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X-band technology applications at FERMI@Elettra FEL project

G. D'Auria

Sincrotrone Trieste ELETTRA, 34012 Basovizza, Trieste, Italy

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ABSTRACT

The current activities and future perspectives involving the use of X-band technology at the Elettra Laboratory are presented. These are mainly related to the development of the FERMI@Elettra FEL project, a fourth generation light source facility, now under commissioning in Trieste. The facility, based on a seed scheme, requires sub-ps electron bunches ($\sim$1 kA), with very high optical qualities, at the entrance of the undulator chain. This is achieved by compressing the beam with two magnetic chicanes.

A large effort has been undertaken to develop an X-band accelerating structure, to be installed downstream the first bunch compressor, before the magnetic chicane. In addition, we are also evaluating the possibility of extending the FERMI FEL wavelength capabilities beyond the foreseen limit of 4 nm, by increasing the linac energy from 1.5 GeV to 2.4–2.5 GeV, using the X-band technology.

1. Introduction

FERMI@Elettra is a soft X-ray, fourth generation light source facility now in the commissioning phase at the Elettra Laboratory in Trieste, Italy [1]. Based on a 1.5 GeV normal conducting S-band linac [2] it will produce very short coherent photon pulses (25–200 fs) in the UV and soft X-ray region (100–4 nm).

The main linac foresees an X-band accelerating section, operating at 11.992 GHz (the forth harmonic of the European S-band), installed downstream the first bunch compressor to linearize the beam longitudinal phase space before the compression [3]. The RF power for this structure is produced by the SLAC XL5 klystron [4], a scaled version of the XL4 tube [5], developed in the framework of a Collaboration between SLAC and three EU laboratories, CERN, PSI and Elettra.

Recently a proposal to increase the FERMI linac energy up to 2.4–2.5 GeV, adding a very short X-band linac segment in the high energy region of the machine, has been presented [6]. The higher operating energy will extend the FERMI FEL spectral range down to the water window (1.0–2.0 nm), which has great potentials for the users community.

The enormous amount of work carried out in the last 15–20 years, in the context of the NLC [7] and JLC [8] projects for high energy e^+/e^- colliders, has resulted in the development of many X-band components, such as high power sources, accelerating structures and waveguide systems. Upon the termination of these projects, this technology received a renewed push from the decision of the CLIC [9] collaboration to lower the main frequency to 12 GHz (previously at 30 GHz) and, more recently, from applications associated with the development of linac based fourth generation photon sources. In this context the scientific interest for the use of X-band technology is rapidly increasing and is mainly focused in the following areas:

a) short accelerating structures to be used as energy linearizers. Such structures are already operating at SLAC–LCLS [10] and Desy-FLASH [11]. Others are planned or under construction, including those for the FERMI@Elettra FEL in Trieste and the SwissFEL at PSI, Villigen [12].
b) Accelerating structures operating with transverse E-fields (deflecting modes) used for beam diagnostics, bunch length and slice parameter measurements (such as emittance and energy spread), or ultra fast kickers, for e-bunch selection inside multi-bunch trains [13].
c) Development of compact room temperature linacs, either operating at high gradients with low duty cycles, or at low gradients with high duty cycle and high repetition rates [14]. In this context, some projects have already been funded and are in construction, LLNL–SLAC [15], while others have been proposed and are under investigations at several laboratories, i.e. Elettra, LANL, Diamond, University of Groningen, etc.

However, despite the great interest shown by the scientific community for the use of X-band technology, the availability of high power components working at these frequencies, such as power generators, accelerating structures and waveguide elements, is still very limited. Most components are not commercially available, and only a handful of laboratories have the know-how at these frequencies. For example, regarding RF power generation, only SLAC has the technology to achieve klystron peak powers above 50 MW in the micro-second range.[1] The RF

[1] A Toshiba ppm (periodic permanent magnets) klystron is also in operation at KEK, producing 50 MW, but limited to 400 ns RF pulse length [16].

E-mail address: gerardo.dauria@elettra.trieste.it

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production represents a major hurdle in the spread and use of X-band technology, especially with regard to the development of extremely compact machines for X-ray production.

Currently there are two activities involving X-band technology on the FERMI@Elettra FEL project:

1. the construction of a short accelerating structure, that will be installed in the low energy part of the linac and used as an energy linearizer;
2. the study for a possible increase of the linac beam energy, in view of a future upgrade of the photon facility and an extension of its spectral range capabilities.

2. The X-band linearizer system for FERMI

FERMI is a seeded FEL that requires very short and dense electron bunches at the entrance of the undulator chain. To produce these bunches, two magnetic bunch compressors have been incorporated in the machine, one at roughly 300 MeV, the other at about 750 MeV. The two magnetic chicanes shrink the beam pulse from 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 achieved using a longitudinal energy–time correlation, imparted on the beam with an off-crest acceleration. The low energy electrons, leading the bunch, travel on a longer path than the high energy electrons at the tail. This allows the electrons at the tail to catch up with those at the head, thus shortening the pulse and increasing the peak current at the chicane output. However, the compression process is dominated by non linear effects such as the sinusoidal RF time-curvature and the second order path-length dependence on particle energy that, particularly for high compression factors, can produce very sharp temporal electron spikes. These spikes produce undesirable collective effects, like Coherent Synchrotron Radiation (CSR), that lead to an overall degradation of the beam quality.

According to Emma [10], to improve the compression process and correct the non-linearities in the longitudinal phase space, a higher harmonic accelerating section, with a much larger RF field curvature, operated in the decelerating mode, is required before the bunch compressors.

2.1. Accelerating structure

Fig. 1 shows the solution adopted for the FERMI linac. Here the linearizer is a 12 GHz structure (fourth harmonic of the S-band) installed before the first bunch compressor (BC1). The same scheme, with an identical structure, will be adopted at SwissFEL.

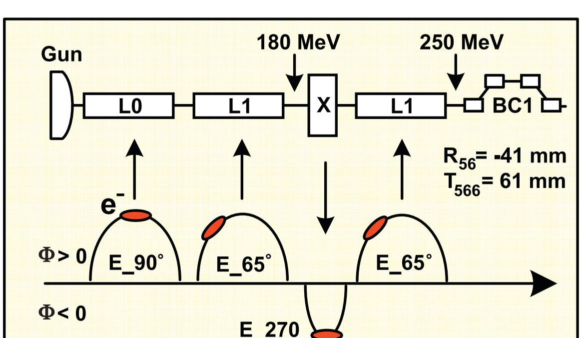

Fig. 1. FERMI linac layout up to BC1 and beam compression process.

The 12 GHz structure, developed in the framework of a collaboration between CERN, PSI and Elettra [17], is now under construction and will be installed on the machine in July 2011. At 1.5 GeV, the linearization process requires roughly 24 MV integrated field, corresponding to a gradient of 32 MV/m, a very conservative figure at 12 GHz.

Table 1 summarizes the main operating parameters for the X-band system.

The structure is 75 cm long (RF active length), constant gradient, 5/6π phase advance per cell and has a large iris aperture, 9.1 mm average diameter.

The geometry adopted, similar to NLC type H75 [18], is a good compromise between a high shunt impedance (high RF efficiency), associated with small apertures, and a low transverse kick (reduced wakes), that asks for the opposite.

The choice of the high phase advance allows the large iris aperture, without losing high efficiency.

To optimize the RF power coupling a dual feed waveguide solution with mode launchers has been chosen. The two RF inputs are fed through a power divider with a WR90 bi-directional coupler at its input, for RF measurements. The output of the structure is connected to two independent RF loads, one of which has a WR90 coupler to monitor the RF field phase and amplitude. Fig. 2 shows the structure and waveguide connections.

Table 1
FERMI X-band structure main operating parameters.

Parameter	*Value*	*Units*
Nominal integrated voltage @ 1.5 GeV	24	MV
Maximum operating gradient	32	MV/m
RF power at the structure	19	MW_{pk}
RF pulse length	≤ 300	ns
Electron pulse length (FW)	5–15	ps
Max pulse repetition rate	50	Hz
Average RF power	≤ 300	W
RF phase	−120	deg
Acc. field phase stability (rms)	0.3	X-deg
Acc. field amplitude stability (rms)	0.5	%

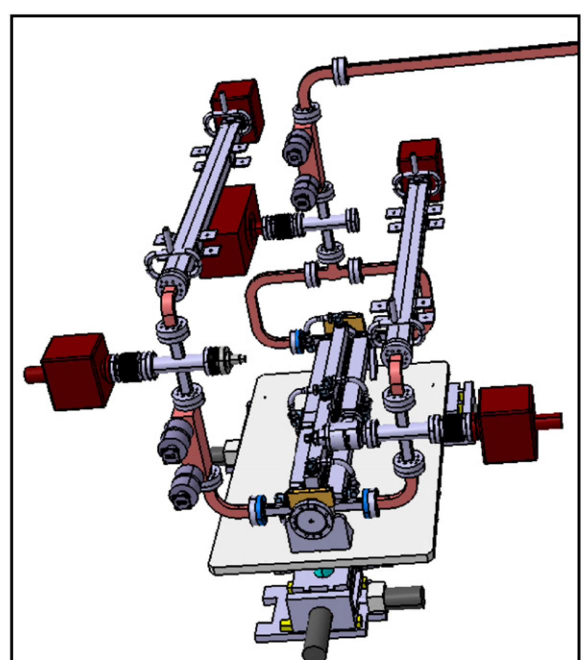

Fig. 2. Accelerating structure and waveguide connections.