# HEAVY ION ACCELERATION IN THE KURCHATOV INSTITUTE CYCLOTRON

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## Abstract

The 1,5-meter cyclotron has been converted into a variable energy heavy-ion isochronous cyclotron with $E_{max} = 60\ q^2/A$. The ion source and its power supply have been improved. Record intensitites of the extracted beam $^6Li^{2+}$, $^7Li^{2+}$, $^6Li^{3+}$, $^7Li^{3+}$, $^9Be^{3+}$, $^{12}C^{4+}$, $^{14}N^{5+}$, $^{16}O^{6+}$ have been obtained.

## I. Introduction

The relationship between the beam current extracted from the cyclotron and the instantaneous current $I_i$ extracted from an ion source is as follows:

$$\bar{I} = I_i \cdot K_M \cdot K_m \cdot K_b \cdot K_a \cdot K_p \cdot K_e \cdot \quad . \ . \ . \ . \ . \qquad (1)$$

where $K_M$ - macroscopic duty factor,

$K_m$ - microscopic duty factor,

$K_b$ - bunching factor,

$K_a$ - transmission factor including the axial transmission losses,

$K_p$ - transmission factor including the residual gas scattering losses,

$K_e$ - extraction efficiency.

All the terms of the relationship (1) are discussed below with reference to increasing the external IAE cyclotron beam intensity.

## II. Ion source

The multiply-charged ion intensity rises with an increase in the instantaneous discharge power provided the necessary discharge voltage is maintained. However, the transition into self-dependent discharge raises obstacles to an increase in the discharge power. In this case the discharge voltage drops down significantly and the intensity of multiply charged ions is reduced or even interrupted.

To prevent the transition into the self-dependent discharge (which is related to cathode heating), a pulse discharge mode synchronous with macropulses of the R.F. dee voltage is adopted for the IAE ion source. Since the discharge pulse power can be larger than the steady state value by $1/K_M$, the pulsed multiply-charged ion current will correspondingly rise higher and as a result the average multiply charged ion current will also rise. There is a definite value of $K_M$ (macroscopic duty factor) which corresponds to $\bar{I}_{max}$. For the IAE ion source $K_M = 0{,}1$.

Generally speaking, the multiply-charged ion output does not depend on the power itself but on the power density, i.e. on the discharge power per unit volume of the arc column[1]. Therefore one can choose an optimal cross-section of the arc column to obtain the maximum intensity of multiply charged ions for a given extraction slit and for the permissible average power of a discharge.

The ion source with direct heating used in the IAE cyclotron has a crucible with a working substance placed near the discharge chamber[2]. The crucible is heated with an electric heater. The gradient of temperature along the crucible is obtained by remote control of compression air supplying a cooling element. The cooling element removes heat from the bottom of the crucible. This gradient of temperature is used for preventing the penetration of liquid Li into the discharge chamber from the crucible. The temperature of the crucible is measured with a thermocouple. The whole device is screened from R.F. currents with copper foils. Fig. 1 shows the parts of the source placed at the center of the cyclotron. The arc column diameter in the source is 0,3 cm and its



0018-9499/79/0400-1996$00.75 

height 10 cm, corresponding to the arc column volume of 0,7 $cm^3$. The maximum power at which the discharge does not transit into the lower voltage regime is about 1,0 kw (P/V=1,5 kW/$cm^3$).

A thyristor modulator for partial discharge of a capacitor bank[3] is used as a power-supply unit. Pulse duration range is 0,2 - 20 ms, peak discharge voltage is up to 1,5 kV, pulsed discharge current is of several tens of amperes. The specific feature of this system is the possibility of constant discharge in the time interval between powerful discharge pulses. Under these operating conditions with a constant discharge up to 0,1 kW the pulsed power per discharge can have 1,5-fold increase without a transition into the low voltage regime and the multiply-charged ion beam intensity will trebled (Fig. 2).

Acceleration of Li and Be-ions is mainly provided at the IAE cyclotron. Under these conditions the choice of a working substance to be loaded into the crucible and its temperature are of great importance. The metallic Li was used to obtain Li-ions. $BeCl_2$ or $BeF_2$ were used to obtain Be-ions. The last salt is preferable if the toxicity is taken into account. Since high change state ion intensity depends upon discharge pressure in this kind of ion source and since the vapor pressure of the working substance varies strongly with temperature, it follows that multicharged ion intensity depends critically upon crucible temperature. This is illustrated in Fig. 3. The life-time of the source is about 40 hours.

## III. Isochronous acceleration operation

The magnetic field for isochronous ion acceleration in a wide mass and energy range[4] was established in the IAE cyclotron to increase the maximum ion energy and to decrease axial losses. In 1976 the IAE cyclotron started its isochronous operation.

One pole tip with sectors and the disk with correcting coils are shown in Fig. 4. Axial losses are eliminated (i.e. $K_a = 1$) because of good magnetic focussing provided by the three pairs of spiral sectors ($\nu_z > 0,1$ for radii greater than 18 cm) and good electric focussing with slit-diaphragms[5] located on the dees along the radii less than 20 cm.

Isochronous ion acceleration is shown on the oscillograms in Fig. 5. These oscillograms were obtained with the nine pairs of capacity pick-up electrodes placed inside the dee. Stroboscopic conversion of signals is provided near the pick-up electrodes and as a result of conversion the low frequency signals are produced and seen on the oscillograph. Any nonisochronous deviation is absent according to the data obtained even from the last pick-up electrodes as it is seen on the oscillograms (~2 % $T_{R.F.}$). Only at the end of acceleration is a phase shift seen. This represents a deviation from isochronism in the extraction region of the beam. The measured microscopic duty factor is $K_m = 0,07$. The calculated bunching factor is $K_b = 1$ when the slit-diaphragms are present. The improvement in beam quality due to isochronous acceleration and the use of the focussing electrostatic deflector make the extraction efficiency factor $K_e = 0,6 - 0,7$. Improvement of the vacuum pressure to $10^{-5}$ Torr, owing to additional diffusion pumps on the acceleration chamber, reduced the residual gas collision losses, i.e. $K_p = 1$.

## IV. Extracted heavy ion beam parameters

Heavy ion energies in the IAE cyclotron are given in Fig. 6 (dots correspond to the operating conditions under which the measurements were done). The external beam average currents for some ions which seem to be the best are given below.

| Ion | $^{6}Li^{2+}$ | $^{6}Li^{3+}$ | $^{7}Li^{3+}$ | $^{9}Be^{3+}$ | $^{12}C^{4+}$ | $^{14}N^{5+}$ | $^{16}O^{6+}$ |
|---|---|---|---|---|---|---|---|
| I(μA) | 15 | 2 | 2 | 2 | 30 | 13 | 1 |

A wide energy range for all the stable isotopes from H to Ne and high intensities of the external multicharged ion beams especially Li and Be, offer great opportunities for further studies at the IAE cyclotron.

 

References


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2) P. Vasiliev et al., Nucl. Instr. Meth. 71, 201 (1969).
3) S. Latushkin et al., Pribori i technica experimenta 3, 27 (1976).
4) Ju. Buzulukov et al., Proc. 7th Int. Conf. on Cyclotrons, 205, Zürich (1975).
5) N. Venikov and N. Chumakov, Atomnaja Energia 11, 247 (1961).


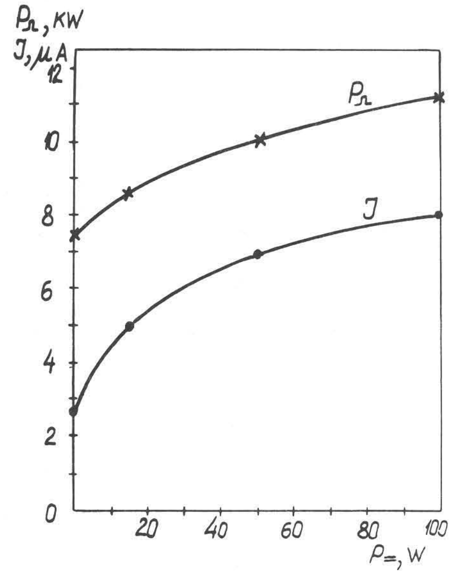


*Fig. 2. Arc discharge pulsed ($P_\Omega$) and external beam intensity $^{12}C^{4+}$ dependence on continued arc column power ($P_=$).*

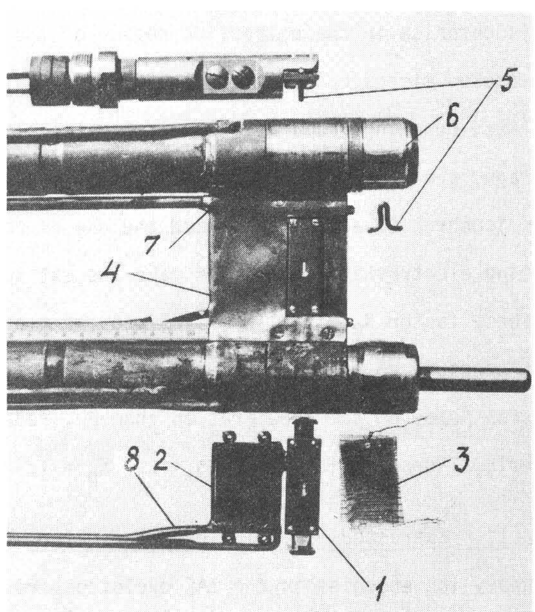


*Fig. 1. Snapshot of the ion source parts to be placed at the center of the cyclotron.*
*1. Discharge chamber, 2. Crucible, 3. Electric heater, 4. Screen, 5. Cathode, 6. Case, 7. Thermocouple lead-in, 8. Air cooling of the crucible bottom.*

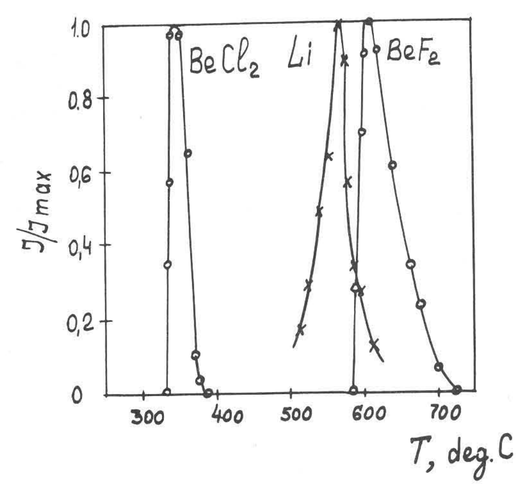


*Fig. 3. $^6Li^{3+}$ and $^9Be^{3+}$ ion current dependance on the working substance temperature.*

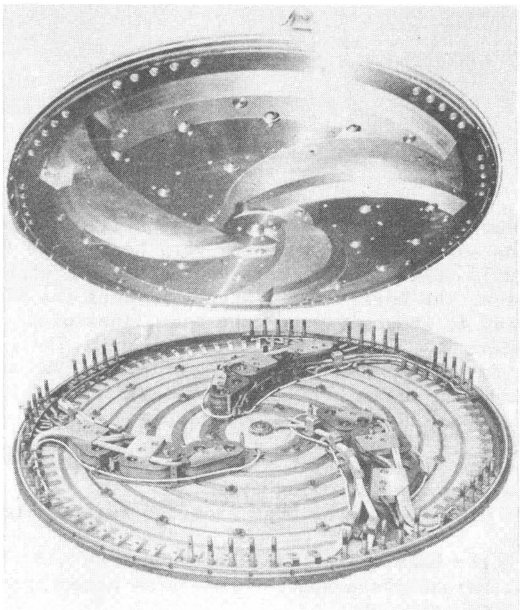

*Fig. 4. One pole tip with sectors and the disk with correcting coils.*

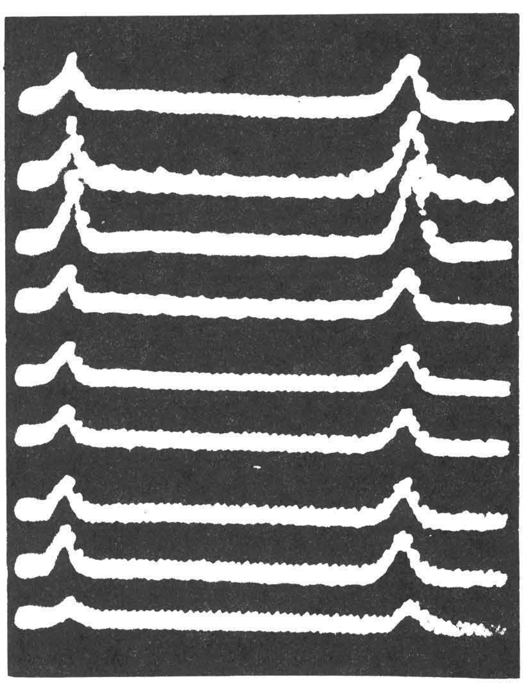

*Fig. 5. Shape and disposition of the beam microbunches at the acceleration radii 21, 31, 40, 53, 56, 59, 62, and 54 cm (from top to bottom) measured with a pick-up electrode system in the dee. Bunches corresponding to two R.F. periods are presented for time-scaling.*

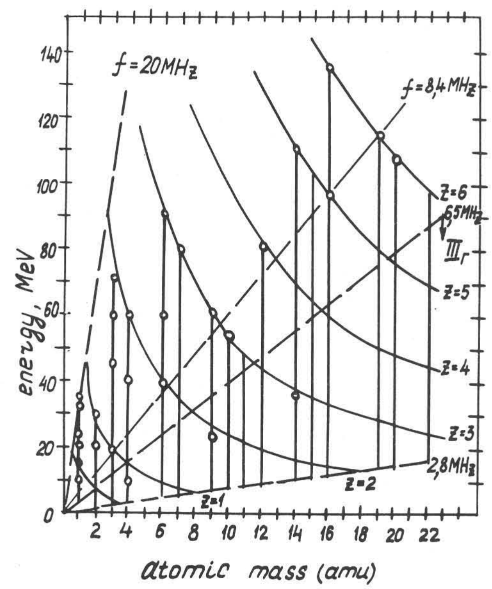


*Fig. 6. Ion energy in the IAE cyclotron. The range lower than f = 6,5 MHz is provided by the third R.F. harmonic. The hyperbolas are the maximum induction limitations for the given ion charges. Dots show operational conditions under which the measurements were made.*