SUMMARY WORKING GROUP 1: STORAGE RING SOURCES

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Abstract

The topics of discussion in the Storage Ring Radiation Sources Working Group are presented. The questions addressed to the participants are the following: What ring parameters may lead to new science? Can we go beyond the present state of the art sources? What critical accelerator technologies require development? Upgrade of existing sources: what is feasible? Is it worth building cost-effective but lower performing rings? Should we build multipurpose or specialised sources?

INTRODUCTION

The Working Group on storage ring radiation sources started with a brief review of the present state of third generation facilities. Today, there are twelve facilities in operation with energies ranging from 1.5 to 8 GeV and three are in the commissioning phase (Fig. 1). About ten rings are in construction or being proposed. These machines cover the ultraviolet, soft X-ray and hard X-ray domains (Fig. 2). Thanks to the development of Insertion Device technology, intermediate energy (2.5 to 4 GeV) machines access hard X-ray science and there is a trend towards the construction of machines in that energy range.

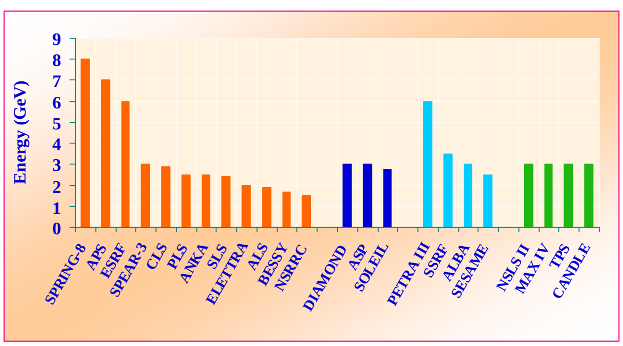

Fig. 1: Storage ring synchrotron radiation sources. Grouped from left to right are: operational, commissioning, construction, and new projects.

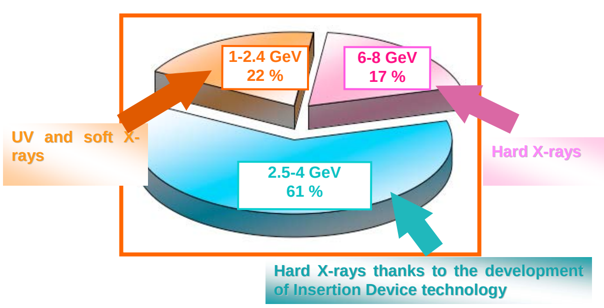

Fig. 2: Distribution of storage ring sources.

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WHAT RING PARAMETERS MAY LEAD TO NEW SCIENCE?

There are a number of relevant figures of merit: increased current for more flux, lower horizontal emittance for more coherence, short pulses for time-structure experiments, photon energy to be tailored by the use of specialised insertion devices.

The definition of a figure of merit is strongly facility dependent. Providing filling pattern options (multibunch with and without gap or with an isolated camshaft bunch, single bunch, few bunches equally spaced) and short pulses with excellent bunch purity for those having a strong time-structure user community (which could use 5 to 33% of total beam time) has a strong priority. The challenge is to satisfy them and flux users simultaneously. One possible idea proposed at ALS consists in kicking one bunch on a different vertical closed orbit in order to obtain a pseudo single bunch operation by spatially separating the light from this bunch from the main bunch train in the beamline (Fig. 3) [1].

For a large number of beamlines, flux is the important figure of merit. There is not a strong demand for beam current increase but when the users get more current, they don't want to step back (ESRF: 100 to 200 mA [2], Taiwan upgrade from 200 to 300 mA [3]). On the machine side, there might be some obstacles for increasing the current: cost issues at CLS, effects of the 7 T wiggler at BESSY, instabilities issues specially for the low energy machines, heat load for optics which is worse for low energy machines operating at high harmonics.

There is a demand for low emittance, depending on the facility. New facilities (PETRA3, NSLS II) are pushing for 1 nm emittances for nanoscience [4]. For machines already in operation (ESRF, APS), scenarios for replacing the lattice by new lattices with smaller emittances and longer straights are being investigated [2].

A general consensus came out from the discussion: retaining the high stability of the photon beam has the highest priority for users. Topping-up is therefore much welcome by users since this technique minimises heat-load variation on beamline components; this operating mode concerns 75% of beamtime at APS, 100% at NSRRC for instance. When used, the gating signal provided to users hides the perturbation induced by the injection kickers.

In general, there is a good synergy between machine physicists and users at each facility.

CAN WE GO BEYOND STATE OF THE ART SOURCES?

There are a number of challenges to be answered:

- How small an emittance is achieved practically in a storage ring?

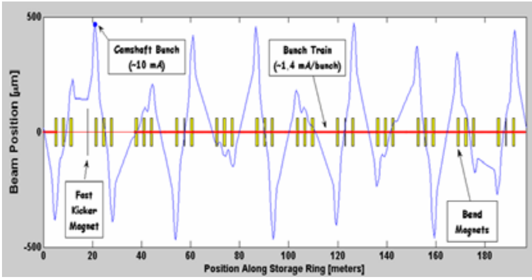

Fig. 3: Pseudo single bunch operating scheme [1].

- How short a pulse length and high a photon flux?
- What can be compromised?

The ways for achieving a lower emittance (typical value is 1 nm for a 3 GeV ring) were discussed. Damping wigglers are proposed for new sources (NSLS II or PETRA3 with up to a factor four in emittance reduction). The impact of these devices on the dynamic aperture looks acceptable (a 15 mm dynamic aperture is quoted for NSLS II whilst a 8 mm aperture is needed for injection) [4,5]. In addition, these damping wigglers may also be used as radiation sources. Storage ring lattices based on feasible bending magnets using a longitudinally varying field may also provide the same order of emittance reduction [6]. Such approach offers an attractive way of building compact low emittance lattices. However a number of issues – loss of flexibility, increased sensitivity to errors, small dynamic aperture – still need to be worked out for achieving realistic designs. Another approach is that of MAX-IV, which is based on small aperture combined function magnets and gives an emittance of 1.4 nm at 3 GeV. Some ideas are proposed to cope with the small dynamic aperture of these reduced emittance lattices which is the most critical at injection: on-axis injection with a very fast kicker, quadrupole kicker, etc. On-axis injection requires an injector with sufficient single-pulse charge – this is a challenge in the case of high single bunch current operating modes.

The question of flexibility (lattice, operating modes) was also raised. Working Group participants agreed on the need for lattice flexibility. There is a non-exhaustive list of possible applications of lattice flexibility: symmetrical compensation of ID effects, low alpha setting, girder distortions, customized beta function, perturbations, and chromaticity over-compensation. This required flexibility might be impacted by the use of gradient magnets.

Most intermediate energy machines under commissioning or construction aim at a beam current of the order of 500 mA [4,7]. As far as the maximum beam current is concerned, single bunch instabilities are the hardest to overcome. ID chamber impedance is the major contributor to transverse mode coupling instability (TMCI). Discrepancy between NSLS simulations, which give higher instability thresholds than experimental results at several facilities, needs to be understood [8]. Microwave instability is also an issue. The theory gives thresholds that are an order of magnitude higher than experiments. This needs to be understood in order to guide and possibly relax the longitudinal impedance budget. There are also possibly new collective effects, such as hollow beams at the Duke storage ring, that have been studied in some detail [9].

Achieving short pulses is of prime importance for storage ring based radiation sources. Although these machines naturally provide bunch lengths of several tens of picoseconds, several techniques aim at changing the time structure of electron bunches and at providing 1 ps bunches: reduction of the momentum compaction (low alpha operation at BESSY), laser-induced energy modulation (femtoslicing used at ALS and SLS), RF orbit deflection with using crab cavities (APS project). The low alpha operation is used at BESSY 2 weeks per year for THz radiation experiments and there is growing interest to increase this time. One constraint for low alpha operation is very low single bunch intensity (even more so in femtoslicing). At BESSY, using a 1.5 GHz harmonic cw superconducting (SC) cavity placed into one straight section and passively run, the RF gradient could be increased by a factor 20, thus generating sub ps bunches and a factor 1000 increase in THz power [10]. For the crab cavity scheme (Fig. 4), the APS study shows that 1 ps pulse could be obtained with a deflecting voltage of 6 MV at 2.8 GHz, with a throughput of between ~1% (slits) to ~30% (optical pulse compression) of the normal photon flux [11]. The design of the SC deflecting cavity addresses a number of fundamental issues (stringent rf error tolerances, cavity design, coupling, damping of lower and higher order modes, etc.) The correction of the vertical emittance blow-up induced by nonlinearities and uncompensated chromaticity is also a critical point, and has been addressed successfully using a sextupole compensation scheme. The steady-state CSR effect could also be an extremely powerful source in the THz frequency range, thus motivating the ALS proposal for optimizing the design of a storage ring as CSR source [12] or the Japanese project of an isochronous racetrack type beam transport preserving the short bunch length of a linac beam [13].

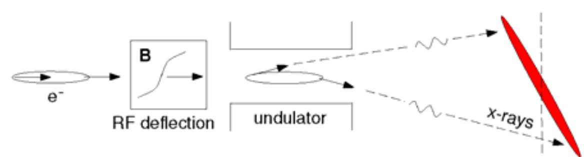

Fig. 4: The chirped pulse can be slitted or compressed [11].

WHAT ARE THE CRITICAL ACCELERATOR TECHNOLOGIES THAT REQUIRE R&D?

The design of cavities with strong damping of higher order modes is a critical item for enabling high beam currents to be stored without any degradation of beam quality induced by coupled bunch instabilities. There are two competing technologies for designing HOM damped cavities: SC versus room temperature technology [14,15].

Concepts of SC cavities for light sources have been developed (SOLEIL: 352 MHz and CESR-B: 500 MHz) and chosen by several new facilities. There is still little operating experience with SC cavities and present reliability figures (1 trip per week with a recovery time of 30 minutes reported by Taiwan [3]) will certainly improve in the future. SC cavities have benefits for high-energy light sources since they provide a high RF voltage per cavity and low power consumption but they are characterised by a high complexity and need a cryogenic system. Room temperature cavities that were developed for mesons factories (Daphne, KEK ARES, ATF, PEP-II) are not very well suited for light sources. But there are recent developments (BINP/Novosibirsk, EU design) that meet CBI thresholds requirements for light sources. These cavities imply simple technology and are cost effective (Fig. 5).

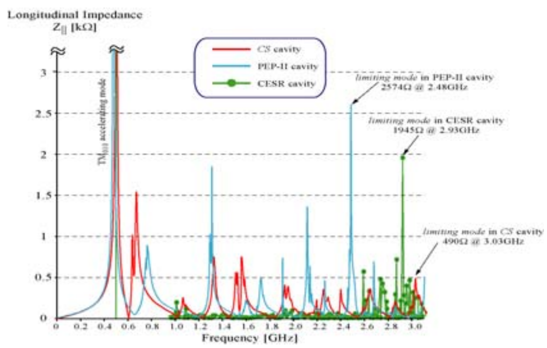

Fig. 5: Comparison of $Z_{||}$ for conventional NC cavity (PEP-II) with HOM-damped NC cavity (BESSY-CS) and SC cavity (CESR-B) [14].

Insertion device technology is now fully mature [16]. It can be noted that the quality of magnets has improved dramatically over years. The approach for building insertion devices is facility related: APS has an industrial-type experience of standard IDs, whilst ESRF is building a series of unique insertion devices. For the future, there is a trend towards the use of small period SC and in-vacuum undulator to reach higher photon energies. Shimming and magnetic measurements of these devices are challenging issues. This type of technology is relevant also for ILC. Evacuation of power from dipoles has also to be considered. There is a strong concern about radiation damage for intermediate and high-energy rings. Several facilities have reported on ID demagnetisation (APS, ESRF). 1500 h of beam is enough to bring a 3 % reduction in magnetic field. Damage is very localised, very likely due to a bad injection. The installation of scrapers for defining apertures is strongly advised.

In the area of theory, a statistical optics method has been developed for ID radiation source characterization in the soft x-ray wavelength regime [17]. Neither geometrical optics (hard x-rays) nor wave optics (VUV) can be used in this mid-wavelength regime.

UPGRADE OF EXISTING SOURCES: WHAT IS FEASIBLE?

The feasibility of proposed upgrades must take into account a number of boundary conditions: cost, limitations on the existing infrastructure, interferences with users. The most frequent proposals concern the replacement of the existing lattice by a new lattice for lowering the horizontal emittance (ESRF) [2], the construction of a new ring to overcome an oversubscribed usage (Taiwan), the installation of canted undulators (APS, SLS, ESRF), an increased beam stability (sub-micron range at Elettra), the use of topping-up, leaving enough room for future developments (ERL at NSLS II) [4]. Replacement ring designs are typically constrained to keep the circumference and radiation source points fixed.

IS IT WORTH BUILDING COST-EFFECTIVE BUT LOWER PERFORMING RINGS? SHOULD WE BUILD MULTI-PURPOSE OR SPECIALISED SOURCES?

Since storage rings started to be used for synchrotron radiation production in the 60's, the trend has always been to build state of the art facilities and to push ring performances to the limits, with consequently increasing costs. Is it time to step back? The idea of building low-cost, medium performance third generation rings was extensively discussed and several advantages were pointed out. Such a strategy could make the use of these sophisticated tools affordable for small institutions or countries [7]. These rings also could be used for preparing experiments before applying for beamtime in the oversubscribed facilities.

Building multipurpose versus specialised rings is also questionable. One could imagine the construction of a synchrotron radiation facility storing beam at any arbitrary energy between 1 and 10 GeV and generating multiple wavelength photons or neutrons (Fig. 6) [18]. Another approach is that of MAX-IV with the building of 2 superimposed rings to decouple the usage of VUV and UV radiation.

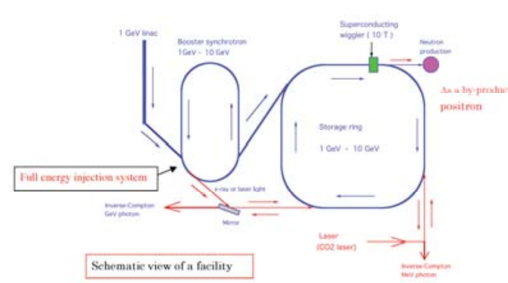

Fig. 6: Schematic of multiple-wavelength facility [18].

The involvement of industry in ring construction was also reviewed. As illustrated by some facilities (CLS, Australian Synchrotron Project (ASP)), the procurement of "turn-key" systems like linacs, boosters, RF systems could be a solution for coping with staffing issues. In this case, the staff can then focus on the more critical design issues relating to the storage ring.

Recently, there have been some ideas for building compact tabletop X-ray sources. There would probably be a market for such devices if they achieve their anticipated performances.

CONCLUSIONS

There was an active and fruitful participation in the Working Group. As compared to the start-up of the first third generation light sources in the 90's where the achievement of design performances was most questionable, ring technology can now be considered as mature. The experience gained from existing facilities benefits new sources. Innovations are continuing: new lattice concepts for reducing the emittance, RF technology, combined-function magnets, improved beam position stability, sophisticated insertion devices. At each facility, the local user community drives upgrades. Despite the advent of SASE FELs and ERLs, breakthroughs in key areas of science and technology still depend on the existence of high performance storage rings. There is no sign of saturation in beamtime subscription by users or construction of new facilities all around the world.

ACKNOWLEDGEMENTS

The authors thank all the participants of Working Group 1 for their contributions and regret any omissions.

REFERENCES

The following is a complete list of speakers and titles of presentations in WG1, including spontaneous contributions and those made on request, both published and unpublished. These are listed in the order of reference in the text.

[1] D. Robin (LBNL) - A novel injection scheme

[2] A. Ropert (ESRF) - Future possibilities at the ESRF

[3] G. Luo and P. Chou (NSRRC) - Operation experience with SRF at NSRRC

[4] S. Krinsky (BNL) - Discussion of the Design of the NSLS-II Storage Ring

[5] Y. Li (DESY) - Study of Dynamic Aperture for PETRA III Ring

[6] A. Streun (PSI) - Longitudinal gradient magnets and low emittance

[7] V. Tsakanov (CANDLE) - Beam Physics Issues in CANDLE Synchrotron Light Source Project

[8] B. Podobedov (BNL) - High Current Effects in the NSLS-II Storage Ring

[9] Y. Wu (Duke U.)– Hollow beam instability at the Duke storage ring

[10] G. Wustefeld (BESSY) – Low alpha operation at BESSY

[11] K. Harkay (ANL) - Status of APS short pulse project

[12] J.Byrd (LBNL) - Observation of CSR from bunches following slicing at ALS

[13] H. Hama (Tohoku U.) - Featuring the Characteristics of the Super Coherent THz Photon Ring

[14] E. Weihreter (BESSY) – HOM-damped SC and NC rf cavities

[15] T. Weis (U. Dortmund) – Operation of the NC EU-HOM-Damped Cavity with Beam at DELTA

[16] E. Gluskin (ANL) - Insertion device R&D

[17] G. Geloni (DESY) - Statistical Optics and Partially Coherent X-ray Beams in 3rd Gen Light Sources

[18] Y. Kawashima (JASRI/SPring-8) - Proposal of a Synch Radiation Facility to Supply UV, X-ray, MeV photon, GeV photon, and Neutron