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WG-B: RING BASED LIGHT SOURCES - SUMMARY

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WORKING GROUP TOPICS

In the six Working Group B sessions there were 21 oral presentations which included:

i/ overviews of many of the current ring based light source projects that are underway or being studied around the world: APS-U, BESSY-VSR, ESRF-EBS, Elettra 2.0, HALS, HEPS, KEK-LS, PETRA IV, SOLEIL upgrade, SPS-II,

ii/ various reviews of 'hot topics' such as injection schemes (Z. Duan), short pulse schemes (A. Jankowiak), round beam challenges (P. Kuske, plenary talk) and collective effects (R. Nagaoka),

iii/ more specific talks on topics such as ion effects, impedances, transient beam loading and less conventional ring-based light source schemes.

WG-B was asked to consider the following questions:

- Are there new ideas for storage ring lattices that could go beyond currently-envisioned MBA lattices?
- Should we be making more use of permanent- or superconducting-magnet technologies?
- Should new facilities plan for a full-energy linac injector to allow pushing the ring as far as possible?
- How can we make short lifetimes workable, so we can continue pushing the emittance down?
- What theory and code developments do we need to ensure that next-generation rings work as planned?
- What experiments can be performed on existing rings to remove uncertainties for next-generation rings?
- Besides rings optimized for ultra-high-brightness, what other types of rings should we be designing?
- What's needed to make first-principles impedance models more accurate in predicting instabilities?
- What commissioning strategies are best for next-generation rings?
- How do storage ring design and beamline design interact; e.g., round vs flat beams, tailoring of beta functions vs lowest emittance?
- Can ultra-bright rings also provide short pulses?
- Is low emittance more demanding of insertion device quality, e.g., phase errors?
- Are there new beam stability challenges and what are the best ways to address these?

Although neither the presentations nor the discussions addressed these questions directly, in the following we will nevertheless attempt to make some relevant comments based on the content of the presentations at FLS2018.

RESPONSES TO QUESTIONS

Are there new ideas for storage ring lattices that could go beyond currently-envisioned MBA lattices?

The hybrid MBA lattice of ESRF-EBS has been adopted for APS-U and HEPS and is the current baseline lattice for PETRA IV and the SOLEIL upgrade. Anti-bends are incorporated in APS-U and in one option for HEPS (with anti-bends and superbends).

Z. Bai presented various MBA lattices with sextupoles distributed throughout the cell for HALS; these have additional symmetry planes and odd-π phase advance in both planes across the mid-plane. 6BA and 8BA lattices were presented with emittances of 26-36 pm at 2.4 GeV with DA of ±1.5-2 mm and large MA. A further MBA lattice type with two pairs of interleaved dispersion bumps with –I transformation between each was presented; a 7BA version of this produces 32 pm natural emittance with DA of ±3 mm and large MA. Adding longitudinal gradient bends, anti-bends, and 2T superbends produces a lattice with 23 pm emittance and similar DA/MA.

I. Agapov presented an alternative lattice for PETRA IV with "double –I optics": in the first part of the arc there is π phase advance between points of maximum dispersion and βx, and in the second part there is π phase advance between points of maximum βy. This was said to require further development, but looks promising.

In other cases the desire for the lowest possible emittance has been compromised for the advantage of gaining additional straight section space in the middle of the arc where insertion devices or other components can be located. What generically might be called "split-MBA" lattices are being considered for Elettra 2.0 (6BA), SPS-II (6BA) and KEK-LS (8BA).

Should we be making more use of permanent- or superconducting-magnet technologies?

We believe that permanent magnet technology in particular has many benefits for future light sources. In a first development of this kind, ESRF-EBS will use permanent magnet longitudinal gradient dipoles. In WG-D, A. Vorozhtsov presented a very interesting design of a high gradient (234 T/m) permanent magnet quadrupole with bore radius of 5.5 mm for possible application in a future upgrade of MAX-IV. The design presented has a tuning range of ±5% which might limit the flexibility of the lattice.

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Should new facilities plan for a full-energy linac injector to allow pushing the ring as far as possible?

A 3 GeV linac injector is considered for SPS-II, however this is in view of a future short-pulse/FEL rather than for beam dynamics reasons. So far, no ring based light source is pushed to an extent where the booster/accumulator emittance or cycle time is a limiting factor and so would benefit from a full energy linac.

How can we make short lifetimes workable, so we can continue pushing the emittance down?

The small emittance required for future light sources naturally tends to reduce the lifetime through Touschek scattering and various ways of dealing with this have been developed. APS-U will use a 3rd harmonic cavity at 1.4 GHz while HEPS will employ low frequency RF and a 3rd harmonic at 500 MHz. Use of a 3rd harmonic cavity in PETRA IV is also being considered.

Short lifetime always places a greater demand on the injector, and this is particularly true for swap-out injection when the whole bunch charge needs to be injected. The required fill pattern uniformity will ultimately determine the cycle time of the injector. For example, in the high brightness mode in HEPS with 680 bunches with 5 hour lifetime, a continuous swap-out at 1 Hz results in nearly a 4% variation of bunch charge along the fill. Clearly a lower lifetime will either worsen the uniformity or require an increased injection rate.

Short lifetime also implies higher electron losses and so requires careful attention to radiation safety issues, particularly for swap-out schemes. This might result in greater emphasis on achieving high injection efficiency to minimise losses.

What theory and code developments do we need to ensure that next-generation rings work as planned?

There is generally a high degree of confidence in the single particle dynamics codes that are in general use and have been widely benchmarked against each other and against real machines. As apparent from the review talk on Collective Effects in Next-Generation Light Sources by R. Nagaoka however, more work is still needed in the area of impedances and collective effects to develop models, cross-check codes and benchmark against experiments.

What experiments can be performed on existing rings to remove uncertainties for next-generation rings?

Almost any experiments comparing non-linear single particle dynamics, impedance measurements or collective effects with simulations have a relevance for next generation rings since any discrepancies could potentially have far reaching consequences. A significant discrepancy between measured and simulated bunch lengthening in MAX-IV was mentioned.

Existing rings also serve as test-beds for new hardware R&D, such as BPM electronics and injection elements (APS), and also different operating modes. For example, tests of round beam operation have been made at APS and are planned at NSLS-II.

Besides rings optimized for ultra-high-brightness, what other types of rings should we be designing?

The vast majority of proposed new rings and ring upgrades are targeting lower emittance, driven by the science need for radiation with higher brightness and higher transverse coherence. There are exceptions however, one being the BESSY-VSR project (see presentation by A. Jankowiak) which is targeting instead short pulses.

S. Khan described Coherent Harmonic Generation experiments in DELTA and the planned ring modification in order to carry out EEHG experiments.

C. Tang presented the outline design of a ring designed for Steady-State Micro Bunching (SSMB). The goal of SSMB is to generate very high power EUV radiation with a small ring (less than 1 GeV), while the EUV power could be as high as 1 kW if successful, and appropriate for the purpose of lithography. The ring could be very cheap and small compared to a machine based on ERL or FEL.

What's needed to make first-principles impedance models more accurate in predicting instabilities?

In his review talk R. Nagaoka referred to a recent comparison between calculated and measured impedance in different machines [V. Smaluk, NIM A888 (2018) 22.] which in the majority of cases showed discrepancies of 100% or more. To pursue the possible origins of discrepancies, the following three possibilities were numerically studied with simple pillbox cavities (using ECHO): 1) Interference of wake fields, 2) Computation mesh size, 3) Impedance bandwidth. The results indicate that while the mesh size and impedance bandwidth influence by typically less than 10%, the interference causes more than 100% of variations. He also pointed out that such interference is likely to be enhanced for next generation rings as both the chamber dimensions and the spacing between objects is further reduced. Clearly this is an area that requires more work, more model and code development and comparison with measurements on existing machines.

What commissioning strategies are best for next-generation rings?

Commissioning strategies are clearly needed for next generation light sources. R. Lindberg pointed out that for APS-U simulations show zero chance of first turn without trajectory correction and low chance of multi-turn capture after first-turn trajectory correction if sextupoles are on. A great deal of effort has therefore gone in to developing a commissioning simulation for APS-U with a high degree of realism including error generation, trajectory correction, first orbit correction leading to stored beam, final orbit correction and lattice correction. Simulations are tracking-based, including physical apertures, injection errors, static and variable and BPM shot-to-shot noise. The conclusion of this study is that fast commissioning is possible with >95% success rate. Y. Jiao also described a commissioning code for HEPS to achieve first turn and then stored beam.

How do storage ring design and beamline design interact; e.g., round vs flat beams, tailoring of beta functions vs lowest emittance?

As a general statement, it is clear that in next generation light sources in particular, ring and beamline design must go hand-in-hand in order to achieve the desired photon beam characteristics at the sample.

Optimum brightness from undulators is obtained in principle with beta functions of the order L/π, where L is the length of the device, however the sensitivity depends significantly on how close one is to, or far away from, the diffraction limit at the photon energy of interest. This is taken into account in the current design of the SOLEIL upgrade lattice with beta functions of 1m in both planes at the insertion device. On the other hand, the latest design of HEPS has alternating high/low beta sections. It is accepted that a lattice with identical cells may benefit nonlinear optimization by keeping more periodicity, but this does not satisfy the range of needs of users.

Round beams (strictly meaning equal beam sizes and divergences in both planes, however equal emittance is also often referred to as a round beam) were discussed by P. Kuske. Round beams are beneficial for the machine (decreased intra-beam and Touschek scattering) but not necessarily for beamlines. At high photon energies brightness and coherence are higher for flat beams than round beams. APS has round beams as the baseline, whereas for PETRA IV round beams were initially of interest but flat beams are now preferred. As P. Kuske pointed out, it might be easier and more stable to obtain 100% coupling than the 10-20% which is required to maintain vertical emittances similar to what is achieved today in many light sources (~10 pm) in rings of 50-100 pm horizontal emittance.

Can ultra-bright rings also provide short pulses?

As mentioned above, most new rings favour low frequency RF and/or bunch lengthening harmonic cavities to mitigate naturally short bunches and hence reduce IBS and increase Touschek lifetime. Nevertheless there is interest in short bunches in Elettra 2.0 and for the SOLEIL upgrade; in the latter case some consideration has been given to implementing the BESSY-VSR double harmonic RF scheme. A study of the same scheme in HEPS was also published some time ago [S-K. Tian et al., Chinese Physics C 39 (2015) 127001].

Is low emittance more demanding of insertion device quality, e.g., phase errors?

There were no relevant presentations or discussion on this point but our opinion is that current state-of-the art phase errors and trajectory correction will be sufficient. Tolerances on field integral (multipole) errors might however be more demanding depending on the sensitivity of the lattice.

Are there new beam stability challenges and what are the best ways to address these?

Orbit stability at the level of 10% of rms beam size is already achieved in existing rings with vertical emittance at the 10 pm level or less, so achieving this in next generation rings with similar vertical emittance and horizontal emittance which is still larger than this value should not be a major problem. Some improvement in bandwidth of correction may be needed to take into account that detectors on beamlines continue to increase in repetition rate. More widespread use of nano focused photon beams may also demand a more integrated approach with feedback from the beamline to the electron beam.

Another stability issue that was mentioned is that of the emittance. It was pointed out that in very low emittance lattices the emittance might be more sensitive to insertion device gap variation, and hence some emittance stabilisation might be needed to prevent fluctuations in intensity being seen by beamline users.