Present Status of AURORA-2D

Toshitada HORI
Laboratory for Quantum Equipment Technology, Sumitomo Heavy Industries, Ltd.
1-1 Yato-machi 2-chome, Tanashi, Tokyo 188 JAPAN

Abstract

A new racetrack type compact SR ring AURORA-2 was designed for soft X-ray source. The bending magnets achieved 2.7 Tesla to keep the ring small without superconducting technology. There are two versions, AURORA-2S and AURORA-2D, and two rings have already been constructed. One was assembled as AURORA-2D and the performance tests with and without a superconducting wiggler were successfully completed. The ring was disassembled then, and now being remodeled to AURORA-2S designed for industrial use. The other is AURORA-2D delivered to Hiroshima University with undulators and called HiSOR.

1 Introduction

Since 1986 we have been developing a compact SR ring AURORA. The main target of the small ring was for industrial use, especially for X-ray lithography. The first version AURORA is unique because of its injection method using half-integer resonance, which enables the ring to be truely circular, the ultimate shape of compactness. AURORA is the only circular ring in the world using superconducting technology by which 3.8 Tesla bending field is generated. After the completion of development and performance tests, the ring was transferred from our Tanashi Lab. to Ritsumeikan University in 1995 [1].

In 1994, we began to design an advanced compact ring with the new concept not relying on superconducting technology but adopting normal conducting magnet with a noble idea which enables us to use such the high magnetic field as comparable to superconducting's [2]. The design has two versions. One design, optimized for X-ray lithography, made the ring as compact as possible, which has a Single quadurupole in each straight section, thus called AURORA-2S. The other made the ring acceptable insertion devices on the sacrifice of compactness, which has two quadrupole Doublets in each straight section, thus called AURORA-2D. In Fig.1 showing layout of AURORA-2D, the distance between two 180° bending magnets is 7m and a part of the straight section, actually 3m is reserved for insertion devices.

Prior to AURORA-2S's achievement tests which is essential for our development, we began AURORA-2D's test first after finishing the assembly in March 1997. After the successful acceleration of AURORA-2D, we immediately started the same tuning on HiSOR in Hiroshima University [3]. Soon HiSOR also acquired the sufficient stored current. After the satisfactory results of AURORA-2D, we started installation of the 7T superconducting wiggler in July, and began the wiggler test intensively from mid August. Fig.2 is an overall view of AURORA-2D taken after the installation. After two weeks testing, we again succeeded in operation with 7T wiggler. This is the first case of small racetrack SR rings that succeeded in beam handling under the existence of a superconducting wiggler.

2 Design Features

The most outstanding feature of AURORA-2 lies in the design of 2.7T normal conducting bending magnet. However, AURORA-2 takes over many advantages of superconducting AURORA, using the 150MeV racetrack microtron as the jnjector [4], cryopanels having high vacuum pumping speed in the vacuum chamber of the bending magnets, self-shielding function especially for AURORA-2S, etc. Another unique feature is in the control system. On the contrary to other control systems, we built simple but flexible, and economical system. It consists of one server and four PC's connected together by LAN. Signals are transmitted on GPIB to all equipments as shown in Fig.3. Under this system, obsolete hardwares are easily replaced.

More precise features of both AURORA-2S and -2D are presented in Reference [2]. The parameters related to the wiggler are listed in Tabel 1. Beam simulation results of AURORA-2D in the presence of wiggler, single and double, are described in References [5], [6].

3 Results of Beam Tests

The test started to transport the beam from the 150MeV microtron to AURORA-2D. After conditions of the injector and BT line were optimized, beam acceleration test started in early April. It took just one week to find the proper ramping pattern keeping the synchronization between both the bending and quadrupole fields. What necessary while acceleration is to take into account the eddy current effect induced in the massive bending magnets made of solid iron, which causes some delay in the rising of magnetic field. Fig.4-a) shows the effect of eddy current which increases in proportion to the exciting speed di/dt. To keep the operation ponit stable, we need to compensate the drift of the point due to the above effect. Thus, we introduced time difference between the ramping pattern of bending and two quadrupoles. We chose the exciting speed 6A/sec for the ramping of bending magnet from 103A to 833A. It takes two minutes to accelerate the beam from 150MeV to 700MeV.

After we investigated the behavior of the ring, commissioning of HiSOR started. We succeeded in accumulating 700MeV beam in both AURORA-2D and HiSOR within a month. In principle the behaviors of two rings were about the same and we did not find any inconvenience derived from individuality of two rings.

3.1 Beam Test of AURORA-2D

The operation of AURORA-2D without wiggler started in April and stopped in July in order to install the superconducting wiggler. As the operation was interrupted once in a while, vacuum improvement work for instance, the net testing period was limited to forty days in total. Within this short period, we recorded 318mA stored current at 700MeV, starting from 384mA of injected beam. The acceleration efficiency was 83% in this case. The maximum injected current at 150MeV recorded 424mA. The life time was limited around 30min at 100mA because of poor vacuum. We did not have time to see the aging effect.

On the contrary to AURORA-2D, HiSOR has been keeping in operation since May and the evidence of aging effect seems guradually coming out. Recently they got 1.5hrs life time at 100mA after the operation only 12A·Hr of integrated dose. They are entering the 10^{-9} Torr vacuum level at 100mA. We could expect the improvement of HiSOR's performance in accordance with the advancing of aging process in the vacuum chamber.

3.2 *Beam Test with 7 Tesla Wiggler*

The main pole of the wiggler is kept at 1.5T while injection and excited to 7T while accumulation. It takes 5.5min. to accelerate the beam from 150MeV to 700MeV. As shown in Fig.4-b), the ramping pattern of the wiggler was made with constant di/dt of the exciting current, actually increased from 14A to 214A by di/dt=0.6 A/sec. It is equivalent to excite the bending field as dB/dt. While ramping, the saturation effect of the bending magnet appears in the last quarter. Therefore, we must increase the exciting current of the bending magnet steeply in the final quarter. If we apply this ramping pattern to the ring without wiggler, we can shorten the acceleration period about 25%, from 2min. to 1.5min.

The test was carried out under the poor vacuum condition, 1×10^{-8} Torr base pressure in the straight section, for we did not have time to wait until good vacuum. The obtained results were as follows; max. injected 150MeV current =116mA, max. accumulated current =19mA, and typical acceleration efficiency =32% starting from 56mA and 18mA remained. This low efficiency is mainly derived from poor vacuum 5×10^{-7} Torr while acceleration. When the starting current was reduced to 18.6mA, then we obtained 61% efficiency with 11.4mA remaining.

4 Future Plan

AURORA-2D has already been disassembled in mid September immediately after the completion of wiggler test. It will reappear as AURORA-2S in early December. It is our primary aim to confirm the performance of the compact ring optimized for X-ray lithography. The configuration of new compact SR ring is shown in Fig. 5, where shielding walls covering the whole machine for the purpose of self radiation protection are illustrated. Next beam test using AURORA-2S is planned to start within this year. The milestone of the coming beam test is to achieve the 500mA stored current, and planned to increase up to 1000mA eventually.

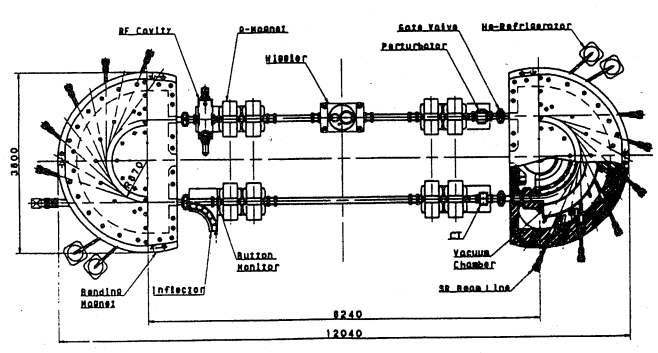

Fig. 1 Plan of AURORA-2D with wiggler.

5 Conclusion

It is proved that the compact SR ring AURORA-2D can co-operate with superconducting wiggler. It is inevitable for a racetrack ring such as AURORA-2D to have some dispersion in the straight section, but not harmful when the value is small. Low energy injection scheme which is common for compact rings is not favorable for a wiggler because of its dynamic field increasing while acceleration, but this condition is also manageable. We experimentally confirmed that in spite of some difficulties small SR rings are capable of installing a superconducting wiggler.

References

[1] "Rits SR Center Activity Report 1996", Ritsumeikan Univ. (1997) pp.3-7.
[2] T. Hori, et al., "AURORA-2: Compact Advanced SR Ring as an X-ray Source", 4th Int'l Conf. on SR Sources and 2nd Asian Forum on SR, Kyongju, Korea (1995) pp.148-158.
[3] K. Yoshida, et al., "Compact Synchrotron Light Source of HSRC", Submitted for Synch. Radiation Instrum. '97, Himeji, Japan (1997).
[4] T.Hori, et al., "Present Status of 150 MeV Racetrack Microtron", Proc. 22nd Linear Accel. Conf. in Japan, Sendai (1997) pp.16-18.
[5] T. Takayama, et al., "Compact Synchrotron Radiation Source 'AURORA-2' with 2.7T Normal Conducting Bending Magnets", Proc. 1996 European Part. Accel. Conf., Sitges, Spain (1996) pp.709-711.
[6] H. Tsutsui, et al., "Aperture Calculation of AURORA-2D Compact Electron Storage Ring with a Super-conducting Wiggler", Submitted for 1997 Part. Accel. Conf., Vancouver, Canada (1997).

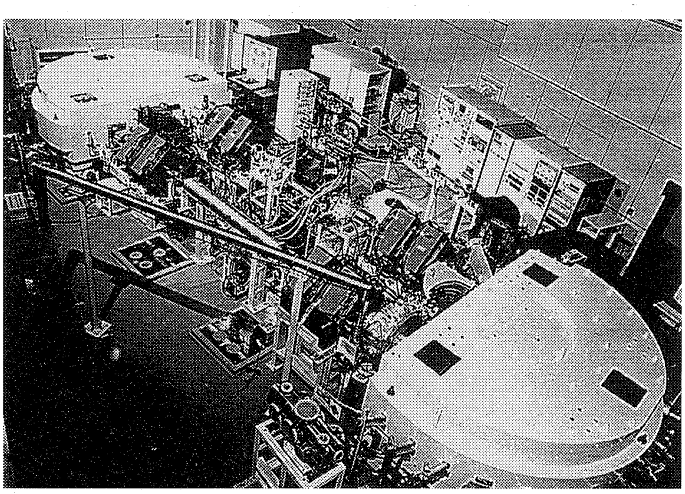

Fig. 2 Whole view of AURORA-2D with wiggler.

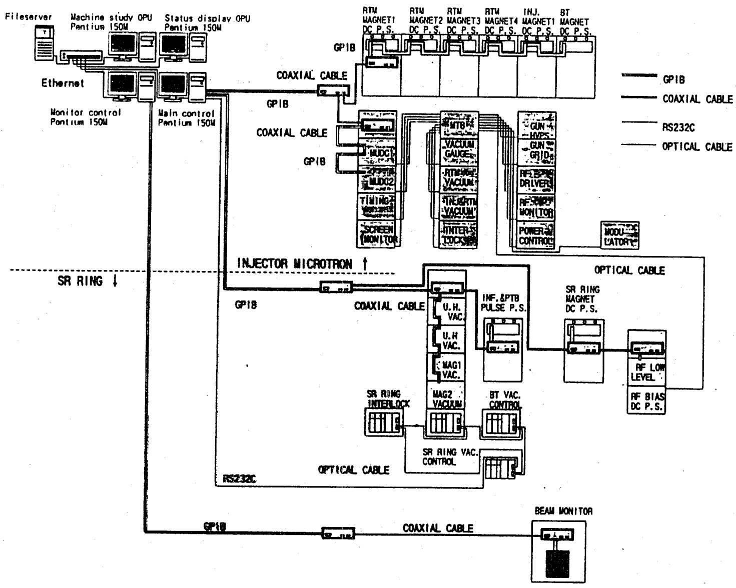

Fig. 3 Control system of AURORA-2D

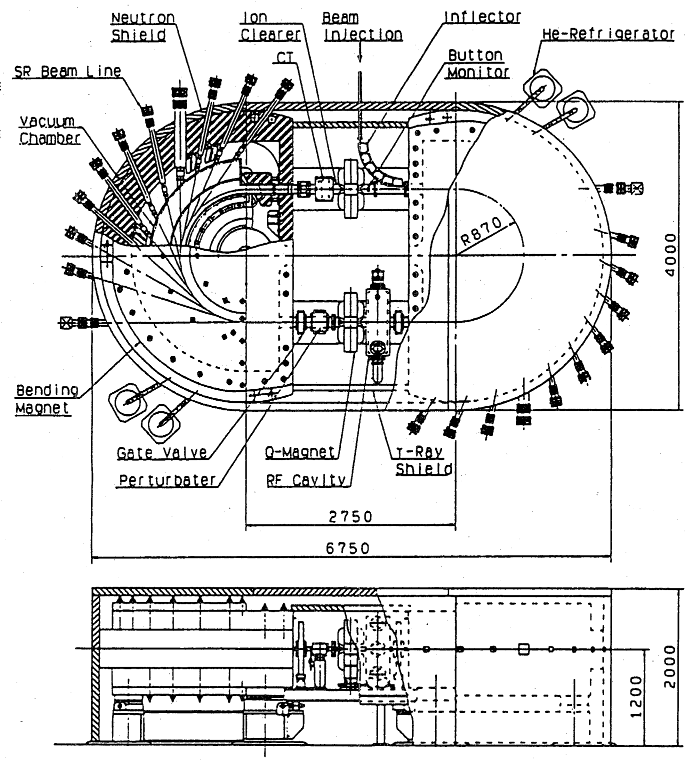

Fig. 5 Schematic of AURORA-2S

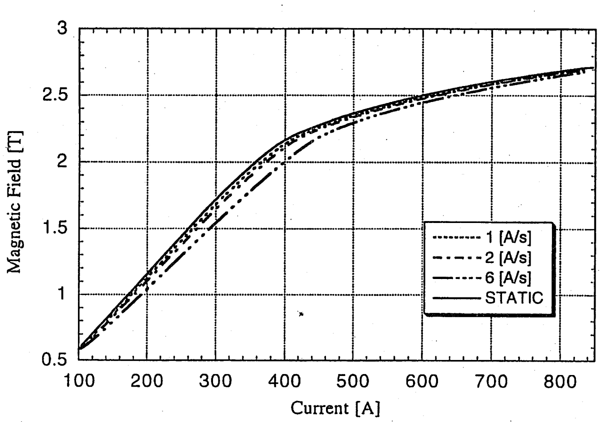

Fig. 4-a) Dynamic excitation characteristics of 2.7 Tesla bending magnets.

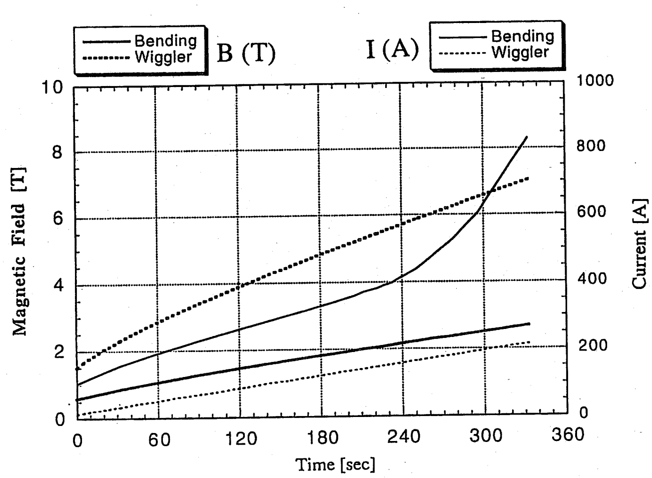

Fig. 4-b) Ramping pattern of both 2.7 T bending magnets and 7 T wiggler.

	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 frequency	0.14651	0.15493	MHz
Momentum compaction	0.16528	0.18530	
Tune horizontal	1.590	1.590	
vertical	1.550	2.100	
Natural chromaticity			
horizontal	-1.4	-2.3	
vertical	-2.8	-3.8	
Natural emittance	474.022	934.564	πnm 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 at 1A	5.712	9.903	hour
Quantum lifetime	>1E+32	7.0E+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 and w/o wiggler