THE RF SYSTEM OF THE SPARC PHOTO-INJECTOR @ LNF*

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Abstract

The S-band linear accelerator of the SPARC Project is in advanced phase of installation and test at the INFN Frascati Laboratories (LNF). The purpose of the machine is to produce low emittance, high peak current electron beams to drive a SASE-FEL experiment. The SPARC RF system consists of an RF gun followed by 3 S-band room-temperature accelerating structures, supplied by 2 pulsed high power klystrons. The use of waveguide variable attenuators and phase-shifters is foreseen to adjust field amplitude and phase independently for each accelerating structure; this will be helpful for tuning the linac working point in the initial machine set-up and for performing velocity bunching experiments in the second phase of the project. This paper reviews the experience in installation and test of the main linac RF structures and subsystems.

INTRODUCTION

SPARC [1] is the normal conducting linear accelerator built up at the Frascati INFN Laboratories to develop a high brightness light source by means of the SASE-FEL process. The electron bunches, emitted by a laser driven RF Gun [2] are accelerated by 3 S-band traveling wave, constant gradient structures. Figure 1 shows the layout of the SPARC RF system which consists mainly of two RF chains. The power sources are the 45 MW peak, 2856 MHz klystrons TH2128C. The klystron n.1 feeds the RF gun and one accelerating section with 4.5 μsec RF pulses, via 3 dB waveguide coupler. Ten per cent of the RF gun power is drawn with a 10 dB coupler to feed an RF deflecting cavity for beam diagnostic purposes and installed at the Linac end.

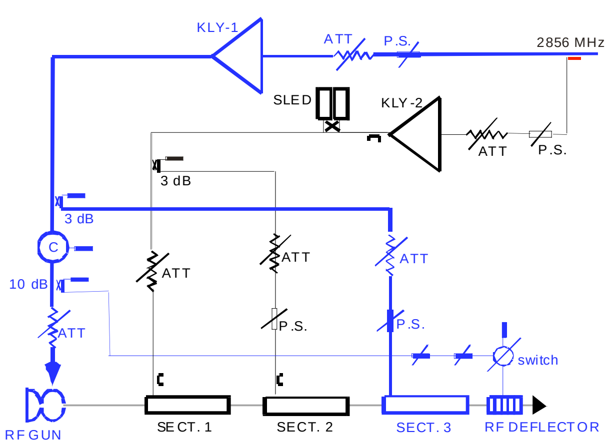

Figure 1: Layout of the SPARC RF system.

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Klystron n. 2 feeds two high gradient accelerating sections through an energy compressor that allows to obtain 60 MW - 0.8 μsec RF pulses per section. The section accelerating field can reach 25 MV/m. The high gradient sections have been manufactured by the Mitsubishi Heavy Industries (JP); the third one has been lend to LNF by the SLAC Laboratories, in the frame of a collaboration with INFN in the field of the high brightness photo-injectors. This structure is supplied by half the power of the klystron n.1 to about 15 MV/m with 4.5 μsec long RF pulses.

All RF chains include waveguide variable attenuators and phase-shifters adjustable independently in order to facilitate the initial commissioning phase.

RF POWER STATIONS

The power stations include the klystrons TH2128C and the pulsed power modulators. The TH2128C is a reliable, 2856 MHz klystron, rated at 45 MW, 4.5 μsec RF pulses. The klystrons are driven by 250 W, high phase stability, solid state amplifiers, made by the Milmega Ltd, UK.

The pulsed modulators, shown in Fig. 2, have been manufactured by the German company PPT. They are standard units with the pulse forming network (PFN) directly charged by a 50 kV DC power supply. The PFN is discharged, by switching the thyratron unit on, through the primary of a 1/15 ratio pulse transformer, housed in the klystron oil-tank. The PFN and the HV transformer are connected with a 50 mm diameter double-shielded coaxial cable. The modulators power the klystrons with 310kV–340A, 5 μsec flat-top pulses at 10 pps. The HV pulse ripple is limited to 0.1 dB thanks to the large number (32) of PFN cells. The stations are remotely controlled via ethernet from the SPARC control room.

Figure 2: Klystron pulsed modulators.

The TH2128C's had already been working in the DAFNE Linac [3] but they had still high enough perveance to be re-utilized adequately in SPARC.

The main data of the SPARC RF stations are gathered in the following Table 1.

Table 1: Main Parameters of the RF Status

Klystron output peak power	45 MW
RF pulse duration	4.5 μsec
RF frequency	2856 MHz
Modulator pulse amplitude	310kV-340A
Modulator pulse rep. rate	≤ 10 pps
HV pulse rise-fall time	0.6 μsec
HV pulse flat-top ripple	< 0.1 %
HV pulse amplitude stability	< 0.1 %

WAVEGUIDE SYSTEM

Under vacuum rectangular WR240 waveguides are adopted to convey the RF power to the gun and to the accelerating structures. The klystron 1 output power is splitted by a 3dB divider. Half power feeds the RF gun through a 4 port differential phase-shift circulator, filled with pressurized SF6 and separated from the waveguide vacuum by ceramic windows. Other half power will feed the last accelerating section, donated by SLAC to LNF. The second waveguide line connects the klystron to the energy compressor (SLED) and is then halved to feed the high gradient accelerating sections with 0.8 μsec, 60 MW peak RF pulses.

Since the beginning of the SPARC design, it was decided to control independently the RF field phase and gradient of the accelerating structures, including the RF gun. This option should be helpful, in the initial machine set-up, to find the best set of parameters that minimizes beam emittance and energy spread. In particular, the velocity bunching experiment, foreseen in a successive phase of the project, requires fine tuning of amplitude and phase of the accelerating units. To this purpose, four 20 dB variable attenuators and two 2π phase-shifters, able to operate in vacuum and to handle high peak RF power, was developed by the German company AFT and are currently under power test at LNF.

Figure 3 shows a picture of an attenuator and a phase-shifter during the cold test in the factory site. Their main specifications are gathered in Table 2.

With four attenuators and just two phase-shifters in the waveguide system, it will be possible to tune phase and field gradient of all RF chains. The attenuators basically consist of a ferrite isolator followed by a 3 dB coupler feeding two counter-sliding waveguide plungers.

RF power adds at one coupler port and subtracts at the other one. The counter-motion of the plungers cancels the phase variation that would be otherwise introduced by the attenuator. Thus, amplitude and phase of the accelerating units can be adjusted without affecting one another. Isolator ports 3 and 4 terminate with ferrite RF loads.

The 2π phase-shifters instead, are simply made of 2 waveguide short-stubs, coupled to a 3 dB hybrid. Both units are driven by stepping motors and remotely controlled via RS232.

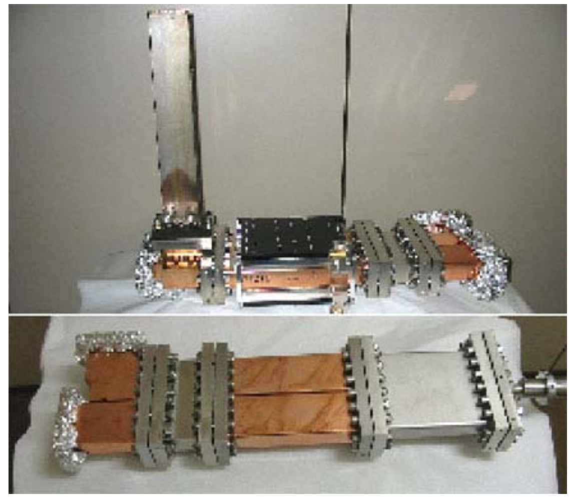

Figure 3: Factory tests of the 20 dB waveguide attenuator (up) and the 2π phase-shifter (down).

Table 2: Main Specifications of Attenuators and Phase-shifters

	Attenuator	Phase-shifter
Input peak power	25 MW – 4.5 μsec [mode 1] 60 MW -0.8 μsec [mode 2]	
Operating range	0 ÷ 25 dB	> 2π
Minimum steps	< 0.02 dB	< 0.25 deg.
Insertion phase variation	± 0.5 deg.	--------
Insertion loss	< 0.18 dB	< 0.3 dB
Input return loss (s11)	< - 26 dB	< - 26 dB

The attenuator isolators, being non-reciprocal devices, contain, under vacuum, ferrite tiles that are significantly outgassing-prone. The attenuators have been therefore baked-out to 120° for more then one week before the power tests. The lowest average pressure reached under baking was in the 10^{-7} mbar range, that decreased further to 10^{-9} range after baking. The residual gas composition, during baking, was mainly due to water and carbon compounds, probably coming from alcohol used in the cleaning process. After baking, the residual gas analysis shows a substantially clean vacuum with presence of H_2, CO, CO_2 and H_2O. The high peak power RF tests of attenuators and phase-shifters are in progress.

ACCELERATING UNITS

The RF gun, consists of a 1.6-cell cavity, equipped with emittance compensating solenoid and manufactured at UCLA. It has been successfully powered to 10 MW peak, 2.5 μsec, 10 Hz and is now in operation routinely. Hence, the cathode field gradient is 120 MV/m and the beam output energy is 5.5 MeV. RF conditioning was smooth and rather short even with the focusing solenoids on. Figure 4 shows the RF gun fully assembled on its support at SPARC.

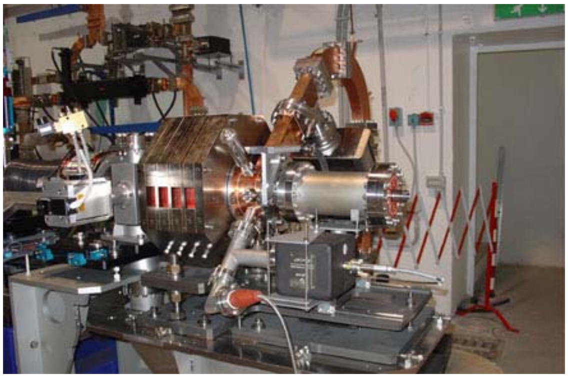

Figure 4: SPARC RF gun assembled at LNF.

Two accelerating sections have been manufactured by MHI (J). They are $2\pi/3$, traveling wave, 3 mt structures, designed to achieve 25 MV/m. An additional same type section, supplied by SLAC and able to reach 20 MV/m, will be installed at the Linac end. The installation of the accelerating structures is foreseen by the fall 2006.

RF DEFLECTING SYSTEM

A system for measuring the bunch length has been studied and is under development. The RF power needed to feed a deflecting cavity (2 MW peak) is derived from the RF gun waveguide line with a 10 dB coupler. The cavity input power and the RF field phase will be adjusted with a variable waveguide attenuator-phase-shifter system, supplied by IHEP (Beijing), that will not operate in vacuum but with pressurized SF6. The deflector can be switched off by turning the power to a dummy load with a waveguide switch, filled with SF6 too. The deflector is a standing wave resonator made of five copper cells, coupled on axis. RF power is slot-coupled to the central cell. The deflecting mode is the 2856 MHz TM110-π. A full size Aluminium model has been manufactured and RF characterized. Figure 5 shows two copper cells under dimensional test. A complete design and the parameter list of the deflecting system can be found in the reference [4].

Figure 5: Two assembled deflector copper cells.

LOW LEVEL RF AND CONTROL LOOPS

Besides the standard RF distribution, the low level system guarantees the phase stability between Laser and klystron output pulses within ± 1 psec. To obtain this very tight requirement, amplitude and phase of the RF signals are sampled and hold at each pulse and the phase drifts are adjusted by means of feedback loops [5]. Figure 6 shows the statistic distribution of the gun phase noise with the feedback closed. The standard deviation is < 0.25°. The master generator signal is amplified to 20 W and multi-splitted to provide stable and high-level L.O. reference signals to the I&Q demodulators. The low level RF system generates the 79.33 MHz Laser driving signal that is the 36th sub-harmonic of Linac frequency.

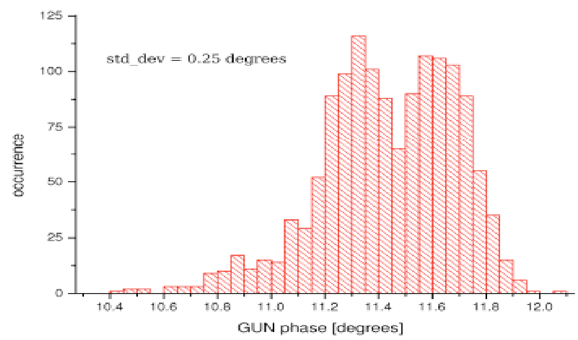

Figure 6: RF gun phase noise statistic distribution.

CONCLUSIONS

The SPARC RF system is in advanced phase of installation. The RF gun has been successfully power tested up to 10 MW, corresponding to 120 MV/m field gradient on the cathode. Furthermore, the power test of the waveguide attenuators and phase shifters are well in progress and, until now, the results are satisfactory. Installation of the accelerating structures is foreseen in the fall 2006 together with the RF deflector line devices. The low level system has been designed to get both pulse-to-pulse and long term required phase stability.

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