A RACETRACK-SHAPE FIXED FILED INDUCTION ACCELERATOR FOR GIANT CLUSTER IONS

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Abstract

Recently the racetrack-shape fixed field induction accelerator (RAFFIA) has been proposed as a unique driver to obtain high energy giant cluster ions [1]. Its essential properties are introduced here. The first realistic model under designing is described. Expected applications of giant cluster ions are briefly described.

INTRODUCTION

Since the first proposal of the RAFFIA it has attracted interests of the related society developing applications of giant cluster ions such as C-60. So far a single-end electrostatic accelerator has been the typical driver for giant cluster ions. Achievable energy there is limited to around 50 keV/nucleon. A synchrotron is suitable to obtain higher energy. However, the restriction on the frequency band-width of RFs requires an expensive and extremely large scale injector. It is a unique choice to employ induction acceleration [2] instead of RF acceleration in order to avoid this restriction.

The racetrack-shape fixed field induction accelerator given in Ref. 1 is much suitable to accelerate giant cluster ions with an extremely large mass to charge ratio, *A/Q,* to high energy in a limited site space for the accelerator, because a large magnetic rigidity is expected with the 90 degrees bending magnet.

Stable covalent-bond clusters, representative fullerene C-60 and Si-108 [3], generally possess a high cohesive energy, which mostly suits to obtain a high charge state. high charge–state ion sources for C-60 or Si-108 are under development. Integrating these cluster ion sources with the RAFFIA, we can realize a unique giant cluster ion driver.

ACCELERATOR

The schematic layout of the RAFFIA is shown in Fig. 1. The accelerator consists of an ion source, circulating ring, and extraction beam line.

Ion Source

Possible giant cluster ion source equipped with a photoionization system is based on the newly-developed laser-ablation type cluster source as shown in Fig. 2 [3], with which a high-intense pulsed beam of Si clusters has been obtained. The typical particle current density at the peak of the Si cluster beam is 6×10^{15} cluster/s cm^2. Spatiotemporally confined mixed gas-phase layer of a hot Si vapor and helium at liquid-nitrogen temperature enables Si clusters to grow up to a certain uniform size;

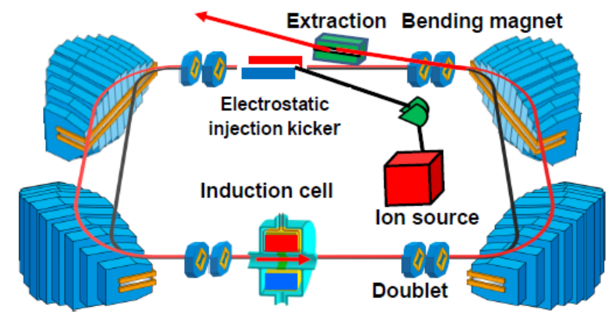

Figure 1: Layout of the RAFFIA with initial orbit (black) and the last orbit just (red).

the monodisperse Si cluster beam brings forth a so small beam emittance as 36 mm mrad., which satisfies the acceptable condition for injection to the RAFFIA.

Circulating Ring

The ring consists of 4 bending magnets of 90 degrees and 8 pairs of doublet Q magnet occupying the two long

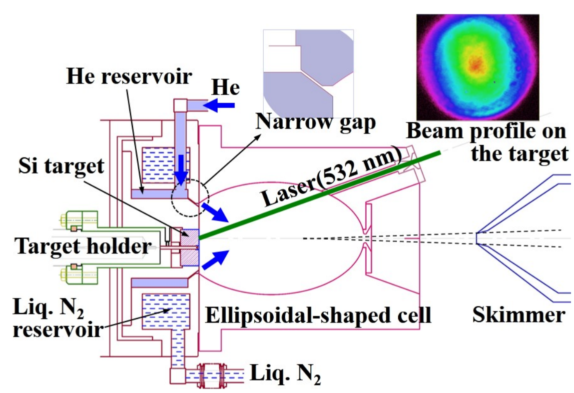

Figure 2: Laser ablation type Si cluster.

straight sections. The injection and extraction regions are placed in the upper straight section. The former is a 20 kV electrostatic injection kicker, which is the same as that being operated in the KEK digital accelerator [4]. There are several choices for the latter. A conventional extraction system consisting of extraction kickers and septum magnets is among them. Meanwhile, the lower straight section is occupied by the induction acceleration cells. Energy gain per nucleon per turn in the RAFFIA is rather small, less than *(Q/A)*x50 keV. A large number of revolution is expected to achieve an attractive energy. Orbit stability in the transverse direction is mostly crucial. In Ref. 1 the reverse field strip in the open front of the bending magnet and negative gradient on the median plane are introduced to improve the vertical focusing (see Fig. 3). It turns out that the introduced focusing effects leads to the sufficient stability for both directions with a help of optimized time-varying doublet fields.

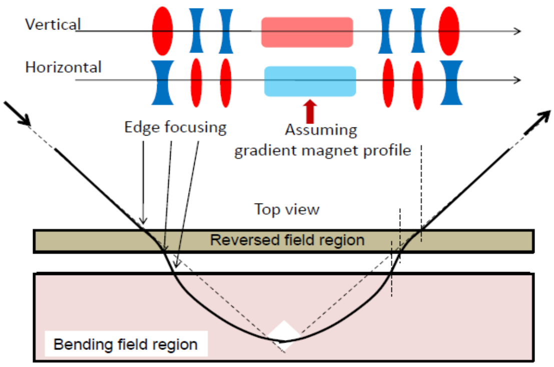

Figure 3: Properties of focusing/defocusing on the median plane.

Beam dynamic studies that have been carried out tell us the following property and crucial issues of the RAFFIA.

(1) Lattice function is achieved by an appropriate configuration of the lattice magnets.
(2) Betatron tunes may swiftly cross resonance lines on the way to extraction.
(3) Long stay of the cluster ions in the accelerator ring requires extremely a good vacuum pressure of order of 10^{-7} Pascal, because the large cross-section of electron capture is quite large at the low energy.

We have seriously considered several cases of the lattice assuming its construction on the KEK or QST site. The construction space is limited and the existing floor condition may eventually restrict on a maximum weight of the bending magnet. Here a typical example is shown in Fig. 4, assuming the beam/machine parameters in Table 1.

Table 1: Beam/Machine Parameters

Ion	**C-60**
A/Q	720/10
Initial energy (E_{min}/u)	0.012 MeV
Final energy (E_{max}/u)	0.6 MeV
B	1.5 T
dB/dx	0.3 T/m
Doublet QF, K_F	1.92 m^{-2} →1.55 m^{-2}
Doublet QD, K_D	1.72 m^{-2} →1.44 m^{-2}
Q_x	6.81 →4.73
Q_y	1.01→1.52

Bending Magnet

The 90 degree bending magnet with the above field gradient as shown in Fig. 5 has been designed. The fringing fields are obvious there. 3D beam tracking simulations considering these fields have carried out. The closed orbit on the median plane is shown in Fig. 6 .

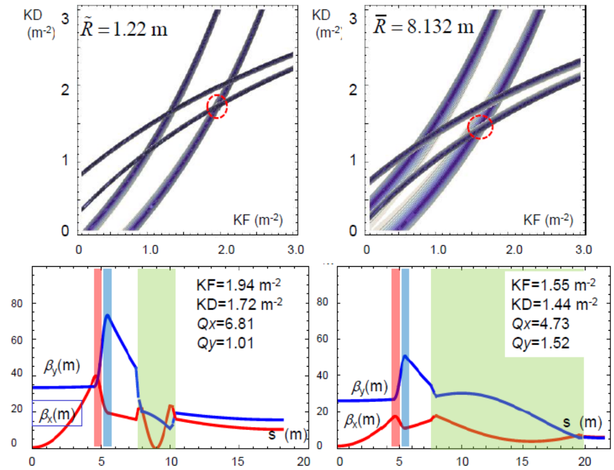

Figure 4: Stability diagram and lattice functions nearby injection and extraction.

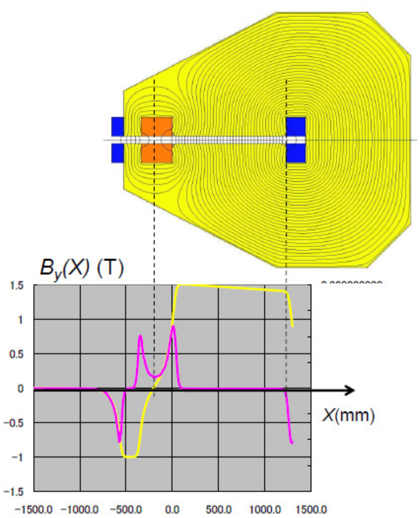

Figure 5: $B_y(X)$ (yellow) and dB_y/dX (red) of the bending magnet with the reverse field strip on the open front.

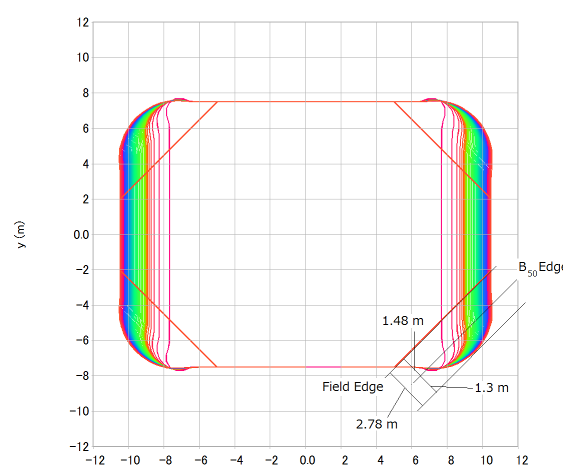

Figure 6: Continuous central orbit from injection to the end of acceleration and shown every 8 turns.

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Extration Device

Item (3) addressed above is most serious for a cluster ion beam circular accelerator. Any out-gassing devices have to be excluded from the beam line in the ring. Magnetic materials for the fast ramping extraction such as ferrite never exist in the beam chamber. The kicker magnet that is operated in air is ideal. However, there is a risk of discharging when operating in high voltage. A kicker magnet, which meets the demand of discharging protection and operated in the double layer vacuum chamber, has been designed [5]. Its outline is shown in Fig. 7.

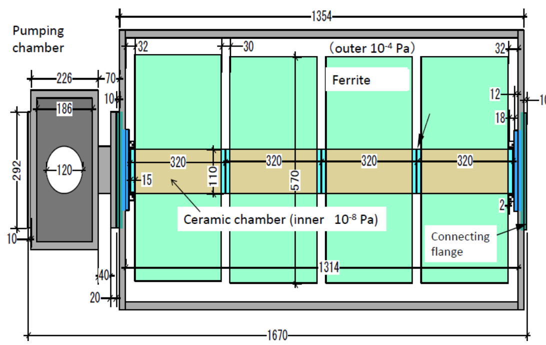

Figure 7: Extraction kicker magnet to work in a double layer vacuum.

Acceleration Device

For the induction acceleration, there seems to be no fundamental issues. However, our experience from the existing induction synchrotrons [4] still suggests several improvements in the induction acceleration system.

(1) DC voltage should vary in a desired pattern in the same acceleration cycle.

(2) A number of solid-state switching elements in the switching power supply (SPS) should be reduced to be as small as possible for the simplicity of gate control.

It is possible to realize a circuit architecture to meet (1) as shown in Fig. 8. A SPS employing original SiC-MOSFET package devices with a larger withstand voltage is under development.

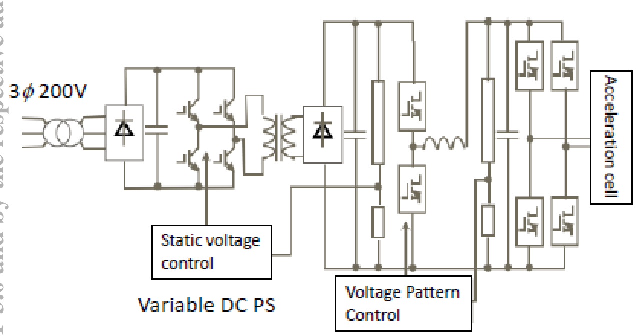

Figure 8: Improved Induction Acceleration System.

IMPACT ON APPLICATIONS

The most attractive feature of the cluster ion is the stopping power that materials have when the ion is introduced in them. It in principle exceeds the case of single Carbon ion by a factor of 60 and even the case of a single U ion. In addition, nonlinear effects, called cluster effects, in the electromagnetic interaction between the projectile ion and electrons surrounding material atoms are expected. Rough estimations suggest that the stopping power may be amplified by a factor of 10.

This features are strongly expected to induce unknown and non-equilibrium states of the matters [6]. Creation of extremely strong micro-size shock waves in water and an ion-track formed in gold or ceramic are among them. The stopping powers are shown in water and some solid-state material in Fig. 9.

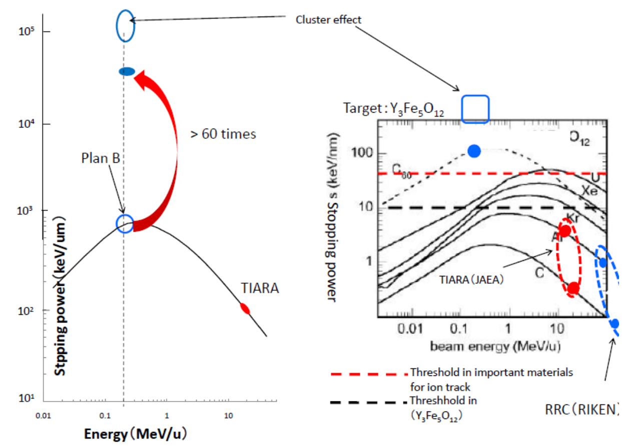

Figure 9: Stopping power of water and $Y_3Fe_5O_{12}$ for C-60 as a function of energy.

SUMMARY

The concept of the RAFFIA has been briefly reviewed and its essential properties are described. An example of practical RAFFIA for the first demonstration is shown here, although a lot of optimization must be done. If our proposal is successfully accepted by the financial agency, we will start to construct this machine and 3 years later cluster ions with an attractive energy will be delivered for various applications.

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