PROFILE GRID MONITOR AND FIRST MEASUREMENT RESULTS AT THE MEDAUSTRON ACCELERATOR

M. Repovz, A. Gyorgy, A. Kerschbaum, F. Osmic, S. Schwarz,
MedAustron GmbH, Wiener Neustadt, Austria
G. Burtin, CERN, Geneva, Switzerland

Abstract

MedAustron is a synchrotron based ion beam therapy center located in Wiener Neustadt/Austria. The MedAustron accelerator design is based on CERN's Proton-Ion Medical Machine Study (PIMMS) [1] and is currently in the accelerator installation and beam commissioning phase. One of the basic measurements for commissioning of an accelerator is also beam profile measurement.

The beam at the end of the Low Energy Beam Transport (LEBT) line and in the Medium Energy Beam Transport (MEBT) line (after the fast deflector) is pulsed. Due to pulsed beam the Wire Scanner Monitor (WSX) cannot be used. To measure a beam profile at these locations a new monitor has been developed – Profile Grid Monitor (PGX). The PGX is also known as harp grid monitor and it contains 64 wires positioned vertically and 64 wires horizontally for measuring the beam profile in both transverse planes. The PGX acquires the current of all 128 wires simultaneously, converts it to voltage, digitizes the values and processes the converted data. The last part of the PGX is a graphical interface for control of the PGX and the display of the beam profile.

INTRODUCTION

Precise knowledge of all beam properties such as position, profile and emittance is crucial for the commissioning of the accelerator and later on for quality assurance checks. Within MedAustron [2] the work-package "Beam Diagnostics" is responsible for providing all the required beam monitors [3].

Among all the beam parameters, the measurement of the beam profile is of paramount importance. As the beam at the end of the LEBT line and in the MEBT line is pulsed, the standard MedAustron wire scanner, which is designed for measuring the profile of a continuous beam, cannot be used. In order to obtain the beam profile of one single beam-pulse in both planes simultaneously, a new Profile Grid Monitor (PGX) was developed. At MedAustron the beam pulse length can vary between 20 µs and 100 µs (for testing purposes up to 500 µs) with energy between 8 keV/u at the end of the LEBT line and 7 MeV/u in the MEBT line. A beam center measurement precision of less than 100 µm is required. Because this paper deals mainly with measuring of the beam profile with the PGX, its moving mechanism will be mentioned only briefly.

The PGX is divided into three parts (Fig. 1):

- Mechanics
- Electronics
- Control

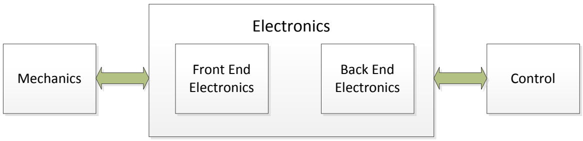

Figure 1: PGX readout block diagram.

MECHANICS

The mechanics (Fig. 2) moves the harp grid in and out of the beam trajectory. The single wires of the harp are charged up when hit by the beam. The resulting charge is then brought to the electronics via four ultra-high vacuum compatible signal feed-throughs.

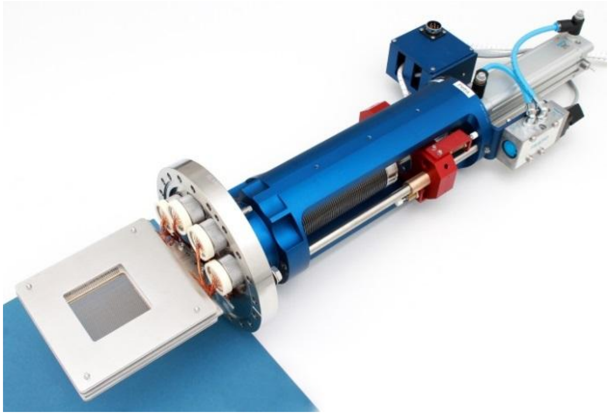

Figure 2: PGX mechanics.

As the PGX is used at two different machine sections two versions of ceramic frames (two different apertures) were developed. For the LEBT line a ceramic frame with 64 wires with a pitch of 1.7 mm to cover transversally 108.4 mm (PGX-A frame; left in Fig. 3) and for the MEBT line a frame with 64 wires and a pitch of 1 mm to cover the beam transfer size up to 64 mm (PGX-B frame; right in Fig. 3). For each aperture size vertical and horizontal frame is needed. The wires used for acquiring the charge are gold plated tungsten wires with a diameter of 100 µm.

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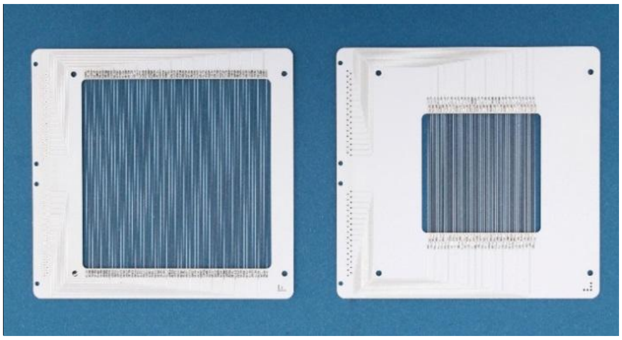

Figure 3: Horizontal PGX ceramic frame types; A type on the right and B type on the left side.

The routing on the ceramic frame is done with silver traces which also serve as pads for soldering of the tungsten wires. In order to achieve the required precise position of the soldering a special holding system was developed (see Fig. 4) for soldering the wires parallel to each other within 100 µm over 106 mm and fixed in position within 50 µm. Four different wire holding systems were developed for the four different ceramic frames.

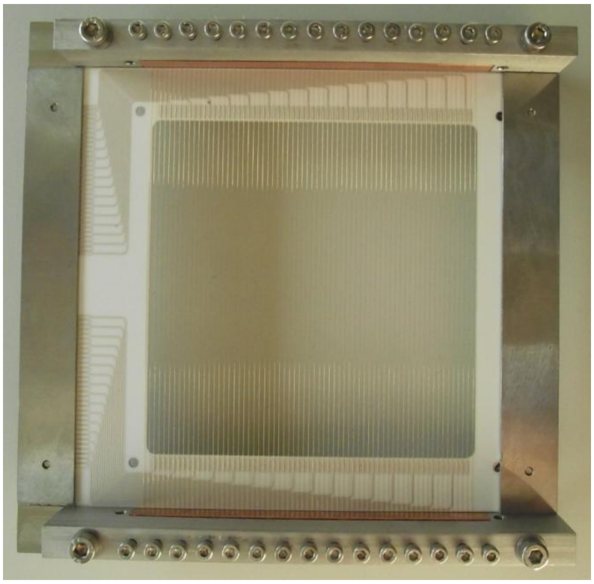

Figure 4: Holding system for soldering the wires on the PGX-A ceramic frame.

For soldering of the capton insulated copper wires which transfer the charge from the harp to the vacuum-side connectors of the through-hole technology is used. Ceramic wire holders are used to decrease the mechanical stress on the solder joints and thereby increase the lifetime of the PGX.

The pneumatic motion system moves the harp in and out of the beam trajectory. The motion system is connected to the interlock system to guarantee that the PGX is outside of the beam during the patient treatment. This system also checks for irregularities in air pressure, monitors the position and reports the overall status to the control system.

ELECTRONICS

The electronics of the PGX is responsible for converting the charge captured by the wires into voltage and amplification. The charge of all 128 wires has to be acquired simultaneously as the beam is pulsed. The beam profile can be acquired every 100 ms.

The electronics chain is divided into two parts:

- Front End Electronics (FEE) which is located next to the accelerator
- Back End Electronics (BEE) is located in the Data Center Room (DCR)

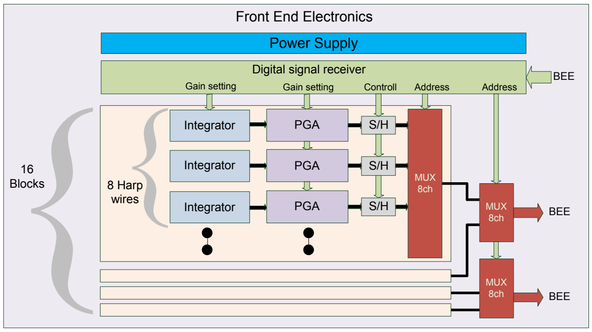

Figure 5: Block diagram of the Front End Electronics.

In the FEE (see Fig. 5) the first stage integrates the beam charge with an integrator that also converts the acquired charge into voltage. The integrator integrates during the “flat top” of the beam pulse. The integration time can vary between 30 µs and 500 µs. The integrator (integrated circuit) has a switch in the feedback loop for selecting desired capacitor value for integration. The capacitor value is one of the gain factors in the whole PGX chain.

The second stage is mainly responsible for the amplification by a programmable gain amplifier (PGA) where the input voltage can be amplified by factor 1, 2, 4 or 8.

The last stage of the FEE is a sample and hold circuit (S/H) and a two stage multiplexer. The S/H holds the voltage values while the multiplexer switches between different channels (128 wires) and the DAQ converts them.

For beam pulses longer than 100 µs two consecutive measurements on each channel are performed to compensate the error that occurs due to charge injection introduced by the switches in the integrated circuit. Oversampling with at least factor of 10 lowers the noise levels. The first measurement is called “zero measurement” and is done before the beam pulse, and serves as the reference measurement. The second measurement is the actual measurement, called “current measurement” where the charge from the beam is acquired only during the flat top of the beam pulse. The zero measurement readout of all 128 channels is done while the integration of the flat top is performed. For beam pulses shorter than 100 µs the zero measurement cannot be performed. The minimum beam pulse length to perform the zero measurement could be lowered with

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faster S/H circuit, multiplexors and lower number of samples. However this is not needed as with beam pulses shorter than 100 µs only crude profile measurements are performed.

The BEE (see Fig. 6) is responsible for conditioning the digital and analog signals that come from and are sent to the controller card. A manual check of the readout (e.g. using an oscilloscope) is possible via SMA connectors on the BEE. The actual signals for the manual readout are provided by the controller card therefore the BEE provides only the interface. One BEE is designed to support 4 FEEs.

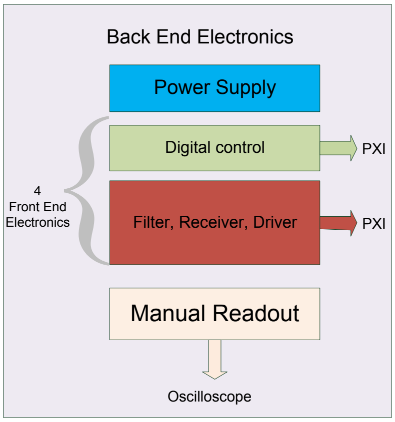

Figure 6: Block diagram of the Back End Electronics.

The PGX needs individual calibration of all 128 channels. From the tests it was evident that the two biggest errors are offset and capacitance value in the integrator's feedback loop. It was concluded that the errors are reproducible so they can be mostly compensated.

CONTROL

Control of the electronics is done in real time with a National Instruments R-series PXI FPGA card installed in the PXI crate and is programed using LabView. The FPGA on the card is a Xilinx Virtex 5 with a 40 MHz clock. The card also contains differential input DAQ which acquires and converts analog voltage values.

The FPGA card was selected to control the high speed digital signals (address bus of the multiplexors, integrator switches and S/H circuit) with the time resolution of 25 ns. The control of these signals is synchronised with the main timing system of the accelerator. The integration of the beam current is initiated only 1 µs after the beam pulse rise time and has to stop before the end of the bunch. The length of the beam pulse has to be predefined depending on the beam current to not saturate the integrator. The low speed digital signals (PGA amplification, selection of the integrator's capacitor) are also controlled with the mentioned card.

The calculation of the current is described in equation (1) where V_{in} represents the input voltage to the DAQ, C_{int} is the integrator's capacitance, A_{PGA} is the PGA's amplification factor and T_{int} is the integration time. The formula theoretically states that infinite gain options are possible as time is one of the parameters. In the case of MedAustron 4 gain factors were chosen to cover the whole beam current range (Table 1).

$$-I = \frac{V_{in} \cdot C_{int}}{A_{PGA} \cdot T_{int}} \tag{1}$$

Table 1: PGX Gain Settings

Gain setting	Integration time (s)	Max wire current (A)
1	450 µ	20 n
2	190 µ	1 µ
3	170 µ	13 µ
4	30 µ	200 µ

The front end controller is also responsible for the compensation of the errors. The measured values of each channel are compensated with the calibration factors obtained during the calibration.

MEASUREMENTS AND FIRST RESULTS

An example of one wire measurement for prototype testing can be seen in Fig. 7. In this example the S/H circuit is disabled as only one channel was measured.

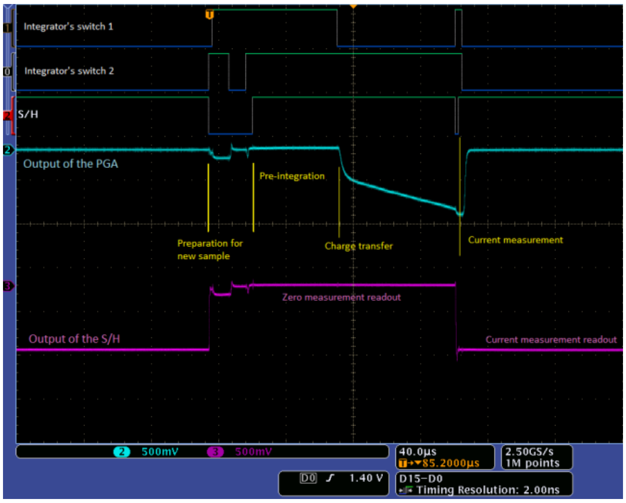

Figure 7: Sequence representation of measuring a channel.

"Preparation for new sample" is the first stage in a measurement where the integrator and its capacitors are discharged. The second stage consists of "pre-integration" and "charge transfer" where in parallel the "zero measurement" is done; charge injection value is acquired by S/H and sent via multiplexor to the DAQ. In the third stage the charge acquired by the PGX harp is transferred to the integrator's feedback capacitor and the integration continues. At the end the "current measurement" is done.

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After the calibration the differences between the channels measured in the laboratory were below 1% which fulfils the requirements for the profile measurement.

The commissioning of the injector at the MedAustron Injector Test Stand (ITS) at CERN was done with the prototype PGX. One of the measurements with the prototype system can be seen Fig. 8.

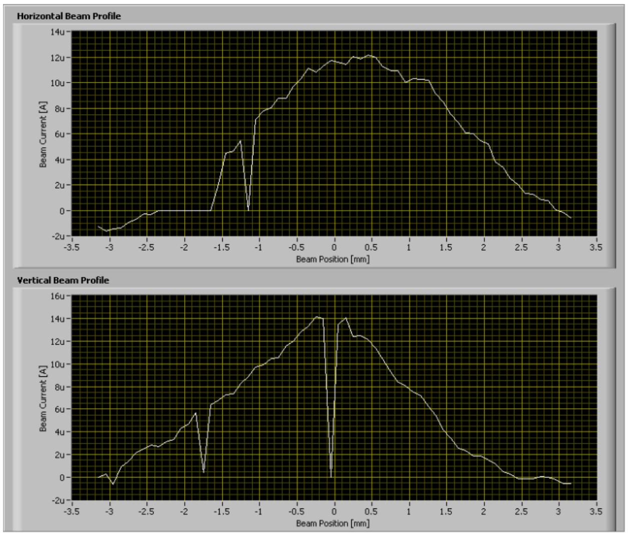

Figure 8: Beam profile measurement with the PGX prototype.

As it can be seen not all channels were working at the time. For the horizontal profile one of the cards had a problem with the power supply and the jumps that can be seen in the profile are due to broken connections of the silver deposition on the ceramic frames. As an improvement, the control software has been modified so that a channel can be disabled and current can be interpolated for beam center calculation in case a wire of the harp breaks or an analog channel malfunctions.

CONCLUSION

The PGX monitor meets the requirements and is ready for beam commissioning of the MedAustron injector.

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