ION SOURCE AND LOW ENERGY BEAM TRANSPORT FOR KEK DIGITAL ACCELERATOR*

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Abstract

An induction synchrotron has been developed and its concept has been fully and experimentally 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 (DA)". An ECR ion source (ECRIS) for the first DA is under development at KEK. The present status of this ECRIS and the following low energy beam transport (LEBT) is described.

INTRODUCTION

The KEK-DA is a recycling of the KEK 500 MeV PS-Booster, which was shut down in March, 2006, and is being renovated as the first DA. One of major renovation works is the construction of a high voltage ion source (200 kV, ECRIS).

The operational schematic of the KEK-DA is shown in Fig.1 and its details are described in three companion papers [3]. An ion beam is directly injected into the KEK-DA from the ion source without a gigantic injector. In order to mitigate space-charge effects during injection, the ion beam is accelerated through a high voltage acceleration column. We have chosen Ar ion for the first beam commissioning.

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.2 depicts the high voltage ion source and the LEBT line. Their details will be described here.

An Ar beam including Ar^{1+}~Ar^{8+} is extracted through the extraction electrode of 14-15 kV and focused in the downstream Eintzel 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 A^{8+} beam is guided to the electrostatic chopper where a 4-5 μsec long pulse is chopped from a 3-5 μsec long pulse.

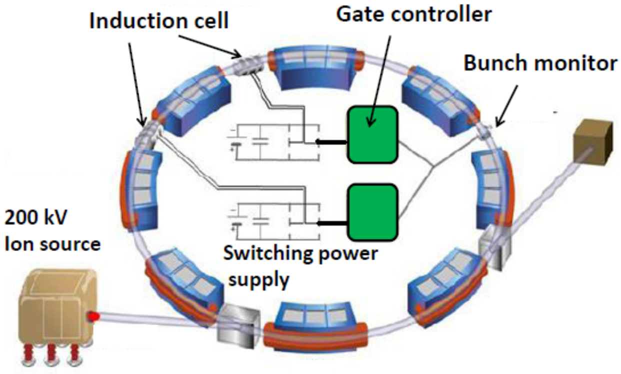

Figure 1: Schematic view of the KEK-DA

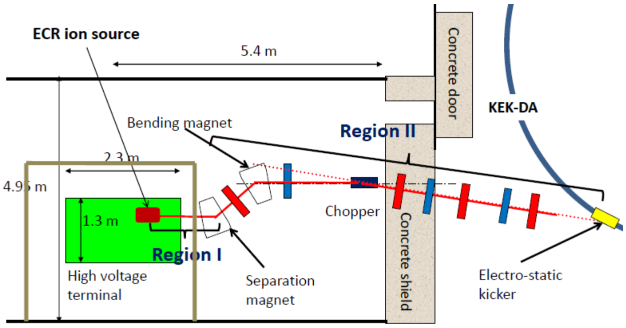

Figure 2: High voltage ion source and LEBT.

ECRIS

An all-permanent magnet ECRIS has been built and tested over the last two years.

Mechanical Design

The mechanical design of this ECRIS is shown in Fig. 3. It shows the complete assembly including two permanent ring magnets and hextapole magnet and return york and the microwave horn antenna and the extraction

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system with a blinder to protect metal ions from spattering on the surface of the insulating ceramic pipe. The position of the antenna horn aperture can be optimized for matching. A plasma chamber with water cooling channels has been designed assuming a CW operation. As a result, the aperture size is rather big compared with a similar x-band permanent ECR such as Nanogan [4].

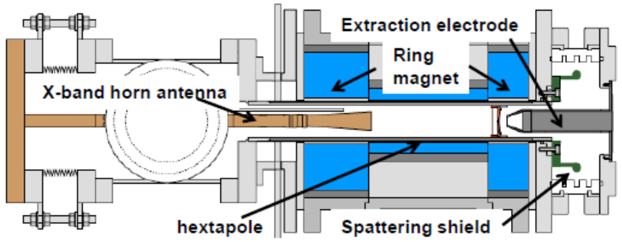

Figure 3: Schematic overview of the mechanical set up of the x-band ECR for The KEK-DA

Magnetic System

The magnetic system for confining the hot plasma electrons should have followed the general policy that a high axial mirror ratio and a strong radial field inside the plasma chamber are important. The realized field distribution is platted in Fig. 4 together with the numerical calculation. In addition, the radial flux density on the inner surface of the plasma chamber (r=20 mm) is 5 kG. The resonance flux density B_{ECR} is 3.3 kG for a frequency of 9.35 GHz. The empirical rule [5] tells us $B_r \sim 2 B_{ECR}$ is desired. The actual field strength is a bit lower than this condition.

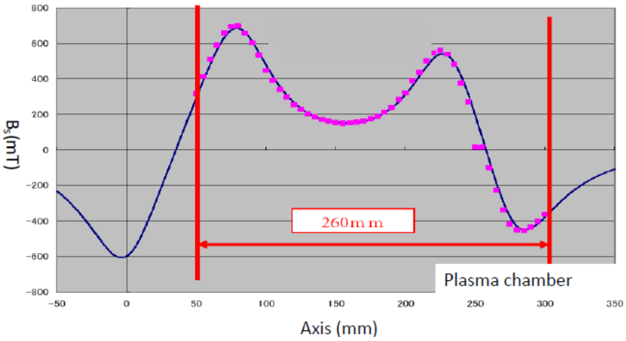

Figure 4: Field distribution through the ECRIS. B_{peak1}=7 kG, , B_{peak2}=5.6 kG, and B_{min}=1.7 kG,

Microwave Heating

9.35 GHz microwaves are provided from a TWT with a maximum power of 700 W. In the present ECRIS, the microwave power is uniformly irradiated in the plasma chamber from the rectangular horn antenna. Since the KEK-DA is operated at 10 Hz, the injection of ion beams at the same repetition rate is expected. An ion pulse is generated in a pulse mode, where the 5 msec long microwave pulse are fired at 10 Hz by controlling the electron pulse length of the TWT.

Extraction System

The geometrical shape of the anode hole fixed at 14 -15 kV and the grounded extraction electrode have been optimized by IGUN simulations. In the early stage, spattering of metal ions on the insulating ceramic pipe wall was serious to result in high voltage breakdown. The screen seen in Fig. 3 was quite effective to keep a clean surface from the direct spattering.

Test Bench and Measurement Results

Charge-state spectrum of the extracted Ar beam, which is guided through the Einzel lens placed just after the extraction electrode and bended by the analyzer magnet was obtained by monitoring a beam current in the downstream Faraday cup. Fig. 5 shows the pulse shape of an individual charge state at Gas flow rate of 0.05 SCCM.

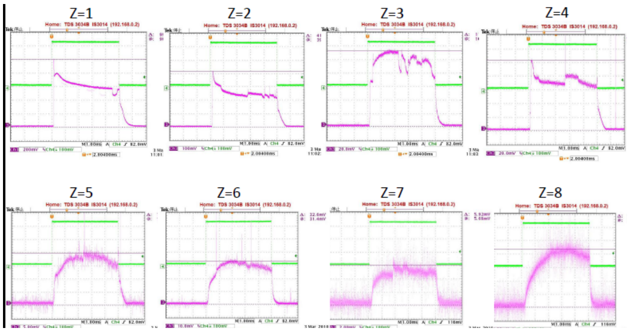

Figure 5: Pulse profiles.Power/pulse length: 600W/5msec

From this result, it is notable that higher charge state ions are created through their middle states with a finite time period of a few msec. Absolute ion intensities have been obtained as functions of the microwave power. The result is shown in Fig. 6.

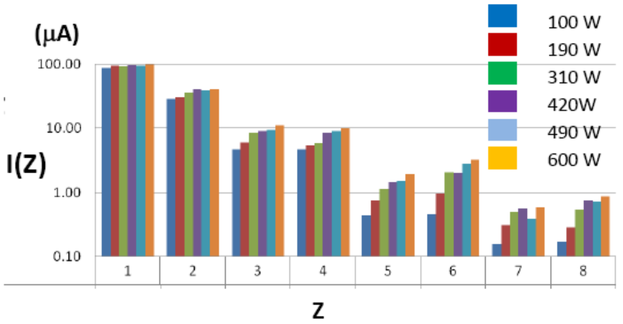

Figure 6: Ion current of an individual charge state for the different microwave power

Beyond Z=4, the ion intensity strongly depends on the microwave power. It is reasonable that the density of high energy plasma electrons takes a crucial role to create deeply striped ions. The density of high energy electrons in the present ECRIS seems to be insufficient for ionization to deeply develop. A possible improvement will be discussed in Summary.

HIGH VOLATGE TERMINAL (HVT)

The ECRIS is embedded inside the HVT. An ion beam of a charge state Z has a kinetic energy of ZeV, where V is a summation of extraction voltage and terminal voltage.

Mechanical Design

A HVT box is put on 6 insulating stands. High voltage is fed by a SPERMAN Cockloft-Walton high voltage generator. Inner devices are power supplied through an insulating transformer. Fig. 7 shows a side view of HVT containing the ECRIS and an acceleration column.

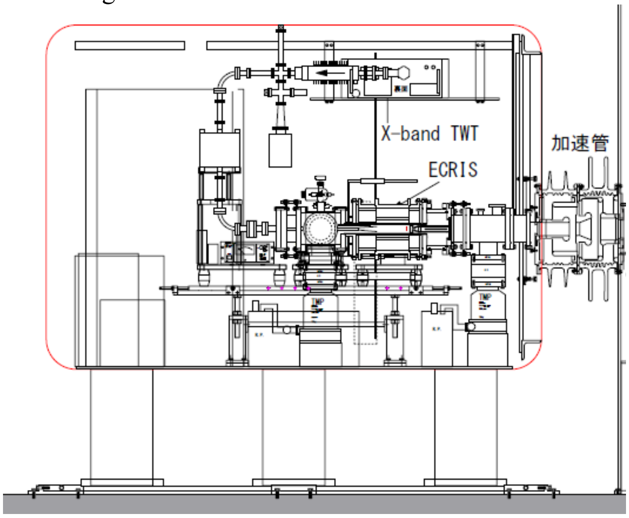

Figure 7: High voltage terminal

Voltage Stability in Pulse Mode Operation

As mentioned earlier, the ECRIS is operated in a pulse mode. In order to stabilize a change in the applied voltage due to the transient beam load, a kind of voltage stabilizing circuit is employed.

LEBT

The LEBT is divided into two regions of Region I and II seen in Fig. 2. Region I with the axial symmetry consists of the Einzel lens located just after the extraction electrode, 185 kV acceleration column with the inner focusing electrodes and the beam drift space up to the entrance of separation magnet. Region II beginning from the entrance of separation magnet and ending at the end of the electrostatic injection kicker has an asymmetric focusing feature.

LEBT Region I

In this region, an Ar beam contains charge state ions of +1 ~ +8. A space-charge limited ion current and beam envelope are calculated by the IGUN code, assuming the experimentally obtained fraction rate among A^{1+} ~ A^{8+}. Fig. 8 shows the beam envelope.

LEBT Region II

Taking into account of edge focusing in two dipole magnets, the lattice has been designed so that the lattice functions match to that of the KEK-DA. Fig. 9 denotes the beta functions in both directions.

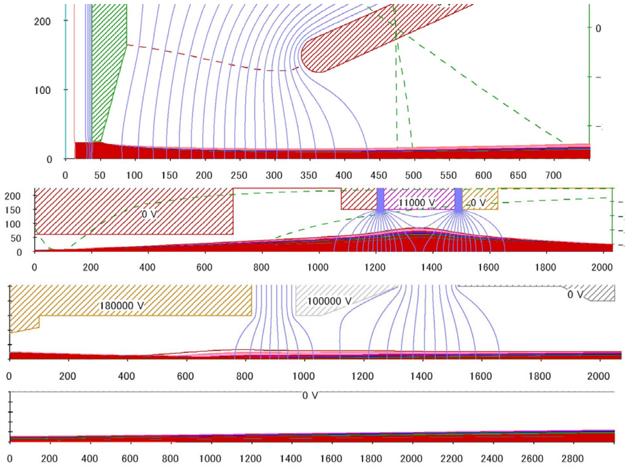

Figure 8: Beam envelope of Region I from the anode hole to the entrance of separation magnet

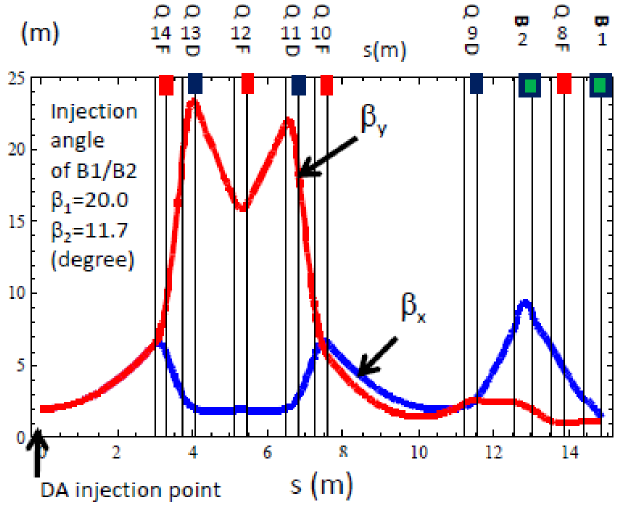

Figure 9: Beam envelope functions in both directions

SUMMARY

The present low ion current of Ar^{8+} may be attributed to the low B_r on the inner surface of the plasma chamber. In addition the region with $B=B_{ECR}$ is far from the central region. In order to improve this defect, a thinner hextapole magnet will be installed into the inner aperture at the expense of reducing plasma-volume.

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