REPORT OF WORKING GROUP III:
RING-BASED SOURCES

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Working Group III addressed the present improvements of ring-based sources that allowed new developments to be identified. The different subjects were discussed in specific sessions: storage ring transverse dynamics, longitudinal dynamics, short electron bunches and modelization, present and ultimate performances of synchrotron radiation, storage ring free-electron laser present performances, users applications, and future prospects. Time was also dedicated to discussions, presentations, and elaboration of new conceptual designs. The working group gathered more than 30 participants from different countries, with representatives of a number of operational synchrotron radiation sources from the first to the third generation (ALS, APS, ASTRID, BESSY II, Brazilian LS, DCI, DELTA, DUKE, ELETTRA, ESRF, ETL, NIJI4, NSLS, UVSOR, Super-ACO, SPEAR3, Spring8, SRS, Taiwan LS, VEPP3, Daresbury) and accelerator physicists of third-generation light sources in design (ASTRID 2, Canadian Light Source, Diamond, SOLEIL, Swiss Light Source). Several members are involved in storage ring FELs, either in operation on DELTA, DUKE, NIJI4, Super-ACO, UVSOR; under construction on ELETTRA; or in design on SOLEIL. Various interests were expressed, such as beam dynamics, small-gap insertion devices, topping-up, lifetime issues, feedbacks, and storage ring FELs.

Multi-user storage ring-based sources operated 146 000 hours around the world in 1998 with 117 available insertion devices and numbers of bending magnets sources. They presently offer a variety of performances in terms of energy (from infrared to hard x-rays), temporal structure, intensity, and polarization for an increasing number of users (10 000 users in three years in Europe). A high number of users will continue to access ring-based sources in the next 20 years, on the new sources under construction (CLS, ANKA, INDUS II, New Subaru, SLS), or in design (SSRF, ASTRID II, DIAMOND, SOLEIL, PF-AR, Tohoku Univ., VSX. LSB) on which new major developments are expected in terms of stability, reliability, fast switching of the polarization, small gaps undulators, and topping-up.

The exploitation of short time scale (in the 100 fs range) is now possible with appropriate detectors, such as the jitter-free streak camera. In that case, the sample is illuminated by a fs laser and by x-rays from ESRF, and the signal is recorded with a 500-fs resolution streak camera, which is trigged with the fs laser. Besides, fs x-rays were produced at ALS by slicing the electron bunch with a fs external laser. Concerning the beam dynamics itself, it appears that the operation with a low or negative momentum compaction factor α leads to a reduction of the bunch lengthening, but the increase of energy spread is not suppressed. Shorter bunches can also be achieved with a high rf voltage. Two-color electron beam in different α buckets were also reported from Brookhaven. For further prospects, sub-ps pulses can be achieved from a storage ring presenting a strong longitudinal focusing at high frequency, leading to a train of microbunches. As an example, several 300-GHz cavities are added to the main rf cavity, and the rf power (8 MV per cavity) is supplied one after the other by a mm FEL synchronized with the main rf cavity. For a 1-GeV beam, eight 8-MV strong focusing cavities provide 200-fs electron bunches and an energy spread of 0.13%. For a 4-GeV beam, 200 fs (respectively 1 ps) bunches are provided with 16 rf cavities at 8 MV (resp. 3 MV). These values already include microwave instability and coherent synchrotron radiation, which ultimately limits the bunch length reduction.

Topping-up was reported. APS experience is fairly positive, although 35 ms gating of radiation is necessary as the ports stay open and beam blows up (and moves) dramatically. This technique should be built into original designs where it is important to have it (such as low energy machines with very poor lifetimes).

Super-straights are under study. Higher brilliance is also expected from long insertion devices, such as the 25-m-long undulator in preparation at Spring8.

Lattice optimizations and reduction of emittance were discussed. The finite dispersion lattice modes have become very popular, and are shown to give more than a factor of 2 emittance reduction. At ESRF, the radiation emitted from a point upstream of the electron beam waist naturally converges further downstream (by moving the waist further downstream than the centre of the straight) and allows the brilliance to be increased by a factor of 2. As a further step, a sketch of a future storage ring-based source was proposed. Based on a twice APS/ESRF type machine including damping wigglers, it presents a circumference of 2 km, more than 30 6-meter-long straight sections for insertion devices, the rest of the machine being occupied by wigglers and rf cavities. The emittance can be reduced down to 20 pm because of the doubling of the circumference, the choice of an energy of 4 GeV, and the use of damping wigglers. With a stored current of 2A in 2000 bunches with a main 350-MHz cavity, the brilliance is 2 10^{24} at 1 Å, i.e., 4 orders of magnitude higher than the operating facilities. The lifetime reduction (1h) is overcome by topping-up. In order to avoid intrabeam scattering, the machine is operated at full coupling, and the bunch is lengthened with a harmonic cavity. This brilliance improvement of four orders of magnitude is achieved with well-known lattices and standard techniques.

So far, SRFELs have demonstrated the record of the shortest wavelength in the oscillator mode around 200 nm at NIJI4, and in the harmonic generation configuration at 100 nm at Super-ACO in the early 90's. They operate at the Fourier limit, either naturally at DUKE and Super-ACO or with an intra-cavity etalon (10^{-6} achieved on VEPP3 in 1990). They are also at the diffraction limit because the transverse coherence is defined by the optical cavity configuration. They offer a high degree of stability (intensity fluctuations of 1%, jitter of the FEL pulse being 5% of the FEL pulse duration, spectral drift smaller than the FEL spectral width). User applications have been performed since 1993 in various scientific domains, taking advantage of the natural synchronization between the FEL and synchrotron radiation for two color pump-probe experiments. So far, SRFELs have not been developed on third-generation synchrotron radiation machines. At short time scale, a collaboration partly financed by the European Union is now developing a FEL on ELETTRA that should provide 1 to 10 W in the 350-150 nm range, and demonstrate pioneering user applications. A FEL is also proposed on SOLEIL on a 14-m-long straight section, providing 5-50 W down to 150 nm coherent harmonic generation from the FEL or from a fs Titanium:Sapphire laser down to 50 nm, with Fourier-transformed ps pulses. With sufficient support, SRFELs should reach 1-100 W down to 20 nm, 2 nm by coherent harmonic generation, in synchronization with synchrotron radiation. SRFELs provide a brilliance up to 10^{26} in the oscillator mode, and 10^{23} on the coherent harmonics. The SRFELs potentialities should be further investigated.

In addition, pulsed bypass was considered. Assuming an instant switch into bypass for a given number of turns, the bypass can contain mini-beta and micro-gap devices, special rf systems, devices that “heat” the beam, extra-long straight, high gain FEL, or harmonic generation down to 4 nm.

A ring-based source variant, the Multi-turn Accelerator Recuperator Source, MARS, was proposed as a conceptual design of a diffraction-limited fourth-generation x-ray source. This idea was first proposed at SRI-97 too, and this scheme combines linear and circular accelerator virtues. It presents an emittance corresponding to the diffraction limit (10 pm.rad at 1 Å), a beam energy spread down to the fundamental limit due to the quantum fluctuations of the undulator radiation ($<10^{-4}$), and uses very long undulators (with 10 000 periods). It provides a large length of temporal coherence and a narrow-peak spectrum, leading to a high spectral brightness. Storage rings present radiation damping and diffusion processes that limit the decrease of emittance and energy spread; linacs offer a low average current on pulse conventional machines whereas super-conducting linacs are very expensive, and both present radiation hazards. In order to avoid these drawbacks, a new scheme is proposed. Electron bunches produced in an rf gun are accelerated in an rf linac up to 10 MeV. Then, they are injected in the booster racetrack microtron recuperator and pass eight times through the accelerating resonators up to 410 MeV. They are then injected in MARS, passing again eight times in rf resonators up to 6 GeV. In the upper accelerator stages several 150-meter-long undulators are implemented, providing brilliant synchrotron radiation. Bending magnets arcs are excellent radiation sources, too. The beam is then decelerated into the different stages of the accelerator, thanks to a proper phasing, limiting the radiation hazard. The average brilliance at 1 Å is 3×10^{23} and the peak brightness is 5×10^{33}. Preliminary cost estimates suggest it would be comparable to ESRF or APS.

Dramatic improvements have been performed from the first generation rings to the third, but still there are new steps to overcome, such as brilliance enhancement, long small gap insertion devices, and topping-up. More than 50 synchrotron radiation machines (in operation or projected) will serve many users in future years. Meanwhile, new directions have to be investigated in detail, such as the large circumference topped-up 4-GeV ring, sub-ps electron bunches in strong focusing rings, SRFELs, and MARS-type sources. The variety of radiation energies from the infrared to x-rays, and even gamma-rays by Compton backscattering should be maintained, together with the versatility in terms of pulse duration and separation.