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AN ASYNCHRONOUSLY OPERATING ERL-RING TYPE COLLIDER PROPOSAL FOR THE TAC PARTICLE FACTORY AND SASE FEL FACILITY

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Abstract. - A SASE FEL facility was first proposed in Feasibility Report of the TAC project in 2000. Main goal of the proposal is, to cover VUV and soft X-rays region (tunable, 1-100 nm) of the spectrum besides IR-FEL, Bremsstrahlung and Synchrotron Radiation proposals of TAC. It was planned that, 1 GeV electron linac of the linac-ring type collider sector of TAC, should asynchronously be used as a driver for the SASE FEL facility. On the other hand, a more promising option, namely ERL, is arising nowadays for both collider and SASE FEL proposals of TAC. Today, ERLs provide a powerful broad range of applications like: electron cooling devices, high average brightness, high power FELs, short-pulse radiation sources and high luminosity colliders. Because of the high luminosity ($\sim 2.3 \cdot 10^{35}$ cm^{-2}s^{-1}) requirement of the TAC collider and high peak power ($\sim$2–3 GW) & high average brightness ($\sim 10^{25}$–10^{30} photons/s/mrad^2/mm^2/0.1%BW) requirements of TAC SASE FEL, 1 GeV electron accelerator sector of the collider should be based on an Energy Recovery Linac. Especially, the average brightness value mentioned above, exceeds the rest of the light sources (existing and proposed) by about 5 orders of magnitude. The asynchronously ERL operation option for both collider and SASE FEL, is still under discussion and R&D stage. Finally, this study points out the feasible linac options for the SASE FEL facility proposal of TAC. In addition, asynchronous operation is discussed for a special RF linac or an Energy Recovery Linac. Furthermore, optimization study results of SASE FEL are mentioned.

A SASE FEL facility was proposed in feasibility report of the TAC project in 2000 [1,2]. The main goal of the proposal is to obtain FEL in SASE mode ranging between VUV and soft X-rays (1-100 nm) region of the spectrum. Furthermore, TAC SASE FEL will also act as a complementary part for covering the electromagnetic spectrum besides IR-FEL, Bremsstrahlung and Synchrotron Radiation proposals of TAC. On the other hand, TAC SASE FEL was planned to be used in scientific research on atom-molucule and cluster physics, plasma physics, condensed matter physics, chemistry, materials science and life sciences. It was first planned that, this facility should be based on the 1 GeV electron linac sector of the collider [3]. But after optimization studies, it was shown that [4] some of the electron beam parameters make linac design complicated for both SASE FEL and collider. To achieve SASE FEL with a peak power about GWs, a peak current about kAs is required. Modifications on bunch sizes and emittance to raise the peak current show that, the driver linac for SASE FEL must disparately be designed from the colliders [4]. Nowadays, a more promising option, namely ERL, is arising for both collider and SASE FEL proposals of TAC. Today ERLs are in request for colliders because of high luminosity requirements. And ERLs are also ideal drivers for high power FELs ranging between VUV to soft X-rays. Therefore, TAC linac-ring type e^-e^+ collider & SASE FEL facility is modified to ERL-Ring type collider. Schematic view of TAC ERL-Ring type collider & SASE FEL facility is shown in Figure 1.

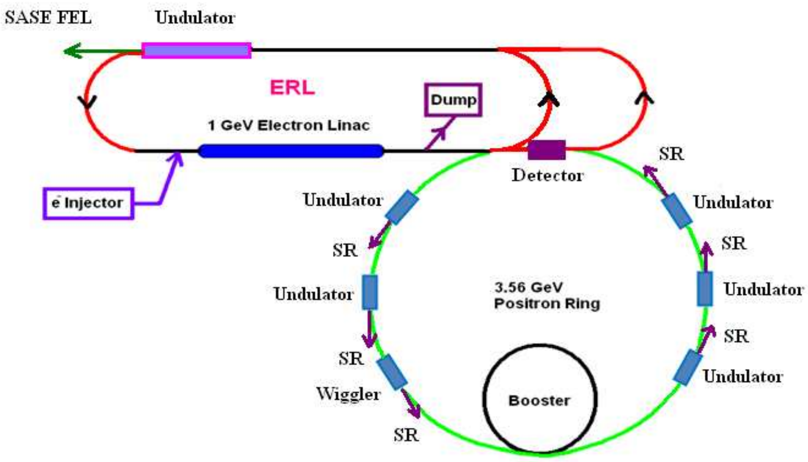

Fig. 1 Schematic view of TAC ERL-Ring type collider & SASE FEL facility

One of the most important parameter for ERL choice is the total electricity cost of the facility. It is well known that, total electric power (P_{total}) can easily be calculated by adding cryogenics power (P_{cr}) to RF power (P_{rf}). For 1 GeV electron beam, total expended power consumption should quite be reduced with a recovery about 90-95 %, hence this case directly lowers the operating cost of the facility.

$$\mathrm{P}_{total} \approx \mathrm{P}_{cr} + \mathrm{P}_{rf}$$

$$\mathrm{P}_{cr} = A\frac{E}{g} + BDEg$$

$$\mathrm{P}_{rf} = P_{beam}\frac{1-\eta_{ER}}{\eta_{rf\to beam}\eta_{wp\to rf}}$$

Where; E is electron beam energy, g is accelerating gradient, A $\approx$ 350 W/m, B $\approx$ 10^{-10} Wm/(eV)^2, D $\approx$ 1 for cw mode and 0.0075 for pulsed mode, $\eta_{wp\to rf}$ $\sim$ 50 % (for SC linacs), $\eta_{rf\to beam}$ $\sim$ 100 % (for cw mode) and η_{ERL} $\sim$ 90-95 %. Proposed 1 GeV electron ERL parameters for TAC collider are given in Table 1.

Table 1. TAC 1 GeV electron ERL parameters [5]

Parameter	**Value**
Electron beam energy (GeV)	1
Number of electrons per bunch (x 10^{10})	2
Beta functions @ IP, β_x/β_y (mm)	80/5
Normalized emittances, $\varepsilon_x^N/\varepsilon_y^N$ (μm)	31/0.1
σ_x/σ_y (μm)	36/0.5
σ_z (mm)	5
Beam current (mA)	0.48

Luminosity requirement ($L \approx 1.4 \cdot 10^{35}$ $cm^{-2}s^{-1}$) of TAC collider can be achieved for the same beam sizes (σ_x, σ_y and σ_z) of electrons and positrons by taking crab crossing into account, where $N^+ = 2.10^{11}$ and f_c = 150 MHz [5].

$$L = \frac{N^+N^-}{4\pi\sigma_y\sqrt{(\sigma_z\tan\theta/2)^2+\sigma_x^2}}f_c$$

On the other hand; during maintanence months of the collider, TAC 1 GeV electron ERL should be operated as a driver for SASE FEL facility. In dedicated light source mode, the *asynchronously* operation of the ERL may be achieved by lowering the charge per bunch and arising the repetition rate providing the same average current value for both collider and light source operations.

In addition, a reference from the World for *asynchronously* operation of a collider as a light source based on a GeV scale ERL, is the eRHIC proposal [6]. The Collider-Accelerator Department at BNL in collaboration with Bates Laboratory at MIT issues the eRHIC ZDR (0^{th}-order design report), which includes a linac-ring eRHIC design based on 10 GeV ERL. eRHIC ERL structure is a high current, cw mode electron accelerator based on 5-cell superconducting RF cavities [6].

On the other hand, TAC SASE FEL optimization studies were based on a planar undulator for a hybrid with iron configuration (See Fig. 2) [7]. In Figure 3 and Figure 4, peak magnetic field and K parameter vs gap (g) and period (λ_u) for the dedicated undulator, are shown respectively. Subsequently, laser wavelength range vs gap (g) and period (λ_u) of the hybrid with iron planar undulator for 1 GeV electron beam, is shown in Figure 5 [7].

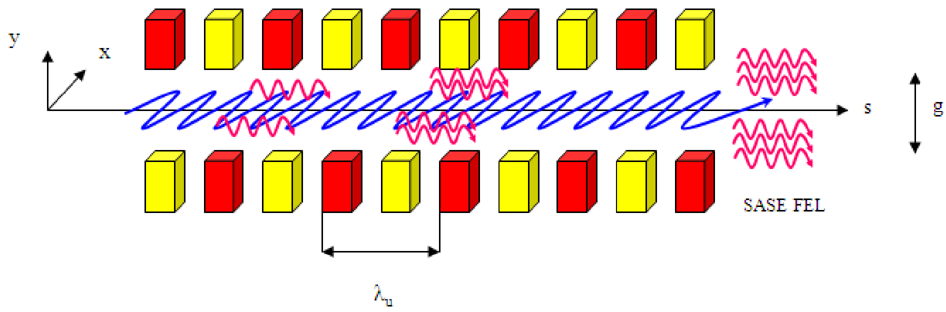

Fig. 2 Schematic view of a planar undulator

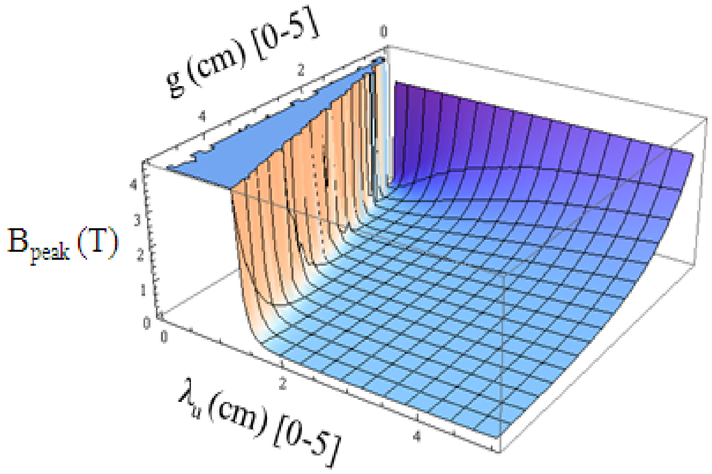

Fig. 3 Peak magnetic field vs gap (g) and period (λ_u) of hybrid undulator with iron

It is wellknown that, there are so many undulator configurations and technologies like: Pure Permanent Magnet (PPM), Hybrid Permanent Magnet (HPM), Superconducting Magnets (SC), Electromagnetic Magnets (EM) and Combined Electromagnetic & Permanent Magnets (EMPM). Optimization studies show that, hybrid with iron undulator configuration can easily tune 1-100 nm range (See Fig. 5). For this reason, TAC SASE FEL optimization is based on an hybrid with iron planar undulator.

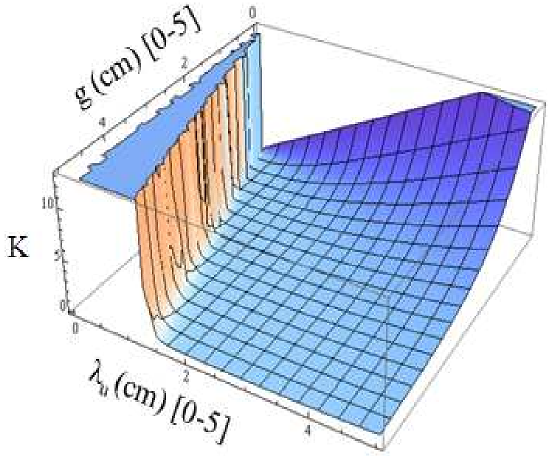

Fig. 4 K parameter vs gap (g) and period (λ_u) of hybrid undulator with iron

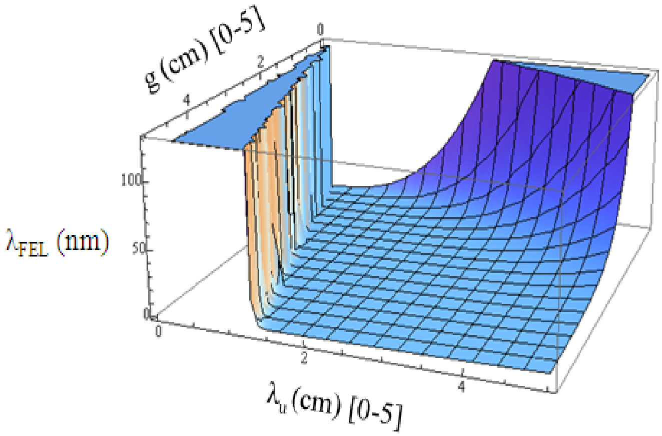

Fig. 5 Wavelength range vs gap (g) and period (λ_u) of hybrid undulator with iron

In Table 1; proposed and operating SASE FEL facilities around the World (their technology, country, laser wavelength range (nm) and situation) are given [8, 9, 10, 11 and 12].

Table 1. Proposed and operating SASE FEL facilities around the World

Project (Technology)	Facility	Country	λ_{photon} (nm)	Situation
LEUTL (NC)	APS	USA	660-130	Since 2001
TTF-I (SC)	DESY	GERMANY	125-85	Since 2002
SCSS (NC)	SPRING8	JAPAN	40	2005
FLASH (SC)	DESY	GERMANY	6.5	Since 2006
X-FEL (SC)	DESY	GERMANY	0.1	2012
LCLS (NC)	SLAC	USA	0.15	2008
SPARC (NC)	ENEA/INFN	ITALY	VUV	Proposal
SPARX (NC)	ENEA/INFN	ITALY	1.5	Proposal
VXFEL (SC)	ELETTRA	ITALY		Proposal
FERMI (NC)	ELETTRA	ITALY	1.2	Proposal
4GLS (SC)	DARESBURY	UK	VUV-XUV	Proposal/ERL

CONCLUSION

The TAC SASE FEL will act as a complementary part to cover the electromagnetic spectrum besides IR-FEL, Bremsstrahlung and Synchrotron Radiation proposals of TAC. Thereby, Turkish scientists and researchers will become acquainted with accelerator based light sources and its range of applications. Furthermore, Technical Design Report (TDR) studies of TAC has been started as an inter-universities project with support of Turkish State Planning Organization (SPO) since 2006. By this time, tentative optimization studies for SASE FEL were completed based on a 1 GeV superconducting RF linac.

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