# SYNCHROTRON RADIATION SOURCES IN THE SOVIET UNION

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Synchrotron radiation (SR) is now recognized to be an important instrument for experimental work in many fields of science. Recently the application of SR in medicine and industry, especially as a light source for microelectronics production have been demonstrated. Thus the development of SR sources has now grown to become a significant and independent dimension for accelerator research and technology.

In the Soviet Union SR work began with the pioneering studies by I.Pomeranchuk, D.Ivanenko and L.Artzimovich, who in 1944 recognized the importance of radiation losses for electron accelerators. After an extensive period of theoretical and experimental research on SR (see for a recent summary [1]) it was finally understood that SR with its unique properties may find applications as a novel source of light.

Work with SR began on a number of electron synchrotrons, that were all initially built for high energy physics. (Table 1).

Research with SR is still going on on these rather old machines, although they do not offer the possibilities that may be found on storage rings [2,3,4]

For studies of electron storage rings a small weak focussing ring H-100, now operating at 160 MeV was built in Kharkov. This ring is still in operation and has shown to accumulate rather high currents (up to 3 A) injected from a linear accelerator. It is used both for SR studies and as a SR source. An important contribution in the development of modern SR sources came from the Institute for Nuclear Physics in Novosibirsk. In the laboratory founded by A.M.Budker a systematic effort to develop electron-positron colliding beam experiments was made. As a result of this effort 3 $e^+e^-$ VEPP storage rings have been built (Table 2) [3,4].

These rings are now used both for elementary particle physics and for a very extensive programme of research and applications of SR. Thus the Novosibirsk SR laboratories have become the main center for such studies in the Soviet Union with many research groups from other countries cooperating [3].

In the VEPP storage rings SR is generated in the bending magnets and insertion devices - wigglers and undulators. One should bear in mind that the spectrun and power of undulator radiation is not what one should mean by SR, but here we will use the general term SR to designate all radiation from these machines and devices. In the VEPP-2M storage ring SR beam lines are directly coupled to the vacuum chamber of the ring with differential pumping used when necessary. At present 6 beam lines and 10 experimental stations are operating. In the larger VEPP-3 and VEPP-4 rings the SR radiation is brought out through berillium windows.

At Novosibirsk an extensive programme for the development of insertion devices has been carried out with many original contribution to their credit. The use of $SmCo_5$ permanent magnets was first explored for building undulators, where the magnetic fields were determined and adjusted by steel poles placed between the $SmCo_5$ blocks. Of special interest is the technology developed for superconducting insertion devices. Here both exceptionally high fields up to 7.5 T in superconducting wigglers [5] and efficient spiral undulators have been built [6] (Table 3). The development of insertion devices that are now placed on all rings has definitely shown the advantage of generating SR in them rather than using SR proper from the dipole bending magnets.

Research on insertion devices has also been done at the C-25P synchrotron, where some novel configurations of coils and permanent magnets for producing circularly polarized radiation have been suggested [7].

The expertise gained in building the VEPP rings has been essential for the design and construction of the first dedicated SR sources (Table 4). The SIBIR-1 storage ring was built by the Novosibirsk group for the I.V.Kurchatov Institute for Atomic Energy in Moscow [8-10]. This ring was completed in 1983, and early in 1984 it reached its design parameters. Electrons are injected from a 60 MeV linac; in the future a microtron injector may be used. In this compact weak focussing ring with rather short straight sections a superconducting 4 T wiggler is inserted that radiates at = 23Å. The ring is operating systematically with 3 of the 16 beam lines in use.

Next to be built is the SIBIR-2 storage ring. This strong focussing ring is designed with an asymmetric lattice with 12 superperiods and long straight sections for insertion devices. Focussing is designed for high luminosity and 3 undulators up to 3 m long and 3 wigglers are to be installed. It has been suggested to use stepped field in the bending magnets to generate SR from different magnetic fields so as to have a variety of SR spectra at the same beam energy (2.5 GeV), although it now seems that this concept may be finally dropped in favour of insertion devices.

With the future development of the VEPP-4 storage ring where the beam energy is to be increased up to 6 or 7 GeV with superconducting wigglers and undulators SR up to energies of 1 MeV may be finally generated. In this case the Novosibirsk group will have SR from a great variety of sources and it will be thus equipped for most uses in the foreseeable future.

An intermediately sized dedicated storage ring ERSINE 16 has been designed at the Erevan Physical Institute (Table 4). Injection is to be from a separate 1 GeV synchrotron, rather than from the ARUS synchrotron. This storage ring will extensively use insertion devices and SR form the bending magnets. In this report we have not, due to lack of space, considered the H.F. accelerating structure and the possibility to modify the time structure of the beam by choosing the number of bunches to be stored.

For calibrating photon detectors and generating short pulses of light a compact high field SR source TROLL has been built at the All-Union Institute for optical and physical measurements in Moscow (SR-86). With a pulsed 10 T weak focussing field the device stores $10^{10}$ electrons and accelerates them to 50 MrV on a R = 1.7 cm orbit radiating SR with $\lambda$ = 1000 Å in pulses 5 $\mu$ sec long once a minite.

It has always been of interest to generate coherent radiation from electrons scattered by a magnetic field. For this purpose the free electron laser (FEL) was invented by Madey in 1971. In fact a FEL with non-relativistic electrons - the orotron was invented by G.Bogo-



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molov and F.Rusin and developed at our laboratory in 1967 [12]. In this device a beam of 10÷20 KeV electrons interacts with a grating placed in an open resonator. The orotron efficiently generates a very monochromatic radiation down to submm wave lengths and is tunable over 1:2 frequency range. Later this device was developed at Kharkov. The optical klystron for the FEL was proposed by A.N.Skrinsky and N.A.Vinokurov [11] and first installed on the VEPP-3 storage ring operating at 350 MeV. This FEL experiment demonstrated amplification of light at 5000 Å and now after redesigning the undulator and the optical cavity FEL operation is to be expected. In future one may expect that much effort will be directed to operate FEL's in conjunction with storage rings for producing short wave SR.

This report does not cover Soviet FEL work but some research pertaining to the development of coherent SR sources should be mentioned. A number of groups have used microtrons for experimenting with FELs. At Tomsk a 6 MeV microtron for this purpose is reported in SR-84. A 30 MeV race track microtron at the Lebedev Physical Institute is being developed for undulator radiation studies [15]. Finally a 15÷20 MeV microtron is in use at our laboratory for such work. It can be shown that the microtron is best compatible with a FEL radiating in the far IR and submm part of the spectrum. Feasibility studies of a CW microtron or a microtron working in long pulses also indicate their promise for conceptual IR FEL's [14]. One may think that in the future the microtron may prove to be of interest for the FEL and we can hope that the results of other groups using the microtron (e.g. Frascati, Italy and Bell Lab's in USA) to substantiate this attitude. On the other hand, a focussing open resonator with the shape of an evolvent has been suggested to excite coherent SR over a substantial part of a circular orbit [13].

One may expect that in the future we should foresee the development of a coherent light sources based on the FEL concept or using a FEL. At present research on the basic physics for such devices is being done, work that should lead to novel and powerful sources of coherent radiation. SR and allied phenomena are really the most efficient ways for generating light. With the advent of coherent SR this efficiency is to be even greater for all the power will be further concentrated not only in the spacial, but also in the temporal, or rather the spectral dimension. Thus we will arrive at the ultimate tunable and monochromatic light source, both efficient and powerful. We can only hope that this remarkable device will be used to illuminate and study, rather than to destroy our future world.

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In reporting progress on SR sources extensive use has been made of results obtained by many groups of scientists. Most of this work since 1975 has been regularly presented at our National SR conferences (SR-75, SR-77, SR-78, SR-80, SR-82, SR-84 and SR-86) [2]. The papers presented at the last conference are to be published in a special issue of "Nuclear Instruments and Methods" due to appear in Summer 1987. Papers from other SR conferences have appeared in the Proceedings of these conferences published in cooperation with the Synchrotron Radiation Committee of the Academy of Sciences. To Dr. G.N.Kulipanov and Dr. E.L.Kosarev of this Committee the author expresses his thanks for cooperation.

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Table 1

Electron synchrotrons as SR sources

| Accelerator | Energy GeV | Radius M | Pulsed current MA | $\lambda_c$ A | Beam X section MM$^2$ | Pulse HZ | SR ports |
|---|---|---|---|---|---|---|---|
| C-60 \|1\|,\|2\| Moscow | 0.68 | 1.98 | 100 | 40 | 2x0.5 | 1 | 2 |
| C-25P \|1\| Pakhra | 1.30 | 4.0 | 100 | 10 | 5x1 | 50 | 2 |
| Sirius \|1\| Tomsk | 1.38 | 4.23 | 80 | 11 | 10x2 | 10 | 2 |
| ARUS \|3\| Erevan | 4.5 | 25 | 10 | 1.54 | 15x5 | 50 | 3 |

Notes: |1| weak focussing synchrotron
|2| long pulse operation
|3| strong focussing synchrotron

Table 2

Storage rings as SR sources

| Storage ring | Energy GeV | Circumfe-rence M | Current MA | $\lambda_c$ A | Emittance nm x rad | SR ports | Notes |
|---|---|---|---|---|---|---|---|
| H-100 | 0.160 | 4 | 3000 | 2300 | | 2 | Linear accelerator injection |
| VEPP-2M | 0.7 | 10 | 200 | 23 | 175 | 4 | |
| VEPP-3 | 2 | 50 | 100 | 3 | 150 | 3 | |
| VEPP-4 | 5 | 120 | 40 | 0.5 | 240 | 3 | VEPP-3 as injector |

Table 3

Wigglers and undulators

| Storage ring | Energy GeV | $\lambda_c$ Å | Magnetic Field T | Period cm | N | Length M |
|---|---|---|---|---|---|---|
| VEPP-2M [1] | 0.7 | 63 | 0.45 | 1.25 | 20 | 0.25 |
| VEPP-2M [2] | 0.7 | 5 | 7.8 | 10 | 6 | 0.7 |
| VEPP-3 [2] | 2.1 | 1.3 | 3.3 | 4.5 | 20 | 0.3 |
| VEPP-3 [3] | 0.35 | 5000 | 0.6 | 3.45 | 22 x 2 | 1.6 |
| VEPP-4 [4] | 5.3 | 0.8 | 0.8 | 27 | 9 | 2.4 |
| VEPP-4 [5] | 5.5 | 0.46 | 1.8 | - | 1+9+1 | 2.0 |
| Sibiria 1 [2] | 0.45 | 23 A | 4.3 | - | 1+1+1 | 0.3 |

Notes: [1] Superconducting spiral undulator
[2] Superconducting wiggler
[3] $SmCo_5$ optical klystron undulator
[4] Damping magnet
[5] Wiggler

Table 4

Dedicated SR sources

| Storage ring | Energy GeV | Circum-ference | Current MA | $\lambda_c$ Å | Emittance nm x rad | Injector | N ports |
|---|---|---|---|---|---|---|---|
| Siberia-1 Moscow [1] | 0.45 | 8.7 | 100 | 61-23 | 230 | Linac 60 MeV | 6 |
| Siberia-2 Moscow [2] | 2.5 | 116 | (100) | 3-1 | 80 | Siberia-1 storage ring | 12 |
| Ersine [3] Erevan | 1.8 | 61 | (100) | 5-3 | 110 | Sinchro-tron 0.5 GeV | 10 |
| HP-2000 [3] Kharkov | 2.0 | 80 | (1000) | 2 | (95) | Linac 1 GeV | 11 |

Notes: [1] Single superconducting wiggler
[2] 3 undulatores and 3 wigglers
[3] Design study