KEK DIGITAL ACCELERATOR AND ITS BEAM COMMISSIONING*

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Abstract

Operation of the KEK digital accelerator, which consists of novel accelerator components such as a permanent magnet x-band ECRIS, an Einzel lens longitudinal chopper, an electrostatic injection kicker, and induction acceleration devices, began. Key features of individual devices and beam commissioning focusing on barrier bucket trapping are described here.

INTRODUCTION

The KEK digital accelerator (DA) is a small-scale induction synchrotron (IS) without a high-energy injector [1]. The concept of an IS was experimentally demonstrated in 2006 [2] through the use of the KEK 12 GeV PS. Instead of an RF cavity, an induction cell is employed as the acceleration device. It is simply a one-to-one transformer, which is energized by a switching power supply generating pulse voltage. Two types of induction cells for acceleration and confinement are utilized. It is a crucial point of the IS that voltage timing is controlled by a gate signal of solid-state switching elements based on bunch signals detected at the bunch monitor. This operational performance enables acceleration of ions from extremely low velocities, and is the reason why the DA does not require a high-energy injector. It is understood from these properties that the DA is capable of accelerating any species of ion, regardless of possible charge state.

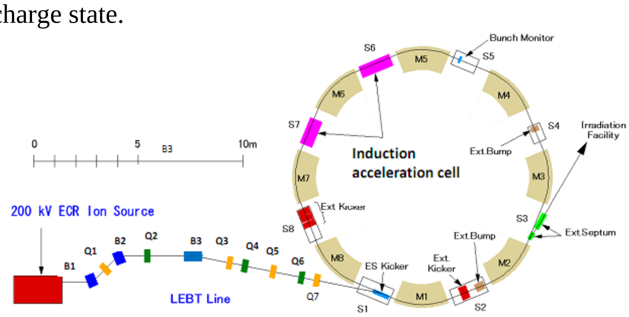

Figure 1: Outline of the KEK Digital Accelerator.

In the KEK DA, schematically shown in Fig. 1, a 5 msec long ion beam is created in the electron cyclotron resonance ion source (ECRIS) and chopped by the newly developed Einzel lens chopper in 5 μsec and post-accelerated in the acceleration column attached with the 200 kV high-voltage terminal (HVT), after which it propagates through the low-energy beam transport line (LEBT) to be injected into the ring with the electrostatic kicker. The electrostatic kicker voltage is turned off before the injected beam pulse completes a single turn in the DA ring, which is a rapid-cycle synchrotron. The injected beam is captured with a pair of barrier voltage pulses and accelerated with pulse voltages, the pulse length and amplitude of which are controlled in digital. He1+ ions beam commissioning in the KEK-DA is described here.

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MACHINE

Permanent Magnet ECRIS [3]

The ECRIS is embedded on the DC 200 kV high voltage platform. In order to minimize the consumed electric power and avoid troublesomeness of water cooling on the high voltage platform, the permanent magnet ECRIS being operated in the pulse-mode (10 Hz and 2-5 msec) has been developed. This ECRIS driven by a 9.35 GHz TWT with a maximum output power of 750 W is capable of producing from hydrogen ion to Argon ion, which are extracted at 14 kV. The HVT including the Einzel lens chopper and the post-acceleration column is schematically shown in Fig.2.

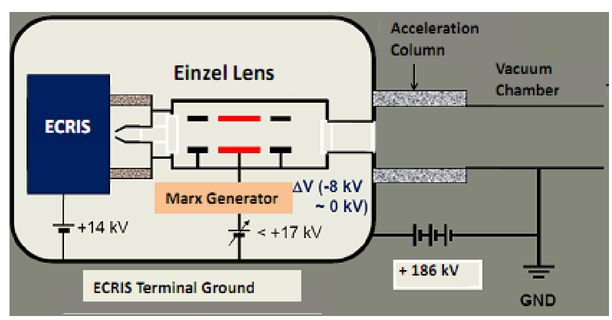

Figure 2: Schematic of the HVT and its contents.

Einzel Lens Chopper[4]

As stated in the above introductive part, the revolution time-period of ions in the KEK-DA is around 10 μsec. The single-turn injection scheme requires a pulse length less than 10 μsec. A pulse chopper upstream is demanded. Beam-handling at a low energy stage is apparently preferable, leading to low yields of secondary electrons, small out-gassing, and low energy X-ray emission. In addition, its low cost motivated us to develop the Einzel lens chopper, which works as a longitudinal chopper and demands only an additional power supply to control the gate voltage. The chopper head is the Einzel lens middle electrode which is necessary for transverse orbit matching. To realize a fast pulse rising and falling time of the chopped pulse, the solid-state switch driven Marx generator has been developed. A 5 μsec-long pulse of minus 6 kV generated by the Marx generator is superimposed on DC 17 kV of the middle electrode, which prevents ions to propagate downstream except for the gating time-period. The chopped pulse is immediately post-accelerated in the DC acceleration column of 186 kV to enter into the momentum selector or charge-state selector region. Figure 3 shows the 5 μsec pulses chopped at the timing of 0.4 msec from the pulse head respectively, which were measured by a Faraday cup.

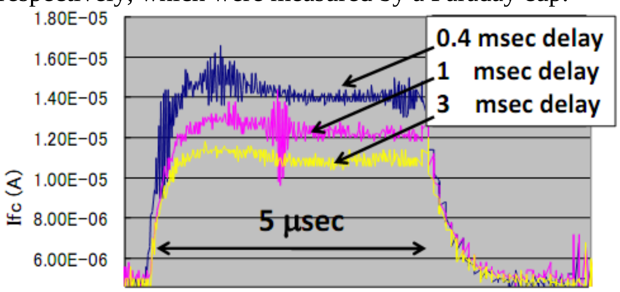

Figure 3: 5 μs chopped pulse profiles, which are chopped at different times from the pulse head of a 5 ms ion pulse.

Low Energy Beam Transport (LEBT)

The LEBT consists of the momentum selector magnet (or charge state selector), other two bending magnets, 7 focusing quadrupole magnets, additional steering magnets, and beam profile monitors.

Ring Lattice

The lattice consists of eight combined-function (FDF) magnets (M1~M8) symmetrically placed along the beam orbit. Eight straight sections are occupied by the electrostatic injection kicker (S1), extraction kicker (S2,S8), extraction septum magnets (S3), induction acceleration cells for beam confinement and acceleration (S6, S7), and correction magnets (S4) and bunch/position monitors (S4,S5). Lattice/beam parameters are listed in Table 1.

Table 1: Lattice/Beam Parameters

Circumference	C_0	37.7 m
Bending radius	ρ	3.3 m
Maximum B	B_{max}	0.84 Tesla
Bet. tune in x/y	Q_x/ Q_y	2.17 - 2.09/2.30 - 2.40
Transition	γ_T	2.25
Energy (Inj.)/ nucleon	E_{inj}	200 keV(Q/A)
Rev. frequency	f	~80 kHz – 3 MHz

Electrostatic Injection Kicker [5]

From a simple reason that for handling of low velocity ions electrostatic fields are much suitable, the electrostatic injection kicker has been employed. Before the injection, two 90 cm long parallel plates are excited to 20 kV through a pulse forming network line, which is required to provide the injection angle of 11.25 degree. To ensure the field uniformity among two plates, one of which is grounded, three middle electrode panels are inserted. Before the ion pulse completes its first turn, the high voltage is turned off by firing thyratrons, which allow charges on the capacitance including the electrode plates to quickly flow to the ground through the register. Actually the electrostatic kicker voltage was tuned off in a few μsec.

BEAM COMISSIOING

Beam Orbit

Betatron motions of an injected bunch centroid caused by injection errors were observed by the diagonal electrostatic position monitor in both directions. It turned out that betatron tunes are close to the design values. The injected He1+ ion bunch performed free-circultion in the KEK-DA at the injection fields of B_{min}=360 Gauss and injection optics was preliminarily optimized by adjusting excitation currents of the steering magnets placed just before the injection point and the COD correction system so as to minimize the beam loss (see Fig.4).

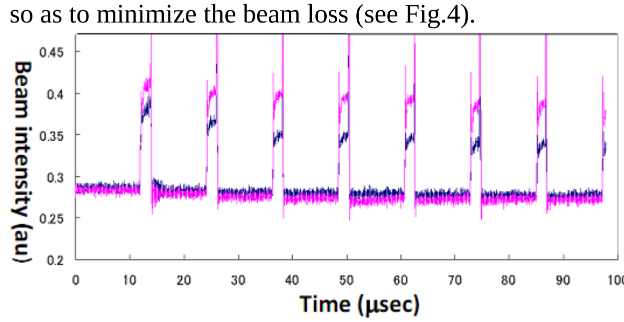

Figure 4: Free circulation of He1+ ion beam; No injection error correction (blue) and with correction (purple).

Barrier Trapping

At the injection energy, the 5 μsec bunch was trapped the barrier voltages that were triggered at the revolution frequency. Figure 5, in which the bunch signal without the barrier voltages is indicated for comparison, shows the trapped He1+ bunch 10 msec after injection.

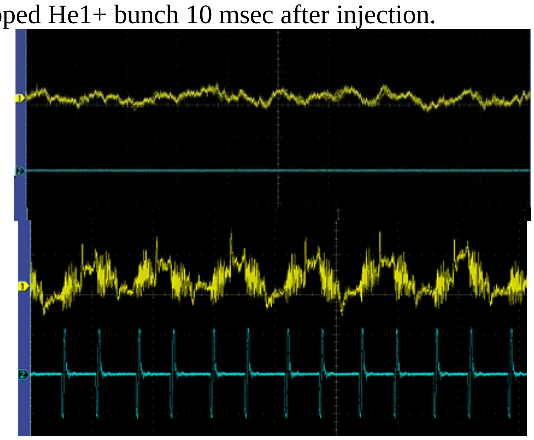

Figure 5: Un-trapped He1+ beam (upper) and barrier bucket trapped He1+ beam (bottom) 10 msec after injection and barrier voltages (sky blue).

Life Time

Bunch intensity integrated over one revolution period is shown in Fig. 6. Exponential fitting tells us a life time of about 4 msec. This magnitude seems not to be determined from electron capture or stripping of concern [1] but from emittance blow-up as a result of interaction with a residual gas.

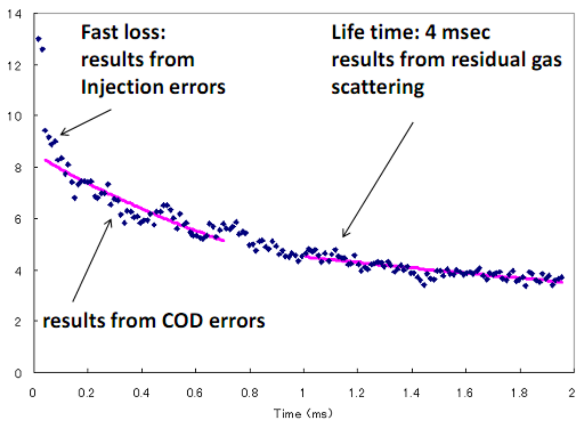

Figure 6: Beam intensity in au after injection.

Barrier Bucket Handling (Bunch Squeezing)

Barrier bucket handling of a long bunch has been expected from early days of induction synchrotron R&D [2]. This was demonstrated by using the present He1+ bunch at the fixed energy. Bunch profiles on the process of bunch squeezing, where the trigger timing for the right barrier voltage pulse is discretely changed by 8 nsec per turn from 0 msec to 7 msec, are shown in Fig. 7. Mountain view of the bunch profile in the same experiment, which delineates typical features of the barrier bucket bunch trapping, is shown in Fig. 8. This experimental result seems to reflect a motion of a bunch injected with an extremely small momentum spread less than 0.025 % and an energy deviation of +0.23 % in the longitudinal phase space. The bunch tail moves forward and a part of the originally bunch head moves backward. Both encounter at 1.5 msec after injection. The latter is reflected by the moving barrier-voltage pulse. The bunch never expands beyond this barrier voltage pulse-edges. Beyond 7 msec, the barrier bucket is fixed. Slightly diffusing of the bunch into the upper region can be attributed to increasing of the momentum spread associated with bunch squeezing.

SUMMARY

We have successfully demonstrated the injection operation of the KEK-DA and barrier bucket beam-handling using He1+ ion beams. What we have observed seem to be within our expectation. Hereafter, the induction acceleration will be continued after summer shutdown.

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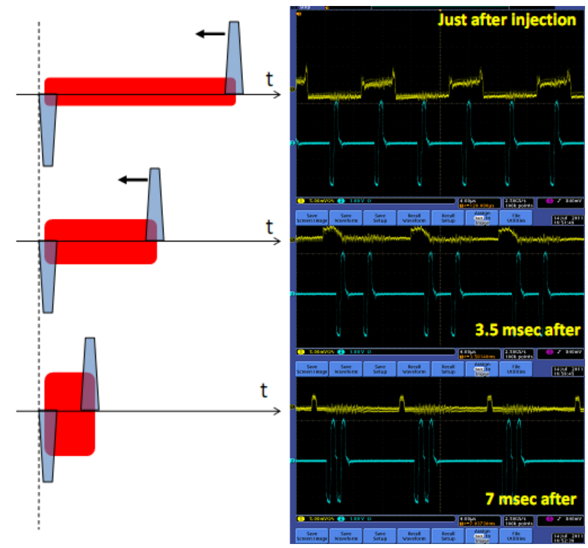

Figure 7: Bunch squeezing experiment (right) and schematic of barrier voltage operation (left).

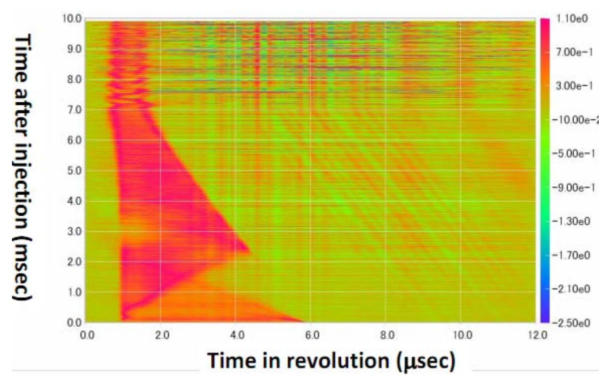

Figure 8: Projection of the mountain views of the bunch profile on the squeezing process.

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