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CURRENT STATUS OF FREE ELECTRON LASER @ TARLA *

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Abstract

Turkish Accelerator and Radiation Laboratory (TARLA), which is supported by the Presidency Strategy and Budget Directorate of Turkey, aims to be a state-of-art research instrument for light source users in Turkey. Two superconducting accelerating modules of TARLA will drive two different planar undulator magnets with periods of 110 mm (U110) and 35 mm (U35) in order to generate high brightness Continuous Wave (CW) Free Electron Laser (FEL) tunable in between 5-350 μm. Additionally, the linacs will drive a Bremstrahlung radiation station to generate polarized gamma radiation. Main components of TARLA, such as injector, superconducting accelerating modules and cryoplant are under commissioning, currently. In this study, we present the current status of the facility as well as expected FEL performance.

INTRODUCTION

TARLA has been proposed as the first accelerator based FEL user facility in Turkey. The facility which has been commissioning is located at Institute of Accelerator Technologies in Golbasi Campus of Ankara University, which is about 15 km south of the capital city of Turkey, Ankara. The first priority of the facility is to make the country understood that the accelerator technology is the only tool for the solution of challenges of the new science. High brightness, tunable and powerful FEL beam will be generated between 5-350 μm by two planar undulators in a period of 35 mm and 110 mm, respectively. Furthermore, 5-30 MeV Bremsstrahlung radiation will be produced for fixed target and astro-physics experiments [1, 2]. The schematic view of the facility is given in Fig. 1.

FACILITY DESCRIPTION

TARLA accelerator design consists of two sections called injector and main accelerating section. Main accelerating section consists of two superconducting RF (SRF) modules will be installed following the high power low energy injector section. Each module has two superconducting Nb cavities operating at frequency of 1.3 GHz and temperature of 1.8 K (super-liquid helium). The cavities that have maximum accelerating gradient of up to 15 MV/m at continuous wave (CW) mode will allow beam to be accelerated up to 50 MeV. The high power beam operating at quasi-CW mode will be employed to generate radiation and secondary particles in a wide energy range to a diverse user community. Main electron beam parameters of TARLA are given in Table 1.

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Table 1: TARLA Main Electron Beam Parameters

Parameter	Unit	Value
Beam Energy	MeV	15 - 40
Max. Average Beam Current	mA	1.5
Max. Bunch Charge	pC	120
Horizontal Emittance	mm.mrad	<15
Vertical Emittance	mm.mrad	<12
Longitudinal Emittance	keV.ps	<85
Bunch Length	ps	0.4 - 6
Bunch Repetition Rate	MHz	0.001-104
Macro Pulse Duration	μs	50 - CW
Macro Pulse Repetition Rate	Hz	1 - CW

Injector

The injector fed by a grid modulated thermionic triode DC electron gun, consists of two buncher cavities operating at 260 MHz and 1.3 GHz, several focusing magnets and diagnostic tools. The electron current is extracted from a tungsten dispenser cathode with a modulated grid voltage yielding bunches with 600 ps inital FWHM length. The bunches will first be compressed in the drift following the energy modulation obtained in the subharmonic buncher (SHB) in order to get into the linear phase range of the second buncher. The following 1.3 GHz fundamental buncher (FB) then introduces enough energy chirp to generate longitudinal (temporal) waist inside the first cell of the first SC cavity via ballistic bunching. Following successful commissioning of electron gun, the injector section has been tested at present.

Accelerator

TARLA main acceleration unit is composed of two similar superconducting linear accelerator modules mounted in a common vessel and constitute so called cryomodules [3], and a bunch compressor section between them. A cryomodule has two TESLA RF cavities [4] with an accelerating gradient of 10 MV/m at CW mode, for each cavity. The beam will further be accelerated to 40 MeV by main accelerating section. The (fixed R_{56}) bunch compressor between the cryomodules will allow highly stable beam by magnetic insertions. The electron beam will reach the required energy by the second cryomodule while reducing the energy spread [5]. Once the electron beam will arrive to the expected energy, it will send either to FEL hall or Bremsstrahlung hall. The parameters of TARLA cryomodule is given with Table 2.

The cryostat and mechanical tuning systems of cryomodules are originated by ELBE project [6]. The tunning system of the cryomodules has been modified slightly by mounting piezo-actuators on lever arms to have better RF performance for pulsed RF operations. The resolution and the speed of

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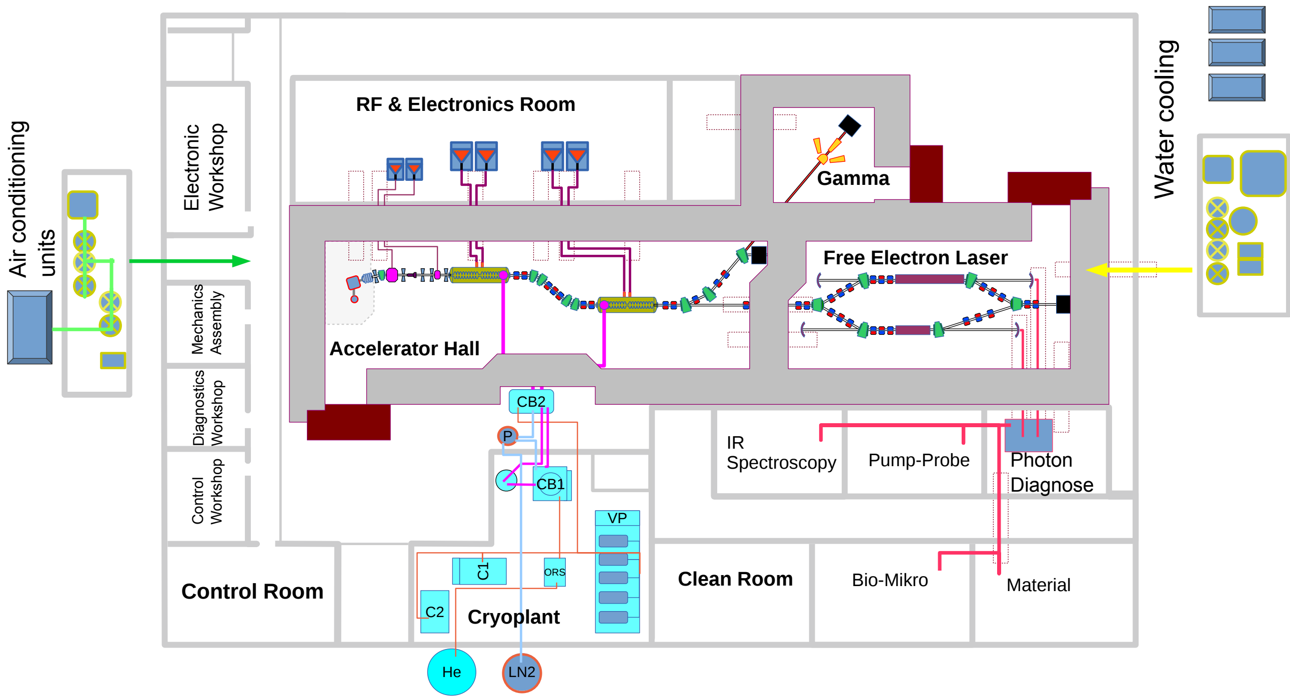

Figure 1: Layout of TARLA facility.

Table 2: TARLA CM Parameters

Parameter	Unit
Frequency @1.8 K (MHz)	1300 ± 0.05 MHz
Tuning Range (kHz)	120 kHz
Ext. Q of Input Couplers	$(1.2 \pm 0.2) \times 10^7$
Ext Q of HOM Couplers	$> 5 \times 10^{11}$
Accelerating Voltage/CM (MV)	> 20
Cryogenic Losses @ Max. Grad. (W)	< 75
Coupler Power @ CW (kW)	≥15
Tunning Resolution	1 Hz
Tunning Speed	1 kHz

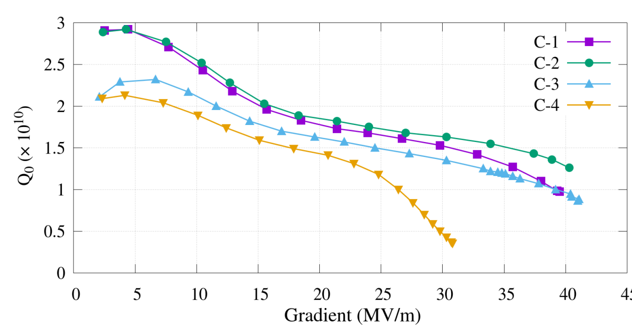

Figure 2: Vertical tests of TARLA cavities.

tunning has been improved from 10 Hz - 5 Hz/ms to 1 Hz - 1 kHz. The cryomodules have been manufactured by Research Instruments GmbH [7]. Each cavity has been tested on its own under XFEL manufacturing conditions and assembled into the helium vessel, after that they were vertically tested at DESY in 2016. Fig. 2 shows the gradient values of TARLA cavities under vertical tests [8]. They were delivered after successful tests results such as coupler and leak tests etc. at the end of 2017.

Helium Plant

TARLA cryogenic system has a capable of 1.8 K superfluid helium at ±0.2 mbar pressure stability. The system allows to provide 4K, 2K and 1.8 K superfluid helium by a compressor station, two cold boxes, a dewar and varm vacuum pumps. TARLA helium plant has been manufactured and delivered by Air Liquide Advanced Technologies [9] in 2016. The main concern of the plant is to provide 16 mbar pressure stability at sub-atmospheric pressure. TARLA helium plant has been performed for a long time operation with test caps instead of TARLA cryomodules. The measurement results show that the pressure is as high stable as while the test caps under a heat load equal to the full heat loss of the cryomodules.

FREE ELECTRON LASER

Two FEL beamlines are planned to cover a broad range of infrared region. Since the users prefer to have long infrared waves, we extend to more than far infrared region to middle. Two optical resonators housing two different NbFe hybrid undulators with periods of λ_{U110} = 110 mm and λ_{U35} = 35 mm will be utilized to have between 5-350 μm FEL. Figure 3 shows possible observable wavelength range for beam energy vs. undulator strengths. Expected FEL parameters are obtained from calculations are listed in Table 3.

In order to estimate the performance of TARLA FEL several simulation tools are investigated during desing study. For instance, in order to simulate the light-beam interaction within the undulator and the propagation of the light outside

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Table 3: Some Resonator and Expected FEL Parameters

Parameter	U35	U110
Wavelength (μm)	3.5-34.	24.-390.
Period Length (mm)	35.	110.
No of Poles (#)	52	24
Length (m)	1.47	2.6
Undulator Strength (min-max)	0.39-1.	1.3-2.5
Max. Peak Power (MW)	10	5
Max. Average Power (W)	0.1 - 100	0.1-90
Max. Pulse Energy (μJ)	10	8
Pulse Length (ps)	1 - 10	1 - 10

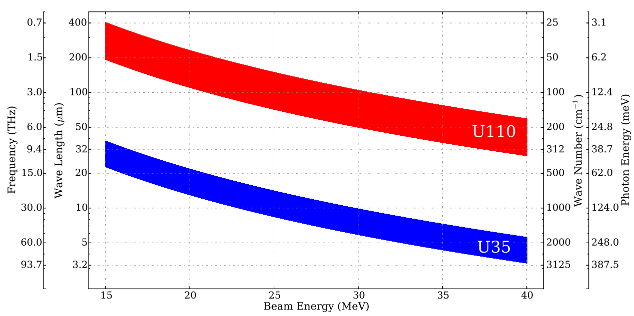

Figure 3: The wavelength range with respect to beam energy and undulator strength for U35 and U110.

the undulator for U35 in which the optical field propagates in free space, we have used GENESIS and Optical Propagation Code (OPC) codes in parallel [10]. Following Figures 4-7 summarizes the simulation results for maximum and minimum obtainable wavelengths from U35.

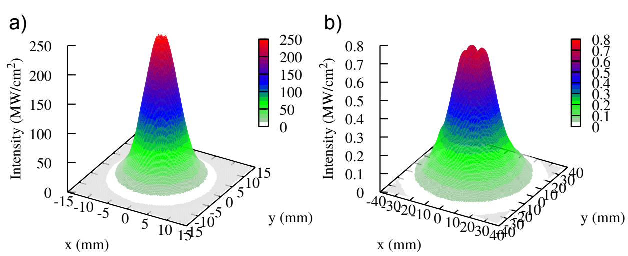

Figure 4: Intra-cavity power intensity of FEL a) for 3.5μm b) for 32 μm.

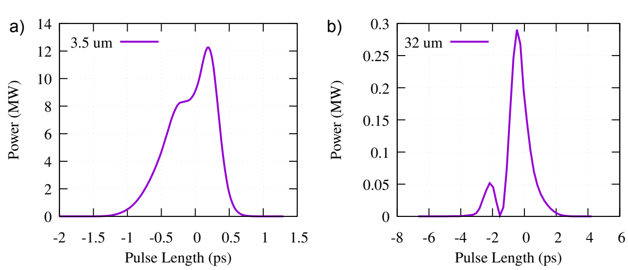

Figure 5: Power vs pulse length of FEL a) for 3.5μm b) for 32 μm.

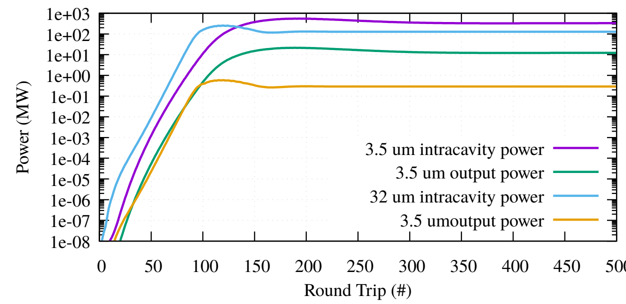

Figure 6: Power vs round trip of FEL for 3.5μm & 32 μm.

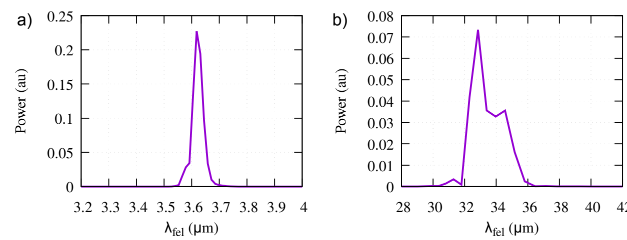

Figure 7: Spectrum of FEL for 3.5μm & 32 μm.

For the FEL generated by U110 will have longer wavelengths thus the natural diffraction of the light becomes so large. In order to guide the electromagnetic wave a waveguide will be employed for this FEL beamline. In parallel to the optical resonator design, we investigate simulation tools to take into account the effect of waveguide propagation inside the undulator.

CONCLUSION

TARLA thermionic electron gun and injector line are in operation, currently [11]. The helium cryoplant has been commissioned and pressure stability by test cups has been promising. The long time operation tests of buncher RF amplifiers are ongoing for phase stabilization to prevent the beam energy spread. The leak tests of cryomodules are succesfully completed at site. The integrated tests of helium plant and cryomodules will be performed as soon as possible, that will be a common time schedule of both companies. After achieving the integrated commissioning of helium plant and cryomodule tests, we are planning that the first cryomodule at 1st quarter of 2020 and the second is at end of the same year, in full operation.

As of the experimental infrastructure, TARLA has already provide a conventional near infrared laser source to the users since 2018. The first FEL lasing we expected to be achieved in 2022 and provide the users at the same year. Besides becoming the first accelerator based light source facility, TARLA also is an aware of being a pioneer facility that constructs an accelerator facility using its own resources in the country. TARLA facility will serve a variety of opportunities to the researchers in basic and applied science especially the ones who need high power laser in middle and far infrared region. Experimental stations for laser diagnostic, Pump-Probe, IR spectroscopy, have been equipping with the machine side synchronously.

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