A FIRST STEP TO TURKISH ACCELERATOR CENTER (TAC): AN INFRARED FREE ELECTRON LASER (IR-FEL) FACILITY*

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Abstract

The third phase of Turkish Accelerator Center (TAC) Project has been studied since 2006, after feasibility and conceptual design phases were completed [1–5]. This phase of the project has two main scientific goals which are writing Technical Design Report of TAC project and establishing an Infrared Free Electron Laser (IR FEL) facility as a first step until 2010.

It is planned that TAC IR FEL facility will operate to obtain 2-185 microns wavelength FEL using 15-40 MeV energy range electron linac and two different undulators which are in 3 cm and 9 cm period lengths [6, 7]. Main research and application areas will be the material science, nonlinear optics, semiconductors, biotechnology, medicine and photochemical processes. In this study, the electron beam line design and the main parameters of electron beam, the characteristics of free electron laser were discussed with several options such as different bunch charge or different undulator material.

INTRODUCTION

A group of scientists from Ankara and Gazi Universities proposed the Turkic Accelerator Center (TAC) project in 2000 considering that there isn't any accelerator based scientific research in our region. During the feasibility and conceptual design studies of TAC, a linac-ring type particle factory and the light sources (synchrotron radiation and free electron laser) was proposed in the frame work of the project [1–3]. According to the proposal, TAC will include a linac-ring type charm factory, a third generation synchrotron radiation facility based on 3.56 GeV positron ring, a SASE FEL facility based on 1 GeV electron linac and a proton accelerator facility based on a few GeV proton linac [3, 5].

In order to become familiar with accelerator and light source technologies in our country and our region, an infrared free electron laser (IR FEL) facility in oscillator mode is proposed as a first step [4, 6, 7]. In 2006, SPO of Turkey charged a team, which includes scientists from 10 Turkish Universities, to write the technical design report of TAC proposal and to construct IR FEL facility as a first step until 2011.

The IR FEL facility which will be situated at Ankara University Gölbaşı Campus, is planned to cover middle and far infrared region wavelengths using a superconducting (SC) linac. It is also planned that the facility will include Bremsstrahlung experimental station which based on the same linac with 20 MeV option to study nuclear physics [6, 7].

ELECTRON BEAM AND FEL

The optimization studies of TAC IR FEL facility was done by taking into account a SC linac which provides an electron beam in 15-40 MeV energy range and two optical resonators which houses planar undulators (λ_{U1}=3 cm; λ_{U2}=9 cm). The obtained FEL will be in 2-185 microns infrared range. General layout of TAC IR-FEL is given in figure 1.

Accelerating Structure and Beam Transport

The main accelerating section will include two ELBE modules which consist of TESLA 9-cell SC structure. These modules can provide 1 mA average beam current at 10 kW beam power (@ CW operation) [8, 9]. In order to have minimum dispersion effects on the electron beam and to use less number of diagnostic tools, the beam line towards the undulators is designed as a straight line (fig. 1).

During electron beam calculations, PARMELA and Mathematica codes are used for longitudinal beam dynamics and the first order transverse beam optics calculations respectively [10, 11]. In order to avoid new design for beam line elements, it has been chosen that the familiar beam line elements with ELBE beam line [8].

The injector part will include mainly a thermionic DC gun, a sub harmonic buncher, a fundamental buncher and 5 solenoids. It has been assumed that the thermionic gun delivers an electron beam about 500 ps bunch length with 10 mm.mrad rms transverse beam emittance, 1.5 mm rms transverse beam size and 13 MHz repetition rate. A sub harmonic buncher and a fundamental buncher operating at 260 MHz and at 1.3 GHz respectively compress the beam to 5 ps bunch length [12].

The beam is inserted into the first accelerating module just after the injector. A chicane is located between two triplets in order to obtain round beam at the entrance of the second module. The electron beam provided by the Linac-2 is transferred into the FEL hall using triplets. The beam easily can be matched with the undulators in this way. The PARMELA results of the beam at the entrance of undulators are given in figure 2.

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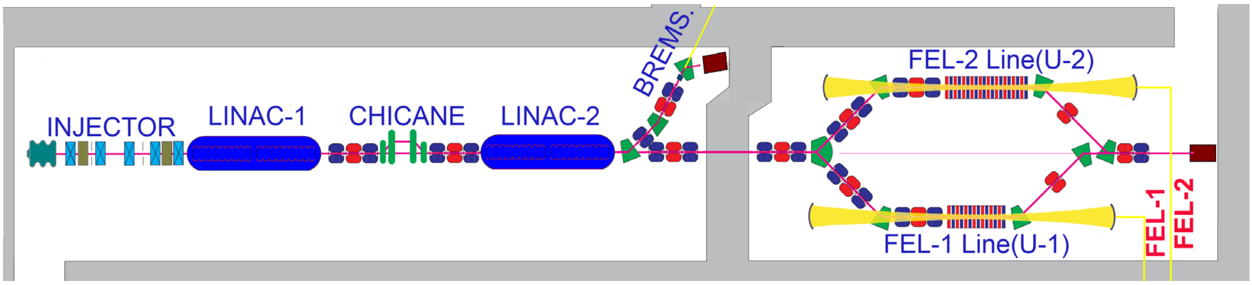

Figure 1: General layout of TAC IR-FEL Facility.

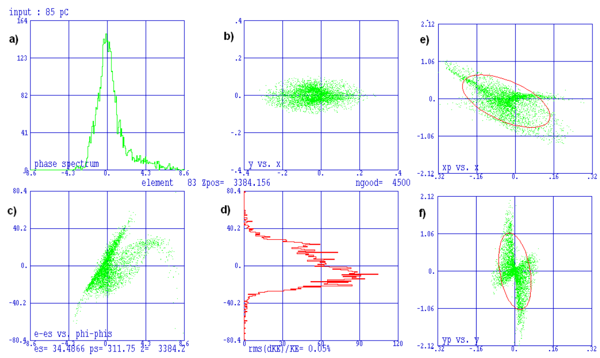

Figure 2: PARMELA results at the entrance of undulators a) Long. phase spectrum, b) Trans. beam profiles, c) Long. phase space, d) Energy spectrum, e) Horizontal phase space, f) Vertical phase space.

The electron beam should be matched both the horizontal and the vertical plane with the optical beam in the undulator. This process is provided by the first order transverse beam dynamics calculations using Mathematica for both FEL lines. The beam envelope variation after Linac-2 through the beam dump for FEL-1 line is given in figure 3.

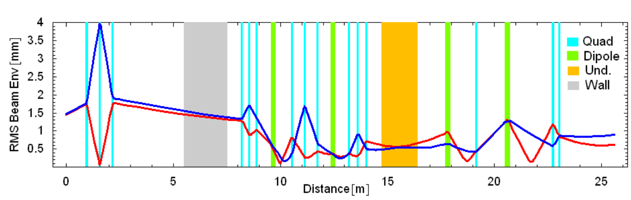

Figure 3: The beam envelope variation after Linac-2 through beam dump for FEL-1 line.

Beam dynamics results are studied for the same module at 16 kW beam power as well.It will be possible to feed the same ELBE module with available 16 kW RF power source without any problem in the near future [13, 14]. Main beam parameters are given in table 1.

Table 1: Main e^- beam parameters of TAC IR-FEL

Parameter	10kW RF	16kW RF
Max Beam Energy (MeV)	40	40
Bunch Charge (pC)	80	120
Average Current (mA)	1	1.6
Rms Bunch Length (ps)	1-10	1-10
Bunch Separation (ns)	77	77
Nor.rms Tran.Emt.(mm.mrad)	<15	<15
Nor.rms Long.Emt.(keV.deg)	<35	<38
RMS Energy Spread (%)	0.05	0.08

FEL Characterization

As the main part for the FEL, the design of the undulator is most crucial for obtaining the necessary wavelength range and spectral properties. An available permanent magnet material Sm_2Co_{17} with 3 cm and 9 cm periods have been chosen to scan desired wavelength range. The resonator and undulator parameters with the results of FEL optimization both for the 1 mA and 1.6 mA options are given in table 2.In order to determine the FEL characterization both FELO which is one-dimensional free electron laser oscillator simulation code (developed by ASTeC CCLRC Daresbury Laboratory, UK [15]) and Mathematica were utilized. Some results for FEL optimization are given with figures (4 - 12) below for both 1 mA and 1.6 mA average beam current options .

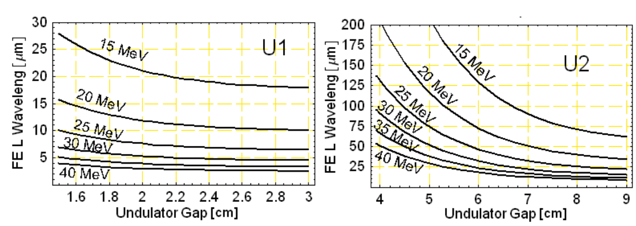

Figure 4: The FEL wavelength tunability vs the undulators' gaps with respect to beam energy. (a)U1 (b)U2

Table 2: Main Parameters of Resonators and FEL

Parameter	**U1**	**U2**
Undulator material	Sm_2Co_{17}	Sm_2Co_{17}
Undulator period (cm)	3	9
Undulator gap (cm)	1.5-3	4-9
Rms undulator strength	0.2-0.8	0.4-2.5
Number of period	56	40
Resonator length (m)	11.53	11.53
Radii of curve of mir. (m)	5.92	6.51
Rayleigh length (m)	0.97	2.08
Parameter	**FEL-1**	**FEL-2**
Wavelength (μm)	2.7-30	10-190
Pulse energy @80 pC (μJ)	2	4
Pulse energy @120 pC(μJ)	4	10
Max peak Pow @80 pC (MW)	8	10
Max peak Pow @120 pC (MW)	12	15
Pulse length (ps)	1-10	1-10

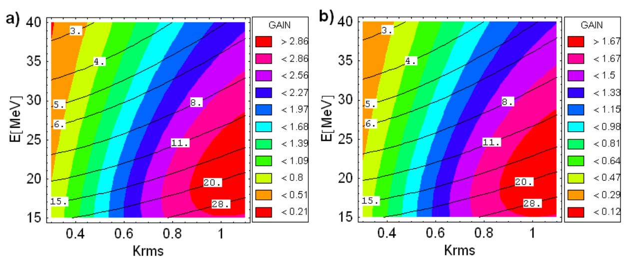

Figure 5: Single pass gain respect to E and K_{rms} for λ_{U1}=3 cm a)I_{avg}=1.6 mA, b)I_{avg}=1 mA

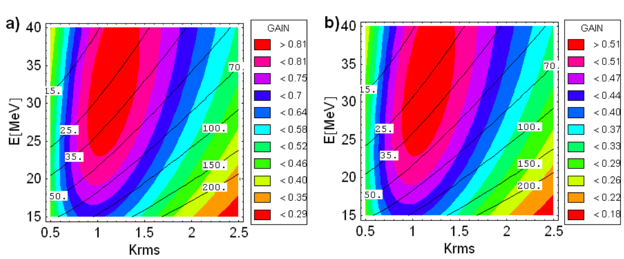

Figure 6: Single pass gain respect to E and K_{rms} for λ_{U2}=9 cm a)I_{avg}=1.6 mA, b)I_{avg}=1 mA

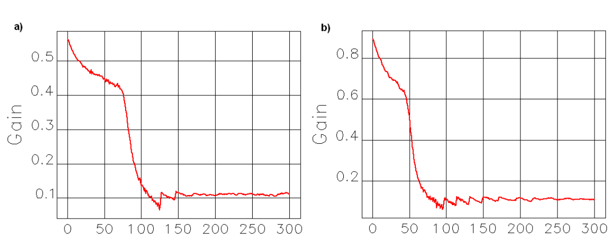

Figure 7: Gain vs passes for 3 μm obtained with U1 (a)I_{avg}=1mA,(b)I_{avg}=1.6 mA

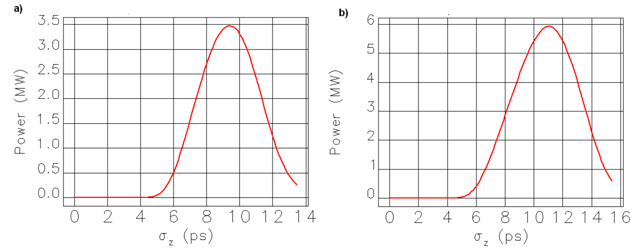

Figure 8: Power vs bunch length for 3 μm obtained with U1 (a)I_{avg}=1mA,(b)I_{avg}=1.6 mA

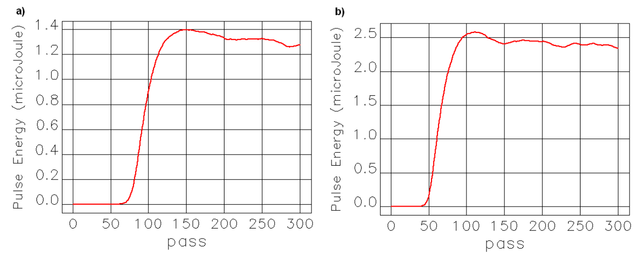

Figure 9: Pulse energy propagation vs passes for 3 μm obtained with U1 (a)I_{avg}=1mA,(b)I_{avg}=1.6 mA

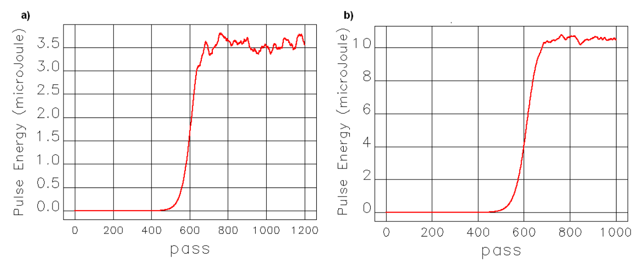

Figure 10: Pulse energy propagation vs passes for 46 μm obtained with U2 (a)I_{avg}=1mA,(b)I_{avg}=1.6 mA

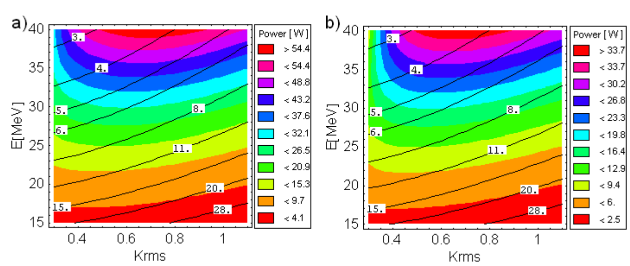

Figure 11: FEL expected output power respect to E and K_{rms} for λ_{U1}=3 cm a)I_{avg}=1.6 mA, b)I_{avg}=1 mA

PROPOSED RESEARCH AREAS

It has been planned that the facility will have been eight experimental stations. The beam will be used in various research programs under cooperation with the national and regional users and research groups. The tunability and short pulse structures of the FEL have opened up new applications in such areas as material sciences, biotechnol-

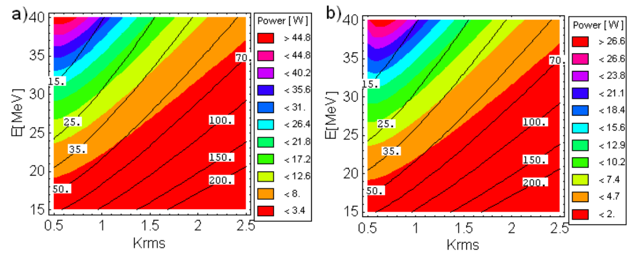

Figure 12: FEL expected output power respect to E and K_{rms} for λ_{U2}=9 cm a)I_{avg}=1,6 mA, b)I_{avg}=1 mA

ogy, nonlinear optics, nanotechnology, photochemistry and semiconductors. The quality and kinds of scientific researches in Turkey will rise with the use of FEL [13].

The first room which is placed in eight is the diagnostic room. FEL physics studies will be searched in this room and the obtained laser will be transported to the other seven rooms. IR spectroscopy, IR imaging and IR microscopy technics will be applied in two of other seven rooms for material science and semi-conductor studies.The other five experimental laboratories will be formed according to the potential of the researchers and to the user needs such as pump-probe experiments, vibrational relaxation time studies, photon echo experiments, sum-frequency generation techniques etc [16–20].

CONCLUSION

The studies related to the accelerator structure, beam transport, FEL diagnostics etc. of TAC IR-FEL facility have been still continuing. The goal of TAC IR-FEL facility is to supply a radiation source which is tunable, coherent and has more average power than traditional lasers for Turkey and its region.

In this study, the optimization results for the superconducting accelerator option are given. Due to the infrastructure situations of our country the normal conducting accelerator option has also been studying. The choice of the accelerator will directly affect FEL's time structure and bring out the kinds of experiments. To select the most convenient structure the potential of the appliers and user needs in our region will be taken into account.

After the completion of buildings of the TAC IR-FEL facility in 2009, the installation of the accelerator structure will start by the end of same year. The first commissioning of the facility is planned to be in the middle of 2011.

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