COMMISSIONING OF FFAG ACCELERATOR AT KYUSHU UNIVERSITY

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Abstract

150 MeV FFAG accelerator is under construction at Center for Accelerator and Beam Applied Science on Ito Campus to promote activities in all related scientific, medical, engineering and educational field at Kyushu University. In this paper, status of the development of hardwares and the results of the beam commissioning of the injector are described.

INTRODUCTION

Center for Accelerator and Beam Applied Science has been established in April 2007 to promote activities in all the related scientific, medical, engineering and educational fields at Kyushu University. The facility mainly consists of a injector cyclotron and a 150 MeV Fixed Field Alternating Gradient (FFAG) accelerator [1-7]. The 150 MeV FFAG, a prototype machine to prove its usefulness for various applications such as proton beam therapy, was developed at KEK. The main parameters of 150 MeV FFAG are summarized in Table 1. Figure 1 shows the schematic layout of the accelerator.

The 150 MeV FFAG was transported from KEK to Ito Campus in March 2008. The construction work of the building of the accelerator facility has finished in August 2008. The beam commission injector cyclotron has finished successfully in December 2008.

The construction of the 150 MeV FFAG has started in January 2009, and almost completed recently. The beam commissioning, the pilot researches on nuclear, medical and life science will be carried out from 2010 to 2013.

In this paper, the results of the magnet alignment of the 150 MeV FFAG, beam commissioning of the injector cyclotron, the optimization of the beam capture process and the present status of the hardware developments are described.

PRESENT STATUS

Commissioning of Injector

As an injector of the 150 MeV FFAG, a Baby-Cyclotron was employed [8]. It delivers protons of 10 MeV. The repetition rate of the operation is 100 Hz. Because of the pulse operation of the FFAG accelerator, the RF duty factor is reduced to 4 %. Therefore, a pulsed beam of about 400 μsec wide is injected into the main ring.

The commissioning of the injector cyclotron has completed successfully and be fully operational. The current of the extracted beam was measured by the beam scraper at the extraction orbit. The measured mean current at 10 MeV was 3μA.

Table 1: Designed Parameters of 150 MeV FFAG

Energy	10 - 125 MeV
Type of magnet	Triplet radial (DFD)
Number of Cell	12
Average radius	4.47 - 5.20 m
Betatron tune (injection)	3.62 (Horizontal) 1.45 (Vertical)
Magnetic field	Focus: 1.63 T Defocus: 0.78 T
Revolution Freq.	1.5 - 4.2 MHz
Repetition	100 Hz / 2 cavities
Beam Current	1.5 nA

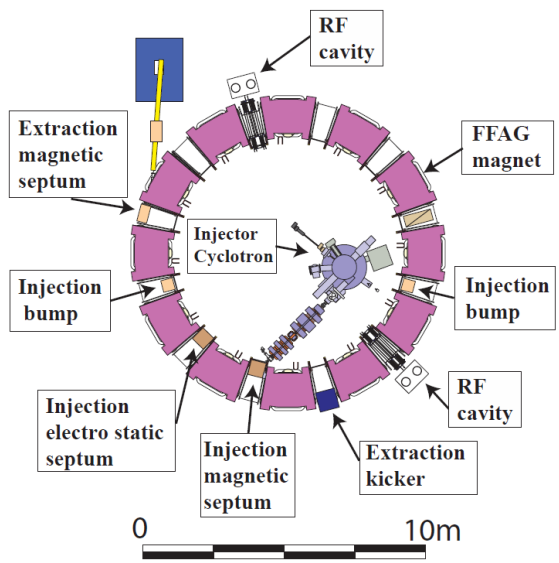

Figure 1: Schematic view of 150 MeV FFAG.

Alignment of the FFAG Magnets

The first step of the alignment procedure was to place 12 horizontal reference points on the floor. The reference points were placed at the corner of the regular dodecagon. The distance between two adjacent points was 1650±0.02mm.

The horizontal alignment of the FFAG magnets was based on the triangulation measuring technique. The FFAG magnets were aligned at their theoretical position with two theodolites which are placed on the reference points as shown in Figure 2. θ_a and θ_b are 55°10'42", θ_c and θ_d are 70°57'50", respectively. The vertical position of the magnets were aligned to the horizontal plane of the theodolites, the level of which was adjusted on the vertical level of the reference points.

Figure 3 shows that the measured horizontal displacement of the FFAG magnets. The results shown in Figure 3 indicate the horizontal alignment was achieved with sufficient accuracy within 0.2 mm. The vertical alignment has completed within 0.1 mm accuracy

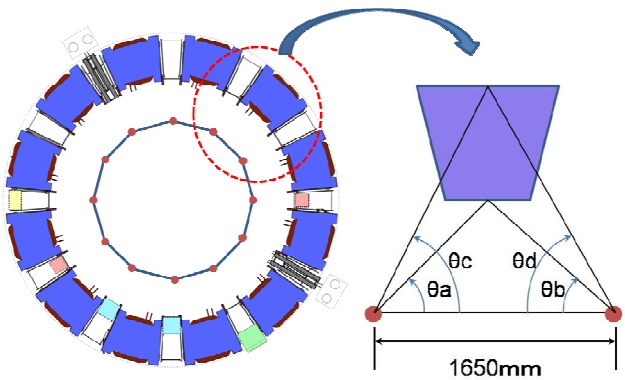

Figure 2: Layout of the reference points and the theodolites.

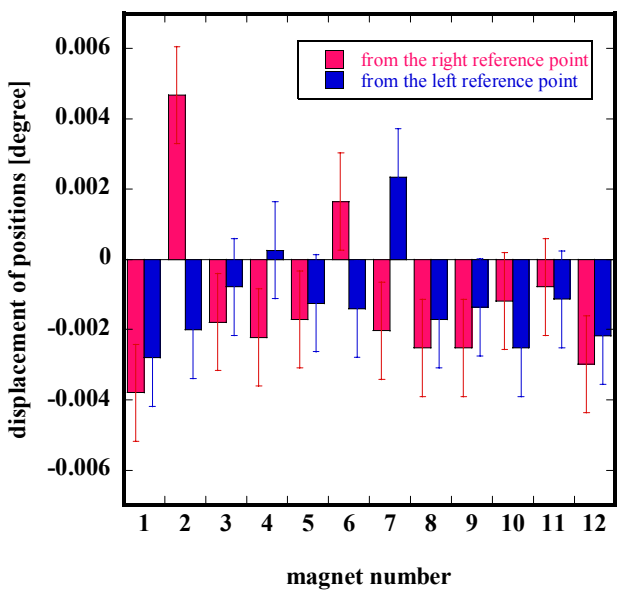

Figure 3: Alignment error at the center of front of the magnet.

Optimizations of the Capture Process

To achieve a 100 Hz repetition operation of the 150 MeV FFAG, the total capture time of the injected beam is constrained to be less than about 1 msec. A new method using a sawtooth rf field, which was proposed recently [9], was applied for the capture process of the injected beam. The result of the numerical simulation indicates that the capture time of 0.11 msec and 90% capture efficiency can be achieved with the sawtooth capture method.

Development of Beam Monitor

The new type of beam monitor [10] has been developed for the beam diagnostics of the 150 MeV FFAG. The beam radius which shifts from 4.47 m to 5.20 m imposes an aperture of the beam position monitor to be over 730 mm. Further, the monitor is desired to provide position information with an accuracy of less than 10 mm to optimize the operation of the accelerator. However, the non-destructive beam monitor to meet these requirements has not been developed hitherto, so that the destructive one has been applied for the beam diagnostics of the FFAG accelerator.

To satisfy these requirements, we have developed a new type of electrostatic pick-up type beam monitor with triangle electrodes. Figure 4 is a photograph of the developed monitor.

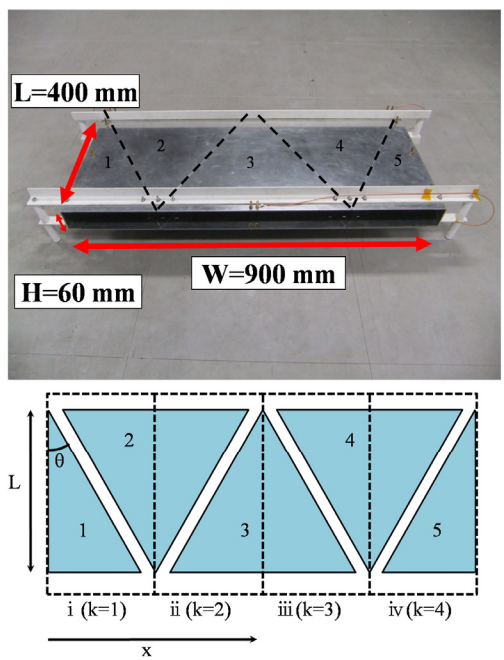

Figure 4: Developed beam monitor for 150 MeV FFAG.

Developed monitor is composed of five electrodes. The amount of electric charge induced on surface of electrodes is in principle proportional to the pass length of the beam trajectory between the electrodes. Electric charges are observed as the pick-up voltage generated between the electrodes and a vacuum chamber. The distance from the edge of the monitor (x) is expressed as

$$x = \frac{L\tan\theta}{2}\frac{q_{k+1}-q_k}{q_{k+1}+q_k} + \frac{L\tan\theta}{2} + (k-1)L\tan\theta \quad (1)$$

Figure 5 shows the calculated position with eq.(1) versus the position of the wire. It can be seen in the figure that the monitor has excellent position linearity. The accuracy of the calculated position is 6.2 mm and The resolution is 4.1 mm.

The result of the experiments shows that the beam monitor has sufficient frequency bandwidth and fills requirements of accuracy. The monitor will be set in the vacuum chamber and tested for measurement.

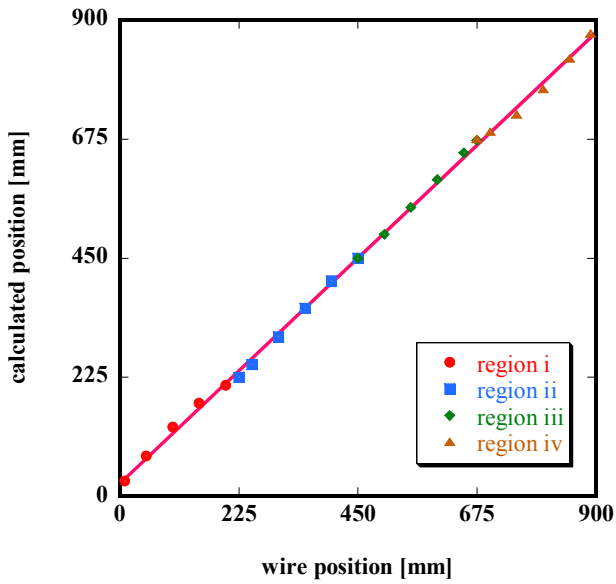

Figure 5: Position calculated from the measured the pick-up voltages using eq. (1).

Extraction Kicker

A magnetic substance installed at the straight section couples fringing field and distorts the closed orbit because the strength of the magnetic field in the straight section of the 150 MeV FFAG is about 400 Gauss. To resolve this problem, the new type of kicker magnet composed of air core coils are developed. The kicker is composed of three air core coils. These coils are connected in parallel so that total inductance of the kicker can be reduced. The measured inductance of the kicker is 0.95 μH

The required orbit separation at the extraction septum should be more than 13 mm [7]. In addition, rise time of the kicker field should be shorter than 250 ns, which is that is the revolution time at the extraction energy. Flat top of the kicker field is also required to be more than 100 ns, the beam width.

The switching power supply for the kicker consists of E2V CX1175 thyratron and PFN network. Designed value of peak voltage and current is 40 kV and 5100 A respectively.

Figure 6 shows measured output current of the power source with the dummy load. The rise time of the current was 170 ns (0-96%), and the flat top was 110 ns. The voltage and current of the power supply are 39 kV and 5100 A respectively. The results of the beam tracking simulation indicates that the sufficient orbit separation of 16 mm at the extraction septum can be obtained.

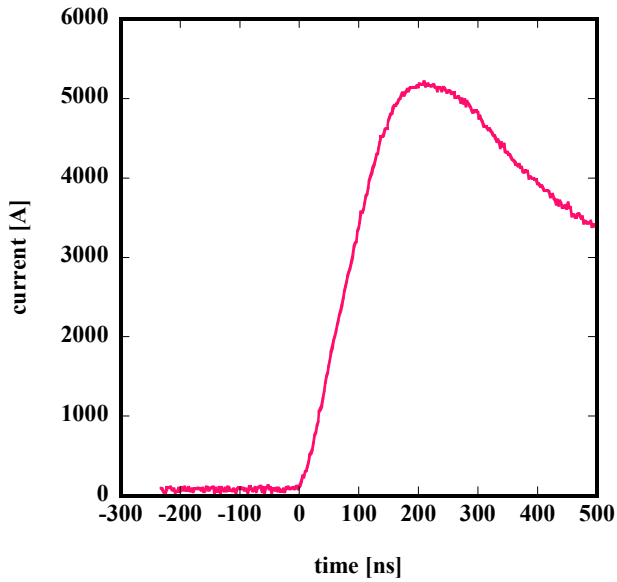

Figure 6: The measured output current.

SUMMARY

New type of kicker magnets and beam monitor has developed for 150 MeV FFAG. The alignment of the FFAG magnets and commissioning of the cyclotron have been completed successfully. The beam commissioning of the main ring will be started soon.

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