AUTOMATED BEAM OPTIMISATION AND DIAGNOSTICS AT MAMI*

M. Dehn, H. Euteneuer, F. Fichtner, A. Jankowiak,
K.-H. Kaiser, W. Klag, H.-J. Kreidel, S. Schumann, G. Stephan
Institut für Kernphysik, Johannes Gutenberg-Universität, D-55099 Mainz, Germany

Abstract

At the **I**nstitut für **K**ern**ph**ysik (IKPH) of Mainz University the fourth stage of the **Ma**inz **Mi**crotron (MAMI), a 0.855 to 1.5 GeV **H**armonic **D**ouble **S**ided **M**icrotron (HDSM), is now on the verge of first operation [1]. To provide an automated beam optimisation, low-Q-TM_{010} and TM_{110} resonators at each linac of the three cascaded **R**ace**t**rack **M**icrotrons (RTM) and the two linacs of the new HDSM are used. These monitors deliver position, phase and intensity signals of each recirculation turn when modulating the beam intensity with 12 ns-pulses (diagnostic pulses, 30 bunches, maximum repetition rate 10 kHz). For operating the HDSM an extended system for displaying and digitising these signals was developed. High-bandwidth ADCs with at least 500 MS/s and memory for digitising up to 256 kpoints allow very comfortable to analyse, calibrate and automatically optimise the beam positions and phases during operation. The system is also used to adjust the transversal and longitudinal focussing according to the design parameters. Synchrotron radiation monitors allow to display beam sizes and positions out of the bending magnets for each turn. Another synchrotron radiation monitor provides the shape of all turns superimposed at the common entrance of the beam into the dipole magnet after passing the linac axis. These monitors are very helpful tools for beam-matching between the RTMs. Therefore similar systems were planned and constructed for the HDSM.

INTRODUCTION

Beam Position Monitoring in RTMs

To facilitate stable acceleration and operation conditions the beam has to be centered on the linac axis which is controlled by means of suitable monitors.

Destructive monitors like simple screens cannot be used as all turns have to be considered and the beam would be lost after passing the screen the very first time.

Therefore non-destructive RF-resonators (TM_{010}- and TM_{110}-mode) at the entrance and the exit of the linac are utilised.

Under normal conditions (i. e. cw-operation) these resonators deliver a signal of all turns stacked on each other and no useful information can be extracted. But using 12 ns diagnostic pulses whose length is shorter than the time of flight for one turn this pulse train then excites the low-Q-resonator ($Q_L \approx 20$) with decay times of about 10 ns individually for each turn.

Under these conditions the signal of the RF-resonators can be digitised and analysed to obtain turn-by-turn position information. These data can be used to compute the required currents of the steerer magnets.

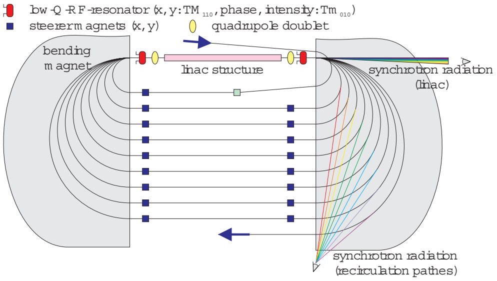

Figure 1: RTM - schematic view shows the typical arrangement of diagnostic elements in a microtron.

Overview MAMI

The situation at MAMI is more complex. There are three cascaded RTMs and the new HDSM is on the verge of operation.

There are RTM1, RTM2 and RTM3 which deliver six signals each (4× position, 1× intensity and 1× phase signals have to be considered) and the HDSM alone contributes 16 signals (2 linacs contribute 8 signals each) as shown in Fig. 2.

The acceleration process takes about 300 ns in RTM1, 3 μs in RTM2 and 10 μs for RTM3 and HDSM each. If the next diagnostic pulse is triggered after the previous one has left the machine (i. e. after about 25 μs) the signals will not overlap.

One specific feature of the HDSM is the acceleration with two linacs. The signals of both linacs can be treated separately but can also be added to reduce the number of signals to be digitised.

Implementation

To avoid the overhead of using individual ADCs for the signals of each RTM and to provide a convenient display a fast multiplexing equipment was developed to show the signals of RTM1, RTM2 and RTM3 consecutively and only six ADC-channels were required to digitise the relevant data.

---

* Work supported by DFG (SFB443) and the German Federal State of Rheinland-Pfalz

Now there are even more signals of the HDSM which could not be dealt with the equipment. Therefore a redesign of the old (and unflexible multiplexer) was accomplished taking into account that still only six ADC-channels should be sufficient.

The multiplexing equipment consists of three main parts:

- A time multiplexer that advances the beam signals synchronously to the acceleration process along the stages. The timing has to be very accurate as the time of flight between RTM1 and RTM2 is about 100 ns.
- A programmable crossbar switch distributes the desired signals to an arbitrary combination of any of six available ADC-channels connected to the multiplexing equipment. In addition the crossbar switch is fast enough to supply individual signal pathes for each diagnostic pulse thus being able to use only *one* ADC-channel in case of failure of ADC modules.
- To display the signals to the machine operator simultaneously the oscilloscope multiplexer selects one signal and adds its associated offset voltage after each diagnostic pulse. This cycle repeats with the trigger frequencies up to 10 kHz signals as shown in Fig. 3 can be provided.

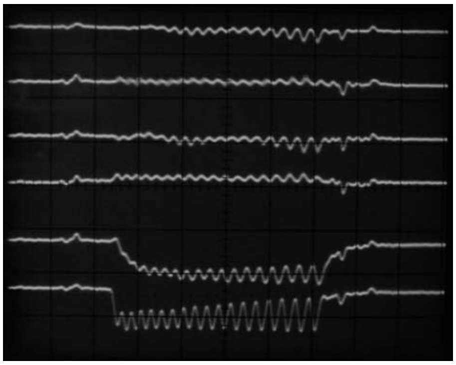

Figure 3: Signal peaks of RTM1 (18 turns) with “multichannel visualisation”: 4× position, 1× phase (signal shows the shift of the synchronous phase) and 1× intensity from top to bottom.

OPERATION

Most of the control is fully automated. Depending on the situation (i. e. during optimisation or error fixing) the operator decides which signals have to be analysed and the equipment is utilised at best.

Using state-of-the-art ADCs with multi-segment operation the data acquisition was improved significantly by triggering many pulses and averaging the raw signals. The current configuration provides up to 10 fully analysed data per second while averaging 20 diagnostic pulses.

As averaging potentially decreases signal bandwidth, the ADCs have to be triggered as synchronously as possible. If desired an electronically generated timestamp pulse can be added to the signals to provide even more timing information.

Data Analysis and Control System

When the raw ADC-data are available the analysis process first averages the data and then determines the exact position of each individual turn peak within the intensity signal by searching the maximum and then fitting a parabola to the data.

The area of every pulse is proportional to the according measurand, for example the position x:

$$x_i \sim \int_{T_i-\frac{1}{2}\tau_{dp}}^{T_i+\frac{1}{2}\tau_{dp}} u(t)dt \qquad (1)$$

where T_i denotes the vertex of the i-th peak of the intensity signal, τ_{dp} is the duration of the diagnostic pulse and $u(t)$ is the signal voltage.

As the area of the peaks is proportional to the beam intensity each integrated peak is then normalised to the corresponding intensity peak (resulting data displayed as bars in Fig. 4).

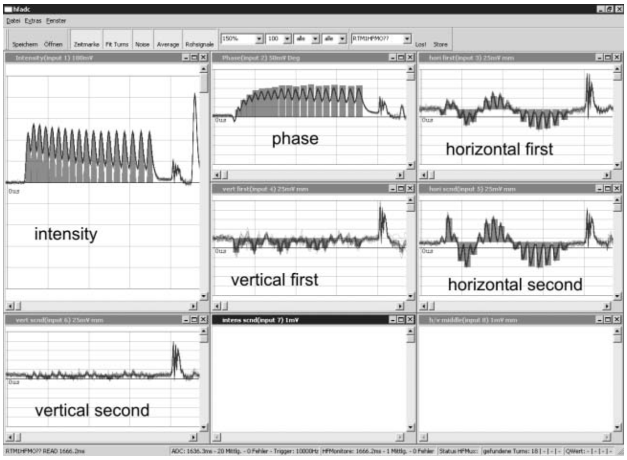

Figure 4: Analysis in progress (RTM1): The averaged signals are analysed. The position signals show the betatron motion of an unoptimised beam (The “bumps” at the right of all signals widgets are the multiplexer switching events).

Beam Optimisation and transversal Focussing

The position data are afterwards fed into a correction routine based on a simulation program [2] which computes the best steerer magnet setting for each return path considering the optics of the affected microtron.

To ensure reliability of this automatic optimisation the transversal focussing has to be controlled by exciting betatron motions in the desired plane and adjusting the quadrupoles on the linac axis accordingly to the required focussing.

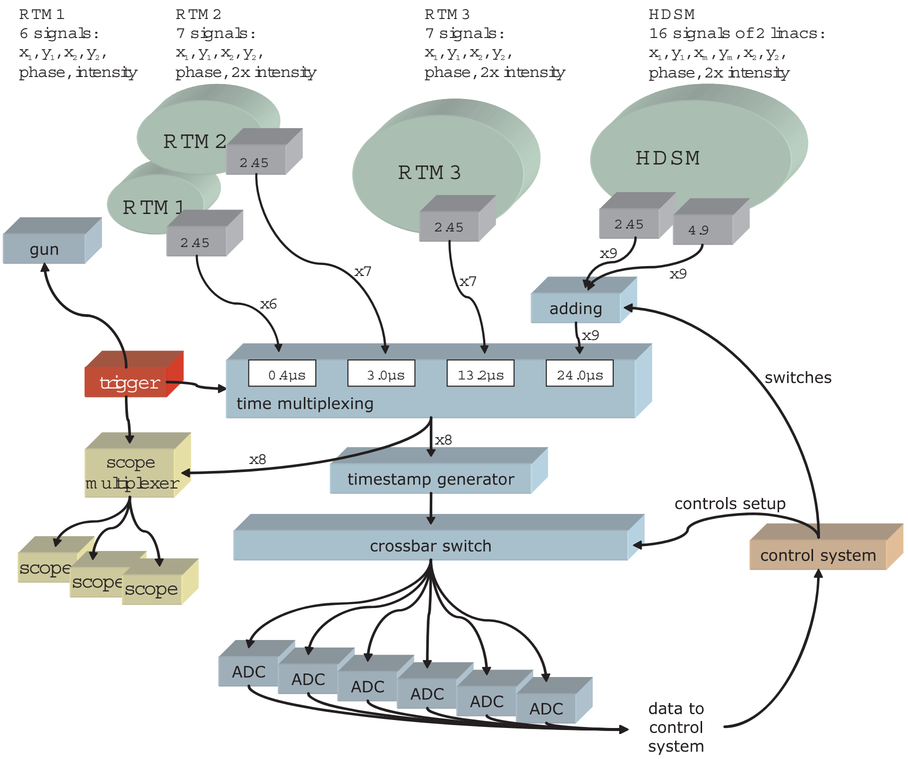

Figure 2: Schematic view of the signals of the low-Q-monitors: Processing starts after the trigger fires the gun. The RF-Signals of all microtrons are fed into the time multiplexer and distributed to the ADC-channels by the programmable crossbar switch. The machine operator observes the signals via the oscilloscopes. The control system selects the appropriate configuration and provides the analysed data.

Longitudinal Focussing

The longitudinal focussing can be adjusted in a matter of seconds by analysing the synchrotron motion in the concerning microtron by tuning the amplitude of the accelerating RF voltage.

Graphical User Interface

The software was completely revised and supports now a GUI to display the data processing online (i. e. the digitised signals along with the fitted data). Furthermore important parameters like timings or scalings can be configured and the results are available immediately as shown in Fig. 4.

SYNCHROTRON RADIATION MONITORS

After the beam positions have been optimised the synchrotron radiation monitors at the end of each linac (see Fig. 1) provide a very useful tool when the beam is significantly mismatched inbetween two stages. Disadvantageous focussing results in a rather defocussed shape of the beam (applies to both cw-operation and diagnostic pulses) as shown in Fig. 5. Drawback of this monitor is the superposition of the beamspots of all turns.

Another monitor displays the beamspots of all turns by means of different mirrors [3]. As all turns are displayed on only one screen the resolution is rather poor. For the HDSM the system was improved to use a pivotable camera which will display only one beam spot.

Figure 5: Matching with synchrotron radiation of RTM2: The main area contains the first 40 turns, turn 41 is deflected to separate the following turns using the betatron motion. Matching gets worse from left to right to demonstrate the usage ($i < 10\,\mathrm{nA}$).

REFERENCES

[1] A. Jankowiak et al., “Status Report on the Harmonic Double-sided Microtron of MAMI C”, this conference

[2] H.-J. Kreidel et al., “Automatic Beam-Steering of the Mainz Microtron”, Proc. of the 1981 Linear Acc. Conference Santa Fe, N.M., LA-9234-c, p.245, 1981

[3] H.-J. Kreidel, “Computer aided Beam Diagnostics and automatic Matching on the Mainz Microtron”, Proc. of the 1988 European Particle Accelerator Conference Rome, June 1988, Vol.2, p.1205, 1988