INJECTOR DESIGN FOR TURKISH ACCELERATOR CENTER FREE ELECTRON LASER FACILITY*

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Abstract

Turkish Accelerator Center (TAC) Infrared (IR) Free Electron Laser facility (FEL) supported by State Planning Organization (SPO) of Turkey will be based on 15-40 MeV energy range electron linac and two different undulators with 2.5 cm and 9 cm period lengths in order to obtain FEL in 2-250 micron wavelength range. The electron linac will consist of two superconducting ELBE modules which houses two 9-cell TESLA cavity in one module and can operate in cw mode. The electron bunches in cw mode which are compatible with the main linac will be provided by a thermionic gun and an injector system which is totally based on normal conducting technology. In this study the injector design for TAC IR FEL is represented and beam dynamics issues were discussed for suitable injection to first accelerating module.

INTRODUCTION

Turkish Accelerator Center (TAC) Project was first proposed in 1997 by some group of scientist from Ankara and Gazi universities with support of State Planning Organization (SPO) of Turkey as a regional project for accelerator based fundamental and applied research [1, 2]. After feasibility and conceptual design studies of TAC an infrared free electron laser (IR-FEL) oscillator faciliy project has started again with support of SPO as a first step of TAC project [3].

The facility which will be similar to FZD Radiation Source ELBE, aims to produce FEL in 2-250 microns range using 15-40 MeV energy range high current electron beam and two undulators that have 25 mm and 90 mm period length [4]. Schematic view of TAC IR-FEL facility is given with Fig. 1. The IR FEL facility will be situated at Ankara University Gölbaşı Campus. It is also planned that the facility will include Bremsstrahlung experimental station which is based on the same linac with 20 MeV option to study nuclear physics [5].

ACCELERATING STRUCTURE

Available two ELBE module which houses TESLA 9-cell super conducting (SC) structure will be used for acceleration the beam. The SC modules where developed at ELBE and afterwards transferred to ACCEL instruments on the basis of a license contract. This module is currently designed to accelerate an electron beam at 1 mA of average beam current for continious wave operation (CW) but has the capability to operate at higher beam power at 1.6 mA [6]. We propose to use the same technology but with increased electron current (1,6 mA instead of 1 mA) for the IR-FEL facility. Thus, this increased beam current is essential to achieve more power of the secondary beams in our facility. Therefore the scientific experiments with these secondary beams can be improved or will be possible only with this improvement of the average beam current. To achieve the higher electron beam power the injector has to deliver this current and the acceleration module needs upgraded RF couplers and new RF sources (16 kW IOTs instead of 10 kW klytrons). Some basic parameters of SC ELBE module are given with table 1.

Table 1: Basic Parameters of SC ELBE Module

Parameter	Unit	Value
RF frequency	MHz	1300
Acceleratig gradient	MV/m	15
Operating tempareture	K^0	1.8
Total cyrogenic loss (@CW)	W	105

INJECTOR

Since main accelerating structure operates at 1.3 GHz the repetition frequency of the bunches should turn out to be at the same frequency or at some fraction of the working frequency of the accelerator. We propose to the pulsed injector mainly deliveres bunches with 260 MHz, 26 MHz and 13 MHz repetition rate which means 4th, 50th and 100th fraction rate of the SC structure frequency. The repetition frequencies of 13 MHz and 26 MHz will be used for FEL applications while 260 MHz repetition rate will be used for Bremsstrahlung experiments. The injector will provide electron bunches at CW operation as well as macropulsed mode. The micropulse and macropulse structure of the beam will be manipulated with the grid voltage barier and macropulser element on the injector beamline, respectively. Schematic view of the whole injector is given with Fig. 2.

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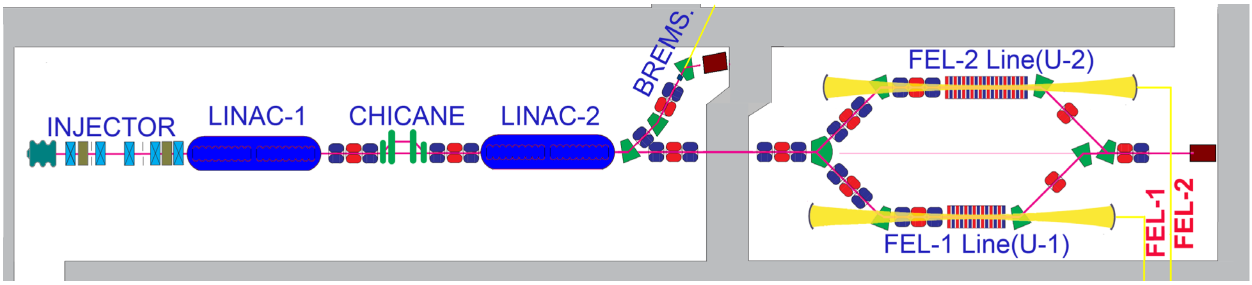

Figure 1: General layout of TAC IR-FEL Facility.

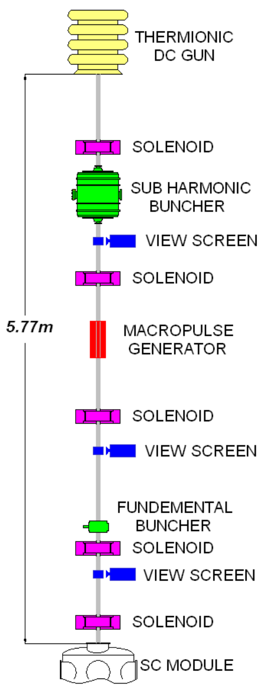

Figure 2: Schematic view of 300 keV injector.

Electron Source

In order to use the beam for differant applications than FEL (i.e. Bremsstrahlung applications) the gun will provide bunches at 13, 26 and 260 MHz repetition rate. Corresponding maximum bunch charges can be simplified 120 pC, 60 pC and 6pC, respectively which means average current is 1.6 mA for all bunch repetitions. Time structure of the beam is given with Fig. 3.

It is planed to use 300 keV thermionic DC gun which was designed for ELBE project. The ELBE gun currently operates at 250 keV and max 77 pC bunch charge in limited transverse and longitudinal emittance values. The length of the bunch is about 500 ps at the exit of the gun. We aim to obtain same emittance values and shorter bunch length (400 ps) for 120 pC bunch charge with some small modifications such as surface improvements of anode cathode and faster pulser electronics.

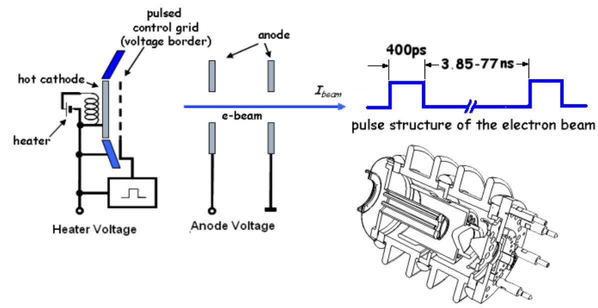

Figure 3: Time structure of electron beam after the gun and gun working principle.

Buncher Cavities and Solenoid Magnets

In order to obtain effective acceleration the bunch, which has about 400 ps length after the gun, needs to be compressed using two step buncher cavities called subharmonic buncher (SHB) and fundamental buncher (FB) cavities which operate 260 MHz and 1.3 GHz, respectively. The buncher SHB and FB cavities will be standard pill box standing wave RF cavities which will approximately have 60 keV and 120 keV gradient, respectively. The solenoid magnets have 5 cm effective length and tuneable magnetic field at centre of solenoid between 150-400 Gauss which corresponds minimum 20 cm focal length at 300 keV. We have used Poission-SUPERFISH code to calculate the fields on the axes in cavities and solenoids [7]. The electric field of the cavities and the magnetic field of solenoids in radial and longitudinal components are given with Fig. 4.

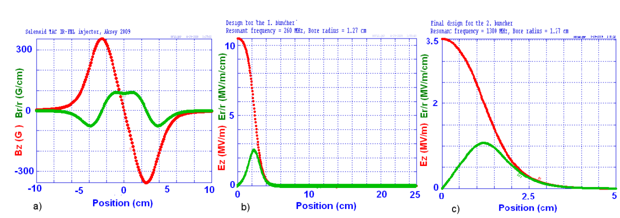

Figure 4: a) Max. magnetic field of solenoid, b) Normalised Electric field components of SHB, c) Normalised Electric field components of FB.

SIMULATIONS

During injector simulations we have used PARMELA code to simulate whole injector [7]. It was assumed that the electron beam delivered from a thermionic gun has $\epsilon_{x,y}\approx$10 mm.mrad total transverse emittace with $\sigma_{x,y}\approx$ 1.5 mm rms transverse beam size and $\sigma_z\approx$400 ps bunch length which are almost similar mesured values at ELBE except bunch length for 250 keV beam energy at 1 mA beam current. We assumed that, for 120 pC bunch charge, the increasing the beam energy will keep the transverse emittance values almost same at the exit of the gun due to reduction of space charge effects. Therefore we have used uniform particle distribution in 6-dimentional particle coordinates $(\sigma_x, p_x, \sigma_y, p_y, \sigma_z, \delta E)$ measured values at ELBE. Positions of buncher cavities were determined for optimum longitudinal phase while solenoid's positions were determined for optimum transverse beam size. We represent some results for 120 pC bunch charge with figures below and calculated beam parameters at the entrance of SC structure is given with table 2.

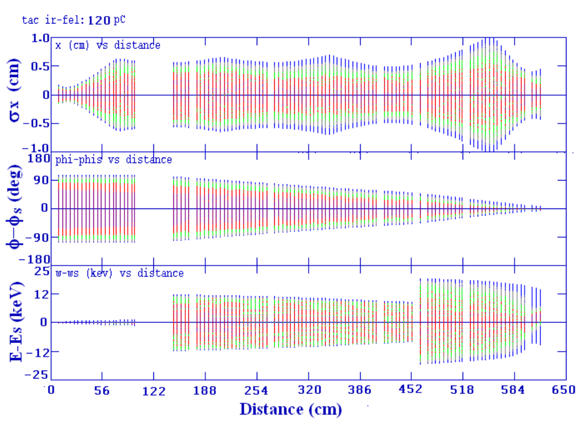

Figure 5: Beam envelope, bunch length and energy spread variations along the injector for 120 pC bunch charge. SC module starts at 577 cm.

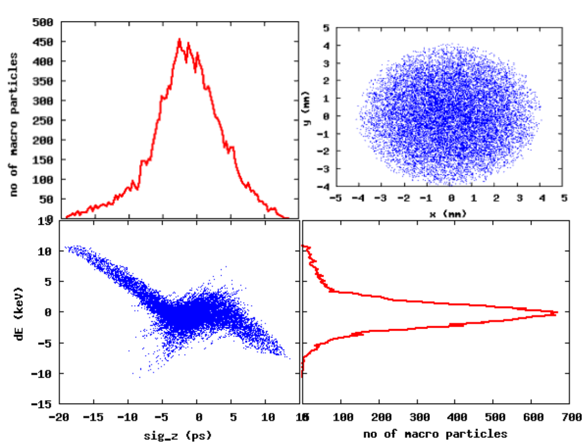

Figure 6: Longitudinal phase space and transverse beam cross-section of the bunch at the first cell of SC structure.

Table 2: Main e$^-$ Beam Parameters of TAC IR-FEL

Parameter	Unit	Value
Beam Eenergy	(keV)	300
Bunch Charge	(pC)	120
Average Current	(mA)	1.6
Rms Bunch Length	(ps)	5.5
Bunch Separation	(ns)	77
Nor.rms Tran.Emt.	(mm.mrad)	<10
Nor.rms Long.Emt.	(keV.ps)	<15
RMS Energy Spread	(%)	<3

CONCLUSION

Manufacturing of the gun and design of gun-grid control electronics already started in Turkey with collaboration of FZD. In 2010, we propose to manufacture other main equipments of the injector after the tests of gun and install the injector test stand in our facility. On the other hand since TESLA cavity is designed for β =0.99 beam but achieved beam velocity is β ≈0.75 at the exit of injector, some problems occur during the capture from injector to SC module at ELBE [8].Since bunch velocity is lower than the RF phase velocity, the fringe field of RF catches the bunch with negative voltage before it enters cell and forces the bunch to be decelerated. The deceleration force makes the longitudinal space to rotate with other words higher energy particles moves at lower phase. We also propose to fix this problem with increasing beam energy up to 400 keV at injector as an update option in our facility.

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