

UPGRADING THE BEAM DIAGNOSTIC OF THE HZB-CYCLOTRON FROM AN ANALOGUE TO A NEW DIGITAL PLATFORM

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Abstract

The HZB-Cyclotron delivers since a long time reliable beam for experiments and Proton Therapy. Now the old analogue beam diagnostic is outdated and hard to maintain. We developed a digital replacement for the multiplexers for 30 Faraday cups and 12 beam profile monitors. Both use as hardware platform a single-board-controller with FPGA-technology with integrated analogue and digital signals in a client-server architecture. Here we present the new features after more than one year of operation.

MOTIVATION FOR THE NEW MULTIPLEXER DESIGN

A layout of the accelerator complex can be found in [1]. Two injectors serve the k=130 isochronous sector cyclotron. One high energy beam leads to the treatment room and one to the experimental station. Overall, 27 Faraday cups and 10 beam profile monitors (BPM) are installed. The beam diagnosis system dates to the eighties, when the accelerator complex was erected. As more and more Faraday cup channels in the analogue cup current system failed due to contact problems in the wire-wrap cabling, a replacement system had to be designed and constructed.

In order to keep the financial effort for the new system in the accelerator within limits, it was decided to use also in the future the excellent working existing current transformers (I/U converter with 5 ranges from 1 nA to 10 μ A full scale) and cabling between measuring points and multiplexer. The converters had been developed in-house and can still be easily repaired. Furthermore, they are working very reliable

One of the challenges for the conversion from the old system to the new design was that it had to be done without impacting on the scheduled beam time, especially not interfering with the scheduled proton therapy blocks. Thus, the installation and commissioning of the new system had to be carried out in just one service period of two weeks. Hence, the new design was developed in a separated setup.

LAYOUT OF THE NEW FARADAY CUP MULTIPLEXER

The following features were described as minimum demands:

- at least 24 channels for Faraday cups and radial probes available
- an auto range feature switching to the active Faraday cup channel in the optimum range of the I/U-converter automatically.

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- the choice to select a fixed range of a selected Faraday-cup channel to display
- two simultaneously measured channels with all information, as both injectors are sometimes operated in parallel
- readout of the I/U-converters with a sampling rate of 10 kHz and processing these data to provide information about the mean value, minimum, maximum, and the standard deviation
- display of the processed values to the operator (Min-Max-Mean-Standard Deviation)

Figure 1 shows the data of a Faraday cup as displayed in the control room. The operator sees which Faraday Cup or radial probe is selected, the range of the I/U converter, the beam intensity of 0.36 μ A, the minimum value of 0.32 μ A, maximum value of 0.4 μ A and a standard deviation of 3.8%. Beam tuning is now easier, especially when aiming for high beam stability, i.e., low standard deviation. Two graphs in the lower part provide the history of the past 100 s. The upper graph shows mean, maximum, and minimum beam intensity. The lower part shows the standard deviation. All these data are updated every 100 ms. The dip in the minimum beam intensity and the rise in the standard deviation shows the influence of a beam profile monitor to the beam: The rotating wires cut a small section of the beam, such influencing the standard deviation quite a lot, while the mean beam intensity is scarcely affected.

For the off-line development of the Multiplexer, 15 I/U converters with current sources were set up. Some of the current sources were connected to function generators to simulate beam instabilities. Thus, the programming of the FPGAs and LabVIEW could be done without using beam time.

The layout of the new system is shown in Fig. 2. The backbone of the system are two sbRIO9637 FPGA boards from NI which are connected via a new backplane interface to the existing I/U converters. All the analogue input signals are sampled simultaneously with a sampling rate of 10 kHz. Every 100 ms the 1000 values of each channel are streamed via TCP-IP to the server, where they are processed to provide the desired values: mean, minimum and maximum beam intensity, and standard deviation

The communication between the server and the display PC is done via EPICS communication. Thus, we use in LabVIEW the CA Lab interface [2], which converts Lab-

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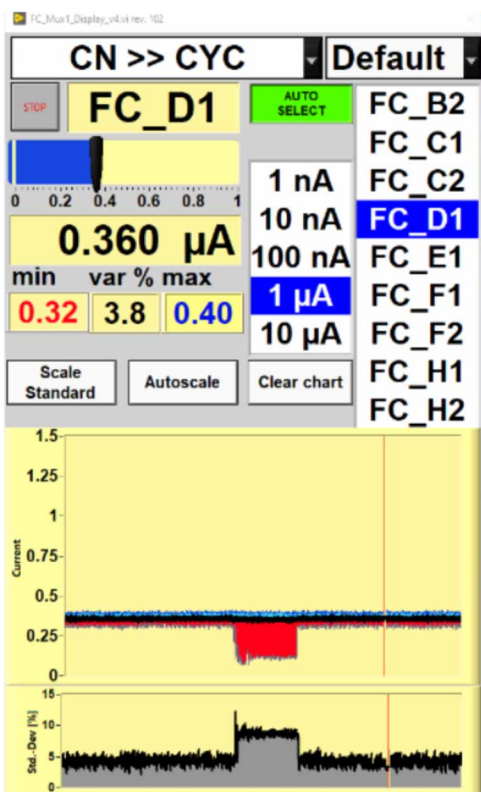


Figure 1: Display showing relevant data of the selected channel (name, range, value); the upper graph shows mean (black), maximum (blue), minimum value (red); the lower graph shows the standard deviation. The graphs show the history of the last 100 s and are updated every 100 ms.

VIEW data to EPICS variables and vice versa. Thus, the server and display-PC only have to be in the same VLAN to exchange data.

Three Multiplexer channels are available: One for the beam line from the Van-de-Graaff injector to the cyclotron, one for the beam line between the Tandatron injector and the cyclotron and one for the high energy beam line. In addition to the required features, an oscilloscope display and alarm processing has been implemented. In the oscilloscope mode the raw values without processing are displayed, meaning that they are displayed with 10 kHz. For example, a 50 Hz periodic noise on the signal becomes visible. This helps when error tracking, e.g., hunting for a noisy power supply. The operator may now also set alarm thresholds for minimum and upper limit of the beam intensity. This is mainly used when the accelerator is in standby. When the beam drops below the threshold or surpasses the upper value an acoustic signal alerts the operator

LAYOUT OF THE NEW BEAM PROFILE MULTIPLEXER

After the successful implementation of the new Multiplexer system for the Faraday cups the idea was close to use the same hardware for the BPM multiplexer. It has only one new backplane interface and sbRIO9637. One further server processes the data and runs a softIOC to transfer the BPM-data as EPICS process variables.

Three out of 16 BPM's can be displayed simultaneously. The distribution of the BPMs to the displays is chosen in such a way that the focussing in dedicated beam line sect-

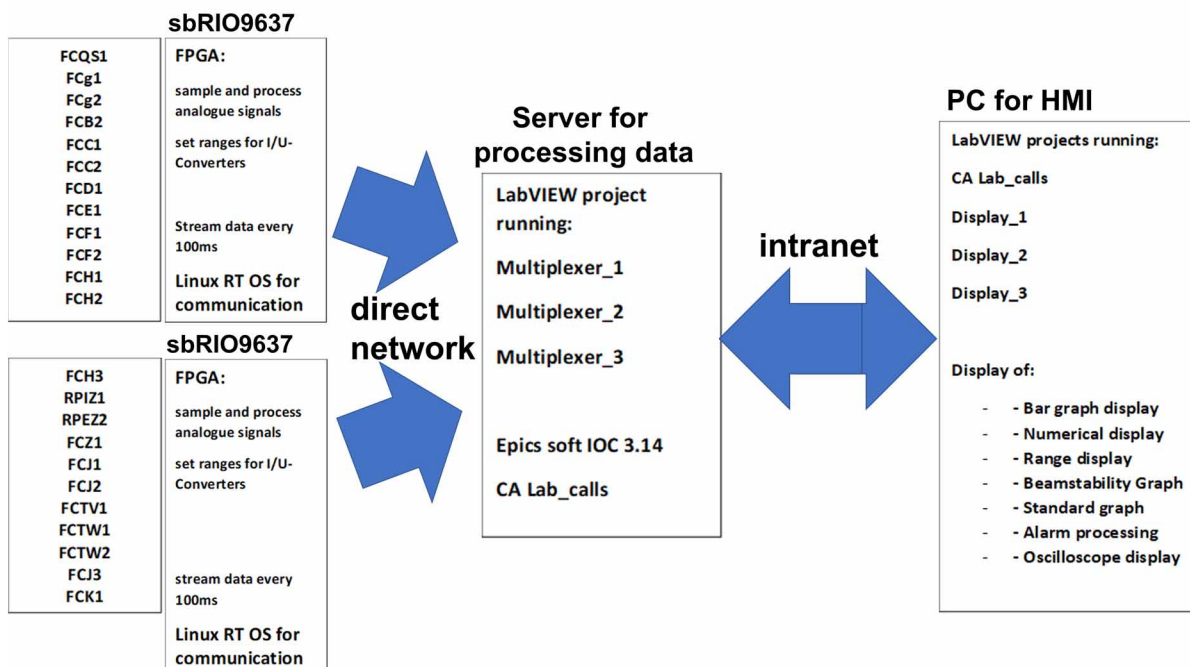


Figure 2: Layout of the new Faraday-cup Multiplexer. There are two FPGA-boards (sbRIO9637 from NI) with a new backplane interface to the I/U-converters. Continuously all analogue input channels from the FPGAs are sampled simultaneously with 10 kHz, after 1000 values each channel values is processed (calculating standard deviation, and mean value, searching for minimum and maximum). These values are streamed to the server via TCP-IP. There, in three separated LabVIEW-projects the streamed data are converted back to current values. Via digital outputs of the FPGAs the range setting is obtained. The processed data are sent to the PC in the control room as EPICS-variables.

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ions is visible. They are updated with 25 Hz, each profile consists of 400 points.

One example is shown in Fig. 3, which displays the focussing after the Van-de-Graff. Beam line calculations requests focal points in the first and third BPM, while the beam is broader in the middle.

It is now possible to save the BPM images and reload them for comparison of the focussing. This reference signal from the same BPM can be overlaid to the live signal, allowing easy beam correction. This is especially important for the last BPM in front of the cyclotron: At this position, the fringe field of the main magnets influences the beam path. For this reason, the beam, especially when using light ions, is not on axis. The fringe field depends on ion species and energy. The ideal position for injection into the cyclotron varies with the above-mentioned parameters. In the past, it was the experience of the operators to identify a beam profile which allows good injection into the cyclotron. By reloading the beam profile of a beam with good injection transmission, the tuning becomes far easier.

CONCLUSION

The new multiplexers are running reliable since 2019. The overall investment was reasonable. The new functions for Faraday cups are very useful in fine tuning the beam stability in respect of focussing of the beam, adjusting phases and amplitudes of the RF-systems. The save-and-restore function of the BPMs is very helpful when comparing beam settings and is often employed. The use of nearly the same hardware set-up for both systems made the development easy and straightforward

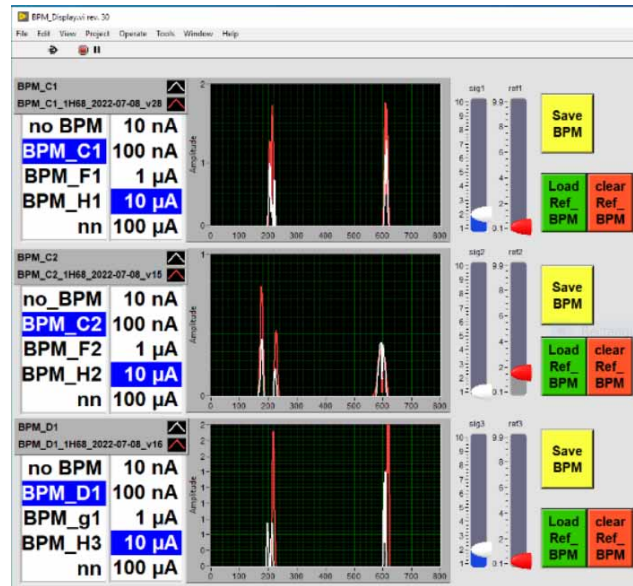


Figure 3: Display of the new BPM Multiplexer system. Up to three BPMs can be displayed simultaneously. Saved BPM images (red) can be overlaid to the actual profile (white). Each profile displays the cross-section of the beam in x- (left) and y-direction (right).

REFERENCES

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- [2] CA Lab, <https://www.helmholtz-berlin.de/zentrum/locations/it/calab/>