OPERATION RESULTS OF COMPACT SR RING "AURORA-2D" WITH 7 TESLA WIGGLER

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Abstract

A new racetrack type SR ring "AURORA-2D" (A2D), compact but reserving straight sections for insertion devices (I.D.'s), has been developed and tested together with a 7-Tesla superconducting (sc.) wiggler. The unique feature of A2D is based on normal-conducting bending magnets whose field strength 2.7-Tesla is somewhat comparable to sc.'s, on the contrary to recent trends of applying the sc. technology to small rings. The concept stands, therefore, on achieving a good performance by the cost-effective and easily-operational ring. Principal parameters of A2D, 700 MeV electron energy and 1.4 nm critical wavelength, show the ring suitable for X-ray lithography. First tested w/o I.D. and later, after achieved the stored current 300 mA, for the first time we have successfully proved the usefulness of the combination of compact racetrack ring and sc. wiggler, where the low-energy-injection scheme was adopted. The summaries of experiments are presented.

1 INTRODUCTION

A series of compact SR rings "AURORA" have been being developed since 1986. The aim is to optimize them for industrial application, especially for X-ray lithography. The first one, A1, which is unique because of its half-integer resonant injection method is the only circular machine in the world, keeping the ultimate shape of compactness. This is one of the typical superconducting compact rings. A1 has been being operated at Ritsumeikan University since 1995 [1] after the completion of our development.

We started designing an another compact ring "AURORA-2" (A2) in 1994 with a new concept of normal conducting magnet which enabled us to handle 2.7 T bending field without superconducting technology [2]. The purpose of developing A2 is just the same as A1's. Because of its racetrack shape, however, A2 has flexibility to accommodate I.D.'s in the straight sections. Thus one version of A2 called A2D which was named after its focusing scheme of quadrupole Doublets was designed for scientific using. Fig. 1 shows the whole view of A2D, where a sc. wiggler is installed in a straight section.

The commissioning started in March 1997 without I.D. and following the satisfactory results, we installed a 7 T sc. wiggler to prove the propriety of A2D used in combination with a high field wiggler. Within a very limited period of several weeks from August, the test was performed and the results greatly encouraged us.

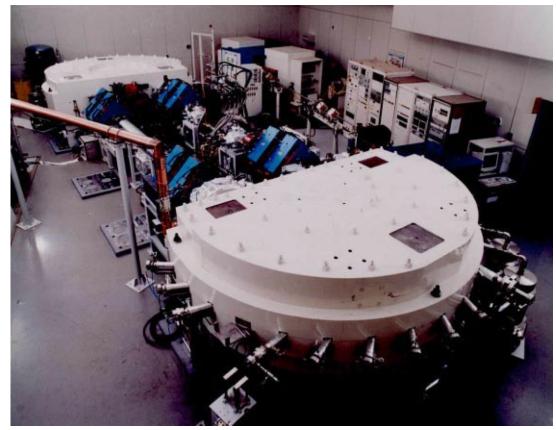


Fig. 1 Overall view of AURORA-2D (A2D).

2 DESIGN FEATURES OF A2D

The most outstanding feature of A2 lies in the design of 2.7 T normal conducting bending magnet. This is achieved by making the pole width narrow at the tip and wide at the base, thus limiting the magnetic saturation effect at around the pole tip. However, A2 takes over many advantages of A1, that is, the injector of 150 MeV racetrack microtron [3] which was seen far front in Fig.1, cryopanels for high vacuum in the bending chamber and easy radiation-shielding scheme, etc. There is another unique feature of A2 in the control system [4]. On the contrary to normal accelerator controls, we built a simple but flexible and economical system. It consists of one server and four PC's connected by LAN all together. Under this system, hardware can be easily replaced to catch up with the newest.

More precise features are well described in the reference [2]. Fig. 2 shows the layout of A2D, where the distance between two 180° bending magnets is 7m and a part of this length 3m is reserved for I.D.

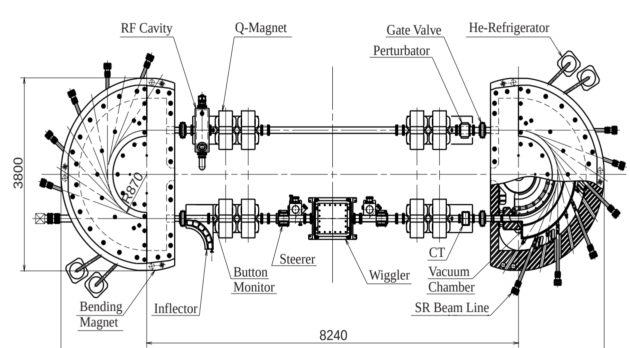


Fig. 2 Plan of A2D with 7 Tesla wiggler.

	A2D	1W7T	
Energy	0.7	0.7	GeV
Circumference	21.946	21.946	m
RF voltage	220	220	kV
Harmonic number	14	14	
RF frequency	191.243	191.243	MHz
Energy aperture	5.937	5.502	MeV
Energy loss	24.424	29.071	keV/turn
Synchrotron freq.	0.14651	0.15493	MHz
Momentum compactio	0.16528	0.1853	
Tune horizontal	1.59	1.59	
vertical	1.55	2.1	
Natural chromaticity			
horizontal	-1.4	-2.3	
vertical	-2.8	-3.8	
Natural emittance	474.022	934.564	pnm rad
Energy spread	0.421	0.444	MeV
Radiation damping time			
horizontal	5.873	5.599	msec
vertical	4.196	3.525	msec
longitudinal	1.836	1.487	msec
Bunch length	32.403	36.164	mm
Touschek lifetime (1A	5.712	9.903	hour
Quantum lifetime	>1E+32	7.00E+24	hour
Field strength BM	2.7	2.7	Tesla
QF	9.4	10.9	Tesla/m
QD	-8.6	-12.3	Tesla/m

Table 1 Parameters of AURORA-2D with & w/o wiggler.

The parameters related to A2D with and without wiggler are listed in Table 1. Beam simulations of A2D in the presence of wiggler(s) are discussed in the references [5], [6]. The SR spectra from bending magnet (λc=1.4 nm) and sc. wiggler (λc=0.54 nm) are shown in Fig. 3.

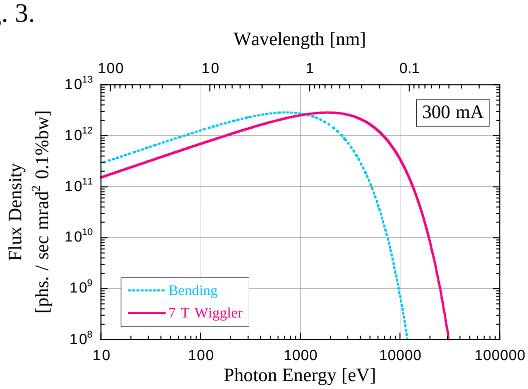


Fig. 3 SR spectra of A2D from bending and wiggler.

3 WIGGLER DESIGN

The 7 T wiggler is a three-pole sc. magnet housed in a compact liquid He cryostat. The schematic of the wiggler is presented in Fig. 4 and its overall appearance in Fig. 5. The system is compact as a whole using 3 sets of small-capacity He refrigerator by which the liquid-N_2-free cryostat came into effective. It means one refrigerator (GM) keeps the thermal shield plates as 80 K instead of liquid N_2. We may need liquid N_2 only when the time of initial cooling down. Another big advantage becomes from Bi-based high Tc sc. current leads by which the heat load of the cryostat is remarkably reduced. One of three He refrigerators is used to keep the current leads as cool as 20 K.

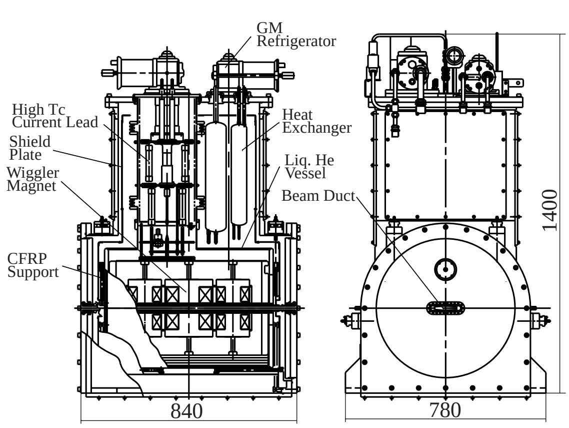
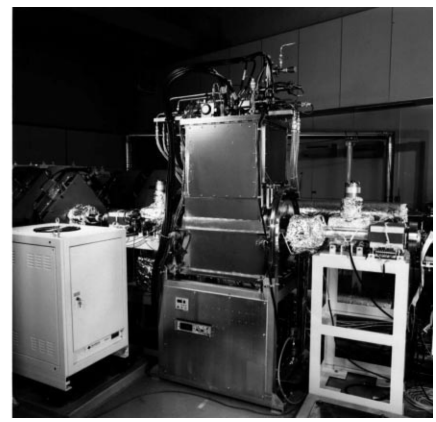


Fig. 4 Schematic view of superconducting wiggler.



Maximum field on beam axis	
Central pole (T)	7
Side pole (T)	-4.6
Magnetic period (mm)	342
Magnetic field integral along beam axis (Gauss cm)	< 400
Coil gap (mm)	40
Vertical aperture of vacuum chamber (mm)	15
Horizontal aperture of vacuum chamber (mm)	86
Stored energy (KJ)	138
Total weight of cooled parts (KG)	700

Parameters	Central Coils	Side Coils
Number of layers	56	52
Number of turns per layer	43.86	45.9
Number of turns per winding	2456	2386
Operating current (A)	214	136
Superconducting wires		
Superconductor	NbTi	NbTi
Ratio of Cu:NbTi	1	1
Dimension (mm)	0.8X1.3	0.56X1.13
Insulation thickness (μm)	70	60
Diameter of filaments (μm)	25	35

Fig. 5 Photo of 7 Tesla wiggler.
Table 2 Parameters of 7 Tesla wiggler.

The main parameters of the wiggler are summarized in Table 2 together with some specifications of the sc. coils. Its total weight is about 1.5 tons. Power consumption of the system is roughly estimated as 40 kW at full excitation. Thus, adding the effect of liquid-N2-free operation, the running cost of the whole system becomes quite low.

4 BEAM TEST RESULTS

4.1 A2D Beam Test without Wiggler

The test started in early April and took just one week to find the proper ramping pattern to keep synchronization between the bending and QF/QD excitation. What necessary to take into account while acceleration is the eddy current effect induced in the massive solid-iron poles, which causes some delay in the rise time of the bending field. To compensate this effect which increases in proportion to the exciting speed di/dt, we introduced time delaying system in between the ramping pattern of those bending's and QF/QD's [7]. It takes 2 min to ramp up the bending field from 0.6 T to 2.7 T by the current from 103 A to 833 A where 6 A/sec of di/dt is adopted, which is equivalent to the beam acceleration from 150 MeV to 700 MeV. Thus, we succeeded in accumulating 700 MeV beam in A2D within a month.

We suspended the test in July to add the sc. wiggler. As the operation was interrupted once in a while by vacuum improvement work etc., the net operation was limited to forty days in total. Starting acceleration from 384 mA, the max. accelerated current 318 mA was achieved, thus 83% of acceleration efficiency was recorded as shown in Fig. 6. The max. injected current at 150 MeV amounted to 424 mA. The lifetime was, however, limited ~30 min at 100 mA because of poor vacuum ~5x10^{-8} Torr which was a natural result of no aging process.

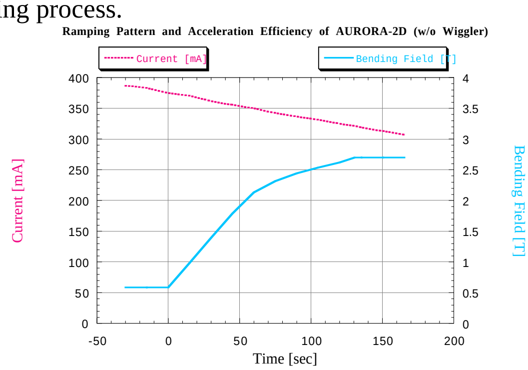


Fig. 6 Typical acceleration pattern of A2D.

Two sets of A2D have been manufactured so far. One is the A2D presented here and the other HiSOR is the ring delivered to Hiroshima University together with two undulators [8]. In principle, behaviors of the two were the same and we did not find any inconveniences derived from their individuality. HiSOR has been kept in operation and owing to the aging effect, lifetime came to 4 hours at 100 mA after 30 AHr integrated current [8]. The Vacuum pressure at 100 mA was entering to the order of 10^{-9} Torr.

4.2 Beam Test with 7 Tesla Wiggler

The test with wiggler started in August immediately after its installation. The main pole of the wiggler is kept at 1.5 T while injection and 7 T in storage mode. It takes 5.5 min to accelerate the beam up to 700 MeV. The wiggler ramping pattern adopts constant di/dt scheme to increase the excitation current, which enforces constant dB/dt scheme upon the bending magnets [7]. The success of this scheme suggests the possibility of shortening the acceleration period to three-fourth (1.5 min) without wiggler.

Though there was no time of vacuum processing baking etc., we dared carry out the test under the poor vacuum ~1x10^{-8} Torr around the wiggler, because of tight schedule. The following results were obtained from 3-week testing, that is, 116 mA of injected current, 19 mA of stored current after acceleration, and 32% of typical acceleration efficiency starting from 56 mA to 18 mA remaining. This low efficiency is due to poor vacuum ~5x10^{-7} Torr near the wiggler while acceleration. When decreasing the injected current to 18.6 mA, we then obtained 61% acceleration efficiency to 11.4 mA remaining. These acceleration patterns were shown in Fig. 7.

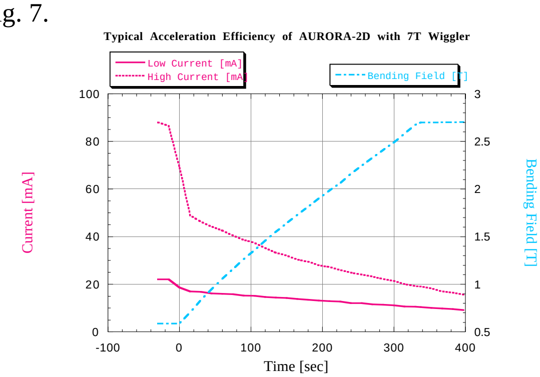


Fig. 7 Some Acceleration pattern of A2D with wiggler.

5 CONCLUSION

It was proved by A2D that even a compact SR ring adopting low-energy injection scheme was able to use in combination with a sc. wiggler. The 150 MeV beam was injected into A2D under the standby wiggler field 1.5 T, and accelerated up to 700 MeV synchronizing the bending field with the wiggler field which was dynamically excited up to 7 T. Thus, researchers can obtain wide varieties of SR source even from a low-cost small machine by means of I.D.'s such as undulator(s) and/or wiggler(s).

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