COMMISSIONING OF 150MeV FFAG SYNCHROTRON

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Abstract

A 150MeV proton FFAG (Fixed Field Alternating Gradient) synchrotron has been constructed to be a prototype for various applications such as proton beam therapy. At the moment, all the components are assembled, and multi-turn injection and beam storage were successfully performed. We are in the phase of beam acceleration up to final energy and expect the beam extraction in a few months. In this paper, beam commissioning results such as orbit correction, tune survey are presented..

INTRODUCTION

There are two technical challenges in the 150MeV FFAG. One is the use of yoke free magnet [1]. The yoke free magnets make the beam injection and extraction easier than the conventional FFAG triplet magnets. The other is beam extraction from the ring, that was not performed in a smaller machine. PoP(Proof of Principle) FFAG.

The construction of the 150MeV FFAG has been started in September 2002 at the east counter hall in KEK, and completed in April 2003[2]. The main parameters of the 150MeV FFAG are summarized in Table 1. Figure 1 shows the schematic layout of the accelerator.

Table 1: Main Parameters of 150MeV FFAG

Type of Magnet	Triplet Radial (DFD)
Num. of Sector	12
k-value	7.6
Beam Energy (MeV)	12→150 (proton)
Average Radius (m)	4.47→5.20
Betatron Tune	Hor. 3.69∼3.80 Ver. 1.14∼1.30
Maximum Field (T) (on orbit)	Focus 1.63 Defocus 0.78
Repetition (Hz)	250

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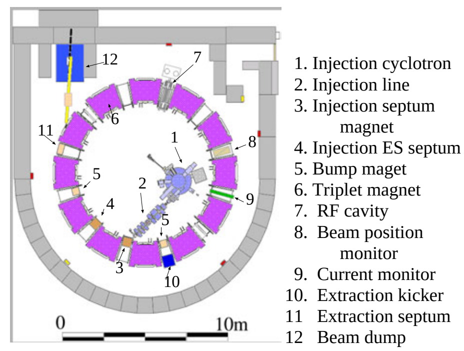

Figure 1: Schematic view of 150MeV FFAG

COMMISSIONING

Injector

As an injector, a cyclotron which delivers a 10MeV proton beam was employed. Because of a pulse operation of the FFAG accelerator, the duty factor of the cyclotron has to be reduced to 1/100 to avoid the beam loss at injection. The modulation of cyclotron RF voltage makes a pulsed beam of about 100 μsec wide to be injected into the ring. In addition, to detect a beam position, a beam chopper, which uses pulsed electric field to make pulse trains with FFAG RF frequency, is installed in the injection line.

Beam Injection

The injection system consists of septum magnet, electrostatic septum, and a pair of bump magnet to make a bump orbit in those septa. An injected beam is deflected by the magnetic septum and its angle is adjusted by the electrostatic septum. To observe beam position, two thin plates are installed near those septa.

First, we steer a beam to a thin plate at the upstream magnetic septum. Once a beam is observed at thin plate, fine-tuning of two septa and magnets is performed. Because of large betatron oscillations initially induced, positions of beam at second and third turn can be detected. Secondly, we adjust parameters with observing beam positions near the electrostatic septum. Figure 2 shows measured beam position when we succeeded in a beam injection for the first time.

Measured beam positions can be transferred to beam location in phase space. Injected beam must be at a parallel position to design orbit with a separation corresponding to bump orbit at the septum. In Figure 2, it is indeed seen that injected beam was around ideal position. After these tuning is finished, bump magnets are exited to make a beam circulate for many turns as shown in Figure 3.

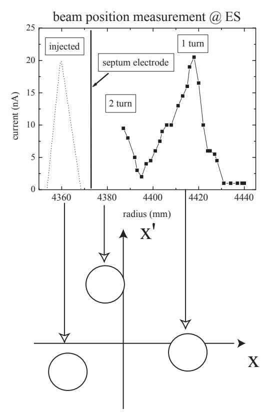

Figure 2: Beam position measured for injection tuning Measured beam position is transferred to beam location in phase space, assuming $\nu_x \sim 3.6$

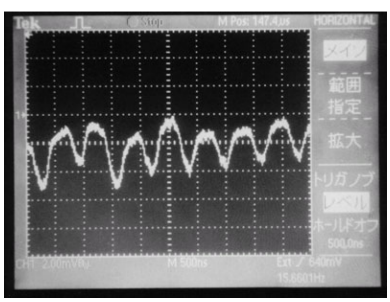

Figure 3: First circulating beam signal obtained by a bunch monitor. Injection beam is chopped shorter than revolution period.

COD source and its compensation

Large gap to realize gradient magnetic field leads a few hundred Gauss of fringing field at straight section. Any magnetic substance installed at straight section couples fringing field and affects beam orbit. Injection bump magnets and core of RF cavity are particularly sources of COD. The magnetic septum seems to be negligible small source, since it does not cover beam orbit. The COD are compensated with permanent magnet and additional bending magnets at the same location of the source as shown in Figure 4. Strength is adjusted by varying number of attached permanent magnet piece ($5 \times 40 \times 60$mm).

When it is correctly compensated, beam position without bump magnets and with bump magnets and compensator becomes identical. Strength of COD suppression magnet for RF is also adjusted in similar way. Figure 5 shows observed beam positions with or without COD compensator.

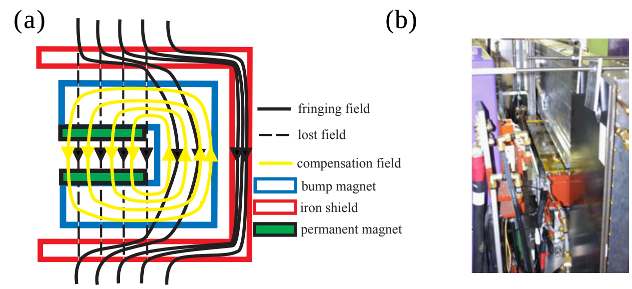

Figure 4: COD suppression magnets (a) Schematic view of Bump (b) Figure of RF COD magnet COD suppression magnet

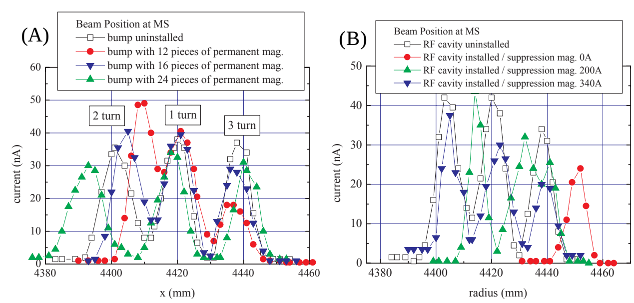

Figure 5: Beam position measurement (a) Bump COD Suppression (b) RF COD Suppression

Measured Tune

Betatron tunes are measured on various conditions. By varying a ratio of focusing and defocusing field strength (FD ratio), tunes can be controlled mainly in vertical direction. Tunes are slightly changed by COD suppression, because of COD caused tune shift. Figure 6 shows the measured tunes for various FD ratio.

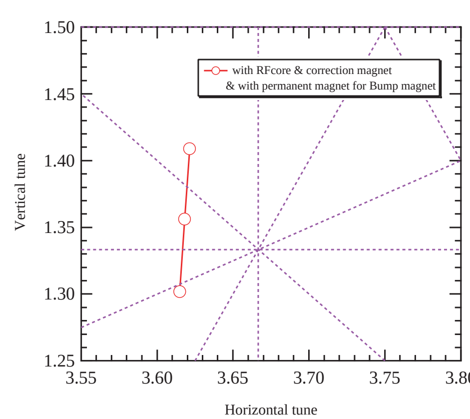

Figure 6: Tune measurement for various FD ratio

In vertical direction, measured value of changes is 0.11 per defocusing magnet coil current of 200A. This agrees with calculation. Tune shift caused by bump magnets is measured to be 0.02 in horizontal direction. It is also consistent with calculation. However, design value of horizontal tune at injection energy is 3.72, whereas measured value of 3.62 with COD corrected. This slight difference might be caused by following three reasons. One is residual COD, which cannot be corrected exactly. Second is that the calculation was made based on field map of single magnet. In reality, twelve magnets are put together to make a ring and there should be magnetic interaction among them. The last is coil current of defocusing magnet is increased at about 1.3 times compared to design value in order to adjust FD ratio. It is due to uncertainty in B-H curve, which is used in the magnetic field calculation. That was crucial to a material for shunt[1].

Beam Acceleration

The RF parameters are summarized in table 2. The RF cavity consists of rectangular 2 cores of 1.0m(hight)×1.7m(width)×30mm(thickness)[4]. A 55kW rf amplifier which consists of two tetrodes(Eimac 4CW25000A) was used.

Table 2: Main Parameters of RF system

Repetition rate	125Hz (DFD)
Harmonic number	1
RF frequency	1.5∼ 4.6MHz
Acceleration Voltage	8kV$_{pp}$
RF output power	55kW
Core material	FINEMET(FT-3M)[3]
Number of Core	2

We tried beam acceleration with the acceleration voltage of 8kV$_{pp}$ and synchronous phase of $15.63°$. The RF frequency was slowly changed from 1.555MHz to 1.755MHz during this process. Before accelerating the beam to the final energy, adiabatic capture and bunching were verified.

The adiabatic capture was successfully carried out as shown in Figure 7. We are to extract the beam from the ring.

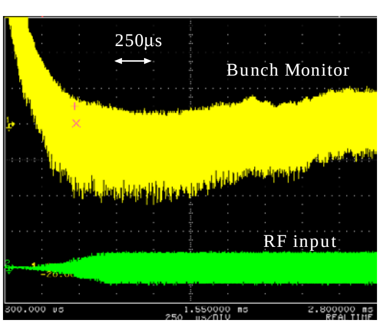

Figure 7: Circulating beam signal observed by bunch monitor

Beam Extraction

Although it is not tested yet, fast extraction with kicker magnet and septum magnet is ready. Figure 8 shows the power supply for kicker magnet. It employs the array of IGBT and can generate the pulse current with a rise time of 130ns. The maximum voltage and current is 70kV and 2000A, respectively. The power supply has already installed in the experimental area and we expect the beam extraction soon.

Figure 8: Power supply of kicker magnet

SUMMARY

The commissioning of 150 MeV FFAG is well in progress. We established beam injection and circulating orbits. We have identified the major source of COD, that is magnetic materials in a straight section where fringing field is not negligible. The COD is sufficiently compensated with permanent and normal magnets put at the right position of the source. Beam acceleration is demonstrated and the accelerated beam will be extracted soon.

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