OPERATIONAL EXPERIENCE WITH THE 18 GHz HTS-ECRIS, PKDELIS*

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Abstract

The high temperature superconducting electron cyclotron resonance ion source (HTS-ECRIS), PKDELIS was installed at IUAC in the beginning of 2005. There were some initial problems with one of the two cryo-coolers for the axial HTS coils and vacuum related problems at the intermediate location for test run. These were rectified subsequently. X-ray Bremsstrahlung measurements are carried out systematically to develop deeper understanding of the ECR plasma production processes. The source and low energy beam transport (LEBT) system are planned to be re-installed on a high voltage platform in the new beam hall III to prepare for injection into high current injector of the superconducting linear accelerator. Recent results of the PKDELIS and operational experience will be reported.

INTRODUCTION

At the Inter University Accelerator Centre, New Delhi, the accelerator augmentation programme involves the development of new accelerators for further boosting the beam energies to above 5 MeV/u (above Coulomb barrier) around mass 100 a.m.u. With the existing tandem accelerator, it was realised that the beam currents and mass range available were not sufficient for most of the experiments in nuclear physics and related areas The tandem-LINAC combination in parallel with a high current injector was proposed to meet the above design goal [1]. An alternate high current injector was proposed based on a reasonable high performing electron cyclotron resonance ion source capable of delivering higher beam currents and covering a wide mass range [2]. In this paper, the operational experiences of the HTS-ECRIS PKDELIS at ground potential (presently) is described. This kind of source was designed for operation on a 400 kV high voltage platform to inject beams with initial velocities at 1 % of the velocity of light and further accelerate to ~ 8 % of the velocity of light before injection into the superconducting linear accelerator. In the near future, the source and low energy beam transport section will be finally shifted for installation on a high voltage platform to prepare for injection into the superconducting linear accelerator. The new beam hall III construction is complete and various beam hall utilities are nearing completion.

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HTS-ECRIS PKDELIS

The HTS-ECRIS PKDELIS is designed for operation at two frequencies, viz. 14.5 and 18 GHz. Further description of the source can be found in earlier publications [3]. The test bench results of the source at Pantechnik, France during the end of 2003 gives more information about the beam currents of various ions extracted which are required for the high current injector [4]. Later, the source was initially installed at our centre at a test set-up position in the beginning of 2005. The source commissioning was delayed due to various problems that are described below.

Cryo-cooler cool down issues

During initial start-up, we had problems with the extraction cryo-cooler which eventually could not cool down the coil to ~ 20 K. This limited the source start-up and delayed the source commissioning. Initially it was thought that that due to the leak in the helium line, the cooling efficiency reduced. After re-charging the line (adding more helium), the cooling did not improve. It was further thought that the helium was contaminated. The helium was completely removed and re-charged again which still did not improve the situation. Since the extraction cryocooler was generating a much feebler sound when compared to the normal operating injection cryocooler which had a loud tapping sound, it was decided to open up the cold head section to investigate further. It was found that the bottom flange was not properly fastened to the piston and this impeded the motion and resulted in poor performance. This was rectified and the efficiency of the cooling improved. The vacuum on the injection side of the source was also poor leading to lower charge states. After these problems were rectified in the beginning of 2007, a wireless control system for operating the source in the middle of 2007 was implemented. The source was finally commissioned during the end of 2007.

Wireless control system

After experiences with other accelerators using fibre optic cables for source control especially in high voltage environments, using a wireless communication would appear to be better in terms of minimising the source downtime especially for running round-the-clock experiments. A wireless control system was developed based on MODBUS RTU on RS 485. Using 2.45 GHz radio modems, and PLC's for interlocking purposes, a client-server based remote control was established and proved economical and highly reliable. The software uses LABVIEW based HMI software.

Source performance

A schematic view of the source together with the low energy beam transport system coupled to a large acceptance analysing magnet [5] is shown in figure 1. below. Typical base pressures at the injection side and post analyser section are 3 x 10^{-7} mbar and 1 x 10^{-8} mbar. A typical spectrum optimised on Ar^{8+} at an absorbed power of 300 W is shown in figure 2.

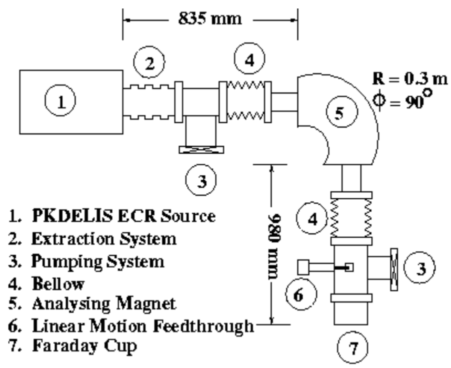

Figure 1: Schematic of the low energy beam transport system

The optimised parameters were RF power, gas pressure, bias voltage, axial field and position of the RF tuner. These were the main determining parameters besides the extraction voltage (for improving the transmission) for obtaining 300 µA of Ar^{8+} at 300 W absorbed power

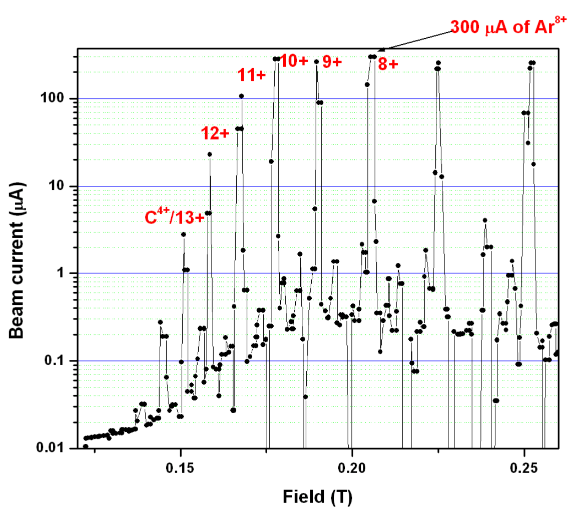

Figure 2: CSD optimised on Ar^{8+}

without using mixing gases. A table showing the optimised parameters is shown below (Table 1.).

Table 1: parameters optimised on Ar^{8+}

parameter	**value**
RF absorbed power	300 W (330 W/30 W)
Extraction voltage	25 kV
Injection vacuum	1.4 x 10^{-4} mbar
Post analyser vacuum	8.6x 10^{-7} mbar
Bias voltage	–134 V
Bias current	0.22 mA
B_{min}/B_{ecr}	0.58
Total source current	4 mA
Injection / extraction field	1.4 T / 0.95 T

Use of mixing gas with argon, the beam current of Ar^{8+} is expected to improve further. Due to a leak in the mixing gas line, it was not possible to further improve the beam currents at present. Further optimisation on Ar^{11+} at higher levels of power showed that it was possible to extract 150 µA of Ar^{11+} at 425 W of totally absorbed power. Figure 3. shows a charge state distribution optimised on Ar^{11+}.

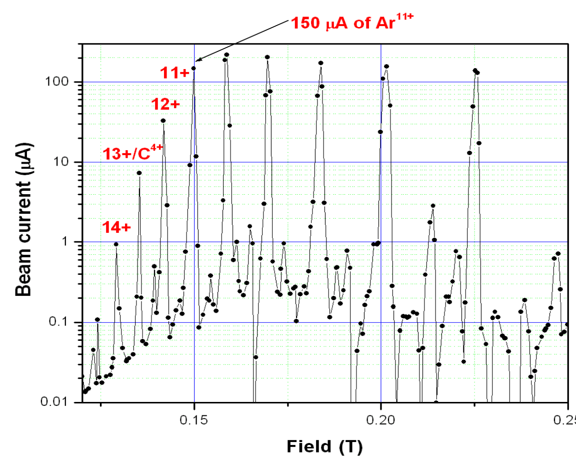

Figure 3: CSD optimised on Ar^{11+}

Table 2: parameters optimised on Ar^{11+}

parameter	**value**
RF absorbed power	425 W (473 W/48 W)
Extraction voltage	20 kV
Injection vacuum	1.1 x 10^{-4} mbar
Post analyser vacuum	6.4 x 10^{-7} mbar
Bias voltage	–110 V
Bias current	0.05 mA
B_{min}/B_{ecr}	0.58
Total source current	3.4 mA
Injection / extraction field	1.4 T / 0.96 T

During the tuning and optimisation of Ar^{8+} and Ar^{11+} beams, it was observed that the best axial field distribution (shown in figure 4.) corresponding to B_{min}/B_{ecr} was best at the value of 0.58 which was the calculated value from the observed injection and extraction fields. This value does not change for medium (8+) and high charge state (11+) of argon although the value of the extraction field changes slightly. From the measurements, it was also observed that the injection vacuum deteriorates when sufficient gas is bled into the source. This may be limiting the build up of higher charge states. Further improvements in the gas injection line/pumping system are being pursued.

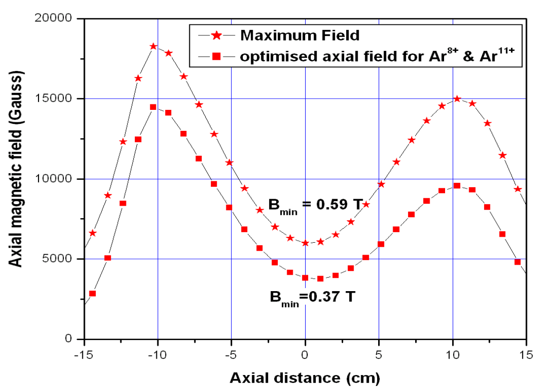

Figure 4: Optimised axial field for Ar^{8+} and Ar^{11+}

X-ray Bremsstrahlung measurements

Besides the beam optimisation experiments of argon for medium and high charge state, it was necesssary to measure the x-ray Bremsstrahlung and if possible to correlate with the beam optimisation experiments for argon. Alternatively these measurements could give further information on the source performance. Therefore, it was decided to measure the x-ray Bremsstrahlung using NaI detector due to the higher efficiency as compared to a germanium detector. X-ray Bremsstrahlung was measured using a 3 inch NaI detector from the ECR plasma along the extraction side through the 0° port of the analysing magnet.

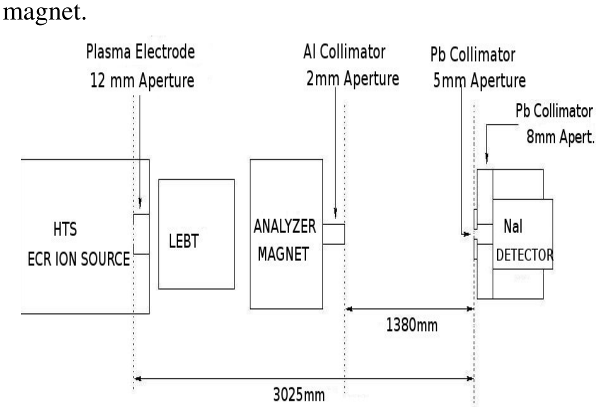

Figure 5: Schematic of X-ray Bremsstrahlung measurement set-up

A schematic of the set-up to measure the x-ray Bremsstrahlung is shown in figure 5. Special care was taken to shield the detector using Pb bricks and to collimate the x-ray Bremsstrahlung from the plasma only. Besides the plasma electrode having an aperture of 6 mm, three additional collimator's are used for proper collimation as shown in the figure. One collimator of diameter 2 mm, length ~ 50 mm and made of aluminium was positioned on the analysing magnet 0° exit port at a distance of 1645 mm from the plasma electrode. An additional collimator made of lead and having a diameter of 5 mm and length 2 mm (positioned at a distance of 1380 mm from the first collimator) was sandwiched on to another collimator of diameter 8 mm and length 50 mm. The detector was positioned behind the last collimator with proper lead shielding around it using 50 mm thick lead bricks. Due to the high count rate, the distance between the detector and the source had to be increased. The x-ray spectra were measured as a function of negative bias voltage keeping the extraction voltage OFF with each measurement taken for 900 seconds (shown in figure 6.). The other parameters relevant for this measurement are shown in table 3 below.

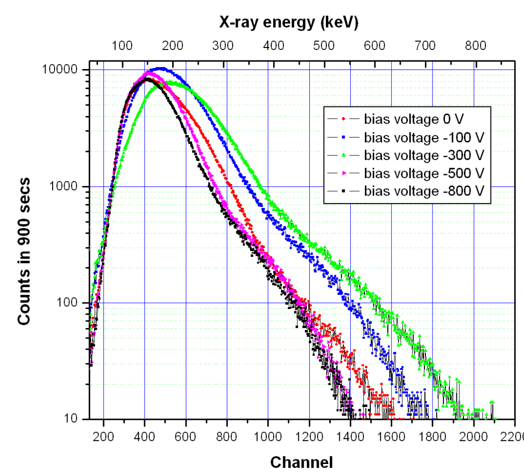

Figure 6: X-ray Bremsstrahlung spectra as a function of negative bias voltage

Table 3: parameters set for X-ray Bremsstrahlung measurements

parameter	value
RF absorbed power	400 W
Extraction voltage	OFF
Injection vacuum	1.0×10^{-4} mbar
Post analyser vacuum	3.2×10^{-7} mbar
B_{min}/B_{ecr}	0.58
Injection / extraction field	1.4 T / 0.95 T

From these measurements, it can be observed that as the bias voltage was increased up to -300 V, the bias voltage had a maximum effect on the x-ray Bremsstrahlung at a value of -300 V in terms of increased x-ray energy (data plotted in green colour) and shift of the peak of the distribution. From the value of -500 V and that at -800 V, the effect was of reducing the x-ray Bremsstrahlung. So it can be inferred that the negative bias effect was best at the value of -300 V. However, in the beam optimisation experiments for argon (Ar^{8+} and Ar^{11+}), the best beam currents at this value assuming similar vacuum conditions, Rf power and magnetic fields were not observed. The best value was -134 V for optimising on Ar^{8+} and -110 V for Ar^{11+}. The explanation for this behaviour is not available at the moment. The errors involved in these measurements are quite small and do not significantly influence this behaviour. It should be pointed out that when the extraction voltage was raised to 20 kV, the slope of the distribution had a bump from 150 keV onwards. Most probably the emission of this additional Bremsstrahlung is due to change of the electron trajectories inside the source. This is shown in figure 7.

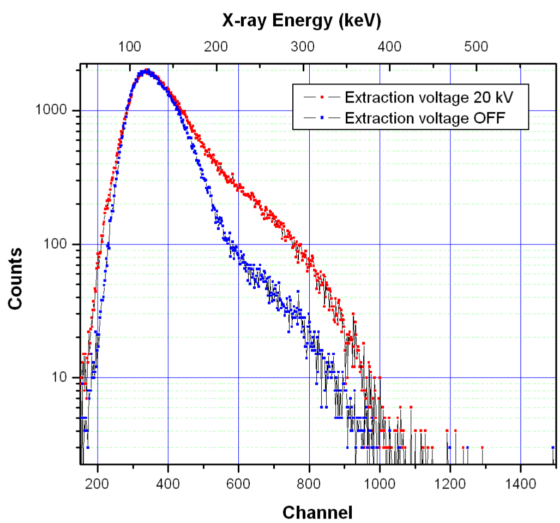

Figure 7: X-ray Bremsstrahlung spectra as a function of negative bias voltage

CONCLUSIONS

From the time the source was commissioned at the test set-up at ground potential, the operational experiences of the source have been satisfactory so far. Much higher beam currents are expected by using mixing gas which was not possible at present due to a leak in the injection line. The source stability has been good. The x-ray Bremsstrahlung shows that there exists high energy electrons measured up to 800 keV at the optimum field corresponding to $B_{min}/B_{ecr} = 0.58$.

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