Summary Statement for the Shanghai Symposium on Intermediate-Energy Light Sources

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Abstract

The *Shanghai Symposium on Intermediate-Energy Light Sources* (SSILS) was held over a three-day period September 21-24, 2001. Participants from over 29 laboratories in 17 countries/regions represented a broad range of interests ranging from storage ring design to advanced synchrotron radiation science. Plans for approximately 10 new 'intermediate-energy' light sources were presented in a variety of construction and planning phases. Parallel focus groups concentrated on ID design, beam line component design, radio-frequency acceleration systems, vacuum chambers, beam stability and feedback. Two of the main goals of the Symposium were to share innovative technology concepts emerging at different laboratories and to provide a forum for communication between accelerator and beam line scientists. In this respect, the SSILS was extremely successful as witnessed by the on-going discussion on where and when to hold the next meeting! Based on topics discussed at the SSILS, we attempt in the following paragraphs to highlight both conventional and emerging technologies that can be incorporated into new and existing storage ring light source facilities.

1 General Remarks

Surprisingly, if one steps-back and takes a broad look across the spectrum of scientific disciplines in existence today, a case can be made for the statement "Science without Synchrotron Light is Impossible!" However debatable, the recent passing of Roentgen's centennial discovery of X-rays coupled with the explosive growth of synchrotron light sources gives credence to this bold statement. One of the prime motivating forces behind the rash of proposals for intermediate-energy light sources is *protein crystallography*. This fast-growing branch of the biological sciences is driving not only retro-fit construction on low- and high-energy storage rings, but guiding design of new light sources into a high-current, ~3 GeV beam energy regime in order to reach the coveted 10 keV photon energy range.

Based on a survey of experience from different laboratories, one concludes that at least four to five years are needed to construct a new synchrotron light source. A range of different approaches to build such machines extends from the simple, less expensive approach to the more comprehensive design. Depending on technical and financial resources, different laboratories are pursuing both concepts. The fast-pace machine requires at least one-year of design, one year of engineering, one year to order parts and construct prototypes and one year for assembly. To accomplish this feat, each phase must be carefully coordinated with all others. Such a machine has yet to be realized in practice. More realistically, the process is far more complicated: International communication and collaborations are very important for constructing a new synchrotron light source.

The basic design and technology related to the storage ring and beam line components are well understood with large equipment and many specialized elements available from industry. The Canadian Light Source, Swiss Light Source and European Synchrotron Radiation Facility are good examples of collaborating with industry. Nevertheless, difficult engineering challenges still remain if one is to achieve very stable mechanical and electrical components, ultra-high vacuum systems and high-power, low-distortion photon beam transport systems. New ideas and technologies are steadily emerging from the design phase into real-use, and development is continuing at a fast pace. Two prime examples are superconducting rf technology and the in-vacuum undulator.

All told, the complexity of a modern light source should not be under estimated. System integration is at the center of any new light source design, particularly for compact high-power machines. Early in the light source design phase the coupling between photon beam properties and the experimental program should be carefully considered - at times brightness, flux density and total flux are not the correct metrics. Instead some experiments are more interested in matching phase-space of the photon beam to phase-space acceptance of the sample.

2 Facility Overview

115 participants attended the SSILS from 29 synchrotron radiation laboratories in 17 countries/regions. Approximately 18 facility reports were delivered covering a range of low-, high- and intermediate-energy machines in various phases of planning, construction or operation.

Table 1 gives a list of storage ring parameters for ILS machines that are either proposed or under construction. From the Table, several interesting trends emerge. First, based on many careful studies and requests from the user community, it is clear that operation in the 2.5-3.5 GeV energy range will satisfy many user needs in the near future. Construction of a machine at significantly lower energy requires high magnetic field devices but does not realize sizeable savings in construction or operational costs. Operation at higher energies (> 3.5 GeV) hardens the photon beam spectrum but can increase operational costs (e.g. P_{rf}~E^4) and create complications with photon beam power without significant improvement in beam quality. In order to enhance radiation output, the circulating current of a typical ILS machine is of the order 300-500 mA. Although high current yields more flux, it can present significant power-loading and vacuum control challenges, particularly for small radius storage rings. Another trend is toward DBA lattices with straight-section lengths on the order of ~5 m and longer straights for more specialized applications. In some cases, alternating β-functions are used to produce smaller spot sizes. The horizontal emittance tends to be in the range of 10 nm-rad while machines featuring fewer cells generate emittances on the order of 50 nm-rad. The larger, more aggressive machines tend to push the envelop on a number of machine parameters (circumference, number of cells, emittance, length of straights, small beam cross-section) while the more modest machines still produce very intense photon beams covering the 10 keV energy range for less cost. 500 MHz RF systems are clearly in the majority.

Table 1 List of storage ring parameters for machines that are either proposed or under construction.

Name	E (GeV)	I (Amp)	ε_{x0} (nm·rad)	Tunes Q_x/Q_y	f_{RF} (MHz)	Lattice	Straights	Circum. (m)
BOOMERANG	3.0	200	11.5*	11.11/4.18	499.65	DBA	12	184.07
CANDLE	3.0	350	8.4*	13.22/4.26	499.65	DBA	16	216
CLS	2.9	500	18.1*	10.22/3.26	500	DBA	12	170.88
DIAMOND	3.0	300	2.0*	29.16/11.35	500	DBA	24	560.4
INDUS-II	2.5	300	58.1	9.2/5.2	505.81	DBA	8	172.47
MOSLA	2.0	300	54	7.1/3.15	500	DBA	8	119.88
SOLEIL	2.5	500	3.1*	18.28/10.26	352.20	DBA	24	354.10
SPEAR3	3.0	500	18	14.19/5.23	476.3	DBA	18	240
SSRF	3.5	300	4.8*-11.8	22.19/8.23	499.65	DBA	20	396
Super SOR	1.6		5.62*	14.26/12.19	500.09		12	249.39
TLS-II	3.0	400	9.8*-28.3	12.2/5.2	500	DBA	16	240

*Natural emittance of dispersion-distributed mode

3 New Technologies

New and emerging technologies were primary topics at SSILS. For the storage ring, a series of 'conventional' technologies can be utilized such as harmonic sextupoles to enhance dynamic aperture. Enlarging the accelerator circumference or permitting finite dispersion in the ID straights achieves emittance reduction. Innovative ideas for the use of straight sections include (1) two ID's separated by a chicane in a single straight section, (2) short ID's in the interior of the magnet cell and (3) a chicane in straight section to separate ID radiation from dipole radiation. All of these options fold into machine design issues concerning number of straights, length of straights and electron beam size in the straights.

The field of insertion device design has reached a high level of maturity. Examples include in-vacuum, mini-gap undulators with total length less than 1 m to almost 30 m. These devices appear to be the wave of the future for applications that require more periods in a fixed space and/or to boost photon beam energy. Elliptical and variable polarized undulators are also a well-established means for applications such as dichroism studies. EPU's and APU's are now available for users at many light source facilities. Fast-switched polarization systems remain an active area of research. To boost photon beam energy from lower energy light sources, superconducting wavelength shifters, super-bend dipole magnets and superconducting wiggler magnets are available. The infrared user community is also expanding. Some of the unique requirements of an infrared beam line are large vertical aperture in the vacuum chamber to pass the photon beam and very tight restrictions on the maximum level of synchrotron oscillations. Bunch 'slicing' has been demonstrated to achieve femtosecond X-ray duration.

New technologies that directly impact machine operation include top-up injection (APS/SLS) and dynamic beam-based alignment (ESRF/SLS). Top-up injection has many benefits including constant power levels on sensitive beam line optics, constant photon flux on the user sample and the option to use small gap devices that would otherwise limit electron beam lifetime. Many modern machines, in fact, observe non-linear coupling effects that result in Touschek-excited electrons lost to small-gap ID chambers. Full-energy injectors are now commercially available and recommended where possible. In the extreme case, top-up morphs into the high-brightness electron recirculating linac. Dynamic beam-based alignment systems typically utilize hydrostatic leveling systems and field modulation to steer the electron beam through the center of quadrupoles. A system designed to monitor horizontal BPM motion is in operation at the SLS. This system and other innovative techniques can be used to remove the effects of physical BPM motion from the orbit monitoring system.

Beam stability is always at the forefront of machine development programs. The conventional figure suggests that the closed orbit must be stable to ~10% of the electron beam size is being modified with new requirements in the sub-micron range. Although fast feedback systems can maintain orbit stability in the ~0.1 Hz-200 Hz range, the remaining challenge is to stabilize the beam for periods of hours, days and weeks. By including X-ray BPMs in the orbit feedback, the distinction between 'local' and 'global' orbit feedback is merged into 'unified' feedback. To maintain electron beam size stability to the order of <0.01% requires power supply stability on the order of $<10^{-5}$ and precision compensation for variable-field ID magnets. Requirements for the stability of beam energy can be as low as $5x10^{-6}$. Tight control of temperature in the storage ring tunnel, on the experimental floor and temperature differential between the two regions has become essential for photon beam stability. Girder vibrations induced by ambient ground motion and resonances driven by reciprocating equipment must be maintained at minimum levels. Several machines require orbit and/or bunch-by-bunch feedback systems to satisfy user needs. Turn-by-turn bunch monitoring systems yield a wealth of information for the accelerator physicist.

Innovations in storage ring technology can be identified for almost all systems. Here we list a few in common use today:

- Magnets
  - Combined-function for compact lattice design
  - Superconducting
  - Permanent
- Power Supplies
  - Switch mode
  - Very low noise
  - Modern pulsed-power methods
  - Wide-band feedback
- RF
  - Superconducting
  - Mode-damped
  - Feedback systems
  - Harmonic cavities
  - Phase modulation
- Control Systems
  - Multi-lab collaborations
  - Commercial software
  - File handling protocols
  - Fast Networks
- Insertion Devices
  - Superconducting
  - Polarized
  - Switched
  - Mini-gap
  - In-vacuum
  - Pole shimming
  - Laser-aided bunch slicing
- Vacuum System
  - Deep-drawn and machine/weld fabrication
  - GlidCop radiation shields
  - High power crotch masks
  - B-factory grade bellows
  - Inserts for fast corrector field penetration
  - TSP, NEG pumps
- Mechanical
  - Stable girder designs
  - Vibration damping techniques
  - Tunnel temperature control
  - BPM stabilization methods
  - Magnet-on-girder assembly
- Feedback
  - Electron beam orbit
  - Bunch-by-bunch (transverse, longitudinal)
  - RF system
  - Photon beam line
- Diagnostics
  - Turn-by-turn measurements
  - Model fitting
  - Photon beam profiles
  - Orbit feedback data
- Beamlines
  - High power optics
  - LN monochrometers
  - Automated sample handling
  - Mirror pitch feedback
  - Mini-hutch
  - Long-trace profiler

4 Summary and Future Prospects

In closing, the program committee would like to thank the participants in the *Shanghai Symposium on Intermediate-Energy Light Sources* for their enthusiastic participation. It is our hope that you were able to share in the wealth of innovative design concepts emerging from different laboratories and to meet and exchange ideas with scientists in the growing field of accelerator and beam line technology.

What does the future hold in store? In the past 20 years storage ring light sources have sprung up like mushrooms. On the near horizon of the next 10-years, one can anticipate more storage rings in the intermediate-energy range for light source applications. It is difficult to foresee the scientific impact of the explosion in high-throughput protein crystallography beam lines. Beyond the near horizon lies the potential for additional high-energy machines or more aggressive projects such as the high-brightness electron-recirculating linac (ERL) or the ‘ultimate’ low emittance storage ring light source. Parallel developments in the FEL community indicate the extremely bright 1-Angstrom laser is nearing reality. Given these developments, the future is bright for the synchrotron radiation community - it makes us more than happy to have friends from afar.