

BEAM POSITION MONITORS USING A RE-ENTRANT CAVITY

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Abstract

Two designs of high resolution beam position monitor, based on a radiofrequency re-entrant cavity, are developed at CEA/Saclay. The first monitor is developed in the framework of the European CARE/SRF program. It is designed to work at cryogenic temperature in a clean environment and get a high resolution with the possibility to perform bunch to bunch measurements. Two prototypes with a large aperture (78 mm) are installed in the Free electron LASer in Hamburg (FLASH), at DESY. The other design with an aperture of 18 mm and a large frequency separation between monopole and dipole modes, as well as a low loop exposure to the electric fields is developed for the Clic Test Facility (CTF3) probe beam CALIFES at CERN. It is operated in single bunch and multi-bunches modes. This paper presents the mechanical and signal processing designs of both systems. Simulation and experimental results will be discussed.

INTRODUCTION

A re-entrant BPM [1] consists of a coaxial cavity arranged around the beam pipe. Passing through the cavity, the beam excites electromagnetic fields (resonant modes), which are coupled by four feedthroughs to the outside. The main radio-frequency modes excited by the beam in the cavity are monopole and dipole modes. The monopole mode signal is proportional to beam intensity and does not depend on the beam position contrary to the dipole mode signal which is proportional to the distance of the beam from the centre axis of the monitor.

Two re-entrant BPMs are installed on the FLASH linac at DESY. The first, operated at cryogenic temperature inside the cryomodule ACC1, in an environment where dust particle contamination has to be avoided, is not discussed here [2]. The second has been qualified with beam in a warm section of the FLASH (TTF) accelerator, achieving 4 μm resolution over a dynamic range of ± 5 mm. Those results are presented in the first part of this paper.

The second part describes the re-entrant BPM designed for the CLIC (Compact Linear Collider) Test Facility (CTF3) probe beam CALIFES [3]. The theoretical performances of this system and the first measurements of the cavity are discussed.

BPM INSTALLED IN THE FLASH LINAC

In the framework of the European CARE/SRF program, the task of CEA/DSM/DAPNIA (Saclay) is the design, the fabrication and the beam test of a BPM in collaboration with DESY. The cold re-entrant BPM

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prototype installed on the linac outside a cryomodule for tests was designed to achieve a high resolution down to 10 μm and to allow bunch to bunch measurements for the X-Ray Free Electron Laser (X-FEL) and the International Linear Collider (ILC). The monopole and dipole modes are around 1.25 GHz and 1.72 GHz. This BPM has high crosstalk isolation (33 dB) and the quality factors are quite low [4]. Spring 2006, during the maintenance time, the re-entrant BPM was installed in a warm part in the FLASH linac (Fig. 1) at DESY.

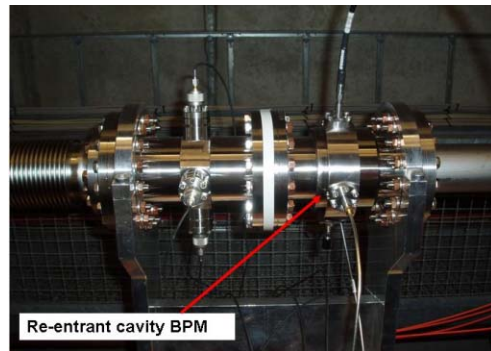


Figure 1: Re-entrant cavity BPM installed in the FLASH linac.

Calibration

After this mounting, the two subsystems, composing the signal processing, were installed and calibrated. The adjustment of phase shifters in the tunnel allows having a high common mode rejection (30 dB at the monopole mode frequency). The gain was modified to improve the resolution and some low pass filters were added on each channel. The new RF signal processing electronics is shown on Fig. 2.

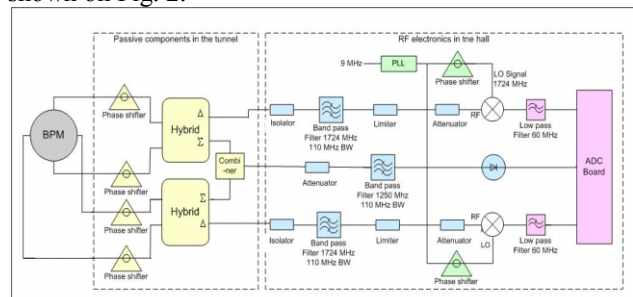


Figure 2: Signal processing electronics.

The synchronous and direct detectors, as well as gain were adjusted to have a linearity range around ± 5 mm.

To carry out the BPM calibration, the vertical and horizontal steerers were used to move the beam. All magnets, between the steerers used and the re-entrant BPM were switched off. The calibration was carried out

in calculating for each steerer setting, the relative beam position in using a transfer matrix between steerer and BPM. The position measured by the re-entrant BPM vs the calculated position was plotted for the horizontal and vertical steerings (Fig. 3).

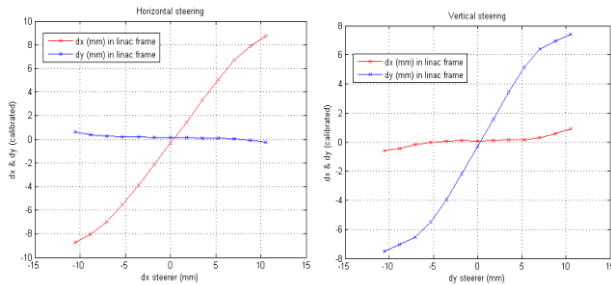


Figure 3: Calibration results in LINAC frame from horizontal (left) and vertical (right) steering.

Figure 3 shows a good linearity in a range ± 5 mm. The BPM resolution has been measured by correlating the reading of the re-entrant BPM in one plane against the readings of all other BPMs in the same plane [5]. In keeping the same dynamic range, the resolution was measured, on the Y channel, around $4 \mu\text{m}$ and on the X channel around $8 \mu\text{m}$ limited only by the electromagnetic contamination in the experimental hall. This difference on both channels can be explained by the fact that the bandwidth of the low pass filters is not the same. Those results are quite similar to the theoretical resolution calculated around $3.65 \mu\text{m}$ with 5 mm beam offset [4]. The noise amplitude on the DOOCs ADC board and on a scope was measured to be about $200 \mu\text{V}$ peak. The charge of the re-entrant BPM was calibrated thanks to the toroids. The resolution for the charge is around 6.35 pC .

This BPM was designed to have the possibility to do some bunch to bunch measurements. The position of each bunch can be known and read by the re-entrant BPM as shown on Fig. 4.

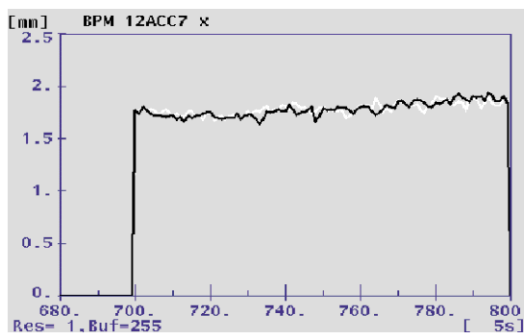


Figure 4: Position of 100 bunches in a macro-pulse read by the re-entrant BPM.

Outlook

In the next studies, the resolution will be improved in adding an amplifier on each channel. As the limitation of the resolution is due to the ADCs noise, to improve the resolution the dynamic range has to be reduced. With a

dynamic range around ± 1 mm, the simulated resolution was calculated to be around $0.5 \mu\text{m}$.

Improvement of the Mechanical Design

To be installed in an X-FEL cryomodule, the mechanical design has to be improved. The alignment of two pieces composing the cavity has to be precise. A cavity was fabricated to adjust the alignment of two pieces and to validate the copper plating of the beam pipe. With a three-dimensional measurement, the alignment of two pieces was measured with an angle around 0.02° . The copper coating was fabricated with the DESY specifications and its thickness was measured to be around $12.7 \mu\text{m}$.

BPM DESIGNED FOR THE CTF3 PROBE BEAM

Coaxial re-entrant cavities [1] have been chosen for the beam orbit measurement - single bunch or 1.5 GHz bunch trains - because of their mechanical simplicity and excellent resolution.

Cavity BPM

A new design, with a large frequency separation between monopole and dipole modes, as well as a low loop exposure to the electric fields, has been developed (Fig. 5).

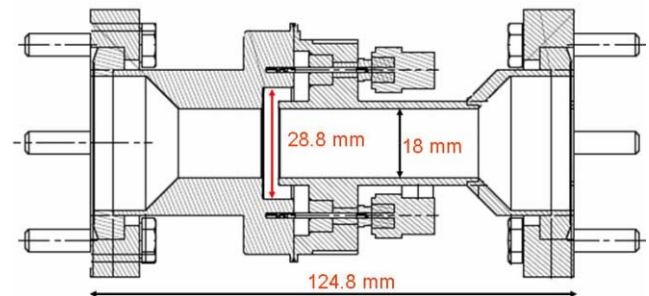


Figure 5: Re-entrant BPM designed for the CTF3 probe beam.

This BPM cavity is fabricated with titanium as compact as possible: 124.8 mm in length and an aperture of 18 mm. Six BPMs will be installed on the CTF3 probe beam CALIFES. The resonant cavity was designed with the software HFSS (Ansoft). The dipole mode frequency has been chosen around 5.997 GHz for a resonant operation with 64 bunches.

Table 1: BPM RF characteristics.

	F (MHz)	Q _{ext}	Longitudinal R/Q (Ω)	
			Offset 2 mm	Offset 5 mm
Monopole mode	3976.2	27.09	22.3	22.2
Dipole mode	5964.4	51.49	1.1	7

The RF measurements, presented in Table 1, are an average of the frequencies and external Q measured on the six BPMs. The longitudinal R/Q were computed with the software HFSS. The mechanical dimension \varnothing 28.8 (fig.5) will be adjusted to have the dipole mode frequency close to the frequency chosen 5.997 GHz.

The standard deviation for the monopole mode frequency is around 5 MHz and for the dipole mode frequency around 8.7 MHz measured on the six BPMs. The cross talk is quite high, it was measured in laboratory better than 28 dB on each BPM.

Electronics

The signal processing uses a single stage downconversion and is shown in Fig. 6. It is composed of standard RF components: hybrid couplers, phase shifters, filters, isolators and I/Q demodulators. The isolation of the hybrids can be adjusted by phase shifters to reject the monopole mode. To reduce the cost, some multipoint switches were used to have one signal processing electronics to control six BPMs.

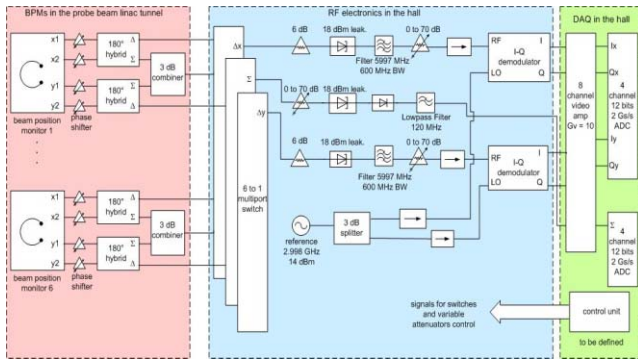


Figure 6: Signal processing electronics.

The control system pilots the switches and variable attenuators.

Theoretical Results

To assess the performance of this system, a model (cavity+signal processing) is elaborated with a Mathcad code based on Fourier transforms [4]. The signal is given by the model (cavity+signal processing) simulation in single bunch mode. The gain was adjusted to get an RF signal level around 0 dBm on the Δ channel with 5 mm beam offset. The position resolution is the rms value related to the minimum position difference that can be statistically resolved. The noise is determined by the thermal noise, the noise from signal processing channel [2] and the noise of ADCs boards. The noise level is about $5 \cdot 10^{-4}$ V. The result gives a resolution around 5 μ m with \pm 5 mm of dynamic range.

The damping time of the cavity is around 2.8 ns and the time resolution is around 10 ns in single bunch [2].

This BPM is, also, operated in multi-bunches mode. As the distance between bunches is very short around 667 ps, a new Mathcad model to simulate the re-entrant BPM in multi bunches mode is being developed.

The ADCs boards were chosen to digitize very fast. The model, DC282 developed by Acqiris, has four channels with 10 bits and a sample rate of 8 Gs/s.

CONCLUSION

The re-entrant BPM installed in the FLASH linac has a high linearity in the range of \pm 5 mm, and high position resolution below 10 μ m (4 μ m for the Y channel and 8 μ m for the X channel). It has the possibility to do some bunch to bunch measurements and its main features are its operation at cryogenic temperature and its large aperture (78 mm). This BPM appears as a good candidate for being installed in the XFEL and ILC cryomodules.

The BPM designed for the CTF3 probe beam is operated with single bunch and multi bunches. The first simulated results are encouraging. The resolution, in the single bunch mode, was calculated around 5 μ m with a dynamic range of \pm 5 mm. At the end of this year, the six BPMs and the electronics will be installed at CERN and the first beam tests will start in 2008.

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