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

K. Takayama[1,2,3,4], A. Adachi[1,3], M. Wake[1], K. Okamura[1,3], and Y. Iwata[5]

[1]High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki, Japan
[2]Tokyo Institute of Technology, Nagatsuda, Kanagawa, Japan
[3]The Graduate University for Advanced Studies, Hayama, Kanagawa, Japan
[4]Tokyo City University, Tamadsutsumi, Tokyo, Japan
[5]National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Ibarali, Japan

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.

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 diver for giant cluster ions. Achievable energy there is limited to around 50 keV/nucleon. A synchrotron or cyclotron may be suitable to obtain higher energy. However, the restriction on the frequency band-width of acceleration RFs requires an expensive and extremely large scale injector. It is a better choice to employ induction acceleration [2] instead of RF acceleration in order to avoid this restriction. As a matter of fact, the synchrotron employing induction acceleration has been demonstrated both in a slow-cycling mode [3] and fast-cycling mode [4] at KEK.

The racetrack-shape fixed field induction accelerator given in Reference 1, which looks like a microtron, seems to be 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.

Not only C-60 but also another attractive giant cluster atom with super lattice structure such as Si-108 [5] is available now. 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.

ESSENTIAL PROPERIES OF THE RAFFIA

The schematic layout of the RAFFIA is shown in Fig. 1. The ring consists of 4 bending magnets of 90 degrees and 8 pairs of doublet Q magnet occupying the two long straight sections. The injection device and extraction region 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.

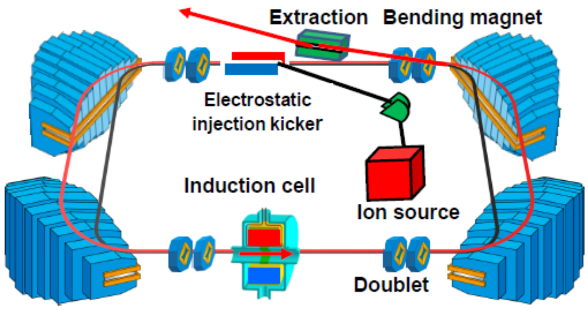

Figure 1: Layout of the RAFFIA with initial orbit (black) and the last orbit just (red).

Energy gain per nucleon in the RAFFIA is rather small, less than *(Q/A)*x50 keV. This means a large number of revolution in the machine. Orbit stability in the transverse direction is mostly crucial. In Reference 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. 2). It turns out that the introduced focusing effects leads to the sufficient stability for both directions with a help of optimized time-

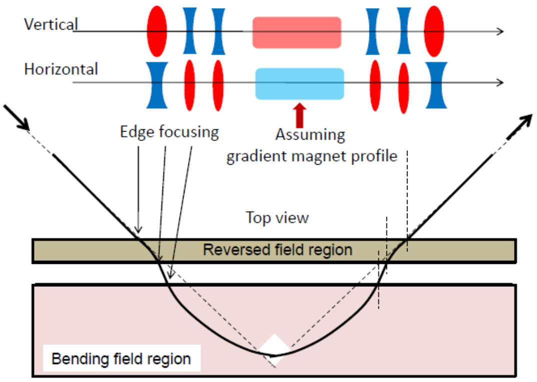

Figure 2: Properties of focusing/defocusing on the median plane.

varying doublet fields.

Preliminary beam dynamic study [1] has delineated the following properties 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.

For the induction acceleration, there seems to be no crucial issues. However, our experience from the existing induction synchrotrons [3,4] still suggests several improvements in the induction acceleration system shown in Fig. 3.

(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). For the latter purpose, a SPS employing original SiC package devices with a larger withstand voltage is under development [6].

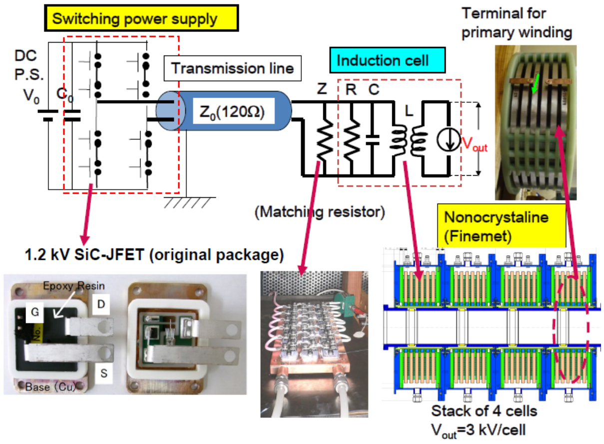

Figure 3: Assumed induction acceleration system.

The beam bunch trapped in a barrier bucket shown in Fig.4 is handled in a desired manner without any delicate control of the circulating path length in an electron microtron so as to always satisfy phase matching with the RF frequency.

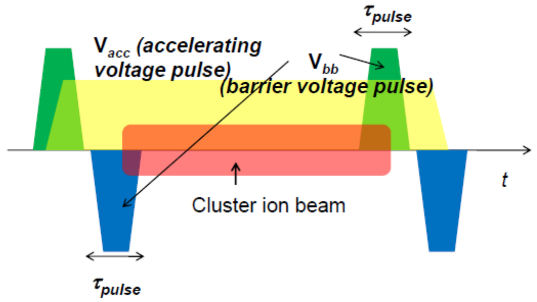

Figure 4: Induction acceleration/confinement scenario.

THE FIRST MODEL UNDER CONSIDERATION

A medium size RAFFIA is being seriously considered, which will be constructed in the KEK site if its construction budget is accepted by the financial agency. The construction space is limited and the existing floor condition eventually restricts on a maximum weight of the bending magnet. The candidate site for the construction is shown in Fig. 5.

It is practically important how big magnets for the RAFFIA are constructed under the given condition. From the practical point of view, we have assumed that the maximum weight of the bending magnet is around 80 ton. It will be segmented into 20 blocks at a manufacturer. The components will be carried in the accelerator tunnel though the access path and assembled into 1 magnet.

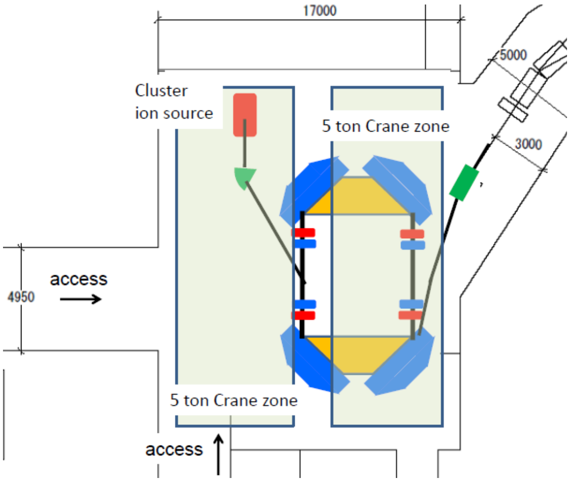

Figure 5: Possible construction site, where the KEK-DA is being operated now.

This restriction suggests us parameters of a possible RAFFIA, which are listed in Table1.

Table 1: Beam and Machine Parameters

Ion	C-60
A	720
Q	10
energy per nucleon	0.2 MeV
Bending magnet	
length, Z_{max}	5.5 m
maximum pole face widt	1.35m
flux density, B_{max}	1.5 T
Gradient, dB/dX	0.3 T/m
Doublet	
K_F	0.80→ 0.91 /m^2
K_D	-1.025→ -1.3 /m^2
Long straight section, L_s	10 m
Lattice function at symmetric point	
β_y	95 m → 30 m
β_y	110 m -> 10 m
Betatron tune, Q_x/Q_y	(0.8 →1.0) / (0.6 →0.52)

The 2D field distribution of the bending magnet is shown in Fig. 6.

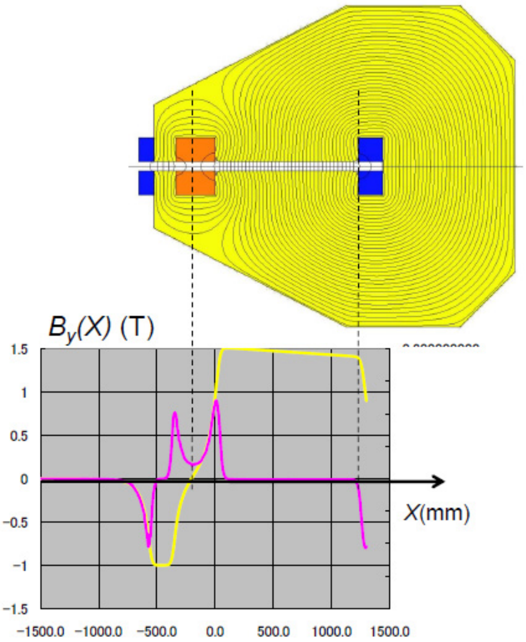

Figure 6: $B_y(X)$ (yellow) and dB_y/dX (red) of the bending magnet with the reverse field strip on the open front.

Assuming the above guiding fields, orbit tracking from the injection to the last stage of acceleration has been carried out by the newly developed 4th-order Runge-Kutta orbit tracking code taking account of the 3D magnetic field extended from the calculated 2 D field distribution. In the present example, the magnet is ramped at the early stage (1-100 turn) so as to provide the orbit stability. Beyond that, its flux density is kept to be 1.5 Tesla. In this sense, the example is a kind of hybrid type among the induction synchrotron and pure RAFFIA.

The central orbit through the acceleration is shown in Fig. 7, where the effect of the reversed field is visible at the lower energy.

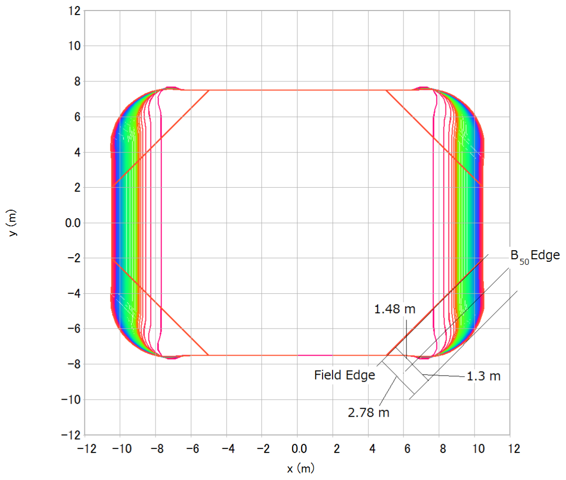

Figure 7: Continuous central orbit from injection to the end of acceleration and shown every 8 turns.

Many issues such as betatron tunes closed to half-integer and integer are left unsolved.

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 C by a factor of 60 and even the case of 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 nonequilibrium states of the matters [7,8]. 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. 8.

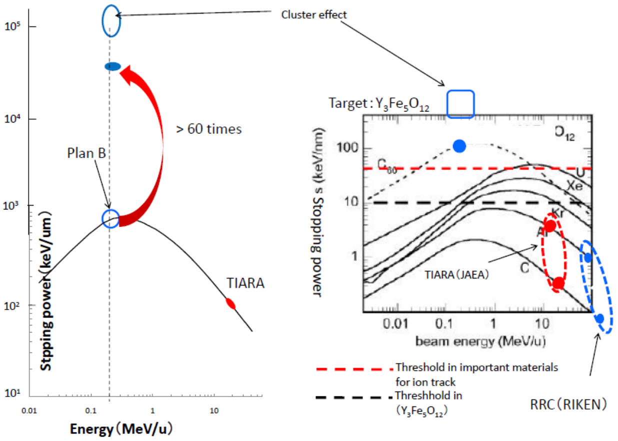

Figure 8: Stopping power of water and $Y_3Fe_5O_{12}$ for C-60 as a function of energy.

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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