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Experimental performance of the chopper for the ESS LINAC

A Caruso[1], A Longhitano[1], G Torrisi[1], L Neri[1], O Leonardi[1], G Castro[1], L Celona[1], D Mascali[1], L Allegra[1], G Gallo[1], S Passarello[1], G Sorbello[2,1] and S Gammino[1]

[1] Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali del Sud (INFN - LNS), Via Santa Sofia 62, 95123, Catania, Italia

[2] Dipartimento di Ingegneria Elettrica Elettronica e Informatica (DIEEI) Viale Andrea Doria 6, 95125, Università di Catania, Catania, Italia

E-mail: `giuseppe.torrisi@lns.infn.it`

Abstract. At the Istituto Nazionale di Fisica Nucleare – Laboratori Nazionali del Sud (INFN-LNS) the beam commissioning of the high intensity Proton Source for the European Spallation Source (PS-ESS) was completed in November 2017. The ESS requires a high intensity proton beam (74 mA pulsed at 14 Hz of repetition rate), with fast Beam pulse rise/fall time ($< 20\ \mu$s). In order to meet the project requirement, an electrostatic chopping system has been used in the Low Energy Beam Transport (LEBT). The design of the control system was done also to be the main element of the fast beam abort system and taking into account the radiation issue in the accelerator tunnel. This paper describes the performances of the chopper. The experimentally-achieved rise/fall times of the beam pulses measured by using an AC Current Transformer (ACCT) at the end of the LEBT collimator, are presented. An experimental investigation of the effects of different amounts and types of gas injected into the LEBT (for the sake of space charge compensation) has been carried out with respect to the beam and chopper parameters.

1. Introduction

The European Spallation Source (ESS), under construction in Lund, Sweden, will use a high current proton LINAC required for generating high flux of pulsed neutrons by the spallation process. The LINAC layout is made of a warm (or room temperature) section and a superconducting section. The warm linac consists of a proton source (75 keV), a LEBT, a Radio Frequency Quadrupole (RFQ) (3 MeV), a Medium Energy Beam Transport (MEBT) line and a 5-tank Drift Tube Linac (DTL) to accelerate the beam up to 90 MeV. Double-spoke resonators and cell-elliptical cavities will accelerate the beam in the superconducting linac up to 2.5 GeV. This paper will focus on the Chopper of the LEBT line (see Fig. 1) of the ESS project. The aim of the LEBT [1] is to transport and adapt the 70 mA beam from the ion source into the RFQ. The beam pulse duration will be 2.86 ms for a repetition rate of 14 Hz; rise and fall time must be lower than $< 20\ \mu$s. In this paper, the chopper requirements, the chopping development, the optimization of the electrostatic fields, as well as numerical and experimental results are presented.

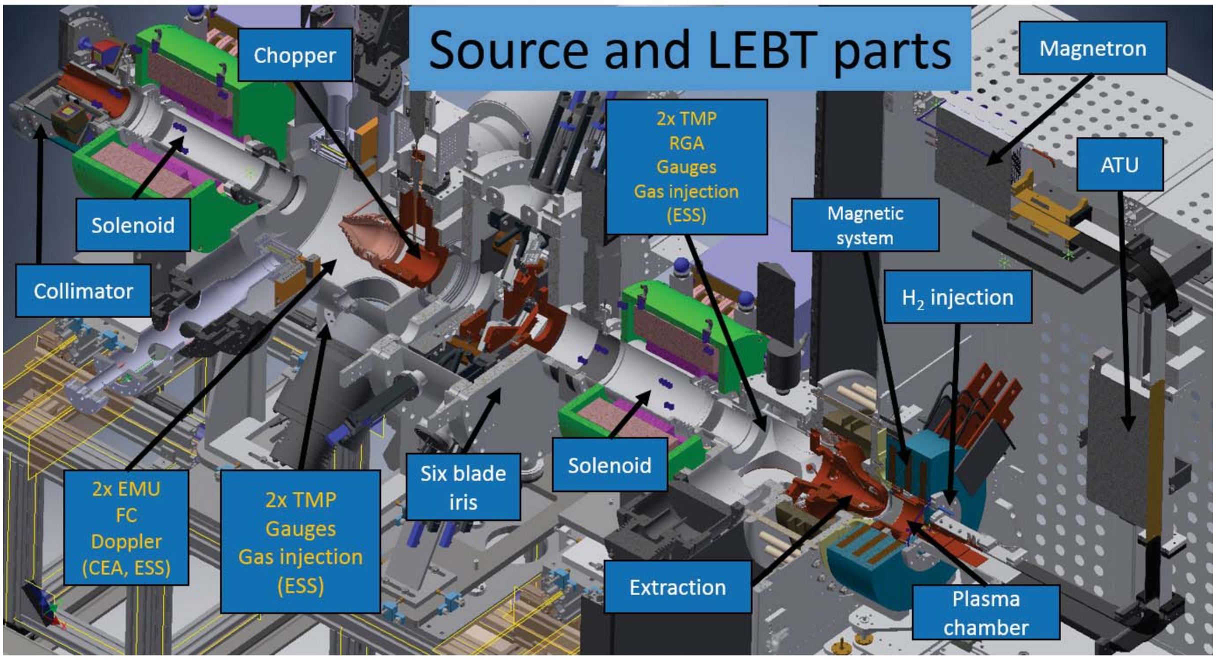

Figure 1. Overview of the ESS ion source and Low Energy Beam Transport (LEBT) included the chopper between the two solenoids.

2. Requirements

The chopper was designed in order to decrease the beam pulse rise and fall time, preserve the Space Charge Compensation (SCC) and limit heating problem due to a focused chopped beam in the LEBT collimator. The recent collaboration between INFN-LNS and Ganil, in the frame of the Spiral 2 project [2], was a good starting point in the design of the ESS LEBT chopper. The position along the beam line and the function of the two choppers, developed for the two projects is quite similar and the time response request is practically the same. The chopper electronic works up to 10 kV, 14 Hz repetition frequency rate, with a rise and fall time of about 15 ns and it was designed to be as reliable as possible because it is part of the beam abort chain of the machine protection system. The design parameters for the chopper power circuit have been reported in Table 1.

Table 1. Design Parameters for the Chopper Power Circuit

Parameters	Design	Measure
Maximum Voltage	-10 kV	-12 kV
Beam Rise/fall time	$< 20\ \mu$s	500 ns
HV Rise/fall time	< 100 ns	15 ns
Duty Cycle	4%	0.01-99.9%
Rep. Rate	14 Hz	< 500 Hz

3. Chopper Development

The development of the ESS was accomplished in two years. In the first year, the power circuit, the feedthrough and the mechanical assembly concept have been studied and tested on a prototype. Reliability and minimization of the maintenance time were taken into account in the design approach of the whole chopper system. Standard commercial devices easy to check and to replace in case of failure have been installed for the power electronic system. For the mechanical assembly concept, we avoid any insulator between the plates, to reduce breakdown probability and capacitive effects. The vacuum feed-through, already assembled with its standard flange, is directly connected to the high voltage electrode.

3.1. Electrical Design

The first consideration in the design was that no significant improvement was observed if the deflecting voltage is applied to both electrode or just in one electrode of the two-parallel-plate standard chopper. Consequently, to simplify the electronic system and the mechanical manufacturing only one of the two electrodes was biased to the required voltage, the other being connected to the ground of the vacuum box. One of the differences between the prototype chopper [3] and the present one, is the voltage bias, set to negative polarity instead of positive. In this way the negative high voltage electrode repels the secondary emission electrons, produced by the beam ionization of the residual gas and decreases the total current drained from the power supply. The block diagram of the chopper system is shown in Fig. 2. The high voltage switch alternatively connects the electrode to ground or to the high voltage power supply following the timing signal repetition rate and duty cycle. A capacitive pick-up probe, placed near the feed-through, detects the high voltage pulse on the electrode for the electronic diagnostic system.

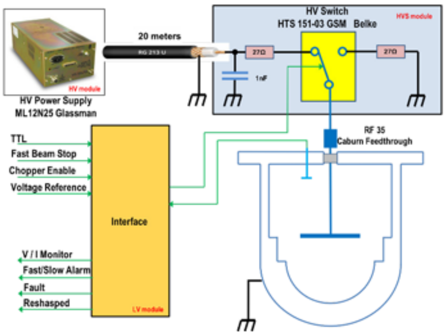

Figure 2. Chopper block diagram.

Figure 3. Interface, power supply and HV switch.

Figure 3 shows the high voltage Solid state switch HTS151-03-GSM by Behlke, the GLASSMAN ML12N25, 12 kV, 25 mA power supply (note that power supply is far from the beam line for radiation hazard) and the 1 nF buffer capacitance, the vacuum feed-through RF-35 by MCD and the electronic interface. The solid state switch consists of two identical mosfet switching paths in "half bridge circuit configuration". Both switching paths are controlled by a common TTL logic driver. The power supply can deliver up to 10kV, 30 mA. The output of the switch are connected directly to the deflecting plate through the RF35, standard ceramic feethrough, in order to avoid any coaxial cable. A total capacitance of about 21 pF was measured at the feed-through connector input. The chopper interface allows a bidirectional communication between the local control system and the main ESS Control System (see Fig. 2).

3.2. Electrostatic Optimization Design

The shape of the electrodes was chosen to be able to provide two electric field components, one for the deflection of the beam and the second for the beam defocusing (see Fig. 4a and 4b). In other layouts, the design is optimized to reduce the fringing field, especially if the chopper

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plates are used in a Wien filter [4]. In our case, a high fringing field is able to defocus the beam. In such a way the chopped beam is spread over a wide area of the LEBT collimator, reducing the heating problem due to a focused chopped beam with a few millimeters diameter. Figure 4b shows, on the right, the transverse electric component used to defocus the beam from the center towards the external zone. The new defocusing chopper requires only one flange for the mechanical assembly (geometry shown in Fig. 4a) while providing a flat transverse field (Fig. 4b, left), preserving the Space Charge Compensation (SCC) inside the LEBT, reducing the required HV power and beam propagation delay and improving the defocusing electric field.

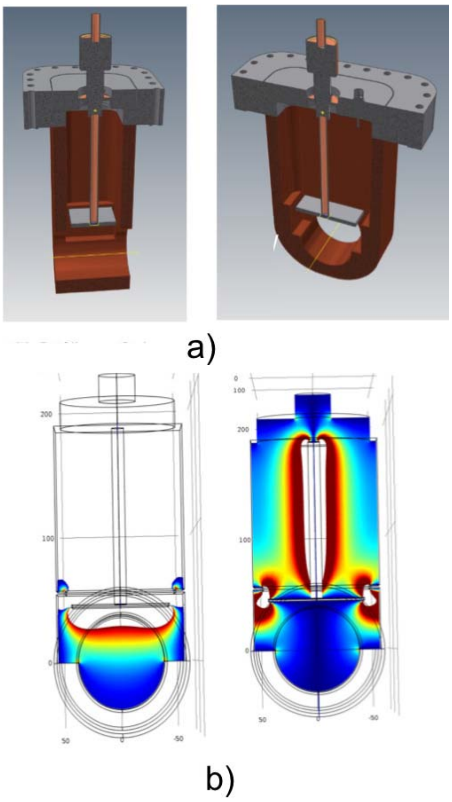

Figure 4. New defocusing chopper: a) cross sections of the chopper in the xz and yz plane; b) deflecting electric field on the left, defocusing electric field on the right.

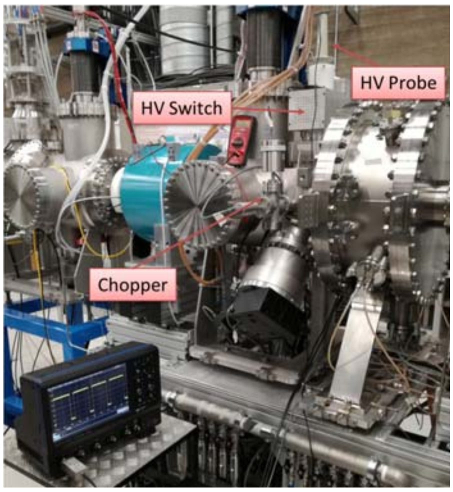

Figure 5. Defocusing chopper with high voltage electronics box installed on the INFN-LNS PS-ESS setup.

4. Experimental Results

The ESS proton source test bench at INFN-LNS (see Fig. 5) for the chopper performance tests consists of: the ion source, the LEBT, the gas injection system, two ACCT measurement units placed at the exit of the source and at the end of the LEBT after the collimator, and a Faraday cup located after the LEBT.

The ACCT located in the collimator was used to measure the rise and fall times of the transmitted beam. When the chopper is switched-on, the beam is deflected: due to the negative polarity of the chopper electrode, the electric field does not destroy the SCC electron cloud but it only empties the region closest to the chopper. In this way, the beam remains compensated in all the other parts of the LEBT. When the chopper is switched-off, the beam starts to travel along the axis and the space charge is allowed to occupy again all the beam envelope. The chopper electric field transition was measured to be of 15 ns while the beam transition time was measured to be around 500 ns. The most important result is that rise and fall times are practically the same. This means that the rise time does not suffer from the SCC time. This is a confirmation that the space charge in the LEBT is almost preserved even if the chopper is turned on. Figures 6 and 7 show rise and fall times measurements of the order of 500 ns; a statistical analysis of this measurement is also shown, resulting in a deviation of the order of 10 ns. Finally, an experimental investigation of the effects of different amounts of gas injected into the LEBT (for the sake of space charge compensation) has been carried out with respect to the beam and chopper parameters. Gas addition of N_2 or H_2 in the LEBT is useful for SCC and emittance reduction. In particular, we observed that for 1 sccm of N_2 in the LEBT, the minimum emittance growth can be obtained. Moreover, we observed an increase of the beam pulse rise time proportional with the LEBT gas addition. However, for 1 sccm of Nitrogen addition, the measured rise time was 703 ns, still below the 20 μs required for the ESS project.

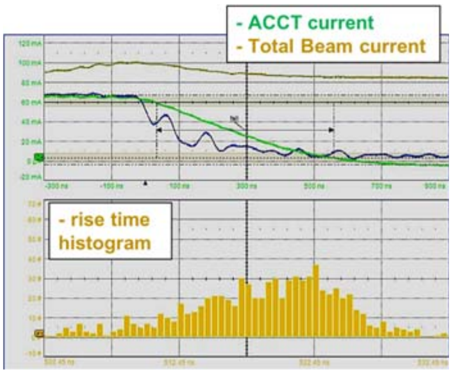

Figure 6. Top, green curve: ACCT current signal measured at the LEBT collimator. Beam pulse fall time is 519 ns. Yellow curve: total beam current. Bottom: histogram of the fall time measurement.

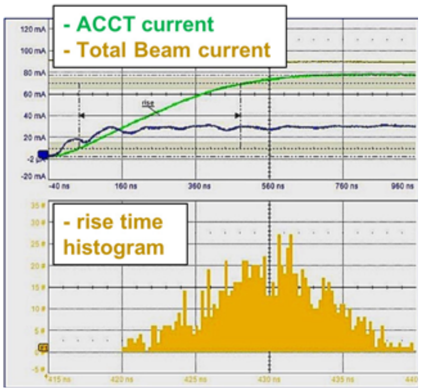

Figure 7. Top, green curve: ACCT current signal measured at the LEBT collimator. Beam pulse rise time is 430 ns. Yellow curve: total beam current. Bottom: histogram of the rise time measurement.

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