First Commissioning Results of the Multicusp Ion Source at MIT (MIST-1) for H_2^+

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Abstract. IsoDAR is an experiment under development to search for sterile neutrinos using the isotope Decay-At-Rest (DAR) production mechanism, where protons impinging on ^{9}Be create neutrons which capture on ^{7}Li which then beta-decays producing $\bar{\nu}_e$. As this will be an isotropic source of $\bar{\nu}_e$, the primary driver current must be large (10 mA cw) for IsoDAR to have sufficient statistics to be conclusive within 5 years of running. H_2^+ was chosen as primary ion to overcome some of the space-charge limitations during low energy beam transport and injection into a compact cyclotron. The H_2^+ will be stripped into protons before the target. At MIT, a multicusp ion source (MIST-1) was designed and built to produce a high intensity beam with a high H_2^+ fraction. MIST-1 is now operational at the Plasma Science and Fusion Center (PSFC) at MIT and under commissioning.

INTRODUCTION

The IsoDAR (Isotope Decay-At-Rest) experiment is designed to measure the disappearance of $\bar{\nu}_e$ in the 10 MeV range over a short baseline of 16 m [1]. Comparing the predicted survival rate with the measured one, IsoDAR will be able to test the sterile neutrino hypothesis and distinguish between models with one and two extra neutrinos that are not in the standard model. Neutrinos are produced isotropically on a target through beta-decay-at-rest of ^{8}Li, which in turn is created by neutron capture on very pure (99.99%) ^{7}Li. To achieve the necessary $\bar{\nu}_e$ flux in the detector, a very high primary proton current (10 mA cw) is required which will be delivered by a compact 60 MeV/amu isochronous cyclotron. To overcome space charge issues during injection and capture, H_2^+ is being accelerated and stripped into protons after extraction from the cyclotron. A cartoon of the IsoDAR experiment set up in the Kamioka mine in Japan is depicted in Fig. 1.

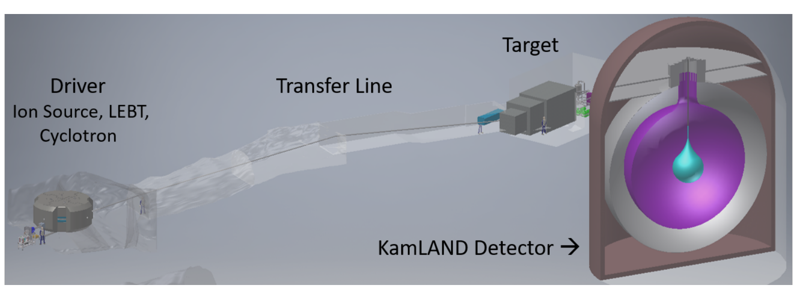

FIGURE 1. Cartoon of the IsoDAR experiment paired with the KamLAND detector. H_2^+ is produced in the MIST-1 ion source, injected into a cyclotron through a spiral inflector, accelerated to 60 MeV/amu , extracted, stripped into protons and transported to the neutrino production target. CAD model courtesy of Larry Bartoszek. (Color online.)

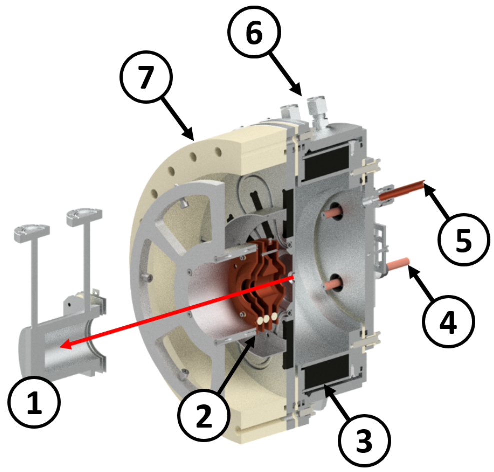

FIGURE 2. Cut view of the MIST-1 ion source. 1. Faraday cup, 2. Extraction System, 3. Permanent magnets (Sm_2Co_{17}), 4. Filament feedthroughs, 5. Gas inlet, 6. Water cooling fittings, 7. Alumina insulator ring.

Experimental studies of the production of a high intensity H_2^+ ion beam and injection into a cyclotron were performed [2] using the off-resonance flat-field ECR ion source VIS (versatile ion source) [3]. The results suggested that the final goal of extracting 5 mA of H_2^+ from the cyclotron was possible, albeit with difficulty, due to a slightly too low initial H_2^+ beam current. Two upgrade routes were conceived: MIST-1, a dedicated ion source for H_2^+ [4], and better pre-bunching with a Radio Frequency Quadrupole (RFQ), directly injecting beam into the cyclotron [5]. Both are being pursued. In this paper we report on the status of the MIST-1 ion source.

ION SOURCE DESIGN

The baseline design of MIST-1 was described in detail in [4]. In short, it is a filament-driven multicusp ion source using Sm_2Co_{17} permanent magnets for confinement and a thoriated (2%) tungsten filament. A 3D model of the ion source is shown in Fig. 2 with the most important items labeled. The main parameters are listed in the following table.

Parameter	**Value (nominal)**	**Parameter**	**Value (nominal)**
Plasma chamber length	6.5 cm	Plasma chamber diameter	15 cm
Permanent magnet material	Sm_2Co_{17}	Permanent magnet strength	1.05 T on surface
Front plate magnets	12 bars (star shape)	Radial magnets	12 bars
Back plate magnets	4 bars in 3 parallel rows	Front plate cooling	embedded steel tube
Chamber cooling	water jacket	Water flow (both)	(1.5 l/min)
Back plate cooling	none	Filament feedthrough cooling	air cooled heat sink
Filament material	98% W, 2% Th	Filament diameter	≈ 1.5 mm
Discharge voltage	max. 150 V	Discharge current	max. 24 A
Filament heating voltage	max. 8 V	Filament heating current	max. 100 A

FIRST COMMISSIONING RESULTS

In the first commissioning phase, a thinner (0.4 mm diameter) pure tungsten filament was used instead of the nominal filament described in the previous section. Currents were measured in a Faraday cup right after the extraction system (see Fig. 2), thus not allowing species separation. All reported currents are total extracted currents. A first systematic measurement of total extracted current versus discharge current is shown in Fig. 3. A clear increasing trend can be observed that suggests the maximum extractable current has not yet been reached. Indeed, during the accumulated

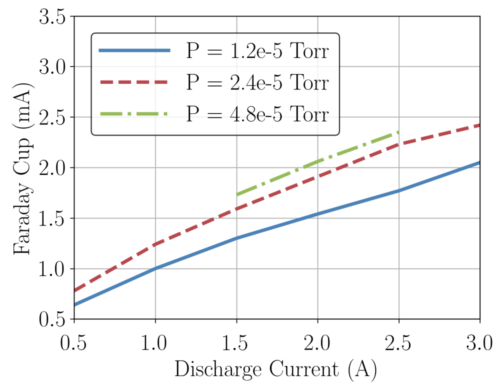

FIGURE 3. Total current vs. discharge for different mass flow settings. The pressure was measured in the chamber shortly after extraction. A clear increasing trend can be seen, suggesting that the upper limit for total extracted current has not yet been reached.

run time of ≈ 30 hours, the source showed good stability for about 4 hours at a time, reaching a maximum current density of 16 mA/cm^2 (4.6 mA total). This is the maximum that can currently be focused into the Faraday cup using the einzel lens incorporated in the extraction system, due to power supply limitations.

SUMMARY AND OUTLOOK

The MIST-1 multicusp ion source is now operational at the MIT Plasma Science and Fusion Center and under commissioning. First results include long-term (≥ 4 hours) stable beams on the order of 4-5 mA total extracted current with a 0.4 mm diameter tungsten filament. First systematic measurements of extracted current as a function of discharge voltage and current as well as gas pressure show increasing trends for all three parameters, only limited by source back plate heating and underperforming extraction electrode power supplies. With improved water cooling and new power supplies, we expect to see a significant increase of total extracted current in the next month. Before the end of the year, the beam line will be extended to include a dipole magnet and two Allison electrostatic emittance scanners (horizontal and vertical) for species analysis and beam quality measurements. Simulations and design are on the way and a dipole magnet as well as two quadrupole magnets are on site already. In the long run, MIST-1 will become part of the RFQ-Direct Injection Project (RFQ-DIP) [5], a test stand for directly injecting H_2^+ beams through an RFQ into a compact test cyclotron.

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