FERMI@ELETTRA: INSTALLATION AND COMMISSIONING OF THE S-BAND RF SYSTEM *

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Abstract

FERMI@Elettra is a single-pass FEL user-facility covering the wavelength range from 100 nm (12 eV) to 4 nm (310 eV) and is located next to the third generation synchrotron radiation facility Elettra in Trieste, Italy. The first electron beam from the photocathode electron RF gun and injector system was extracted in August 2009. Commissioning and installation of the remaining linac and linac systems are continuing and will alternate through this year. The linac is based on S-band technology. It uses fifteen 3 GHZ 45 MW peak RF power plants powering the gun, the accelerating structures and the RF deflectors, and when completed will be able to deliver greater than 1.5 GeV electron beams to the FEL undulator system. This paper provides a summary of the installation activities and discusses the performances results of the main subassemblies both during the initial checkouts and through the commissioning of the accelerator.

INTRODUCTION

The FERMI@Elettra FEL facility is composed of a warm S band linac and a single pass seeded FEL [1]. The accelerator (figure 1) consists of the photocathode gun, five S-band linacs, an X-band system to linearize the bunch compression process, a laser heater to control the uncorrelated energy spread, two bunch compressors to increase the peak current and the beam transport system to the undulators. The main beam parameters at the linac exit are listed in table 1. The facility is in the commissioning phases [2].

Table 1: FERMI Linac Specifications

Parameter	
Repetition rate	50 Hz
Bunch energy range	0.9-1.5 GeV
Bunch charge	≤ 800 pC
I_{peak}	800 A
Bunch length (full width)	~ 1 ps
ε_{slice}	≤ 1.0 μm
σ_E (uncorr.)	≤ 150 KeV

The S band system is composed of 15 RF plants (14 plus one spare) and a total of 18 accelerating structures. In addition the plants power the gun and the three RF deflectors. The linacs are built re-arranging the original Elettra injector, adding nine accelerating structures, seven of which where provided by CERN and two to be acquired [3], [4].

SYSTEM DESCRIPTION

The layout of the systems powered by each klystron is shown in figure 1. The spare transmitter (K0) can replace either of the first two klystrons.

Table 2: Accelerating Structures Parameters

Parameter	S0A-S0B	C1-C7	S1-S7
Mode	TW2/3π	TW 2/3π	BTW3/4π
Frequency (MHz)	2998.01	2998.01	2998.01
Total length (m)	3.2	4.5	6.15
Filling time (μs)	0.903	1.5	0.757
Attenuation (Np)	0.603	0.7	0.611
Acc. gradient (MV/m)	15.8	13.1	23.6
Energy gain (MeV)	50	60	145

Accelerating Structures

There are four types of accelerating structures (see table 2 for the parameters of the already installed ones):

- S0A and S0B are constant gradient travelling wave (TW) structures, operating in the 2/3π mode, on-axis coupled. They are from the old Elettra injector.
- C1-C7 are also constant gradient TW structures, operating in the 2/3π mode, on-axis coupled. These structures were provided by CERN after LIL decommissioning.
- S1-S7 are constant impedance backward travelling wave structures (BTW), operating in the 3/4π mode and are magnetically coupled. These structures are equipped with SLED systems. These structures are from the old Elettra injector.
- C8 and C9 will be TW structures, operating in the 2/3π mode, on-axis coupled [5]. Following the measurements of the induced kick to the beam in the coupler cell, it was decided to exchange the new structures with the first two presently installed. The input and output coupler cavities shall be of the symmetric double-feed type with diametrically opposed sidewall-coupling aperture. The geometry should minimize quadrupolar field asymmetries. The call for tender will be launched in the next months.

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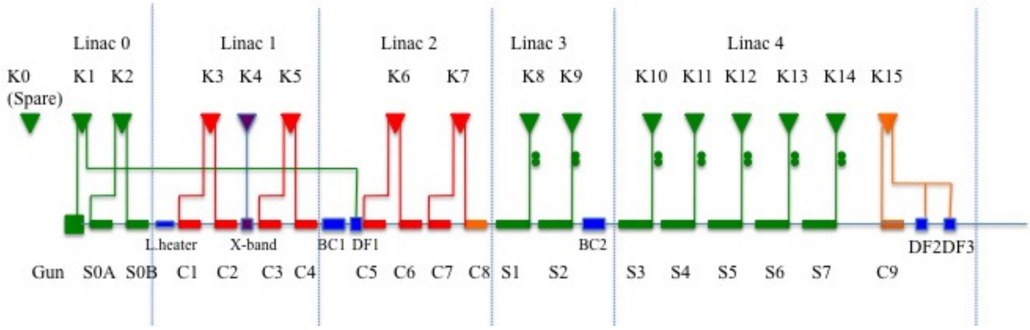

Figure 2: Layout of the linac

RF Transmitters

All the RF transmitters are identical. The modulators (320 kV, 350 A, 4.5 µsec pulse at 50 Hz) are conventional PFN type, using a thyratron as switching element. Due to time reasons, the first six modulators are still working at 10 Hz (as the present gun) and will be upgraded to 50 Hz in the next months. The klystron type is TH2132A from Thales (3 GHz, 45 MW peak in a 4.5 µsec width).

The drive amplifier is a 450 W peak solid state A class amplifier, provided by Microwave Amplifier Ltd. Due to the stringent stability requirements, special attention has been giving in minimizing pulse-to-pulse variations in phase and amplitude.

Figure 2: One of the modulators

RF Power Transmission

The power transmission is performed using OFHC WR284 waveguides, working either under ultra high vacuum or under SF6 pressure. Pressurised attenuators and phase shifters are used to control the phase and amplitude of the power to the deflectors. The remaining waveguide phase shifters in the other plants are under vacuum. An array of switches is used to connect the spare system to replace either one of the two klystrons or to the load. The entire WG circuit is temperature stabilised.

LLRF

The specification on amplitude and phase stability are 0.1 % in amplitude and 0.1° in phase at 3 GHz. To meet such specifications, state of the art digital technology must be adopted [6].

The two main electronic boards (a front end board and a digital processing board) have been specially developed (figure 3). The front-end board has five RF input and two RF output channels, in addition to various triggers, diagnostic and base band I/O. The RF board makes the conversion between RF (3 GHZ) and IF (99 MHz) signals and hosts all the frequency dependent component. The digital processing board implements a Virtex 5 FPGA with 2 GBytes of on board RAM, which performs all controls, diagnostic and external communication. One LLRF chassis will be installed for each accelerating structure. The system is developed in the frame of a collaboration agreement between Sincrotrone Trieste and Lawrence Berkeley National Lab.

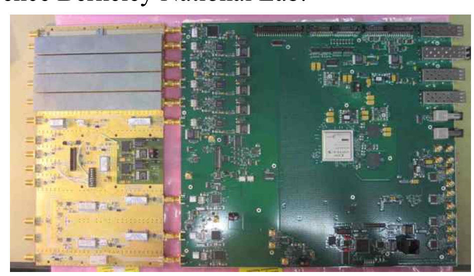

Figure 3: RF front-end (left) and digital processing board (right)

INSTALLATION

Installation of the S-band system started at beginning of June 2009 with the installation of the first two modulators. Since then, installation and commissioning phases have alternated. At the time being, all modulators have been installed and set to work, with the exception of K15 and K0. K15 is currently under installation since it is required by middle November, when the first high-energy deflector is installed. The installation of K0, which is the spare system, will follow. All accelerating structures and waveguide circuits have been positioned, connected, aligned and put under vacuum (see figures 4 and 5). RF conditioning is either concluded or in course.

An “intermediate LLRF system” has been installed for all the plants. These systems, instead of the FERMI digital processing board (in construction), use another board, the so-called LLRF4 board designed at LBNL by L. Doolittle. This solution allows to perform the basic functionalities required to the LLRF, although the ultimate performances can be attained only with the new boards.

STATUS AND COMMISSIONING

All tests which do not imply producing RF can be done without the need of prohibiting access to the tunnel, so the first part of modulators' operation and functionalities test can be done in advance.

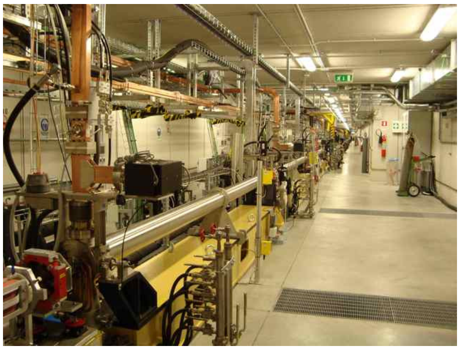

Figure 4: View of linac 1

Each subsystem of the modulator is individually tested before the modulator is switched on. After the completion of the tests of interlocks and controls and the installation of the klystron, the modulator is switched on in diode mode and the pulse is increased up to the final value, according to klystron specifications. The application of high voltage to the modulator, as well as the high voltage conditioning, has been always very smooth requiring only a few hours. The requirements on the high voltage pulse have been met not only in terms of maximum values but also in terms of the other requirements, such as pulse width, risetime/falltime and flatness (better than ± 1 %).

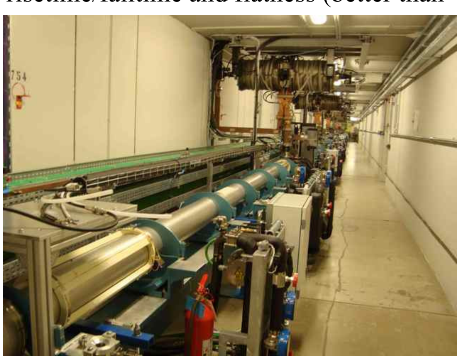

Figure 5: View of linac 4

RF operation of the plant and conditioning of the accelerating structures can be done only in the commissioning periods. To speed up this procedure, we have implemented an automatic conditioning program developed in collaboration with the FERMI controls area. The program controls the amplitude and length of the RF pulse delivered by the klystron and automatically increases or decreases these values according to the vacuum levels. The program is flexible and allows different conditioning strategies. At the time being, all systems up to linac 2 have been RF conditioned, while the conditioning of linac 3 and linac 4 is being completed. For the SLED equipped structures we start with the SLED cavities detuned and after having reached the desired power level, we tune them in.

The conditioning of the structures has been smooth. As for the waveguide circuits there were some difficulties in one circuit due to the bad behaviour of a pressurised waveguide attenuator. After having understood that this was due to the design of the absorbers and replacing them, also this component was conditioned in few hours.

All intermediate LLRF systems are now in routine operation on the plants. The firmware installed, provided by L. Doolittle from LBNL, performs the basic amplitude and phase controls. In addition, the 180° phase reversal is operational and the OCXO PLL optimised. The tests on the digital board prototype are under completion, to be followed by the construction of the series and the retrofitting in the chassis. Significant work will be needed for the porting of the existing firmware and for the development of all the remaining features.

Beam commissioning started in August 2009. During the first phase up to November 2009, linac 0 was commissioned. In the following phases (alternated with installation periods) till July 2010, commissioning proceeded up to BC1 (300 MeV). During the last commissioning period, the beam was passed through the entire linac and sent to the beam dump at the end of it. The measurements' results show that the optimized beam, at low charge, meets the requirements, which also means that the S-band systems perform as required.

CONCLUSIONS

FERMI@Elettra is now under commissioning. The new run restarted on the last days of August with all the S-band RF plants and structures available and will proceed with two runs before the end of the year. The first light to the user facility is scheduled at beginning of 2011.

Installation of the components of the S-band systems is completed with the exception of C8 and C9, of the last plant, which powers the high-energy deflectors, and the upgrade of the LLRF to the final boards. These last two activities will be completed by the end of the year.

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