HEBT DIAGNOSTICS FOR COMMISSIONING, CONTROL AND CHARACTERIZATION OF THE IFMIF-EVEDA ACCELERATOR

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Abstract

The beam diagnostics system in the High Energy Beam Transport (HEBT) line [2] of the IFMIF-EVEDA accelerator [1] will be responsible of the beam transport up to the beam dump, and the control and characterization of the 9 MeV high-current deuteron beam delivered by the Half Wave Resonator cavity (HWR). The layout of the diagnostics devices along the line and the challenging issues that will be faced due to the especial requirements of the accelerator are discussed in this paper.

INTRODUCTION

The ion source and the low energy beam transport line, the RFQ and the HWR cavities represents the essential components which deliver the outstanding properties of the IFMIF-EVEDA beam. However, the reliable operation of the HEBT is crucial for the validation and safe work of the IFMIF-EVEDA accelerator. Therefore, the necessary beam diagnostics devices for a safe operation and validation of the high intensity beam will be developed in parallel. These diagnostics will be located essentially along the HEBT, which will contain the Diagnostics Plate [4] for the characterization of the beam and other important devices for the beam control and transport. The design of the diagnostics of this beamline will face several challenges, coming from the delicate high-intensity low-energy beam operation. Hereafter, the diagnostics that will be installed to attain these goals will be detailed, and a brief explanation of the main design issues will be given.

DIAGNOSTICS LAYOUT

The positions of the diagnostics along the line are determined by the beam transport conditions: beam mismatch, halo generation or beam positioning. The monitors on the line are: DC and AC current transformers (DCCT and ACCT) to measure the DC and AC beam current fluctuations and external noise; Stripline Beam Position Monitors (SBPM), to measure the position, the mean energy by Time Of Flight (TOF), and the bunch length and longitudinal emittance with buncher scans (BS); transverse profile monitors (TPM), based in ionization (BTPM) or fluorescence (FPM), which will be also used to measure the transverse emittance with quadrupole scans (QS); halo monitors, like segmented rings (SHM), either for control or characterization of the halo; and beam loss monitors (BLM). Figure 1 shows the position of the main diagnostics devices. The diagnostics for validation are grouped in the first of the line on the Diagnostics Plate, in order to precisely characterize the beam from the HWR. Due to the relatively long length of the beamline, the beam optics parameters are changing along the HEBT (Tab. 1).

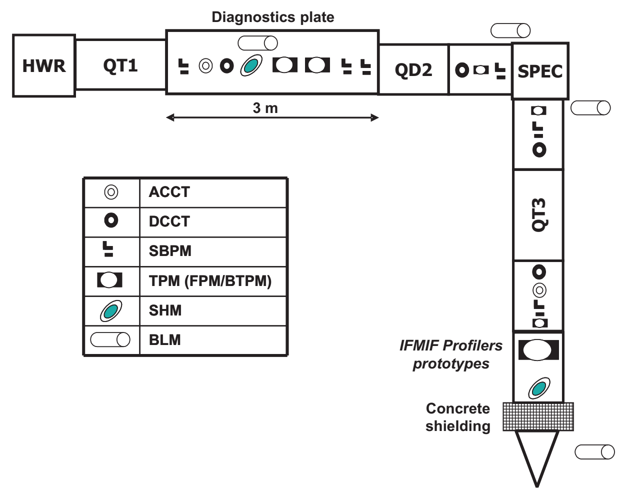

Figure 1: Sketch of the position of the main diagnostics along the HEBT. The lengths of the elements are approximative and scaled. Definition of the acronyms are given along the text.

Parameter	Value
Beam pipe length (m)	≈ 11
Beam pipe diameter (mm)	100/200
Bunch frequency (MHz)	175
Beam energy E (MeV)	5/9
β	0.0727/0.0975
Mean current $\langle I_b \rangle$ (mA)	0.5/125
Pulse length T_p (μs)	100/CW
Duty factor (%)	0.1/CW
Bunch length σ_z (ns)	0.15/1.5
Transverse size $\sigma_{x,y}$ (mm)	1/40

Table 1: Beamline mechanical properties and range (approx.) of the beam properties along the HEBT.

Diagnostics plate section

The diagnostics plate is widely reported in [4]. It contains the most essential diagnostics for the validation of the accelerator technology. The location of the DP in

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the HEBT was carefully chosen to characterize as close as possible the real beam out of the accelerating structures. For this reason, the DP is located just downstream the quadrupole triplet at the extraction of the HWR (QT1). The triplet is necessary both for beam transport and to carry out quadrupole scans for emittance measurements. Downstream the DP a quadrupole doublet (QD2) is installed to handle the beam during transverse size scans with QT1 for the transverse emittance measurements.

Magnetic spectrometer section

The magnetic dipole in the middle of the HEBT (SPEC) serves to shield sensitive accelerator components of the backstream neutrons from the beam dump. However, due to the high average beam power (1 MW), the beam should be very carefully controlled in this dispersive region, to avoid any beam loss or even a bigger damage. For this reason, beam loss monitors will be placed along the dipole to react fast to any beam loss. In addition, the injection and extraction will be controlled by a set of DCCT's and SBPM's. Both sets will be completed with a transverse profile monitor for the measurement of the energy spread. The resolution of these monitors needs optimizing to achieve the required energy spread resolution.

IFMIF profiler and Beam Dump control

The last part of the beam line has an increasing aperture since the size of the beam is increased by a quadrupole triplet (QT3) to adapt the power deposition to the requirements of the beam dump. The design of the instrumentation located in this area will be more complicated due to the bigger aperture of the beam pipe, as it will be explained later. In addition, due to the vicinity to the beam dump, these diagnostics will support the highest radiation levels in the accelerator vault outside the beam dump room. Even though all these are drawbacks for the instrumentation, it is an advantage for the tests of the transverse profile monitor for the target of the future IFMIF accelerator (ITPM). On the other hand, in this drift region, the beam should be controlled to avoid too high power densities (> 200 kW/cm^2) in the beam dump because of beam size reductions, or beam losses in the beam pipe before the dump. A profile monitor, an SHM and a beam position monitor will be installed for this purpose 1 m upstream the beam dump.

MEASUREMENT CHALLENGES

IFMIF-EVEDA will be the first accelerator in achieving such high deuteron current. In combination with the CW nominal operation or with long beam pulses (down to 100 μs), any interceptive diagnostics device could be destroyed. In addition, even though the beam energy is low compared to other accelerators, the range of the deuterons in the material is also quite short. That means all the power will be deposited in a very small area, increasing the energy density and limiting the use of interceptive diagnostics.

Debunching In the longitudinal plane, without any buncher cavity, the bunches are getting longer along the HEBT. As discussed in [4], this debunching process will affect the high frequency components of the image current accompanying the beam. These components will be further reduced downstream the diagnostics plate, due to the increase in the beam pipe diameter, and the longer length of the bunches. Figures 2 and 3 shows the variation on the time and frequency domain signal components in the first and last SBPM's in the line. The first SBPM (BPM1) is located in the DP, 1 m downstream the exit of the HWR, and the last SBPM (BPM6), is located 2 m upstream the beam dump entrance. The beam pipe diameter in BPM1 is 100 mm and in BPM6 is 200 mm. There is a clear reduction of high frequency harmonics in BPM6, which are almost negligible for $n \geq 2$.

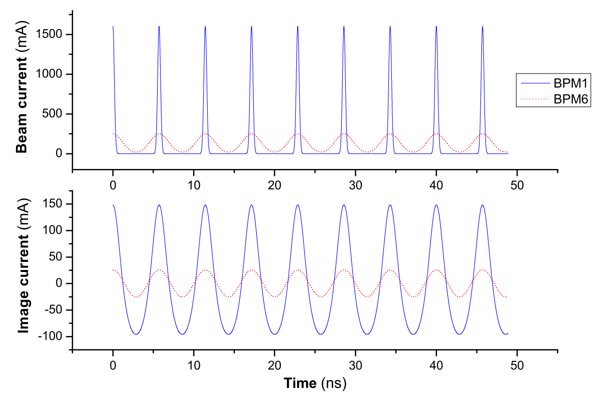

Figure 2: Comparison of the beam and image current at different BPM positions along the diagnostics plate.

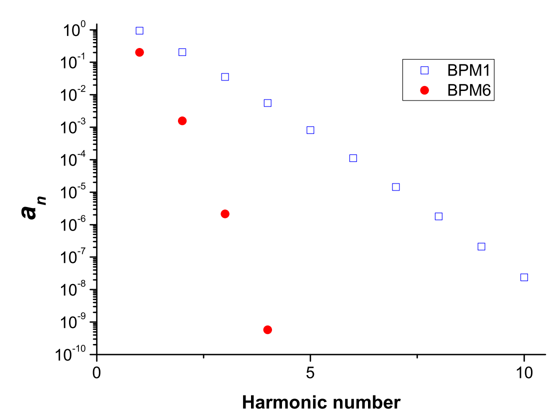

Figure 3: Comparison of the frequency components of the image current at the beginning (BPM1 position) and end (BPM6 position) of the HEBT.

Beam damage Out-of-control bunches could cause a strong damage along the HEBT. According to [5], the time before causing a stress damage in the material is given by:

$$\Delta t = \frac{2\pi e \sigma_x \sigma_y}{I_0 R_{max}(E_0)} q_{max}, \quad (1)$$

where e is the elementary charge constant, σ_x and σ_y the beam rms size in the horizontal and vertical direction respectively, I_0 the average beam current, R_{max} the Bragg peak maximum, E_0 the mean beam energy and q_{max} the maximum heat density value before mechanical failure. Although it is very unrealistic that such an accident can happen during real operation, it represents a conservative estimation of the reaction time for the Machine Protection System. Figure 4 compares the time for stress damage and melting of the material in case of a perpendicular impact in a copper structure at different points of the HEBT. The

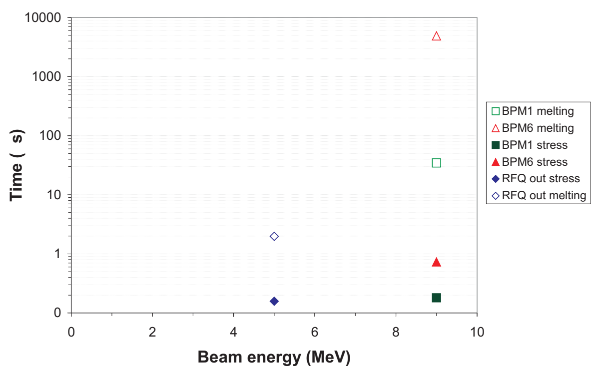

Figure 4: Damage time caused by an out-of-control bunch impacting perpendicularly to a stainless steel wall.

stress damage criteria produces maximum reaction values almost one order of magnitude smaller than those calculated and used in SNS and J-PARC [5, 6]. Therefore, further simulations should be carried out in order to evaluate a reaction time as input for the MPS under more realistic failure conditions.

Radiation damage In addition to structural damage, any beam loss along the accelerator will activate the materials and produce a high neutron and gamma flux. To keep the maintenance of the accelerator hands-on, the beam losses are to be limited to less than 1 W/m. This requirement imposes a strict condition to the beam loss or halo monitor, which need to monitor unexpected fast losses down to 10^{-6} beam particles or control the halo growth. The monitors will be connected to the Machine Protection System, which must turn off the necessary devices to limit the losses in less than 10 μs, as seen before.

MONITORS SUMMARY

The list of the main diagnostics devices to be installed in the HEBT is given in Tab. 2. It is important to point out that

Beam parameter	Monitor	Quantity
DC current	DCCT	4
AC current	ACCT	2
Position	SBPM	6
Transverse profile	FPM	1
	BTPM	1
	TPM/ITPM	3/1
Transverse halo	SHM	2
Transverse emittance	QS	1
Longitudinal emittance	BS	1
Energy spread	SPEC	1
Mean energy	TOF	1
Longitudinal profile	SBPM	1
Beam losses	BLM	TBD

Table 2: Preliminary list of the monitors used in the HEBT for the measurement of several beam parameters (DP included).

due to the mechanical flexibility of the DP, another devices could be installed in the future for further tests. For example, transverse profilers, like Secondary Emission Monitors or Wire Scanners, could be installed to cross-check or complement the non-interceptive profilers at low current or low duty cycle. In the same way, fast faraday cups or particle detectors might be studied.

CONCLUSIONS

In spite of some challenging and exciting requirements, the beam diagnostics system for IFMIF-EVEDA seems feasible at this stage. Some critical points for the operation of the machine, like the control of the beam losses and the beam halo, the measurements with electromagnetic detectors, or the measurement with a non-interceptive transverse profile monitor, will be followed up very closely during all the development of the project.

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