ACCOMPLISHMENT OF HIGH DUTY CYCLE BEAM COMMISSIONING OF LINEAR IFMIF PROTOTYPE ACCELERATOR (LIPAc) AT 5 MeV, 125 mA D^+

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The main achievements of the present study are summarized as follows:

- Successfully demonstrated the high-duty cycle operation of the LIPAc, achieving a maximum duty cycle of 8.75%. This is significant progress from the 0.01% reported at FEC2023.
- Characterization of the beams to be injected into the superconducting linac in the future phases, including the use of interceptive and non-interceptive diagnostics.
- Validation of beam transport simulations by comparing them with experimental measurements, leading to improved simulation accuracy.
- Identified several technical challenges, such as the overheating of RF couplers due to multipacting.

1. INTRODUCTION

The International Fusion Materials Irradiation Facility (IFMIF) Engineering Validation and Engineering Design Activity (IFMIF/EVEDA) is underway [1]. This aims to construct an accelerator-driven intense neutron source using the D-Li nuclear reaction to study the effects of high-energy neutrons on potential candidate materials constituting a fusion DEMO reactor. The Linear IFMIF Prototype Accelerator (LIPAc) is being commissioned in Rokkasho, Japan under the Broader Approach (BA) agreement between EU and Japan. The mission of LIPAc is to validate the acceleration of a 125 mA deuteron beam to 9 MeV in continuous wave (CW) mode. The commissioning of LIPAc has been performed progressively in several phases. While the Superconducting RF Linac (SRF Linac) has been assembled in Rokkasho, the LIPAc which was in the intermediate configuration intended for high-duty beam operation so-called “Phase B+” commissioning. The main objective of this phase was to validate the deuteron beam acceleration by 5 MeV RFQ at a high-duty cycle and characterization of the beams to be injected into the SRF Linac in the final configuration of the LIPAc. The main outcomes of Phase B+ Stage 1 (pilot beams) and low duty cycle (up to 0.01%) operation were reported at FEC2023 [2]. Since then, RFQ conditioning was advanced with careful attention to discharge. Consequently, high-duty operation progressed and was successfully completed in June 2024. This paper presents the key findings and the outcomes throughout this phase and discusses the vision for the construction of the fusion neutron source.

2. RESULTS FROM THE PHASE B+ STAGE 2

The Phase B+ Stage 2 aimed the beam characterization of the nominal beam current of 125 mA D^+ at low duty cycles. The beam current was increased to about 115 mA, which was close to the nominal one of 125 mA. Beam characterization using interceptive diagnostics and verification of non-interceptive beam profilers such as the Fluorescence Profile Monitor and beam loss monitors have been completed. Since only non-interceptive diagnostics can be used in high-duty operations, it was important to verify these devices at this stage. The deuteron beam was transported to the beam dump without significant particle loss. Nonetheless, some small losses were detected in unexpected areas, and some differences of the beam profiles were observed between measurement and simulation. This was thought to be caused by inaccurate simulations of the magnetic field of the magnets in the beam transport line, which we corrected experimentally [3]. The new simulation results were in excellent agreement with the measurements. As a result of the successful verification of the beam transport simulation, the prospect for Stage 3 and following phases became more certain.

3. RESULTS FROM THE PHASE B+ STAGE 3

The Stage 3 began at the end of March 2024 with the objective of increasing the duty cycle to 10%. Ultimately, we achieved a maximum duty cycle of 8.75% with a pulse width of 3.5 ms and a repetition period of 40 ms. This accomplishment is a significant milestone of the project, demonstrating the ability of the LIPAc RFQ design to operate at high duty cycles. As shown in Fig. 1, the beam current reached approximately 119 mA at HEBT (the entrance of the Beam Dump), and the RFQ transmission was about 90%, aligning well with the design simulation. However, it was identified that the current O-ring RF couplers, eight of which are installed in the RFQ, are a bottleneck for achieving higher duty cycles. Fig 2 (right) shows the light signals due to multipacting in the RF couplers, and it was confirmed that the multipacting changed at different rates among the couplers. This induced transient in the RF reflections shown in Fig. 2 (left) due to load variation, causing frequent interlocks before RFQ reaching steady state. This phenomenon, which has been observed experimentally for the first time, was crucial to uncover as it provides valuable insights for the improvement of the coupler as well as the high duty operation in the future. Despite this issue, the RFQ cavity itself worked well with minimal beam loss. If the coupler problem is resolved, higher duty cycle operation is promising. Additionally, it was found essential to improve the control system, including processes to increase the duty cycle, timing systems, and quick restart of the beam.

4. CONCLUSION

The high-duty cycle beam operation of LIPAc, in its Phase B+ configuration, concluded at the end of June 2024. The achievements in Phase B+ have laid a strong foundation for future advancements towards CW operation as well as the SRF Linac commissioning. Moreover, these advances contribute to the broader goal of constructing an accelerator-driven high-intensity neutron source to study the effects of high-energy neutrons on fusion reactor materials.

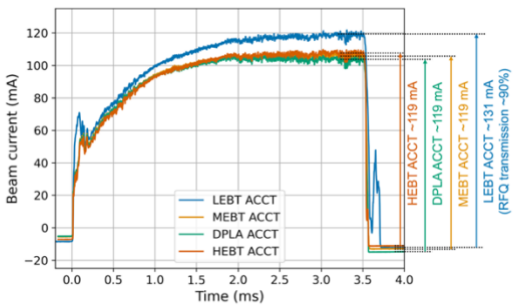

Fig. 1. Beam current waveform when 8.75% duty cycle was achieved.

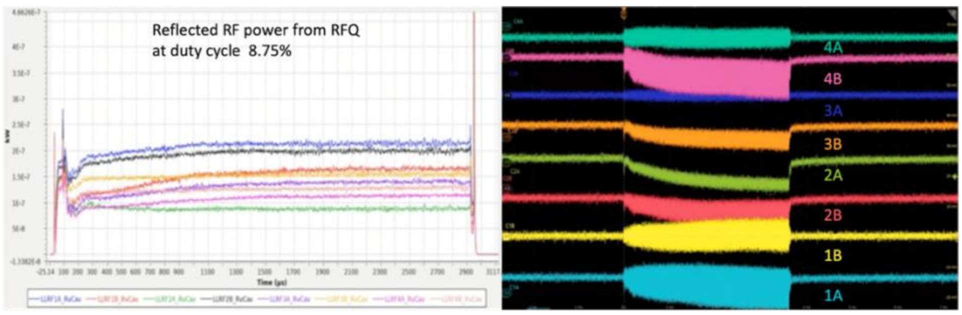

Fig. 2. (left): RF reflections in the RF chains. (right): Light signals due to multipacting in the RF couplers.

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