BEAM EXTRACTION OF THE POP FFAG WITH A MASSLESS SEPTUM

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Abstract

We propose a new extraction scheme with a massless septum magnet in FFAG accelerator, with which the DC beam can be extracted. The system consists of a combination of massless and ordinary septa without kickers. After passing through the massless septum, the beam tail is stretched by the field gradient of the massless septum magnet, and that can be extracted with an ordinary septum. From the result of the tracking simulation, the principle of the extraction scheme is verified. The result of the performance test of the massless septum indicates that the magnet works well as designed, and this scheme is feasible.

INTRODUCTION

After the first proton acceleration of the Proof of Princple (PoP) FFAG synchrotron, we have been studying the scheme of the beam extraction from it.

Due to the fast beam acceleration of FFAG accelerator, fast extraction with high repetition kicker magnet is ordinary adopted as the beam extraction scheme of FFAG. Therefore he development of kicker with high repetition rate is a technical challenge. On the other hand, the slow extraction scheme using the resonance of horizontal betatron oscillation requires complicated control system. Here, by making use of the characteristics of FFAG accelerator, a novel slow extraction scheme is proposed.

BEAM EXTRACTION WITH A MASSLESS SEPTUM MAGNET

The proposed scheme employs so called "massless septum" which is proposed by LANL group [1] [2]. Typical configuration of the magnet is shown in Figure 1, and the generated field is typically as shown in Figure 5. The field of the massless septum is divided into two types. One is flat field region and the other is the region with field gradient. The region with the field gradient is the key of the proposed scheme.

The principle of the extraction schemes is as follows. As the beam is accelerated, the orbit approaches to the region with field gradient. Finally, when a part of the beam traverses the region, the beam tail is stretched by the field gradient (Figure 1 (a)). The beam tail is scraped with ordinary septum, and extracted (Figure 1 (b)). It is the basic idea of the proposed extraction scheme. After that, the beam tail is returned to the closed orbit in the secondary massless septum magnet (Figure 1 (c)).

Similar to the case of slow extraction, the high efficiency of the beam extraction is expected when the extraction scheme with massless septum magnet is employed. Because the tail of the beam that is developed with massless septum magnet is sufficiently long compared to the thickness of the coil or wire. the efficiency of beam extraction with a massless septum magnet can be obtained as below:

$$\epsilon = 1 - \frac{t}{\Delta X / \cos\alpha} \quad (1)$$

ϵ, t and ΔX are the efficiency of the extraction, the thickness of the electric septum and the moving distance after the acceleration, respectively. α is an acute angle between the beam and it's tail.

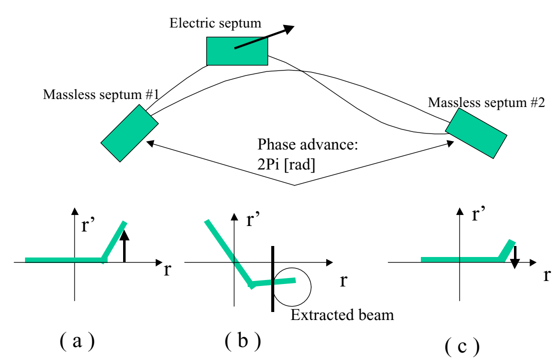

Figure 1: Extraction scheme with massless septum magnet (a) beam tail is developed (b) beam is extracted with an electric septum (c) beam tail returned to the closed orbit

TRAKING SIMULATION OF THE BEAM EXTRACTION WITH MASSLESS SEPTUM

To examine the feasibility of the extraction scheme with the massless septum magnet, single-particle tracking simulation using Runge-Kutta method was carried out in the PoP FFAG synchrotron. For the simplicity of the simulation, the beam is assumed to be linealy distributed (See Figure 1).

Figure 2 shows that the configuration of the extraction system for the simulation. Since the phase advance per one

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cell of the PoP FFAG is nearly equal to 90 degree, two massless septum magnets are separated by 4 cells in this extraction scheme. The result of the simulation is shown in Figure 3 As the result of the tracking simulation, the principle of the extraction scheme is verified.

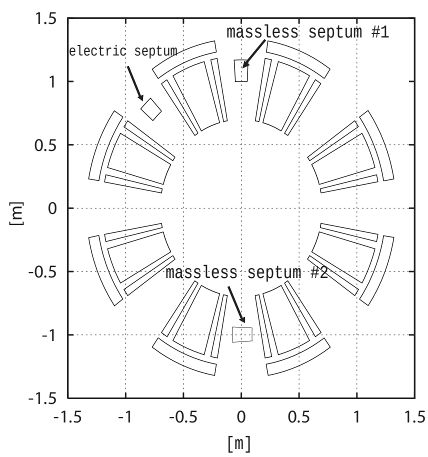

Figure 2: Configuration of the extraction system.

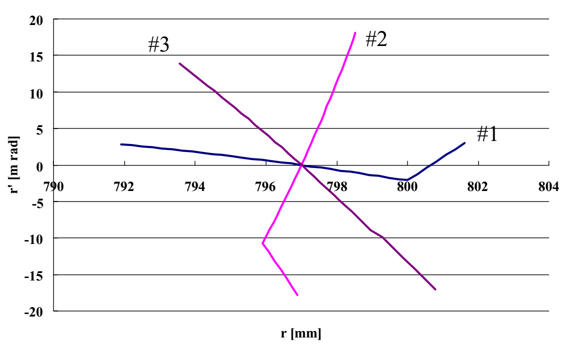

Figure 3: Shape of the beam in the phase space at the first masless septum magnet (#1), electrostatic septum (#2) and the second massless septum magnet (#3).

DESIGN OF THE SEPTUM MAGNET

A septum magnet has been designed for the purpose to examine the feasibility of use the massless septum magnet. the calculation of magnetic field were carried out with the computer code POISSON. The upper half of the designed magnet is shown in Figure 4. The calculated field lines are also presented in the same figure.

The horizontal size and vertical size are 17cm and 4.5cm respectively. A pair of shims is put on the pole edges to pump the magnetic field. The gap height from the medium plane is 5mm in the extracted beam region. When the coil currents are 1000AT, the magnetic flux density in the

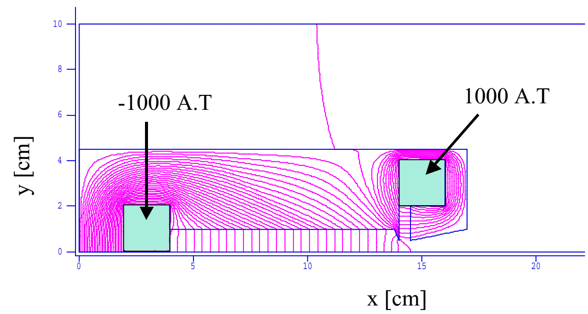

Figure 4: Upper half of the designed magnet. The calculated field lines are also presented in this figure.

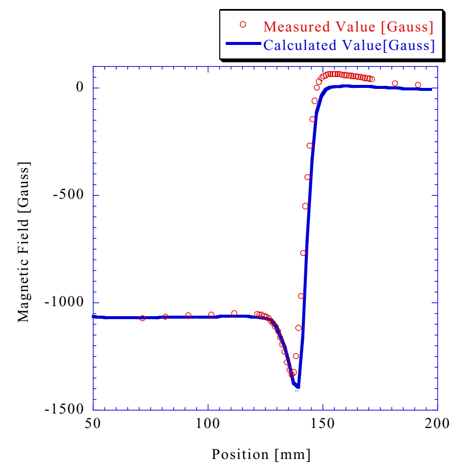

Figure 5: Magnetic flux density at the median plane plotted as a function of the horizontal position.

extracted region is 0.1 T. In Figure 5, the magnetic field strength at the median plane is plotted as a function of the horizontal position from left edge of magnet.

We made have built a model of the massless septum magnet based on the field calculation, and The measurement of the magnetic field was carried out. The result of the measurement also is shown in Figure 5. This figure indicates that the calculation result and the experiment result show well agreement. The picture of the magnet is shown in Figure 6.

EXPERIMENT WITH THE PROTOTYPE MAGNET

Using the PoP FFAG synchrotron, the perfomance of the prototype magnet was investigated. The aim of the experiment was confirming the effect that the beam tail is stretched by the field gradient of the magnet. The massless septum magnet was installed in the chamber of straight section (Figure 2 #1). The ring Faraday cup was installed at the exit of the magnet to observe of the beam. In this experiment, we have compared the beam oscillation when the magnet was excited and not excited. The typical experimental result is shown in Figure 7. In this figure, when the magnet is not excited, the rising edge of the signal is sharp. The signal of the faraday cup is rising gradually, and the rise time becomes fast when the magnet is excited. This result indicated that the beam traversing inside of the massless septum has been successfully extracted.

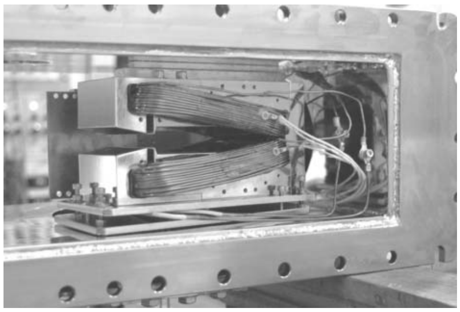

Figure 6: Picture of the massless septum magnet.

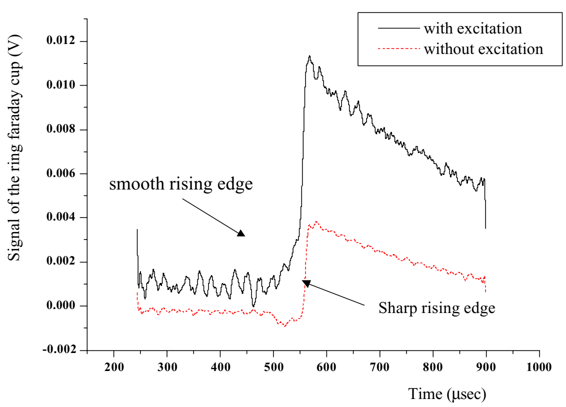

Figure 7: Signal of the faraday cup with excitation magnet and without

SUMMARY

We have proposed a new extraction scheme with massless septum magnet, and the feasibility of the scheme is examined. From the result of the tracking simulation, the principle of the extraction scheme is verified. The result of the performance test of the massless septum indicates that the magnet works well as designed, and the extraction scheme is feasible.

To realize the scheme, the additional simulation in detail and experiment are now going on.

REFERENCES

[1] J. Liu et al., Proc. of the Advanced Hadron Facility Accelerator Design Workshop, 1988.

[2] H. S. Butler et al., Proc. of the advanced Hadron Facility Accelerator Design Workshop, 1988.

[3] Eugene P. Colton, Slow Extraction At LAMPF II, IEEE Trans. on Nucl. Scie., Vol. NS-32, No.5, 2439(1985)

[4] M. Aiba et al., "Beam Injection And Extraction in 150MeV FFAG", Proc. of European Particle Accelerator Conference, 1076(2002)

[5] M. Aiba et al., "DEVELOPMENT OF A FFAG PROTON SYNCHROTRON", Proc. of 7th European Particle Accelerator Conference, 581 (2000)

[6] M. Yoshimoto et al., "RECENT BEAM STUDIES OF THE POP FFAG PROTON SYNCHROTRON", Proc. of Particle Accelerator Conference, 3254 (2001)