ESS EMITTANCE MEASUREMENTS AT INFN CATANIA

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Abstract

Beam characteristics at low energy are an absolute necessity for an acceptable injection in the next stage of a linear accelerator, and are also necessary to reduce beam loss and radiation inside the machine. CEA is taking part of ESS linac construction, by designing Emittance Measurement Units (EMU) for the Low Energy Beam Transport (LEBT). The EMU are designed to qualify the proton beam produced by the INFN Catania ion source. The design corresponds to an Allison scanner, using entrance and exit slits, electrostatic plates and a faraday cup. The beam-stopper protects the device and can be removable to fit to beam power. It has been manufactured by the CEA/LITEN with copper tungsten HIP technique. This article report the first measurements on the ESS injector in CATANIA in one dimension.

INTRODUCTION

Beam characteristics at low energy are an absolute necessity for an acceptable injection in the next stage of a linear accelerator, and are also necessary to reduce beam loss and radiation inside the machine. CEA is taking part of ESS linac construction, by designing Emittance Measurement Units (EMU) for the Low Energy Beam Transport (LEBT). The EMU are designed to qualify the proton beam produced by the INFN Catania ion source. This measurement has been decided to be time resolved, allowing to follow the beam emittance reduction, during the pulse length. A 1MHz acquisition board controlled by EPICS save raw data to an archiver in order to be able to post process the measurements for time resolution. The design corresponds to an Allison scanner, using entrance and exit slits, electrostatic plates and a faraday cup. The beam-stopper protects the device and can be removable to fit to beam power. It has been manufactured by the CEA/LITEN with copper tungsten HIP technique. This article report the first measurements on the ESS injector in CATANIA in one dimension.

Table 1: Margin Specifications

ESS Beam Parameters	Value
Energy	75 kV
Intensity	90 mA
Repetition rate	14 Hz
Duty Cycle	10%

The emittance measurement unit is positioned in the LEBT section after the ion source for beam characterization before being injected into the RFQ. A pair of EMU were design by CEA Saclay in order to qualify the beam in both transverse planes. Both EMU are Allison scanner [1] type and must handle a beam describe in Table 1.

An Allison scanner is composed of an entrance slit, a pair of plates for electrostatic deviation, a rear slit and finally a collector with its electron reppeler electrode. All those parts compose the head of the EMU and is located behind a beam-stopper, adapted to the project beam peak power density. Both elements are mounted on a moving actuator to scan entirely the beam. The second EMU scan the beam perpendicularly to the first one. The scheme of the head is describe in Figure 1.

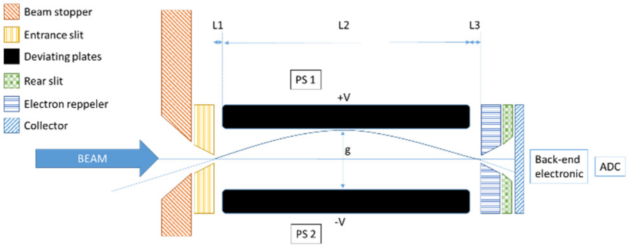

Figure 1: Scheme of an Allison scanner.

When the scanner moves to a measurement position, the step-changed voltages are fed to the deflection plates. The divergence angle of the ions passing through the rear slit, and collected by the faraday cup, can be calculated from the voltage applied on the deflection plates. The measured position, divergence angle and beam current are collected to the computer through an AD card. The program, measuring and processing the data, can handle both pulsed and constant beam. In order to obtain correct emittance results, subtracting background and setting threshold value is extremely important. The program is designed to calculate the root-mean-square emittance, the beam size, the biggest positive and negative divergence angle and the boundary emittance.

THE ENTRANCE SLIT / STUDY OF THE MATERIAL

The entrance slit width plays a major role in the measurement: it has to be well water cooled in order to minimize the thermal dilatation of the slit. If excessive thermally induced dilatation occur, leading to a reduction of the slit width, the intensity collected will be biased thus changing the emittance value. At CEA Saclay, this problematic has been studied with a pulsed beam dedicated to the ESS project. The thermal deposition of the beam power has been simulated both in: CW mode for the mean beam power in order to evaluate the first order deformation of the entrance slit, then a second simulation in pulsed mode with the real instantaneous beam power over several pulses was calculated.

Definition of the Most Intense Beam

In the case of the ESS LEBT, the most intense beam appeared to occur before the entrance of the RFQ, where the beam size decreases after being focused by the second solenoid. The minimum beam size at this point is 3 mm radius sigma. Considering the beam parameters of the beam, a bi-gaussian model has been modelled, the peak energy density is about 140 W/mm².

Material Choice

The most intense beam has an energy of 75 keV. Several materials have been considered, and compared from a thermal and mechanical point of view. It appeared that those materials have a high density and led to a Bragg peak very close to the surface (0.5 µm for Tungsten) according to SRIM[2]. Therefore, the power deposition of the beam was considered to be applied only on the surface (not volumetric).

First, the capacity of the material to keep its mechanical properties, even at high temperature, the criterion described in [3], as being the ratio of the peak stress over the yield strength at the considered peak temperature, has been used. By this mean, TZM (Titanium Zirconium Molybdenum) appeared to be a very satisfactory candidate.

Then, as it is requested to lower the thermal expansion of the slits to maintain a constant aperture, a second criterion has been used [4]. This criterion relates the mechanical properties of the material, to its thermal conductivity and expansion coefficient. High values of this criterion lead to high yield strength and high thermal conductivity, with low thermal expansions. Different material have been compared, but the following graph only shows the comparison between TZM and another good thermal conductor: pure copper.

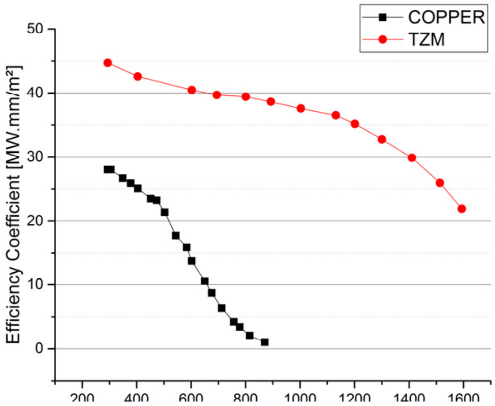

Figure 2: Efficiency coefficient of Copper and TZM alloy.

The TZM alloy appeared to be the best available candidate and has therefore been chosen to constitute the entrance slits of the EMU. One can also note that the total emissivity of TZM has been estimated to be about 0.05, to remain conservative [5].

Thermo-mechanical Simulations

As a first approach, static thermal simulations using the mean power deposited into the slits, have been undertaken. But, in order to study the "dynamic" thermal behavior of the slits, transient simulations using the pulsed beam (real peak intensity every 14 Hz during 8 ms). The dynamic of the thermal phenomena is not really simulated, but as the time sampling it realistic enough, it gives a good approximation.

Different cases have been considered (different position of the beam on the entrance slits), but the worst overall condition lead to a maximum temperature of 261°C, a maximum Von Mises stress of 140 MPa and a decrease of the thickness of the aperture of 13.2 µm.

BEAM DUMP TO STOP THE BEAM POWER / HIP TUNGSTEN COPPER

The beam dump must fulfil several requirements: handle the maximal beam density, protect the measurement head and finally select particle of the beam whom divergence is in the range of ±150 mrad. The beam dump is water-cooled: water flows through stainless steel tubes circulating into the copper body, as close as possible to the tungsten shielding. Tungsten is used to prevent the copper from being damaged and pulverized into the chamber and nearby equipment. The entrance slit must have 100 µm width and 100 mm large. The beam stopper was assembled with the HIP process, developed by CEA/Liten in Grenoble. This assembling process reduces differential thermal dilatation between materials having very different thermal expansion coefficients such as tungsten and copper. The complex inox water circuit is deposit between two thick copper layers. This assembly is covered by carbon layer. The different primary parts are positioned into a stainless steel casing under vacuum. Once sealed, the "montage" is submitted to a static pressure (outside the casing and inside the cooling channels) of 1400 bar into an oven heated up to 900°C. The main advantage of this assembling process, except being able to assemble thermically very different material, is the homogenously assembly of the parts, leading to a good global exchange coefficient between the different parts in contact.

FINAL TESTS AT INFN CATANIA

Installation of the EMU in Catania was made December 2016, all security tests were performed to test the failure procedures (water flow default, vacuum default, end of run default and MPS default). The installation inside the Catania chamber was problematic but solved by modifying the size of the electron shielding around of the EMU head.

Before launching a measurement, the front-end electronic gain value was fixed with signal amplitude less than

10 volts for the highest value otherwise the 1 MHz sampling rate electronic could be damaged. On the raw data waveform (Figure 3), an offset of 2 mV can be observed, and the noise level around this offset is approximately few tens of µV (1 rms).

The ESS beam is set to 70 mA extracted current at 75 keV with 14 Hz repetition rate with 6ms pulse length. On Figure 3 a high resolution measurement is presented with 100 positions (in X-axis) with 400 angles (in Y-axis) at each position. The color are in log representation. Several structures are visible, the main beam and also some low intensity noises.

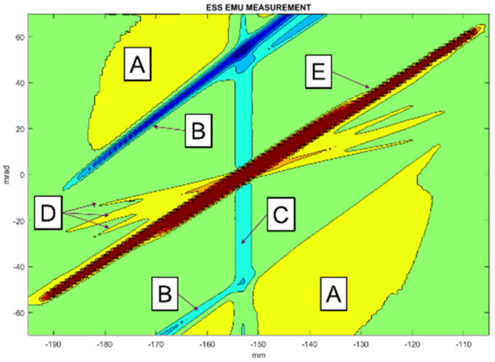

Figure 3: High resolution measurement in log of the ESS ion source, 400 angles per position, for 100 positions.

With the off-line reconstruction program we can estimate the scalar values of the emittance for this measurement and also for the same measurement set but with 25 and 50 positions instead of 100. The results are presented in Table 2. This result showed that the number of position can be reduced up to 25 without changing the emittance value, and making the measurement faster.

Table 2: Values of the Normalized Emittance

Number of Positions	**Normalized emittance π.mm.mrad**
100	0.2270
50	0.2273
25	0.2259

On the reconstructed measurement plot Figure 3, five Regions are visible:

- Region A is a positive signal, produced by scattered ion on the electrostatic plates,
- Region B is negative: this signal is produced by ions on the edge of exit slit. Repeller electrode has a weak effect on its intensity when negatively bias with values of -500Volts,
- Region C represent the effect of the neutral ions impinging the edge of exit slit, this signal is also negative.
- Region D extra beam lines, not well understood at first
- Region E, main peak of the extracted beam, with protons and all the molecular ions.

The first 3 Regions are well known are and also reproducible on other EMU devices when measurements are made at source exit. If we look at a position -180 mm and draw the intensity collected versus the angle (Figure 4) we can notice:

- The main peak E has and angular resolution better than 0,35 mrad.
- The comparison between the amplitude of the main peak E and the extra line D show that we have a high electronic dynamic range around 10^3.

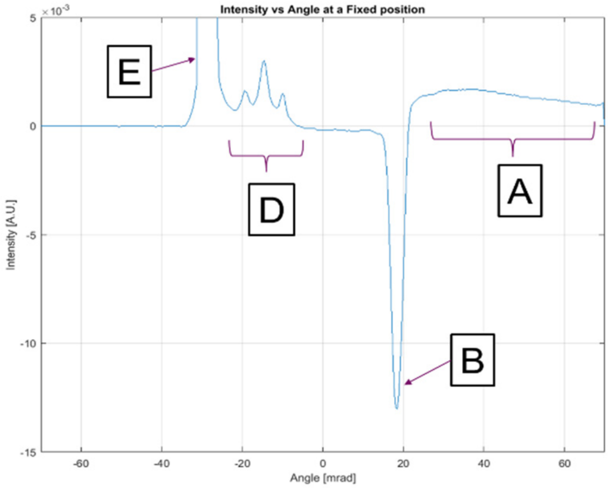

Figure 4: Intensity at position -180mm.

Those extra beams are still under investigation. It is very likely that these ions with a lower angle are extracted from the ions source, and so have a lower energy than 75 keV. One reasonable explanation is that both molecular ions produced and extracted by the ion source (H_2^+ and H_3^+) can intereact with the residual gas to produce ligther ions: Proton or H_2^+, whos energy will be reduced by the mass ratio.

CONCLUSIONS

The choice of the materials and the mechanical design of the different parts of EMU was challenging and risky at the same time. The HIP technic remains one of the best process for assembling different materials with different thermal dilatation coefficient. The TZM material for the entrance slit were not yet heated up too much with the divergent beam at source exit but they are still the best material for keeping the slit aperture constant.

The results of emittance scans demonstrate that the EMU designed by CEA Saclay exceeds the specifications. The EMU is now fully commissioned and can be used to characterize the beam.

REFERENCES

[1] Paul W. Allison *et al.*, *IEEE Transactions on Nuclear Science*, Vol. NS-30, 2204-2206 (1983).
[2] SRIM `http://www.srim.org/`
[3] S. Virostek *et al.*, LBNL-47341, Berkeley, CA, USA (2001).
[4] J. H. Leinhard *et al.*, *Journal of Heat Transfer*, 120(1), 1998.
[5] E. Fors, PhD Thesis, Kungliga Tekniska Högskolan Stockholm, 2012.