AN ANALYTICAL INVESTIGATION OF TIME-DEPENDANT DISCHARGE ON ELECTROSTATIC DEFLECTOR AT NIRS-930 CYCLOTRON

T. Honma, Y. Sakamoto, S. Hojo, T. Okada, K. Komatsu, N. Tsuji and S. Yamada
National Institute of Radiological Sciences, 4-9-1, Anagawa, Inage-ku, Chiba 263-8555, JAPAN

Abstract

A phenomenon of a time-dependant discharge on an electrostatic deflector has been investigated in NIRS AVF-930 cyclotron. The discharge occurs as a function of time interval of a few to around fifteen minutes, which is in inverse proportion to an arc power of ion source and applying voltage on the deflector electrode, even if the normal accelerated beam is intercepted at central region. It has been supposed to be induced by a certain kind of irrelevant ions having very low-energy, act as an initiator for the discharge. In this paper the details of the discharge phenomenon and some results of the investigation are presented.

INTRODUCTION

One of the breakdown phenomena by an electric discharge on a deflector system in the cyclotron will be discussed. Although many kind of studies and efforts have been made[1],[2],[3] for the electric discharge previously, however, this study introduce made about one certain phenomenon leading to the discharge.

The NIRS-930 isochronous cyclotron[4] was constructed in 1975. The cyclotron having K=110 consists of four sectors and two Dees (86 deg.) connected to moving panel type of rf-cavities. The frequency-range of 10.7-21 MHz covers 1st and 2nd harmonic in the acceleration modes. The stable beams of proton with energy up to 70 MeV, deuteron, ^{3}He, alpha and few kind of heavy ions are sufficiently delivered with the extraction efficiencies of 50 ~ 85 % operated with in a deflector-field less than 85 kV/cm (~ 60 kV at 7 mm gap). Fig.1 shows a drawing of the electrostatic deflector system with a photograph of the entrance-part of it. About five years ago, a "floating septum system"[5] had been developed in order to preserve the pre-septum electrode by the thermal damage owing to the irregular beam hitting, and used in daily operation. The system is able to read-out the beam current on the pre-septum, which is insulated from the earth potential.

Recently, a strange electric discharge had occurred to the deflector system. The discharge was not in the usual high-tension spark, because it was set only 25~30 kV, which was comparatively low-voltage on the deflector.

In the following sections, the phenomenon of the discharge on the electrostatic deflector and some result of analytical investigations are described.

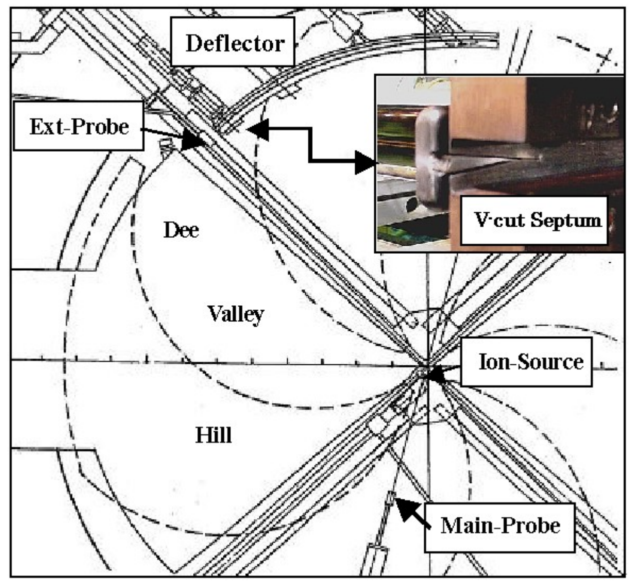

Fig. 1. Plane view of NIRS-930 cyclotron. Electrostatic deflector system and photo of its entrance part of septum are shown.

DISCHARGE PHENOMENA

The discharge was induced in the following situations:

a). It occurs in the acceleration of multi-charged ions as $^{4}He^{2+}$, $^{12}C^{4+}$, etc using an internal ion-source, and operating with the 2nd-harmonics mode for the acceleration.

b). It was around 25-30 kV applying to the deflector, which had been easily and reliably obtained in the daily operation, because a holding capability of the deflector voltage was up to 60 kV in the cyclotron.

c). It occurs that even if the acceleration beam does not pass into the deflector, where the beam is intercepted perfectly by Main-probe, Mid-point beam shutter, and Ext-probe, positioned at the radius of about 4.5 cm, 40 cm and 90 cm each, respectively.

d). It depend on a time elapsed form the arc "ON", where the time interval is almost inverse proportion to the arc-current of the ion source and a level of the applying voltage on the deflector electrode.

e). It did not occur when the applying voltage on the deflector was modulated periodically as a function of the time interval, that was roughly 30 kV in 2-min and 0 volt in 30-sec, respectively.

f). It has been not happened when substitute a set of the ion source and the puller for an another one, here the latter having slightly narrow slit-width of each.

All of these circumstances have been confirmed in the several-times examinations.

DISCHARGE MECHANISM

From the situations described above, the origin of the discharge can be supposed to be induced by something irrelevant ions producing in the ion source. For example in the acceleration of $^4He^{2+}$ beam, another ion of $^4He^{1+}$ produced in the ion-source having very low-energy is traveling to the outer radius taking a chorocoidal motion along with Hill-Valley boundary. The ions hit a high voltage deflector-electrode (cathode) passed through the opening V-cut septum (see in Fig.1), where plural secondary electrons are emitted from the surface of the cathode by the ion. Here the electrons are drifting in a gap between the cathode and the septum taking with a scalloped orbit and /or a cycloid motion in horizontal plane, and change its motion to vertical direction. Then the electrons are accelerated to the anode plates (upper or lower) taking with helicoidal motion. Resulting in this process, Grow-discharge is generated by ionization in the residual gas, and becomes even stronger with time dependence.

Ion orbit

The first object is to investigate the certain ion trajectory, which expected to hit the cathode. The orbit study has been made with a computer code[5] developed at IPCR (Institute of Physical and Chemical Research), and was performed with the existing internal ion-source and puller configuration, where the cyclotron-parameters are set to acceleration of the $^4He^{2+}$ with energy of 40 MeV in the daily operation take into account. In such study ion of $^4He^{1+}$ is used for the test-particles with the various initial conditions near the Hill-Valley boundary. Eventually some kind of trajectories may be possible to satisfy the expected obit with initial energy range of 10 to 20 keV. In Fig.2 the typical two cases of trajectories is shown for $^4He^{1+}$ ion having 15 keV with slightly different its initial angle at the starting position. In the first case (orbit-1) the ion gains its kinetic energy at the initial stage, and in the second case (orbit-2) it gains at the final stage owing to cross the acceleration-gap with suitable RF-phase, respectively. Those ions hit a high voltage cathode pass through the opening V-cut septum, where the kinetic energy of the ions becomes almost 50 to 100 keV.

Electron orbit

A several times secondary electrons per ion are emitted from the surface of the cathode by bombardment of the $^4He^{1+}$ ions. In order to investigate the electron motion in the electric and magnetic fields, a computer code was

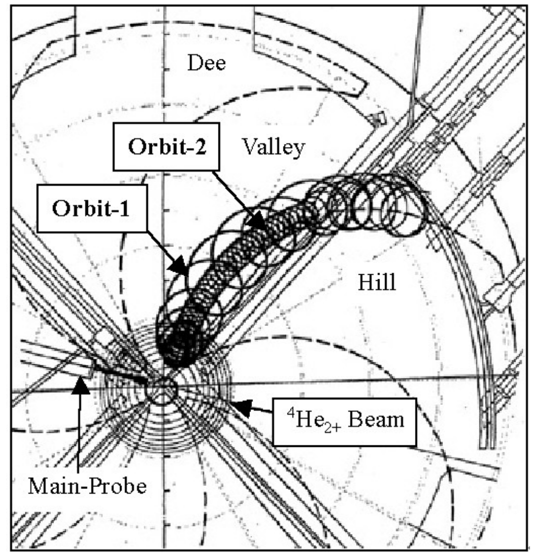

Fig.2. Two case of $^4He^{1+}$ ion orbits, with normal acceleration beam of $^4He^{2+}$, see in text.

developed. Three-dimensional electric field is applying to the calculation, hence the field distribution is obtained by using MAXWEL-3D[6] based on a model of the existing configuration of the deflector system as shown in Fig.3. A typical electron trajectory having initial kinetic energy of 50 eV is shown in Fig.4. The electric field pushes the electron toward the septum then it gains velocity; the magnetic field bends its orbit in the azimuthally direction. Ultimately, the electron returns to the cathode with the initial kinetic energy. If the electron is not absorbed, it follows a scalloped and /or cycloid orbit, and its kinetic energy change in the range of 50 to 800 eV. Since the magnetic field varies in the azimuthally direction, the

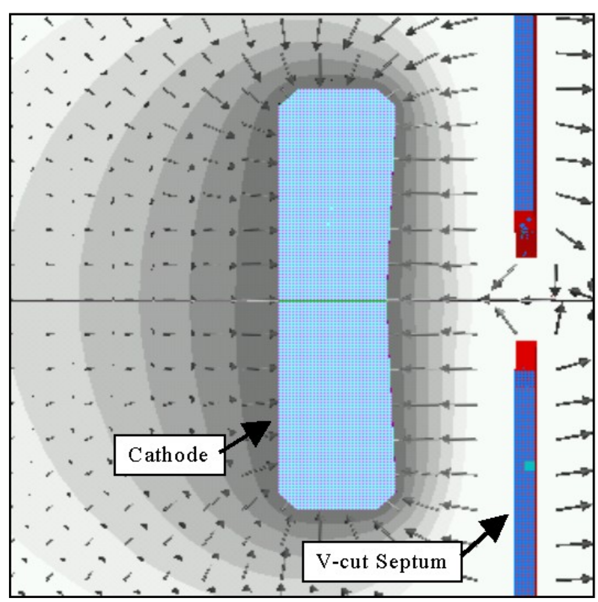

Fig. 3. Electric field distribution in gap between cathode and V-cut septum on cross-sectional plane.

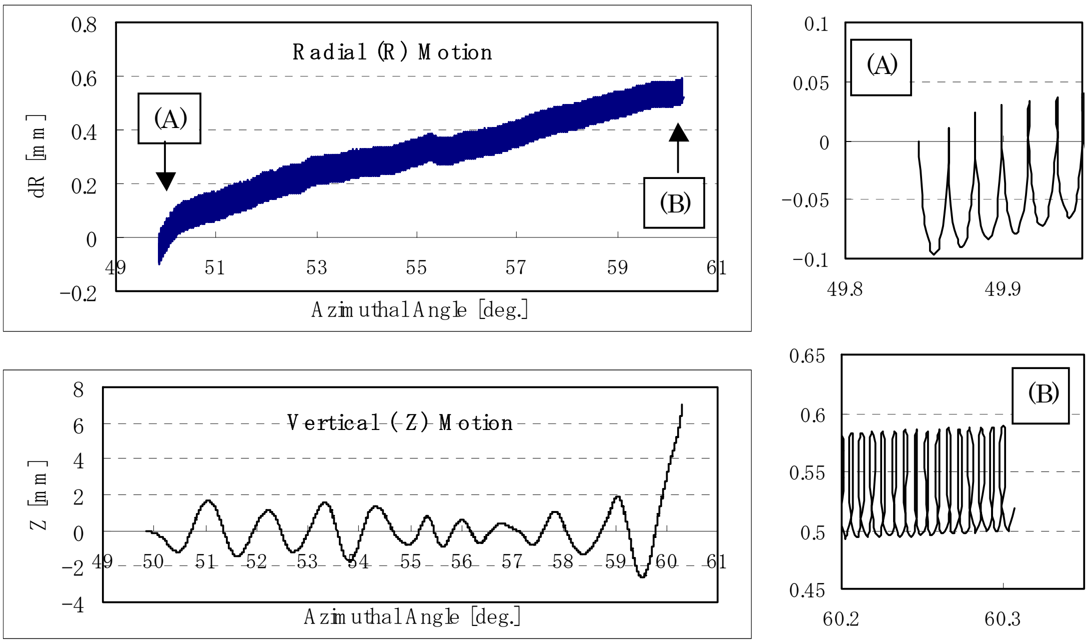

Fig. 4 Typical electron trajectory in gap between cathode and septum. Horizontal scale represented the azimuthally angle measured from the centerline of Dee-No.1 (see in Fig. 1) taking a clockwise. Amplitude of “dR” means the displacement to the reference radius of R = 905 mm. Initial position in the calculation is about 1 mm up-stream from the end of the “V-cut”.

amplitude of the orbit becomes decrease with a slightly rising field in the region. After traveling some distance along with the azimuthally-direction in the gap, the motion of electron is changed to the vertical direction, and is accelerate to the anode plates (upper or lower) taking with helicoidally motion.

CONCLUSION

In this study we described one of the electric discharge on a deflector system. The discharge was depending on the arc current of the ion source and also proportion to a time elapsed from arc “ON” even if the beam has not pass into the deflector where the main beam was intercepted perfectly by Main-probe and additionally internal beam shutter. During our investigations, we draw the following conclusion that; the discharge is induced by irrelevant ions produced in the ion source. For example the ion of $^{4}He^{1+}$, having very low-energy in the acceleration of $^{4}He^{2+}$ beam, is traveling along the Hill-Valley boundary to the outer radius taking with a chorocoidal motion. The ions hit a high voltage deflector-electrode (cathode) passed through the opening V-cut septum, here several times secondary electrons are emitted from by the surface of the cathode. The electrons are drifting in a gap taking with cycloid motion in horizontal plane and change its motion to vertical direction. Then the electrons are accelerated to the anode plates (upper or lower), and bombard the anode surface. Among those processes electrons collide with residue gas molecules (mainly of He-gas) and create another electron-ion pair in the region of interest. The ions, having suitable kinetic energy from the residue gas, are back to the cathode and release several times secondary electrons. Resulting, it seems to be most probable to generating Grow-discharge by the ionization in the residual gas, and becomes even stronger with the time dependence.

The work, however, will continue to investigate the real Grow-discharge in the region of interest in order to confirm the fact.

ACKNOWLEDGEMENT

The authors would like to thank Dr. A. Goto of IPCR for his useful discussions during the study.

REFERENCES

[1] C.R. Hoffmann et al., Proc. 13th Int. Conf. on Cyclotron and their Applications, Vancouver, 1992, p577.
[2] Thomas Kuo et al., Proc. 13th Int. Conf. on Cyclotron and their Applications, Vancouver, 1992, p596.
[3] D.P. May et al., Proc. 13th Int. Conf. on Cyclotron and their Applications, Vancouver, 1992, p602.
[4] H.Ogawa,et al, IEEE Trans. Nucle. Sci. NS-26,No2, (1978) p1988.
[5] T.Honma et al., Proc. 16th Int. Conf. on Cyclotron and their Applications, East Lansing, Michigan, 2001, p126.
[6] A. Goto et al., Scientific Paper of Institute of Physical and Chemical Research, 74, 136-145,1980.
[7] "MAXWELL 3D" Field simulator, version 4.1, Ansoft corporation.