# APERTURE CALCULATION OF AURORA-2D COMPACT ELECTRON STORAGE RING WITH A SUPERCONDUCTING WIGGLER

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*Abstract*

Dynamic apertures of AURORA-2D 700MeV compact electron storage ring with a 7 Tesla wiggler are calculated with a tracking program NABO which uses a sixth order Runge-Kutta method. Also dynamic apertures are calculated by a symplectic tracking program SAD to see the validity of using Runge-Kutta method. Sufficiently large dynamic apertures are obtained.

## 1 INTRODUCTION

AURORA-2[1,2] has two versions S and D. AURORA-2S is designed as a synchrotron radiation source for X-ray lithography. It has two 180 degrees 2.7 Tesla normal conducting bending magnets and two quadrupole magnets.

AURORA-2D is designed for scientific applications. It has two 180 degrees 2.7 Tesla normal conducting bending magnets, eight quadrupole magnets, and two 3 m straight sections. Up to two insertion devices can be installed in the straight sections. Two AURORA-2D accelerators were assembled in Hiroshima University and Tanashi works of Sumitomo Heavy Industries, Ltd. They successfully accumulated 30 mA at 700 MeV in the first operation without insertion devices. We think that the accumulated current will increase as the vacuum will become well. One 7 Tesla wiggler will be installed in the ring at Tanashi works and tested in July.

In this paper, we calculate dynamic apertures for AURORA-2D with a 7 Tesla super conducting wiggler. We used a particle tracking code NABO developed by Takayama. NABO is based on a sixth order Runge-Kutta method. It reads measured magnetic field data in median plane, calculates twiss parameters, makes chromaticity correction, and calculates dynamic apertures. Runge-Kutta method is powerful for treating measured magnetic field directly. But it is thought that a multi turn particle tracking by this method is risky because the symplectic condition is violated by numerical error. We also calculated dynamic apertures by a particle tracking program SAD[3] which satisfies the symplectic condition.

## 2 LATTICE PARAMETERS

Figure 1 shows the top view of AURORA-2D. It has two 180 deg. bending magnets (BM), four focusing quadrupoles (QF), and four defocusing quadrupoles(QD). Bending magnets have an edge angle to function as defocusing quadrupoles. Dipole and sextupole magnetic field components can be generated in QF's and QD's by auxiliary coils in them. Sextupole component in QF's and QD's may be used for chromaticity correction. One of the two straight sections is occupied with a 7 Tesla wiggler. The magnetic flux density in the wiggler were calculated by TOSCA. The wiggler is now under fabrication. Spectra of light from bending magnets and 7 Tesla wiggler are shown in figure 2.

For the calculation of natural chromaticities, the well known formula:

$$\xi = \oint \beta\eta K ds / 4\pi ,$$

is not applicable to small rings because the formula does not include the effect of the second order aberrations in bending magnets[4]. Though the natural chromaticities can be calculated by complicated linear theory, they were calculated by NABO and SAD tracking codes because of easiness. Table 1 shows the parameters of AURORA-2D. Necktie diagrams are shown in figure 3. Lattices are shown in figures 4 and 5.

## 3 DYNAMIC APERTURE

Chromaticities are corrected before the aperture calculation. Figures 6 and 7 show the results. The cross symbols are by NABO. The lines are by SAD. Ideal magnets are assumed in the calculation by SAD. Effect of the third order aberrations in BM's can be seen. Differences between the results of NABO and those of SAD are due to the imperfection of actual quadrupole field in QF's and QD's, and the errors of the measured data.

Dynamic apertures are shown in figures 8 and 9. They are at the center of the straight section. Solid lines are by NABO. Dots are by SAD. Broken lines show 10σ of the beam size. Vertical emittance is assumed to be the half of the natural emittance. Apertures by NABO are considerably smaller than those by SAD because NABO uses the measured data which has the physical limit. Vertical limits are due to the physical aperture in BM's, and the horizontal limits are due to the physical aperture in QF's.

Apertures become considerably small if the 7T wiggler is installed. Some part of 10σ volume is out of the aperture calculated by NABO. This is not so much

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problem because the vertical emittance is overestimated. If typical x-y emittance coupling of 0.01 is used, the 10σ volume become small in the vertical direction by a factor of 7 and is well within the aperture.

## 4 CONCLUSION

Dynamic apertures of AURORA-2D with a 7 Tesla wiggler are calculated by NABO and SAD. Apertures are sufficient for the practical operation.

## 5 ACKNOWLEDGEMENTS

The authors wish to thank Prof. Kamada and Dr. Ohmi of KEK for helping us to use SAD.

## REFERENCES


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[3] 'Sad Home Page', http://www-acc-theory.kek.jp/SAD/sad.html

[4] W. Hardt, J. Jaeger and D. Moehl, 'A General Analytical Expression for the Chromaticity of Accelerator Rings', CERN PS/DL/LEAR/Note82-5 1982


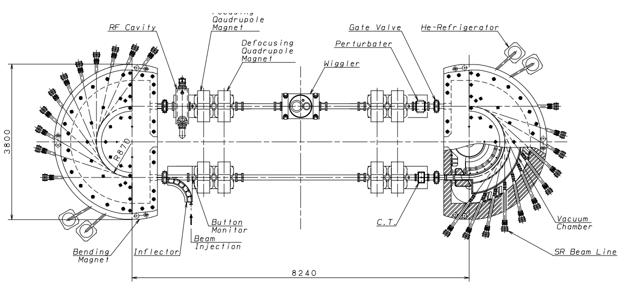


**Figure 1 Top view of AURORA-2D with one wiggler**

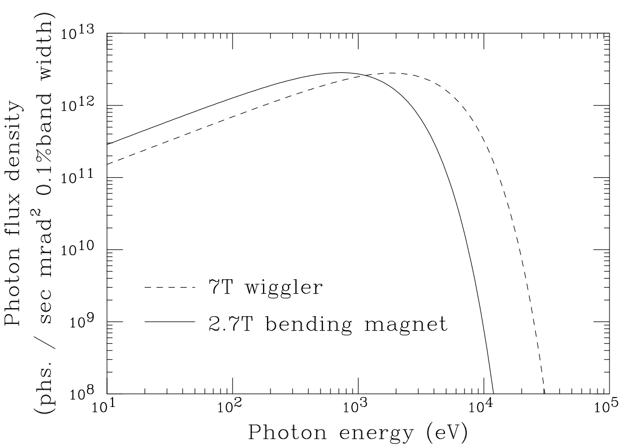


**Figure 2 Spectra from bending magnets and 7T wiggler. Beam energy is 700MeV. Beam current is 300mA.**

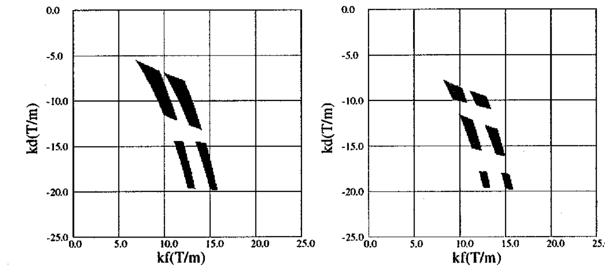


**Figure 3 Necktie diagrams. The diagram of the left hand side is of no insertion device type. The diagram of the right hand side is of single 7T wiggler type.**

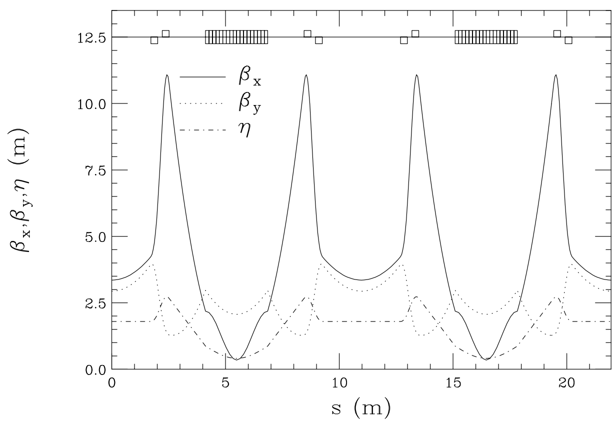


**Figure 4 Lattice of no insertion device type**

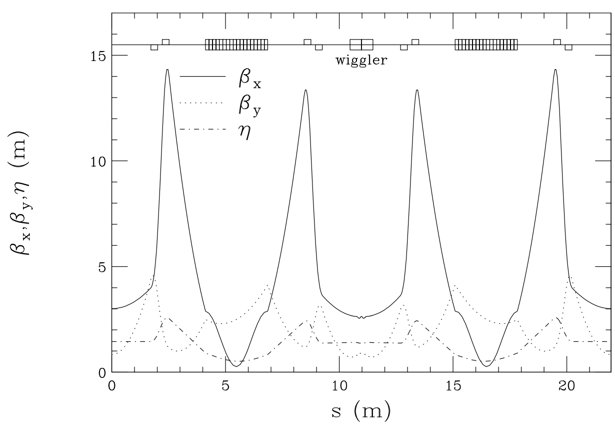


**Figure 5 Lattice of single 7T wiggler type**

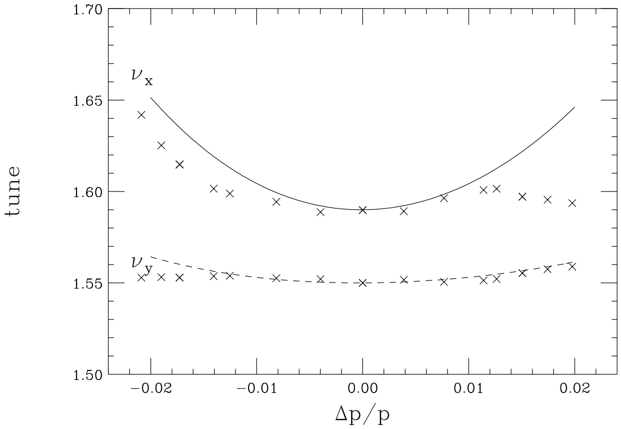


**Figure 6 Tune plot of no insertion device type. Cross symbols are by NABO. Lines are by SAD.**

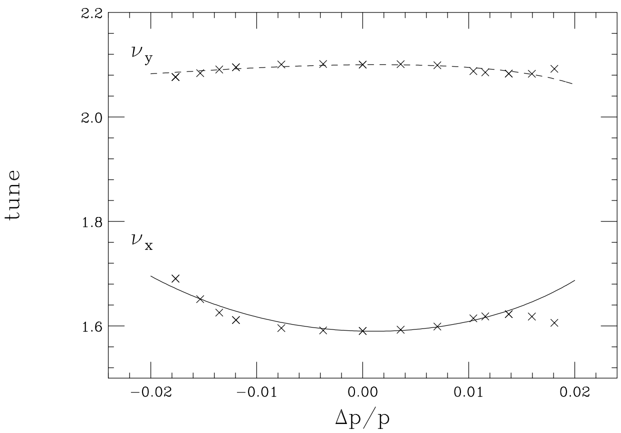


**Figure 7 Tune plot of single 7T wiggler type**

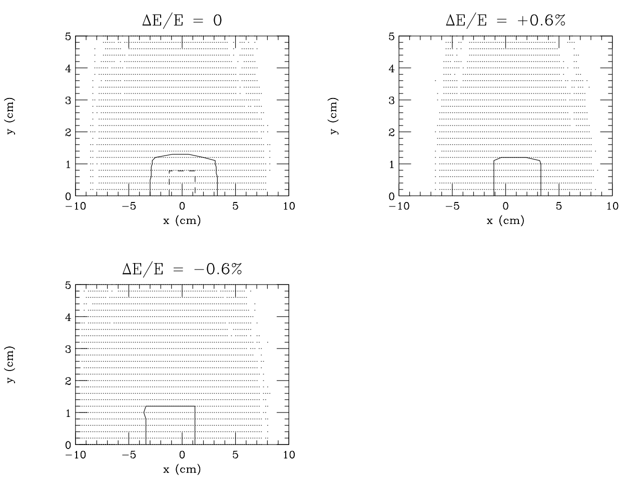


**Figure 8 Dynamic aperture of no insertion device type. Solid lines are by NABO. Dots are by SAD. Broken line shows 10σ of the beam size.**

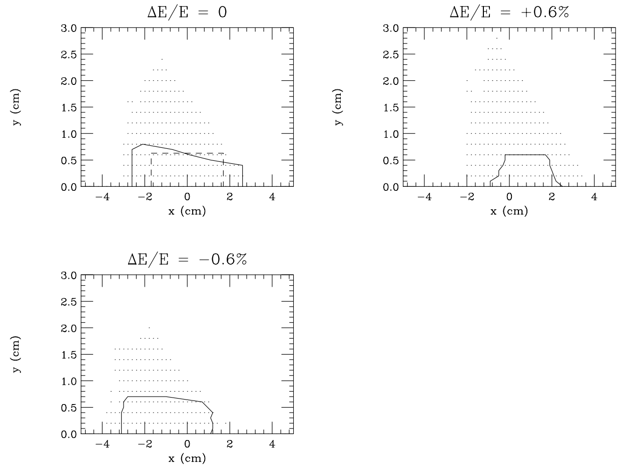


**Figure 9 Dynamic aperture of single 7T wiggler type.**

| | *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 Lattice parameters of AURORA-2D**