COLD CATHODE ION SOURCE FOR IBA CYCLONE®230

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Abstract

At IBA, we use a P.I.G. floating cathode ion source for injection in the CYCLONE®230 cyclotron. The purpose of the project is to investigate how the present ion source could be replaced by a P.I.G. cold cathodes one with a longer lifetime. Experiments described in this article were done on a dedicated test setup to benchmark the different modes. A new chimney design has been developed to test cold cathode mode in CYCLONE®230 without any other mechanical modifications.

INTRODUCTION

The floating cathode source uses a tantalum filament which needs to be replaced typically every 5 to 7 days. Cold cathodes ion sources are already used in other IBA cyclotrons and allow a much longer period between two maintenance operations. H^+ cold cathode ion source has been developed with AIMA for the new synchrocyclotron. Pulses are very short (few µs) during capture process in the synchrocyclotron, but much longer pulses (few ms) are produced in the isochronous CYCLONE®230 cyclotron.

TEST CAMPAIGN

The test bench developed with AIMA for the synchrocyclotron source five years ago was modified to allow vertical insertion of the CYCLONE®230 source shaft in the same setup. The 1.7 Tesla large aperture magnet (see Fig. 1) and all the equipment were installed on an elevated platform, so the ion source can be vertically inserted in the vacuum box (see Fig. 2).

Figure 1: 1.7T test magnet and the vacuum system at AIMA.

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Figure 2: CYCLONE® 230 source arm mounted on a dedicated insertion system underneath test magnet.

The three measurement plates collecting the different ion species and the puller electrode are at DC high voltage (15kV). The ion source is at ground potential. All these elements are located in a vacuum chamber as shown in Fig. 3.

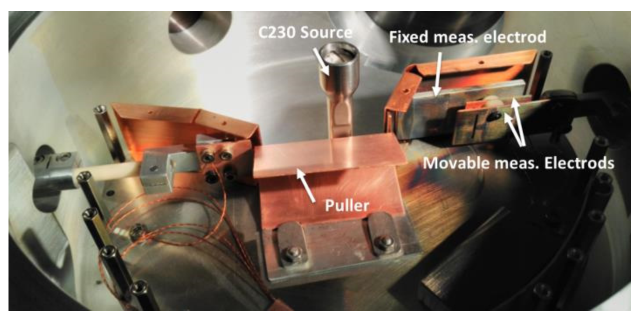

Figure 3: Test bench vacuum chamber, high voltage top plate removed. One can observe the chimney, the puller and measurement electrodes.

Arc and filament power supplies are standard CYCLONE®230 equipment. In floating cathode mode, we operate at arc voltage (Varc) below 200V. Since the cold cathode mode requires at least 800V to light up a plasma, the arc power supply was modified to generate pulses up to 500V and an additional 1 kV commercial DC power supply was connected in series.

FLOATING CATHODE SOURCE BASELINE

The first experiment consisted in recording a baseline of the actual floating cathode ion source on the test bench. The aim is characterising the source performances as function of parameters of its own design, i.e. independently of the isochronous machine central region environment. The extraction gap has been minimized for 15 kV extraction voltage and fixed on the setup.

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During a treatment scanning sequence the arc current (Iarc) is fast scanned over a large band: Iarc ramps are suitable to observe the complete band of operating points, for a given set of parameters.

To obtain the pulse illustrated in Fig. 4, gas flow is 2SCCM (optimized value), chimney slit dimensions are nominal, filament current is set in order to maximize arc power, i.e. Varc is saturated (220 V) at maximum Iarc setpoint (330 mA). Up to 2.8 mA instantaneous H+ current (IH+) can be produce on this condition.

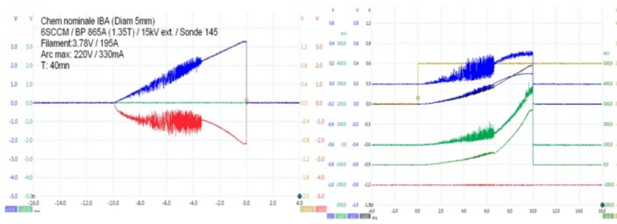

Figure 4: Left: Arc parameters, Iarc setpoint in blue, from 0 to 300mA in 10ms, Varc in red (min=-200 V); Right: H+ current (IH+) measurement in green (max=2.8 mA), other species (H_2^+ and H_3^+) total current measurement in blue (max=5 mA).

For higher filament current, Varc and IH+ are smaller for a given Iarc set point. Since we have modified the power supply to study the behaviour at higher Varc (up to 500 V) new working points have been investigated during this 'baseline' campaign with the filament source. Moreover, hot cathode modes with various types of polarisation have been tested as well. The main observation could be similar in all these potential improvements: bringing more power in the arc can either increase the H+ production, or reduce the filament current, which should impact its lifetime.

COLD CATHODE EXPERIMENT

We first removed the filament and mount a Tantalum cathode on its support to brought it to arc potential. To power the anti-cathode, we created a new isolated connection in the vacuum box.

Iarc and Varc of one hundred pulses (1ms length) are shown in Fig. 5. Gas flow is optimized at 5SCCM for nominal chimney slit size. A DC constant polarization of 740 V is superposed with pulsed Varc. Iarc setpoint is 70 mA. In that configuration the pulsed Varc reaches -220 V at the end of pulses (see Fig. 5), which is the saturation value of arc power supply of CYCLONE®230.

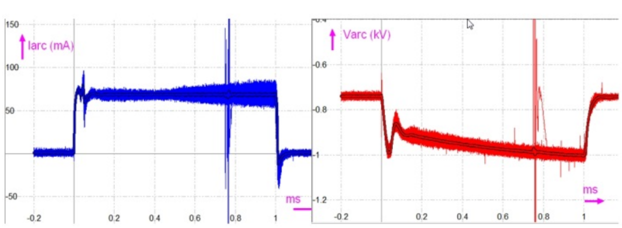

Figure 5: 100 Arc pulses of 1 ms produced at 50 Hz. Iarc (blue) and Varc (red).

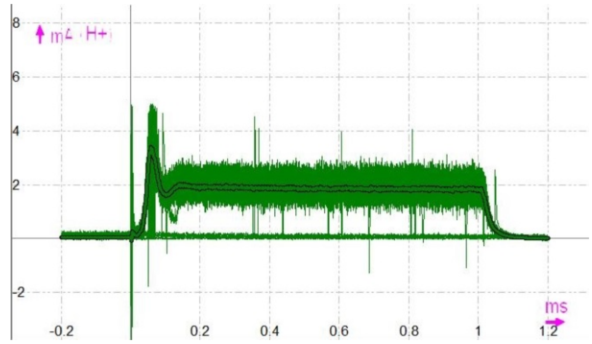

Figure 6: 100 H+ current pulses of 1ms produced at 50Hz repetition rate.

In Fig. 6 we observe the one hundred IH+ pulses obtained with these settings. 2000 νC mean charge per pulse is measured, pulse to pulse charge stability is 2.7% of mean value (1σ). Ignition overshoot last around 50 µs and reaches 3.5 mA maximum value. For a given Iarc set point and a given slit size, we observed higher protons production in cold cathodes mode than in floating cathode mode. Ignition overshoot amplitude and length decrease with dVarc/dt which is an increasing function of Iarc (with our power supply). We decided to reduce the size of the chimney slit by a factor 3 in order to work at higher Iarc set points, which strongly reduces the overshoot for a given IH+ production. This modification also leads to higher stability of the charge per pulse. Beam transmission in CYCLONE®230 central region will be increased, and it reduces optimal gas flow from 5SCCM to 1SCCM.

Another option to get rid of the overshoot applying enough DC arc voltage is to avoid ignition, i.e. maintaining a (very) small DC extracted beam. In that case CYCLONE®230 control system would have to eliminate this 'dark current' between pulses.

We have investigated production of longer pulses at high repetition rate in order to demonstrate that cold cathode mode can be suitable for uniform scanning/ double scattering US/DS treatment modes. Pulses of 9 ms at repetition rates up to 100 Hz are generated.

For a given Iarc set point, we observe that Varc is an increasing function of the repetition rate. 100 arc pulses of 9 ms at 100 Hz are illustrated in Fig. 7. Only pulsed Varc is plotted (in red), 600VDC Varc is applied in series. Stable pulses were obtained with 1050 V total arc voltage for 30 mA Iarc, when 850 V are required at 10 Hz repetition rate. In order to work with long pulses in cold cathodes mode power supply will have to deliver more voltage, and arc current is limited to 30 mA for 1000 V total arc voltage. Nevertheless, H+ production is sufficient with the nominal slit size in that case.

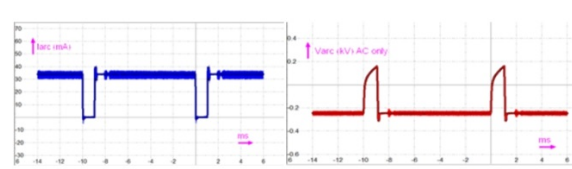

Figure 7: Arc current (blue) and arc voltage (red) for longer pulses.

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COLD CATHODE, USING LAB6

Setup was modified to test Lanthanum Hexaboride (LaB6) cathodes, see Fig. 8.

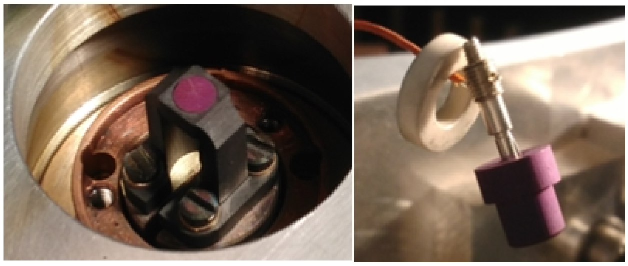

Figure 8: Left: LaB6 cathode chip and support, installed on CYCLONE®230 filament support. Right: LaB6 a-cathode with polarization pin.

As shown in Fig. 9, Ignition potential is 400 V, which can we obtained with the CYCLONE®230 arc power supply with small modifications. Improvements are mandatory to increase dVarc/dt in order to avoid overshoots and oscillations at ignition.

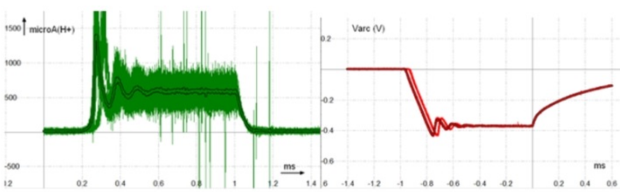

Figure 9: 100 IH^{+} pulses (left) and Varc with Lab6 cathodes (right).

NEW CHIMNEY DESIGN

A new chimney design needed to be developed in order to validate some of these concepts in the CYCLONE®230 IBA cyclotron. It is mechanically compatible with the present cyclotron central region design.

In the new design a polarization is brought to the anti-cathode through a small vertical pipe in the chimney body connecting the cathode and the anti-cathode electrically, see Fig. 10.

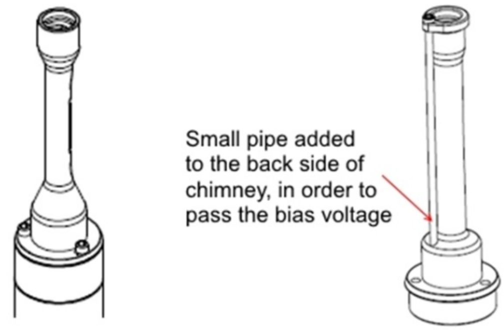

Figure 10: Regular floating cathode chimney vs modified cold cathode chimney.

Cold cathode source is currently being produced and should be tested on site in Q4 2016.

CONCLUSION

The results obtained on test bench confirm that cold cathodes mode is an alternative to filament solutions with a potentially longer life time. Possible improvements on filament source have also been identified and tested. It has been verified that cold cathodes mode is suitable for long pulses at high duty cycle rate. A new chimney design is being built. Full integration in CYCLONE®230 systems requires a new power supply with a faster regulation in order to avoid prohibitive overshoot at arc ignition.

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