THE X-BAND SYSTEM FOR THE FERMI@ELETTRA FEL PROJECT

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Abstract

The single pass FEL facility FERMI@Elettra, in construction at the Elettra Synchrotron Radiation Laboratory in Trieste, requires very short electron bunches with a very high beam quality at the entrance of the undulator chain. To linearize the longitudinal phase space before the bunch compression, mitigating the effects of Coherent Synchrotron Radiation (CSR), a 4th harmonic accelerating section (12 GHz) will be installed before the first magnetic chicane. Here an overall description of the X-band system under development is reported.

INTRODUCTION

FERMI@Elettra [1] is a 4th generation photon user facility, in the last phase of its construction stage, at the Elettra Laboratory in Trieste. The low energy part of the accelerator, up to 300 MeV, has been already installed and commissioned [2]. FERMI is based on a warm S-band linac [3] and a single-pass seeded FEL, covering a photon range from UV up to soft X-ray (100-4 nm).

Table 1 summarizes the main parameters of the electron beam at the linac exit.

Table 1: Main Electron Beam Parameters at the Linac Exit

Parameter	***Value***	***Units***
Energy	1.2-1.5	GeV
Charge	0.8	nC
Peak current	800	A
Bunch length (rms)	280	fs
Slice normalized emittance	1.5	µm rad

To produce high density electron bunches, two magnetic bunch compressors have been incorporated in the machine layout, one at 250 MeV, the other at 600 MeV. The two magnetic chicanes shrink the beam pulse from the 10 ps (FW), supplied by the photoinjector, down to the 280 fs (rms) requested at the linac exit, reaching a peak current close to 1 kA. In a magnetic chicane the compression is performed utilizing a longitudinal energy-time correlation imparted on the beam, when it is run off crest in the previous accelerating sections. In the chicane the low energy electrons, leading the bunch, travel on a longer path than the high energy electrons placed on the bunch tail. This allows the electrons on the tail to catch up those at the head, with a net result of a pulse shortening and a higher peak current at the chicane output. Unfortunately, the off crest acceleration and the curvature of the RF accelerating field in the linac induce non linear components in the longitudinal distribution of the electron bunch. This leads to an increase of the Coherent Synchrotron Radiation instabilities (CSR) in the magnetic chicanes and a degradation of the overall compression process. A possible solution to correct the non-linearities in the longitudinal phase space is the use of a higher harmonic accelerating section with a much larger curvature of the RF accelerating field, operated in the decelerating mode, before the bunch compressor [4]. For FERMI we have chosen to use an X-band structure, 12 GHz (4th harmonic of the S-band).

SYSTEM REQUIREMENTS AND LAYOUT

The X-band structure will be installed before the first bunch compressor at roughly 180 MeV beam energy, where the space charge forces are less effective. Fig. 1 shows the linac layout up to the first bunch compressor, with the operating parameters of the first linac segments.

At 1.5 GeV the maximum voltage requested on the structure is 24 MV, corresponding to a gradient of 32 MV/m, that could be easily reached at 12 GHz. Moreover, if in the future the linac energy will be slightly increased (i.e. up to 1.8 GeV), we have estimated that the final requirements on the gradient would not exceed 35-36 MV/m, still reachable in the X-band region.

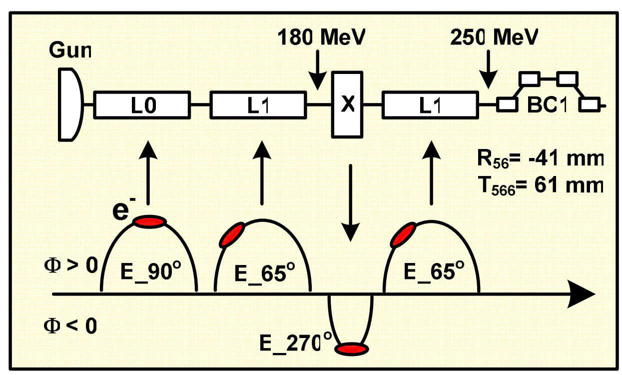

Figure 1: Linac layout up to BC1 and beam compression process.

Table 2 summarizes the operating requirements for the X-band structure.

Table 2: Main Operating Parameters of the X-band Struct.

Parameter	***Value***	***Units***
Nominal voltage @1.5 GeV	20-24	MV
Maximum operating gradient	32	MV/m
RF power at the structure	13-19	MW_{pk}
RF pulse length	500	ns
Electron pulse length (FW)	5-15	ps
Max pulse repetition rate	50	Hz
Average RF power	500	W
RF phase	-120	deg
Acc. field phase stability (rms)	0.5	X-deg
Acc. field ampl. stability (rms)	0.5	%

HARDWARE

Klystron and HV Modulator

The 12 GHz high power RF source is a scaled version of the SLAC XL4 klystron. A collaboration agreement between different EU laboratories, CERN, PSI and Elettra has been signed between 2008 and 2009 with SLAC for the development and the production of a new X-band tube, XL5, operating at the European frequency of 11.992 GHz. Table 3 summarizes the main parameters of XL5.

Table 3: Main Parameters of the XL5 Klystron

Parameter	***Value***	***Units***
RF frequency	11.9942	GHz
RF output power (peak)	≥ 50	MW
Max RF pulse length at full power	1.5	µs
Max pulse repetition rate	100	Hz
RF gain	≥ 50	dB
Efficiency	> 40	%
Max anodic voltage	450	KV
Perveance	1.15	µP

The SLAC construction program foresees in total five XL5 tubes, one for CERN, two for PSI and two for Elettra (one in operation and one spare). The first klystron already produced, the one for CERN, has been successfully tested at SLAC last March, exceeding the expected performance, and soon will be sent to CERN. The first klystron for Elettra is expected to be delivered in September 2010. Fig. 2 shows an XL5 picture in the final dressing stage.

Figure 2: XL5 klystron.

The 50 Hz HV modulator is an optimized version of the conventional thyratron, pulse forming network (PFN), and pulse transformer modulator already developed for the FERMI S-band plants, for which there is extensive experience at Elettra. A 50 KV high stability power supply (≤5*10E-5) will directly charge a 1.1 µs (flat-top) PFN, discharged on the klystron cathode through a double gaps thyratron (E2V CX1536X) and a step-up transformer (N=1:20). Particular care has been given to the PFN design. The internal inductance of the capacitors and the total inductance of the circuit have been optimized to improve the pulse rise/fall time, obtaining a usable pulse flat-top of 1.0 µsec without exceeding 2.5-2.7 µsec FWHM. Fig. 3 shows the pulse shape we expect to have on the primary side of the pulse transformer, 1.1 µsec @99% flat-top, 2.3 µsec FWHM. The inner pulse is a magnification of the fat-top on a 1% vertical scale.

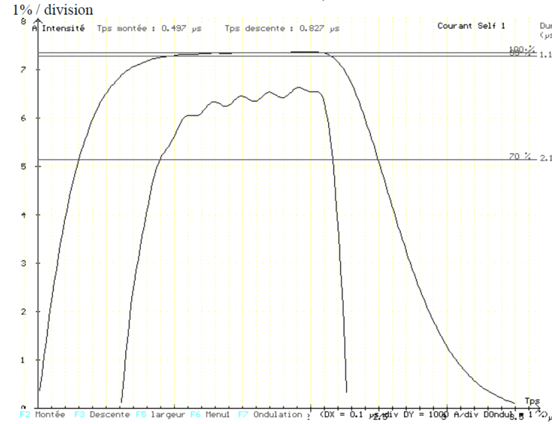

Figure 3: Pulse shape estimation of the PFN with a total external inductance of 2.0 µH.

X-band Accelerating Structure

The accelerating structure is now under development in the framework of a collaboration between CERN, PSI and Elettra. The RF design has been completed and a constant gradient, with large iris aperture (9.1 mm avg.), 5/6 π phase advance has been chosen. For the cell geometry and the coupling irises particular care has been given to minimize the wake field effects, while still retaining good efficiency. To optimize the RF power coupling a dual waveguides solution with mode launchers has been used. This choice allows for a higher grade of symmetry of the electric field in the coupling cells, with a significant reduction of the RF field and the heat load at the coupling irises. Table 4 shows the main characteristic of the structure.

Table 4: X-band Structure Main Characteristic

Parameter	***Value***	***Units***
Structure type	5/6 π, const. grad.	
Working frequency	11.992	GHz
Overall length	0.965	m
Active length	0.750	m
Iris diameter (average)	9.1	mm
Filling time	100	ns
RF pulse length	≤ 1.0	µs
Pulse repetition rate	≤ 100	Hz
Max heat load @ 40 MV/m	2.5	KW

The structure is composed of 73 cells and integrates two alignments monitors for accurate beam steering and trajectory correction. Nevertheless, we are also investigating several solutions for fine remote mechanical adjustments of the structure in the transverse plane (i.e. ±0.5 mm max in x.y, with a fine step of 50 µm and a position reproducibility less than 20 µm). The manufacture of the disks for four accelerating structures (two for PSI and two for Elettra) has already started and several will be delivered to CERN by the end of May for mechanical and brazing tests. We expect to have the first structure ready for installation at the end of January 2011.

WG Circuit and LLRF System

The power connection from the klystron to the accelerating section, is made with a WR 90 rectangular waveguide (see Fig. 4). The total length of the circuit is less than 10 m and we expect to keep the RF power losses below 30%. The use of a circular WG would greatly reduce the losses, however the availability of high power circular components is very limited at this time. Most of them, i.e. mode converters, ceramic windows, vacuum valves, bends, etc. have been developed at SLAC for the NLC program, but are not readily available and further R&D is requested for their frequency scaling and fine tuning at 12 GHz. Some efforts in this direction are in progress at CERN in the framework of the CLIC collaboration, but the time required to have a full RF characterization of these components does not fit with our present time schedule. The main consequence and drawbacks for the lack of these key components is that we cannot de-couple, from the vacuum point of view, our WG circuit and the accelerating section from the klystron. In case of a tube replacement we are obliged to vent the entire WG circuit with a negative impact on the operation. To overcome this difficulty, we have designed the first part of the WG circuit with the possibility for easy upgrading in the future. With the expected RF losses we need to operate the klystron at about 40 MW peak power, to ensure the requested power at the cavity input. This is well within the 50 MW capability of the tube. Moreover, even if the absolute losses are not important, the entire WG circuit will be temperature stabilized within +/-0.05 ^{o}C, to limit the RF phase variations.

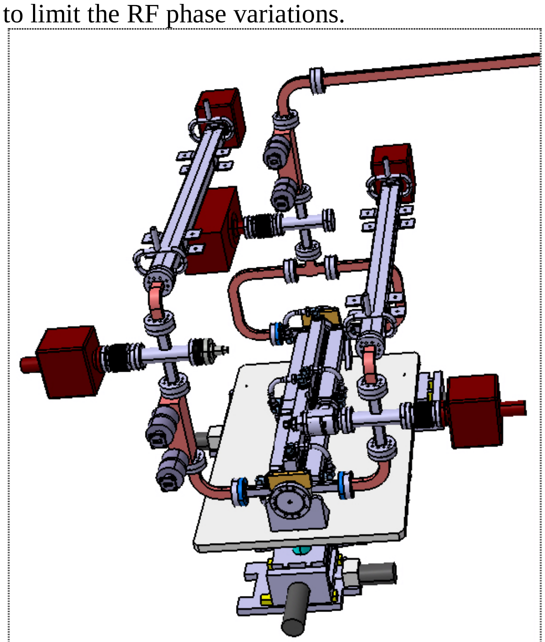

Figure 4: Accelerating structure and WG connections.

The X-band LLRF control system will be built around the existing S-band LLRF system as shown in Fig. 5. Due to practical constraints on filter bandwidth and ADC/DAC sampling rates, a double frequency conversion is required for the generation of the sampled signal. By the judicious choice of LO1 the first down/up conversion leads to the exact frequency (S-band) suited for the existing LLRF system. The key feature necessary for this scheme is the generation of a LO at three times the S-band frequency. Unfortunately this clock can not be generated by simply multiplying and/or adding the existing frequencies. This presents a challenge since the output must be phase locked to the existing clock (241.6 MHz) and have an integrated phase noise on the order of 20 mdeg.

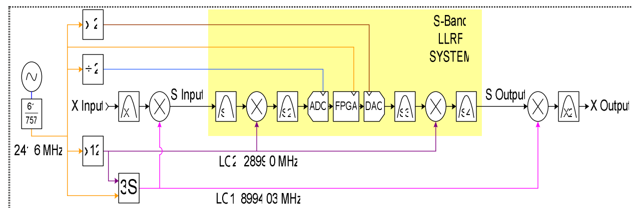

Figure 5: X-band LLRF system layout with the S-band system yellow shaded.

CONCLUSION

An X-band system for the FERMI@Elettra FEL is under development at Sincrotrone Trieste. It will be installed before the first magnetic bunch compressor of the linac, to compensate the non linearities in the beam longitudinal phase space, optimizing the compression process. Most of the components have been developed in a framework of scientific collaboration between different laboratories, SLAC, CERN, PSI and Elettra. The first high power klystron, operating at the European X-band frequency of 12 GHz, has been successfully tested at SLAC, exceeding the expected performance. A strong effort, still in progress, has been undertaken to develop the accelerating structure and some of the key waveguide components. The availability and optimization of the X-band system can play an important role for the future upgrading of the FERMI@Elettra FEL.

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REFERENCES

[1] FERMI@Elettra Conceptual Design Report, Jan '07.
[2] G. Penco et al. "The FERMI@Elettra commissioning" this Conference.
[3] G. D'Auria et al. "Linac Upgrading Program for the FERMI Project: Status and Perspectives", PAC07, Albuquerque, NM, USA, TUPMN029.
[4] P. Emma "X-Band RF Harmonic Compensation for Linear Bunch Compression in the LCLS" SLAC-TN-05-004, LCLS-TN-01-1, (2001).
[5] M.Dehler et al, "X-band RF structure with integrated alignment monitors", Phys. Rev. ST Accel. Beams, 12, 062001 (2009).