THE TABLETOP SYNCHROTRON MIRRORCLE-6X

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Abstract

The construction of the tabletop synchrotron MIRRORCLE-6X is completed. The 6-MeV microtron beam test and the injection to the synchrotron are in progress. The electron beam current extracted from the Microtron is reached 100 mA with 500 ns pulse duration and 400 Hz repetition rate. The measured main magnetic field distribution of the synchrotron showed good agreement with calculation, which promise 20 mm•mrad acceptance.

INTRODUCTION

Novel x-ray source based on a low energy tabletop synchrotron has been proposed by Yamada [1,2] and is demonstrated with its brilliant x-ray production by using MIRRORCLE-20, which is a 20 MeV synchrotron having 15 cm orbit radius, and 1.2 m magnet OD [3]. For the x-ray production an inelastic collision of circulating relativistic electrons with a tiny target placed in the central orbit is utilized. The observed brilliance of hard x-rays is comparable to SR. This novel source is unique by its few μm x-ray source size, which is determined by target size, by its high energy transfer rate, and by its broadband x-ray spectrum of from few KeV up to the energy of injected electron dominated by the hard components.

Photon Production Lab. Ltd. [4] commercializes this novel source and develops even smaller synchrotron MIRRORCLE-6X, which is the 6 MeV version composing of the 60 cm OD magnet. The expected brilliance is order of 10^{11} photons, which will be the 1000 times more of MIRRORCLE-20. The total flux exceeds that of conventional SR.

At the beginning MIRRORCLE-20 was developed for FIR lasing according to "Photon Storage Ring" (PhSR) theory [5]. The PhSR required the space for placing a concentric barrel-shaped optical resonator inside the chamber surrounding the electron orbit, so that the outer diameter of the main magnet body became 1.2 m. Moreover it was designed to storage 50 MeV electrons at maximum in 15 cm orbit radius using a normal conducting magnet. By decreasing the electron energy to 6 MeV and aiming at only the x-ray generation, the MIRRORCLE-6X is designed to be the 60 cm outer diameter and 28 cm height, which are the one half in the diameter and one quarter in the height of MIRRORCLE-20.

The fabrication of the MIRRORCLE-6X is completed at present through the physical designing by computer simulations and mechanical designing. An overview of the completed MIRRORCLE-6X is shown in Fig. 1. We have started commissioning of the Microtron injector, and the beam injection to the synchrotron in September.

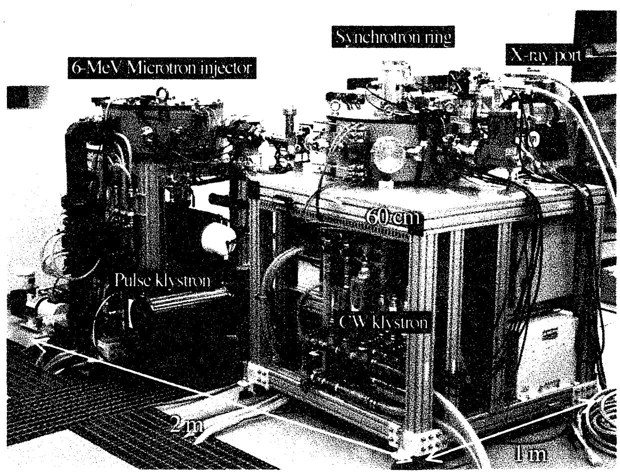

Figure 1: An overview of the portable synchrotron "MIRRORCLE-6X".

In this paper, MIRRORCLE-6X specifications and the feature of x-ray beam lines are given. Results of the beam test on the 6-MeV Microtron injector are shown. The 1/2-integer resonance injection method utilized in the MIRRORCLE-6X is also explained.

MIRRORCLE-6X SPECIFICATIONS

MIRRORCLE-6X specifications are listed in table 1. The 6-MeV microtron is the type, which has a LaB6 electron emitter inside the single cell-accelerating cavity. The electrons are extracted directory by the RF field. Because of this scheme we are able to apply strong magnetic field, which results in the 60 cm small out diameter magnet. The RF source is a powerful pulse klystron that utilizes multi-beam with 30 kV low anode voltage. The output power is 5 MW at peak, 5 kW on average, and 45 % efficiency with the 80 cm x 30 cm compact body. Operating frequency is 2.45 GHz.

The synchrotron is made of one peace of cylindrical normal conducting magnet of 60 cm OD. The 1/2-integer resonance is selected to provide stronger vertical focusing power compared with the 2/3-integer resonance used for MIRRORCLE-20, which is suitable to minimize the vertical x-ray source size. To introduce the 1/2-integer resonance injection scheme the n-value of the magnet field is set to 0.72 over 10 cm in radial direction around the central orbit. The expected beam size is less than mm in vertical, and 10 mm in horizontal. The perturbator to trigger the 1/2-integer resonance is one-tern air core magnet, which produces ±0.42 T•mm magnetic field at ∓30 mm from the central orbit.

The synchrotron accommodates three x-ray beam ports as seen in Fig. 2 together with the beam dynamics. Each port is assigned to X-ray crystallography, X-ray microscope, X-ray fluorescent analysis, and X-ray imaging. The X-ray microscope and X-ray crystallography beam line is equipped with a focusing element made of multi-layered 8-set of cylindrical mirrors aligned in concentric.

Table 1: MIRRORCLE-6X specifications

Synchrotron	Orbit radius: 15 cm Magnet outer diameter: 60 cm (Normal conducting magnet) Acceleration frequency: 2.45 GHz
Injector	6-MeV Microtron Peak current: 100 mA Pulse width: 1 μs Repetition rate: 400 Hz
Radiation scheme	Target radiation
Radiation angle	80 mrad
Photon spectrum	Continuous from 1 keV to 6 MeV
Time structure	Variable pulse width: 200 ns - 10 ms Repetition: Max 400 Hz
Intensity	1.2 R/Pulse
Imaging time	1 Pulse (200 ns)/Frame (576 cm^2)
Maxmum output	500 R/s
Calculated brilliance	5.5×10^{11} Photons/s/mrad^2/mm^2/0.1%λ
Calculated total photons	2.5×10^{11} Photons/s/0.1%λ

Resonance injection scheme

The resonance injection method is considered to be a time reversal of half integer resonance extraction. Its method is similar to the super-conducting synchrotron AURORA [6,7,8], and is different from MIRRORCLE-20, which uses the 2/3-integer resonance.

In resonance injection scheme, the perturbator (PB) placed under the main magnetic field kicks the beam electron toward outside from the central orbit and gradually changes its orbit to the central orbit. Phase plot of radial motion in the capture process is shown in Fig. 3. The beams injected on or near the separatrix are trapped

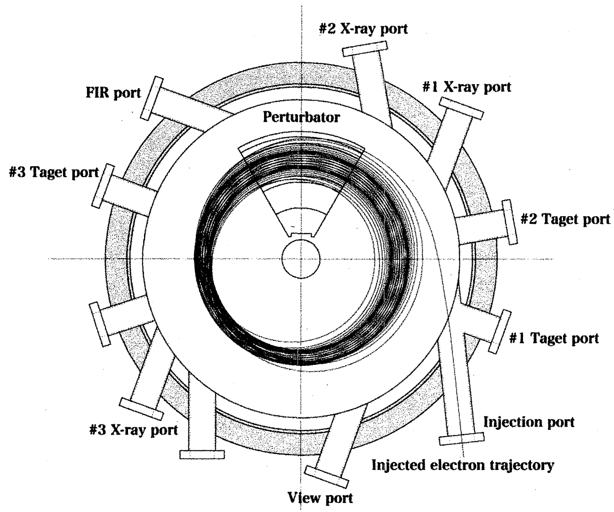

Figure 2: Injection trajectory on the median plane of the MIRRORCLE-6X obtained by the computer simulation is shown.

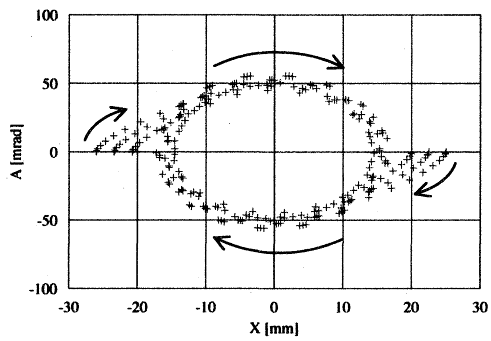

Figure 3: Phase plot of radial motion showing the capture process.

in the stable area after 20 turns by damping the PB field in a synchronized way. Thus the PB dose not disturb the orbiting electrons, the resonance injection method makes a continuous beam injection possible. This is an essential factor for the high brilliance x-ray production.

Injection trajectory

The main magnetic field distribution of the synchrotron was designed by the code TRIM. The computer simulation of the injection trajectory was made by the code DYNA to decide the position and angle of the injection port. We found that the measured magnetic field distribution is in good agreement with calculated one around the central orbit as shown in Fig. 4. However, the measured magnetic field around the fringe has some deviation from the calculated one. To take into account the effect of the fringing field to the injection trajectory, we have carried out the computer simulation by using the measured magnetic fields. We found that the 6-MeV electron beam can be injected from the designed injection port to the synchrotron as shown in Fig. 2.

The injection of the electron beam to the synchrotron is in progress. According to the last two experiences of the exact circular ring, AURORA and MIRRORCLE, we believe that the injection will be carried without problems as theoretically predicted.

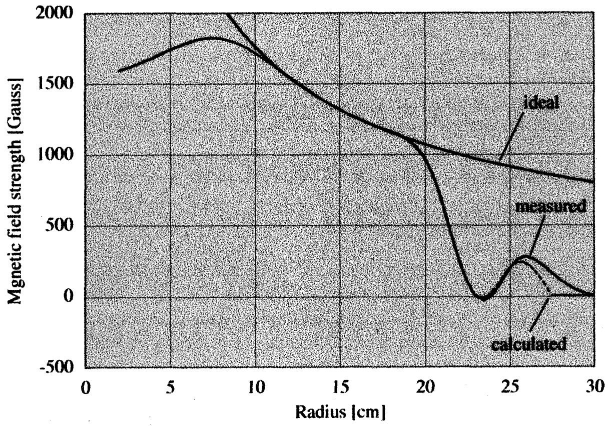

Figure 4: Main magnet field distributions.

COMMISSIONING OF MICROTRON

Commissioning of the 6-MeV microtron injector started on Sep. 20, 2003. At the first operation, the electron beam current of 5 mA was recorded with the probe placed in the last orbit. After by adjusting the cavity form, and by adjusting the median plane by changing slightly the current of the upper and lower coil, as a result, the electron beam current of more than 100 mA was extracted from the microtron. We use iron extraction channel. The pulse duration was 500ns as shown in Fig. 5. The fast current transformer (BERGOZ Instrumentation FTC-082-05:1) is used to measure the beam current. The emission of 1300 mA from LaB6 single crystal is obtained by heating with accelerated electron beams from the filament at 500V and 50mA. Accordingly the capture efficiency of 7.7 % is reached. The beam current of 100 mA with 400 Hz repetition rate guarantees that the X-ray brilliance of MIRRORCLE-6X is 1000 times higher of MIRRORCLE-20. In this project the back ground radiation from the cavity and the iron extraction channel is the important subject to be minimized. We will minimize these radiations dramatically by introducing electron-focusing elements inside magnet for medical and industrial use of this machine.

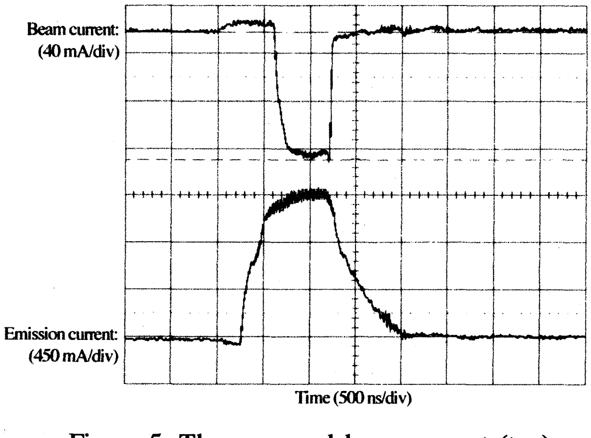

Figure 5: The measured beam current (top) and emission current (bottom).

CONCLUSION

The construction of MIRRORCLE-6X, the world smallest synchrotron was completed and the extraction of 100 mA from the classical microtron was achieved. The injection of electron beam to the synchrotron is in progress. The measured magnetic field distribution is in good agreement with calculated one around the central orbit. The 6-MeV electron beam should be injected through the designed injection trajectory. We are quite optimistic to this operation from the past experiences of Aurora and MIRRORCLE-20.

The microtron capture efficiency of 7.7 % is not so high. We hope we are able to increase some more by fine-tuning.

In summarizing, MIRRORCLE-6X will provide satisfactory x-ray flux for variety of applications. The high brilliant x-ray beam generated by only 60 cm OD synchrotron can be utilized on site in medical and industrial applications, which will change the paradigm of X-ray business.

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