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LAB-INDUSTRY COLLABORATION: INDUSTRIALISATION OF A NOVEL NON-INTERCEPTIVE TURN-KEY DIAGNOSTIC SYSTEM FOR MEDICAL APPLICATIONS

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Abstract

A novel non-interceptive beam current monitor prototype was successfully developed to measure the ultra-low beam currents (0.1-10 nA) with a 1 Hz measurement bandwidth at the Paul Scherrer Institute's (PSI's) proton radiation therapy facility, PROSCAN. The monitor resonance frequency is tuned to a harmonic of the beam pulse repetition rate, enabling a larger signal-to-noise ratio compared to those of broadband systems. Since the tuned frequency certainly differs for other facilities, such a system requires customisation. To enhance the application of the monitor to a turn-key system, a fast digitiser solution allowing (1 kHz data rate) streaming of measurements to various control systems is of importance as well. In this paper, we report on the industrial challenges associated, such as quality, reliability, repeatability and customisability, online monitoring, turn-key system, etc. in manufacturing a working novel prototype from a research environment. A fruitful collaboration between PSI, Bergoz Instrumentation, and Instrumentation Technologies is foreseen to make it happen, from a first-of-a-kind industrialised product to be tested in the lab, to a product line in a catalogue.

INTRODUCTION

In proton therapy facilities such as at PSI [1], monitoring of low beam currents (0.1-10 nA) with high accuracy and precision is of crucial importance as it is directly related to the delivered dose and its related errors. Ionisation chambers (IC) are typically used in such facilities [2, 3] for beam current measurements but with strict regulations during therapy. As a potential alternative, a non-interceptive beam current monitor was successfully developed and tested at PSI. Here, we report on the prototype development and validation at PSI, industrialisation of the turn-key diagnostic system, and challenges associated with the process.

PROTOTYPE DEVELOPMENT AND VALIDATION AT PSI

A non-interceptive beam current monitor (BCM) working on the principle of electromagnetic resonance was developed [4, 5] at PSI (shown in Figure 1) as part of an EU Horizon 2020 project from the Optimisation of Medical Accelerators (OMA) network. The BCM operates at the fundamental mode of resonance which is tuned at the second harmonic of the beam repetition rate i.e. 145.7 MHz. It has been tested successfully with beam currents in the range of 0.1-10 nA for energies 230-70 MeV [5–7] and the resolution achieved was 0.05 nA. The beam current response is highly position-independent (0.03 %/mm up to 60 % of the beam pipe aperture) and beam-size-independent [5]. This was achieved using a 1 Hz measurement bandwidth digital system developed by PSI [8].

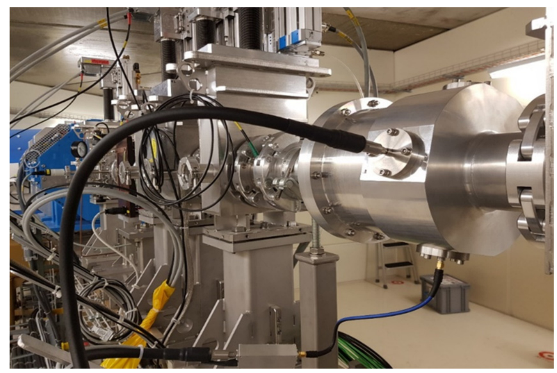

Figure 1: Prototype dielectric-filled re-entrant cavity resonator (BCM) installed at PROSCAN.

To take advantage of the BCM's fast response, a low-noise and wide-dynamic range digitiserr with a wider measurement bandwidth and various interfaces for the user and Control System integration purposes, the Libera Digit 500 provided by Instrumentation Technologies, was identified and customised. Digital down-conversion (I/Q demodulation) of the digitised signal was implemented in its FPGA. The resonator response as a function of beam current measured with the Libera Digit 500 (with 1 kHz refresh rate) is shown in Figure 2. The response is linearly proportional to beam currents higher than 0.5 nA with the same beam current resolution as before.

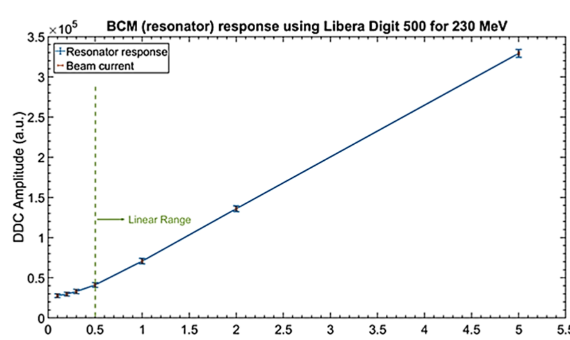

Figure 2: Prototype BCM response (in arbitrary units) measured by the customised Libera Digit 500. The beam current reference is measured using an IC.

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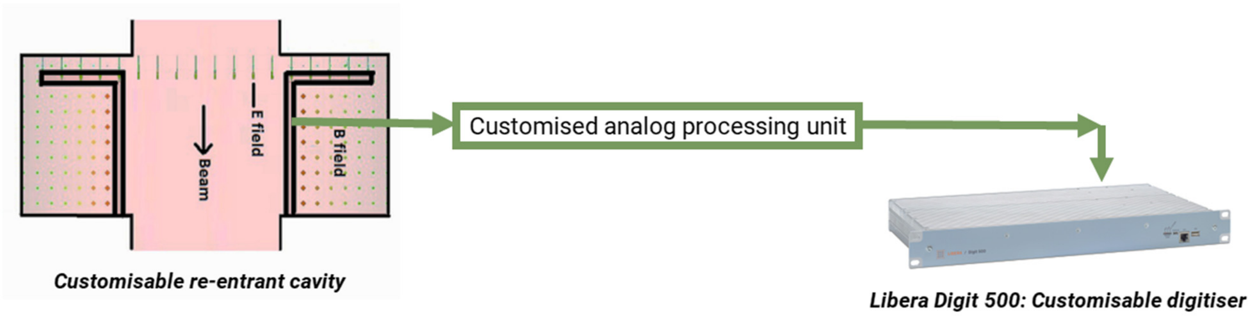

Figure 3:Graphical representation of the non-interceptive turn-key diagnostic system, CRCDS (Cavity Resonator Current Diagnostic System). The re-entrant cavity and the analog processing unit to be developed by Bergoz Instrumentation and the digital solution developed by Instrumentation Technologies.

NON-INTERCEPTIVE TURN-KEY DIAGNOSTIC SYSTEM

Bergoz Instrumentation will lead the collaboration with PSI, and Instrumentation Technologies to industrialise a non-interceptive turn-key diagnostic system, CRCDS (Figure 3).

The CRCDS solution will consist of a re-entrant cavity, analog front-end processing unit, and a digitiser with down-conversion and interfaces for the user and the Control System. All these components are customisable for a given user facility.

CHALLENGES IN INDUSTRIALISATION

The challenges associated in the industrialisation of the CRCDS solution are customisation of the re-entrant cavity and digital solution for each beam configuration (narrow-band signal), series production, medical facility integration, and a fast response digital solution with a large dynamic range.

Customisation of a cavity should not compromise on its compactness, performance (high accuracy and precision), and integration in beam transport lines, the key criteria needed in medical applications. This would help in the adoption of the system in different facilities but would affect the repeatability in series production.

Customisation of the digital solution should not affect the wide dynamic range, typically $\geq$ 80 dB, (corresponding to 0.1-1000 nA of beam current in medical facilities). Also, it is important for the digital solution to not compromise on the fast response from cavities for a given excitation.

Thus, the CRCDS solution must accommodate a compact diagnostic device with minimal customisation but maximum flexibility.

APPLICATIONS

Since cavity systems are known for providing an unsaturated response over a large dynamic range, the CRCDS solution is expected to be of useful application in charged-particle radiation therapy facilities, FLASH experiments, radio-isotope production facilities, etc. to name a few.

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