SUCCESSFUL BEAM INJECTION TO THE SMALLEST SYNCHROTRON AND BRILLIANT X-RAYS PRODUCTION

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Abstract

We have made a successful beam injection to the world smallest electron storage ring by the 2/3-resonance injection method. Usefulness of the resonance injection to the extremely small ring was demonstrated. The brilliance of the produced x-ray is not high but the total flux exceeds the synchrotron. The advantage is in the high coherence, and in the wider angular distrubution.

1. INTRODUCTION

Downsizing of accelerator must be an important subject for the 21 Century accelerator communities. There are many cutting edges such as novel accelerator scheme using higher microwave frequency or a laser, or micro fabrication of the accelerator column, and so on. Our approach is the down sizing of synchrotron. Our beam injection scheme, we hope, will open up new application fields.

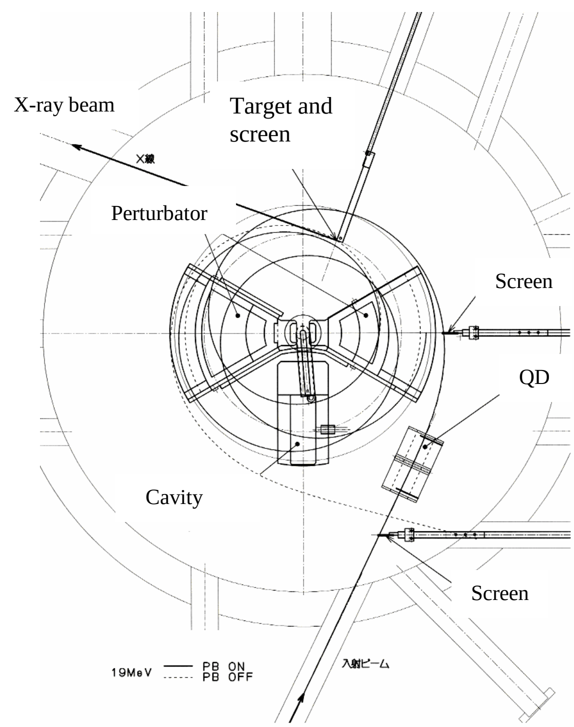
We have made a successful beam injection to the world smallest electron storage ring by the 2/3-resonance injection method [1]. The 20 MeV tabletop electron storage ring named "MIRRORCLE-20" is composed of a single peace of normal conducting magnet of 1.2 m out diameter and 0.15m orbit radius. The usefulness of the resonance injection to the small ring of 1m-orbit circumference was demonstrated. No fast response kicker magnets are available so that the standard beam injection scheme is not useful. This method has been successfully adapted firstly by AURORA with a 1/2-resonance method [2].

Since this ring is exactly circular we are not able to measure the stored beam current, but the ionization counter measures the generated x-ray beam intensity from target placed in the orbit as bright as synchrotron light. The x-ray beam is generated by the bremsstrahlung with a thin Al or Pb-target placed in the orbit. The brilliance is not high but the total flux exceeds that of the synchrotron. The advantage is in the high coherence, and in the rather wide divergence. This source is suitable for the phase contrast x-ray imaging of large specimens.

2. 2/3 RESONANCE INJECTION METHOD

The beam injection is an established technology for a large synchrotron. But when the synchrotron orbit circumference is extremely small, we have to adapt a new technology. The circumference of our ring is only 1 m or 3 nsec. There are no such fast kicker magnet is made in the past. A use of horizontal betatron resonance moderates the conditions on the necessary kicker force and the pulse width. On the other hand, however, the beam instability appears. The successful beam injection is made when the pulse width invoking the resonance and the heating speed is valanced.

Fig. 1. Pair of perturbators, a microwave cavity, and a quadrupole doublet (QD) is placed inside the vacuum chamber under the strong magnetic field.



MIRRORCLE is an exact circular machine similar to AURORA. Purterbator (PB), the pair of one- turn coils to excite the betatron resonance, is placed under the main magnetic field, so the coil is made of air core and generates as much as 300 gaus. The pulse width of the half sinusoidal shape of the Perturbator (PB) was the subject to be studied. The configuration of PB and the beam trajectory is shown in Fig. 1. Each purterbator kicks beam toward inside at the outer and inner edge of the orbits, respectively. The n-value of the main magnetic field is set close to 0.54, while the n-value 0.556 corresponds to the 2/3-betatron tune. In principle the additional perturebator field makes the betatron tune as close as 2/3. If the n-value apart further from 0.556, more pertuerbator force is required.

Fig. 2. Change in the phase diagram at the injection point as the perturbator force changes.

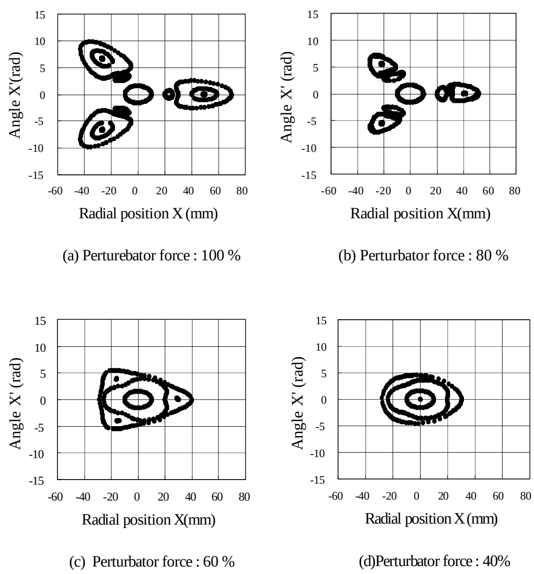
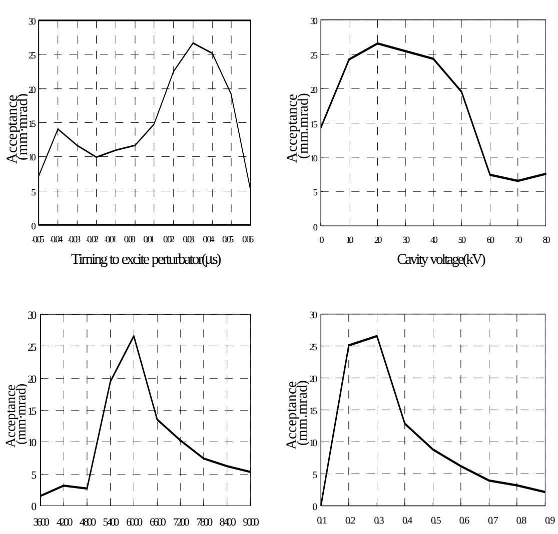


Fig. 3. We have studied the perturbator coil current, the pulse width, the timing, and the cavity voltage.



The phase diagram at the injection point shows the dynamical change of the tune, as the perturbator force is changed as time, which is shown in Fig. 2. The meaning of the 2/3 resonance is clear from Fig. (a) and (b). When the PB force is lower than 40%, the resonance disappear and the beam is captured in the central orbit as seen in Fig. (c) and (d).

The effect of the PB was studied by searching the parameters such as the PB coil current, the pulse width, the timing to excite it, as well as the ring cavity voltage. The results are shown in Fig. 3. We found the optimized parameters to be 0.3 μsec pulse width, 6000A coil current, and 60 kV cavity voltage. We learned that the too large cavity voltage decreases the acceptance. The obtained acceptance is about 30 mm·mrad.

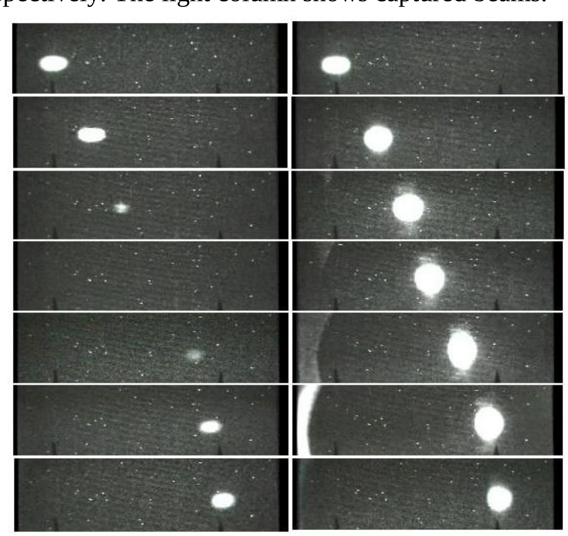
3. EXPERIMENTAL RESULTS

3.1 BEAM INJECTION

The beam diagnostics of the exact circular and extremely low energy synchrotron is another problem. A current troid cannot be used as same as AURORA, since it disturbs the main magnetic field. In addition there are no fast response photon detectors at this critical wavelength region of synchrotron light. The solid sate FIR detector is also sensitive to X-rays. Until now we do not have a means to measure the stored current.

To monitor the stored beam current we use radiations from a 5 mm wide and 5μm thick Al foil. The ZnS fluorescent martial painted on the Al foil is used for viewing the beam position.

Fig. 4 Screen monitor made of Al foil(5μm) painted with ZnS is used to view the circulating beam in the ring. The left and light columns show beam positions as the screen is moved in radial direction with and without perturbator, respectively. The light column shows captured beams.



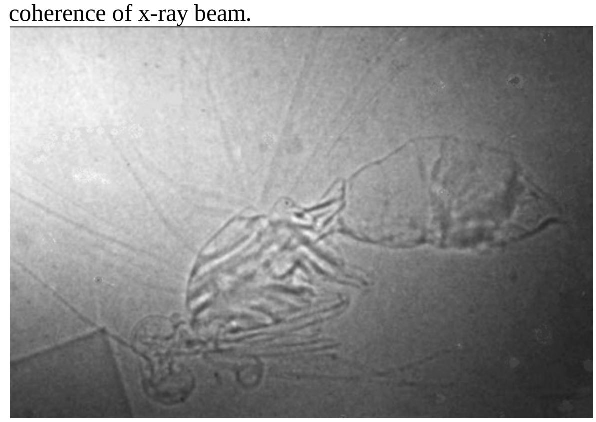
The injection trajectory must be specified exactly to excite the resonance. At the first step we ensure the beam position with the screen monitor at the target position (see Fig. 1) by moving the screen monitor. When the first and second turns are identified, we excite the PB. The results are seen in Fig. 4. If the PB is not excited we see only the first and second turn beams, but with excited PB the beam spot turns to extremely bright at the center, and can be seen at any points around the central orbit within ±50mm. So the beam is circulating. If the injection conditions are setup properly, the resonance appears at 75% PB current while the maximum is 6600A. We have obtained the maximum injection efficiency at 90% PB. These results are quite consistent with our simulation shown in Fig. 3.

3.2 FUTURE OF THE NEW X-RAY SOURCE

Measurement of the beam current is difficult. Only we can show the x-ray intensity from the target. Since photon coutings are also impossible, we show in Table 1 the radiation dose measured by the calibrated ionization chamber. The DOSE of MIRRORCLE; 100 R/s/10mA/15cm^2, indicates 100 Rontogen/s integrated over 15cm^2 area at 10mA injected beam pulse current and at 30Hz operatin. In this case the 5 mm wide and 0.5mm thick Al target was used, but 5μm thick Al foil gives nearly equal results. The dose is independent of the target thickness. If that is thin, the beam just circulates longer time. The radiation power is namely determeind by the injector power, since the ring power is only one KW. This is not enough to recover the beam energy, but contribute only to the radiation damping. On the other hand the unit of SR power is of standard. We see here the brilliance of MIRROCOE which is yet the order of the rotating anode source, but the total photon is comparable to the SR undulator radiation. The MIRRORCLE radiation is characterized by the large angular spread. This beam is useful for the x-ray imaging of large specimes like a human body compared with SR.

Another feature is the high coherence. Most of radiations are generated within a few100 ns time window. This is due to the short lifetime, an order of μs, which corresponds to 1000 times revolution. This means that the coherence of MIRROCLE should be counted so as 10^6 times more of the average photon number. This is one of the reasons why we see the enhanced edge in the x-ray image due to interference shown in Fig. 5. Fine structure of the soft tissue is imaged with hard x-rays.

Fig. 5 X-ray image of a butterfly taken by MIRROCLE. The edge of the soft tissue is enhanced due to the high coherence of x-ray beam.



4. CONCLUSION

We have discussed the successful beam injection to the smallest ring, and novel feature of the produced x-ray beam such as the high coherence and large angular spread. According to this success, the construction of the second machine has beean appproved by the Ministry of Education and Science. We have started constracting MIRRORCLE-6X, which is the 6 MeV version. Foot print of the machine will be 1 x 0.5 m^2.

5. REFERENCES

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Table 1. X-ray beam DOSE measured by an ionization counter is compared with the SR undulator source(PF-AR).

	MIRRORCLE-20X	5GeV SR light source(PF-AR)
Radiation scheme	Target radiation	Undulator
Radiation angle	25mrad	< 1mrad
Photon Spectrum	Broad band from few keV~20 MeV	33 keV
Time structure	Pulse; ~1μs, Repetition 30Hz	Continuous; 400MHz
Max DOSE	100 R/s/10mA/15cm^2	135R/s/25mA/106cm^2
Calculated Brilliance	6.8E+08 Photons/s/mrad^2/mm^2/0.1%λ	3.0E+15 Photons/s/mrad^2/mm^2/0.1%λ
Calculated Total photons	1.3E+8 photons/s/0.1%λ	3E+7photons/mrad/s/0.1%λ