# SIGNAL LEVEL CALCULATION FOR THE PETRA III BEAM POSITION MONITOR SYSTEM

G. Kube, M. Werner, DESY, Hamburg, Germany

*Abstract*

The new high–brilliance light source PETRA III at DESY requires measurement and control of the closed orbit with a resolution of better than 1 $\mu$m (rms). For this purpose it is planned to install about 220 button type beam position monitors (BPMs). To guarantee a good performance of the BPM electronics, the button signals have to meet several criteria in time and frequency domain. Therefore signal levels for different monitor types included for installation have been estimated. In this article the calculation results are summarized together with a comparison of measured monitor signals, and the expected position resolution will be discussed for the detection electronics *Libera*, developed by *Instrumentation Technologies*.

## INTRODUCTION

Starting mid of 2007 the PETRA II accelerator at DESY will be converted in a new high-brilliance synchrotron radiation source PETRA III. Therefore nearly 300 meters of the 2.3 km long storage ring have to be rebuilt completely. For measurement and control of the closed orbit about 220 electrostatic beam position monitors (BPMs) are forseen: one BPM per standard FODO cell and additional BPMs at the locations of insertion devices. Due to the unconventional asymmetry in the ring geometry there exist different vacuum sections with varying cross–section. In order to guarantee the required measurement and control of the closed orbit with a resolution of 0.3 $\mu$m (rms) at the insertion devices a necessary prerequisite is good performance of the BPMs and their detection electronics, and the button signals have to meet several criteria in time and frequency domain.

In order to study the transient signal behavior for all monitor types included for installation the signal levels have been estimated. The signal modelling follows the method described in Ref. [1] but is generalized such that arbitrary vacuum chamber geometries and beam positions can be taken into account. For this purpose a boundary element method described in Refs. [2, 3, 4] was utilized which is based on a numerical solution of the integral representation for the scalar potential. The calculated monitor signals are compared to measured ones and the expected position resolution will be discussed for the *Libera* detection electronics.

## SIGNAL MODELLING IN TIME DOMAIN

The first step is to calculate the image charge induced by the beam as function of time. Assuming an ultra relativistic beam with normal distributed longitudinal beam profile of length $\sigma_b$ and a circular button with diameter $d_B$ it can be expressed as

$$Q_i(t) = Q_{i0} \int_{-d_B/2}^{+d_B/2} \mathrm{d}z \, \frac{e^{-\frac{(z-ct)^2}{2\sigma_b^2}}}{\sqrt{2\pi}\sigma_b} \sqrt{1-(2z/d_B)^2} \quad (1)$$

with $Q_{i0}$ the induced charge calculated from a two-dimensional electrostatic problem assuming a point charge, which can be derived directly via standard electrostatic methods. For the calculations presented in this paper a boundary element method described in Refs. [2, 3, 4] was used. The dynamics in the signal generating process is described by the integral expression.

From Eq.(1) the image current follows as time derivative from the charge

$$I_i(t) = \frac{\mathrm{d}Q_i}{\mathrm{d}t}. \quad (2)$$

The button voltage in frequency domain is the product of the Fourier transformation $\mathcal{I}_i(\omega)$ of the current Eq.(2) and the impedance seen by this current. The dominant parts of the latter are the impedance of the cable $Z_0$ shunted by some parasitic button capacitance $C_B$, i.e. $\mathcal{Z}(\omega) = Z_0 \,||\, (i\,\omega C_B)^{-1}$. The button voltage in time domain is finally obtained by the inverse Fourier transform

$$U_i(t) = \mathcal{F}^{-1}[\mathcal{U}_i(\omega)] = \mathcal{F}^{-1}[\mathcal{Z}(\omega)\mathcal{I}_i(\omega)]\,. \quad (3)$$

In order to study the transient signal at the input of the detection electronics the frequency response of the connecting coax cable has to be taken into account. According to Refs.[1, 5] for a coax cable with skin effect losses it is given by

$$\mathcal{H}_{coax}(\omega) = e^{-(1+i)\sqrt{\omega/\omega_e}} \quad (4)$$

with $\omega_e$ the frequency for which the amplitude is attenuated by a factor of $e$.

The calculation of the relevant quantities was realized as a MATLAB script with graphical user interface, allowing simplified operation and control of the input parameters. The calculated pickup signal in Fig.1 for a BPM with circular vacuum chamber profile installed in PETRA II agrees well with the signal recorded by an oscilloscope. For the calculation the scope was modelled as first order low pass filter with corresponding bandwidth. Besides the example shown in Fig.1 additional comparisons were performed for the ELETTRA low gap BPM (elliptical chamber profile), and the DIAMOND primary BPM with racetrack resp. arc BPM with octagon profile, all of them showing satisfactory agreement with corresponding fast oscilloscope measurements.

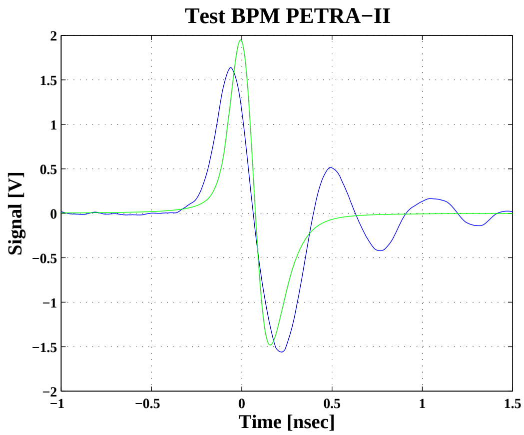


Figure 1: Calculated pickup signal (green line) and measured ones (blue line) for a circular beam pipe BPM (ø120 mm) installed in PETRA II. The beam with 1.1 mA bunch current and (1 $\sigma$) bunch length of 14.3 mm was assumed to be centered in the beam pipe. The signal was recorded with a 4 GHz bandwidth scope and 20 dB attenuation. The connection between pickup and scope was performed via a 22 m long 2.6/7.3AF coax cable.

## PETRA III MONITOR SIGNALS

It is planned to install BPMs with at least five different vacuum chamber cross sections in PETRA III. The most critical ones shown in Fig. 2 are the low gap monitor and the arc monitor for the new octant where the insertion devices will be installed.

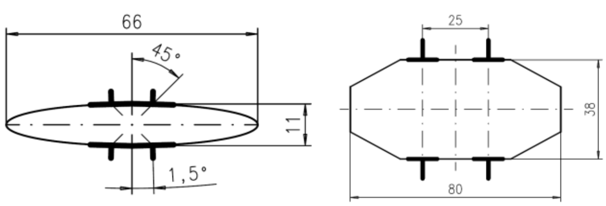


Figure 2: Vacuum chamber cross section of the two monitor types for the new octant: the low gap monitor (left) has an elliptical profile and will be installed close to the insertion devices, the arc monitor has an octagon chamber profile. Both monitors have buttons with diameter ø11 mm.

The subsequent signal analysis is presented for these two BPM types with the beam parameters as follows: beam energy E = 6 GeV, total current I = 100 mA, bunch length $\sigma_z$ = 40 psec (1 $\sigma$). The calculations were performed under the assumption of operation in the time resolved mode, i.e. the fill pattern consists of 40 bunches equally distributed in the machine. This mode corresponds to a bunch charge of 19.2 nCb resp. $1.2 \times 10^{11}$ particles per bunch. For the other standard operational mode (multibunch mode) with 960 bunches and I = 100 mA the calculated signal levels are reduced by a factor of 24. In order to take into account the influence of the connecting cable between the BPM electronics module and the pickups a 20 m long RFA 3/8”-50

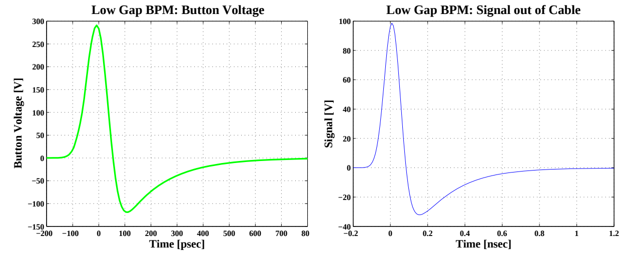


Figure 3: Calculated signals at the button (left) and behind the cable (right) for the low gap BPM, assuming the beam centered onto the monitor axis. The influence of the cable is to smear out the signal and to reduce its amplitude by about a factor of three.

coax cable was considered, resulting in a characteristic frequency $f_e$ = 11.6 GHz.

Figs. 3 show the transient signals at the button and behind the cable for the low gap monitors. The signals of the arc monitors are about a factor of three smaller than for the low gap BPMs.

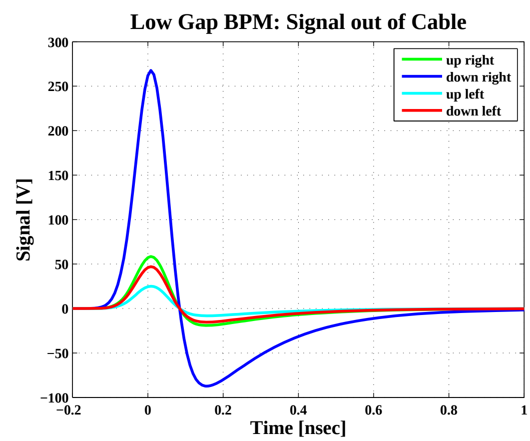


Figure 4: Calculated pickup signal outputs from the cable for the low gap monitor, assuming a beam with 3 mm transverse offset in both planes.

The situation becomes even worse if the beam has an offset with respect to the monitor axis. Fig. 4 shows the transient signals for the low gap BPM behind the cable, assuming 3 mm transverse beam offset in both planes. This is beyond the maximum peak voltage of most BPM electronics and for their non–destructive operation the consequence is that the signal should be attenuated and filtered.

## FREQUENCY DOMAIN MODELLING

Signal processing of the BPM electronics is usually performed for only one specific frequency component by special filtering, in the present case it is the signal component at $f_0$ = 500 MHz. Therefore it is helpful to consider the signal modelling additionally in the frequency domain. The key value in the frequency domain is the transfer impedance $\mathcal{Z}_T(f_0)$ which gives the relation between beam current $\mathcal{I}$ and the amplitude for the button signal. With the model of a current source working on a cable shunted by the button capacitance and Fourier transform, for short bunches it is

$$\mathcal{Z}_T(f_0) = \frac{\hat{U}(f_0)}{\mathcal{I}} = \frac{2\pi f_0 Z_0}{\sqrt{1 + (2\pi f_0 Z_0 C_B)^2}} \frac{d_B^2}{4\, c\, d_{eq}} \quad (5)$$

with $\hat{U}$ the amplitude of $U_i(t) = \hat{U}\cos(2\pi f_0 t)$ to a load of $Z_0$ connected to the button, and $d_{eq}$ the equivalent bunch to button distance which can be calculated by an electrostatic field solver (e.g. CST studio) by just solving the field distribution in a thin chamber slice with magnetic boundary conditions on either side of the slice.

## SIGNAL ATTENUATION

For the following discussion a -7 dBm signal for a centered beam and a peak voltage behind the cable of 400 V for 3 mm beam offset are assumed (e.g. example Fig. 4 including additional safety margin).

To reduce the peak voltage the following solutions are possible: a) insertion of lowpass or bandpass filters between BPM buttons and electronics [6], b) insertion of attenuators between BPM buttons and electronics, or c) use of long cables with enough attenuation.

If attenuators are used to reduce the peak voltage of the signal, the 500 MHz spectral component is reduced as well. For better illustration two theoretical electronics devices will be discussed with maximum allowed peak input voltages of 2 V and 80 V, respectively. The resolution of these devices is assumed to be like in Fig. 5.

For a maximum peak input voltage of $U_{max}$ = 2 V at the BPM electronics, an attenuation of Att = 46 dB is necessary for a peak voltage of 400 V. So the 500 MHz amplitude will be reduced to -53 dBm. Figure 5 shows a resolution of $\approx$ 1.5 $\mu$m for a monitor constant $K_M$ = 10 at 1 kHz bandwidth. For $U_{max}$ = 80 V the attenuation can be reduced to Att = 14 dB, resulting in a 500 MHz amplitude of -21dBm. For the same conditions as above the resolution will improve to $\approx$ 0.3 $\mu$m. According to the specifications of such attenuators the temperature sensitivity is $<$ 0.0001 dB/(dB °C) and the power sensitivity is $<$ 0.001 dB/(dB W). The temperature sensitivity can be converted directly in a position dependence on the temperature difference of attenuators:

$$\frac{\Delta Pos}{\Delta T} < 5.8 \times 10^{-6} \cdot K_M \cdot \mathrm{Att[dB]}\ . \quad (6)$$

The power sensitivity can be converted in a position dependence on a beam offset $O_{Beam}$:

$$\frac{\Delta Pos}{O_{Beam}} < P_{att} \cdot 2.3 \times 10^{-4} \cdot \mathrm{Att[dB]}\ . \quad (7)$$

This results in a position change per degree Celsius difference (between the four attenuators) $\Delta P_T$ and in a drift $\Delta Pos$/mm offset ($P_{att}$ = Power at attenuator $\approx$ Power after cable for centered beam = 0.25 W; low gap BPM with $K_M$ = 5.3 mm):

Table 1: Sensitivity on the attenuator parameters.

| $U_{max}$ | Att | $\Delta P_T$ | $\Delta Pos$ |
|---|---|---|---|
| 2 V | 46 dB | $<$ 1.4 $\mu$m / °C | $<$ 2.6 $\mu$m / mm |
| 80 V | 14 dB | $<$ 0.4 $\mu$m / °C | $<$ 0.8 $\mu$m / mm |

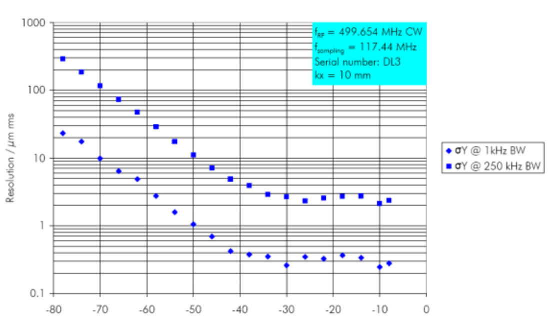


Figure 5: Resolution of the "LIBERA Electron" beam processor at two different bandwidths. Picture taken from Ref. [7].

## SUMMARY

In the present paper the BPM monitor planned to use in the new arc of PETRA III is discussed in view of signal levels and sensitivity. It was shown that the huge signal levels require additional attenuation and estimations were presented to demonstrate the attenuator influence on the accuracy for position measurement.

## ACKNOWLEDGEMENTS

The authors acknowledge I. Krouptchenkov for performing the measurement at PETRA II, K. Wittenburg for discussions and support in preparing the manuscript, G. Rehm (DIAMOND) and E. Lonza (ELETTRA) for providing information about their monitor signal levels, E. Plouviez (ESRF) for information about the filtering, and Instrumentation Technologies for the information about the *Libera* electronics.

## REFERENCES


[1] S.R. Smith, in Proceedings of BIW'96, Argonne, Illinois, AIP Conf. Proceedings **390** (1997), 50.

[2] T. Shintake et al., Nucl. Instr. Meth. **A 254** (1987) 146.

[3] A. Stella, DAΦNE Technical Note **CD-10** (1997).

[4] G. Kube, *Sensitivity Estimation for the PETRA-III Beam Position Monitors based on a Boundary Element Method*, DESY Technical Note **07-01** (2007).

[5] R.L. Wigington, N.S. Nahman, in Proc. IRE **45** (1957), 166.

[6] E. Plouviez, private communication.

[7] A. Kosicek, in Proceedings of PAC'05, Knoxville, Tennessee (2005), 4284.