BEAM INJECTION INTO EMMA NON-SCALING FFAG

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Abstract

Non-Scaling FFAG has unique characteristics of large transverse acceptance and rapid beam acceleration with a relatively small beam excursion for a fixed field accelerator, and broad range of application is expected. To demonstrate the feasibility as a practical accelerator, construction of a test machine called EMMA is proposed. The project is planned to build a Non-Scaling FFAG which accelerate an electron beam from 10MeV to 20MeV. As the nature of a test machine, the injection and extraction scheme must accommodate large varieties of conditions. Due to the nature of the accelerator, that is the betatron tune changes drastically changes during beam acceleration, the requirements enforces a different approach in the design of injection system compared to the conventional circular accelerators, and make it challenging. In the paper, the injection scheme of EMMA non-scaling FFAG is described.

INTRODUCTION

Recent years, NS-FFAG (non-scaling Fixed Field Alternating Gradient) accelerator has been drawing attentions due to its unique features. It is capable to accelerate a large emittance beam rapidly with relatively smaller orbit excursion. The lattice basically consists of linear elements, and this gives freedom to change operation points by varying the magnet setting. In this sense, it is a separated function accelerator. The feature gives simplicity and flexibility in machine design and operation. The small beam excursion for a fixed field circular accelerator makes energy variable beam extraction easier. With the above characteristics, it is expected to have broad range of application from practical use like medical accelerator to fundamental science like muon accelerator for neutrino factory.

However, NS-FFAG is completely a novel accelerator concept and it does really need to demonstrate the feasibility by constructing a real machine. With the motivation, EMMA (Electron Machine for Many Applications) is proposed [1] It is a project to design and build a 20MeV electron NS-FFAG to establish the feasibility of NS-FFAG as a practical accelerator. It is also designed as the scale-down model of muon accelerator for neutrino factory. Thus, as the acceleration scheme, a novel acceleration scheme, which employs a fixed frequency rf cavity and use the region outside of rf bucket for acceleration [2], is adopted. With the scheme, the acceleration is to be completed in about 10 turns [3]. The detailed of the machine design can be seen in [3].

The machine is to be built in the ERLP (Energy Recovery Linac Prototype) hall of Daresbury laboratory in UK and ERLP itself is used as the injector. Within 3 years, the construction is to be completed and used for accelerator study after that.

REQUIREMENTS FOR INJECTION SYSTEM

The main purpose of EMMA is to study the beam dynamics of NS FFAG. It requires EMMA to change the injection and extraction condition arbitrarily. The requirements are summarised as follows

(1) The injection energy and extraction energy should be varied in the entire energy range (10~20MeV) for all the operation modes.

(2) The amplitude of injected beam should be varied arbitrarily within the designed beam acceptance of 3π mm (normalized).

Due to the nature of NS-FFAG, whose tune varies during acceleration, the first requirement is a real challenge in the design of EMMA injection scheme. Fig 1 shows tune variations of typical operation modes in EMMA [2]. As a beam is accelerated, the tune tends to get reduced.

In Table 1, the requirements for the injection system is summarized.

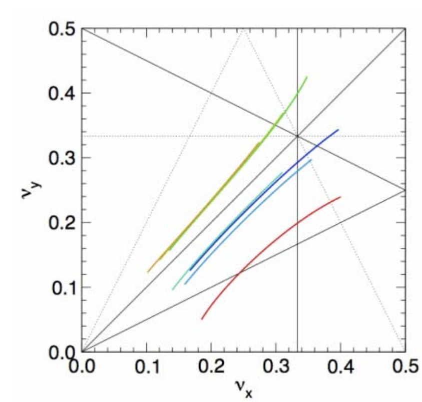

Figure 1: Tune variation of EMMA NS-FFAG

INJECTION SCHEME

Considering the machine requirements and beam characteristics, fast injection using kicker and septum is employed. For the injection direction, horizontal direction was adopted due to smaller tune variation and simplicity of orbit configuration. Then the problem is how to configure the injection elements. To achieve the fast acceleration, it is required to install as many rf cavities as possible. In the original design, the rf cavity is to be installed every one cell of EMMA ring. In the current design, to make compromise with the injection and extraction system, three consecutive drift spaces were provided for each of them.

Table 1 Requirements for injection and extraction system of EMMA ring

Injection energy	10~20MeV (arbitrary)
Extraction energy	10~20MeV (arbitrary)
Acceptance	3π mm(normalized)
Range of tune variation/cell	0.1~0.4(Horizontal) 0.05~0.45(vertical)
Horizontal beam excursion @ center of drift space	15mm
Vertical aperture @ center of drift space	20mm
Drift space	21cm (10cm is available for apparatus)
Kicker rise time	30ns (beam evolution period: 55ns)

In an ordinary synchrotron, whose tune is constant during acceleration, the design of injection scheme is rather straightforward, that means it can be dedicated to a single operating condition. However for a tune varying system, the rigid scheme employed in synchrotron would not work. Such system requires more flexible approach having knobs to absorb the tune variation. In order to adjust the phase advance of different injection condition with the current lattice configuration, an injection system with two kicker magnets and a septum magnet is employed, and tracking study using tracking code, ZGOUBI[4], was carried out to investigate feasible configuration and specifications of the system. In the beam injection in various phase advances, in order to minimize the difference of phase advance among the injection conditions, the best configuration is to occupy three consecutive drift spaces for kicker and septum, at the first glance. But for confirmation, other configurations were investigated as well in the study.

In the tracking study, half of drift space, 10cm, is assumed available for kicker and septum, and the kicker field can be reversed at will. Reversed tracking from the circulating orbit is carried out. The initial beam is matched with the circulating beam. As the criteria of injection, the kicked beam should be outside of the septum at the position of septum. Here, 3mm thick space is presumed as the septum conductor and margin. To simplify the discussion, the sharp edge field profile is taken in the tracking.

Figure 2 shows an example of injection tracking study for a typical operation mode. Here, normalized emittance of 3π mm is taken as the beam size of the injected beam. The kickers and septum are installed in three consecutive drift spaces, and beam is observed at the position of septum. In these figures the maximum kicker field is 0.6kgauss, and septum field was set zero.

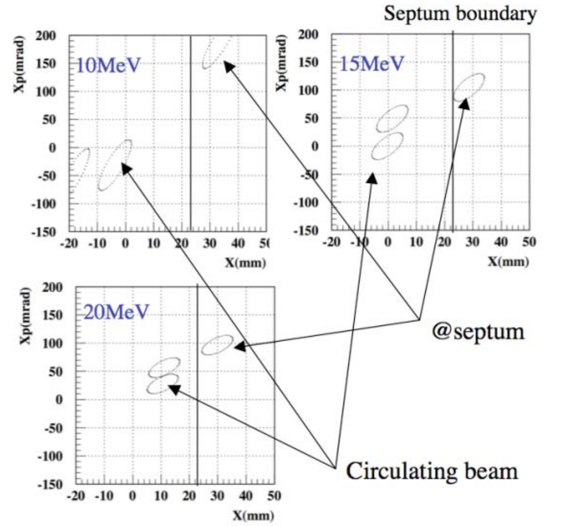

Figure 2 Phase space distribution of the injected beam of a typical operation mode

From the point of view of the injection line design, the smaller beam distribution at the septum, the better, and it requires optimization of kicker field. For the optimization, all the combinations of kicker field were investigated for every injection condition, that is three typical operation modes and injection energy from 10MeV to 20MeV with every 1 MeV step.

Figure 3 shows a typical phase space distribution of beam center at the septum position of a typical operation mode. In the scanning, each of kicker field was varied independently with a precision of 0.05kgauss up to ±0.6kgauss.

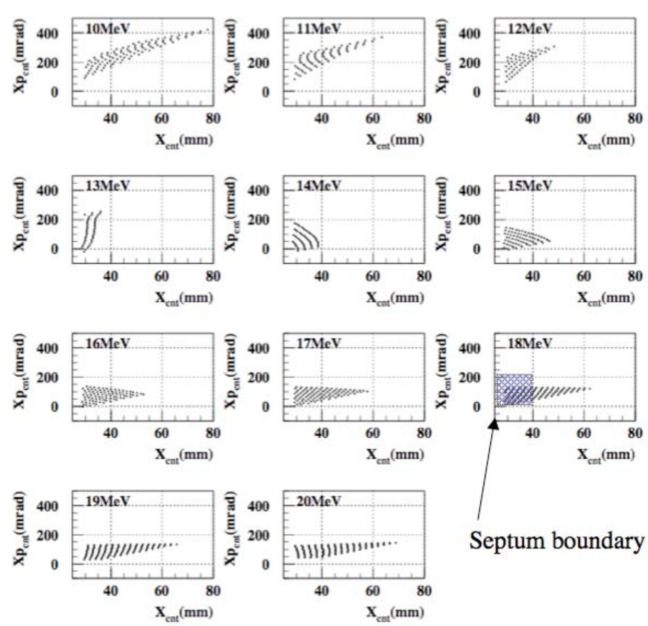

Figure 3 Beam center distributions in the phase space at the injection septum of a typical operation mode. The shaded region in 18MeV is that in common among all the investigated injection conditions

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The region covered by dots is the region where kicked beam position can be shifted by varying the kicker field within the range of ±0.6kgauss.

Then, the optimization of injection was carried out, making similar plots of the entire investigated operation modes and picking up the combination of kicker strength for each injection condition so that the beam center distribution is minimized in the phase space. The optimization was carried out for several configurations of injection elements. Figure 4 shows the best result. In the configuration of Figure 4, three consecutive drift spaces are used for kickers and septum, and beam is injected from outward. With the results, it can be concluded that, with a pair of bipolar kicker of maximum field strength of 0.6kg, beam injection into EMMA ring is feasible. In the study, the beam is intended to inject into the center of the phase space. That means with varying the kicker field, amplitude of injection error can be arbitrary controlled.

Considering the required aperture and rise time, if half-sine wave kicker is adopted, the specifications of the power supply are still within reasonable ranges.

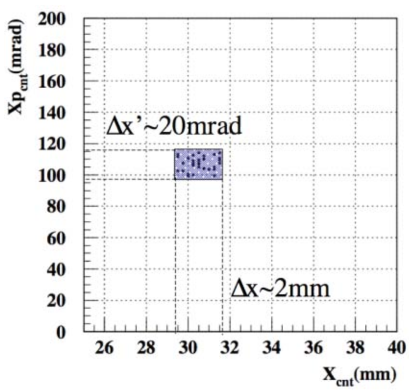

Figure 4 Optimized beam center distribution of all the injection conditions

FUTURE WORK

Present study concentrates on the issue of kicker specifications, whether a sufficient orbit separation can be obtained with kickers of reasonable specifications. In the next step, contribution of the septum should be taken into account, since septum also works as a steering magnet and it surely contributes to reduce the injection error.

In addition, tracking study with a realistic 3D field is also a must. Due to the tight geometry of the ring, the cell of EMMA ring is a strongly coupled system, and it inevitably requires tracking study with realistic 3D field to finalize the injection scheme

For the beam extraction, once the optimization scheme of beam injection is established, the similar optimization procedure and elements configurations can be used, since the requirements for extraction is similar to that of injection and the only difference is the direction of tracking.

SUMMARY

EMMA NS-FFAG aims to demonstrate the feasibility of NS-FFAG as a practical accelerator. Due to the nature, its injection system must accommodate broad varieties of injection condition. To investigate the feasibility, a tracking study using ZGOUGI was carried out. The result indicates that it is feasible with reasonable specifications of apparatuses, though it requires confirmation with tracking study using realistic 3D field

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