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PROGRESS OF LIQUID LITHIUM STRIPPER FOR FRIB *

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Abstract

The Facility for Rare Isotope Beams (FRIB) at Michigan State University is building a heavy ion linear accelerator (linac) to produce rare isotopes by the fragmentation method. At energies between 16 and 20 MeV/u ions are further stripped by a charge stripper increasing the energy gain downstream in the linac. The main challenges in the stripper design are high power deposited by the ions in the stripping media and radiation damage to the media itself. To overcome these challenges, self-recovering stripper media are the most suitable solutions. The FRIB baseline choice is a high-velocity thin film of liquid lithium. Because liquid lithium is highly reactive with air, we have implemented rigorous safety measures. Since May 2018, the lithium stripper system has been operated safely at an offline test site to accumulate operational experience. We successfully completed a 10-day long unattended continuous operation without any issue, which proved the reliability of the system. We present in this paper that the recent progress of the liquid lithium stripper for FRIB.

INTRODUCTION

Michigan State University was charged by the Office of Science of the Department of Energy of the US to design and build the Facility for Rare Isotope Beams (FRIB) at the end of 2008. The facility is funded by the Office of Nuclear Physics with contributions and cost share from the State of Michigan and Michigan State University. The goal of the facility is the production of rare isotopes produced by the in-flight separation method. This method provides fast development time for any isotope and allows short lived isotopes to be available. The facility will provide fast, stopped and reaccelerated beams of secondary ions.

One of the main components of the facility is a driver linac capable of producing beams of ions from the low mass region up to U at energies above 200 MeV/u and with a total beam power on target of 400 kW [1]. The linac is folded in three segments running parallel to each other with two 180 degree bends in between. After the first linac segment and before the first bend a charge stripper is located to increase the Q/A of heavy ions by more than a factor two. The FRIB baseline choice of the charge stripper is a high-velocity thin film of liquid lithium. For beam commissioning (low intensity, lighter ion beams), however, a conventional carbon stripper is used.

This paper describes the current status of the liquid lithium stripper commissioning.

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DESIGN OF LITHIUM STRIPPER

Design and Construction

Figure 1 shows the layout of the FRIB liquid lithium stripper at the offline test site. The module consists of a liquid lithium loop including a main vacuum chamber, a secondary confinement vessel, an argon safety subsystem, a vacuum subsystem, and an electron gun (E-gun) diagnostics subsystem. The lithium loop is completely contained by the secondary confinement vessel.

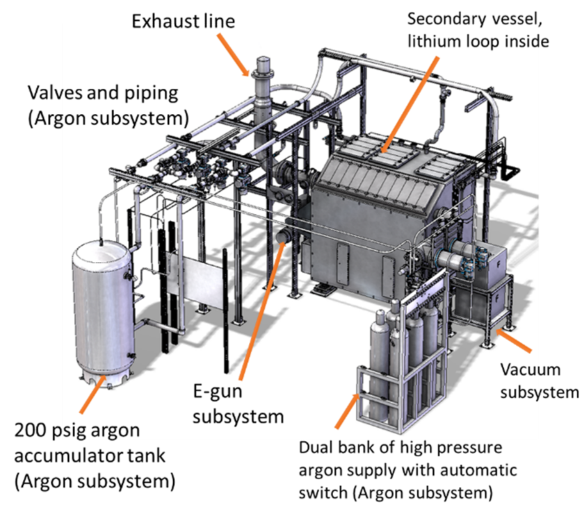

Figure 1: Liquid lithium stripper module at offline test site.

Lithium Loop

The liquid lithium loop (Figure 2) consists of an electromagnetic pump (EMP), particulate filter, nozzle assembly, vacuum chamber, lithium charge tank, and plumbing. The EMP can produce a high pressure flow of more than 1380 kPa (200 psi) at a flow rate of 10 cc/s. In the vacuum chamber, there are a nozzle and a deflector to produce a lithium film, which is formed by hitting a round lithium jet emerging from the nozzle onto the deflector (Figure 3). This film formation scheme was established in Argonne National Laboratory (ANL) [2], and the film stability and capability of removing high-power heat deposition were demonstrated under a collaboration work between FRIB and ANL [3, 4].

Secondary Confinement Vessel

This serves as a safety component. The vessel is filled with argon during operation to provide an inert environment blanket around the lithium loop so that in case lithium leaks out of the loop, it is still able to be confined in an inert atmosphere and will not catch a fire.

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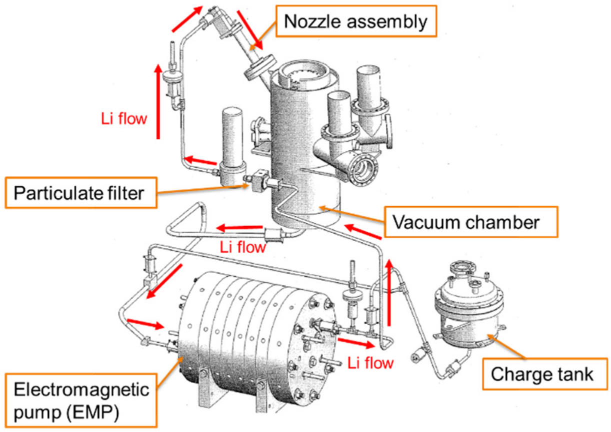

Figure 2: Lithium loop layout.

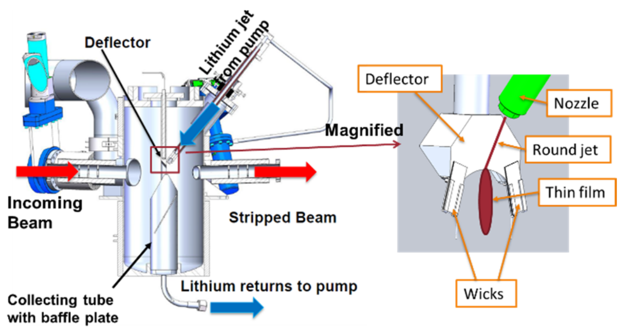

Figure 3: Vacuum chamber cross section and schematic of film production scheme.

Argon Safety Subsystem

This also serves as safety equipment. There are four main functions: 1) to keep filling the secondary vessel with argon during operation, 2) to backfill the vacuum chamber when loss of vacuum is detected, 3) to flood the secondary vessel with high pressure argon in case that an excessive pressure, which is considered an indicator of a fire, is detected in the vessel, and 4) to flood the vacuum chamber with high pressure argon in case that an excessive pressure, which is again considered an indicator of a fire, is detected in the vacuum chamber.

Vacuum Subsystem

This subsystem consists of two cryopumps, a dry scroll pump, gate valves, a residual gas analyser and vacuum gauges.

Electron Gun (E-gun) Subsystem

This serves as a stripper film thickness/stability measurement tool. We use 30-keV electrons to measure the liquid lithium stripper film thickness. A transmission of electrons at an energy depends on a film thickness. This dependence gives us a way to estimate the film thickness. The details of the status of the electron gun subsystem are given in a paper in this conference [5].

RECENT PROGRESS TOWARD ONLINE OPERATION

Offline Tests (Commissioning)

The assembling of the lithium stripper module was completed in December 2017. After that, and before the start of operation, we had the module reviewed intensively by external lithium experts and the FRIB laboratory. Upon the successful completion of those reviews, we started the operation (commissioning).

The first step of the commissioning was to load the charge tank with 2.5-kg lithium, which was completed in May 2018. This was the first handling of large amount of lithium in the FRIB laboratory. We discussed the loading procedure extensively so that we could accomplish this task in a safe manner. Thanks to this careful approach, we were able to finish lithium loading without any issue.

Then we proceeded to the next step: lithium charging of the loop. Since this was considered lithium operation, we filled the secondary vessel with argon and enabled all the safety subsystems including the argon safety subsystem. We heated up the whole lithium loop including the charge tank up to the operating temperature of 220 °C. Then we pressurized the charge tank with argon to push liquid lithium into the loop. We successfully charged the loop with the lithium in August 2018, and got ready for liquid lithium circulation with the EMP.

We achieved the first liquid lithium circulation with the EMP in the same month, August 2018. Following this achievement, we tried a continuous operation for 48 hours. For this operation, we trained new operators so that three shifts were able to be arranged daily, each attended by two operators. The main purpose of this operation was to demonstrate the maturity of the system for future unattended operation. The result was excellent: we were able to run the system for 50 hours with no interruption, no alarm, and no safety interlock activated. The system had been stable for the entire period. The EMP worked as designed and all the instrumentations worked well. We concluded this demonstration was a success.

In March 2019, we achieved unattended continuous operation for more than 10 days. Except for only one minor issue, the system did not require any human interventions for the entire operation period. Figure 4 shows the trends of major flow parameters during the operation. Table 1 shows major operating parameters during this unattended operation, which are equivalent to the parameters for the online operation during beam stripping.

Figure 5 shows a photo of the liquid lithium film produced in the vacuum chamber. Liquid lithium emerges as a round jet out of the nozzle, impinging on the deflector and forming a thin film. The film was produced at a jet speed of 61 m/s (EMP discharge pressure of 135 psi) at a vacuum pressure of 10^{-7} Torr.

Along with the lithium operation, we have been working on the electron gun subsystem. Details are reported in Ref. [5]. We finished the offline test of the electron gun subsystem in March 2019, and integrated it into the lithium system in June 2019 and commissioned in July 2019.

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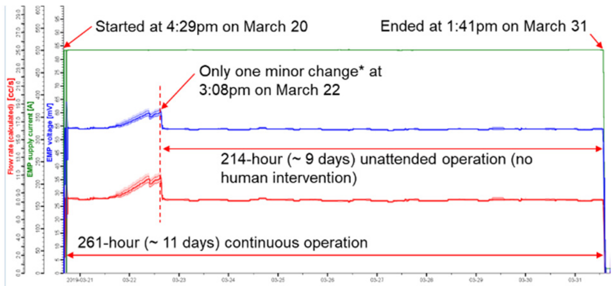

Figure 4: Trends of major flow parameters during 10-day unattended continuous operation.

Table 1: Major Operating Parameters During the Unattended Operation

Parameter	Value
EMP supply current	500 A, equivalent to a discharge pressure of 135 psi
EMP voltage	54 mV, equivalent to a flow rate of 8.2 cc/s
Vacuum pressure in chamber	10^{-7} Torr
Total operating period	261 hours (~11 days)

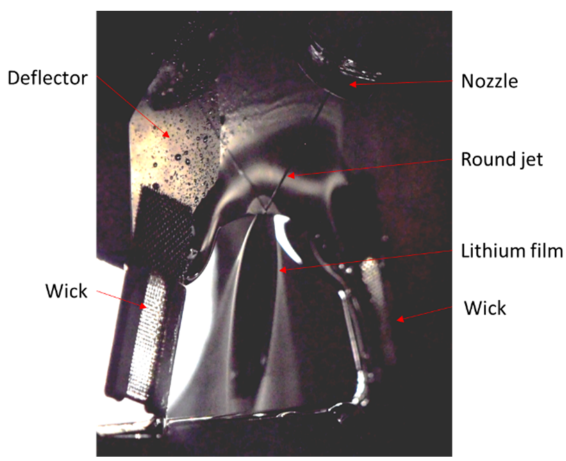

Figure 5: Liquid lithium film at a speed of 61 m/s (EMP discharge pressure of 135 psi) under vacuum (10^{-7} Torr).

Maintenance

Establishing the maintenance plan and detailed procedures is one of the goals for the commissioning at the offline site. In between operations, we have been implementing various maintenance works, especially focusing on maintenance works that require lithium handling. Lithium loop components that are expected to require regular maintenance are the nozzle and the deflector. Figure 6 shows photos taken during demonstration of nozzle tip replacement, which went well without any issues. The deflector replacement has been also demonstrated.

Path Forward

The next step is to characterize the lithium film stability with the electron gun subsystem. In 2020, we plan to bring the lithium stripper into the accelerator tunnel and commission it with ion beams.

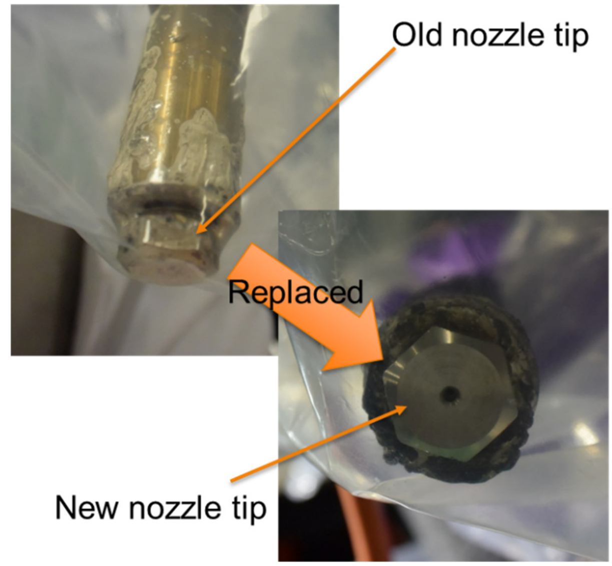

Figure 6: Demonstration of nozzle tip replacement.

SUMMARY

Since the FRIB chose liquid lithium as its baseline charge stripping media, we have strived for establishing the liquid lithium stripper. We have so far constructed the lithium stripper module at an offline test site and been commissioning the module accumulating operational experience and developing maintenance plan and procedures. The goal is to commission the module with heavy ion beams, which is scheduled for next year, 2020.

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