DEVELOPMENT OF FFAG ACCELERATOR AT KEK

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Abstract

The 150MeV proton FFAG accelerator is constructed and a beam is extracted at the final energy. This is the prototype FFAG for various applications such as proton beam therapy. We are now in preparation for using an extracted beam in the practical applications.

INTRODUCTION

Right after the success of PoP (Proof of Principle) FFAG synchrotron, design and construction of a larger scale FFAG were started. That is to be a prototype for various applications such as proton beam therapy. Energy was chosen at 150MeV. The beam commissioning of injection and acceleration has been successfully performed till April 2004.

The main parameters of the 150MeV FFAG synchrotron are summarized in Table 1, and Figure 1 shows the schematic layout of the 150MeV FFAG.

Table 1: Main Parameters of 150MeV FFAG

Type of Magnet	Triplet Radial (DFD)
Number of Sector	12
k-value	7.6
Beam Energy (MeV)	10 to 125 /12 to 150
Betatron Tune (at injection)	Horizontal 3.7 Vertical 1.4
Average Radius (m)	4.47 – 5.20
Rf frequency	1.5 – 4.6MHz
Repetition	100Hz/1 Cavity

BEAM COMMISSIONING

Injection

As an injector of the 150MeV FFAG synchrotron, a cyclotron was employed. It delivers protons of 10MeV. The injection system consists of a magnetic septum, a position adjustable electrostatic septum, and a pair of bump magnets. An injected beam is first deflected by the magnetic septum, and its position and angle are adjusted by the following electrostatic septum. [1] [2]

There is a technical adaptation for the injection bump magnets. In the original design, the bump magnets consist of ferrite cores. It turns out that the ferrite cores couple fringing field and ferrite core is saturated magnetically. To avoid the saturation, we install iron shield around them. However, orbit is distorted due to irons. To compensate the fields, permanent magnets are attached. Although the structure of bump magnets becomes complicated, the beam injection with the bump magnets and the beam acceleration were successfully performed.

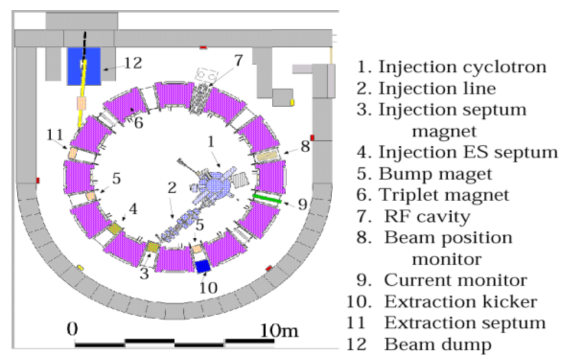

Figure 1: Layout of 150MeV FFAG synchrotron.

To simplify the structure, the magnets that consist of air core coils were finally developed and employed. The maximum magnetic field of the magnets is about 550 Gauss with the pulse current of 2000A. And the beam injection with these magnets and the beam acceleration are also successfully performed. We chose the magnets that consist of air core coils because they have advantage over the magnet consisted of ferrite in terms of COD compensation.

Acceleration

Since the magnetic field of FFAG synchrotron is fixed, the acceleration cycle only depends on the sweep rate of the rf frequency. In other words, acceleration cycling rate can be very high if an rf cavity with high voltage and broadband is available. A high gradient rf cavity using MA (magnetic alloy) core are employed for the 150MeV FFAG synchrotron in order to satisfy these requirements. The design parameters of rf amplifier are summarized in Table 2. [4], [5]

Table 2: Design parameters of rf amplifier

Repetition rate	100Hz
Harmonic number	1
Acceleration Voltage	8.0 kVpp
rf output power	55kW
Core material	FINEMET(FT-3M) [4]

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It was found that the fringing field of FFAG magnets reduces shunt impedance. And it also becomes a source of COD because of coupling between fringing field and MA core. To resolve the problem, iron magnetic shield is installed. To compensate COD, additional bending magnets are attached next to the cavity.

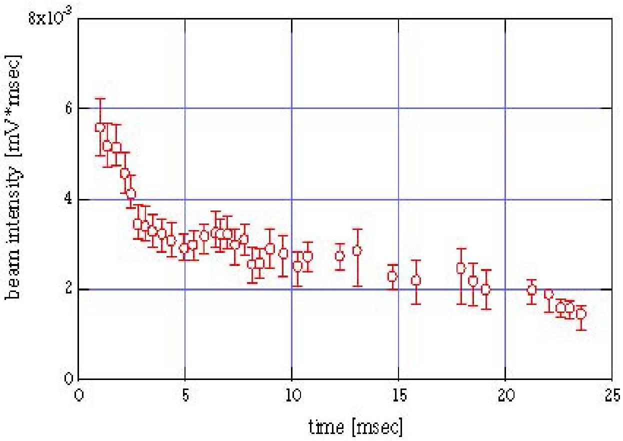

Figure 2: Beam intensity during acceleration.

The beam acceleration up to the extraction energy has been performed. First, the injected beam is captured adiabatically over first 1msec, and then accelerated up to the extraction energy. During acceleration, the acceleration voltage and the synchronous phase were kept at 8kVpp and 30 degree respectively. In order to observe the accelerated beam, a bunch monitor is installed at the straight section. The intensity is read as the time integration of bunch signals of the bunch monitor.

Figure 2 shows that beam intensity. The horizontal axis is the time. It indicates that the beam acceleration is successfully performed.

The beam loss occurs just after the acceleration is started. The phase shift after adiabatic capture causes the beam loss. The simulation supports this result.

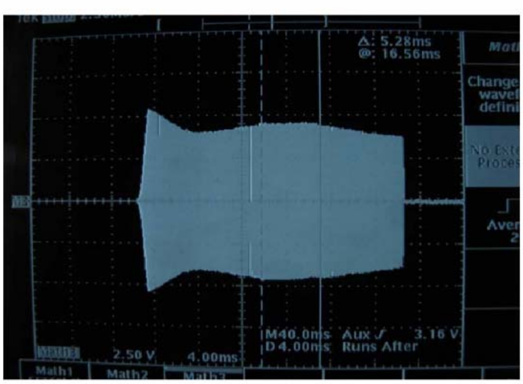

Figure 3: Voltage level of rf amplifer. The dip of rf voltage is observed at 5.0 ms. the horizontal scale is 4.0 ms/division.

Another source of beam loss is the temporary drop of the rf voltage. The Figure 3 shows the rf voltage during the beam acceleration. The reduction of rf voltage occurs because of not enough power of the rf amplifier. This will be solved by improvement of the power source, and it is in preparation now.

Tune Survey

The survey of horizontal and vertical tune was performed. The horizontal tune is measured with the rf knock-out method. The bunch monitor that consists of thin triangular electrode is installed at a straight section. The vertical tune is measured with the rectangular bunch monitor. In order to excite the vertical betatron oscillations, electrodes are installed.

Figure 4 shows that the fractional parts of tune. The measurement range of horizontal tune is limited because electrode is not covered in the full range of orbit excursion.

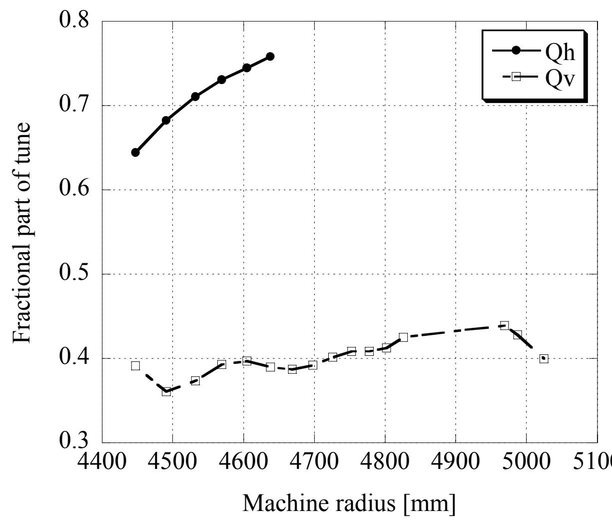

Figure 4: Fractional parts of horizontal and vertical tune along the machine radius.

Extraction

Figure 5 shows the layout of components for the beam extraction system. The extraction system consists of a fast kicker magnet and a magnetic septum. The kicker magnet is composed of a pair of rectangular 4 turns coils. The power supply for the kicker magnet employs an array of IGBT modules. In the present condition, it supplies the pulse current with a rise time of 250ns. The maximum voltage and current are 72kV and 1650A, respectively. The maximum repetition rate is 250Hz.

The beam displacement is observed with a Faraday cup. It is installed at the centre of the straight section where the injection septum is installed. Figure 6 shows the profiles of the extracted beam and the circulating beam. It was observed that the maximum displacement by the kicker magnet is about 15mm.

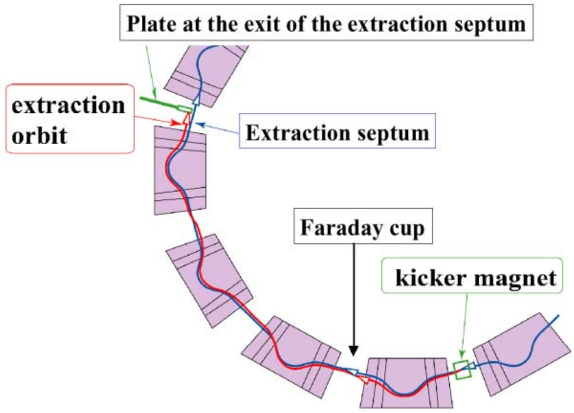

Figure 5: layout of extraction system and Faraday cup.

The beam displaced by the kicker is further deflected with the extraction septum. To observe the extracted beam, copper plate is installed at the exit of the extraction septum. When the extraction septum is excited with current of 650A, the beam is successfully extracted.

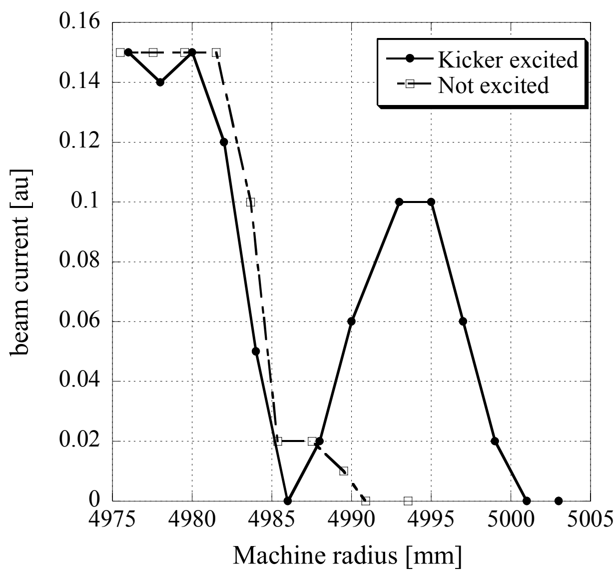

Figure 6: displacement of beam position after exciting kicker magnet at the injection septum.

SUMMARY

The beam acceleration and extraction of 150MeV FFAG synchrotron is successfully demonstrated. We are now in preparation for using an extracted beam in the practical applications.

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