Feasibility Study of the Erlangen Synchrotron Light Source

D. E. Berkaev, P. M. Ivanov, I. A. Koop, A. P. Lysenko,
I. N. Nesterenko, A. V. Otboev, E. A. Perevedentsev,
P. Yu. Shatunov, Yu. M. Shatunov, A. N. Skrinsky, A. A. Valishev
Budker Institute of Nuclear Physics, Novosibirsk, 630090, Russia
A. Magerl, E. Steffens, *University of Erlangen-Nürnberg*

Abstract

This report presents results of the feasibility study of the Erlangen synchrotron light source. ESSQ will cover – on a regional scale – the rapidly increasing need for high-quality synchrotron light in the hard X-rays as well as intermediate regime. The complex will be used for various practical applications of the synchrotron radiation (SR): in chemistry, biology, crystallography, material science. At the second stage it is assumed to set forth a concept of the Energy Recovery Linac (ERL) to achieve ultimate brilliance of the SR.

1 INTRODUCTION

By the proposal of the Synchrotron Study Group at the University of Erlangen-Nuernberg the possibility of a modern 3rd generation light source at Erlangen has considered. An evolutional design concept permits in the second step an upgrade to a 4th generation Energy Recovery Linac (ERL) light source with improved brilliance, time resolution and beam coherence.

Basic complex includes 3.5 GeV electron storage ring, a synchrotron on a full energy and injector linac of about 250 MeV. The synchrotron will provide almost continuous beam injection up to the top storage ring energy (top-up mode). Hence, the beam current in the storage ring will be stable with accuracy of about 1%.

2 LAYOUT OF THE FACILITY

The general layout of the accelerator complex in the race-track option is shown in the Fig. 1. It consists of the main storage ring with numerous beam lines from insertion devices, booster-synchrotron (in purple) placed inward to the storage ring, linac and injection channels (in green). The storage ring as well as the synchrotron has a race-track shape: two arcs and two long (about 34 m) drifts. This allows one to place in one of these drifts a long sectioned undulator, and also house the injection in the second drift. The perimeter of the main ring is 459.2 m.

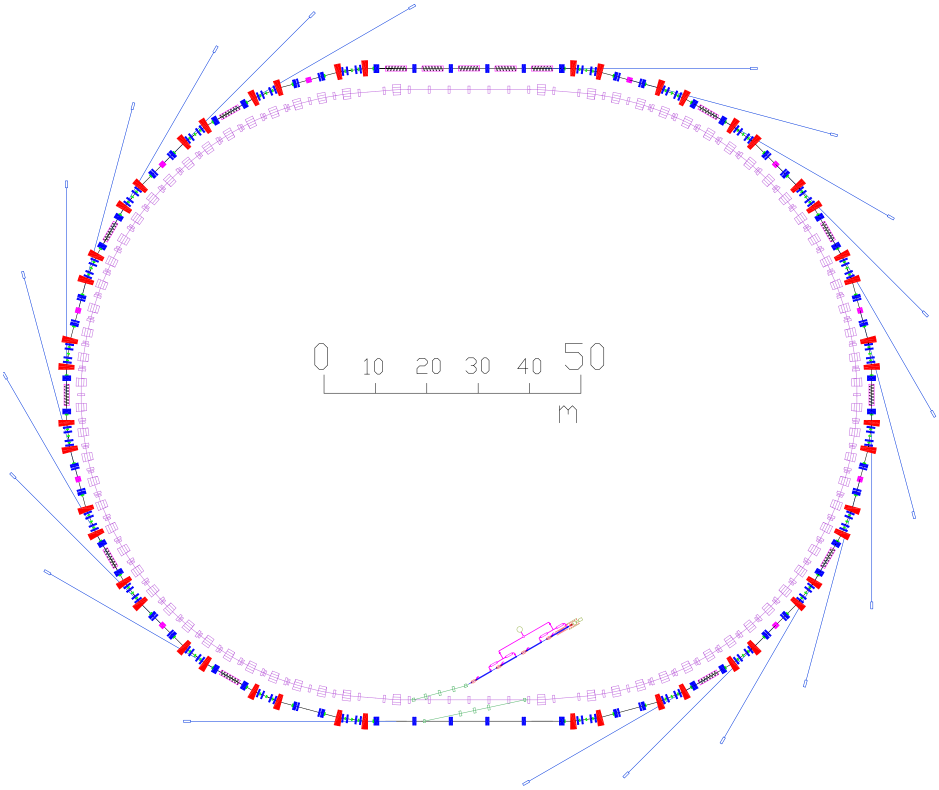

Figure 1: ESSQ layout (Phase I).

3 MACHINE AND BEAM PARAMETERS

A list of the main machine parameters with damping wigglers are on and off at 3.5 GeV is presented in the Table 1.

Table 1: General parameters of ESSQ
(in the race-track option)

Parameter	wigglers off	wigglers on	units
Circumference, C	452.15		m
Betatron tunes, $\nu_{x,y}$	39.84 10.77		
Energy, E	3.5		GeV
Momentum compaction factor, α	$5.6 \cdot 10^{-4}$		
Damping times, $\tau_{x,y,s}$	10.84 10.877 5.435	4.46 4.47 2.25	ms ms ms
Arc radius, ρ_{arc}	57.32		m
Bending radii, $\rho_{1,2}$	23.35 7.78		m
Bending field, $B_{1,2}$	0.5 1.5		T T
Horizontal beam emittance, ε_x	1.643	0.84	nm·rad
Momentum spread, $\sigma_{\Delta E}$	$8.3 \cdot 10^{-4}$	$1.63 \cdot 10^{-3}$	
Energy losses/turn, ΔE	0.767	1.86	MeV
RF frequency, f_{RF}	500		MHz
RF harmonic number, q	600		
RF voltage, V_{RF}	1.1	2.5	MV
Synchrotron tune, ν_s	$4.3 \cdot 10^{-3}$	$6.5 \cdot 10^{-3}$	
Bunch length, σ_l	0.8	1.08	cm
Beam current, I_b	200		mA
Total SR power, W	1.53	373	kW

4 INSERTION DEVICES AND PARAMETERS OF THE SYNCHROTRON RADIATION

There are several options for SR users in this machine.

First is radiation from bending magnets. Also in the short and long drifts of the achromat wigglers and undulators are planned to be installed. And there is a special long straight for placing a much longer undulator.

One of the long straights is planned to be used for installation of an extremely long undulator, which is composed from several short sections of about 4–5 m long. Between undulator sections doublets are placed forming the unity matrix for both betatron planes.

The second long drift will be used for housing the RF system and for injection purposes.

We have considered the SR spectra from possible insertion devices: wigglers and undulators. These devices consist of many poles with alternating polarity, so the beam trajectory inside such a device is a wavy line. The main difference between wiggler and undulator is in the value of parameter K:

$$K = \gamma\Theta,$$

where Θ is the maximum trajectory angle during the passage through an insertion device, γ is a relativistic factor.

Figure 2 shows the photon flux from a wiggler and Fig.3 presents the brilliance of an undulator. The term brilliance means the photon flux in a unit phase space. All the spectra were computed with the XOP code [5].

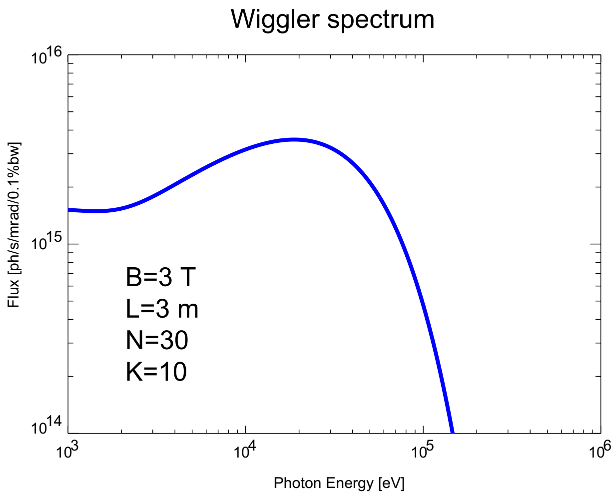

Figure 2: The photon flux from a wiggler depending on emitted photons energy in photons/s/0.1% band width/mrad, $I_b = 1$ mA.

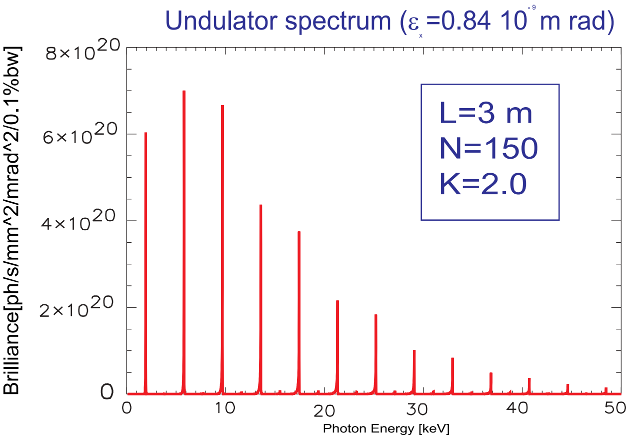

Figure 3: Brilliance of an undulator.

5 ERL-CONCEPT FOR ESSQ

The idea of recycling beam energy via the use of superconducting linac was proposed first in 1965 by Tigner [6] for colliders. To implement Energy Recovery Linac (ERL) or originally MARS (Multiturn Accelerator-Recuperator Source) concept for generation of synchrotron radiation beams was proposed in 1997 by G.N.Kulipanov, A.N.Skrinsky and N.A.Vinokurov [7] and later several other proposals were published [9, 10, 11].

The main advantage of the ERL approach is the possibility of achieving an extremely small 6-dimensional bunch emittance. This opens, in principle, the way for generation of high-brilliance photon beams using very long undulators, which should be installed on the arc before the electron beam returns for recuperation.

Let us remind the main ESSQ beam parameters in the storage mode: the energy $E = 3.5\ GeV$ ($\gamma \simeq 7000$), average beam current $I = 200\ mA$, rms energy spread

$\sigma_\delta = 0.001$; rms bunch length $\sigma_s = 6.7\ mm$; geometrical emittances $\varepsilon_x = 7.2\ nm \cdot rad,\ \ \varepsilon_y \leq 0.05\ nm \cdot rad$.

This means, that a normalized horizontal ESSQ emittance in the storage mode is equal to: $\varepsilon_n \equiv \gamma\varepsilon_x \simeq 50$ mm·mrad.

This quantity is about 50 times as large as that cited in many proposals, such as TESLA FEL at DESY [8], ERL project at Cornell [10] or at Berkeley [11]. So, implementation of the ERL concept in the ESSQ design may give a substantial improvement of the beam quality for purposes of generation of the synchrotron radiation.

For comparision with a regular synchrotron light source (see Fig. 3) Fig. 4 presents the spectrum from a specialized undulator for the beam parameters discussed above.

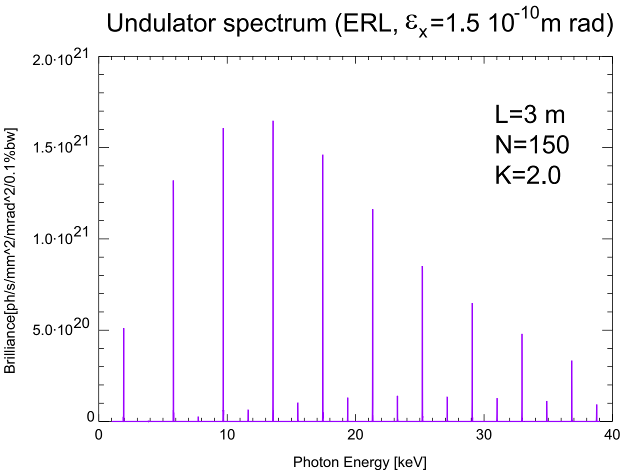

Figure 4: The brilliance of an undulator in ERL concept conditions.

6 CONCLUSION

To achieve 10 or 100 mA of average current seems to be possible only by using a DC, laser-driven photoemission gun. Only a DC gun can operate at extremely high repetition frequency. However an RF photo-gun, operated with the normal-conducting cavity may provide a lower longitudinal emittance [11].

We did not find any killing argument against the use of ERL concept, but many technical problems look very challenging. For instance, it is not completely clear whether it is possible to operate with such a high density of the heat load at $2\ ^\circ K$, of about 50 W/m. Also nobody has ever accelerated such a high average current and the problem of Beam Break-up instability remains unresolved.

7 REFERENCES

[1] A. A. Sokolov and I. M. Ternov, *Sov. Phys. Doklady*, **8**, 1203 (1964).

[2] R. P. Walker, ”Synchrotron Radiation”, *in Proc. of 5th General Accelerator Physics Course, CERN 94-01*, 437 (1994).

[3] J.S. Bell, “Hamiltonian mechanics”, in Proc. of CERN Accelerator School, Oxford, England (1985), p.37

[4] H. Grote, F.C. Iselin, “The MAD Program (Metodical Accelerator Design) Version 8.19, User’s Reference Manual”, CERN/SL/90-13 (AP)

[5] XOP — X-ray oriented programs, http://www.esrf.fr/computing/scientific/xop

[6] M.Tigner, *Nuovo Cimento* **37**, p.1228-31(1965).

[7] G.N.Kulipanov, A.N.Skrinsky and N.A.Vinokurov ”MARS - a Project of the Diffraction-Limited Fourth Generation X-ray Source Based on Supermicrotron”, *Proc. of SRI-2000*. See also: G.N.Kulipanov *et al.*, J.of Synchrotron Radiation v.5 pt.3(1998)p.176; G.N.Kulipanov *et al.*, Preprint INP 97-103, Novosibirsk, 1997.

[8] TESLA Technical Design Report, DESY 2001-011, March 2001.

[9] G.R.Neil *et al.*,NIM A445, p.192-196 (2000).

[10] I.V.Bazarov *et al.*, ”The energy recovery linac (ERL) as a driver for X-ray producing insertion devices”, *Proc. of APAC-2001*

[11] J.Corlett *et al.* ”A dedicated Synchrotron light source for ultrafast X-ray science”, *Proc. of SRI-2000*.

[12] H.Bruck ”Theory of cyclic accelerators”.

[13] V.V.Anashin *et al.* ”Damping ring for electrons positrons BEP”, BINP preprint 84-114 (1984).