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BEAM DIAGNOSTICS AND INSTRUMENTATION FOR MESA*

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Abstract

For the new Mainz Energy recovering Superconducting Accelerator (MESA) a wide range of beam currents is going to be used during machine optimization and for the physics experiments. To be able to monitor beam parameters like beam current, phases and beam positions several different kinds of beam instrumentation is foreseen. Some components have already been tested at the Mainz Microtron (MAMI) and others have been used at the MELBA test accelerator. In this paper we will present the current status of the instrumentation.

INTRODUCTION

During different phases of operation (optimization, experimental beam time, machine test and diagnostics) the beam diagnostics systems have to deliver important information about the state of the accelerator. It may be helpful to selectively record rarely occurring phenomena with high time resolution while during experimental beam times the same monitors should deliver continuous data streams for offline data analysis.

In the following section the most important requirements to operate the accelerator and to provide important data for the experiments are presented.

Beam Diagnostics

The beam position relative to the reference particle can be described by three coordinates x, y and phase ϕ along with their corresponding x', y' and energy deviation ΔE to propagate the coordinates along the different elements of a beam line. It is also important to monitor the dimensions σ_x and σ_y of the bunch in each coordinate and the density distribution σ_ϕ and energy spread σ_E.

This can be achieved by using different kinds of beam monitors. A rough overview for the placement of beam position monitors (either screens or radio frequency monitors) and phase/intensity RF monitors is illustrated with red dots in Fig. 1.

The following sections will give an overview about the instrumentation at MESA.

Screens and Wire Scanners

At MESA different kind of screens will be used. The most important ones are installed within the MESA low energy beam line (MELBA). The design of the devices as shown in

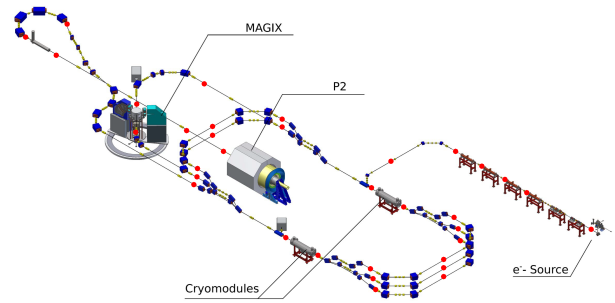

Figure 1: Placement of most important diagnostics at MESA. The red dots mark possible installation locations for diagnostic systems (screens, wire scanners, RF monitors).

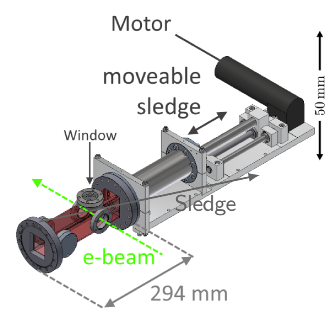

Figure 2: CAD drawing of the scanners used in MELBA to hold a view screen and wires from profile measurements.

Fig. 2 combines a view screen (luminescence or transition radiation) and wires to be able to image the beam spot and measure the dimensions with a very good resolution [1].

Radio Frequency Monitors

Bunched beams induce electromagnetic fields along the beam pipe which can be used to monitor some beam parameters. To amplify the signal output usually cavities can be used where the beam excites resonant fields at harmonic frequencies of the bunch repetition rate. To reduce the size of the installed cavities at MESA the second harmonic (i.e. 2.6 GHz) will be used.

RF cavity monitors have a limited time resolution depending on the loaded quality factor Q_L of the resonant system. Individual bunches cannot be resolved by such types of monitors, only short bunch trains with a minimum spacing of several 10 ns can be distinguished [2]. The signals also do not contain information about the distribution of the measured parameter (i.e. only horizontal position but not the horizontal beam size). It is not possible to distinguish the accelerated and the decelerated beam in CW mode.

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A single beam position monitor usually consists of two RF cavities (copper, aluminum, stainless steel) as shown in Fig. 3. Two cavities can even be replaced by a single resonator if the precision of the measurement is less important. The signal processing has to be split: amplification and mixing of the RF signals can be installed close to the cavity and digital data acquisition will have place in a shielded bunker area.

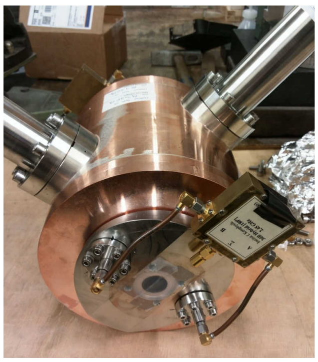

Figure 3: New prototype of the 2.6 GHz high Q cavity Beam Position Monitor for MESA developed and tested in house at MELBA [3].

Signal Acquisition

The RF signals have to be converted to lower signal frequencies to be further processed. This will be done by mixing with appropriate reference frequencies. If the reference frequency corresponds to the resonator frequency the resulting signals can directly be displayed on an oscilloscope but are more susceptible to noise pickup along the cables and stability of the relative phase between the reference signal and the beam phase. That will be the preferred method while MESA will be optimized after a fresh set up of the accelerator.

Using intermediate frequencies the final output signals are modulated with the difference of the reference and the beam frequency (in-phase and quadrature components: I&Q). The signals are much less susceptible against signal noise or other distortions but the wave form cannot be used to directly see the beam position when using an oscilloscope.

Both kinds of signal preparation have been studied and compared [3].

REQUIREMENTS DURING OPERATION AT MESA

Physics Experiments Operation (CW) The two main experiments (P2 and MAGIX) require continuous monitoring of the beam position and direction at the interaction point to reconstruct the trajectories at all times in order to meet their experiments precision goal. To deliver these data the RF cavity monitors have been chosen as they proved to be very reliable during the last decades at MAMI. For the P2 experiment a setup consisting of one intensity/phase monitor (for luminosity) and four BPMs to control the beam position via feedback loop are foreseen. Two additional monitors will measure the beam position independently of the stabilization system and feed the experimental data acquisition. The fundamental feedback system has been demonstrated at MAMI already [3].

A second system consisting of two intensity/phase monitors is planned to monitor the variation of the time-of-flight through a magnet system with longitudinal dispersion to measure and correct the short term beam energy fluctuations. Such an energy stabilization system at MAMI has been developed for the parity violation experiments of the A4 collaboration [4, 5].

Another very important system using an intensity monitor within the MELBA is used to stabilize the beam current at the highest possible bandwidth to compensate for the helicity correlated intensity fluctuations caused by the laser system. At the same time two BPMs might provide a position feedback also.

The MAGIX experiment will also be equipped with one intensity/phase monitor and at least two BPMs as well.

Pulsed Operation (during Routine Optimization of MESA) As a goal of beam optimization, the beam has to be centered all along the beam line. That is most important at the superconducting RF cavities to reduce the excitation of transversal higher order modes. This can be achieved by installing four BPMs (i.e. one in front of and another one behind each SRF cavity).

Using short but high intensity beam pulses of less than 50 ns length (bunch train) and low loaded Q_L type RF cavities the consecutive passes through the SRF cavities during acceleration and deceleration can easily be separated (approx. 200 ns time-of-flight (ToF) for one recirculation). The result will be four peaks for each signal at a distance corresponding to the time-of-flight for each recirculation and can be displayed easily on an oscilloscope or digitized for automatic processing. An example of how these signals will look like is given in Fig. 4.

The maximum bunch train length (or duration) is limited by two effects:

- If the pulse train duration reaches the ToF of a single recirculation it will not be possible to distinguish the signals of each turn.
- If the pulse train duration reaches the ToF of the full acceleration process the signals of the accelerated beam and the decelerated beam in ERL mode will also begin to overlap.

This limitation is valid for all RF cavity monitors being installed at any position along the recirculation lines where the beam passes more than once.

The maximum repetition rate of the bunch trains is limited by the time-of-flight for the complete acceleration and deceleration process (less than 1 µs) resulting in an upper limit of 1 MHz bunch train repetition rate.

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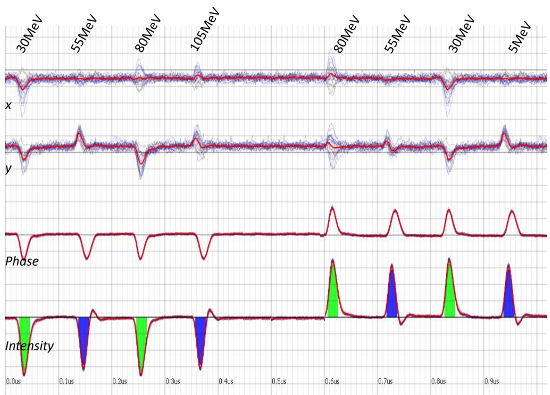

Figure 4: When MESA uses pulsed operation with 10 ns long bunch trains the signals of the main accelerator would look like shown here (a simulation). The picture shows the down converted signals of the BPMs and phase- and intensity monitors before each cryo module (green/blue: first/second cryo module) in energy-recovery mode (180° phase shift in the center).

Together with a new laser system being investigated at the moment [6] which can provide different programmable laser bursts while being synchronized to the accelerator RF it will be possible to ramp up the beam current from 0 nA (1 bunch per second) up to 50 μA (10^6 bunches per second) at full bunch charge (0.77 pC) with full information about the beam positions at each individual BPM.

Data Acquisition (DAQ) During experimental operation the signals of the RF monitors will be continuous and can either be converted to DC signals ($f_{\text{reference}} = f_{\text{BPM}}$) or modulated to an intermediate frequency. These LF signals can easily be acquired continuously using modern digitizing equipment.

The processed data can be used to stabilize the beam parameter with feedback loops and for the experimental data acquisition [3]. This can either be a free-running DAQ or in the case of fast helicity switching for the P2 experiment an externally synchronized DAQ.

During pulsed operation the requirements are different. All signal peaks occur after a fixed time-of-flight after the bunch is emitted by the electron gun (+/- a few degrees phase, i.e. a few picoseconds).

All components of the DAQ (digitization or display on a scope) must fulfill the requirement of ”less than 0.2 ns” jitter relative to the external trigger to avoid a broadening of the acquired signals which could be learned from the MAMI accelerator beam diagnostics.

Modern ADC systems promise trigger jitter/resolution as low as 25 ps / 50 ps like from Teledyne SP Devices [7] or Libera/Instrumentation Technologies [8] and can be used as a DAQ for automated beam alignment.

The combination of ADC with FPGA will help to reduce the amount of data presented to the operator by automatically analyzing the acquired data (base line subtraction, pulse identification/characterization) and only displaying the beam position/deviation in physical units. After this drastic data reduction further processing can be easily achieved using slow software controls for automatic/assisted beam optimization.

Beam Current Measurements

To measure the absolute beam current a DC-DC current transformer (”Förster probe”) can be used. Such a device is already available from MAMI. The best location will be close to one of the SRF cavities of the main accelerator where multiple beams sum up and increase the resolution of the measurement. The precision of the present device is in the order of a few 100 nA for a single beam passing it. If the beam passes multiple times the sensitivity increases accordingly.

The low bandwidth of smaller than 1 Hz is enough to monitor the beam current continuously but cannot be used for feedback loops to compensate helicity correlated intensity fluctuations. However, the RF cavity intensity monitors presented above can be calibrated using the DC-DC current transformer.

CONCLUSION AND OUTLOOK

With the current research and development MESA will be equipped with a functional instrumentation to operate reliably during experimental runs and machine optimization. Most of the equipment already proved the functionality at the MAMI accelerator also at Johannes Gutenberg-University.

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