AN OPTIMIZATION STUDY FOR AN FEL OSCILLATOR AS TAC TEST FACILITY

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Abstract

Recently, conceptual design of Turkic Accelerator Center (TAC) proposal was completed. Main goal of this proposal is a charm factory that consists of a linac-ring type electron-positron collider. In addition, synchrotron radiation from the positron ring and free electron laser from the electron linac are proposed. The project related with this proposal has been accepted by Turkish government. It is planned that the Technical Design Report of TAC will have been written in next three years. In this period, an infrared oscillator free electron laser (IR FEL) will be constructed as a test facility for TAC. 20 and 50 MeV electron energies will be used to obtain infra red free electron laser. The main parameters of the electron linac, the optical cavities and the free electron laser were determined. The possible use of obtained laser beam in basic and applied research areas such as biotechnology, nanotechnology, semiconductors and photo chemistry were discussed.

INTRODUCTION

Approximately 10 years ago, linac-ring type charm-tau factory with synchrotron light source was proposed as a regional project for elementary particle physics [1]. Starting from 1997, a small group from Ankara and Gazi Universities begins a feasibility study for the possible accelerator complex in Turkey with the support of Turkish State Planning Organization (DPT) [2]. The results of the study is published in [3] and presented at EPACs [4-6]. Starting from 2002, the conceptual design study of the TAC project has started with a relatively enlarged group (again with the DPT support).The TAC CDR has been completed in 2006.

At this stage, TAC project includes:

- Linac-ring type charm factory
- Synchrotron light source based on positron ring
- Free electron laser based on electron linac
- GeV scale proton accelerator
- TAC-Test Facility.

The schematic view of the factory and light sources part of the Turkic Accelerator Complex is given in Fig. 1.

The conceptual design report has been completed in 2006 that has been continuing since 2002. Now the technical design report (TDR) studies has begun by a relatively enlarged group with the contributions of 9 Turkish universities.

Besides TDR studies it is proposed to build a linac based infrared FEL as the test facility. It is planned that TAC IR FEL will cover the 2-16 µm wavelength range. The possible applications of TAC IR FEL are described as material science, biotechnology, semiconductors, medical physics and photo-chemistry. One of the main goals of constructing an IR FEL facility in Turkey is to introduce accelerator and light source technology to the research groups of mensioned areas and to open a window for national accelerator laboratory.

In this paper, the main parameters of electron source, electron linac, optical cavity, undulator magnet that being the main parts of oscillator FEL and the parameters of the obtained laser as well were presented.

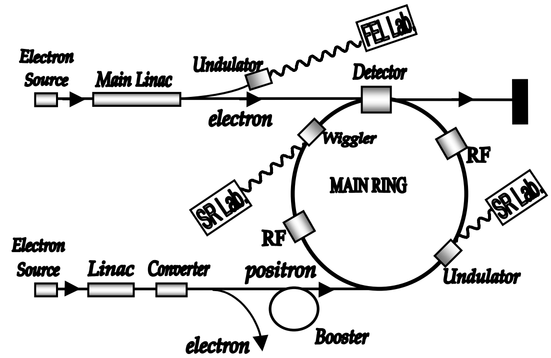

Figure 1: The schematic view of the tAC charm factory complex.

FEL OSCILLATOR

The IR FEL must have a number of characteristics that will make it suitable for the range of applications that is designed for, namely;

i. Having an undulator magnet with a variable air gap to achieve the necessary wavelength tuning range,

ii. Electron beam of the appropriate energy,

iii. Electron beam quality (low emittance, short bunch length, high peak current and small energy spread)

In an FEL oscillator the radiation that is obtained from the undulator is trapped between two mirrors. The radiation interacts with the electron beam in its each round trip in the cavity.

An FEL oscillator operates in low gain regime where the paramount parameter is low gain parameter given as,

$$g_0 = \frac{16\pi}{\gamma}\lambda[m]\lambda_u[m]N^3\frac{J[A/m^2]}{I_0[A]}\xi f_b(\xi)^2 \quad (1)$$

where γ is the beam energy in terms of electron rest mass energy, λ is the fundamental wavelenght of emitted radiation, λ_u is the period length and N is the period number of the undulator, J is the current density,

I_0 is the Alfvén current (1.7 kA) and f_b is the Bessel correction [7].

Other parameters can affect the gain and must be taken into account when calculating it. To ensure overlapping between electrons and photons the cavity lenght should be adjusted in such a way that it equals the distance between two adjucent electron bunches. The FEL interaction tends to slow down the optical packets in the interaction region thus a further correction is needed. The inhomogeneous broadening corrections specified in reference [8] has been taken into account through the calculations.

TAC IR FEL FACILITY

A linac based infrared FEL has been proposed to obtain 2.62 and 16.4 μm radiation from the beams that have the energy of 20 MeV and 50 MeV. Schematic view of TAC IR FEL is shown in Fig. 2.

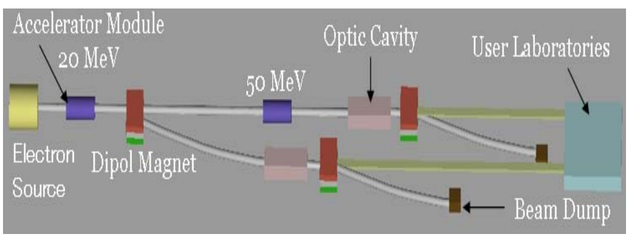

Figure 2: Schematic view of TAC IR FEL facility.

Optimization results for parameters of electron source, electron beam, undulator magnet and optical cavity were given in Tables 1, 2, 3 and 4, respectively.

Source

The CeB_6 has been chosen as the cathode material since it provides long-term, stable operation at current densities up to 50 A/cm^2 besides other properties summarized in Table 1 [9].

Table 1: Parameters of CeB_6 cathode

Brightness (A/cm^2-sr)	10^7
Short-term beam current stability (%rms)	<1
Typical servise life (hr)	1500+
Operation vacuum (torr)	10^{-7}
Work function (eV)	~2.5
Evoparation rate (g/cm^2-sec)	1.6×10^{-9}

The normalized rms thermal emittance of a hot cathode is given by [10],

$$\varepsilon_{n,rms} = \frac{r_c}{2}\sqrt{\frac{k_b T}{m_e c^2}} \, . \tag{2}$$

It has been proposed to use a CeB_6 cathode with a radius of 5.6 mm supplying 50 A/cm^2 at ~1800 K to obtain a thermal emittance less than $1\ \pi mm.mrad$ with respect to the equation (2).

Electron Beam

Table 2: The electron beam parameters

Parameter	IR FEL I	IR FEL II
Electron Beam Energy (MeV)	20	50
Current Density (A/cm^2)	3.2×10^7	2×10^8
Microbunch Charge (nC)	2.50	2.50
Peak Bunch Current (A)	62.5	62.5
Average Current (mA)	6.25	6.25
Source Emittans (π mm mrad)	0.5	0.5

Undulator

The undulator parameters as given in the Table 3 have been chosen to produce the desired radiation wavelength fullfiling the resonant condition (3) where K is the undulator strength parameter.

$$\lambda_r = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right) \tag{3}$$

In Table 3, B_0 is the peak magnetic field and g is the gap of the undulator.

Table 3: Undulator parameters

λ_u (cm)	3.5
K	0.934
N	120
B_0 (T)	0.286
g (mm)	22

Optical Cavity

A six meter long optical cavity was proposed to use for the facility.

Table 4: The optimized cavity parameters

L_c (m)	6.0
R_1 (m)	4
R_2 (m)	3
Z_R (m)	1.2

R_1 and R_2 are the radius of curvature of the mirrors that one is semi-transparent and the other is fully reflective. Z_R is the Raylegh length. After several successive round trips the radiation that reaches the saturation intra cavity intensity leaves the cavity from the semi transparent mirror and is taken to the
user laboratories by means of the waveguides.

IR FEL

Table 5: The TAC IR FEL parameters

Radiation Parameters	**TAC IR FEL I**	**TAC IR FEL II**
Radiation wavelength λ_r (μm),	16.4	2.62
Photon Energy (eV), (1st Harmonic)	0.057	0.4723
Peak Brightness (photons/s/mm^2/mrad^2/0.1%bg)	7.0734x10^{28}	1.105x10^{30}
I_s , Intra Cavity Saturation Intensity (W/cm^2)	2.8x10^6	1.1x10^8
Flux (photons/s/%0.1bg) (1st Harmonic)	3.8x10^{16}	2.4x10^{17}
Output Power (KW)	3.125	1.250
Pulse Lenght (ps)	6.56	1.05
Pulse energy (mJ)	0.102	0.64
G (%), Gain	220	72
g_0 , gain parameter	2.45	0.98

Tunability

For the experimental purposes it is important to produce a radiation in a wide wavelength range. A wavelength tunability of 16-70 μm for 20 MeV and 2.4-14 μm for 50 MeV can be achieved with an undulator of variable gap between 1.5 – 3 cm

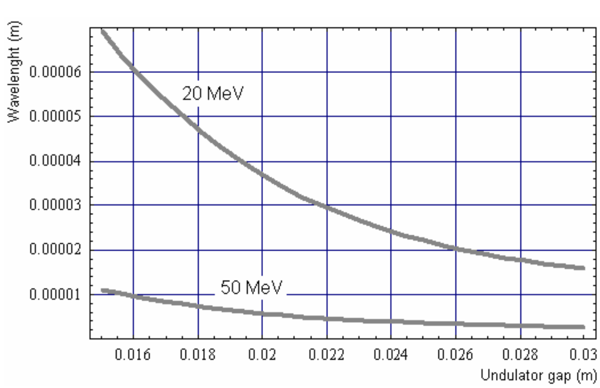

Figure 3: Tunability for 20 and 50 MeV.

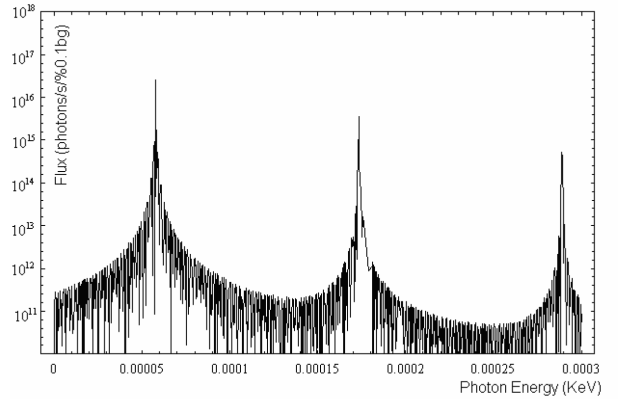

Figure 4: Flux peaks for the beam energy of 20 MeV.

Applications

The obtained radiation is planned to use for medical applications [11] such as human neurosurgery; material sciences [12] such as research with semiconductors; biotechnology such as research of radiation effects on biological samples and photochemistry such as investigations on radiation absorbtion spectroscopy of surfaces with sum frequency generation method.

CONCLUSIONS

TAC IR facility will be commissioned in 2010. Four experimental stations are planned. Facility will give the opportunity to use an FEL beam in research for national and regional users. The capacity and quality of scientific research in Turkey will rise with the use of FEL. Finally, TAC IR FEL facility will be a first step of the national accelerator complex.

ACKNOWLEDGMENT

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