INJECTION/EXTRACTION SYSTEM OF THE MUON FFAG FOR THE NEUTRINO FACTORY

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Abstract

Nonscaling FFAG is required for the muon acceleration in the Neutrino Factory, the baseline for which is under investigation in the International Design Study (IDS-NF). In order to inject/extract the muon beam with a very large emittance, several strong kickers with a very large aperture are required distributed in many lattice cells. Once sufficient orbit separation is obtained by the kickers, the final degree of separation from the lattice is made by the septum, which needs to be superconducting. The geometry of the symmetric solutions allowing to inject/extract both signs of muons is presented. The preliminary design of the kicker system is given.

INTRODUCTION

The Neutrino Factory (NF) based on the muon storage ring is expected to be the next generation facility for a precise determination of the parameters describing the neutrino oscillation phenomenon. In particular, the CP violation in the leptonic sector can be discovered, which may give some insight into the matter-antimatter asymmetry of the Universe. At the time of a possible construction of the NF, the results of the potential new physics from the Large Hadron Collider will be known and together with the precision data from the NF could lead to the creation of a new particle physics model, superior to the current Standard Model. In order to realise this exciting research scenario, several problems in accelerator physics have to be addressed and successful solutions established. The International Design Study (IDS-NF) [1] is currently performing a detailed study of the Neutrino Factory facility. In particular the design of the muon accelerator, which needs to boost the muon beam energy from ~150 MeV at the capture downstream the pion production target, up to 25 GeV at injection to the decay ring. The main constrains, which dictate the design are the large required normalised acceptance of 3 π.cm.rad and the short muon life-time (2.2 us at rest). According to the current IDS-NF baseline, the acceleration from 12.6 GeV to 25 GeV is foreseen in the Non-Scaling Fixed Field Alternating Gradient (NS-FFAG) machine. The electron model of this new type of accelerator - EMMA is presently under construction at the Daresbury Laboratory jn the UK and commissioning will start very soon [2]. The magnetic field in the NS-FFAG magnets contains only dipole and quadrupole components and is constant with time. These machine properties enables an extremely fast acceleration (in 8-16 turns) of a large emittance muon beam. One of the main difficulties in realising the NS-FFAG remains the beam injection and extraction. This paper describes the current status of the injection/extraction system studies performed in the framework of the IDS-NF.

FFAG LATTICE

The FFAG lattice consists of identical and relatively short FDF triplet cells. The strong focusing needed to obtain a very small orbit excursion is performed in the combined function superconducting magnets. The momentum compaction is adjusted in order to create the quasi-isochronous optics, which is required in order to allow for the acceleration with high and fixed frequency RF cavities. The 3 m long drift sections can host two superconducting RF cavities. Most of the drifts, will be filled with the RF cavities, but several "empty" drifts are foreseen for other machine subsystems. The parameters of one of the most promising lattice are shown in Table 1. Further optimisation of the lattice parameters is still expected [3].

Table 1: Parameters of NS FFAG based on triplet

Number of cells	64
Circumference	546 m
RF voltage	1.119 GV
Max field in F magnet	3.6 T
Max field in D magnet	6.5 T
F magnet radius	15.3 cm
D magnet radius	11.5 cm
Muon decay	5.6 %
Injection energy	12.6 GeV
Extraction energy	25 GeV

INJECTION/EXTRACTION GEOMETRIES

Injection

Due to the relatively high value of the horizontal betatron function in the drift at 12.6 GeV (~10 m), the horizontal injection was chosen as a baseline solution [5]. The superconducting septum magnets are needed, one for each sign of muons, placed on both sides of the cells occupied by the kickers as the different polarity beams travel in opposite directions in the machine. They are used to bring the injected beams close to the circulating beam. Then 3 2.4 m long kicker magnets, each centred in the 3 m long drift section are used to put the injected beams on the circulating beam orbit. The values of the magnetic field in kickers has a mirror symmetry with respect to the central kicker, which allows one to reuse the same elements for both signs of muons.

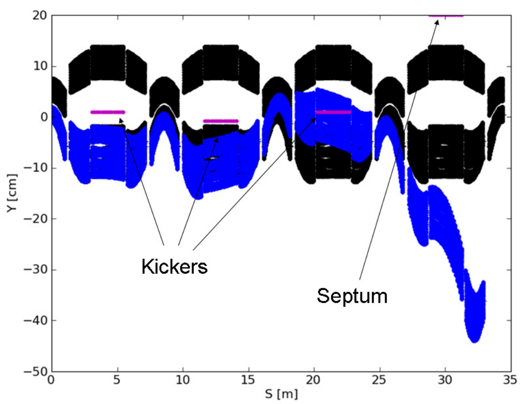

Figure 1: Layout of the baseline horizontal injection system for the muon FFAG based on triplet cells. Only beam with one sign of muons is presented and the direction of the injected beam is from right to left.

The geometry of the baseline injection scheme is shown in Fig. 1, where only one muon beam polarity is included. The parameters of the injection system are shown in Table 2.

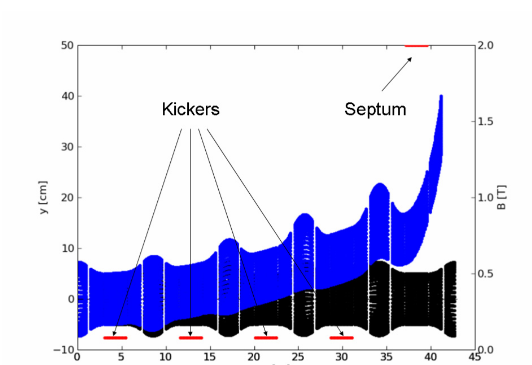

Figure 2: Layout of the baseline vertical extraction system for the muon FFAG based on triplet cells. Only beam with one sign of muons is presented and the direction of the extracted beam is from left to right.

Extraction

At extraction energy the vertical betatron function is higher than the horizontal one, which immediately suggests using this plane. In addition the low vertical phase advance per cell allows one to coherently add contributions from distributed kickers building the separation between the circulating 25 GeV beam and the extracted beams. The current baseline scheme [4, 5] consists of 4 kickers, which can be used for both signs of muons. The final beam extraction is performed using one superconducting septum magnet for each muon beam sign, located in the consecutive cells, symmetrically with respect to kickers. For both injection and extraction, 2 cm septum thickness was assumed. The geometry of the baseline extraction scheme is shown in Fig. 2, where only one muon beam polarity is included. The parameters of the extraction system are shown in Table 2.

Table 2: Parameters of the injection/extraction systems

	Injection	Extraction
Type	horizontal	vertical
Number of kickers	3	4
Magnetic field in kickers	0.085 T	0.078 T
Kicker/septum length	2.4 m	2.4 m
Septum field	2 T	~4 T
Total number of cells used	5	6

KICKER SYSTEM

In order to meet the requirements of the NF beam time structure, where the muons will be captured in 3 independent bunch trains created by 3 proton bunches at the pion production target separated by about 80-100 us. To realise these three consecutive pulses (see Fig. 3) we propose to use three independent Pulse Forming Networks (PFNs), each delivering one pulse and equipped with several Thyratron type fast switches connected in parallel.

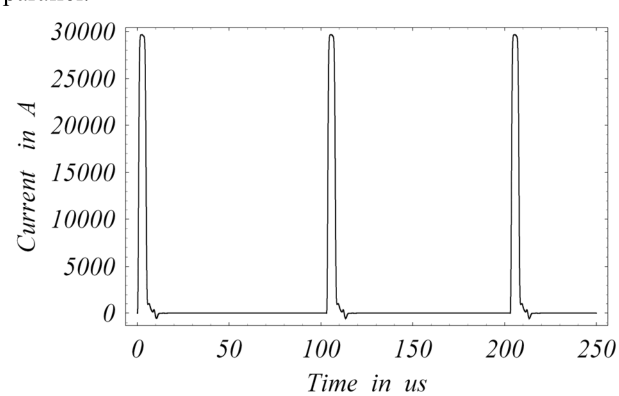

Figure 3: Three pulses for the kicker magnet from the independent PFNs for the NF operation based on three muon bunch trains.

Based on beam optics studies, the baseline kicker parameters were estimated. Each PFN has an impedance of 1 Ohm and is charged at 60 kV. The kicker magnet is subdivided into 12 smaller kickers (6 for positive and 6 for negative currents), which is necessary to meet the rise/fall time requirement; each PFN powers three sections. Each section of the kicker magnet requires added capacitance in order to match the PFN impedance.

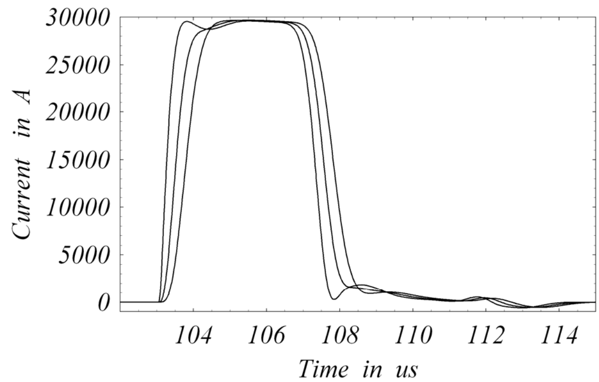

Figure 4: Three pulses in consecutive kicker subsections simulated using PSpice code.

Using a standard Rayleigh type PFN with 20 meshes the required mesh inductance is 100 nH and the mesh capacitance is 100 nF. The PFN is connected with 10 m of coax wire to the kicker magnet. The coax wire needs to be of the same impedance as the PFN, which could be realized by using 50 coax wires of type RG-220 in parallel. The circuit is terminated with a 1 Ohm resistor. The parameters of the kicker system are shown in Table 3. The three pulses travelling in the consecutive kicker subsections are shown in Fig 4.

Table 3: Preliminary parameters of the kicker

Kicker field	0.1 T
Kicker aperture	0.3m x 0.3 m
Voltage	60 kV
Max current	30 kA
Rise/fall time	1.5 us
Kicker inductance	3 uH
System impedance	1 Ohm
Number of kicker subsections	12
Number of PFNs per kicker	12
Total length of the kicker	2.4 m

CONCLUSIONS

The preliminary injection/extraction geometries for the muon NS-FFAG, compatible with both signs of muons were identified. The horizontal plane was chosen for injection and the vertical one for extraction. The kicker magnet parameters were estimated based on the beam dynamics studies and the preliminary design of kicker charging system was performed. The obtained results are close to fulfil the requirements. The more optimised design of the kicker system and more detailed scheme for impedance matching will be addressed. Also the design of the superconducting septum needs to studied.

REFERENCES

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