INJECTION AND EXTRACTION SYSTEM FOR THE KEK DIGITAL ACCELERATOR*

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Abstract

The PS-Booster is now being renovated as the first Digital Accelerator (DA) [1]. In this project, argon beam from the ECR ion source is injected to the DA by an electrostatic beam kicker. Another electrostatic device with the same structure is used for chopping the beam before injection. The beam extraction system comprises bump, septum and kicker magnets, which are installed in a vacuum. Pressure level is crucial for successful acceleration of ion beam [2]. Therefore, we decided to put the septum magnet outside the vacuum, since it dominantly contributes to the vacuum pressure more than the other magnets. This paper describes the electrostatic beam chopper, injection kicker and newly developed vacuum duct for the septum magnet.

INTRODUCTION

New acceleration system using an induction cell has been developed by using the KEK 12-GeV PS [3]. We call an accelerator using the induction acceleration system "Digital Accelerator". The KEK PS-Booster has shut down in March, 2006, after 28 years operation for supplying a proton beam to the KEK 12-GeV PS, a neutron source, a muon source and a medical facility for cancer therapy. View of the PS-Booster is shown in Fig. 1, where H^- injection system is seen in this side of the ring.

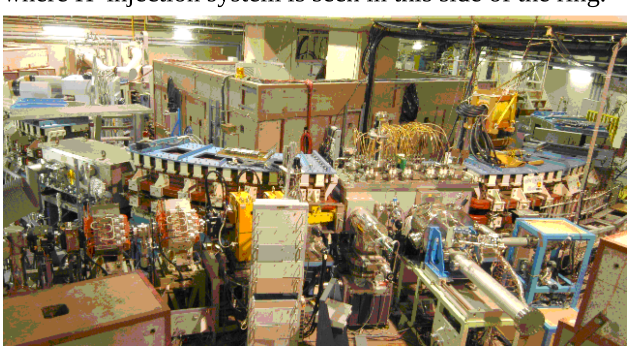

Figure 1: View of the KEK PS-Booster.

We are now renovating the PS-Booster as the first Digital Accelerator (DA) by introducing an induction acceleration system instead of the existing rf system [4]. In this project, an argon beam from the ECR ion source is directly injected to the DA. The ECR ion source (ECRIS) is newly developed for this project [5]. An ion beam from the ECRIS is injected to the Digital Accelerator at a repetition of 10 Hz.

Fig. 2 illustrates the schematic of the KEK DA complex. An argon beam from the ECRIS is chopped by the electrostatic beam chopper on the LEBT line. Thus, a few μsec beam pulse is obtained, as shown in Fig. 3, and transported to the DA ring. The beam pulse is kicked by the electrostatic beam kicker to merge into the ring orbit at the straight section S1 of the DA ring.

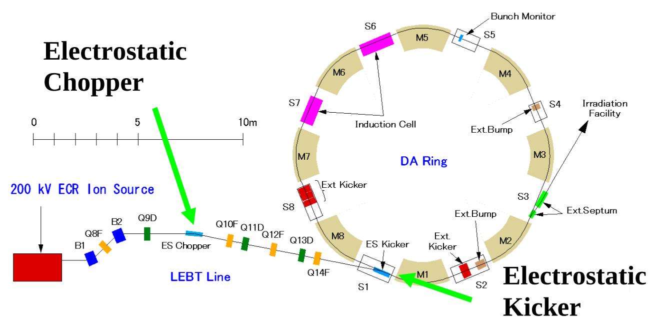

Figure 2: Schematic of the DA complex.

The beam is extracted by the existing extraction system, which comprises bump, kicker and septum magnets. Two bump magnets are placed at S2 and S4. Kicker magnets are placed at S2 and S8. Septum magnets are placed at S3. These magnets were in a vacuum so far. Pressure level is crucial for successful acceleration of an ion beam. Therefore, we decided to put the septum magnet outside the vacuum and prepare two vacuum ducts. One is inserted in the magnet gap and the other placed at outside of the septum plane. Since the septum magnet dominantly contributes to the vacuum pressure more than the other magnets, we expect that vacuum level will be drastically improved.

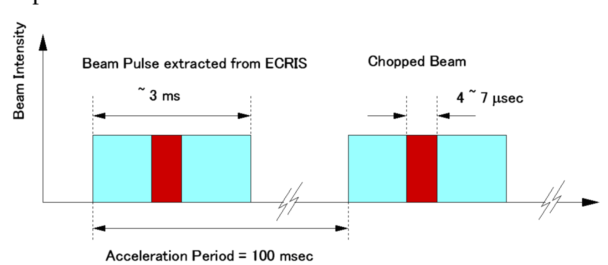

Figure 3: Beam from ECRIS and chopped beam.

The details of the electrostatic chopper/kicker and newly developed vacuum duct for the septum magnet are described in the following subsections.

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INJECTION SYSTEM

Overvew of Electrostatic Chopper/Kicker

Electrostatic chopper and kicker are horizontally deflecting devices with the same structure, as schematically shown in Fig. 4. In the figure, a photograph of the electrostatic kicker is shown. This device comprises anode and ground electrodes, and six correction electrodes which ensure the field homogeneity throughout beam passage. For this purpose, the applied voltage between anode and ground is divided by voltage dividing resistors, which connect two adjoining electrodes from the anode to the ground electrode.

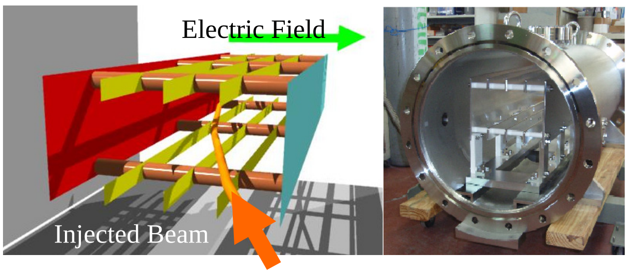

Figure 4: Schematic of the electrostatic chopper/kicker and photograph of the kicker.

Operation conditions for chopper/kicker are different according to their functions. The chopper generates a pulsed field to deflect a small fraction of the beam to the DA ring, while the kicker keeps a field until beam injection is completed. Both devices are intended to be excited by a pulse forming network (PFN). An all-solid state Marx generator is now being developed as another candidate for excitation of the chopper. Voltage patterns expected for excitation of the chopper and the kicker are schematically shown in Fig. 5.

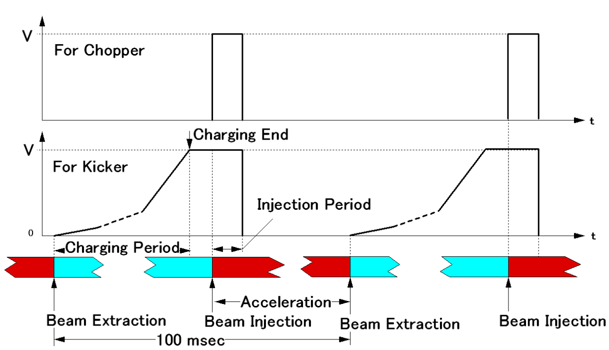

Figure 5: Expected voltage pattern for chopper/kicker.

Characteristics of the chopper/kicker are listed below:

- Deflection Angle 11.25 deg
- Length 800 mm
- Maximum Voltage 20 kV
- Aperture (W x H) 200 x 100 mm^2

Distribution of the Electric Field

The field distribution of the chopper/kicker was evaluated by TOSCA/OPERA3D, which is a simulation code for electrostatic problem. Fig. 6 shows a model of the chopper/kicker for field evaluation. In the field evaluation, voltage of the chamber wall and the ground electrode (the grey plane) is fixed at zero. Voltage at the anode (the red plane) is fixed at 20 kV. Voltages at subsidiary electrodes are fixed at 15 kV, 10 kV and 5 kV from left to right on both upper and lower sides.

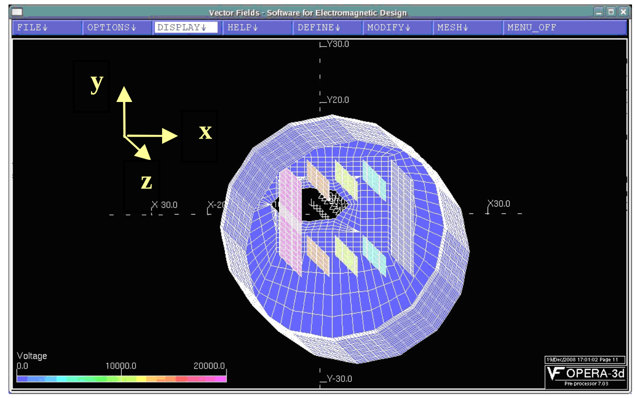

Figure 6: Model of the chopper/kicker for field evaluation by TOSCA/OPERA3D.

In Fig. 7, the resultant distribution of the horizontal component of the electric field (E_x) placed at the center of both y and z, is plotted as the Model0. The field distributions obtained in other two cases are also plotted. One is the case where each subsidiary electrode is floated (Model1). In the other case, there is no subsidiary electrode (Model2). As shown, subsidiary electrodes, which connected each other with dividing resistors, are needed to ensure the field homogeneity.

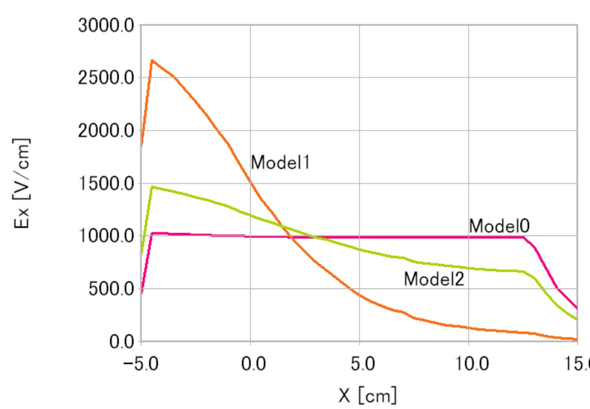

Figure 7: Distribution of the horizontal component of the electric field E_x placed at the center of both y and z.

Voltage Measurement

As mentioned above, the appropriate voltage distribution at each subsidiary electrode determines the good field homogeneity. In order to confirm such uniformity, voltage measurement was performed. The chopper/kicker was excited by a voltage with the sinusoidal waveform by using the circuit illustrated in Fig. 8. As shown, dividing resistors are connected at the outside of the vacuum chamber so as to avoid outgas from the resistors.

Frequencies of the exciting voltage were set at 1 kHz, 10 kHz, 100 kHz and 1 MHz.

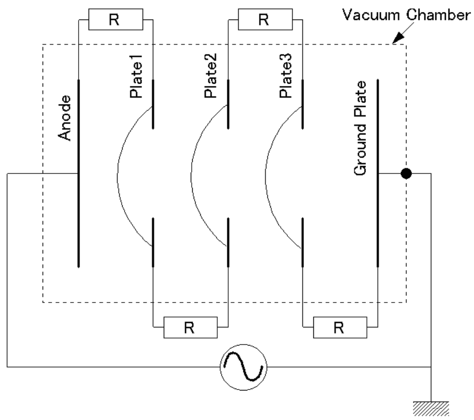

Figure 8: Circuit for excitation of the chopper/kicker for voltage measurement.

Fig. 9 shows the results of the voltage measurement at each electrode with the dividing resistor of 1 MΩ. Resistor value was determined by taking account of current ratings of the power supply. Here, the measured voltage is normalized by the anode voltage at x = 1.0. Voltages at plate1, plate2 and plate3 are plotted at x = 0.75, 0.5 and 0.25, respectively. The voltage distribution becomes non-linear drastically beyond 10 kHz, and approaches some definite distribution.

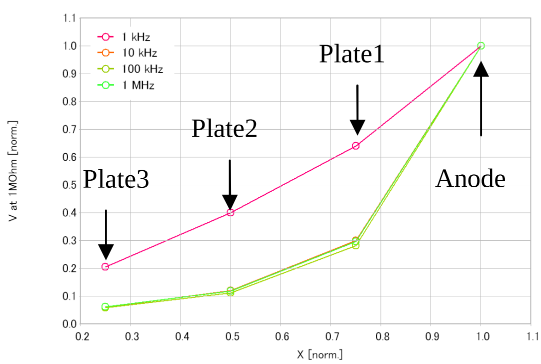

Figure 9: Voltage distribution among electrodes.

Stray Capacitance

It was found that the voltage distribution among electrodes strongly depended on the frequency of the exciting signal. Such behaviour implies that stray capacitances between electrodes and the ground affect on the voltage distribution as well as the dividing resistors. We estimated the stray capacitance to reproduce the frequency dependence of the voltage distribution by using a circuit simulation program, SPICE. The optimized capacitances are around 50 pF with respect to the ground or between subsidiary electrodes.

In order to ensure a linear voltage distribution even in a pulse operation of the chopper/kicker, the capacitance of 330 pF, which is sufficiently larger than the stray capacitance, is put parallel to each dividing resistor.

VACUUM DUCT FOR THE SEPTUM MAGNET

A circulating beam interacts with a residual gas during acceleration in a ring vacuum, and some fraction of the beam losses. Therefore, pressure of the ring vacuum is crucial for successful acceleration of the argon ion in the DA project [2]. A septum magnet is installed in a vacuum chamber of the DA ring, and outgas from its surface has dominantly contributed to the vacuum pressure more than the other magnets installed in vacuum. Therefore, we decided to put the septum magnet outside the vacuum.

Fig. 10 shows the septum magnet and newly developed two vacuum ducts seen from upstream. The left duct is for circulating beam and the right for an extracted beam. Both ducts are welded to a single flange at upstream, while they are separated at downstream so that an eddy current loop is not formed. The right duct is cooled by water to remove heat generated by eddy loss. Magnetic field in the duct was measured, and it was found that the contribution from eddy currents was sufficiently small.

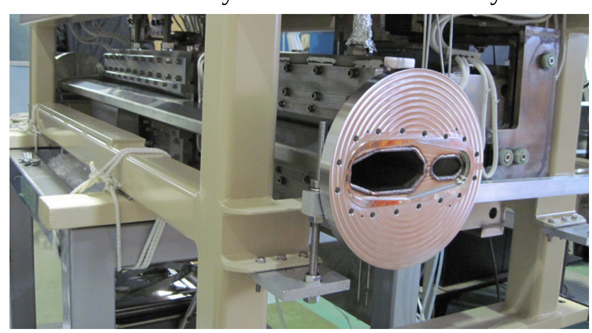

Figure 10: Septum magnet and new vacuum ducts seen from upstream.

SUMMARY

Electrostatic chopper/kicker with subsidiary electrodes has been developed for chop/kick of the beam pulse. It was found that the dividing capacitance to compensate the stray capacitance is required to obtain the field uniformity as well as the dividing resistor.

In order to improve vacuum pressure drastically, we decided to put the existing septum magnet outside the ring vacuum. For this purpose, new vacuum duct has been developed.

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