Nuclear Inst. and Methods in Physics Research, A 936 (2019) 25–26

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

A pixelated Faraday cup for proton beam diagnostics

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ARTICLE INFO

Keywords:
Proton beam
Diagnostic tools
Faraday cup

ABSTRACT

Diagnostics tools are largely used to tune and set up beams in a vast range of applications. They include particle and nuclear physics, medical physics up to material science and biology, just to mention a few. The requirements on the detectors used to monitor the beam condition accordingly with the specific case. We present here a pixelated Faraday cup we built and used for beam profile monitoring with the peculiar characteristic of simultaneously measuring the proton beam position, shape and intensity. The detector covers a large range of currents from a hundred μA down to a few nA perfectly matching the range of the proton beam intensity delivered by a 1 MeV Cockcroft–Walton accelerator. The pixel size allows for a beam position determination better than 1 mm.

Contents

1. Introduction

Since the early 1980s, accelerator science went through an impressive development. Accelerators are the prime tool for research in high energy physics but they are also the most versatile tool for characterizing materials and for producing nano-structured devices. They play a major role in advanced cancer therapy and radio-surgery, and there are a lot of other applications in every day life such as sterilization of medical supplies and food, or trucks inspection just to mention a few.

Beam diagnostic tools used to tune and monitor the beam delivered by accelerators went through a similar trend. A Faraday cup has been present in every beam line since the beginning. We present here a new revisitation of a Faraday cup: a pixelated one with the unique characteristic of simultaneously measuring the beam intensity and the beam profile — beam spot and position. This tool has to be used along a proton beam delivered by a Cockcroft–Walton accelerator. We will show that it is capable of measuring a large range of currents, from a hundred μA down to a few nA, perfectly matching the range of the proton beam intensity. The pixelated size allows for a beam position determination better than 1 mm. The electronics used to perform these measurements and the Graphical User Interface (GUI) which allows for the remote control of the detector will be also discussed.

2. The Cockcroft–Walton accelerator and the proton beam line

The proton beam to be measured is delivered by a 1 MeV Cockcroft–Walton accelerator [1,2], characterized by a tunable terminal voltage (range: 100–1000 kV) and beam current (range: 1–100 μA) and it is used for the calibrations of the MEG and MEG II experiments [3,4]. A typical focused beam spot size immediately after the accelerator gate valve at a 1 m distance from the accelerator chain is $\approx 1 \times 1\ \mathrm{mm}^2$ (FWHM) and the angular divergence is $\approx 5 \times 5\ \mathrm{mrad}$ (FWHM). The total length of the proton beam line is of the order of 10 m, including an extensible beam line bellows with a maximum stroke of 2.3 m. The beam line ends inside a superconducting solenoid with a maximum field intensity of 1.25 T.

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https://doi.org/10.1016/j.nima.2018.10.021
Received 26 June 2018; Received in revised form 18 September 2018; Accepted 2 October 2018

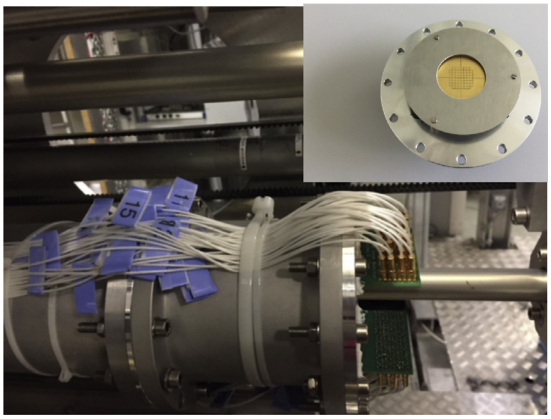

Fig. 1. The pixelated Faraday Cup.

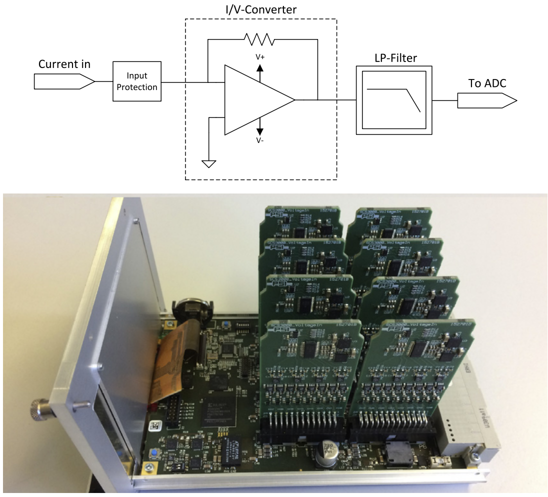

Fig. 2. SCS3000 frame with eight cards installed and the block diagram of a current meter channel.

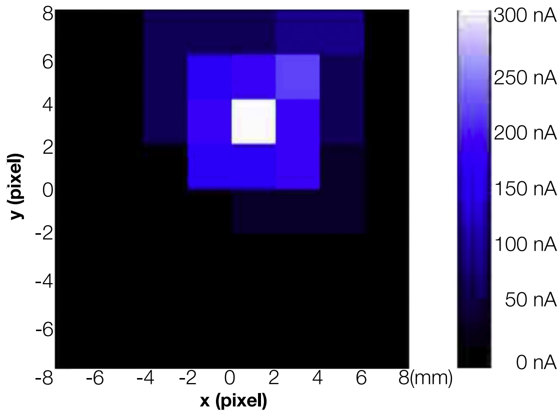

Fig. 3. The reconstructed beam position for a measured 1 μA current. Each pixel measures 2×2 mm^2.

3. The detector

Fig. 1 shows two pictures of the pixelated Faraday cup. It is made of a vacuum beam pipe insulated from the rest of the proton beam line via a PEEK spacer and hosting the pixelated active target: a matrix of 8×8 copper channels with a pixel size of 2×2 mm^2 and gaps of 0.13 mm in between. The target is realized with a semi-flex printed circuit board (PCB) that serves also as a feedthrough, being epoxy-glued to the terminal flange.

The readout of the pixel matrix is done with the SCS3000 system developed at the Paul Scherrer Institute. In this configuration all the 8 slots are equipped with analog current readout modules. Each module hosts 8 channels, consisting of an input protection, a current to voltage converter and a 3rd order Bessel low pass filter (Fig. 2).

The 8 conditioned analog signals are sampled at 125 Hz by a multichannel ADC included on the module. The combination of a high precision, low drift active input stage with almost zero input impedance, followed by a high resolution $\Delta\Sigma$-ADC with a full-scale range of 125 μA leads to a 18 bit noise free resolution corresponding to ~500 pA. After calibration, the offset including drift over temperature as well as the gain drift are also less than this ~500 pA.

4. Results and conclusions

Both the measured beam current and position (gravity center) have been found to be consistent with what has been measured by a normal Faraday cup and a quartz crystal detector coupled to a camera, used as a reference. The total current is obtained by summing all the currents measured by the single pixels. Different algorithms are used to extract the beam position: The current weighed pixel coordinate mean and the left–right/top–bottom current asymmetry. An example of a reconstructed beam position is shown in Fig. 3 for a beam current of 1 μA. Labview is used as GUI.

In conclusion we built, tested and successfully integrated into the MEGII Cockcroft–Walton beam line at the Paul Scherrer Institut a prototype of pixelated Faraday cup. Its performance has been confirmed comparing the results obtained with that measured with other reference detectors. The main new characteristic of this detector is its capability to simultaneously measure the beam current (large current range from 10 nA to 100 μA) and the beam position (better than 1 mm).

Acknowledgments

The authors thank the Paul Scherrer Institut as host laboratory and for the technical support. This work was supported in part by the grant MIUR, Italy Montalcini D.M. 2014 n. 975.

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