TIARA-REP-WP8-2012-010

Test Infrastructure and Accelerator Research Area

Status Report

Design of the Accelerating Structures for a High Gradient Acceleration R&D Infrastructure

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Test Infrastructure and Accelerator Research Area

Design of the Accelerating Structures for a High Gradient Acceleration R&D Infrastructure

WP8.1 / Study of SPARC upgrade in energy

MS30- 26 July 2012

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Content

This report summarizes the work which has been carried out to reach MS30, "Design of the accelerating structures", within the framework of TIARA, Work Package 8 (HGA, High Gradient Acceleration), Task 8.1 (Design of the accelerating structures).

1. Introduction

SPARC is a test-facility in operation at the INFN Frascati National Laboratories (LNF) and is aimed to produce high brightness electron beams to drive SASE-FEL experiments in the visible light exploring all the most critical issues of the future X-ray source subsystems. The beam is generated by a 1.6 cells standing wave RF gun and accelerated with three constant gradient, $2\pi/3$, travelling wave structures [1]. The SPARC energy will be upgraded from about 160 to >260 MeV by replacing a low gradient S-band travelling wave section with two 1.4 m long C-band structures [2]. The main motivations for this upgrade are both the shifting of the SASE radiation closer to the ultraviolet region and the improving of beam dynamics and seeding experiments. The choice of the C-band instead of the S-band was dictated by different considerations:

- (a) to explore the C-band acceleration combined with an S-band injector that, at least from beam dynamics simulations [3], seems very promising for the achievable beam quality;
- (b) to reach higher accelerating gradients and therefore higher energies in a shorter length;
- (c) to gain experience with a rather new RF technology in the light of further upgrades of the SPARC photo-injector. Other important laboratories have proposed or already use the C-band technology for FELs (e.g. PSI in Switzerland and Spring8 in Japan). Synergies with these laboratories have been considered and collaborations have been started.

The new C-band structures will be fed by a 50 MW klystron Toshiba ET37202. The high voltage pulsed modulator and the 400 W solid state driver for the klystron have been manufactured respectively by ScandiNova (S) and MitecTelecom (CDN) and have been already installed and power tested at LNF. The new system will also include a pulse compressor presently under development.

2. Electromagnetic structure Design

The C-band structures are travelling wave (TW) constant-impedance (CI) sections. A detailed illustration of their design criteria can be found in [4]. The CI choice has been proposed to ease the mechanical design, the fabrication process and to reduce the cost of each structure. This choice has been also addressed to obtain a quasi-uniform accelerating field along the structure since the decay of the RF pulse amplitude along a CI section is compensated by the exponential shape of the SLED pulse [5], resulting in a rather constant profile of the RF field along the structure. The iris apertures have been chosen as large as possible to simultaneously obtain: (a) the lowest peak surface electric field; (b) an average accelerating field of (at least) 35 MV/m with the available power from the klystron; (c) the highest pumping speed; (d) the shortest filling time of the structures that allows feeding the units with a shorter RF pulse with a reduction of the breakdown probability.
Each structure has 75 accelerating cells. The final single cell profile with its main dimensions is given in Figure 1, while Table I reports the main structure parameters.
The design of the TW cells has been done optimizing the structure performances has a function of the iris aperture (a) and iris thickness (t). Figure 2 shows the main structure figures of merit as a function of these two parameters. In particular we have calculated: the average accelerating field (E_{acc_av}) after one filling time, the peak surface field (E_s peak) at the beginning of the RF pulse, the field un-flatness (FU) and the filling time of the structure when the structure itself is fed by a SLED-type input pulse. The peak surface field has been calculated in two different conditions. The first one is related to the case of the maximum input power that we considered available from the klystron, the second one in the case we consider an average accelerating field of 35 MV/m.
Following the design criteria illustrated at the beginning of this paragraph we decided to adopt an iris aperture of 7 mm with 2.5 mm thickness and an elliptical shape with r2/r1=3/4. In the final cell profile we have decided to round one sharp edge of the cell outer profile, in order to increase the quality factor as much as possible.

Table I - Accelerating structure parameters

PARAMETERS	FINAL STRUCTURE
RF Frequency (f_{RF})	5.712 [GHz]
Phase-advance per cell	$2\pi/3$
Number of accelerating cells (N)	75
Structure length included couplers (L)	1.44 m
Group velocity (v_g/c)	0.0283
Field attenuation (α)	0.206 [1/m]
Series impedance (Z)	34.1 [MΩ/m^2]
Shunt impedance (r)	82.9 [MΩ/m]
Filling time (τ_F)	150 [ns]
Power flow @ E_{acc}=35 MV/m	36 [MW]
$E_{s\ peak}/E_{acc}$	2.17
$H_{s\ peak}$ @ E_{acc}=35 MV/m	87.2 [kA/m]
Pulsed heating @ E_{acc}=35 MV/m	<1 °C
Maximum average accelerating field with available power from klystron	140 (96)[MV/m]
Maximum Energy gain (and with average E_{acc}=35 MV/m)	64.1 (42) [MeV]
Output power	$0.60 \cdot P_{in}$
Average dissipated power @ 10 Hz	59.6 [W]

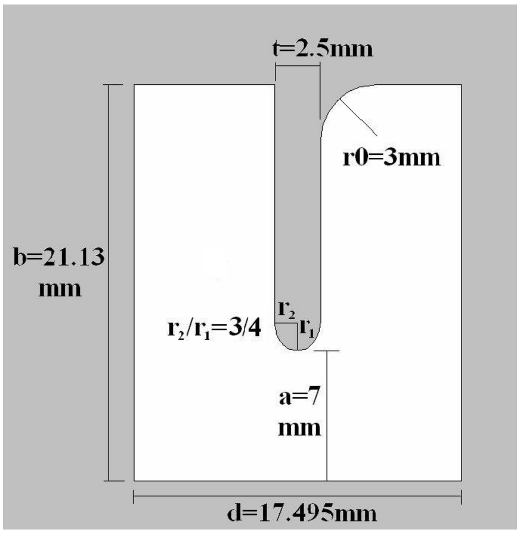

Figure 1: Single cell final dimensions

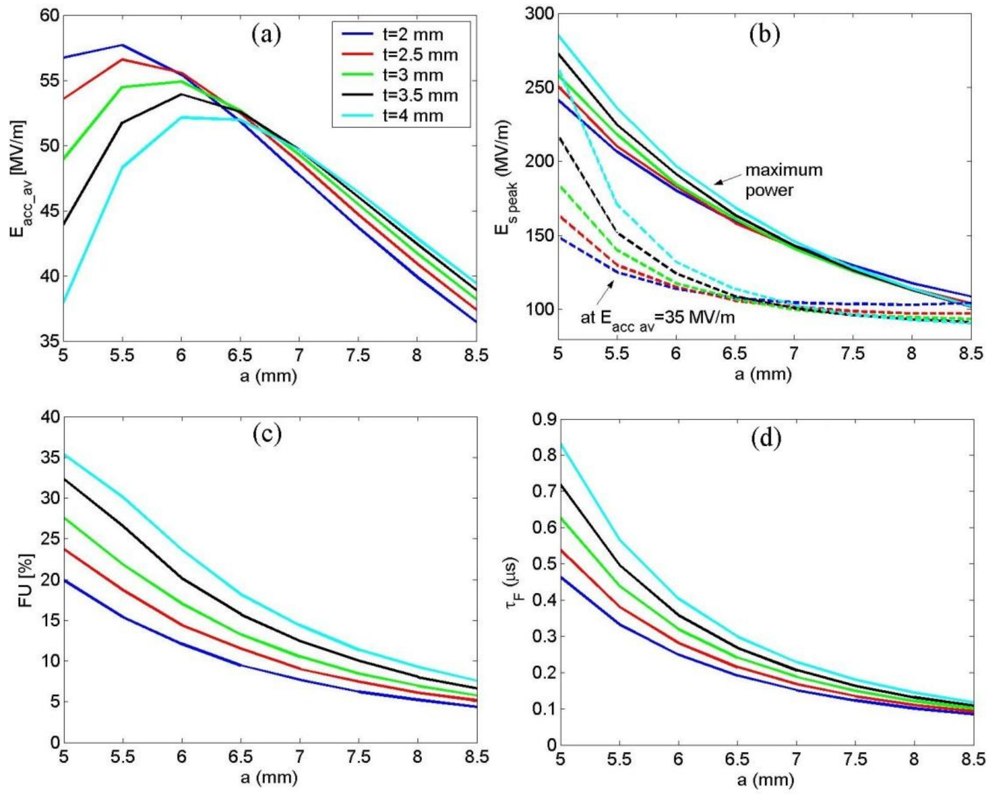

Figure 2: Main structure figures of merit as a function of the iris aperture and thickness: (a) average accelerating field after one filling time; (b) peak surface field at the beginning of the RF pulse; (c) FU; (d) filling time of the structure

A wide and complete discussion on coupler design to minimize the surface magnetic field and, therefore, the coupler damage at high input power, is given in [6]. We adopted for our design the "waveguide coupler" that allows to simultaneously obtaining low pulsed heating [7] and a compact feeding system.

The sketch of the complete coupler with few TW cells is given in Figure 3(a). The design has been divided in two parts, the coupler and the splitter. The first one has been designed by tuning the coupling iris and the outer radius of the first cell (shown in Figure 3(b)) to match the waveguide mode TE_{11} with the accelerating mode TM_{01}-like. The design has been done using HFSS and following the procedure illustrated in [8]. As an example the amplitude and phase of the accelerating field and the accelerating field "seen" by a particle on crest are given in Figure 4 for a 5 cell accelerating structure.

The splitter dimensions (shown in Figure 3(c)) have been found by minimizing the reflection coefficient at the input port. Due to the symmetry of the system this simultaneously gave the optimization of the output splitted power. The final obtained reflection coefficient was <-40 dB.

Concerning the peak magnetic field (and the related peak pulsed heating) on the coupler iris, it is lower than that in the single cell, as expected.

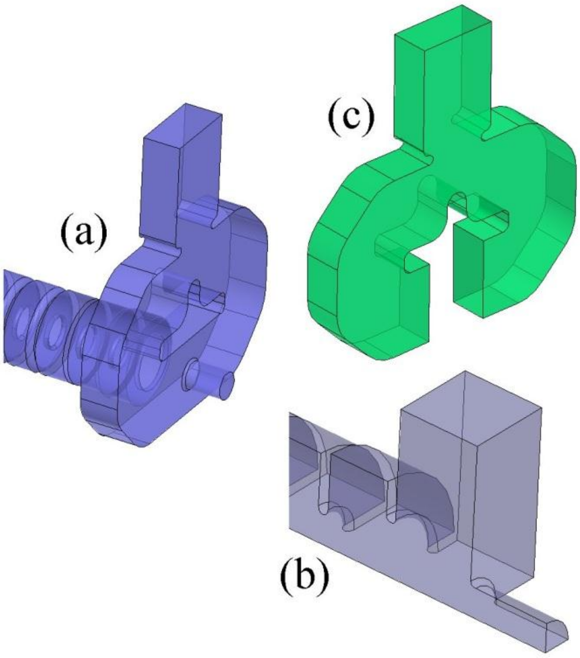

Figure 3: (a) sketch of the complete coupler with few TW cells; (b) detail of the waveguide coupler; (c) detail of the splitter

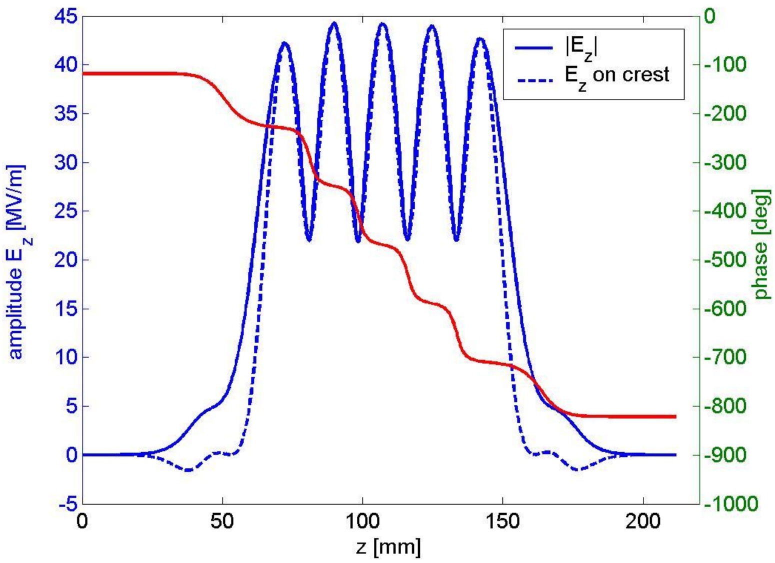

Figure 4: Amplitude and phase of the accelerating field (5 cells structure) and accelerating field "seen" by a particle on crest

3. Mechanical Design

The final mechanical drawing of the SPARC C-band structure is given in Figure 5. The input coupler includes the splitter while, for the output one, we decided to have two symmetric ports to be connected to two RF loads.

The mechanical drawings of the single cell are shown in Figure 6. Each cell has been machined as a "cup" and includes one iris. The cooling system has been integrated in each cell with 6 cooling pipes.

Three tuners at 120° have been inserted. They allow for deforming the outer wall of each cell in both directions. The input coupler is divided in two halves that will be assembled and brazed with the input flange. It will also include one cooling pipe. Its mechanical drawing is given in Figure 7.
To minimize the number of brazing processes, the rectangular waveguide of the output coupler has been designed in order to be realized by an electron discharge machine. The coupling irises and the pipe will be turned by a computer controlled milling machine. Its mechanical drawing is given in Fig. 8. Also the output coupler will include a cooling pipe. All RF flanges are of the DESY-type.

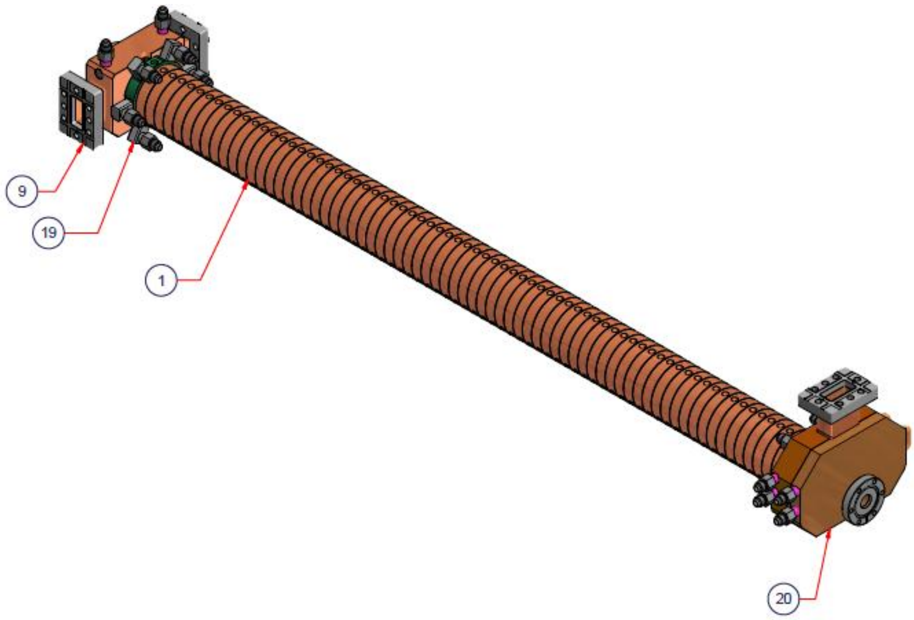

Figure 5: SPARC C-Band structure

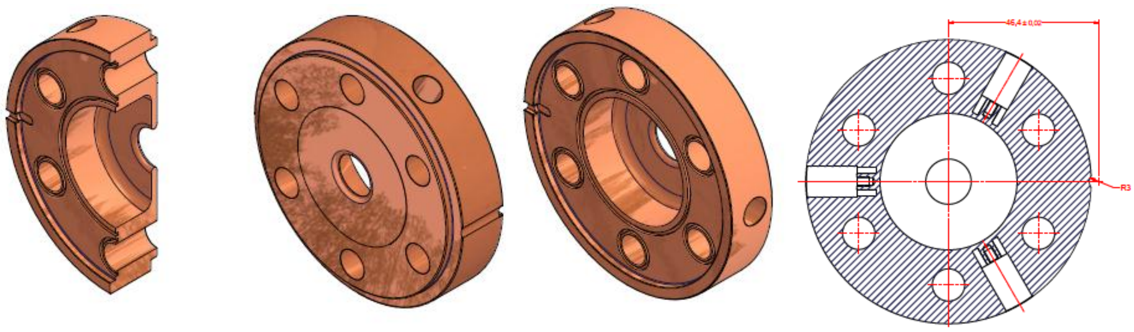

Figure 6: Mechanical drawing of the single cell

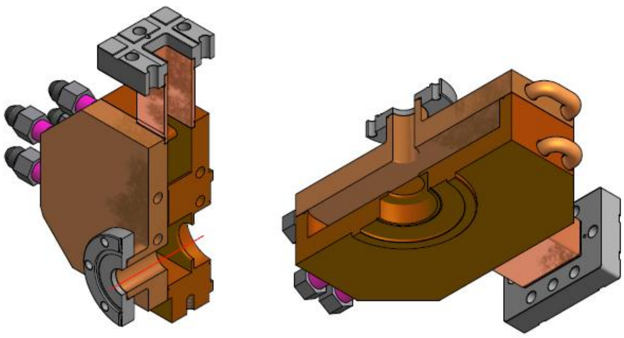

Figure 7: Mechanical drawing of the input coupler

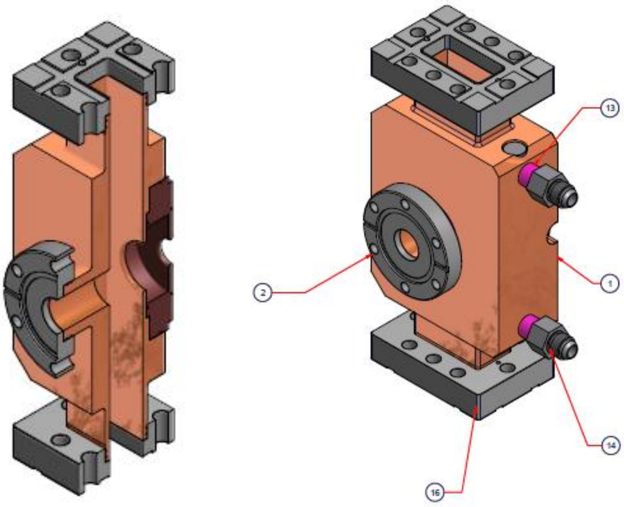

Figure 8: Mechanical drawing of the output coupler

4. References

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