COMMISSIONING OF THE LINAC4 ION SOURCE TRANSVERSE EMITTANCE METER

B. Cheymol[a,b], E. Bravin[a], C. Dutriat[a], A. Lokhovitsky[a], U. Raich[a], F. Roncarolo[a], R. Scrivens [a,] E. Zorin[a], [a]CERN, Geneva, Switzerland, [b]Universite Blaise Pascal, Clermont-Ferrand, France.

Abstract

LINAC4 is the first step in the upgrade of the injector chain for the LHC, and will accelerate H[-] ions from 45 keV to 160 MeV. Currently the ion source is installed in a test setup and its commissioning started at the end of 2009. A slit-grid system is used to measure the transverse emittance of the beam at the exit of the source. The results of the measurements have been compared with analytical and numerical predictions of the performance of the emittance meter, addressing the system resolution, accuracy and sensitivity. The outcome of this analysis has been used to improve the design of a new slit-grid system foreseen for the commissioning of LINAC 4 at higher energy locations.

INTRODUCTION

A picture of the emittance meter developed for the source front-end and the Low Energy Beam Transport line (LEBT) is shown in Fig.1.
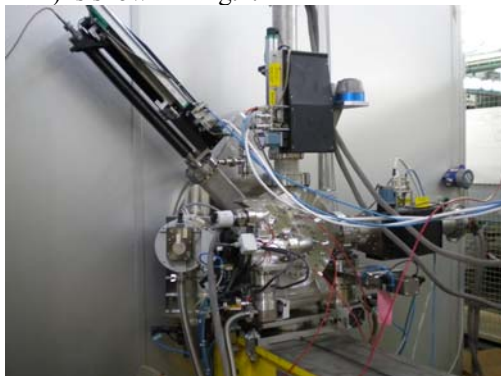

Figure 1: LINAC4 emittance meter.

The system consists of two SEM-grids and one stainless steel blade inclined at 45 degrees relative to the vertical axis. The blade is 1 mm thick and two 100 μm gaps have been machined, one parallel to the horizontal axis, the other parallel to the vertical axis. The thickness of the blade is reduced to 200 μm around the gaps. The two SEM grids are positioned 20 cm downstream the slit, each monitor can be moved separately. The grids consist of 40 tungsten wires separated by 0.75 mm. The diameter of the wires is 40 μm. Each wire is connected to a separate acquisition channel and sampled at 160 kHz. Both the blade and the SEM grids are moved using stepping motors. For each slit position, the corresponding

grid can be moved with steps of 50 μm in order to improve the overall resolution. A schematic diagram of the system for one transverse plane is presented in Fig.2.

A Faraday cup is positioned 8 cm downstream the SEM grid in order to monitor the current of the beamlet during the emittance measurement and to measure the full beam current when the slit is out.

In between the SEM grids and the cup two polarization guard rings have been installed to minimize the recoil of secondary electrons from the cup to the wires.
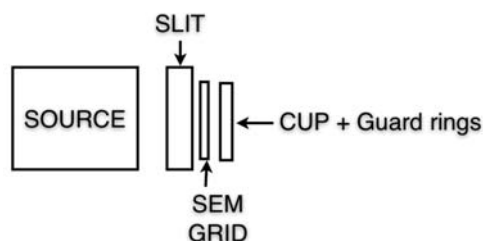

Figure 2: Diagram of the emittance meter.

POLARIZATION GUARD RINGS SIMULATIONS

According to the Sternglass theory [1] describing secondary emission (SE), about 3 electrons are produced for each 35-45 keV H[-] ion impinging on a tungsten or stainless steel surface.

Secondary emission of electrons is expected from the slit, from the Faraday cup and in general from any location where H[-] are lost (beam pipe, guard rings, etc). The energy range of the electrons is about 10 eV +- 5eV.

As shown in Fig 3 the Faraday cup consists of a measurement plate and two guard rings (P1 and P2). These three parts are all made of stainless steel and can be polarized independently.
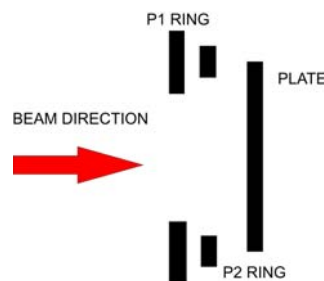

Figure 3: Diagram of the Faraday cup.

06 Beam Instrumentation and Feedback

T03 Beam Diagnostics and Instrumentation

The effect of the guard rings polarization has been studied with the CST Microwave Studio suite [2] by simulating the tracks of the secondary electrons in the polarization electrical field. The secondary emission has been simulated by two electrons sources, one located at the surface of the plate, the other at the surface of the P1 ring. The source consists of electrons with Ek= 10 eV +- 10 eV and isotropic angular distribution.

For the measurement of the full beam current, when the slit is out, a negative voltage on the P2 repels secondary electrons back to the cup, thus minimising the measurement errors. One simulation example is shown in Fig.4.
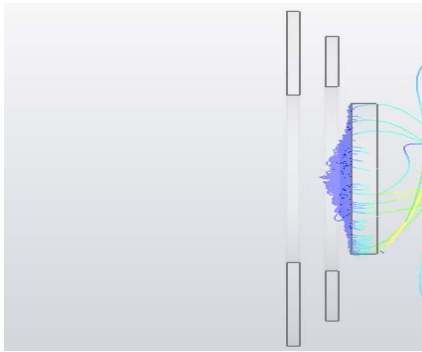

Figure 4: Trajectories of the electrons emitted by the cup with V_{P2}= -500 V.

During emittance measurements, it is necessary to minimise the recoil of electrons from both P1 and the cup. A configuration allowing the measurement of both, the beam current and the emittance was initially considered, with $V_{P1} > 0$ and $V_{P2} < 0$. In fact in this configuration a large number of electrons from the cup can reach the wire grid, as shown in Fig. 5a. Indeed, $V_{P1} > 0$ minimises the emission of electron from P1, but also modifies the field generated by P2 alone and vanishes the effect on the electrons generated at the cup.
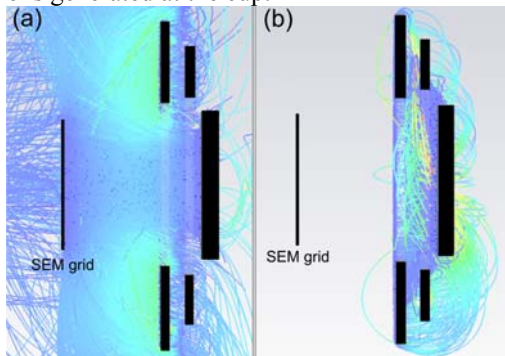

Figure 5: Trajectories of the electrons emitted by the cup with V_{P1}=+500 V and V_{P2}= -1200 V (a) and trajectories of secondary electrons emitted by the cup and the P1 guard ring for V_{P1}= V_{P2}= V_{CUP}=+500 V (b).

The only solution found so far for an unperturbed wire signal consists in polarising P1, P2 and the cup with a positive voltage (Fig. 5b). This has the inconvenient of

not allowing the simultaneous measurement of the beamlet's current.

COMMISSIONING OF THE EMITTANCE METER

In a first commissioning phase, the LINAC 4 source has been delivering a 35 keV and 20 mA H⁻ beam. During this phase it was possible to commission and validate the emittance meter.

Different measurement sessions were dedicated to
- benchmark the simulations presented in the previous section and establish the best bias voltages for the beam current and emittance measurement
- characterise the beam emittance, even though the source was delivering a reduced power compare to the design value (45 keV and 80 mA H⁻ beam) .
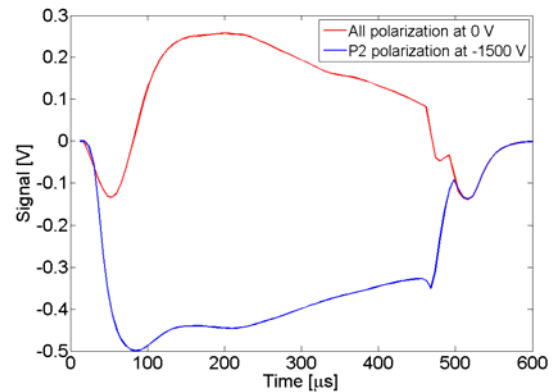

Figure 6: Current measurements on the cup for two P2 polarization.

Fig.6 shows the result of a beam current measurement (with the slit in the parking position) by monitoring the charge collected at the Faraday cup, with $V_{P1} = V_{P2} = V_{CUP} = 0$ (red line) and with $V_{P1} = V_{CUP} = 0$, $V_{P2} = -1500$ (blue line). The measurement is in perfect agreement with the simulations presented above: with no bias on P2 a large number of electrons escape from the cup, on which a positive charge is measured. The measurement also shows a typical example of the source beam current evolution during the 400 μs pulse. This kind of measurement can be used to tune the source parameters in order to optimise the transmission up to the cup.

With the slits scanning the transverse beam distributions, several measurements were performed with different combinations of the three bias voltages, while measuring the beamlet's distribution with the wire grid. Fig.7 refers to a scan in the vertical plane and shows the signals of the wires when the slit is positioned at the centre of the beam. For each wire the average between 100 and 300 μs from the beam pulse start is plotted. The negative signals on the wires not directly hit by the beamlet when $V_{P1} = V_{P2} = V_{CUP} = 0$ (blue line) indicate secondary electrons backscattered from the cup. The same

06 Beam Instrumentation and Feedback

T03 Beam Diagnostics and Instrumentation

effect is evident when V_{P1} = 400, V_{P2} = -1300, V_{CUP} = 0 (red line). This confirms the simulation results, that is: V_{P1}> 0 modifies the electric field pattern generated by V_{P2}< 0 so that a large fraction of the secondary electrons generated at the cup hit the wires. With all biases at +300 V (black line on the plot), all secondary electrons generated at the cup (and possibly on P1) are kept on the plate, and the signals from the wires are unperturbed as predicted.
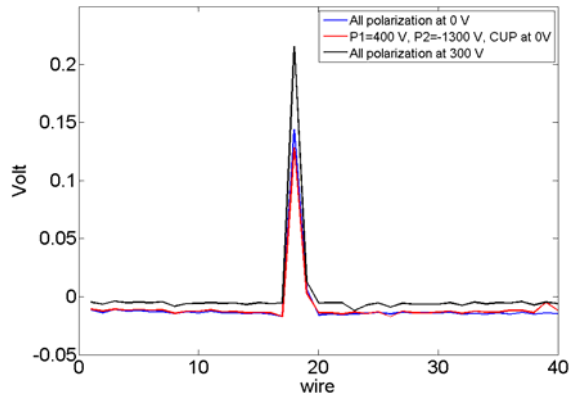

Figure 7: Average signals on the SEM grid wires for 3 polarization settings.

BEAM EMITTANCE MEASUREMENT

After establishing the optimal polarization settings, it was possible to perform the first slit and grid scans for characterising the beam emittance. An example of vertical phase space reconstruction is shown in Fig. 8, when averaging the data acquired in the central period of the 400 us beam pulse.
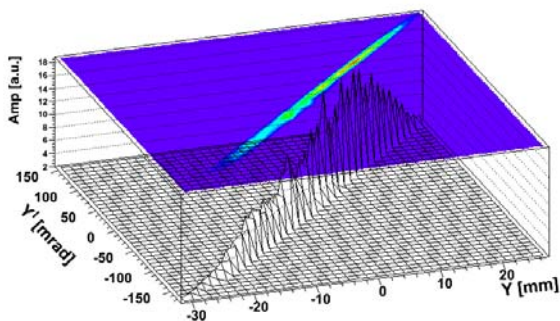

Figure 8: Vertical phase space reconstruction from a slit-grid scan, averaging the data in the central part of the 400 μs beam pulse.

The slit was moved in steps of 750 μm and for each slit position the wire grid was moved in several 125 μm steps. For a better visualisation of the phase space distribution, in the plot the data have been interpolated. From the measurement, the Twiss parameters and emittance values have been determined with a first approximation algorithm, based on the calculation of the RMS distributions (in y and y') after eliminating all wire's

signals < 0. The development of a more sophisticated algorithm, based on the SCUBEEx code [3] is in progress. The examples of measurement results are shown in Table 1. It is possible to observe the remarkable agreement with respect to the expected values for the LINAC4 source [4].

Table 1: Nominal and measured beam parameters of the source for the vertical plane.

	Emittance [rms]	Alpha	Beta
Measured value	0.26 pi.mm.mrad	-35.8	6.24mm/pi.mrad
Nominal value	0.25 pi.mm.mrad	-24.4	4.3 mm/pi.mrad

For the same vertical emittance scan, the evolution of the emittance during the beam pulse is presented in Fig.9.
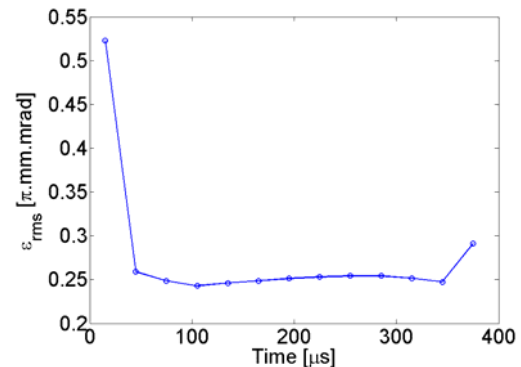

Figure 9: Evolution of the beam emittance during the pulse.

The plot demonstrates how the beam quality deteriorates in terms of emittance at the beginning and the end of the pulse.

CONCLUSIONS

According to the simulation and the results from the commissioning of the emittance meter, the polarization settings for emittance and current measurement have been found. Nevertheless, it will be very useful to measure the beam emittance and current on the P1 guard ring and the cup during the same scan. These additional studies are ongoing. The measurement of the beam parameters and beam stability during one pulse shows a good agreement with the design values even if at an early stage of the source commissioning.

REFERENCES

[1] Theory of Secondary Electron Emission by High-Speed Ions, E.J. Sternglass, Phys.Rev. 108(1957) 1.
[2] CST Microwave Studio®
[3] Minimum ellipse emittance analysis with SCUBEEx code, B. Bazak, L. Weissman, J. Instrum. 3 (2008)
[4] Engineering parameters for diagnostics for a source test line for LINAC4, R.Scrivens

06 Beam Instrumentation and Feedback