RF ACTIVATION AND PRELIMINARY BEAM TESTS OF THE X-BAND LINEARIZER AT THE FERMI@ELETTRA FEL PROJECT

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Abstract

FERMI@Elettra is a fourth generation light source facility presently in commissioning at the Elettra Synchrotron Radiation Laboratory in Trieste, Italy. It is based on a seeded FEL driven by an S-band (3 GHz), 1.5 GeV normal conducting (NC) linac, that provides ultra short high current e-bunches using two stages of magnetic compression. To linearize the beam longitudinal phase space and also improve the compression process, a forth harmonic RF structure (12 GHz) has been installed upstream of the first magnetic chicane. This paper reports a brief description of the X-band plant, the RF activation of the structure and the preliminary beam tests.

INTRODUCTION

FERMI@Elettra [1] is a 4th generation light source, now in an advanced commissioning stage at ELETTRA, the Italian national laboratory for the Synchrotron Radiation. The main parameters of the FERMI project for the two expected FEL lines are shown in Table 1.

Table 1: FERMI Main Parameters

Parameter	*FEL1*	*FEL2*
Wavelength (nm)	80-20	20-4
Electron beam energy (GeV)	1.2	1.5
Bunch charge (nC)	0.5-0.8	
Peak current (A)	600–900	
Bunch length (FWHM, fs)	600	
Normalized emittance (slice, μrad)	≤ 1.2	≤ 1.0
Energy spread (slice, KeV)	≤ 250	≤ 150
Repetition rate (Hz)	10–50	

FEL1, based on a single stage high gain harmonic generator (HGHG), has already provided photons for users and is currently in the final phase of optimization and commissioning towards nominal performance.

FEL2, based on a double cascade of HGHG and a fresh bunch technique, has entered the commissioning phase, with expected completion in 2013.

As shown in the Table 1, both FEL lines require a very dense beam at the entrance of the undulator chains, with FEL2 simultaneously requiring a bunch of sufficient length to allow the use of the fresh bunch technique.

To fulfill these requirements two magnetic bunch compressors, BC1 and BC2, and an X-band (12 GHz) accelerating structure have been installed on the machine. The two bunch compressors shrink the e-pulse increasing the beam peak current. Meanwhile, the X-band structure, with a much larger RF voltage curvature, optimizes the compression process by removing all of the bunch non-linearities caused by the S-band off crest acceleration and by the second order optics in the magnetic chicane [2].

Figure 1 shows the machine layout before the first magnetic chicane, the compression process, and the e-bunch shapes as seen on a monitor upstream of BC1, with and without the X-band correction.

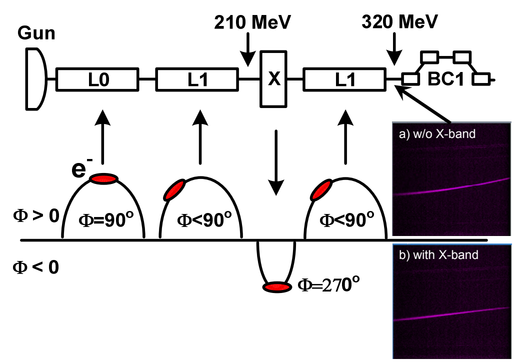

Figure 1: Machine layout upstream BC1 and compression process.

X-BAND SYSTEM

Figure 2 shows the layout of the FERMI X-band system as well as the operating requirements of the main components [3]. It includes: a HV modulator based on standard PFN technology - completely developed and assembled in-house; a 50 MW, 12 GHz "XL5" klystron, designed and produced at SLAC [4] by scaling a previous model (XL4), which operated at a slightly different frequency; and a 750 cm (RF active length) accelerating structure developed and produced in collaboration with CERN and PSI [5].

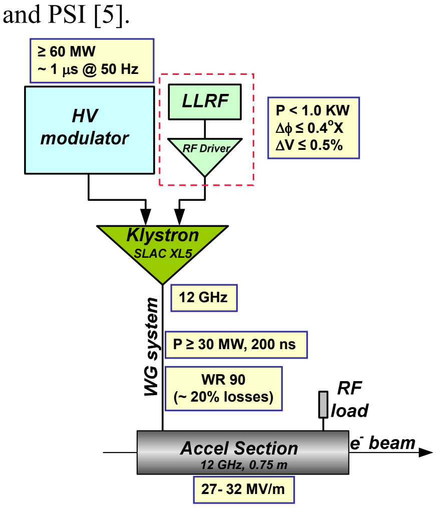

Figure 2: X-band plant layout with the main sub-systems requirements.

The power connection between the klystron and the accelerating section is made with a WR 90 rectangular waveguide. Most of the waveguide components in the circuit were not commercial available and some of them

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have been scaled from an existing 11.4 GHz design. Two mode converters and a vacuum valve assembly, developed in collaboration with CEA-France [6] and produced by industry, have been installed at the output of the klystron. These prevent the venting of the structure in case of klystron replacement. The total length of the circuit is less than 10 m and accounts for roughly 20% of the RF power losses. To limit the RF phase variations, the circuit is temperature stabilized to within +/- 0.05 ^{o}C.

The klystron RF driver is a commercial available 2 kW TWT amplifier, while the LLRF system has been assembled in house, using the existing S-band digital system along with a low-noise frequency up/down conversion chassis (3/12 GHz X-box), developed in collaboration with industry. For the first beam tests we have used a non-optimized preliminary version of the X-box.

The accelerating structure, shown in Fig. 3, has a dual feed at the input and output and is composed of 73 cells. It integrates two alignment monitors for accurate beam steering and trajectory correction. We have also foreseen the possibility to move the entire structure in the x-y plane, by fine remote adjustments. This allows a maximum x-y deviation of ± 0.5 mm (peak-to-peak) while keeping a fine step size of 10 µm with position reproducibility better than 5 µm.

The structure and the waveguide system were installed on the linac in October 2011, but they were not immediately connected to the klystron to allow for the RF tube processing on waveguide loads [7].

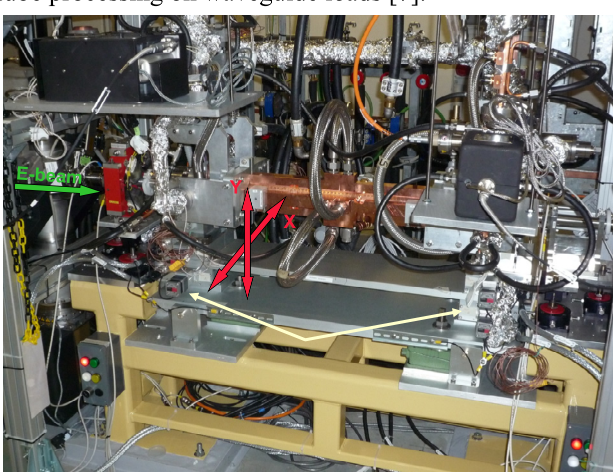

Figure 3: X-band structure assembly.

Considering our needs in terms of accelerating structure gradients and the power losses in the waveguide circuit, we processed the klystron up to 35 MW peak RF power and 500 nsec pulse length. We had in total 678 hours of operation on waveguide loads, at 50 Hz pulse repetition rate.

In conjunction with the tube conditioning, some tests were carried out on the idle structure to verify the transverse wakes effects [8] and the beam emittance degradation versus the beam offset. Data was collected steering the beam ± 1.0 mm off-axes (x-y) using a 350 pC bunch with a 6.5 ps length (FWHM), see Fig. 4. The results showed that the structure was properly aligned and that no particular emittance degradation is expected if the beam stays aligned on the axes within one hundred microns. In February 2012 the structure and the waveguide circuit were connected to the klystron for the RF conditioning of the entire system. This activity was completed within three weeks, in approximately 250 hours of operation. The structure and the waveguide components were conditioned up to 35 MW, 500 ns RF.

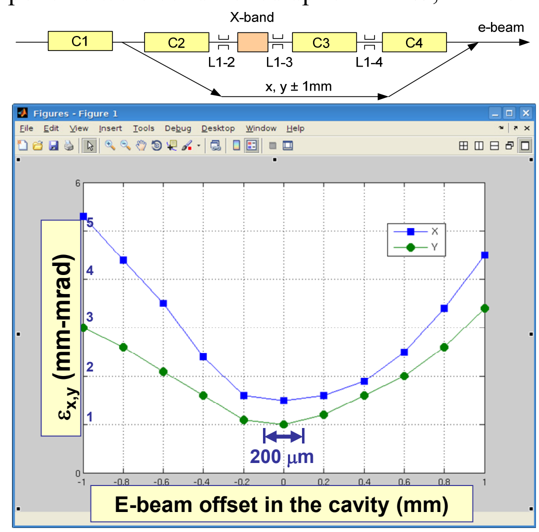

Figure 4: Beam emittance degradation vs beam on-axes offset with the X-band structure idle.

We did not experienced any particular problems in operating the waveguide circuit at the above mentioned power levels, and after roughly 100 hours of operation the vacuum of the entire circuit dropped below 1-2*10E-8 mbar. Also, with regard to the section, we easily reached a gradient above 30 MV/m, well beyond our needs and at the beginning of March 2012 we started the first beam tests.

PRELIMINARY BEAM TESTS WITH RF

Figure 5 shows the structure energy gain (operating on crest) versus the klystron anodic voltage, with the expected and measured curves in good agreement.

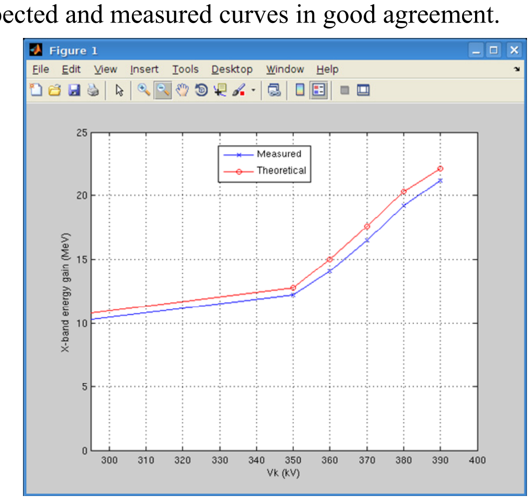

Figure 5: Measured X-band structure energy gain.

All the beam tests have been done using a machine configuration with a single bunch compressor (BC1-

on/BC2-off), 400 pC bunch charge, and 7.5 ps bunch length (FWHM).

Preliminary evaluations on the emittance at BC1, with the X-band active, did not show any particular degradation, but a more detailed study must still be performed.

With the cavity set at 20 MeV, and the chicane at a compression factor between 5 and 6, the beam has been run on the decelerating crest of the X-band RF. Using two RF deflectors the bunch charge distribution has been measured, both at BC1 (320 MeV) and at the end of linac (1.2 GeV), with the X-band On/Off (see Fig. 6). Note that the vertical coordinate on the images represents the longitudinal coordinate in the bunch.

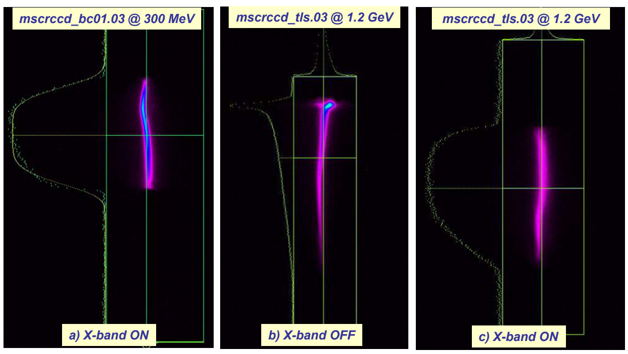

Figure 6: Bunch charge distribution with the X-band On/Off as seen at BC1 (320 MeV) and at the end of the linac (1.2GeV).

The flat-toping effect of the charge distribution inside the bunch, induced by the X-band, is quite evident in comparing the (a), (c) images, with respect to (b), which shows the typical 'spiky' distribution of the charge induced by the magnetic compression.

Figure 7 shows the pulse-to-pulse current profile after BC1 for 150 pulses, with the X-band RF On/Off.

The jitter of the compression factor is evident. This is, probably due to a non perfect synchronization of the X-band RF to the beam. We are currently investigating the issue, testing different solutions, with an in-depth check of the beam synchronization and LLRF systems.

CONCLUSION

The X-band linearizer for the FERMI@Elettra FEL has been completed and installed on the machine.

The 12 GHz RF plant has been put in operation and is now capable of producing more than 35 MW peak RF power with a 500 nsec pulse width, at a 50 Hz repetition rate. The waveguide system and the accelerating structure have been RF conditioned reaching a 30 MV/m gradient in the structure. At present the entire system has been operational for over 1400 hours showing high reliability.

Preliminary tests, carried out with the beam, have provided good results, although the stability of the beam and the compression process still need to be corrected and optimized. Further tests are underway to clarify the problem and optimize the compression process, which plays an extremely important role, especially for FEL2.

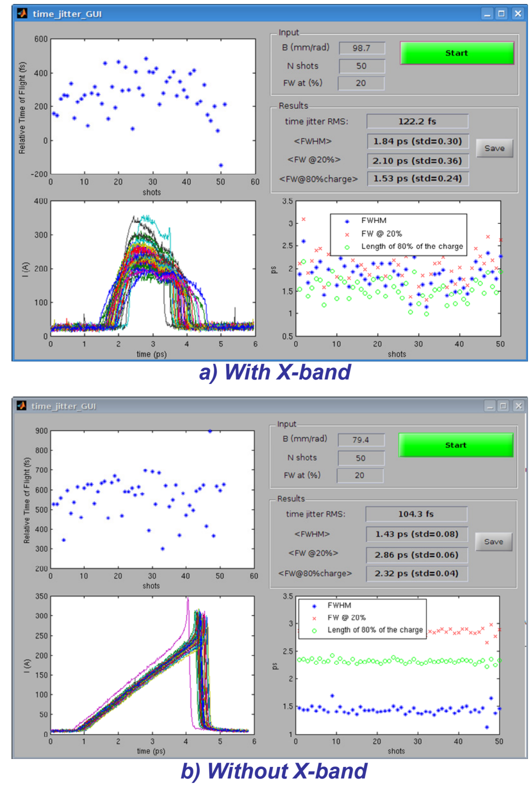

Figure 7: Current profiles at BC1 with and without X-band.

ACKNOWLEDGEMENTS

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