photons/sec/eV). The machine is based on a RF Linac operated at C-band (5.712 GHz) with an S-band photoinjector similar to SPARC [2], delivering a high phase space density electron beam in the 300-720 MeV energy range. The repetition rate of the machine is 100 Hz and, within the RF pulse, up to 32 electron bunches will be accelerated, each one carrying 250 pC of charge, separated by 16 nsec.

Downstream the photoinjector four C-band accelerating structures boost the energy up to 300 MeV for the low energy interaction and eight more accelerating sections bring the electron beam energy up to 720 MeV for the high energy Compton scattering.

C-BAND ACCELERATING STRUCTURES DESIGN

The linac booster is composed of 12 TW disk loaded structures working in C-Band. Each structure is 1.8 m long and the field phase advance per cell is 2π/3. The design of the structures follows the criteria we have adopted for the SPARC C-band sections [3]. In particular, the dimensions of each cell have been optimized to simultaneously obtain: (a) the lowest peak surface electric field on the irises; (b) an average accelerating field of 33 MV/m with an available power from the klystron of 40 MW; (c) the largest iris aperture compatible with the previous points to increase the pumping speed of the structure, to reduce the dipole wakefield intensity and the filling time of the structure itself. The reduction of this last parameter allows reaching higher accelerating gradient since shorter RF pulse length reduces the breakdown rate probability [4].

Since the ELI-NP linac operation is necessarily multi-bunch, in order to achieve the requested photon flux, the structures have been designed with an effective damping of the HOM dipoles modes to avoid beam break-up instabilities [8]. Several possible schemes for dipole mode damping can be found in the literature [5]. The solution that we have adopted for the ELI-NP structures is based on a waveguide damping system and is very similar to the design adopted for the CLIC structures at CERN [6]. The final mechanical drawing of the C-band traveling wave structures is given in Fig. 1 while the main parameters are reported in Table I.

Table 1: Main parameters of the C-Band structures.

Structure type	Quasi-Constant gradient
Working frequency (f_{RF})	5.712 [GHz]
Number of cells	102
Structure length	1.8 m
Working mode	TM_{01}-like
Iris half aperture radius	6.8 mm-5.8 mm
Cell phase advance	2π/3
RF input power	40 MW
Average accelerating field	33 MV/m
Accelerating field	37-27 MV/m
Average quality factor	8850
Shunt impedance	67-73 MΩ/m
Phase velocity	c
group velocity	0.025-0.014 (v_g/c)
Filling time	310 ns
Output power	0.3*Pin
Pulse duration for beam acceleration (τ_{BEAM})	<512 ns
Rep. Rate (f_{rep})	100 Hz
Pulsed heating	<6^{o}C
Average dissipated power	2.3 kW

Each cell of the structure (shown in Fig. 2) has four waveguides that allows the excited HOMs to propagate and dissipate into silicon-carbide (SiC) RF loads. The cells have four tuners and eight cooling pipes to sustain the 100 Hz operation. The SiC tiles have been optimized to avoid reflections and are integrated into the structure.

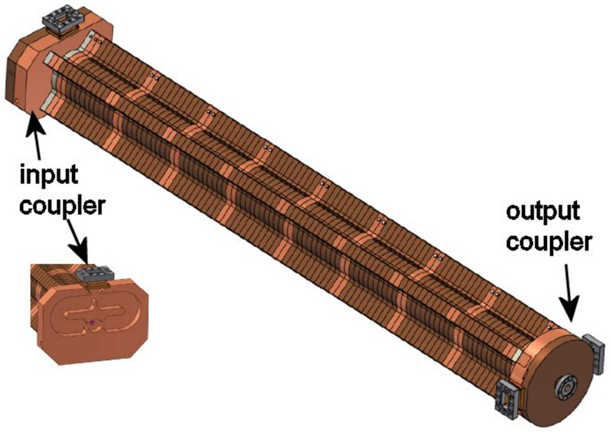

Figure 1: C-Band travelling wave structures.

A thorough optimization analysis of the mechanical and electromagnetic design has been carried out to simplify the mechanical drawings and the fabrication procedure thus reducing the overall cost of production maintaining, at the same time, the structure performances. In particular the geometry of the SiC absorbers has been strongly simplified as shown in Fig. 2. In each stack of 12 cells (Fig. 2) there are four SiC long absorbers, each stack is brazed and all stacks are finally assembled and brazed with the input and output couplers. The input and output couplers have a symmetric feeding and rounded edges to reduce the pulsed heating of the surfaces. The input coupler (shown in Fig. 1 integrates a splitter to allows the symmetric feeding while the output one has two symmetric outputs connected to two RF load. The single cell, the damping system and the couplers have been designed using HFSS [7].

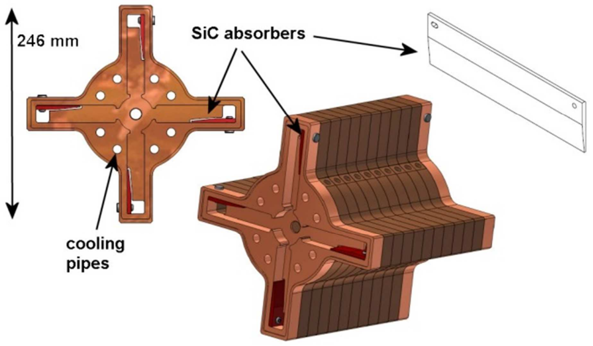

Figure 2: cells of the TW structures with SiC absorbers.

Each structure is fed by a single klystron with a constant RF input pulse and the apertures of the irises have been shaped to have a quasi-constant accelerating field (from 37 to 27 MV/m). It has been decided to adopt such a design with respect to a constant impedance structure because, in this last case, to have an average accelerating field of 33 MV/m, the field in the first cells has to be increased of more than 43 MV/m giving potential problems from the breakdown rate point of view. On the other hand a perfect constant gradient structure requires very small irises at the end of the structure with a consequent increase of the dipole mode R/Q, reduction of the pumping speed and beam clearance.

MULTI-BUNCH ISSUES: BEAM BREAK-UP AND BEAM LOADING

Of particular concern in the ELI-NP linac is the multi-bunch beam break (BBU) driven by the transverse wakefields [8]. Due to tight requirements on the narrow bandwidth of the gamma ray photon beam, which in turns asks for very low transverse emittances, we must carefully evaluate the emittance degradation due to BBU, and minimize as much as possible its dilution [12,13].

To verify the performance of the damping system, GdfidL [10] and CST [11] simulations have been performed. The result of the transverse wake field simulation is given in Fig. 3 and shows a reduction of the quality factor of the first dipole mode from about 11000 (without damping) to less than 100. Such wakefield does not perturb the multi-bunch transverse beam dynamics as verified by the tracking code we have developed to study the BBU in the ELI linac [9,12].

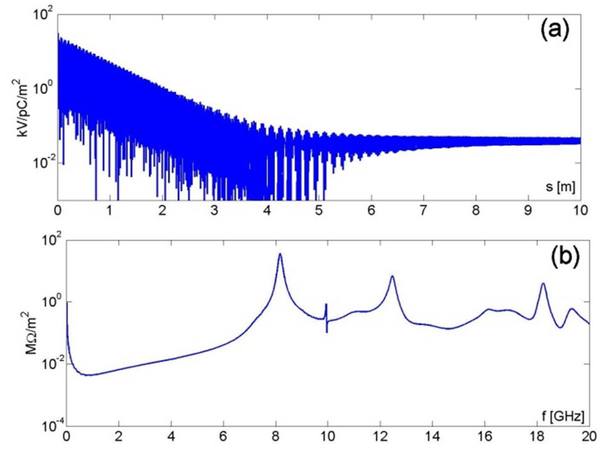

Figure 3: Transverse wake per unit length (a) and transverse impedance (b) obtained with GdFidL (20 cells plus 2 couplers, σ_z=5 mm, mesh step 500 μm).

Also the beam loading effects have been studied. The main effects of the beam loading is the decrease of the accelerating field gradient in the structure since the effective field can be assumed as a superposition of the RF field and of the induced longitudinal wakefield.

The energy spread generated along the train by beam loading effects is given in Fig. 4 (blue curve). The curve shows both the transient beam loading than the steady state regime. The steady state is reached since the bunch train is longer than one filling time of the cavity. From the figure it is evident that, if not well compensated, the beam loading effects could produce an unacceptable energy spread along the bunch train. There are quite a few techniques to compensate these unwanted effects; some of them are based on a proper modulation of the amplitude and phase of the RF input power [12], others are based on a proper choice of the beam injection, with respect to the power filling time of the structures.

In our design we have chosen to use the amplitude modulation of the input power along the beam train to compensate these effects. The correct amplitude modulation of the RF pulse necessary to reduce the energy spread has been calculated and is given in Fig 5 , showing that the beam loading in each cavity can be well compensated (local compensation) such that the induced energy spread is reduced to values much lower than the required ones as shown in Fig. 4 (red curve). The residual energy spread does not produce any beam dynamics perturbation and induces a tolerable energy modulation at the interaction points.

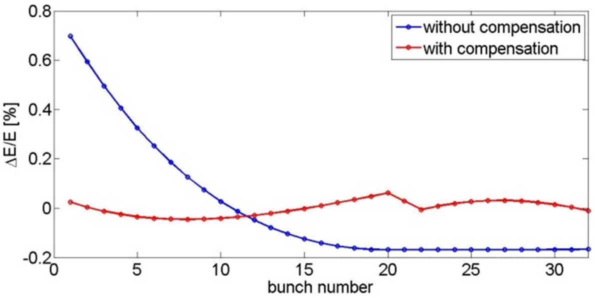

Figure 4: energy spread induced by beam loading in the C-Band structures with and without compensation.

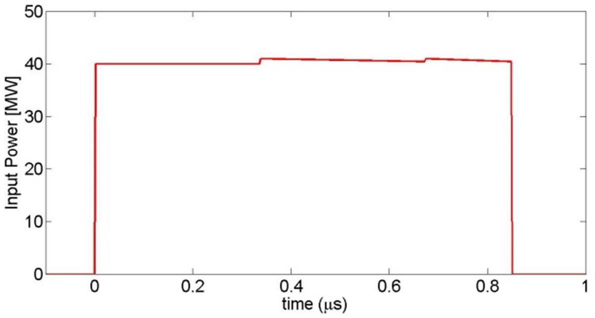

Figure 5: input power profiles to compensate the beam loading in the C-Band structures.

PROTOTYPES AND REALIZATION STRATEGY

An intense activity of prototyping has been started to setup and optimize the realization process of the structures. First prototypes (given in Fig. 6) have been realized to verify the feasibility of the machining of the cells and of the brazing process. We are now focalizing in the realization of two prototypes previous the realization of the first complete structure. The first prototype is a full scale device without precise internal dimensions that we would like to build in order to test the full brazing process, verifying eventual structure deformations and vacuum leaks. This prototype does not include SiC absorbers. The second prototype is a device with a reduced number of cells that we would like to realize to test the RF properties of the structure at low and high power. This second device includes the SiC absorbers and has precise internal dimensions with tuners.

CONCLUSIONS

The linac energy booster of the ELI-NP European proposal EGammas foresees the use of 12 travelling wave C-Band structures. In this paper we have illustrated the main design criteria of such structures. They are 1.8 m long, quasi-constant gradient travelling wave sections and integrates an HOM damping systems to reduce the impact of the long range dipole wakefield on the multi-bunch beam dynamics. Simulations performed with time domain codes confirmed the effectiveness of the damping system to suppress the BBU instability. An intense prototype activity has been started and is focused on the realization of a first complete structure.

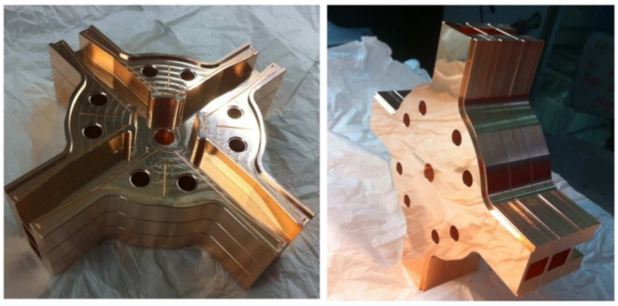

Figure 6: prototypes of the ELI C-band structures.

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REFERENCES

[1] C. Vaccarezza, et al., proc. of IPAC 12, p. 1086, New Orleans, 2012. The TDR of ELI-NP Egammas Proposal will be published soon after Tender official deadline - may 2013.
[2] M. Ferrario et al., PRL 104, 054801, (2010)
[3] D. Alesini, et al., The C-Band Accelerating structures for SPARC photoinjector energy upgrade, accepted JINST, 2013.
[4] V.A. Dolgashev, Proc. of PAC 05, Knoxville, p 595, 2005.
[5] Roger M. Jones, PRST-AB 12, 104801 (2009).
[6] W. Wuensch, in Proc. of EPAC 08, Genoa, 2008.
[7] www.ansys.com
[8] A. Mosnier, Instabilities in linacs, CAS School: 5th Advanced Accelerator Physics Course, Rhodes, 1993
[9] D. Alesini, et al, proc. of IPAC12, New Orleans, 2012.
[10] www.gdfidl.de
[11] www.cst.com
[12] A. Bacci, et al., Electron LINAC optimization to drive bright Compton back-scattering gamma-ray sources , accepted JAP, 2013.
[13] V. Petrillo et al., NIM A693 (2012) 109.