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DEVELOPMENT OF A SMALL COLD CATHODE TYPE PIG HEAVY ION SOURCE FOR THE TOHOKU AVF CYCLOTRON

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Abstract.- A small cold cathode type PIG heavy ion source was designed and examined in connection with the CYRIC cyclotron[1] which has the K-number of 50 MeV (Model 680 machine by the design of CGR- MeV). The characteristics of the ion source were measured with nitrogen gas for various operating parameters such as gas flow rate, arc power consumption and pulsing duty factor. At the present stage, the life time of the ion source is approximately 6 hours for an 84-MeV $^{14}N^{5+}$ ion beam with an intensity of 3.5 μA at R =650mm.

1. Introduction.- The CYRIC cyclotron is a 4-sectored variable energy AVF machine with the extraction radius R_{ext} = 680 mm and the K-number of 50 MeV. The cyclotron routinely accelerates light ions (p, d, ^{3}He and ^{4}He), and the acceleration of heavy ions is also expected by choosing appropriate harmonics, i.e., H = 2, 3, 4 and, possibly, 5. Fig.1 shows the resonance chart of our cyclotron. Due to the very limited space and the sophisticated geometrical conditions in the center region of the cyclotron, design of a small heavy ion source which can effectively produce multiply charged ions is indispensable. The above limitations give us some additional difficulties to produce highly charged ions with such a small ion source. These difficulties are mainly caused by the limited arc power consumption due to the limited anode cooling capability and the sputtering at certain places besides the arc chamber. Furthermore, the sputtered material from cathodes deposits onto the anode and sometimes it makes a short

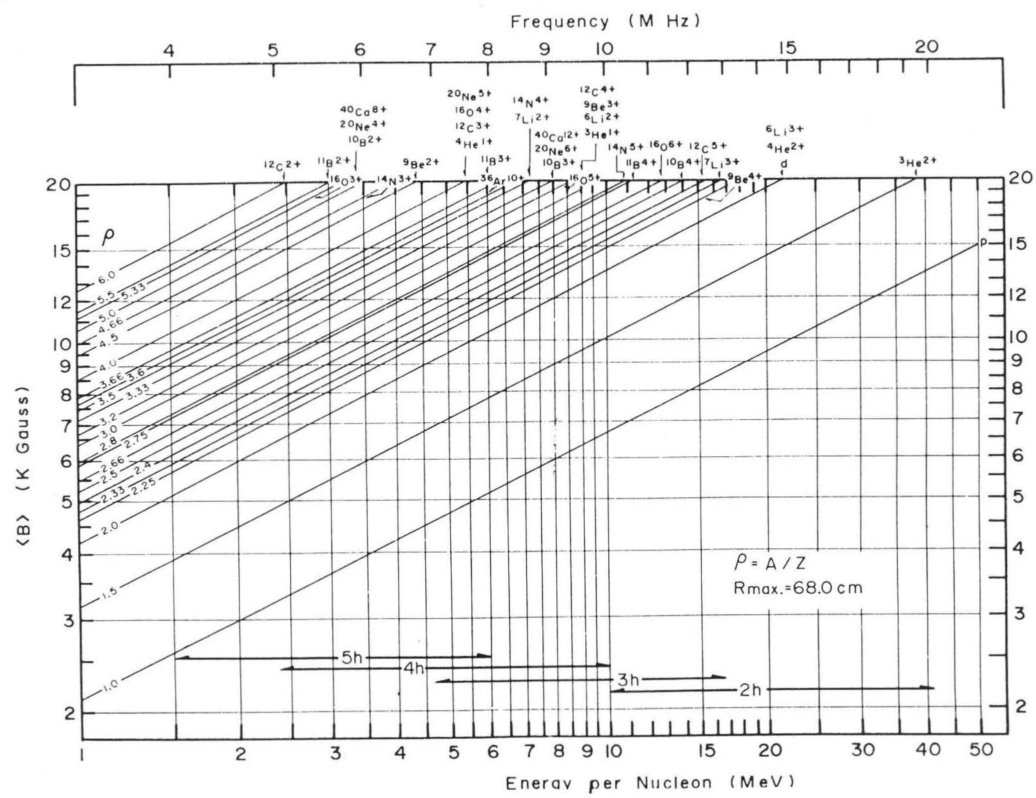

Fig. 1 : Acceleration energies for various ions versus average magnetic field and particle frequency. 2h, 3h, 4h and 5h indicate the mode number of harmonic acceleration; $\omega_{R.F.} = h \cdot \omega_{particle}$.

circuit across the arc. As a result of our experience, most of these difficulties have been eliminated for the present small ion source.

In order to obtain the optimum design and operational parameters, the following two characteristics of the ion source have been tested. The one is the accelerated beam intensity versus the diameter of the arc chamber, and the another is the beam intensity versus the duty factor and the pulse width for pulse operation.

2. Designing of the Small Heavy Ion Source.- The PIG sources for multiply charged ions have been reviewed[2)], and ionization of some kinds of gases in a pulsed discharge has been investigated by Pigarov and Morozov[3)]. In the present work, an internal cold cathode type PIG heavy ion source was designed to be fitted into the 36-mm diameter ion source shaft which could be inserted into the operating position through the lower pole of the cyclotron. The construction of the ion source is shown in fig. 2. The anode and the cathode holder are made of water cooled copper and stainless steel, respectively. The cathode holder makes the electrical connection between two cathodes, and is covered with Ta pipes to protect itself from the sputtering by discharges between the electrodes. The two water cooling lines of the cathodes coming out through the ion source shaft are insulated by the base insulator made of alumina. The cooling water flow rate is the same for the cathode and the anode, and is limited to 3 liters per minute, and we limited the input power for the ion source to about 2 kW. In order to avoid the short circuit caused by the sputtered material from the Ta cathodes, an insulating wall made of boron nitride was placed between the bottom cathode and the anode inside. The bore diameter of the arc chamber was designed to be 8 mm. This diameter can be reduced by inserting a cylindrical Ta sleeve. The capacity of the arc power supply is 30 kW, and it can be operated in both DC and pulsing modes. Since the beam current from the ion source for higher charge state ions is fairly sensitive to the gas flow rate, the gas control system is provided with an electric piezo valve for fine adjustment at a minimum flow rate of 0.02 cc/min. The schematic diagram of the gas control system, the arc power supply and the ion source is shown in fig. 3.

3. Experimental Results and Discussion.- Typical internal beam profile of the 84-MeV $^{14}N^{5+}$ ions measured by the integral beam probe is shown in fig. 4. The loss of beam intensity was about 40 % during the acceleration through the isochronous field from R = 100 mm to R = 650 mm. For an optimum pulse operation, the maximum beam intensities obtained were 3.5 μA and 5.0 μA for $^{14}N^{5+}$ and $^{14}N^{4+}$ ions, respectively, at R = 650 mm. The intensity of the $^{14}N^{5+}$ beam extracted from the cyclotron was 1.5 μA. The accelerated $^{14}N^{5+}$ ion beam of E = 84 MeV was identified from the kinematics of elastic scattering on a Au target.

In order to determine the optimum diameter of the arc chamber bore, the dependence of the beam current on the arc chamber bore diameter was measured by inserting a Ta sleeve of 5.0-mm or 6.4-mm inner diameter into the arc chamber. The result is illustrated in fig. 5. It is shown that the beam intensity increases with the decrease of the diameter. The beam intensity also depends on the duty factor of the pulses. Fig. 6 shows the beam intensity as a function of the pulse width for the duty factor as a parameter. The maximum values in fig. 6 were plotted as a function of the duty

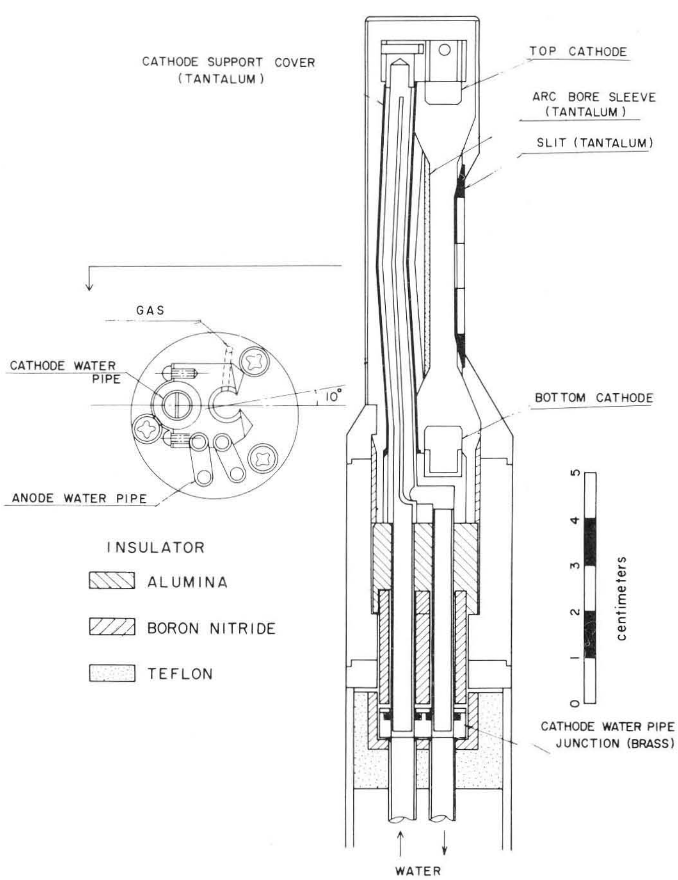

Fig. 2 : Sectioned view of the small PIG ion source for heavy ions. An arc-bore sleeve can be switched to one of other sizes.

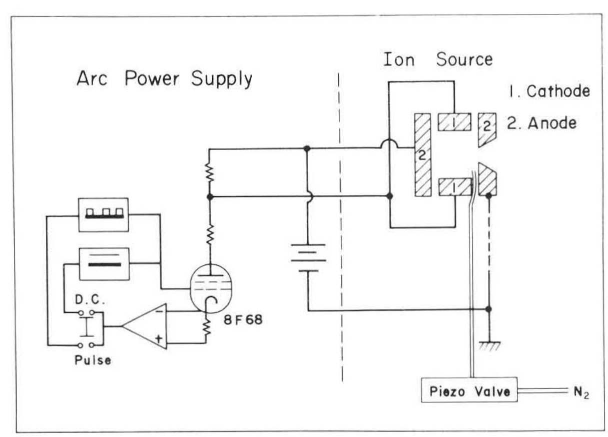

Fig. 3 : Schematic diagram of ion source system with gas control and power supply.

factor in fig. 7, showing the dependence of beam current on the duty factor. During these measurments the gas flow rate and the arc power consumption were kept constant. In fig. 6, one can see that there is an optimum pulse width for each duty factor. There is also an optimum value of the duty factor as seen from fig. 7. A duty factor of 30 % with 3 msec pulse width and 10 msec period seems to be an optimum choice for the present heavy ion source. A similar tendency was also observed for $^{14}N^{4+}$ ion beam. Present data will be analyzed using a plasma model.

We summarize the present results as follows.

1. Our small heavy ion source gives more than 1 μA of extracted beam of $^{14}N^{5+}$, and is practical.
2. The life time of the Ta cathodes in the pulse operation is at least 6 hours for a supplied electrical power of 2 kW.
3. The gas control system is very reliable at a gas flow rate of less than 0.02 cc/min. This is extremely important because production of higher charge state ions is sensitive to the gas flow rate.
4. The arc chamber of a smaller bore diameter gives a higher intensity ion beam.
5. Optimum values of the pulse width and duty factor are obtained for $^{14}N^{5+}$ and $^{14}N^{4+}$ ion beams.

4. References.

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2) J. R. J. Bennett, IEEE Trans. Nucl. Sci. NS-19, 48 (1972).
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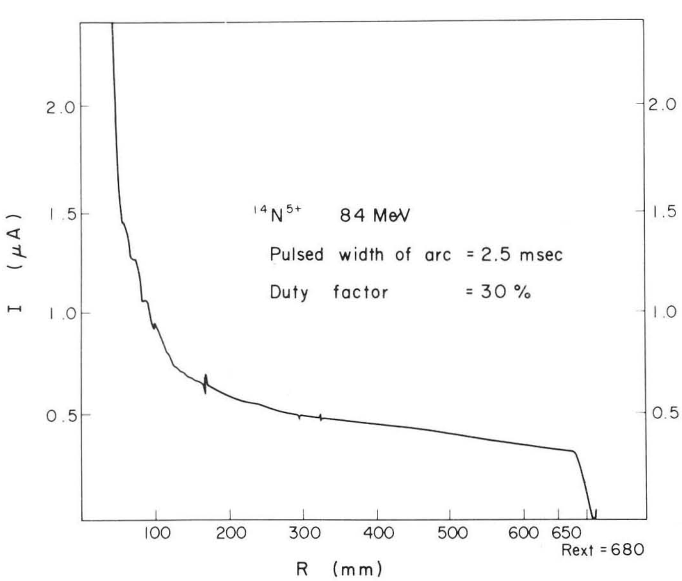

Fig. 4 : An internal beam profile of 84 MeV $^{14}N^{5+}$ ions.

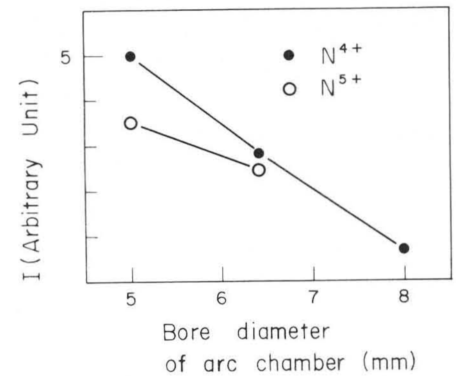

Fig. 5 : The relation between the diameter of arc chamber bore and the beam current at R = 650 mm.

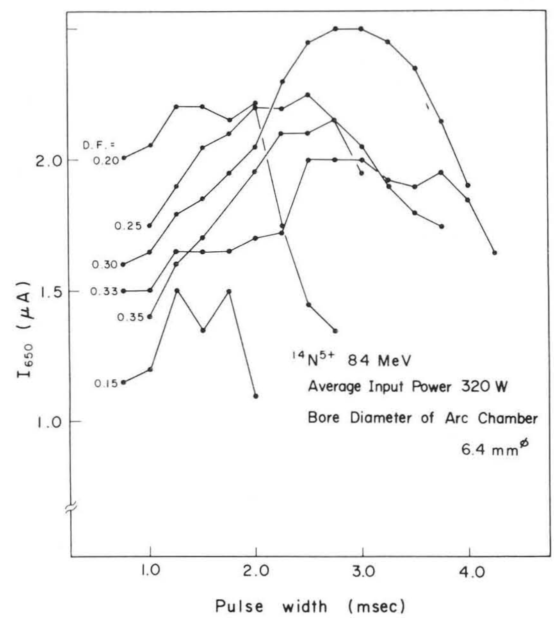

Fig. 6 : Beam intensity at R = 650 mm as a function of the pulse width for given duty factor. Parameters D. F. indicate the duty factors.

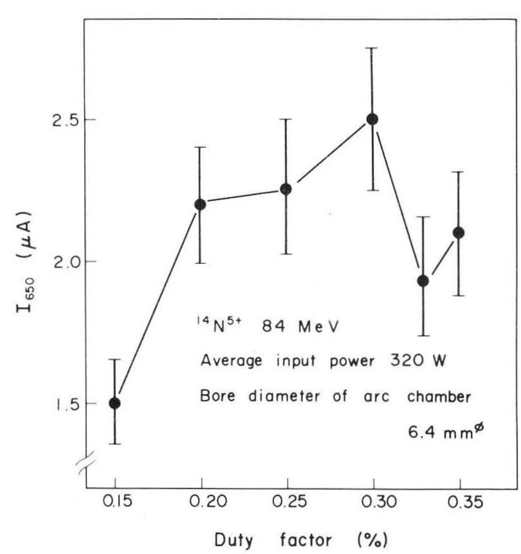

Fig. 7 : Beam intensity at R = 650 mm as a function of the duty factor.