TEN YEARS OF COMPACT SYNCHROTRON LIGHT SOURCE AURORA

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Abstract
From mid 1980's, we have been developing compact SR rings named AURORA. The first one, AURORA-1 (A1), which employed a superconducting magnet to make the ring as compact as possible, has unique features came from its constitution, one circular 360° bending with no focus magnets. After observed first SR in 1989, we continued to improve the whole system, then transferred to Ritsumeikan Univ. in 1995. It has been in routine operation since then. In parallel with the A1's improvements, we started developing another concept in early 1990's. We adopted normal conducting magnets instead of superconducting's to the second, AURORA-2 (A2), keeping compactness by increasing the bending field, 2.7 Tesla, as high as somewhat comparable to the superconducting's. The most outstanding feature of A2 lies in the bending magnets, whereas the configuration of A2, racetrack, is very conventional. There are two versions in A2; one pursued compactness, the same purpose as A1, for X-ray lithography, and the other modified for scientific research taking advantage of its capability of accommodating insertion devices (ID's). In 1997, the latter was installed in Hiroshima Univ. as HiSOR in combination with two undulators. On the contrary, the former has been in commissioning at our Tanashi Works.

1 INTRODUCTION

A compact synchrotron light source has been being developed since mid 1980's from the viewpoint of optimization for industrial use, especially for X-ray lithography. AURORA was originally designed under the trends of those days in applying superconducting technology to such the small SR rings. A1, the world's smallest SR ring, is quite unique by its constitution of a single-body superconducting bending magnet, to which the function of weak-focusing is added to avoid additional focusing magnets. To make the system compact as a whole, a 150-MeV racetrack microtron was newly developed as a reliable and stable injector. The operation of the total system is quite simple, therefore to be suited for industrial application. Extremely small beam size in vertical, originated from very weak x-y coupling, is another attractive feature for scientific experiments.

It proved somehow inadequate to the industrial system, however, because of rather a long maintenance period and recovery time from failure. We thus concluded to adopt room-temperature magnets avoiding super-conducting technology in the second version under the restriction of maintaining A1's compactness. It was achieved by an innovative idea of dipole magnets that brought us enough a high magnetic field for normal conducting magnets.

We have some flexibility in the design of new AURORA, depending on how to use straight sections of the racetrack ring. One which pursued compactness by the shortest straight section is called AURORA-2S (A2S), where S means Q-<u>S</u>inglet in the straight section. This quadrupole acts on horizontal focusing, whereas edge-focusing on vertical. The other having 3-m free space in the straight section is called AURORA-2D (A2D), where D means Q-<u>D</u>oublet. A2D has 4-sets of the doublet. Two types of ID, undulator and/or wiggler, are available for A2D. A2D in combination with two undulators was constructed in 1997 as HiSOR. Furthermore, the capability to install even a superconducting wiggler in such a compact ring as A2D using the low-energy-injection scheme was also proved by the other A2D.

2 THE FIRST AURORA (A1) [1-5]

A1 is the only circular ring in the world, which is the ultimate shape of compactness. The ring's outer diameter is ~3m, whereas the orbit diameter is 1m. The ring is unique because of its injection method using half-integer resonance. A1 is one of typical superconducting SR rings of those days, however, which was considered inevitable to produce a compact one. After the end of R&D, A1 was moved to Ritsumeikan University who established SR Center in 1996.

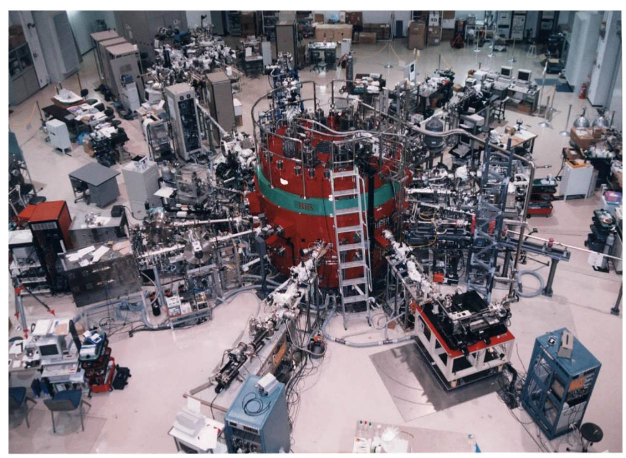

Fig. 1 **Whole view of AURORA facility at SR Center in Ritsumeikan University.**

Soft X-rays are intensively used for various analyses in material science. Micro-machining is one of unique applications, where LIGA and TIEGA (Teflon Included Etching Galvanicforming) are included. Some of 16 beam lines in total are able to use photons even at 3m distance from the source point, which is one of a merit of self-shielding. It means that the users can greatly benefit by a higher photon density than that of other rings. In addition, it was recently measured by interferometer that the beam size σy is quite small, 17μm, in spite of a larger emittance than 10^{-6} m·rad [6]. The beam is usually maintained 0.14mm of σy, however, to avoid too short Touschek lifetime. Thus, the ring is operated twice a day of injection, starting from 300mA stored current and terminated at about 150mA after 6 hours of accumulation.

3 THE SECOND AURORA (A2) [7, 8]

A2 is a compact ring of racetrack type using normal-conducting magnets, which takes over many advantages of A1, the 150-MeV injector microtron [9], cryopanels for high vacuum, self-shielding function, etc.

3.1 HiSOR — A2D with undulators [10, 11]

One A2D with two undulators was built at Hiroshima Synchrotron Radiation Center (HSRC) as HiSOR, which was established in 1997 by Hiroshima University. The most outstanding feature of HiSOR lies in these linear and helical undulators. These devices offer the users higher flux densities than 10^{15} photons/sec/mrad^2/0.1%b.w. at 300 mA of the specified current, covering a spectral range from a few to hundreds eV.

Fig. 2 Overall view of HiSOR at HSRC in Hiroshima University.

In the early stage of A2D's commissioning, we recorded 318 mA of stored current at 700 MeV, starting acceleration from 384 mA of 150-MeV injected beam which resulted in 83% of acceleration efficiency. After the completion of vacuum system upgrading, the beam lifetime was improved to 10 hours at 100 mA, where the vacuum pressure was $1x10^{-9}$ Torr on the average. The operation cycle has reduced to twice a day from three times a day since then. The integrated current has passed beyond 100 A·Hr. At present, ten of sixteen beam lines, two of them are for undulators, has already been occupied.

3.2 A2D with 7 Tesla Wiggler [12-15]

The system check of A2D with a superconducting wiggler was performed in 1997 within a very limited period, ~3 weeks of net commissioning, prior to the reassembling to A2S. The test was carried out under the very poor vacuum condition, $\sim 1x10^{-7}$ Torr while beam injection and acceleration, because of no baking and aging process for beam ducts and vacuum chambers. The result was, however, very satisfactory for us.

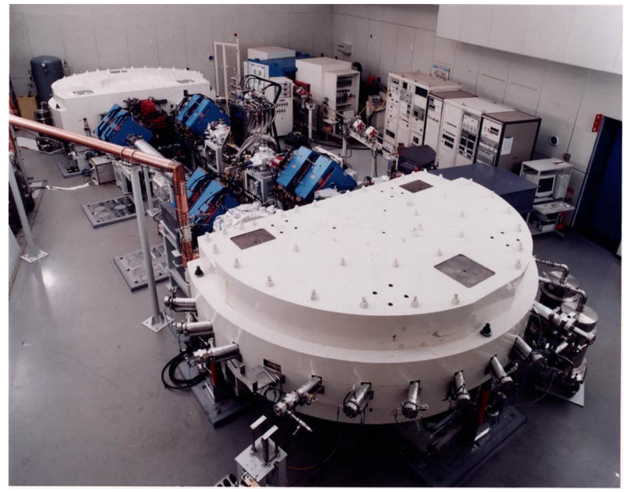

Fig. 3 Photo of A2D with 7 Tesla wiggler taken at our Tanashi Works.

We succeeded in proving the fact that even a compact ring with low-energy-injection scheme like A2D can accommodate a superconducting wiggler as an ID.

The test condition was as follows: The main pole of the wiggler is kept at 1.5 Tesla while injection, and ramped up to 7 Tesla taking 5.5 minutes of acceleration. The accumulated current was limited to 19 mA because of the poor vacuum in a short test period. We have acquired enough evidence, however, to confirm that the compact ring with 7 Tesla wiggler should work well notwithstanding a large amount of influence on the beam from the wiggler.

3.3 A2S [16, 17]

A2S is the world's smallest normal conducting SR ring. After the successful test of A2D, it was immediately disassembled and reassembled to A2S in late 1997.

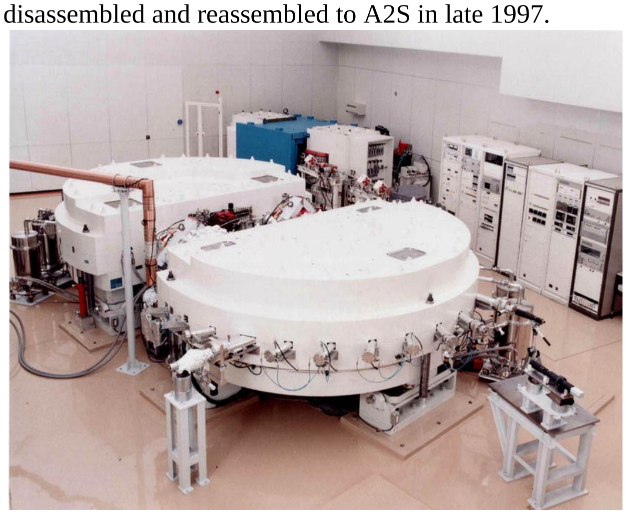

Fig. 4 Photo of A2S before wrapped up in the shielding materials.

Successfully curing the coupled bunch instability using the new RF cavity by which harmful HOM's were greatly suppressed, we went beyond the specification within a month and recorded 719 mA of stored current so far. Commissioning of A2S has been continued to improve the lifetime, where 3 hours at 500 mA is observed after 120 A·Hr of the integrated current. We found no difficulties in the acceleration when ramping more than 800 mA of injected beam up to 700 MeV in two minutes. The maximum injected beam already exceeded 1A. The reliability check had been done prior to covering the ring with radiation shielding materials as seen in Fig. 5, that is, more than ten days of 24-hours-a-day operation terminated successfully.

Fig. 5 Photo of A2S after coverd with the polyethylene neutron shielding.

4 CONCLUSION

More than a decade, we have been developing compact SR rings for industrial applications. Recently, the applications are extending from X-ray lithography to micromachining such as LIGA and TIEGA. A1 is convenient to obtain high dose rate with ease by placing a target close to the source.

We established a system of easy-handling by eliminating superconducting elements from A2. It was proved to accept either undulators or superconducting wigglers in A2D as ID's, thus even such a small SR ring as HiSOR is quite useful for scientific researches.

Another variation, A2S, has been proved to accumulate much more current than specified. The reliability was checked by a long-term continuous operation. Next step to be proved is its self-shielding capability. The ring is ready for exposure test of X-ray lithography, where a special beam line and a new SR stepper are in the final stage of preparation.

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	A2S	*A2D+W*	*A1*
Energy (GeV)	0.70	0.70	0.575
Stored current (A)	0.5 (1.0)	0.3	0.3
Circumference (m)	10.97	21.95	3.14
RF voltage (kV)	160	220	120
Harmonic number	7	14	2
RF frequency (MHz)	191.36	191.24	190.86
Energy loss (keV/turn)	24.42	29.07	19.34
Tune : horizontal	1.46	1.59	0.797
Vertical	0.73	2.10	0.604
Natural ε (π mm·rad)	0.528	0.935	1.68
Radiation damping :			
horizontal (msec)	2.13	5.60	1.3
vertical (msec)	2.10	3.53	0.43
longitudinal (msec)	1.04	1.49	0.16
Bunch length (mm)	26.5	36.2	52.0
Touschek life (hour)	20.	9.9	*(0.5)
Bending field : B (T)	2.7	2.7	3.8
n-value	0.0	0.0	0.365
QF (T/m)	12.5	10.9	—
QD (T/m)	—	-12.3	—

Table 1 Parameters of A2S, A2D+wiggler, and A1. *under the extremely small εx-εy coupling (~$2x10^{-4}$)