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Development of calorimetry methodology for beam current measurement of the Linear IFMIF Prototype Accelerator (LIPAc)

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ABSTRACT

The goal of LIPAc (Linear IFMIF Prototype Accelerator) is to achieve a 125 mA, 9 MeV, CW (continuous wave, i.e. 100% duty cycle) deuteron beam with an average beam power of 1.125 MW. In the beam current measurement, it is considered that calorimetric measurement is advantageous for high current and CW operations since it is not subject to secondary electrons, etc. In calorimetric measurements, it is necessary to measure the temperature rise of the cooling water as accurately as possible. We applied this method to LIPAc proton beams at the Beam Stop unit. In order to check the reliability, we inserted a heater in the cooling loop as a heat source and obtained correlation between the applied and measured power, which was found to be 1.0. Moreover, using this heater, accuracy of this measurement with respect to the flow rate of the cooling water was investigated. Due to heat transfer and the fluctuations of water temperature, etc., there is a range of flow rates in which the measurement error can be minimized with our calorimetric measurement system.

1. Introduction

IFMIF (International Fusion Material Irradiation Facility) will generate neutrons with a broad peak at 14 MeV for qualification and characterization of suitable structural materials of plasma exposed equipment of fusion power plants [1]. IFMIF is presently in its EVEDA (Engineering Validation and Engineering Design Activities) phase. As part of IFMIF Validation Activities, the LIPAc Linear accelerator, currently under installation and commissioning in Rokkasho, Japan [2], will traverse the frontier of 1 MW beam average power in 2020, with its target of 9 MeV and 125 mA CW deuteron beam. LIPAc is composed of a H^+/D^+ source, a Low-Energy Beam Transport (LEBT) line, a Radio-Frequency Quadrupole (RFQ), a Medium-Energy Beam Transport (MEBT) line, a Superconducting Radio Frequency LINAC (SRF Linac), and a High Energy Beam Transport (HEBT) line, which transports the beam down to the final Beam Dump. LIPAc installation and commissioning is divided into different phases. The first phase (Phase A − 100 keV) started in November 2014 and continued in 2016. The second phase (Phase B − up to 5 MeV) will start in 2017. The third and fourth phases (C & D) will follow till the end of fiscal year 2019 with the integrated commissioning of the LIPAc up to 9 MeV (see Fig. 1). The injector of LIPAc is composed of a 2.45 GHz ECR ion source based on the CEA Saclay knowhow and two decades long experience with its high intensity light ion source design [3] and a LEBT line to transport and match the beam into the RFQ using a dual solenoid focusing system with integrated H/V steers. The injector commissioning (phase A) is divided into three phases. In phase A1, the emittance was measured between the two solenoids while it is measured just downstream the RFQ injection cone during phase A2 (current phase, this can only be possible in the absence of the RFQ from its final position). In phase A3, we plan to measure the emittance just downstream the 5-electrodes beam extraction system in order to characterize the source itself. The realization of this last phase is still under discussion. Results obtained during phase A1 and intermediate results obtained during phase A2 have been reported and show promising performance [4,5]. In the commissioning activities setup, originally the beam current measured

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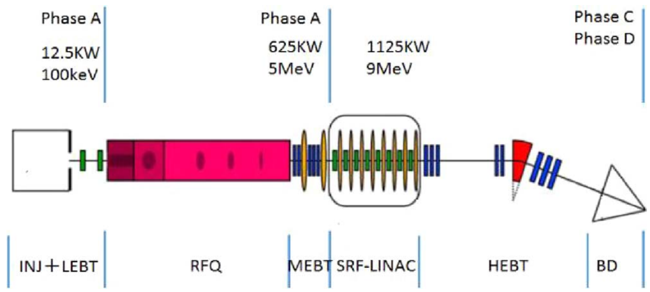

Fig. 1. Schematic view of LIPAc and commissioning Phases.

on the beam stop (BS) are from electrical measurements (same principle as for a Faraday cup). The calorimetric measurement method allows the reduction of the impact of secondary electrons on the beam current measurement. Some doubts about the current values measured were in place driven by the influence of secondary electrons, to assess the validity of the current values obtained through electrical methods and calibrate if needed, it is necessary to cross-check with the calorimetric ones [6]. In order to develop calorimetric measurements in LIPAc injector, we performed the experimental campaign detailed in this paper. In Section 2, a summary of our calorimetric measurement method will be provided. Section 3 describes our first attempt of the beam current measurement applied to the injector of LIPAc at Rokkasho site, followed by different techniques to improve the calorimetric measurement and validate the results. Conclusions will be given in Section 4.

2. Calorimetric measurement system of injector of the LIPAc

2.1. Equipment and instruments of calorimetric system

The energy of the irradiation beam is converted into heat in the Beam Stop (BS), which in turn presents a cooling water system. The calorimetric method analyses the temperature rise value of the water cooling the BS. The LIPAc has such a capability by using a display of various thermocouples (TC) of type K to measure the temperature of water flowing through cooling channels in the BS of the LEBT. A programmable universal digital converter was used as measuring instrument adapted to a TC of type K. The precision of these TCs is ± 0.5 °C; in turn, the accuracy of the programmable universal digital converter is ± 0.2 °C. As measurement instrument of water flow, an ultrasonic water flow meter was selected. Finally, the BS counts with an electrical measurement system to compare the beam current (see Fig. 2).

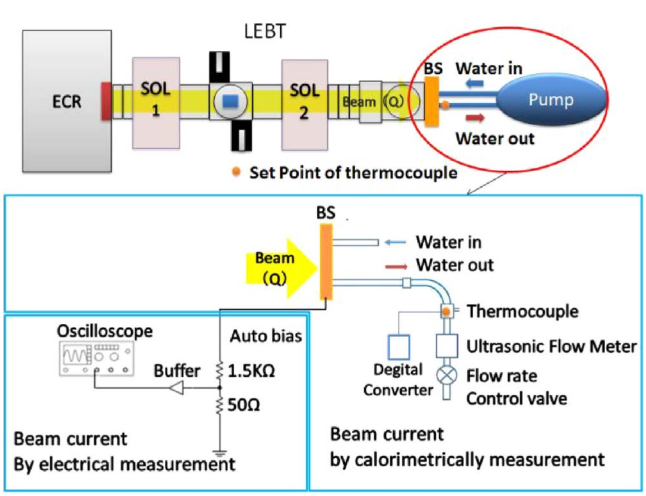

Fig. 2. Schematic view of location of TC for BS in the LEBT.

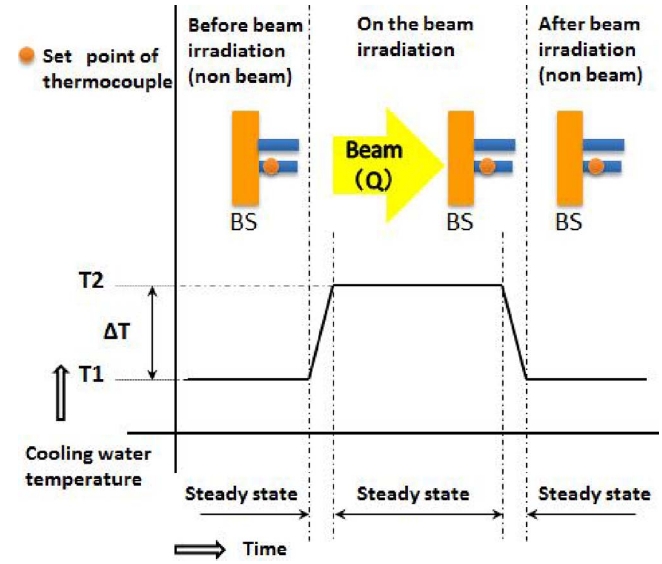

Fig. 3. Chronological change of cooling water temperature evolution by the beam irradiation.

2.2. How to calculate the beam current from calorimetric measurement

Fig. 3 shows chronological change of cooling water temperature value and the beam irradiation.

The cooling water flow value is constant. Before beam irradiation, the cooling water temperature value, T1, is in steady state. Once the beam is 'on', under constant beam conditions, the cooling water temperature value increase until reaching a steady state, T2. Time constant is estimated from diffusivities in ms. After beam is 'off', the cooling water temperature value returns to its original steady state, T1, again. The measurement of the temperature values is done with same TCs. In our estimations, we neglect the transients since T1 and T2 are values in steady state under defined and constant beam conditions, and transients fast. The cooling water temperature variation value was determined by means of the calorimetric measurement system (see Fig. 2). Fig. 4 shows the layout of the BS. The BS was installed under UHV environment in the LEBT and it is thermally insulated from the other LEBT constitution components thanks to 4 non-metal low thermal conductivity spacers. The contact surface of the spacers is just few cm^2. As main object of this experiment, we aim to determine the trends between the beam energy and the ΔT of the cooling water. Based on such assumptions, we calculated the beam current using the following formula:

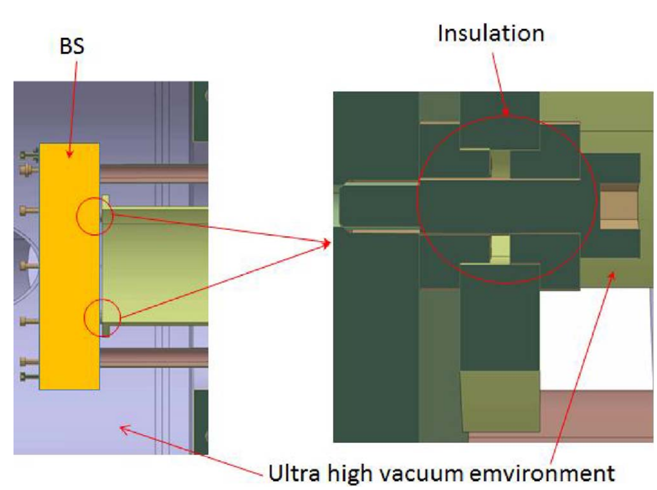

Fig. 4. Layout of the Beam Stopper.