COMMISSIONING OF THE CERN LINAC4 WIRE SCANNER, WIRE GRID AND SLIT-GRID MONITORS AT 3 AND 12MeV

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Abstract

The CERN LINAC4 has been fully commissioned up to 3 and 12 MeV. The H^- beam transverse profile distributions were measured by both wire grids and wire scanners. A slit-grid system located on a temporary diagnostics bench was used to characterize the transverse emittance during the three different stages of commissioning: at the exit of the RFQ, at the exit of the MEBT line and at the exit of the DTL1 tank. The wire signal is a balance between the negative charge deposited by the stripped electrons from the H^- and the charge lost due to secondary emission. Optimal settings were found for the repelling plates used to suppress secondary emission, which were confirmed by electromagnetic simulations. In addition, suppression of the secondary emission due to the beam space charge was observed. The benefit of changing the wire scanner geometry in order to minimize the cross-talk between horizontal and vertical wires is also discussed.

INTRODUCTION

As part of the CERN LHC injector chain upgrade, Linac4 will accelerate H^- ions from 45 keV to 160 MeV. The ion source, the LEBT line, the RFQ and the MEBT line have been installed and commissioned in the Linac4 tunnel. The first DTL tank has been installed and has successfully accelerated the first beam to 12 MeV. While the 3 MeV beam commissioning has been completed, the 12 MeV commissioning is still on-going. In this paper the performance of the wire devices used to characterize the beam transverse profile is discussed, in particular with respect to the biasing electrodes used to suppress secondary emission and to repel secondaries produced by the temporary commissioning beam dumps. The performance of the LEBT wire grids (at 45 keV), of the MEBT wire scanners (at 3 MeV) and of the slit-grid emittance meter of the movable test bench are presented. The emittance meter has been used for the 3 MeV beam characterization and will soon be used for the beam at 12 MeV as well.

LEBT SEM GRIDS

The wire grid in the LEBT consists of two planes, one for the horizontal profile and one for the vertical profile, each composed of 24 wires with a pitch that varies from 1mm in the middle of the grid to 3 mm and then 5 mm while getting closer to the frame. All wires are 40 μm diameter gold-plated tungsten wires. At the energy of 45 keV, the H^- ions are stopped in the wires as their range is only about 0.2 μm. The current signal generated on the wire is given by the positive charge (+1) of the proton stopped, the negative charge of the stripped electrons (which can be as large as -2 if they are not back-scattered) and the positive charge due to the secondary electron emission generated by the proton entering the wire surface. The secondary emission yield of a 45 keV proton in tungsten is about 3.5, when calculated with the well-known Sternglass formula [1]. According to this

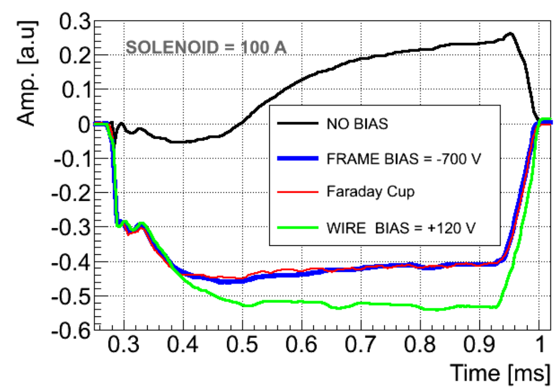

Figure 1: Central wire signal vs time with no bias, frame bias=−700 V and and wire bias=120 V.

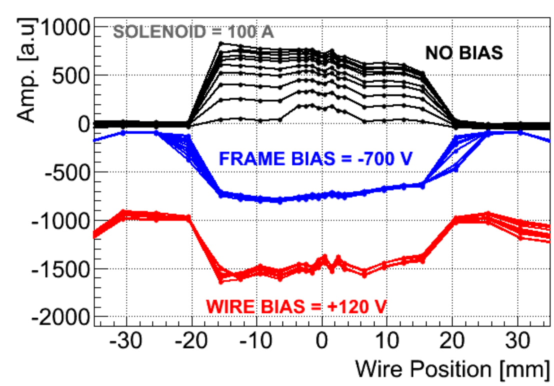

Figure 2: Beam profiles with no bias, frame bias=−700 V and and wire bias=120 V. For each case, different lines correspond to sampling at different times along the linac pulse.

estimate, even if the stripped electron back-scattering coefficient is not known, the wire signal is expected to be positive, owing to the strong contribution of secondary emission. The experimental results are actually more complicated than this simplified model. The calculation does not take into account the effect of secondary emission suppression due to the negative space charge of the H^- beam. Space charge suppression of secondary electron emission is a well-known phenomenon described in literature [2, 3], and looks as it plays a key-role in the wire signal generation for the Linac4

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H^- beam at 45 keV. According to the beam focusing condition, determined by the LEBT solenoid upstream of the grid, the signal polarity was observed to change. With a relatively large beam size the signal polarity is mainly positive, while for smaller beam sizes the polarity changes to negative, as secondary emission gets strongly reduced by the negative space-charge of the H^- beam. The unwanted strong dependence of the signal polarity on the beam size and the not fully understood effect of secondary emission variation during the linac pulse, convinced us to setup a secondary emission suppression system. The aim was to obtain a constant negative signal, independent of the beam size, with a magnitude determined only by the electron charge deposition. Two possibilities were tested: a negative bias voltage to metallic frames upstream and downstream of the grid (at 5 mm distance) and a positive bias voltage to the grid wires.

The sum of all wire signals versus time for different bias conditions are compared to the downstream Faraday cup signal in Fig. 1, whereas the corresponding beam profiles are shown in Fig 2.

Three main effects can be noticed:

1. both methods (frame bias and wire bias) are highly effective in suppressing secondary emission so that the wire signals and the beam profiles are negative during the whole linac pulse;

2. the wire bias generates a negative offset on all the wires, clearly seen in the acquired profiles which show a negative baseline much higher than the one acquired with the frame bias. This could be explained by the fact that a positive voltage on the wires is not only suppressing secondary emission by the wires themselves but also attracting background electrons, such as the secondaries generated by the beam pipe wall in the LEBT line. The negative frame bias is instead able to suppress secondary emission from the wires and at the same time to repel electrons generated by the pipe walls;

3. only the case with frame bias results in a faithful reproduction of the beam current pulse measured with the Faraday cup.

Following these results, a negative bias to the grid frames was permanently adopted.

WIRE SCANNERS

The LINAC4 MEBT is equipped with two wire scanners, each consisting of two 33 μm carbon wires, one horizontal and one vertical, mounted on the same fork support which scans the beam at 45 degrees. The evidence for thermionic emission and its use to monitor the chopping were discussed in [4].

At 3 MeV the contribution of secondary emission is lower than at 45 keV, so that a negative signal is expected, as negative charge deposition dominates over secondary emission. Nevertheless, secondary emission still maintains a strong effect, as seen when polarizing the wires with higher and higher positive voltages. In this case it is evident that the main signal increases while secondary emission is more and more suppressed. At the same time the wire cross-talk is enhanced, as more and more secondary electrons are attracted by the neighboring wire [5]. This effect was clearly recorded after the wire fork layout was modified and the wires mounted in a L-shape geometry (in the previous design the wires were crossing in the center). In this layout the horizontal and vertical signals are recorded shifted in time (and consequently in transverse coordinates). The profiles measured with different wire bias voltages are shown in Fig. 3. The experiment clearly shows evidence of the cross-talk for bias voltages larger than 5 V.

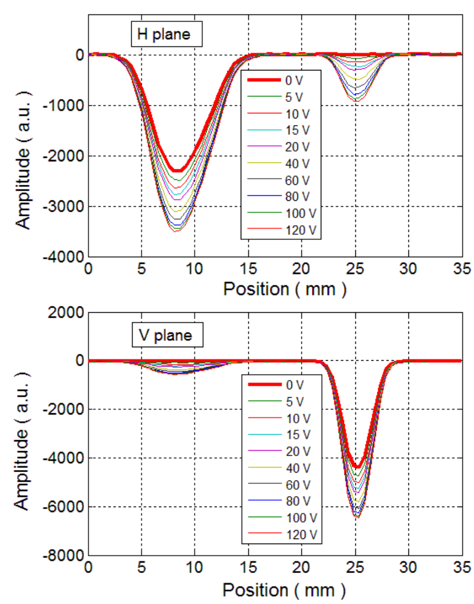

Figure 3: Horizontal and vertical wire scans for different wire bias settings. For each plane the smaller peak is the signal from the other plane wire.

SLIT-GRID EMITTANCE METER

A slit-grid system is installed on a diagnostics bench [6] that has been moved to different locations during the 3 and 12 MeV commissioning (exit of the RFQ, exit of the MEBT and exit of the DTL1 tank). The slit consists of a novel saw-tooth geometry designed to cope with the power deposition at the two different energies [7]. This system has been extensively used to characterize and tune the H^- transverse distributions as already published in the last two years [4, 8]. Here we describe the slit-grid commissioning and validation in terms of biasing the electrodes.

Secondary emission and back-scattering arising from the diagnostics bench beam dump (located just downstream of the grid detectors) can compromise the signal to background ratio from the wire. In order to reduce this effect, two solutions were considered: to give a negative bias to the grid

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frames or to bias two circular repelling electrodes (rings) placed around the beam pipe in between the grids and the dump.

These solutions have been extensively simulated with the CST Particle Studio®suite [9]. The simulations predicted that biasing the rings with −200 V suppresses electrons from the dump, while a higher voltage (−700 V) is needed for the grid frame. During experiments with beam, it was evident that a frame bias of −700 V was able to reduce the background and enhance the signal by suppressing secondary emission from the wires, while a ring bias of −200 V was not so efficient. As shown in Fig. 4, it was necessary to increase the rings bias to -1700 V to obtain the effect expected from simulations.

The reason for which biasing the wire grid frame is more

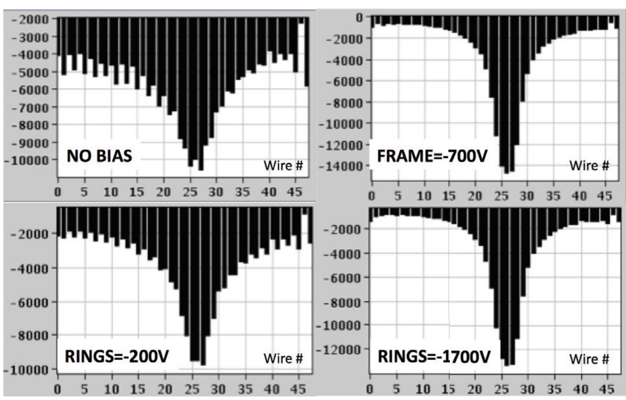

Figure 4: Emittance meter SEM grids signals (in arbitrary units) during measurements at 3 MeV with different bias settings.

effective than biasing the repelling rings has not been fully understood. However it is believed that the frames are more effective in repelling background secondaries coming from the vacuum chamber, as they are located closer to the grids and placed both upstream and downstream.

Since permanently biasing the rings to −1700 V (close to the HV power supply limit) was not considered to be reliable enough, it was decided to connect the rings to ground and bias the frames to −700 V. The decision was also driven by systematic studies that included slit-grid scans with different bias settings. Both the conditions FRAME BIAS = −700 V, RINGS BIAS = 0 V and FRAME BIAS = 0 V, RINGS BIAS = −1700 V proved to provide an excellent suppression of the background and gave very similar results in terms of transverse phase space, profile and emittance.

As an example, Fig. 5 shows how the horizontal profiles are almost identical. The operational settings were also validated by comparing the slit-grid method to other available systems. At first it was possible to use the slit as a scraper (from 0 to 100 % scraping while scanning the slit through the beam) and read the remaining beam current on a downstream beam current transformer. The derivative of the beam current as a function of slit position gave the beam profile. Excellent agreement was found when comparing the results

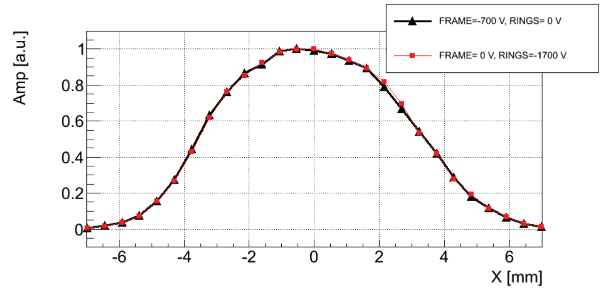

Figure 5: Comparison of the beam profiles inferred by projecting the horizontal phase space measured during two slit-grid scans with different bias settings.

from the two techniques. The case for the vertical profile is shown in Fig. 6: the agreement on both the Gaussian fit of the beam core and the shape of the non-Gaussian tails is well below the 5 % level.

As a further cross-check, a prototype novel laser-based emittance meter (under design for future measurements at 160 MeV) installed on the same diagnostics bench gave very similar results at 3 MeV for both profile and emittance measurements [10].

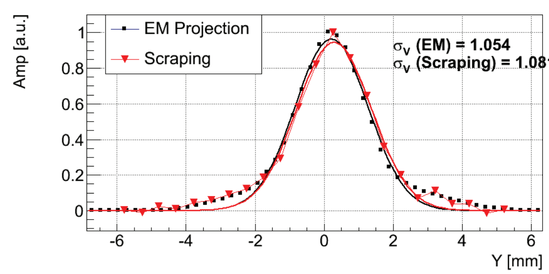

Figure 6: Comparison of vertical beam profiles obtained with a slit-BCT scan and with an emittance scan (frame bias = −700 V, rings bias = 0 V).

CONCLUSIONS

Dedicated measurements during the LINAC4 beam commissioning up to 3 MeV allowed the best settings for the various profile monitors to be defined, with a negative bias (−700 V) found to be best for the LEBT and emittance meter SEM grid frames. The emittance meter grids will also be used at 12 MeV and the same settings are expected to be the optimal. In order to suppress any wire cross-talk while preserving the signal quality, it was found that no bias should be applied to the MEBT wire scanners.

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