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DEVELOPMENT OF A NEW MEASUREMENT SYSTEM FOR BEAM POSITION PICKUPS IN THE LINAC AND BEAM ENERGY MEASUREMENT (TIME OF FLIGHT) IN THE MEBT FOR MedAustron

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Abstract

The MedAustron Ion Therapy Centre is a synchrotron-based particle therapy facility which delivers proton and carbon beams for clinical treatment. Currently, the facility treats roughly 44 patients per day and is improving its systems and workflows to further increase this number. MedAustron was commissioned and is operational without fully integrated systems for measurements of "time of flight" (beam energy) in the MEBT and beam position in the LINAC. This paper presents the newly developed system for these use cases, which will improve the overall commissioning and QA accuracy. It will unify the hardware used for the cavity regulation in the injector low level radio frequency system LLRF and the synchrotron LLRF. It will furthermore be used for SYNC pickups, Schottky monitors and the RF knock-out exciter. The new system is based on the CotS MicroTCA platform, which is controlled by the MedAustron Control System based on NI-PXIe. Currently it supports fiber-optic links (SFP+), but other links (e.g. EPICS, DOOCS) can be established. The modular implementation allows for integration with other components such as motors, amplifiers, or interlock systems and will increase the robustness and maintainability of the accelerator.

INTRODUCTION

After the Low Energy Beam Transfer (LEBT) line the beam is pulsed (with an electrostatic deflector) and accelerated with an RFQ and an Interdigital H-Mode Drift Tube Linac (IH-DTL) cavity (part of the linear accelerator) followed by the Medium Energy Beam Transfer (MEBT) line. Starting after the IH-tank and continuing along the complete MEBT line the Phase Probes (PHPs) for beam energy measurements are placed (4 locations in total) whilst to determine the beam position a Four-Button Probe is located at the entrance of the IH-tank.

These measurement devices are now integrated into a new system that has been developed in collaboration with Instrumentation Technologies.

The developed system description and operation will be elaborated, followed by the first measurement results and concluded by the advantages and disadvantages of the selected implementation as well some short information about the outlook.

SYSTEM DESCRIPTION

For the readout electronics and data processing an off the shelf piece of hardware has been selected. One of the requirements was the need to use the same electronics for beam position measurement with the pickups in the LINAC, beam energy measurement (Time of Flight) as well as Injector LLRF [1].

The hardware selected is based on the MicroTCA.4 architecture for which Vadatech is the company that provides all the needed components. The crate foreseen to be used for the complete injector system is presented in Fig. 1 with all its connections.

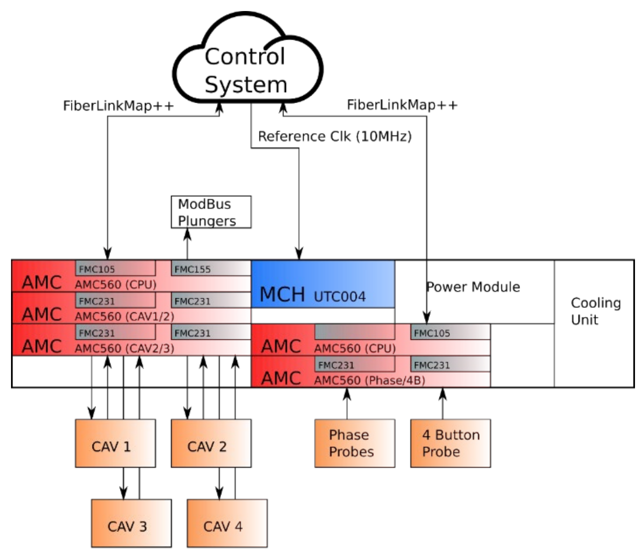

Figure 1: The MicroTCA crate and its connections.

For the four Phase Probes one FMC231 card [2] is needed and for the Four-Button Probe an additional FMC231 card on the same AMC560 card [3] is required. For communication with the MedAustron control system a proprietary protocol on FiberLinkMap++ is used which goes via SFP+ optical connection on a second AMC560 card equipped with a FMC105 card [4]. The other AMC560 cards with an MC231 and an FMC105 are to be used for the injector low lever RF.

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OPERATION

In this paragraph operation of the system is presented (Fig. 2).

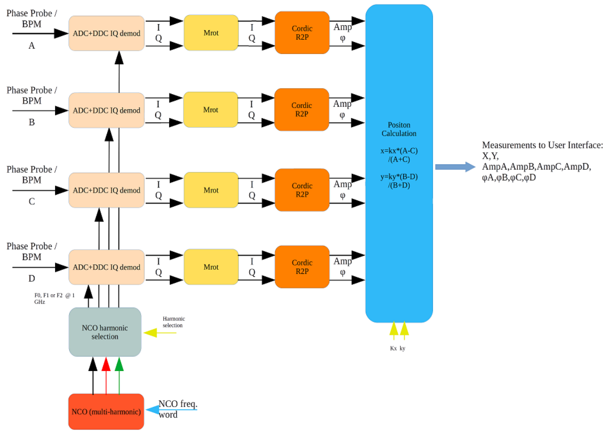

Figure 2: Block Diagram of the Digital Signal Processing scheme used.

With the relatively low Linac frequency of 216.816 MHz, a direct sampling approach is used. The RF signals generated by the Phase Probes and the Four-Button Probe are amplified in close proximity to the probes, sent to the MicroTCA crate and digitized without any specific analog front end. The same group delay for all probes is ensured by using exactly the same cable lengths and amplifiers.

After the direct sampling analog to digital conversion the signals are converted to baseband by downmodulation with a numerically controlled oscillator. The resulting in-phase and -quadrature signals are then filtered in multiple stages and converted to amplitude and phase information individually for each Phase Probe or each button of the Four-Button Probe.

Knowing the distance between the Phase Probes the phase information gathered in the previous steps can be used to calculate the velocity of the particles and from there the energy of the particles.

On the other hand, the amplitudes measured by the Four-Button Probe can be used to calculate the position of the beam inside the beam pipe. The basic assumption for this calculation is that the two opposing buttons generate the same amplitude signal if the beam passes exactly in the center of the beam pipe.

MEASUREMENTS

The Time of Flight measurements shown here were acquired during an amplitude scan of the IH-DTL. The results show a good energy resolution but also multiple issues with the beam, which remain to be investigated. First, the currently used LLRF + amplifiers do not properly regulate either amplitude or phase in the IH-DTL, resulting in a huge energy variation during single pulses. Second, with different energy outputs of the IH-DTL, the phase of the debuncher located between the second and the third phase probe has to be adjusted. As this wasn't done during the amplitude scan, the debuncher changes the energy considerably for some IH output energies.

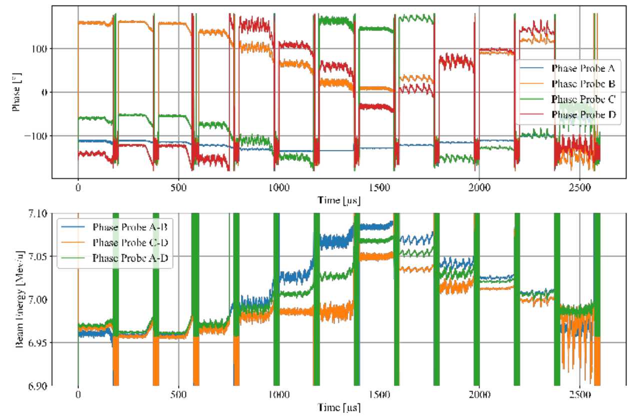

Figure 3: Phase measurements of the 4 Phase Probes available (Top); Calculated Particle Energy (Bottom).

For the position measurements the first results are not as promising as for the ToF measurements. First of all, a lot of crosstalk was seen from the IH-DTL (the Four-Button probe is directly mounted at the entrance of the IH). Therefore the presented measurements were taken at the second harmonic. The second issue found is that the calibration data for the used probe is outdated and questionable. Currently it is unknown if this calibration was never measured or if the data was lost in the last ten years without using this measurement device. Unfortunately without valid calibration data it is unknown which difference between the two opposing probes corresponds to which absolute position offset.

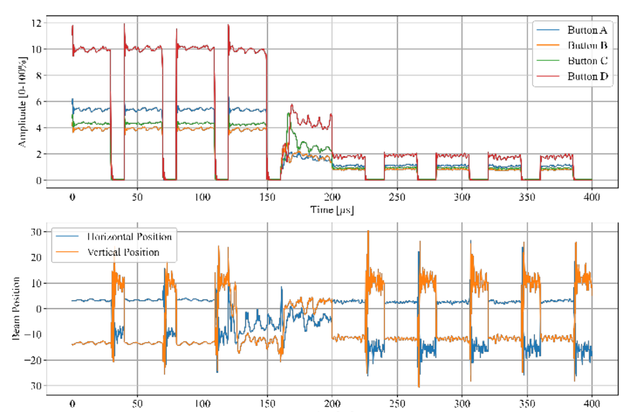

Figure 4: Amplitude Measurements of the 4 Buttons in the BPM measured at the 2nd Harmonic (Top); Beam Position without proper scaling (Bottom); Particle Species changed after 200 µs.

SUMMARY

The system is already in use for beam verification and is being used for Helium beam commissioning [5]. With the first measurements performed some unexpected beam behaviour was observed which needs to be further investigated.

The operation (measurements) is currently only possible via a local web interface (see Fig. 5). To have the system available via the MedAustron Accelerator Control System (MACS) some integration work is needed, which is foreseen as a next step.

Figure 5: Amplitude and TOF measurement with “local” web user interface.

To measure beam position of the IH-DTL and TOF a manual procedure which involved corrections and had errors was used. With the new measurement system this is simplified and makes the four-button probe and phase probes much more usable.

OUTLOOK

The platform selected is also foreseen to be used for measurement of the beam position in the Synchrotron where shoebox pickups are installed. The beam position measurement itself has already been proven, thus (if needed) an adaptation to a new electrical interface will be done. In addition, the same hardware is foreseen to be used also for Schottky pick-up measurements as well as synchrotron low level RF (LLRF) and RF knock-out extraction. A simplified block diagram of the synchrotron LLRF with the position feedback from the shoebox pickups is presented in Fig. 6.

Having the same hardware for all the mentioned systems will bring a reduction of operational costs by having a lower number of different hardware components in use. This will drastically lower the number of different required spare parts as well as number of hours spent on trainings for different components.

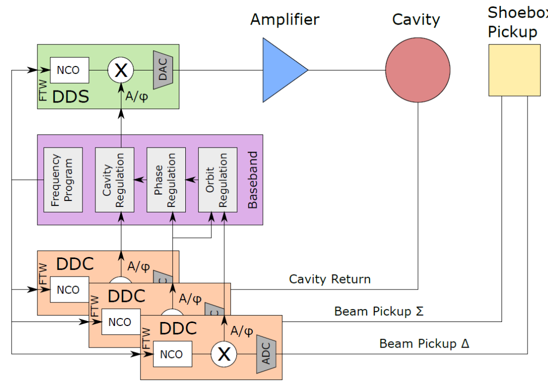

Figure 6: Block diagram of Synchrotron LLRF in connection with Shoebox pickup.

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