# COMMISSIONING OF THE CAVITY BPM FOR THE FERMI@ELETTRA FEL PROJECT

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*Abstract*

The Cavity Beam Position Monitor (BPM) is a fundamental beam diagnostic device that allows the measurement of the electron beam trajectory in a non-destructive way, with the micron resolution. Ten Cavity BPM systems have been installed along the undulator chain in the FERMI@Elettra [1] FEL1 project. In this paper we discuss the installation, commissioning and performance of these Cavity BPM systems. We have carried out preliminary operations during a pre-beam period, such as alignment and fine tuning of the RF vacuum cavities. During the commissioning each BPM has been calibrated by mechanically moving the support on which the BPM is mounted. We have estimated the single shot resolution in presence of beam jitter by reading the beam position synchronously over many electron bunches, from three or more BPMs. Subsequently the algorithms have been improved, and the results are here described, together with a first resolution assessment.

## INTRODUCTION

The Cavity BPM is a diagnostic tool capable of determining the electron beam transversal position. Ten Cavity BPMs are nowadays successfully installed and tested in the FEL 1 undulator hall of the FERMI@Elettra project [1]. This paper treats the mechanical realization of the cavities, the inspection of the resonant frequencies, and crosstalking, the tuning, the calibration and the first resolution measurements of the cavities.

## MANUFACTURING

This section covers the machining of the Cavity BPMs, out of solid copper. A series of 14 Cavity BPMs has been produced at Cinel Strumenti Scientifici [2]; 10 cavities have been employed in the FEL 1 undulator chain. Figure 1 shows the building blocks of the Cavity BPMs prior to assembly.

In order to match the resonant frequencies of the reference and position cavities, the reference cavity is endowed with radial tuners that can only increase the resonant frequency, while the position cavity has longitudinal tuners that can only decrease it. All the tuners produce a permanent deformation on the copper.

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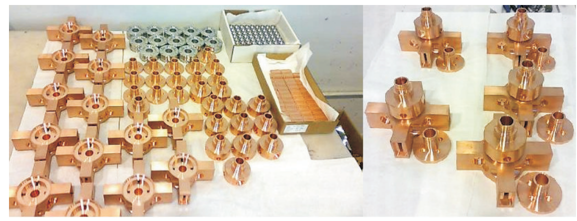

Figure 1: Parts of the Cavity BPM, before brazing

## WORKBENCH MEASUREMENTS

This section reports the measurements made with the vector network analyzer. The parameters of interest are the resonant frequencies and the crosstalking effect of the position cavity.

### *The Resonant Frequencies*

The resonant frequencies have been measured before and after brazing. The aim is that of ensuring that the resonant frequency of the reference cavity is lower than the one of the position cavity. Only if this condition is satisfied, the two frequencies can be matched with the tuners. Otherwise, the reference cavity must be rectified in order to decrease its resonance frequency. The frequencies of three samples of reference cavities, measured before and after brazing, are reported in Table 1.

Table 1: Resonant Frequencies ($f_{RES}$) of the Reference Cavity

| Reference cavity $f_{RES}$, $[MHz]$ | | | |
|---|---|---|---|
| BPM# | Before Brazing | After Brazing | $\Delta f$ |
| 1 | 6495.7 | 6499.4 | 3.7 |
| 2 | 6494.0 | 6500.3 | 6.3 |
| 3 | 6496.8 | 6501.0 | 4.2 |

The frequencies of three samples of position cavities, measured before and after brazing, are reported in Table 2. The frequency “before brazing” is a mean of the two polarizations, vertical and horizontal.

### *Crosstalking*

The crosstalk between the orthogonal ports has been evaluated by measuring the $S_{21}$ parameter with the network analyzer. The average value is -51.1 dB.

Table 2: Resonant Frequencies ($f_{RES}$) of the Position Cavity

| Position cavity $f_{RES}$, $[MHz]$ | | | |
|---|---|---|---|
| BPM# | Before Brazing* | After Brazing H. Polarization | After Brazing V. Polarization |
| 1 | 6506.7 | 6502.8 | 6502.3 |
| 2 | 6509.8 | 6502.5 | 6502.6 |
| 3 | 6506.5 | 6503.7 | 6503.3 |

## INSTALLATION

Ten Cavity BPMs have been installed in the undulator hall, in the "FEL 1" undulator chain. Each Cavity BPM has a dedicated mover, as shown in Figure 2.

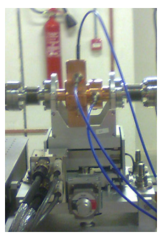

Figure 2: The Cavity BPM with the dedicated mover.

Each mover has a range of about ± 0.8 $mm$ with a 1 $\mu m$ encoder resolution. The movers will be used for the calibration with the electron beam.

## TUNING

The tuning has been performed in the tunnel with the portable network analyzer, with the devices at a ultra vacuum level of $10^{-9}$ $mbar$. Table 3 reports the tuning of three samples of Cavity BPMs for FEL 1.

Table 3: Tuning of the Cavity BPM

| | Resonant Frequencies $[MHz]$ | | | $\Delta f$ $[MHz]$ | | |
|---|---|---|---|---|---|---|
| # | R. Cav. | BPM H. | BPM V. | H.-V. | H.-R. | V.-R. |
| 1 | 6502.52 | 6502.56 | 6502.53 | 0.03 | 0.04 | 0.01 |
| 2 | 6504.78 | 6504.94 | 6505.04 | -0.10 | 0.16 | 0.26 |
| 3 | 6503.58 | 6503.69 | 6503.63 | 0.06 | 0.11 | 0.05 |

'H.' is the Horizontal polarization of the position cavity
'V.' is the Vertical polarization of the position cavity
'R.' is resonant frequency of the reference cavity

The tuners allow the adjustments of the desired resonant frequency with an accuracy below 100 kHz.

## BEAM MEASUREMENTS

This section describes the measurements performed in the control room with the electron beam. The entire electronic and data acquisition system has been developed in-house [3] [4]. The "Real Time" feature allows the synchronous data acquisition of a set of shots stamped with the bunch number. The most important on the field verifications carried out were the calibration and the resolution measurement.

### *Calibration*

The calibration is required for the conversion factor '$k$' estimation. This parameters translates the arbitrary unit value measured by the electronics into a displacement of the electron beam (expressed in $mm$) with respect to the center, with a 10% of accuracy. The first basic algorithm, assuming that the electron beam is not changing its position with respect to the Cavity BPM center, is based on the following operations:

1. Move the Cavity BPM with the mover of a known step;
2. Read the variation of the arbitrary unit number given by the electronics;
3. Repeat the previous steps for a complete sweep of the mover's range, and calculate the calibration coefficient.

The calibration factor has been calculated by averaging 160 acquisitions. Figure 3 shows the result of the calibration: each read value is consistent with the corresponding mover displacement.

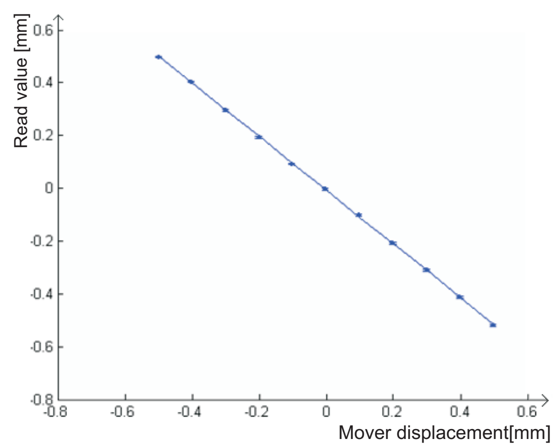


Figure 3: Calibration of the Cavity BPM.

This algorithm has been improved, with the technique of Ref. [5], which is independent of the beam jitter. The results are comparable.

### *Resolution*

The resolution of a single BPM is assessed among cavities with the same characteristics. This resolution method correlates the reading of the BPM of interest with the readings of the others BPMs [6]. The procedure assesses the resolution with '$p$' pulses and '$n$' BPMs. The BPM of interest is indexed with '$m$', and is placed as shown in Fig. 4.

The reading of the electron beam offset measured with the BPM of interest ('$m$') is compared with the predicted

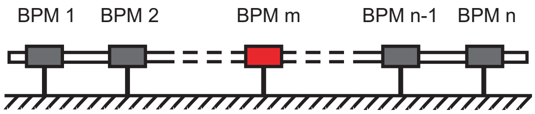


Figure 4: BPMs placement and numbering.

value by all the other BPMs. In the presence of beam transversal instability, the data of many bunches are collected and plotted in Fig. 6, which shows the predicted value (vertical axis) corresponding to the measured values (horizontal axis).

The standard deviation of the errors is related to the resolution of the BPM of interest as follows:

$$\sigma_m = \sqrt{\frac{1}{p}\sum_{i=1}^{p}(x_{i,measured} - x_{i,predicted})^2} \quad (1)$$

According to [5], the resolution value estimated from three BPMs is given by:

$$BPM\ resolution = \frac{\sigma_m}{\sqrt{1^2 + (\frac{z_{12}}{z_{13}})^2 + (\frac{z_{23}}{z_{13}})^2}} \quad (2)$$

where $z_{ij}$ is the distance between the $i_{th}$ and the $j_{th}$ BPM.

The first three Cavity BPMs in the spreader section have been used for the resolution assessment (Figure 5).

Figure 5: The first three Cavity BPMs in the spreader section.

The readings of these Cavity BPMs are obtained shot by shot in "Real-Time" mode, in presence of beam jitter. Figure 6 represents the predicted-measured value of the Cavity BPM of interest. The measured resolution is nearly 4 $\mu m$ from 50 $pC$ up to 270 $pC$ of bunch charge. A series of improvements in the electronics chain are already known to be beneficial for the increase of the measurement accuracy. Upgrade activities comprise:

1. Modification of the ADC coupling transformers (the actual ones have a lower bandwidth).
2. Improvement of the $\mu$TCA power supplies with low noise ones.
3. Fine tuning of the phase delays using a remote stepper motor.
4. Insertion of a programmable attenuator in the reference signal to increase the weight of the position signal at higher charges.

## CONCLUSION

The Cavity BPMs have been successfully manufactured, installed, and tuned in the undulator hall of the FEL 1 section. Special care has been used while tuning the resonant

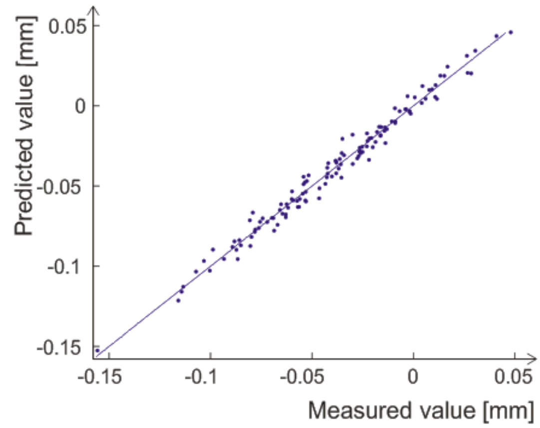


Figure 6: Plot of the predicted-measured values of the electron beam position.

frequencies. The entire system, including the electronic and the data acquisition method, has been started-up and debugged for the first time in the last commissioning (Run 6). The calibration has been performed with the movers. The first resolution measurements have been carried out with the first three Cavity BPMs in the spreader section. However, many improvements are still to be made in the electronic system.

## ACKNOWLEDGMENTS

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