BEAM EXTRACTION OF 150MEV FFAG

M. Aiba*, Y. Mori*, H. Nakayama, K. Okabe*, Y. Sakamoto, A. Takagi, R. Taki#, and Y. Yonemura†
High Energy Accelerator Research Organization
1-1 Oho, Tsukuba, Ibaraki, 305-0801 Japan

Abstract

A beam extraction from FFAG has been performed for the first time at 150MeV FFAG constructed in KEK. 150MeV FFAG is expected to be a prototype for various applications. Therefore beam extraction is one of important goals. The extraction scheme is a fast extraction. Extraction efficiency more than 90% has been achieved. Details of the extraction devices and beam study are described in this paper.

INTRODUCTION

Fixed Field Alternating Gradient (FFAG) accelerators [1] have an ability to generate a high repetition pulse beam more than 100Hz since its guiding field is constant in time not to limit repetition rate. On one hand, it will be possible to provide large current beam with this feature. On the other hand, a beam having characteristic time structure, that is, a pulse beam of several hundred Hz will be available for applications such as a charged beam cancer therapy of spot scanning technique.

A 150MeV FFAG, which is expected to be a prototype machine for various applications, has been developed at KEK [2-6]. The design parameters are summarized in Table 1. Even there have been three FFAGs, two of which are electron machines constructed in MURA project [7] and one is proton machine of PoP FFAG constructed in KEK [8], beam extraction from FFAG have not been performed since these machines are dedicated to proof the principle of FFAG. Beam extraction is naturally essential for applications, and we need to demonstrate it. Beam extraction with high repetition operation has been tried in 150MeV FFAG.

The experiment of beam extraction was carried out preliminary in March and May 2005, and the extraction with 100Hz operation was successfully performed in November 2005. Details of the extraction devices and beam study are described in the following sections.

Table 1. Design parameters of 150MeV FFAG.

Lattice	Triplet (DFD)
Number of sectors	12
k-value	7.6
Beam energy (MeV)	12-150
Average radius (m)	4.47-5.2
Betatron tune	Hor: 3.69 - 3.80 Ver: 1.14 - 1.30
Maximum field On orbit (T)	F: 1.63 D: 0.78
RF frequency (MHz)	1.5 - 4.0
Repetition rate	100Hz/cavity

HARDWARES

The extraction scheme is fast extraction commonly used in synchrotrons while a kicker magnet and a septum magnet should work at 100Hz. Proton beam bunch is accelerated with rf voltage and extracted every 10msec. The layout of extraction devices and calculated extraction orbit in FFAG ring are shown in Fig 1 and in Fig 2, respectively.

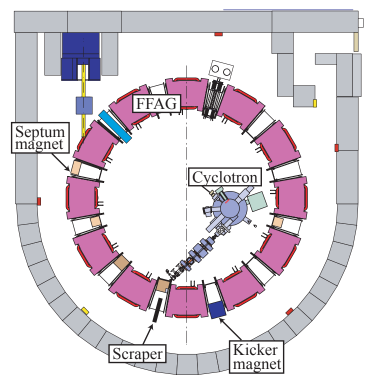

Fig 1. Layout of extraction devices.

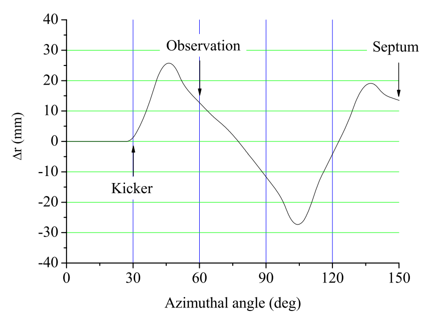

Fig2. Calculated extraction orbit.

Kicker

A requirement for the kicker magnet, which is an air-cored magnet, is about 500Gauss magnetic field with length of 0.6m. The maximum voltage and current of kicker power supply are 70kV and 2000A, respectively. The switching part of kicker power supply is a MOSFET (Metal Oxide Semiconductor Field-effect Transistor) array. Figure 3 shows a picture of kicker power supply and its switching part. The revolution frequency at extraction energy is about 4MHz and the observed rise time of kicker field is about 200nsec.

* Present address: Kyoto University Research Reactor Institute.
# On behalf of Graduate University for Advanced Studies.
† On behalf of Kyushu University.

(a)

(b)

Fig 3. Kicker power supply (a) and switching part (b).

Septum

A requirement for the septum magnet is about 4kGauss magnetic field with length of 0.5m. Furthermore, a thickness of the septum should be as thin as possible. The extraction septum magnet is a pulse magnet with a fringing field suppression plate. Figure 4 shows a cross-section drawing of the septum magnet.

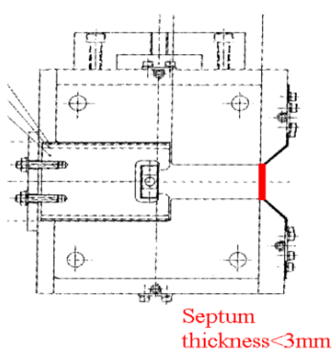

Fig 4. Cross-section drawing of extraction septum.

A thickness of septum is less than 3mm. High efficiency of beam extraction is expected with this septum magnet.

Timing module

Since a pulse width of septum magnet excitation is 150μsec a rough adjustment of timing, within a few μsec, is good enough. It is, however, important to adjust timing precisely between the excitation of kicker magnet and beam bunch. An arbitrary waveform generator, which generates low-level of acceleration rf voltage, is employed to feed parallel an trigger for the kicker power supply. The timing for the kicker magnet excitation can be precisely defined with the module, and time jitter between low-level rf and the trigger for the kicker power supply is only a few nsec in this system.

"Return-yoke free" magnet

The magnet of 150MeV FFAG is "return-yoke free" magnet [2] in which there is no return yoke inner and outer side of the magnet. Figure 5 shows a picture of the magnet together with its schematic magnetic circuit.

(a)

(b)

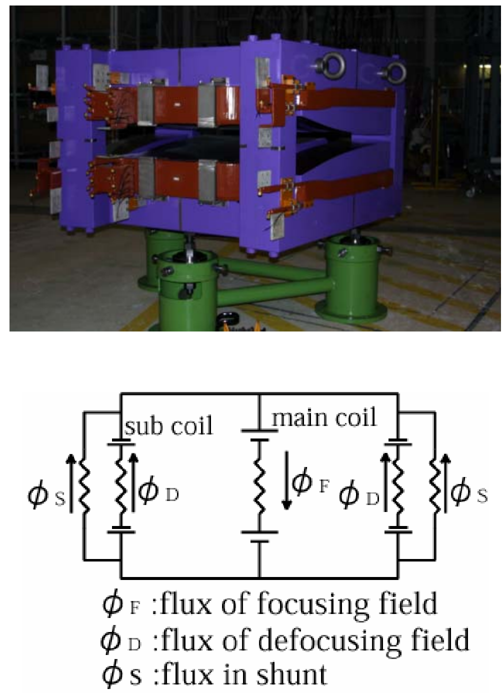

Fig 5. A picture of "return-yoke free magnet" (a) and magnetic circuit (b)

With the magnet, it is possible to extract beam from the region of FFAG magnet. If the beam is extracted from the region of straight section, the extraction septum magnet should bend the beam in large angle with small curvature radius. Therefore return-yoke free magnet drastically reduces a requirement for the extraction septum magnet.

BEAM STUDY

Beam extraction has been performed following the procedures below.

- Confirm that accelerated beam reaches near by the extraction septum magnet.
- Excite the kicker magnet and measure a separation between the orbits of circulating beam and kicked beam.
- Excite the septum magnet in accordance with kicker magnet excitation and observe extracted beam with a fluorescent screen.

Beam orbit in 150MeV FFAG shifts toward outer radius during acceleration like in cyclotron. For high efficient extraction, the final orbit should be near by the extraction septum magnet. When the beam is accelerated in excess of the final energy, it will hit the extraction septum magnet. An electrode, a destructive current monitor, is set at the entrance of the extraction septum magnet temporarily to detect over accelerated beam. With a signal from this electrode we confirmed that accelerated beam reaches near by the extraction septum magnet.

In order to measure a separation between the orbits of circulating beam and kicked beam, a movable scraper, which is inserted from outer side of the ring, is employed. A current of beam hitting to the scraper was measured by changing the scraper position. The observation point was selected at the next section down from the kicker magnet since the separation at this point is almost the same to one of the septum magnet section as shown in Fig 2. Figure 6 is typical result of the measurement.

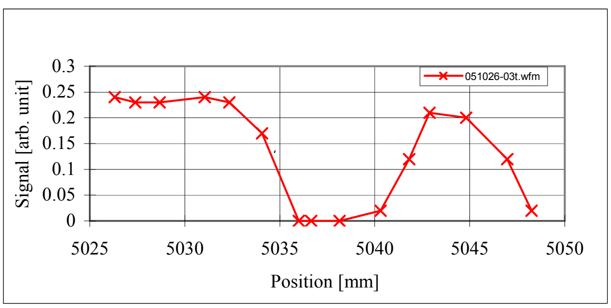

Fig 6. Typical result of separation measurement.

In Fig 6, it is clearly seen that the kicked beam is separated from the circulating beam. To maximize the separation, a position and angle of the kicker magnet were modified iteratively.

In order to observe an extracted beam, a fluorescent screen and a CCD camera were set as shown in Fig 7 schematically, and a screen shot of CCD camera is shown in Fig 8.

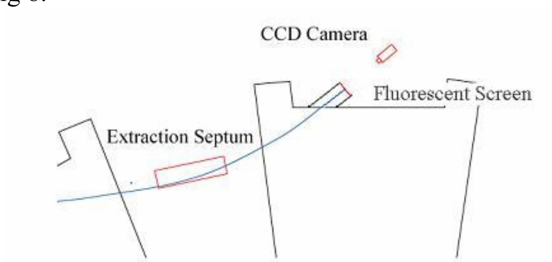

Fig 7. Set up of fluorescent screen and CCD camera

Figure 9 shows signal from bunch monitor. It is seen that beam is injected, accelerated and extracted within 10msec.

Fig 8. A screen shot of CCD camera.

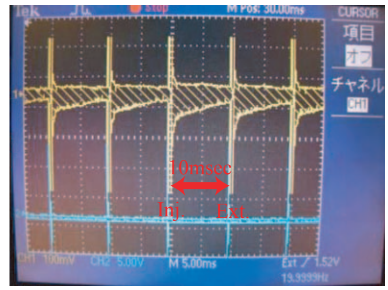

Fig 9. Signal from bunch monitor.

Beam current at the final energy orbit and at the extraction beam line (the same point to the fluorescent screen in Fig 7.) were measured. We found then that the extraction efficiency was more than 90%.

DISCUSSION AND SUMMARY

The scheme of fast extraction has worked in 150MeV FFAG as well as in synchrotrons. Fast extraction scheme will be available even in higher energy FFAG by means of multiple kicker magnets to secure enough beam separation.

The extraction beam energy, which is estimated from measured beam position at the final energy shown in Fig 6, is about 100MeV. At this moment, injection beam energy is 10MeV while it is expected to be 12MeV in the design parameter.

In summary, we have successfully performed beam extraction of 150MeV FFAG with 100Hz operation. It can be said that our experimental results have shown a great potential of FFAG.

REFERENCES

[1] T. Ohkawa, originally proposed at the symposium on Nuclear Physics of the Physical Society of Japan in 1953.

[2] M. Aiba et al., Proc. of PAC01, pp3254-3256

[3] J. Nakano et al., Proc. of EPAC02, pp1028-1030

[4] T. Yokoi et al., Proc. of EPAC02, pp1076-1078

[5] Y. Yonemura et al., Proc. of PAC03, pp3452-3454

[6] Y. Yonemura et al., Proc. of EPAC04, pp2640-2642

[7] F.T.Cole et al., Rev. Sci. Instrum., Vol.28, No6, p403 (1957)

[8] Y. Sato et al., Proc. of EPAC00, pp581-583