TURKISH ACCELERATOR CENTER (TAC) PROJECT
http://bilge.science.ankara.edu.tr

Yeşim Cenger
Ankara University
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Introduction

- Accelerator technology ➔ a generic technology ➔ locomotive of the development in almost all fields of science and technology.
- Accelerator technology should become widespread all over the world.
- Existing situation: a large portion of the world (the South and Mid-East) is poor on the accelerator technology.
Projects in Middle East

- SESAME in Jordan (by UNESCO)
- CANDLE in Armenia

- Turkish Accelerator Complex
  - light sources
  - particle physics experiments
  - proton and secondary beam applications
Short chronology of the TAC project

- Approximately 10 years ago, linac-ring type charm-tau factory with synchrotron light source was proposed as a regional project for elementary particle physics.

- 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).
  - http://bilge.science.ankara.edu.tr
The results of the study are published in

and presented at EPACs
Ö. Yavaş etc al, EPAC 2006

Starting from 2002, the conceptual design study of the TAC project has started with a relatively enlarged group (again with the DPT support). This stage is completed in 2005. The results are published in
S. Sultansoy et al., PAC 2005
Yeşim Cenger
Ankara University

Short chronology of the TAC project (cont.)

Present Status:
TAC Project supported by Turkish State Planning Organization (DPT)
Grant No: DPT2006K-120470
Period of: 2006-2010

10 Turkish universities:
Ankara Univ. (Coordinator) + Boğaziçi, Doğuş, Dumlupınar, Erciyes, Gazi, İstanbul, Niğde, S. Demirel, Uludağ Universities
30 staff + 50 graduate students

Main Goals of the TAC Project:
- To establish Institute of Accelerator Technologies
- To prepare TDR of TAC
- To construct TAC Infrared FEL
TAC Project includes

- TAC-Test Facility (IR-FEL)
- Free electron laser based on electron linac
  - TAC IR FEL Test Facility
- Synchrotron light source based on positron ring (*3rd generation)
- GeV scale proton accelerator
- Linac-ring type charm factory ($L = 10^{34} \text{ cm}^{-2} \text{s}^{-1}$)
After the feasibility and the conceptual design studies it was decided to construct a charm factory which also will serve to obtain free electron laser and synchrotron radiation.

TAC facility will include:
- 1 GeV e- linac
- 3.56 GeV positron ring
## Tentative parameters of TAC charm factory

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$e^-$-linac</th>
<th>$e^+$-ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy, GeV</td>
<td>1.00</td>
<td>3.56</td>
</tr>
<tr>
<td>Particles per bunch, $10^{10}$</td>
<td>0.55</td>
<td>11.00</td>
</tr>
<tr>
<td>$\beta$ function at IP, cm</td>
<td>0.45</td>
<td>0.45</td>
</tr>
<tr>
<td>Normalized emittance, $\mu$m·rad</td>
<td>6.17</td>
<td>22.00</td>
</tr>
<tr>
<td>Bunch length, cm</td>
<td>0.10</td>
<td>0.45</td>
</tr>
<tr>
<td>Transverse size at IP, $\mu$m</td>
<td>3.76</td>
<td>3.76</td>
</tr>
<tr>
<td>Beam-beam tune shift</td>
<td>-</td>
<td>0.056</td>
</tr>
<tr>
<td>Collision frequency, MHz</td>
<td></td>
<td>30</td>
</tr>
<tr>
<td>Luminosity $(H_D \cdot L)$</td>
<td></td>
<td>$1.4 \times 10^{34}$ cm$^{-2}$s$^{-1}$</td>
</tr>
</tbody>
</table>
SR in linac-ring type machines

- Chosen emittance (3 nm·rad) of the positron small enough ➔ a third generation light source (< 20 nm·rad)

- Number of insertion devices and beam lines of TAC SR Facility and their specifications depend on realization of SESAME and CANDLE projects as well as on user potential in our region.
Proton Accelerator

- TAC proton accelerator proposal consists of 100-300 MeV energy linear pre-accelerator and 1-5 GeV main ring.
- The average beam current values for these machines would be ~30 mA and ~0.3 mA, respectively.
- Proton beams from two different points of the synchrotron will be forwarded to neutron and muon regions, where a wide spectrum of applied research is planned.
Planned uses of proton accelerator

- **Muon region**
  - fundamental investigations
    - test of QED and
    - muonium-antimuonium oscillations...
  - applied investigations with $\mu$SR method
    - High-$T_c$ superconductivity
    - phase transitions
    - impurities in semiconductors...

- **Neutron region**
  - applied physics
  - molecular biology
  - fundamental physics
OSCILLATOR FEL

Wavelength of FEL: \[ \lambda_{SEL} = \frac{\lambda u [m]}{2\gamma^2} \left(1 + \frac{K^2}{2}\right) \]

- \(\lambda u\) : Undulator Period
- \(\gamma\) : Lorentz Factor
- \(K\) : Undulator Strength

- A relativistic electron beam coming from a linac is inserted to a sinusoidal magnetic field (undulator magnet).
- While passing through the undulator, electron beam losses some of its energy and emits radiation.
- The radiation emitted from the beam is trapped between two mirrors.
- When the radiation power is saturated, it is taken out of one of the mirrors via a hole.
Before building a medium size accelerator complex
- to get experience on accelerator technology on smaller scale
- to train young accelerator physicists
we plan to build infrared free electron laser (IR FEL) on 15-40 MeV e-linac until 2010.

IR FEL thought to work in oscillator mode.

Two Undulators will produce laser at wavelength range of 2-180 μm.
The Place of TAC IR-FEL
TAC Test Facility (IR-FEL)

TAC Oscillator IR-FEL includes:

- an electron linac (15-40 MeV energy range)
- two optical resonators
- two undulators ($\lambda_{U1}=3\text{cm},\lambda_{U2}=9\text{cm}$).
## TAC IR LASER FACILITY
### Accelerator Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>ELBE IR FEL</th>
<th>TAC IR FEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron beam energy / MeV</td>
<td>12 - 40</td>
<td>15 - 40</td>
</tr>
<tr>
<td>Bunch charge /pC</td>
<td>77</td>
<td>200</td>
</tr>
<tr>
<td>Average beam current /mA</td>
<td>1</td>
<td>2,6</td>
</tr>
<tr>
<td>Microbunch duration /ps</td>
<td>1 - 10</td>
<td>5</td>
</tr>
<tr>
<td>Microbunch repetition frequency /MHz</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Macro pulse duration /ms</td>
<td>0.1 - 40 /cw</td>
<td>0.1</td>
</tr>
<tr>
<td>Macro pulse freq. /Hz</td>
<td>1 - 25</td>
<td>1</td>
</tr>
</tbody>
</table>
TAC Infrared-FEL

Laser wavelength tunability with respect to the undulators gap

The laser wavelength is planned to scan 2 - 190 microns range
# Preliminary parameters of TAC IR-FEL

<table>
<thead>
<tr>
<th>Linac Parameters</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Energy [MeV]</td>
<td>15-40</td>
<td></td>
</tr>
<tr>
<td>Bunch Charge [pC]</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Bunch Length [ps]</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Bunch Repetition Rate [MHz]</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Average Current [mA]</td>
<td>2.6</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Undulator Parameters</th>
<th>U-1</th>
<th>U-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period [cm]</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Magnetic Field [T]</td>
<td>0.1–0.35</td>
<td>0.1–0.27</td>
</tr>
<tr>
<td>K Parameter</td>
<td>0.3–1</td>
<td>0.8–2.3</td>
</tr>
<tr>
<td>Number of Periods</td>
<td>90</td>
<td>40</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FEL Parameters</th>
<th>U-1</th>
<th>U-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation Wavelength [μm]</td>
<td>2–27</td>
<td>10–190</td>
</tr>
<tr>
<td>Pulse energy [μJ]</td>
<td>0.01–3</td>
<td>0.01–3</td>
</tr>
<tr>
<td>Average Power [W]</td>
<td>0.1–10</td>
<td>0.1–10</td>
</tr>
<tr>
<td>Average Flux [photons/s.eV]</td>
<td>~10^{15}</td>
<td>~10^{15}</td>
</tr>
</tbody>
</table>
TAC Infrared-FEL

Schematic view of TAC IR-FEL facility
<table>
<thead>
<tr>
<th></th>
<th>1. Undulator (λ_u = 9 cm)</th>
<th>2. Undulator (λ_u = 3 cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W.L. Range for 15 MeV e⁻ [µm]</td>
<td>70 – 190</td>
<td>18 – 27</td>
</tr>
<tr>
<td>W.L. Range for 20 MeV e⁻ [µm]</td>
<td>40 – 107</td>
<td>11 – 15</td>
</tr>
<tr>
<td>W.L. Range for 25 MeV e⁻ [µm]</td>
<td>26 – 68</td>
<td>6,98 – 10,5</td>
</tr>
<tr>
<td>W.L. Range for 35 MeV e⁻ [µm]</td>
<td>14 – 35</td>
<td>4 – 5,2</td>
</tr>
<tr>
<td>W.L. Range for 40 MeV e⁻ [µm]</td>
<td>10 – 27</td>
<td>2,6 – 4,43</td>
</tr>
<tr>
<td>W.L. Range for 15 MeV e⁻ [µm]</td>
<td>24 – 64</td>
<td>7,5 – 9,5</td>
</tr>
<tr>
<td>W.L. Range for 20 MeV e⁻ [µm]</td>
<td>14 – 35</td>
<td>4,21 – 5,63</td>
</tr>
<tr>
<td>W.L. Range for 35 MeV e⁻ [µm]</td>
<td>5,5 – 12</td>
<td>3,44 – 3,15</td>
</tr>
<tr>
<td>W.L. Range for 40 MeV e⁻ [µm]</td>
<td>4 – 9,5</td>
<td>1,5 – 1,9</td>
</tr>
</tbody>
</table>
Halbach formula

\[ \hat{B} = a \exp\left( b \frac{g}{\lambda_0} + c \left( \frac{g}{\lambda_0} \right)^2 \right) \]  

(1)

where both \( \hat{B} \) and \( a \) are expressed in units of Tesla and \( b \) and \( c \) are dimensionless. The results

<table>
<thead>
<tr>
<th>Case</th>
<th>Description</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>Gap Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>PPM Planar Vertical Field</td>
<td>2.076</td>
<td>-3.24</td>
<td>0</td>
<td>( 0.1 &lt; g / \lambda_0 &lt; 1 )</td>
</tr>
<tr>
<td>B</td>
<td>PPM Planar Horizontal Field</td>
<td>2.400</td>
<td>-5.69</td>
<td>1.46</td>
<td>( 0.1 &lt; g / \lambda_0 &lt; 1 )</td>
</tr>
<tr>
<td>C</td>
<td>PPM Helical Field</td>
<td>1.614</td>
<td>-4.67</td>
<td>0.620</td>
<td>( 0.1 &lt; g / \lambda_0 &lt; 1 )</td>
</tr>
<tr>
<td>D</td>
<td>Hybrid with Vanadium Permendur</td>
<td>3.694</td>
<td>-5.068</td>
<td>1.520</td>
<td>( 0.1 &lt; g / \lambda_0 &lt; 1 )</td>
</tr>
<tr>
<td>E</td>
<td>Hybrid with Iron</td>
<td>3.381</td>
<td>-4.730</td>
<td>1.198</td>
<td>( 0.1 &lt; g / \lambda_0 &lt; 1 )</td>
</tr>
<tr>
<td>F</td>
<td>Superconducting Planar, Gap = 12 mm</td>
<td>12.42</td>
<td>-4.79</td>
<td>0.385</td>
<td>( 12 \text{mm} &lt; \lambda_0 &lt; 48 \text{mm} )</td>
</tr>
<tr>
<td>G</td>
<td>Superconducting Planar, Gap = 8 mm</td>
<td>11.73</td>
<td>-5.52</td>
<td>0.856</td>
<td>( 8 \text{mm} &lt; \lambda_0 &lt; 32 \text{mm} )</td>
</tr>
<tr>
<td>H</td>
<td>Electro-magnet Planar Gap = 12 mm</td>
<td>1.807</td>
<td>-14.30</td>
<td>20.316</td>
<td>( 40 \text{mm} &lt; \lambda_0 &lt; 200 \text{mm} )</td>
</tr>
</tbody>
</table>

Table 1: Fit coefficient \( a, b \) and \( c \) defining the peak field as a function of the ratio of gap over period as defined in Eq.(1).
Flux of FEL

\[
F_n(K) = \begin{cases} 
\xi = \frac{1}{2} \frac{K^2}{1+K^2} \rightarrow \text{for helical undulators} \\
\xi = \frac{1}{4} \frac{K^2}{1+K^2/2} \rightarrow \text{for planner undulators}
\end{cases}
\]

\[
\xi n^2 \left[ J_{(n-1)/2}(n\xi) - J_{(n+1)/2}(n\xi) \right]^2
\]

\[
\frac{d^2 F_n}{d\omega d\Omega} \bigg|_{\theta=0} = 1.74 \times 10^{14} N^2 E^2 [GeV] I[A] F_n(K) f(n\nu_n)
\]

\[
f(\nu) = \left( \frac{\sin \nu/2}{\nu/2} \right)^2
\]

\[
\varepsilon_n = n\varepsilon = \frac{0.947 n [E(GeV)]^2}{\lambda_u (cm)(1+K^2/2)}
\]

\[
\nu = 2\pi N \frac{\varepsilon_n - \varepsilon}{\varepsilon_n}
\]
\( E_e[\text{He}^	ext{7}] \rightarrow 40,\ 2\alpha[n] \rightarrow 0.03,\ g[m] \rightarrow 0.018,\ I[A] \rightarrow 40,\ \text{bar. say} \rightarrow 1,3 \)
Brightness of FEL

**Brightness**

\[ B = \frac{F}{4\pi^2 \sigma_x \sigma_z \sigma'_x \sigma'_z} = \frac{F}{4\pi^2 \varepsilon_x \varepsilon_z} = \text{foton} / \text{s} / \text{mm}^2 / \text{mrad}^2 / \% 0.1 \text{bg} \]

In practical units...

**Saturation Brightness**

\[ B_s \approx 3.977 \times 10^{42} \left( \frac{E[\text{GeV}]}{N} \right)^4 \frac{\sigma_z[\text{mm}]}{(\lambda_u[\text{cm}][Kf_b(K)])^2} \]

**Peak Brightness**

\[ B_p \approx 6.4 \times 10^{37} \frac{i[A]}{N} \frac{E[\text{GeV}]^3}{\lambda_u[\text{cm}]L_c[\text{cm}]} \frac{\sigma_z[\text{mm}]}{1 + K^2} \]

**Electron beam divergence**

\[ \sigma'_{x,z} = \sqrt{\varepsilon_{x,z} \beta_{x,z}} \]

**Electron beam transverse dimensions**

\[ \sigma_{x,z} = \sqrt{\varepsilon_{x,z} \beta_{x,z}} \]
E=40 MeV için 3 ve 9 cm periyotlu lazerlerden elde edilebilecek tepe parlaklığın açılığa göre değişimi

\[ \lambda_u = 3 \text{cm} \]

\[ \lambda_u = 9 \text{cm} \]
Ankara Üniversitesi
Virancık (50. Yıl) Kampüsü
GÖLBAŞI
Building Plan of TAC IR FEL
Experimental stations are planned to make research on Biomedical Science, Semiconductors, Material Science, Nonlinear Optics, Photo-Chemistry and Nanotechnology.
Time Schedule

2000:
- Completion of the Feasibility Report

2005:
- Completion of the Conceptual Design Report

2006-2007:
- Completion of optimization for the IR FEL
- Starting Technical Design Report study for TAC

2008:
- Construction of buildings for the Institute and TAC-IR FEL Facility

2009-2010:
- Installation of the TAC IR FEL
- Completion of the TAC Technical Design Report

2011:
- Commissioning of TAC-TF
- Governmental decision on approval of TAC project

2015:
- Completion of charm factory and light source part of TAC project.

2017:
- Completion of proton accelerator and experimental stations
• The accelerator based light sources have become the most promising and modern tools for the basic research and technology in the 21st century.

• In this work, related with an oscillator FEL, an example for one of the light sources in the TAC (Turkish Accelerator Centre) has been presented covering two possible energy options of 15 and 40 MeV with a wavelength range of 2-180 microns by means of a variable gap undulator.

• In future TAC project will go on to be a focal point for the scientific societies in Turkey and in our region with its synchrotron and FEL sources that have been studying under the research of several collaborating scientists and engineers.
International Collaborations

- **CERN** (Geneva)  
- **DESY** (Hamburg)  
- **BESSY** (Berlin)  
- **FZR** (Dresden)  
- **4GLS** (Daresbury)  
- **iFEL** (Osaka Univ.)  
- **John Adams Inst.** (Oxford Univ.)  
- **ELETTRA** (Trieste)  

since 1996
Announcements

- **III. UPHUK**
  3rd National Particle Accelerator and Applications Congress
  17-20 Sept. 2007, Bodrum, Turkey

- **III. UPHDYO**
  3rd National Particle Accelerator and Detectors Summer School
  20-24 Sept. 2007, Bodrum, Turkey

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you can come to TURKEY easily!

You have a still time.

Bodrum is well known in the other countries especially for go on holiday.

http://www.bodrum-bodrum.com/
(more information about Bodrum)
Thank you for your attention…