STATUS OF THE C-BAND RF SYSTEM FOR THE SPARC-LAB HIGH BRIGHTNESS PHOTOINJECTOR*

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Abstract

The high brightness photo-injector in operation at the SPARC-LAB facility of the INFN-LNF, Italy, consists of a 150 MeV S-band electron accelerator aiming to explore the physics of low emittance high peak current electron beams and the related technology. Velocity bunching techniques, SASE and Seeded FEL experiments have been carried out successfully. To increase the beam energy so improving the performances of the experiments, it was decided to replace one S-band travelling wave accelerating cavity, with two C-band cavities that allow to reach higher energy gain per meter. The new C-band system is in advanced development phase and will be in operation early in 2013. The main technical issues of the C-band system and the R&D activities carried out till now are illustrated in detail in this paper.

THE SPARC-LAB AT FRASCATI LNF

The SPARC-LAB is a research facility of the INFN Frascati Laboratory (LNF) whose purpose is to conduct advanced research in the field of high brightness, low emittance electron beams [1]. The facility, able to operate also in the velocity bunching configuration, feeds six 2m. long undulators and integrates the 150 MeV S-band photo-injector with a 220 Terawatt, Ti:Sa ultrashort laser system. FEL radiation in the SASE, Seeded and HHG modes have been performed from 500 nm down to 40 nm wavelength. The photo-injector SPARC, a single bunch electron accelerator, consists of a laser driven RF Gun followed by three traveling wave (TW), constant gradient, 2π/3 accelerating cavities, with the first two immersed in a solenoidal field to keep down the beam emittance growth. A second beam line has been also installed and is now hosting a narrow band THz radiation source.

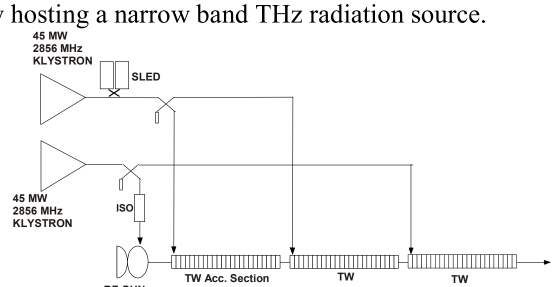

Figure 1: the SPARC photoinjector present layout.

To improve the performances of the experiments and recuperate the energy that is lost in the velocity bunching configuration. it was decided to increase the beam energy by replacing the third S-band section with two, 1.4 m. long, C-band TW accelerating structures that allow to operate at higher gradient. The choice of a higher frequency, e.g. the X-band, was also considered but then discarded because more expensive and technically more challenging.

THE C-BAND RF SYSTEM

The C-band technology is relatively new in linear accelerators compared to the standard and widely used S-band systems. Nevertheless it can be considered sufficiently mature since it is already employed in other accelerator laboratories like the Spring8 (JP) and the PSI FEL (CH) facilities.

R&D of the Accelerating Structure

The third S-band accelerating section, that is a 3 m. long SLAC-type unit, shown in Fig.1will be replaced with two, 1.4 m., C-band sections supplied with a 50 MW, 5712 MHz Toshiba klystron through a SKIP-type pulse-compressor [2]. In order to ease design and construction, the C-band sections are constant impedance (CI) structures with large (14 mm) iris diameter to minimize the surface electric field on the iris edges and improve the pumping speed. Also, the group velocity increases and this reduces the filling time. It must be remarked that the typical exponential decay of the input compressed pulse is partially compensated by the RF losses of the CI structure, resulting in a quasi-constant field amplitude along the section. Input and output waveguides are coupled to the beam-pipe instead of to the end-cells. A 50 cm long prototype was designed at LNF and built by a local firm. Brazing and vacuum test have been made at LNF [3].

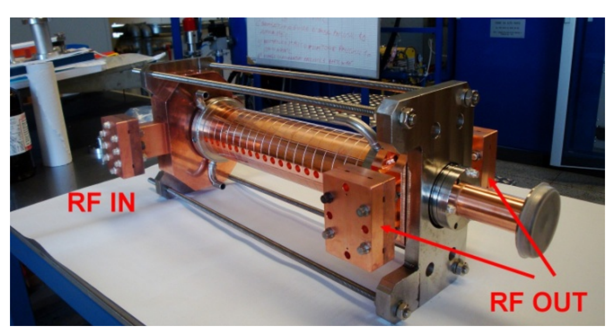

Figure 2: The C-band prototype tested at KEK.

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The prototype, shown in figure 2, has been power tested at KEK, in the frame of a collaboration established ad hoc with the INFN.

The KEK RF station consists of a 50 MW - 2.5µsec Toshiba E37202 klystron, followed by a pulse compressor. The results of the power tests, reported in detail in the ref. [4], was very successful and well beyond our expectations. The C-band prototype was tested up to 110 MW peak - 200 nsec - 50 Hz to a maximum average gradient of 55 MV/m, with a breakdown rate of the order of 10^{-6} bpp/min after about 300 hours of RF conditioning. A picture of the prototype is shown in figure 2.

Following the positive results of the KEK power test, we started the construction of two 1.4 m accelerating sections. The next figure 3, shows the concept of the beam-pipe coupling. This type of coupling allows the first RF cell to be mechanically unperturbed, i.e. there are no slots on the cell outer wall that normally cause heating and degrade the performances.

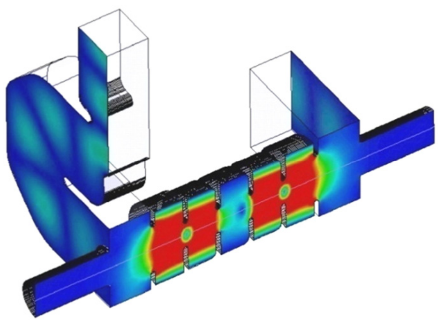

Figure 3: The waveguide beam-pipe coupling.

Further, the symmetric coupling guarantees low quadrupole components on the longitudinal axis [3]. The same concept of beam-pipe coupling is applied at the accelerating section output, with two opposite flanges without combiner. So we use 2 loads per section but the power dissipated by each load is halved.

The actual accelerating structures consist of 71 cells and are 1.4 m. long, to leave 20 cm for the insertion of a pumping unit in the 3 m. left available by the 3rd S-band section. The new C-band sections have been manufactured The cells and the waveguide couplers have been machined by a local firm; then, low power test and brazing of two halves have been made at LNF where a vacuum furnace of 80 cm of internal height is available. After joining mechanically the two halves, the first C-band section was tuned at LNF by adjusting the plungers on each cell wall. The last brazing will be made shortly by a local firm, where a 2 m. long vacuum furnace is available. The C-band actual section in shown in the next figure 4.

The figures 5 and 6 show the low power measurements made in laboratory with the bead perturbation technique. The following table 1 shows the main specifications of the C-band accelerating structures.

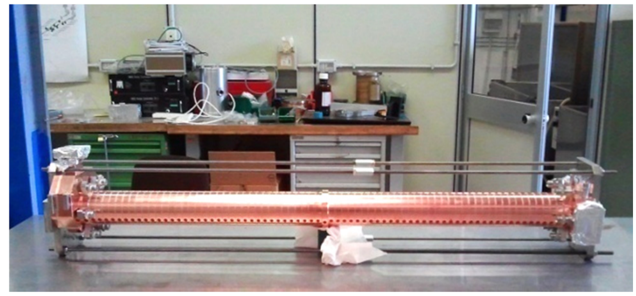

Figure 4: The two halves of one C-band section before the final brazing.

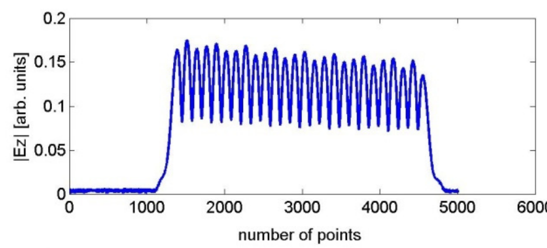

Figure 5: RF field profile of half C-band section.

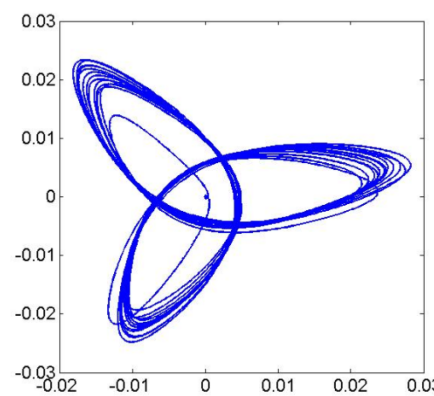

Figure 6: Phase advance per cell in the polar plane.

Table 1: C-band Structures Main Parameters

Frequency (MHz)	5712
type	TW, CI
structure	Disk loaded
Phase advance per cell	$2\pi/3$
n. of cells	71
Coupling type	beam-pipe
Iris radius (mm)	7.0
Group velocity/c	0.0283
Shunt impedance (MΩ/m)	82.9
Surf. peak E field/Acc. field	2.17
Filling time (nsec)	150
Total length with couplers (cm)	140

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The RF power needed to produce the accelerating field is about 60% of input power. The residual 40% will be dissipated by two RF water-loads, supplied by CML-Engineering, connected to the output coupling ports of the accelerating sections.

The Power Transmission System

The layout of the complete C-band system is presented in figure 7. The RF power will be distributed to the accelerating structures by means of a network of rectangular WR187 waveguides (WG) made of OFHC copper. The total WG length from the klystron to the accelerating sections is about 10 m. and the RF losses are of the order of 10% since the attenuation is 0.035 dB/m.

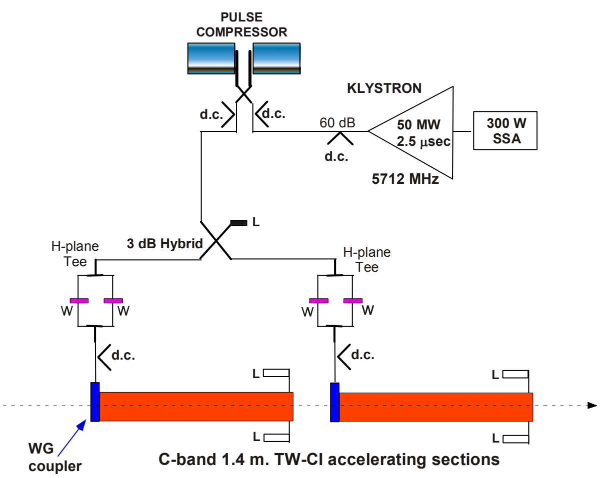

Figure 7: Layout of the SPARC C-band system

The C-band pulse compressor (PC) is under construction by the Division of Technology Development of the IHEP, Beijing, China. It is a double slot coupled cylindrical resonator system that follows the concept of the model "SKIP" developed by KEK. The PC output power is divided in two by a 3 dB hybrid junction and then delivered to the accelerating sections through two RF windows. The RF is split and recombined with two H-plane Tees. In this way the peak power through each RF window is halved as we are not sure of the actual capacity of them to handle power levels in excess of 100 MW peak.

The H-plane Tee s11 is -20 dB and the phase unbalance between outputs is about 1°. They have been designed and brazed at LNF. The machining was made by the local firm Comeb.

The RF Power Station

The RF power station consists of the Toshiba klystron E37202 driven by a solid state 400 W amplifier supplied by MitecTelecom. The pulsed klystron modulator is also a full solid state system made by Scandinova. The table 2 lists the main parameters of the RF power station. The klystron have been successfully RF tested on a dummy load up to 40 MW – 2 μsec – 10 Hz. The klystron RF conditioning is still ongoing.

Table 2: C-band Power Station Main Parameters

Frequency (MHz)	5712
Max klystron power (MW)	50
RF pulse width (μsec)	2.5
Klystron input RF power (W)	300
Klystron beam voltage (kV)	350
Max RF pulse rep. rate (Hz)	10

The Low Level RF System

The control of the C-band accelerating structures will be achieved by a digital low level RF (LLRF) system where all RF signals are down-converted to intermediate frequencies which are then digitized and processed with powerful digital processing platforms. The drive signal is finally up-converted to control the RF high power chain The schematic layout of the digital control system is shown in the figure 8..

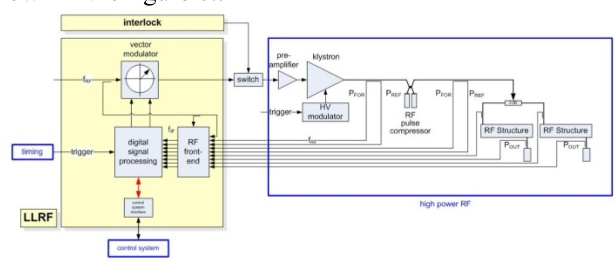

Figure 8: Schematic layout of the digital LLRF system.

A processing board based on VME64x is under development by the PSI laboratory (CH) in collaboration with INFN. It includes a multi-core PowerPC processor and a high performance field programmable gate array Xilinx Virtex-6 on the main board and provides a variety of I/O interfaces. The goal of the digital signal processing is to implement all static algorithms like the digital down-conversion from intermediate frequency to base-band, filtering, I/Q to amplitude/phase conversions and averaging calculations in firmware in the FPGA while using the PowerPC for more sophisticated high level applications like pulse-to-pulse feedback algorithms.

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[3] D. Alesini et al., SPARC-RF-11-002, LNF Techn. Note.

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