INITIAL COMMISSIONING OF DEDICATED SR RING "AURORA-2S" FOR X-RAY LITHOGRAPHY

H. Miyade, D. Amano, H. Murata, T. Hori, T. Takayama
Laboratory for Quantum Equipment Technology, Sumitomo Heavy Industries, Ltd.
1-1 Yato-machi 2-chome, Tanashi, Tokyo 188-8585 Japan

Abstract

A new type compact synchrotron light source "AURORA-2S" (A2S) optimized for X-ray lithography has been being developed based on the conventional normal-conducting technology, on the contrary to the recent trends of applying the superconducting technology to small SR rings. Operation of A2S is, therefore, simplified and the maintenance period shortened, which are the serious factors for industrial applications. The outstanding concept of racetrack-type A2S lies in normal-conducting 180º bending magnets whose field strength 2.7 Tesla is somewhat comparable to the superconducting's. It makes A2S as compact as preceding superconducting rings. Other major specifications are 700 MeV electron energy, 1.4 nm critical wavelength, 191 MHz of RF with 7 harmonic numbers, and designed current 500 mA. Early in this year, commissioning of A2S started.

1 INTRODUCTION

We have been developing compact SR rings since 1986. The target is for industrial use, especially for X-ray lithography. The first AURORA which is unique because of its shape, the only circular ring in the world, has the ultimate shape of compactness. This is one of typical superconducting SR rings. The machine was transferred to Ritsumeikan Univ. in 1995 after its final upgrade, and has been in scheduled operation since then [1].

We started designing of an advanced compact ring AURORA-2 in 1994 under the novel concept of normal conducting magnet which enabled us to handle 2.7 Tesla bending field without superconducting technology [2]. There exists two versions; the one is AURORA-2S, a version having quadrupole Singlets, thus called A2S, and the other AURORA-2D, a version having quadrupole Doublets, thus A2D. The former is designed as a dedicated ring for X-ray lithography achieving a ultra-compact normal-conducting ring, and the latter for various scientific researches with the help of insertion devices such as undulator/wiggler. Fig. 1 shows the whole view of A2S.

Prior to the commissioning of A2S, performance test of A2D was carried out in 1997 within a limited term. Following the satisfactory results including the achievement of designed stored current 300 mA (w/o wiggler) and successful operation under the existence of 7 Tesla wiggler, we started disassembling of A2D and finished remodeling to A2S in early 1998 [3,4,5].

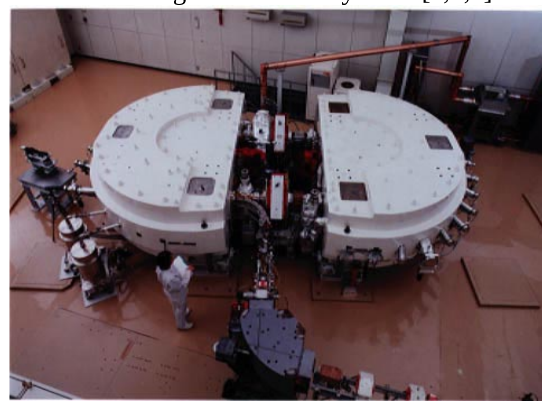

Figure 1: Overall view of AURORA-2S (A2S).

It should be noted that another A2D-type had also been simultaneously constructed, and installed in Hiroshima Univ. with two undulators. Except the insertion devices, all the specifications are the same as A2D's. This SR ring, named HiSOR, has been routinely operated since 1997 [6].

2 DESIGN FEATURES OF A2S

The most outstanding feature of AURORA-2 originates in the idea of 2.7 Tesla normal-conducting bending magnets [2]. Of course, the ring takes over many advantages of the original AURORA, the injector 150 MeV racetrack microtron [7], cryopanels for high vacuum in the bending chamber, for instance, and especially for A2S, radiation protection by self-shielding. The concept of this shielding is schematically described in Fig. 2, where the inter-bending section is reinforced by lead plates for γ-ray shielding and the overall surfaces around the ring are covered with polyethylene plates for neutron protection. By these treatments, the building to house A2S needs no additional radiation shielding. Thus, the great merit of cost reduction is introduced.

Another unique feature of AURORA-2 lies in the control system. On the contrary to other accelerator control, we built simple but flexible, and cost effective system. It consists of one server and four PC's connected together by LAN as illustrated in Fig. 3. Commands and/or signals are transmitted mainly on GPIB to all equipment. Under this composition, obsolete hardware be easily replaced to catch up with the newest computer technology.

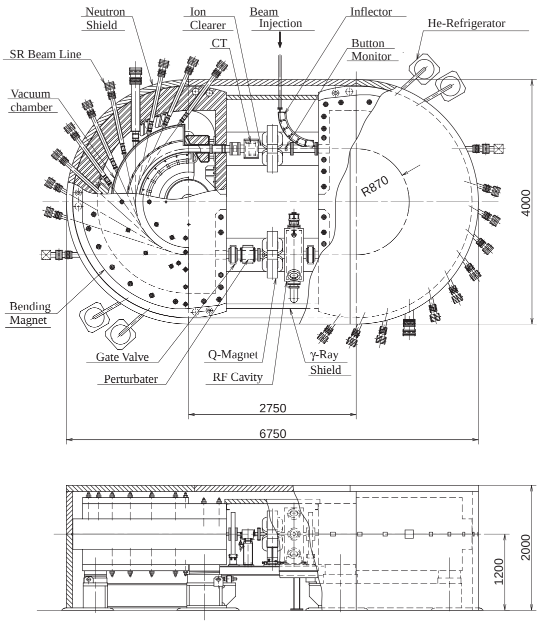

Figure 2: Schematic of A2S.

Precise features of A2S, and A2D also, are described in the reference [2]. The parameters related to A2S are extracted in Table 1. Unlike A2D, A2S has no defocusing quadrupole (QD). It generates vertical focusing force by the pole-edge angle of the bending magnets. According to the radiation damping time, about 0.4 sec at 150 MeV injection energy, the repetition rate of beam injection is set to 2~3 Hz.

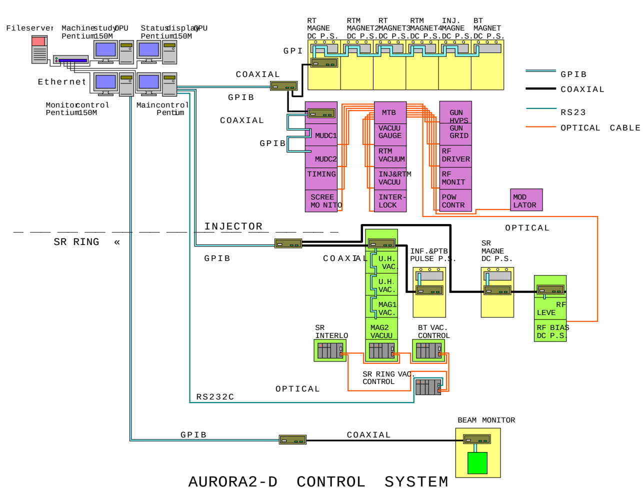

Figure 3: Control system of A2S

3 STATUS OF A2S BEAM TEST

The beam test of A2S started in early 1998. The method of beam injection, acceleration and accumulation is in principle the same as the one adopted for A2D. We need be careful to maintain synchronization only between the bending and QF fields. Increasing rate of the exciting current di/dt of the bending magnets is fixed to 6 A/sec, the rate used for A2D, to hold the same cancellation of eddy current effect induced in the massive solid-iron poles. Some delays in uprising of magnetic field due to eddy current effect are seen in Fig. 4 depending on the magnitude of di/dt.

Aurora-2S		
Energy	0.7	GeV
Circumference	10.97	m
RF voltage	220	kV
Harmonic number	7	
RF frequency	191.36	MHz
Energy aperture	7.72	MeV
Energy loss	24.42	keV/turn
Synchrotron frequency	1.42	MHz
Momentum compaction	0.196	
Tune : horizontal	1.46	
vertical	0.73	
Natural chromaticity :		
horizontal	-1.68	
vertical	-0.82	
Natural emittance	527.6	π nm·rad
Energy spread	0.449	MeV
Radiation damping :		
horizontal	2.13	msec
vertical	2.10	msec
longitudinal	1.04	msec
Bunch length	26.5	mm
Touschek life time	6.6	hours(at 1A)
Quantum life time	$>10^{32}$	hours
Field strength : Bending	2.7	Tesla
QF	12.5	Tesla/m
QD	None	Tesla/m

Table 1: Parameters of AURORA-2S.

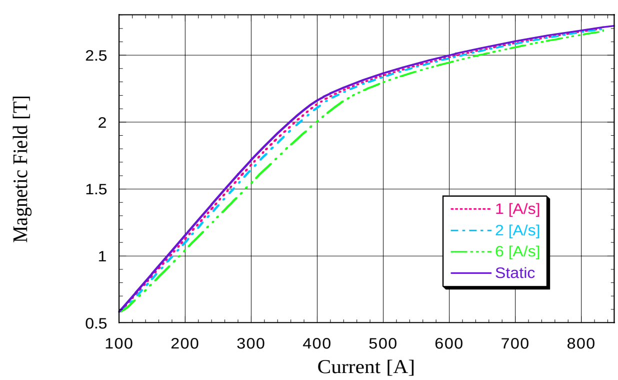

Figure 4: Dynamic excitation characteristics of 2.7 Tesla bending magnets.

Thus, it takes two minutes to ramp up the bending field from 0.58 to 2.7 Tesla, by the exciting current from 103 A to 833 A. The ramping pattern is generated by constant di/dt of the exciting current. However, applying constant dB/dt to the pattern, we could shorten the beam acceleration period about 25%, from 2 min. to 1.5 min.

A standard acceleration pattern is in Fig. 5, which was recorded at the test of A2D without wiggler. The pattern for A2S is just the same. Related to the commissioning of A2D, we recorded 318 mA stored current at 700 MeV within the very limited time. The injected current 384 mA and 83% of acceleration efficiency are seen in Fig. 5. The maximum injected current recorded 424 mA [3,4,5]. We could not compile enough data to estimate the beam lifetime, however, HiSOR has been kept in operation and it has come to ~4 hours lifetime at 100 mA after 36 AHours of integrated current. The vacuum of HiSOR was improved to 10^{-9} Torr at 100 mA [6].

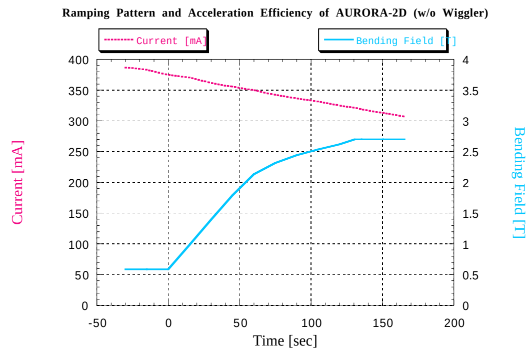

Figure 5: Typical acceleration pattern of A2D.

With regard to A2S, we need some improvement in injection efficiency. At present it recorded 340 mA and we are making effort to double the quantity in order to prove 500 mA accumulation. It will be tried in the next step to double the amount again, aiming 1 A accumulation. We found no difficulties, so far, in the acceleration from 150 MeV to 700 MeV in two minutes. We have been not intensively trying to increase the accumulated current, therefore, the record is halted at 110 mA with the acceleration efficiency of 70 %, after recorded in March 1998. Concerning vacuum, the bending section where the cryopanels effectively evacuate the residual gas is quite satisfactory to $1\sim2\times10^{-10}$ Torr without beam load.

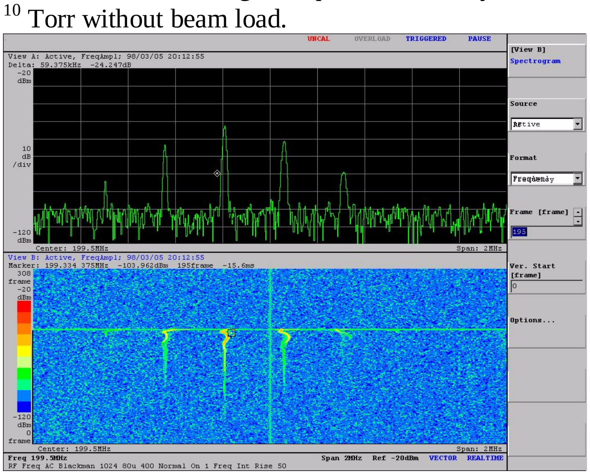

Figure 6: Damping time measurement at injection.

Our main concern is directed to analyse the phenomena of unexpected beam instability observed at injection. It seems some longitudinal coupled bunch instability caused by HOM of the RF cavity, for many satellite peaks of the synchrotron oscillation are seen from very low current, less than 1mA for instance. The damping time of transverse oscillation was measured by a real time spectrum analyser and found too short, a few msec in typical, to enhance transverse instabilities. One shot of the signals is shown in Fig.6. The highest peak at 199.3 MHz in the upper half is related to betatron oscillation (νx=1.3) and the separation 250 kHz between any two adjacent peaks corresponds to synchrotron oscillation. On the other hand, the lower half shows the same spectra in the time scale from up to down with 80 μsec resolution and 25 msec full scale. The point abruptly these peaks appeared (in yellow) is the moment when the injection kicker is excited, and the signals disappear soon.

In parallel with those beam experiments, some device like HOM damper is in preparation, and the further optimization of the cavity is also in progress.

4 CONCLUSION

Following the conceptual design of new compact SR ring A2S using normal-conducting magnets which generate as high field as 2.7 Tesla, a prototype was manufactured and has been under commissioning. The ring is optimized for industrial applications, especially for X-ray lithography by the critical wavelength 1.4 nm. Another unique feature of A2S stands in its radiation-free configuration. By the self-shielding capability, users have great benefit in hand, because no thick concrete wall is necessary for A2S installation. The beam test of A2S is in progress trying to increase the injected current for the achievement of designed accumulation 500 mA. It is expected to be achieved after suppressing the strong coupled bunch instability observed at injection. Some tools are in preparation to suppress the phenomena.

*This work was done under the financial support from Japan Key Technology Center.

6 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 & 2nd Asian Forum on SR, Kyongju, Korea (1995) pp.148-158.

[3] T. Hori, "Present Status of AURORA-2D", Proc. 11th Symposium on Accel. Sci. and Tech., Harima, Japan (1997) pp.534-536.

[4] T. Hori, et al., "Development of New Compact SR ring AURORA-2", submitted to APAC'98, KEK, Tsukuba, Japan, March 23-27, 1998.

[5] T. Hori, et al., "Operation Results of Compact SR ring AURORA-2D with 7 Tesla Wiggler", this conference.

[6] K. Yoshida, et al., "Commissioning of a Compact Synchrotron Radiation Source at Hiroshima University", submitted to APAC'98, KEK, Tsukuba, Japan, March 23-27, 1998.

[7] T. Hori, et al., "Present Status of 150 MeV Racetrack Microtron", Proc. 22nd Linear Accel. Meeting in Japan, Sendai (1997) pp.16-18.

[8] K. Aoki, et al., "Control System for HiSOR", Proc. Int'l W.S. on Controls for Small- & Medium-Scale Accel., KEK, Tsukuba, Japan, Nov. 11-15 (1996) pp.26-30.