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TURKISH ACCELERATOR COMPLEX, FEL RESONATOR SYSTEM

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Accelerator technology is an important tool for the development in almost all fields of science and technology. Considering the importance of accelerator technology, a feasibility report and conceptual design report (CDR) on Turkic Accelerator Complex (TAC) in Turkey has been completed in 2005. It is proposed that the complex will contain a collider, light sources (SR, FEL) and a proton accelerator. Beginning of 2006, third phase of the TAC project is started with the collaboration 10 Turkish Universities. There are three main goals of this phase: to built Institute of Accelerator Technologies, to write the Technical Design Report of TAC, and to construct linac based infrared free electron laser facility to use in basic, applied research, and to get experience on related technologies. TAC IR-FEL will be covered range of 2-250 microns that based on 15 - 40 MeV e-linac. The main system of TAC project is briefly presented while calculated resonator and mirror system parameters for TAC IR-FEL Resonator and optic cavity system such as maximum density, saturation density, power, pulse energy, RMS pulse length are obtained and explained in more detail. In this research, diffraction losses are calculated by using mirror parameters in GLAD Program. In order to maximize FEL efficiency, controlled optic cavity system, stability and beam quality of the out-coupled signal are needed. FEL parameters are given depending on electron beam parameters.

1. INTRODUCTION

Turkish Accelerator Center, Infrared Free Electron Laser (TAC IR-FEL) Project will contain an electron linac in 15-40 MeV energy range with two optical resonators in order to obtain FEL in 2.5-250 microns range. TAC IR-FEL is shown in figure 1. The optical resonators which will have same lengths but the undulators will have periods of 2.5 and 9 cm.

The facility will be located in Ankara University, Gölbaşı Campus and the commissioning is planned to be by the middle of 2012.

2. ACCELERATOR

The electron beam with tunable energy in 15-40 MeV can be injected to undulator-1 and undulator-2 line independently. Linac structure of TAC IR-FEL is shown in figure 2 with other main equipments.

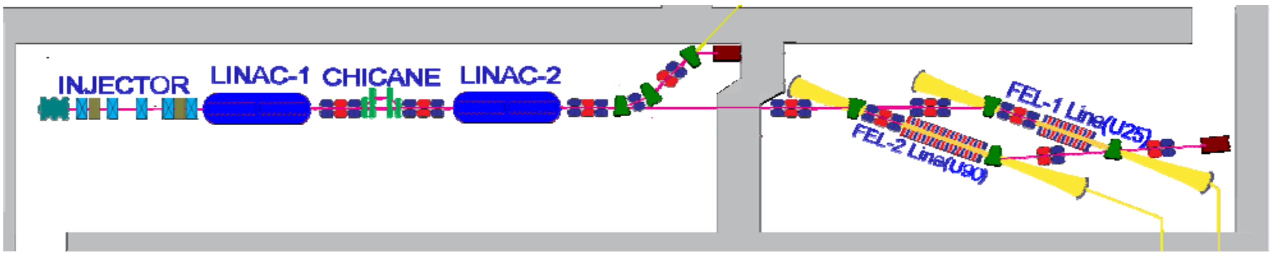

Fig.1. TAC IR-FEL Facility

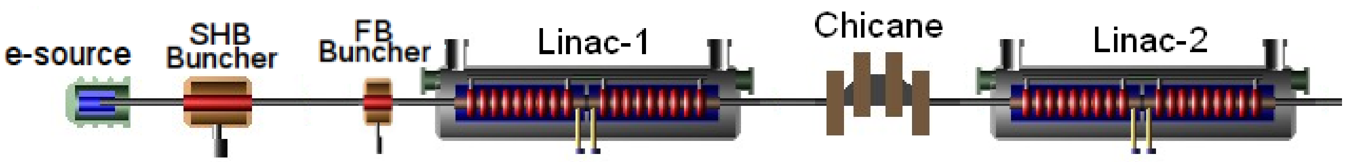

Fig.2. TAC IR-FEL linac

In order to obtain high quality FEL, the electron beam should have high peak current, short bunches, minimum energy spread, and low emittance [1]. In order to effective acceleration the bunch which has about 500 ps length after the gun needs to be compressed using two step buncher called subharmonic and fundamental buncher cavities which operates 260 MHz and 1.3 GHz, respectively [2]. The bunch after injector is compressed up to 10 ps and has 250 keV energy. A booster linac can be proposed which will be used for capturing and accelerating beam up to 1-2 MeV. PARMELA code has been used to define the beam parameters at the entrance of undulators. In simulations, the beam was assumed as it has 30 mm.mrad total emittance and 100 pC bunch charge at the exit of the gun. For TAC IR-FEL, fundamental electron beam parameters are given in Table 1. As an average beam current, 1.6 mA is taken into account and it was accepted that preferred normalized RMS longitudinal emittance and normalized RMS transverse emittances are limited with same values.

3. OPTICAL RESONATORS

Two optical resonators will be used in Turkish accelerator Complex, IR-FEL System with same length which houses same family planar undulators. The undulators have different periods and housed between at the center of different kind mirrors with same distances.

Table 1: TAC IR-FEL electron beam parameters

Parameter	Value
Energy [MeV]	15-40
Bunch Charge [pC]	120
Average Beam Current [mA]	1.6
Bunch Repetition Rate [MHz]	260-13
Bunch Length [ps]	1-10
Norm. RMS Transverse Emittance [mm mrad]	<15
Norm. RMS Longitudinal Emittance [keV.ps]	<100
Pulse Duration	CW/tunable

Table 2: Fundamental parameters of SmCo type undulators

Parameter	Undulator-1	Undulator-2
Magnet Material of the undulator	SmCo	SmCo
Period Length (mm)	25	90
Number of periods	60	40
Magnet block dimensions (width*height*thickness)(mm)	74*26*10.5	90*90*35
Steel pole dimensions (width*height*thickness)(mm)	74*18*2	70*20*10
Magnetic gap (mm)	15	40
Effective field (T)	0.3591	0.4205
K_{rms}	0.71	2.5

UNDULATORS

Scanning large wavelength region is possible with wide tunable undulator's strengths as well as wider tunable electron beam energy according to FEL wavelength equation. Therefore, we have chosen 25 mm and 90 mm undulator periods for scanning 2.5-250 microns FEL wavelength with 15-40 MeV range electron beam in TAC IR-FEL System. SmCo magnet material hybrid-type undulators with iron poles is proposed. Fundamental parameters of undulators which are available in market are given in table 2.

The numbers of the undulator poles were determined with optimum gain and optimum intra cavity power. The strength for undulator-2 is limited at 2.5 although it can be increased up to 3. The strength of undulator-1 is limited by the minimum gap. The beam pipe is considered to have 1.5 cm radius between the undulator-1 layers.

3.1. MIRROR PARAMETERS

In optical resonator electromagnetic fields can exist whose distribution of amplitudes and phases reproduce themselves upon repeated reflections between the mirrors. These particular field configurations compromise the transverse electromagnetic modes of a passive resonator. Oscillator FEL systems, which includes 2 mirrors, are mainly in Gaussian Mode, which is explained with TEM_{00}. Symmetric and concentric resonator types are chosen as optical cavity system. Symmetric and concentric systems have several advantages such as small waist, big mirror spot. The mirrors will be covered by Au or Cu materials and will have holes with the diameter between 0.5 and 2 mm to get light out and have reflectivity around %95 [3].

The distance of mirrors is related with the electron bunch repetition. In TAC IR-FEL system, the bunch repetition rate is 77 ns and corresponding mirrors distance is L_c=11.53 m. Minimum spot size for the lowest order TEM Mode occurs at the Rayleigh length ($Z_R \approx L_u/2$) for an undulator length L_u. Beam waist, beam spot size, radius of curvature of the mirrors, spot size on mirrors, and Rayleigh length are obtained by the equations:

$$w(z) = w_0[1+(\frac{\lambda z}{\pi w_0^2})^2]^{1/2} \quad (1)$$

$$R(z) = z[1+(\frac{\pi w_0^2}{\lambda z})^2] \quad (2)$$

$$\omega^2(0) = \omega_0{}^2 = \frac{\lambda_R}{2\pi}\sqrt{L_c(2R-L_c)} \quad (3)$$

$$Z_R = \frac{\pi\,\omega_0^2}{\lambda_R} \quad (4)$$

The main parameters of the optical resonator systems which consists the undulators that have 2.5 and 9 cm period lengths at the center between mirrors is given in table 3.

Table 3: The main parameters of optical resonators.

Parameter	Resonator-1	Resonator-2
Undulator period [mm]	25	90
Undulator length [m]	1.50	3.6
Optic cavity length, L_c [m]	11.53	
Resonator Type	Symmetric, concentric	
1st Mirror, radius of curvature, R_1 [m]	5.92	6.51
2nd Mirror, radius of curvature, R_2 [m]	5.92	6.51
Rayleigh length, Z_R [m]	0.97	2.07
Mirror Material	Au / Cu	Au / Cu
Radius of out coupling hole [mm]	2/3/4	2/3/4

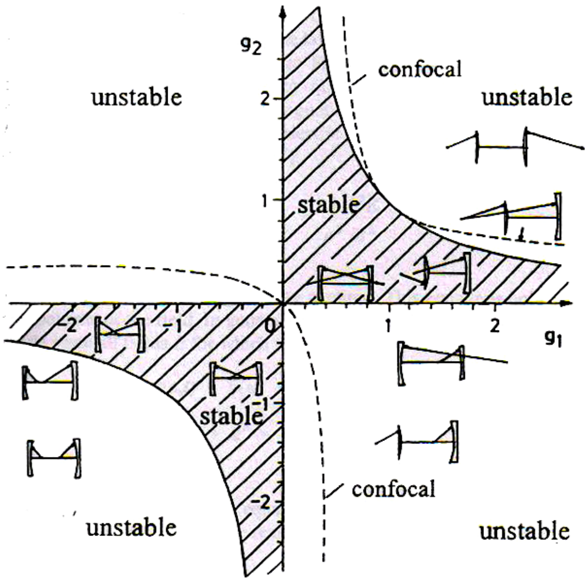

Fig. 3. g_1, g_2 and resonator types

Stability condition for a stable resonator:

$$0 < (1 - \frac{L}{R_1})(1 - \frac{L}{R_2}) < 1 \quad (5)$$

This condition is derived from a paraxial ray tracing in a periodic convergent lens sequence where $g_1 = 1 - L/R_1$ and $g_2 = 1 - L/R_2$. As one can see from the Figure 3, multiplication of the stability parameters, g1 and g2, is housed ın the stable area which is shaded.

3.3. MIRROR COATINGS

Mirror coating is important to obtain preferred transmitted light and to know the reflected percent. In TAC IR-FEL System, metallic protected silver and gold are thought to be chosen as mirror material. The highest wavelength for coating is Zns 0.38-25 micron, it has transparent region, and 2.55 diffraction index. For coating, Ion Beam sputtering is chosen in order to deposit dielectric coatings. This energetic process generate layers with bulk-like indices of refraction, resulting in a better durability of the coating [4, 5].

Table 4. Physical properties of coating materials used for laser mirrors

Material	Index of Refraction	Transparent Spectral Range
Na_3ALF_6	1.35	0.20-14um
MgF_2	1.37	0.22-2um
SiO_2	1.46	0.20-8um
HfO_2	1.95	0.22-12um
ZrO_2	2.10	0.34-12um
Ta_2O_5	2.16	0.30-10um
TiO_2	2.25	0.35-12um
ZnS	2.55	0.38-25um

3.4. DIFFRACTION LOSSES

In TAC IR-FEL System, diffraction loss and energy losses are simulated with the GLAD 5.2 Code [6]. GLAD is written to calculate the performance of laser systems that have defined direction of propagation. By using GLAD 5.2 version, diffraction losses and energy passes are worked out and following histograms are obtained by using optic cavity and TAC IR-FEL parameters. Figure 4, the diffraction loss for 1.5 m undulator wavelength case with silver mirror coating. For silver 0.480 micron and for gold 0.650 micron have be taken for wavelength range.

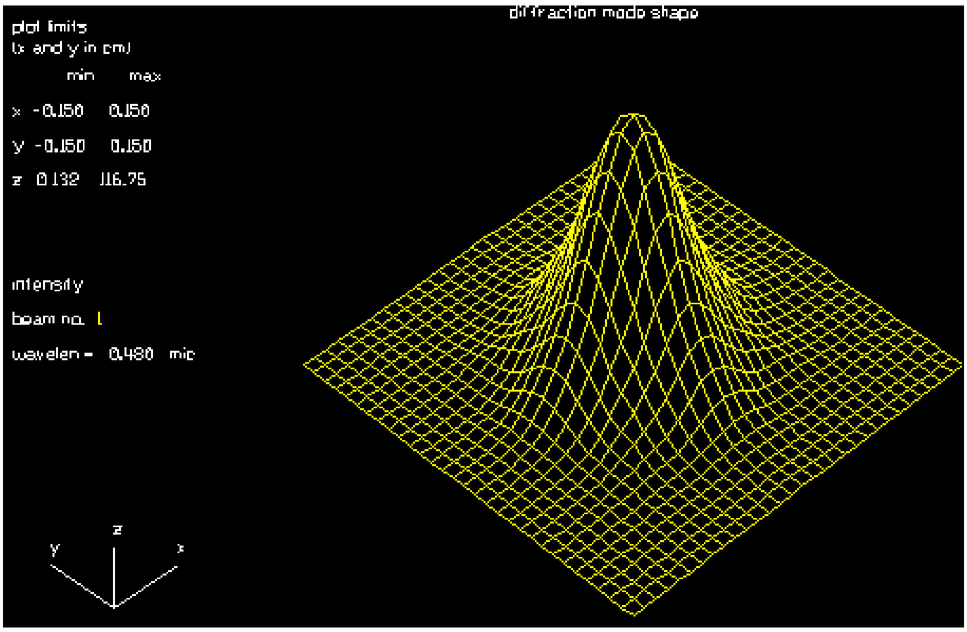

Fig.4. Diffraction mode shape for TAC IR-FEL System for silver coating

3.5. WAVE PROPAGATION

In TAC IR-FEL System, wave propagation in the resonator is studied with the Genesis 1.3 and Optical Propagation Code (OPC) programs [7-8]. Genesis simulates undulator in the resonator while OPC simulate the light fro the undulate through mirrors. From this simulation, one can obtain TEM Modes that suits the TAC IR-FEL Resonator System. From the equation $W_{pl}=C_{pl}\omega_0$, where $C_{00}=1$, $C_{01}=1.5$,$C_{10}=1.9$, $C_{11}=2.15$, $C_{20}=2.42$, $C_{21}=2.63$ and $\omega_0=0.002891$ m beam waist. W_{00}, W_{01},W_{10}, W_{11}, and W_{20} TEM modes are smaller than the undulator gap, thus these modes can be attainable modes for Undulator-1 in TAC I-FEL System. In undulator-2, W_{00}, W_{01},W_{10} can be obtained within the undulator gap where beam waist is 0.01121 m and Rayleigh length 2.078 m with the stability parameter, $g_0=-0.77$. These TEM_{pl} Modes related with the radial intensity of the beam which is given by Laguerre polynomials. The radial intensity distributions are normalized to the spot size of a Gaussian Beam profile.

4. TAC INFRARED-FREE ELECTRON LASER

For the Concentric resonator, the Filling factor is greater than (for λ_u=2.5 cm: λ=2.5-27 μm and for λ_u=9 cm: λ=11-250 μm) 50% in the output FEL wavelength. To obtain FEL in 2.5-250 microns range using 15-40 MeV energy electron beam inclined us to use undulators that have 2.5 cm and 9 cm period lengths which we call undulator-1 and undulator-2 respectively. In calculations we have taken in consideration the electron beam to have 1,6 mA average current , 1ps bunch length, 13 MHz repetition rate, 15 mm.mrad normalized transverse emittance and 100 keV.ps normalized longitudinal emittance. The obtained FEL wavelength is given by an analytical well known expression:

$$\lambda_r = \frac{\lambda_u}{2\gamma^2}\left(1+a_u^2\right) \quad (6)$$

where λ_u is undulator period length, a_u is rms undulator strength parameter and γ is the Lorentz factor that is a measure of the electron energy. Small signal gain for planar undulators is calculated by using:

$$g_0 = \frac{16\pi}{\gamma}\lambda[m]\lambda_u[m]N^3\frac{J\left[A/m^2\right]}{I_0[A]}\xi f_b(\xi)^2 \quad (7)$$

where J shows Bessel Function while I_0 shows Alfven current. N stands for number of periods in the undulator and ξ shows undulator parameter which is related to the Bessel Functions. Gain for single pass is:

$$G_{max} = 0.85*g_0 + 0.19*g_0^2 + 4.12*10^{-3}*g_0^3 \quad (8)$$

For TAC IR-FEL system, one can obtain small single gain as 0.006175 and gain for single pass is approximately found as 0.00645 for undulator-1 with 2.5 cm wavelength. Electron beam energy spread, finite emittance, longitudinal slippage and Chesworth filling method correction factors are used for calculating the ideal gain. It is considered %10 cavity losses, 120 pC bunch charge, %0.1 beam energy spread and 15 mm.mrad RMS transverse emittance for both undulator simulations. Only bunch lengths and cavity detuning were considered to be different for better coupling in the resonators.

5. CONCLUSION

Due to longer electron bunch length, for longer wavelength FELs the laser pulses are longer and reach up to 10 ps. The main parameters of the FEL which can be produced by undulator-1 and undulator-2 for 120 pC bunch charge are given in Table 5 as the results of analytical calculations, FELO, GENESIS and OPC simulation codes. For several FEL and other technology applications, in order to improve technology, industry and science in Middle East Area, it is volunterely decided to construct Turkish Accelerator Center, which includes IR-FEL System besides Synchrotron Radiation, Proton Accelerator, Particle Factory, and SASE FEL System.

Table 5: Expected Main Parameters of TAC IR-FEL for 1,6 mA average beam current

Parameter	Undulator-1	Undulator-2
Wavelength [μm]	2.5-27	11-250
Micropulse repetition rate [MHz]	13	13
Max. Peak Power [MW]	~5	~2.5
Average Power [W]	0.1-40	0.1-30
Max. Pulse energy [μJ]	~10	~8
Pulse length [ps]	1-10	1-10

6. ACKNOWLEDGEMENT

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