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TESTS OF A LOW-ENERGY PEPPERPOT BASED ON A MICRO-CHANNEL PLATE FOR HIGH CURRENT PROTONS SOURCES 4D-EMITTANCE CHARACTERIZATION*

A. Thézé†, B. Bolzon, A. Dubois, G. Ferrand, O. Tuske
Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA-Irfu),
Institut de Recherche sur les lois Fondamentales de l'Univers, Gif-sur-Yvette, France

Abstract

In the scope of high current protons sources characterization, the CEA is working on a 4D-emittancemeter based on the pepperpot technology. After some unsuccessful developments with phosphorous scintillators, we decided to test micro-channel plates (MCP) for measurements of proton beams at very low energy (typically between 50 and 100 keV). MCP are supposed to resist to proton beams at very low energy better than scintillators. This work presents some results for MCPs with an Advanced Light Ions Sources Extraction System (ALISES) on the Banc d'Etude et de Test de Sources d'Ions (BETSI).

INTRODUCTION

In recent years, there has been a growing interest in accelerator instrumentation, particularly emittancemeter. Beam characterization through emittance measurement is a key factor in improving the efficiency of beam transport systems.

Nowadays, most emittancemeters are 2D emittancemeters, measuring the [x-x′] or [y-y′] phase space. Although studies on 4D-emittancemeter (given in a single shot the six projections: x-x′, y-y′, x-y, x′-y′, x-y′, y-x′) have become increasingly numerous in recent years, one problem re-mains: projection resolution. The fundamental principle of the 4D-emittancemeter (pepperpot) is described as the re-construction of position and angular distribution of the beam as like the slit-scan method but in a single shot by applying a metallic mask which has equidistant pinholes with the same diameter [1].

In this way, the angular and position resolutions of the projections depends on the diameter of the holes, the distance between them, and the resolution of the imaging device. Thus, the resolution will in most cases be lower compared to e. g. a slit-grid-assembly [2].

To achieve better resolution, the Accelerator Research and Development Laboratory (LEDA) at CEA Saclay has rethought the principle of the 4D-emittancemeter by proposing a pepperpot that scans the beam as an Allison scanner emittancemeter. Measurement is no longer performed in a single shot, enabling more data to be acquired. The first 4D-emittancemeter was designed in 2016 for low-energy (some keV) and intermediate-energy (some MeV) beams [3]. Due to unsuccessful developments with phosphorous scintillators for characterization of ion sources, the specifications were reduced.

Today, the laboratory focuses its studies on a 4D-emittancemeter with a MCP. The diagnostic is designed to be tested on an ALISES source producing a 50 keV beam of 28 mA, on BETSI [4] since this source is easily available for the experiments. Results are presented in this paper.

PREVIOUS WORK

The first version of the emittancemeter built in 2016 was made of a pepperpot with an integrated cooling system, a scintillator and a synchronized CCD camera. The entire diagnostic is linked to a displacement system consisting of two stepper motors (along the x and y axes).

When the pepperpot was manufactured, the assembly welds failed to withstand hot isostatic pressing, resulting in deformation, loss of thermal conductivity and loss of flatness, making it difficult to drill the sampling holes. In addition, several scintillators were studied and tested [5] but no one satisfied the need for ion sources characterization because of the first atomic layers of the scintillators quick degradation. Even with MeV beams, the scintillators degradation was too quick for precise measurements.

Combining the pepperpot defects and the scintillator heterogeneous light signal degradation (due to certain areas more exposed to the beam), the results obtained for a beam on the Injecteur de Protons à Haute Intensité (IPHI) (3 MeV, 9 mA, 1 Hz, 1 ms pulse time) were not those ex-pected (see Fig, 1).

The data obtained could not be processed, and none of the six projections gave an accurate and precise emittance value [3]. At lower energy (around 60 keV), scintillators were destroyed after a single pulse.

UPDATED EMITTANCEMETER

The pepperpot was redesigned without the cooling system making the manufacturing easier. Thermal simulations were carried out using COMSOL software. An aluminium plate with the dimensions of the pepperpot was tested in front of the ALISES 3 source beam (1 Hz, 29 mA and 65 kV) [6]. Various operating cycles were tested in order to measure the maximal local temperature and to avoid dam-aging the pepperpot before measuring the emittance. For a 10 % duty

* Work supported by the Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA, France)
† anna.theze@cea.fr

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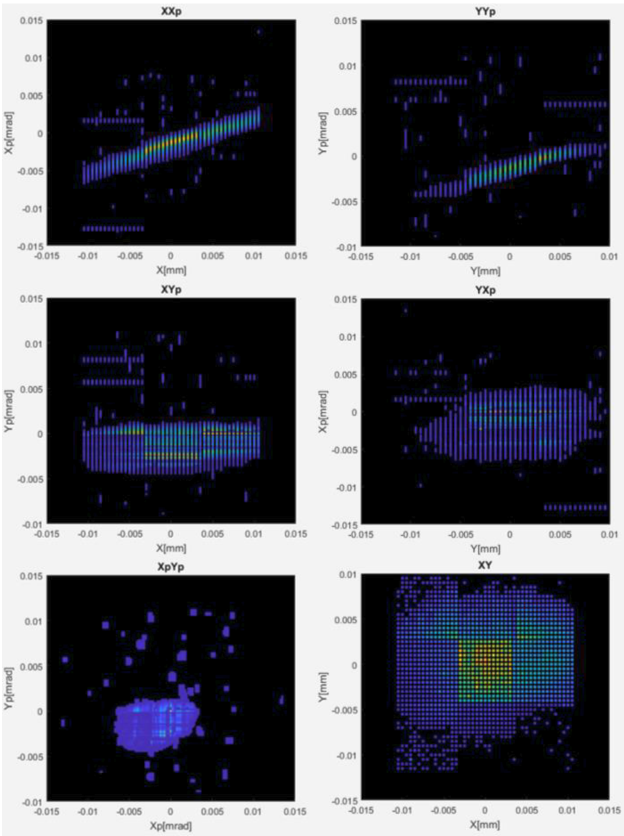

Figure 1: The 6 emittance projections obtained by the 4D-emittancemeter designed in 2016.

cycle, the maximum temperature measured was 81 °C. At this duty cycle, no water cooling system is required.

The scintillator has been replaced by a MCP. Most recent 4D-emittancemetters use them due to their good temporal resolution [7]. When the ion beam enters a channel and strikes the wall, several secondary electrons are emitted due to the electric potential between electrodes. They then strike the opposite channel wall, emitting further secondary electrons. The electrons thus move towards the end of the MCP while repeatedly striking the inner wall of the channel. The phosphor screen behind the MCP receives electrons rather than protons, limiting its degradation.

The MCP used is a Hamamatsu MCP F2225-21P with the small channel diameter (12 µm), large effective surface diameter (42 mm) and an integrated phosphor screen.

The displacement system has been retained. It was described in [3]. The available 2D-displacement increases greatly the spatial resolution (x and y) of the measurement. The operator can define the step size of the acquisition.

The spatial resolution of each shot of a pepperpot 4D-emittancemeter is determined by the distance between the holes. This resolution is limited by the size of the spots on the imaging plane, which must not overlap. Angular resolution is determined by the spatial resolution of the position-sensitive detector and by the pepperpot-MCP distance.

By adding a displacement system that scans the entire beam along the x and y axes, spatial resolution depends essentially on the step size, which can be far lower than the single shot resolution. In this case, the measurement is no longer instantaneous, the number of required shots is given by the square of the ratio between the single shot resolution and the step size.

Main design parameters are listed in Table 1.

Table 1: Main Design Parameters

Parameters	Value	Unit
Number of holes	69	—
Hole-to-hole distance	4	mm
Holes diameter	⌀ 0.06	mm
Pepperpot to MCP distance	60	mm
MCP active diameter	⌀ 42	mm
Materials of mask	Al	—

The camera uses for the acquisition is an AV MAKO G-419B POE bought in 2013 with 12 bit colour depth (monochrome) and a 2048 × 2048 pixel resolution.

RESULTS

The emittance projections presented in this part were obtained with the new version of the 4D-emittancemeter on ALISES 2 on BETIS. The source parameters are as fol-lows: 1 Hz, 28 mA, 40 keV beam, with a pulse time of 10 ms.

These values are a compromise to obtain a fully formed beam and minimize the energy absorbed by the pepperpot. A LabVIEW™ program controls the system. It moves along a trajectory known as a “vertical comb”. For a chosen distance and number of points, the acquisition system collects images with the camera, with the defined step size. The acquisition system recorded data at regular intervals of 0.5 mm over 4 mm along the x and y axes. This gives a final spatial resolution of 72 × 72. 81 acquisitions were made for one emittancemeter measurement. A python program has been written to reconstruct the phase-space distributions from these acquisitions (see Fig. 2).

Each hole in the pepperpot has a different dimension due to the precision of the manufacturing process. Therefore, the quantity of particles incoming (beam sampling) differs from hole to hole.

To overcome this problem, a calibration process was carried out: At time t, an acquisition is made for a known pepperpot position. A second acquisition is then made under the same conditions, with the pepperpot offset by 4 mm along the X or Y axis (inter-hole distance).

Assuming that the beam profile does not vary over time, beam sampling should be the same.

By comparing the two acquisitions, it is possible to calibrate the sensitivity of each hole. By convention, the calibration of the central hole is 1. After calibration, emittance projections are shown in Fig. 3.

To evaluate the MCP and the phosphor screen response over time and demonstrate that its reliability is better than that of a scintillator, a first acquisition was made and then a

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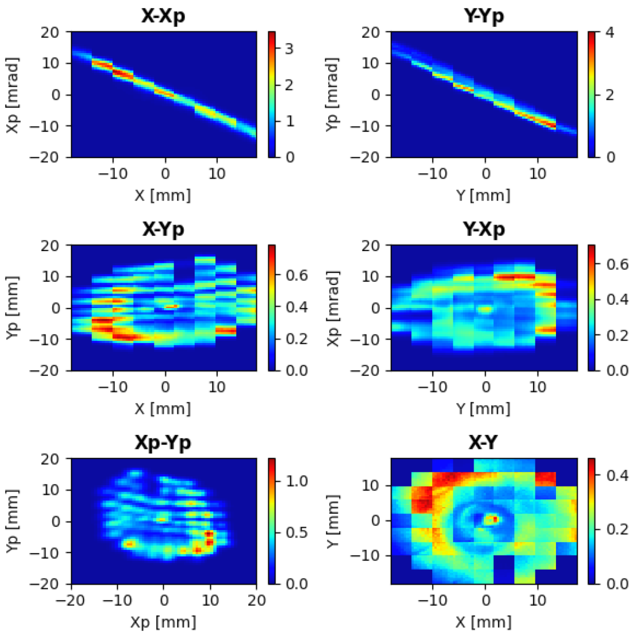

Figure 2: The 6 emittance projections obtained before calibration.

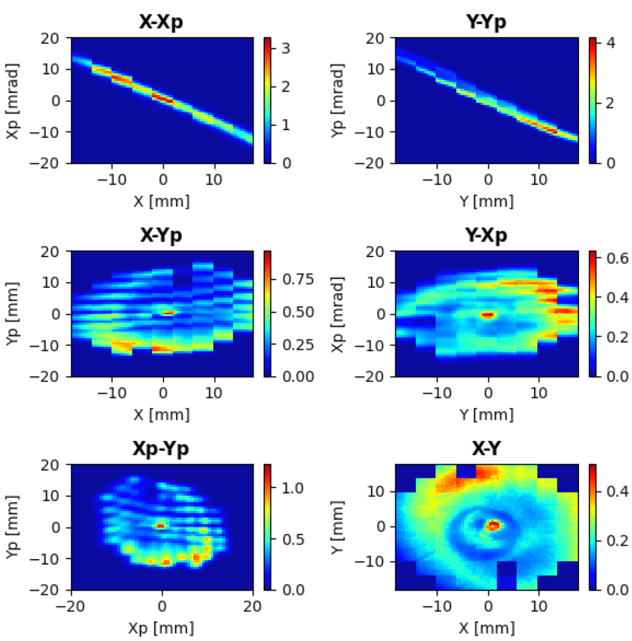

Figure 3: The 6 emittance projections obtained after calibration.

second acquisition was carried out under the same conditions a few moments later (see Fig. 4). The MCP response did not seem to deteriorate in the face of the proton beam, unlike the scintillator used in the first version.

CONCLUSION

In conclusion, this article presents the progress made in the first development of a moving 4D-emittancemeter based on pepperpot technology.

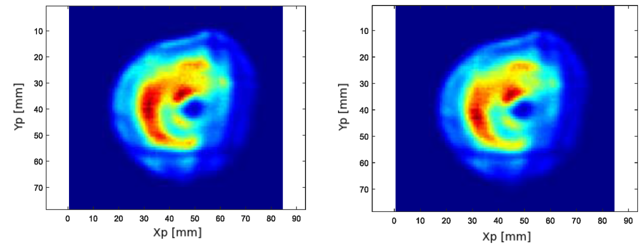

Figure 4: First (on the left) and second (on the right) x′-y′emittance projections.

Initially faced with difficulties with phosphorus scintillators, the study turned to the use of microchannel plates (MCP), because of their reliability over time.

The 4D-emittancemeter displacement system has enabled more accurate and detailed measurements of proton beam emittance projections. In addition, the results obtained validated the MCP as a better alternative to scintillators for such applications.

However, MCP have limitations. They require several elements that are not easy to integrate on a beam line (MCP + P-screens + camera) and cannot differentiate ions and atoms or molecules. Other acquisition methods will be studied and developed in the near future.

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