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STATUS REPORT ON THE AECR-U ION SOURCE AT KVI-CART

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Abstract

A new hexapole, equipped with a pole tip field of 0.87 T has been installed in the AECR ion source. The new hexapole improves the performance of the source, which includes an observed enhancement in all charge state distributions. For the xenon charge state distribution this resulted in a significant increase of the higher charge states that now allows for the production of an $^{129}Xe^{33+}$ beam with intensities of 0.5 μA (collimated beam) that can be used for regular operations.

INTRODUCTION

The interest in intense highly-charged heavy-ion beams used by experimentalists and radiation hardness researchers motivates us to further develop our AECR-U ion source [1]. As the production of intense highly-charge heavy-ions ions requires high-magnetic longitudinal and radial confinement fields, a degraded hexapole with pole tip fields of 0.72 T limits us to achieve the high beam-currents for the highest charge-states of heavy ions. The most optimal design strength of the longitudinal and radial magnetic fields with respect to the heating frequency has experimentally been found and described by scaling laws [2]. According to the law $B_{rad} = 2 \times B_{ecr}$ our radial field should be close to 1 T ($B_{ecr} = 0.5$T). The new hexapole has pole tip fields of 0.87 T; a little lower than the optimal B_{rad} of 1 T. Furthermore, with the installation of the new hexapole, the homogeneity of the magnetic field along the bars improved from 14% to 5% and the maximum value of each bar does now vary within a range of 0.15 Tesla instead of 0.4T. In this paper we describe the exchange of the hexapole including the modification on the plasma chamber. Furthermore, we present beam intensity measurements before and after the replacement of the hexapole and discuss these measurements. Finally, the paper will be close off with the conclusions and a future outlook.

THE HEXAPOLE REPLACEMENT

The conceptual idea behind the design of the hexapole structure is that the design aims for a low background vacuum in the plasma chamber. This is done by incorporating six radial pumping ports in between the magnet bars (Fig.1a.). Unfortunately, it comes with the cost of having no magnetic material at the location of these pumping ports. Therefore, the maximum achievable pole tip fields are lower than for example a Halbach structure [3]. Background pressures are achieved in the order of 2 x 10^{-8} mbar measured on top of the vacuum chamber. The original design [4] has six pumping slots. But due to a rupture of the aluminium wall between the cooling system and the vacuum chamber of the original chamber, we have changed the six pumping ports of the original design into 6 x 3 smaller pumping slots which, close to the plasma chamber, end in an array of 8 holes with a diameter of 4.8 mm (Fig.1b, 2) which increases the integrity of the support structure.

The Support Structure of the Magnet Bars

The hexapole support structure is made from an 7075 T6 aluminium cylinder in which spaces have been machined by wire cutting in which the six magnetic bars are mounted (Fig.1). The six magnet-bars, made of Nd-Fe-B material, are each build up by two rows of 10 blocks (Fig.1,2), and mounted in a stainless steel AISI 304 can to prevent the magnetic material to oxidize. All blocks are made of MCE N5064 material and have an identical shape with an easy axis of 43 +/- 2% deg (Fig.1f). During operation, the left over spaces around the bars are also used for cooling. The cooling water is directed specifically to the area of the loss-lines (Fig.1c), where the electrons hit the aluminium plasma chamber on the inside. This is done by filling up all the space around the bars with SS sheets and rods (not shown).

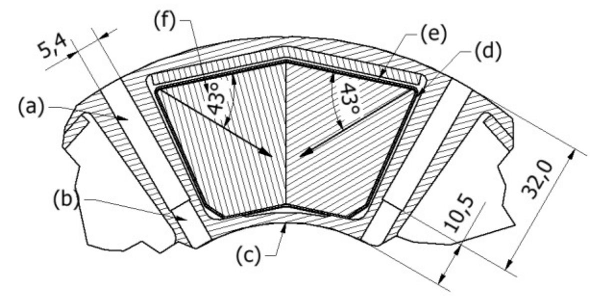

Figure 1: A through cut of a section of the aluminium hexapole container including the canned magnet bar, (a) pumping ports, (b) pumping holes, (c) loss-lines, (d) space filled with SS sheets, (e) can, (f) easy axis.

Pole Tip Field Measurement.

After assembly of the bars in the aluminium container, the hexapole is mounted in a magnetic-field measurement setup. In this setup the hexapole, supported by a v-shaped base, is positioned such that a hall-probe (LPT-141-10s), located at the center line of a hexapole bar, can be moved along the plasma wall. As the actual hall-probe "loop" is located asymmetrically in the head of the hall-probe, a holder is made such that the actual loop inside the probe is symmetrically in front of a pole on a radius of 32.92 mm. The distance between the source axis and the plasma chamber wall is 38.2 mm. To obtain the magnetic field values (Fig.3) at the wall the measured values have been multiplied by $(38.1/32.9)^2$ as the magnetic field quadratically increases as function of the radius. The magnetic field is measured over 300 mm with steps of 1 mm. At every step the longitudinal position and the radial magnet-

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ic field are recorded. In the magnetic field measurements one is able to identify the glue space between the blocks as they give a small dip in the magnetic field (<1.5%) as can be seen in figure 3.

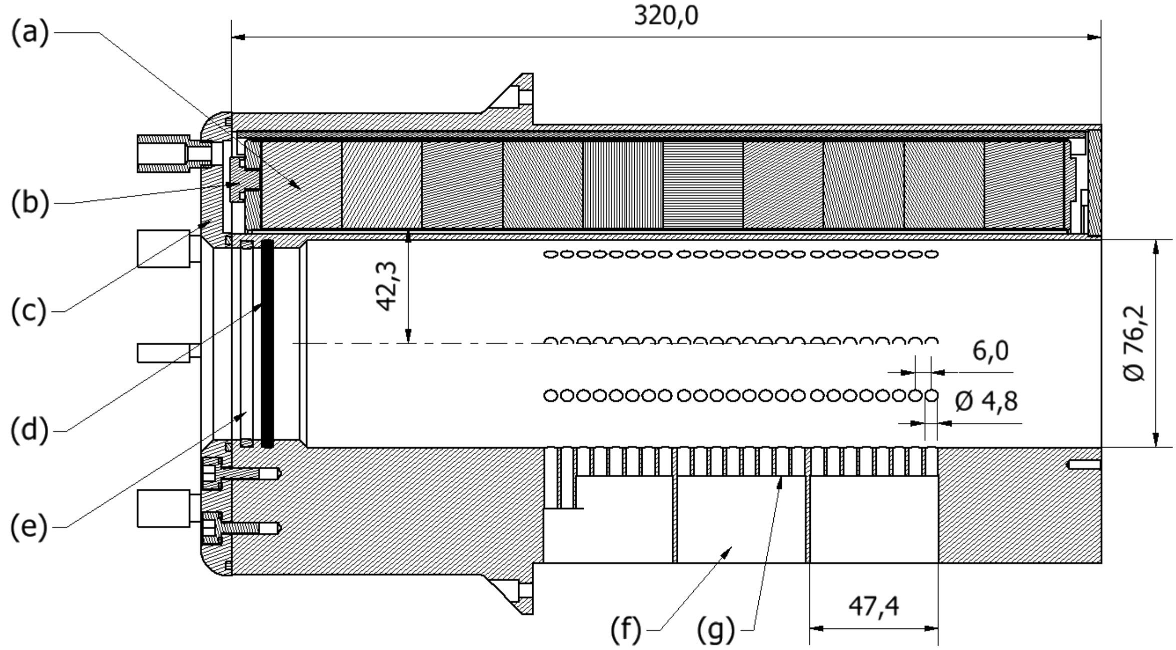

Figure 2: A cut through the hexapole on axis. (a) 10 blocks of magnet bar, (b) closure of the can, (c) lid of the container, (d) RF seal, (e) vacuum seal, (f) pumping ports, (g) pumping holes.

MEASUREMENTS

The measurements of the maximal achieved beam current per charge-state for xe-129, before and after the replacement of the hexapole, are presented in table 1. In both cases, the measurements were carried out with a conditioned ion source. 'Conditioned' means that first the ion source runs for 6o hours on oxygen to remove mainly the carbon contaminants in the plasma.

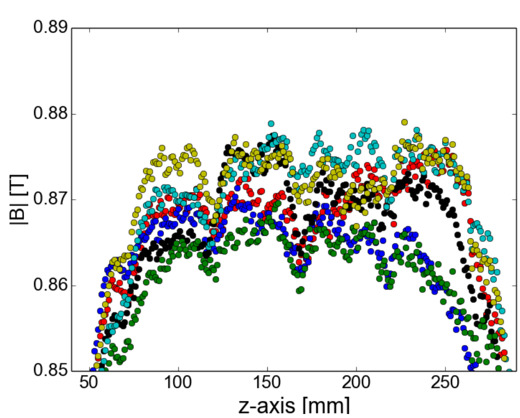

Figure 3: Measured absolute radial magnetic field at radius 38.2 mm of the centre. The different measurements are colour code depending on the pole.

Secondly, another 60 hours is used to reach stable operation to measure the highest beam current per charge-state for the highest charge-states of xenon. The operational pressure in the plasma chamber is < 10^{-7} mbar and oxygen is used as a mix gas. The optimal bias disk voltage is low in all measurements and ranges from -10V to -60V. Also, double frequency injection was used in all measurements. The frequency of the TWT ranges from 11.5 to 12.3 GHz. The klystron delivered a power of 800 W for the measurement done before the replacement of the hexapole while the optimal power of 500 W was needed after the replacement of the hexapole. The beam currents were measured by a collimated Faraday cup (Ø6 mm) in the image plane of the analysing magnet (see table.1).

RESULTS AND DISCUSSION

The maximum beam intensity of the $^{129}Xe^{33+}$,measured with the new magnet bars, is a factor of 8 higher with respect to the $^{129}Xe^{33+}$ measured with the old magnets (see Table 1.). Even more, now the $^{129}Xe^{34}$ and $^{129}Xe^{35+}$ are detectable and can be used for injected in the AGOR accelerator. The intensity of $^{129}Xe^{29+}$ stays the same. So, we conclude that the increase of the pole tip fields of the hexapole works very well for high charge states of xenon. Regarding the extracted intensities from the source with respect to the collimated intensities measured at the faraday cup in the image plane of the analysing magnet, one can reason that the extracted intensities are probably a factor of 6 higher as the transmission of the analysing magnet is roughly 50% (for oxygen) and a further attenuation occurs by the collimation at the faraday cup (33%). However, highly-charge heavy-ions tend to be extracted

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close to the axis and therefor the factor of 6 might be an overestimation [5].

Table 1: Measured Xenon Beam Currents

Xenon charge	**Beam current** [μA] **Old hexapole**	**Beam current** [μA] **New hexapole**
29	3.3	3.3
30	1.5	2.7
31	0.68	1.7
32		
33	0.053	0.44
34		0.2
35		0.07

CONCLUSIONS AND FUTURE OUTLOOK

The replacement of the hexapole resulted in an improvement of a factor 2.5 for the $^{129}Xe^{31+}$ xenon production and a factor of 8 for $^{129}Xe^{33+}$ production. Even more, higher charge states were detectable as the $^{129}Xe^{34}$ and $^{129}Xe^{35+}$ were measured. Due to this improvement KVI-CART is able to provide intense highly-charge heavy-ion beams for experiments and radiation hardness tests for third parties. To increase the intensity even further, an einzel lens will be installed in between the ion source and the analyzing magnet to improve the transmission through the analyzing magnet. Furthermore, to reduce the carbon cleaning-time of the ion source, we plan to demonstrate in the near future that the plasma chamber will be less contaminated with carbon during the production of carbon beams when CO_2 gas is used rather than CH_4 gas.

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REFERENCES

[1] H.R. Kremers, J.P.M. Beijers, S. Brandenburg and J. Mulder, *High Energy Physics and Nuclear Physics*, vol 31, supp. 1, p. 90, (2007).

[2] D. Hitz, A. Girard, G. Melin, S. Gammino, G. Ciavola, L. Celona, "Results and interpretation of high frequency experiments at 28 GHz in ECR ion sources, future prospects", *Rev. Sci. Instrum.*, vol. 73 pp. 509–512, (2002).

[3] K. Halbach, *Nucl. Instrum. Methods*, vol 169, p. 1 1980.

[4] Z.Q. Xie, C.M. Lyneis, in: *Proceedings of the 13th International Workshop on ECR Ion Sources*, College Station, 26-28 February 1997, p. 16.

[5] M.A. Leitner, D.C. Wutte and C.M. Lyneis, *Proc. 2001 Particle Accelerator Conf.*, June 18-22, Chicago, IL, 2001, p. 67.