KEK DIGITAL ACCELERATOR FOR MATERIAL AND BIOLOGICAL SCIENCES*

K.Takayama[#,1,2,3], T.Adachi[1,2], T.Arai[1], Y.Arakida[1], M.Hashimoto[1], T.Iwashita[1], E.Kadokura[1], M.Kawai[1], T.Kawakubo[1], T.Kikuchi[4], K.Koyama[1], Tadashi Kubo[1], Tomio Kubo[1], K.Motiki[5], H.Nakanishi[1], H.Okamura[6,7], K.Okamura[1,2], K.Okazaki[8], T.Sano[5], H.Someya[1], A.Takagi[1,2], K.Takaki[9], H.Tanaka[9], Leo Kwee Wah[2], M.Wake[1,2], and T.Yoshii[4]

[1]KEK, Tsukuba, Ibaraki, Japan
[2]Graduate University of Advanced Studies (KEK), Tsukuba, Ibaraki, Japan
[3]Tokyo Institute of Technology, Nagatsuda, Kanagawa, Japan
[4]Nagaoka Technology and Science University, Nagaoka, Niigata, Japan
[5]Tokyo City University, Tokyo, Japan
[6]RIKEN, Wako, Saitama, Japan
[7]BNL, Upton, New York, USA
[8]Nippon Advanced Technology Co. Ltd. (NAT), Tokaimura, Ibaraki, Japan
[9]Iwate University, Morioka, Iwate, Japan

Abstract

An induction synchrotron has been developed and it has been demonstrated in 2006 [1]. Since the induction acceleration system has no limit on a frequency band-width, arbitrary ion species can be accelerated at their possible charge state. Direct injection of an ion beam from an ion source to the synchrotron is possible. We call such a synchrotron as "All-ion accelerator" [2] or "Digital Accelerator". The present status of the first Digital Accelerator under construction at KEK is reported.

INTRODUCTION

The KEK-DA shown in Fig.1 is a recycling of the KEK 500 MeV PS-Booster, which was shut down in March, 2006, after 28 years operation as an injector of the KEK 12-GeV PS, a neutron source and a driver of the cancer therapy, is being renovated as the first Digital Accelerator (DA). Major renovation works are listed below.

1. Construction of a high voltage ECR ion source (200 kV, ECRIS)
2. Introducing of an electrostatic chopper and electrostatic kicker for injection
3. Replacement of the existing RF cavities by induction cells
4. Change in the repetition frequency of the accelerator ring (20 Hz -> 10 Hz)
5. Improvement of vacuum
6. Replacement of the existing in-vacuum devices such as a septum magnet for extraction and a bunch monitor by out-vacuum ones

90 % of the construction work has been completed. An outline of each item is briefly explained below.

It is noted that the term of "Digital Accelerator" expresses the following characteristics:

- Since an induction cell is a simple 1 to 1transformer driven by a switching power supply, there is no limitation of band-width in a lower side. (Its maximum repetition rate is limited to MHz because of a heat-deposit capacity in the solid-state switching element.)
- The induction cell is excited by a pulse current and generates a constant flat voltage, which is triggered every turn by a gate-control signal digitally created from a pick-up signal in a fast bunch monitor by the digital signal processor (DSP).
- Acceleration voltage in a usual rapid cycle synchrotron must be varied in a sinusoidal way. In the KEK-DA, this is realized by controlling the pulse-density through an acceleration cycle.

The operational schematic of the KEK-DA is shown in Fig.2. It is noted that a gigantic injector is unnecessary.

Figure 1: Photograph of the KEK-DA, It consists of 8 FDF combined-type magnets. Machine parameters: C_0= 37.7 m. B_{max}=1.1 T, f=10 Hz, V_{acc}<3.2 kV, ν_x/ν_y=21.1/2.3.

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#takayama@post.kek.jp

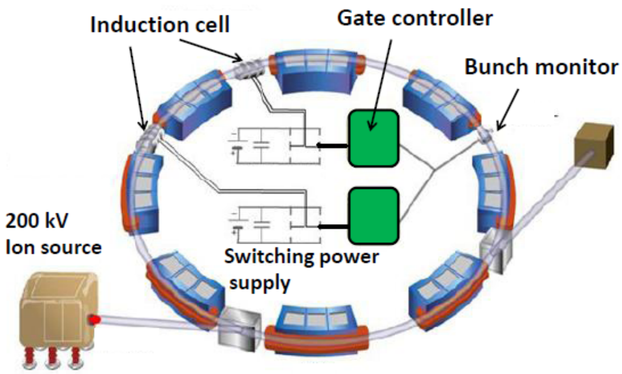

Figure 2: Schematic view of the KEK-DA.

The confinement of an ion bunch and acceleration are carried out by employing different induction cells.

THE KEK DA ACCELERATOR COMPLEX

In the early days of KEK-DA, ions such as H, C, O, Ne, and Ar will be provided by the newly developed ECRIS; a few years later a laser ablation ion source, which is being developed by Okamoto of BNL [3], will be employed to provide high charge-state metal ions such as Cu, Ag, and Au. At beginning Ar^{8+} is used for beam commissioning and irradiation tests of a proposed target to explore functionally novel materials [4].

Ion Source and LEBT

A permanent magnet ECRIS is a unique solution when an ion source for a main accelerator has to be mounted in a high voltage terminal, because it does not require a large amount of electric power and its size is small and its weight is less than 50 kg. Since 2008 a pulse-mode x-band ECRIS has been developed. Fig.3 depicts the high voltage ion source and the low energy beam transport (LEBT) line. The beam quality and the charge spectrum are being measured at the test bench. Its details are reported in the companion paper [5].

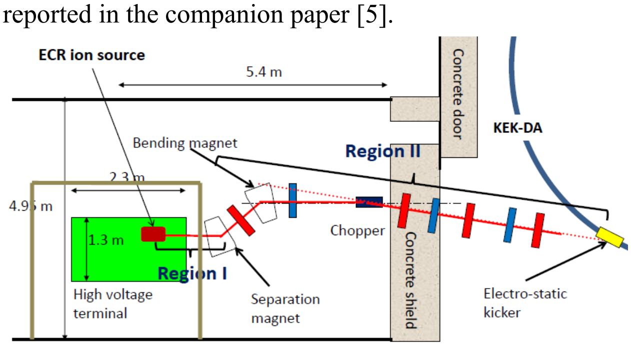

Figure 3: High voltage ion source and LEBT.

An Ar beam including Ar^{1+}~Ar^{8+} is extracted through the extraction electrode of 14-15 kV and focused in the downstream Einzel lens system and guided into the main acceleration column of 185 kV with inner focusing electrodes and enters into the separation magnet to be selected a desired charge state (Z) ion beam. Through the quadrupole focusing channel, the Ar^{8+} beam is guided to the electrostatic chopper where a 4-5 μsec long pulse is chopped from a 3-5 msec long pulse. The chopper is energized by a newly developed all-transistor Marx generator [6]. Hereafter the ion beam is guided through the former proton beam line to the DA.

Injection System

An ion beam is injected at the straight section called S1.

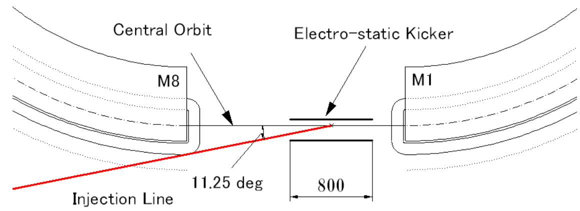

Figure 4: Injection region into the KEK-DA.

Fig, 4 shows the orbit geometry in the injection region. The angle between the injected line and the central orbit in the DA ring is designed to be 11.25 deg at the injection point. The 800 mm long elctrostatic kicker comprises an anode electrode and a ground electrode. Six correction electrodes assure the field homogeneity throughout beam passage. An anode voltage, V_{anode}, is given by

$$V_{anode} = \frac{d \cdot V_{ion}}{L} \sin 2\theta \cdot \quad (1)$$

where, L the length of the deflector, d the electrode gap size, V_{ion} the voltage of the ion source and θ the deflection angle. The anode voltage will be around +20 kV in our case. Using the 3D field distribution evaluated by the computer code TOSCA, beam orbit simulations have been carried out by the Runge-Kutta method. The longitudinal phase plot is shown in Fig.5 assuming a possible beam emittance.

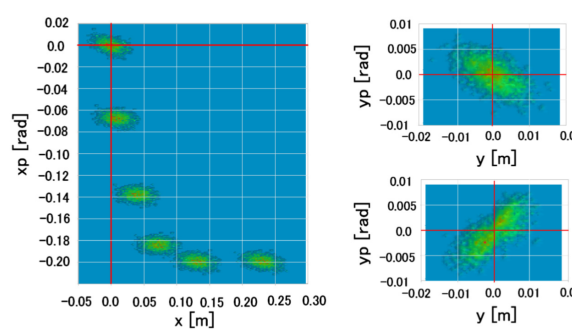

Figure 5: Phase space distributions of the beam. Left: in horizontal direction through the injection and Right: just at the deflector end.

It turns out that emittance blowup is negligibly small. More details are discussed in the companion paper [6]. After injection, a beam consisting of Ar^{8+} ions of 10^9 will be accelerated to 25.3 MeV/au.

Power Supply of the Main Magnets

Eight magnets in the former Booster and one monitor magnet placed in a power supply building had been excited with a repetition of 20 Hz by using a resonant network, as shown in Fig. 6. These 9 magnets are distributed into 3 groups. A parallel circuit of a capacitor and an inductance of the secondary winding of a choke transformer is connected to each magnet group.

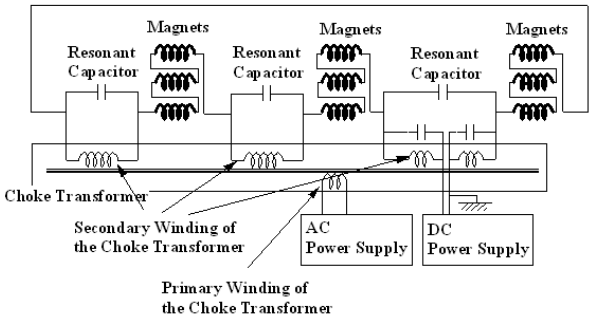

Figure 6: Resonant network of the KEK-DA magnets.

The DA is required to operate at a repetition of 10 Hz because of an available voltage for present induction cells. In order to satisfy such a requirement, the capacitance must be increased by a factor of 4. A resonant frequency of the network has been already adjusted by rearrangement of the existing capacitor units.

Ring Vacuum

A circulating beam interacts with a residual gas during acceleration. Possible interactions are scattering and electron capture/stripping by gas molecules. Especially, the latter is dominant for a low energy ion. The ring vacuum is crucial for successful acceleration of the argon ion. The existing experimental data [7] implies that a pressure in the order of 10^{-9} Torr must be realized in the ring vacuum to obtain 50 % survivals at least. Typical vacuum pressure was 10^{-7} Torr in the former Booster. Outgassing devices such as kickers, bump/septum magnets must be put outside the ring vacuum as much as possible. Furthermore, additional ion pumps will be introduced into the DA ring.

Extraction System and HEBT

A beam is extracted by a fast extraction system, which comprises two bump magnets, four kicker magnets and two septum magnets. The latter septum magnets are operated in air [6] to improve a vacuum. A vacuum chamber has been installed in the aperture of septum magnets. The high energy beam transport (HEBT) line, which is the former 500 MeV beam transport line, guides ion beams to the irradiation area.

Induction Acceleration System

9 induction cells have been installed in two neighbouring straight sections: i.e., 3 cells at upstream and 6 cells at downstream. Among them, 3 cells are used for beam confinement and the other cells are used for acceleration. Fig. 9 shows an assembly of induction cells.

Figure 9: An assembly of 6 induction cells.

An individual cell is driven by a switching power supply capable of handling an electric power of 50 kW at 1 MHz. Trigger of these cells must be synchronized with the circulation of an ion bunch, which varies from a few tens of kHz to ~ 2 MHz. Limitations of the operational capability of the induction acceleration system:

- Maximum repetition rate (< 1 MHz)
- Maximum pulse length (< 2 μsec)
- Constant output voltage (< 2 kV) through the acceleration cycle,

require a ganged control of the induction acceleration systems [8] including the programmed intermittent operation, the sequential operation in time between a pair of cells, and intermittent operation due to the real time ΔR feedback. Details of the acceleration scenario and the present status of the acceleration system are described in the companion paper [9].

SUMMARY

The present status and its main profile of the Digital Accelerator based on the induction synchrotron concept, which is capable of accelerating arbitrary ion species with their possible charge state, has been described. The first beam commission is scheduled during 2010.

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