

# Introduction to the A0 BPM System

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## Abstract

A short description of the bunch position monitor (BPM) system, recently installed at the A0 photoinjector at Fermilab, is given.

## 1 System Overview

The beamline of the A0 photoinjector at Fermilab is equipped with seven button BPM *pickup stations*. Six of them were recently equipped with a set of BPM *read-out electronics* developed and manufactured at DESY. This BPM electronics was designed in the mid 80's for the HERA electron storage ring. Today it is used in all electron (positron) machines on the DESY site and has also being successfully operated at three button BPM pickups in the injector part of the TESLA TEST FACILITY (TTF).

Figure 1 shows a schematic of the BPM installation at A0. The BPM pickup stations are numbered *BPM 0* through *BPM 6*. Currently five BPM read-out electronics channels are available (1...5). More may follow, but will require additional hardware to accomodate the readout electronics.

*BPM 0* is situated just downstream of the gun and the secondary solenoid. *BPM 1* was installed downstream of the superconducting 9-cell cavity after cross x3. *BPM 2* is currently not connected to the BPM read-out system. *BPM 3* and *4* are in the low beta section before cross xL2 and after xL5, respectively. *BPM 5* sits near the end of the straight section of the beamline,

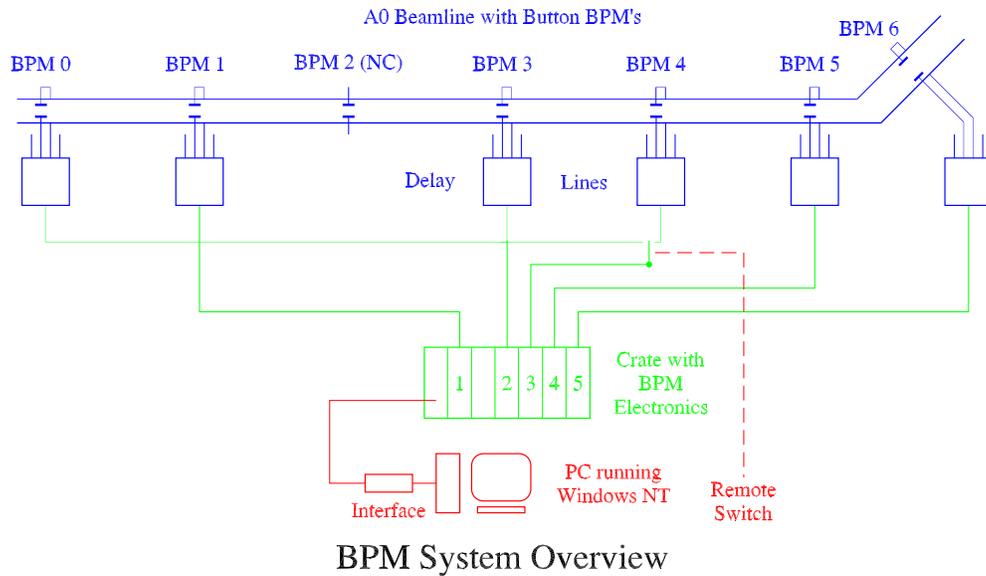


Figure 1: Overview of the BPM system of A0.

and *BPM 6* monitors the beam after the spectrometer dipole magnet. This BPM has a larger aperture than the other BPM's along the beamline. Since currently there are only five separate read-out channels available, *BPM 0* and *BPM 4* share the same electronics channel. A coaxial switch in A0 control room, allows to select either BPM.

The 4 signals (namely up, down, left, and right) of each button pickup are connected to a delay line circuit which delays each signal by a different amount. To minimize the influence of noise the delay line are located closely to the BPM pickup inside the A0 cave. The delay lines allow use a single cable to connect each BPM to the readout electronics outside the A0 cave. The single outputs of the delay line circuits are connected by heavily shielded cables to a rack outside the cave which accommodates the BPM readout electronics. There are two 19" crates: one for the readout electronics and another one for the power supplies. After signal processing, the digitized data is send from the leftmost crate controller module through a RG 58 cable to an interface box situated in the A0 control room. This box is connected to the parallel port of a standard PC running Microsoft Windows NT. All necessary controls and handling of the data is done with this PC. The normalized and calibrated beam positions of the five BPM channels is graphically presented

in an orbit display. The orbit display program has some additional features, which allow storing orbit data into a file, displaying a difference orbit, etc. An initialization file keeps important system information, like calibration data, etc.

## 2 Delay-Lines and Cabling

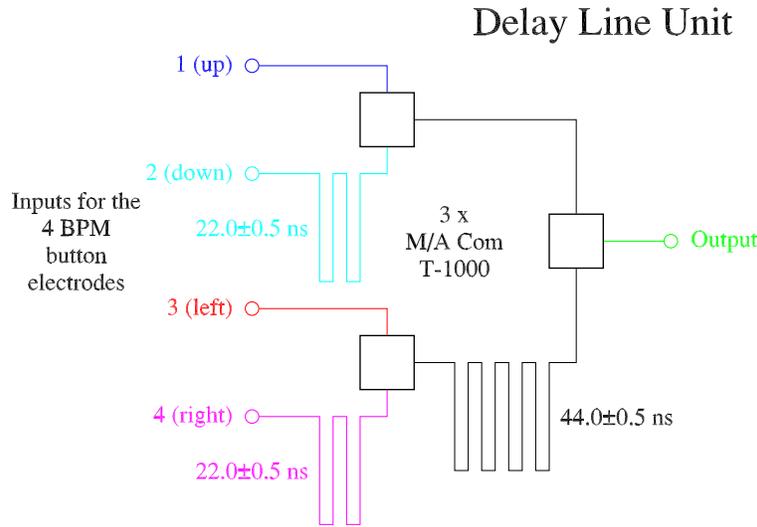


Figure 2: Delay line schematics.

Figure 2 shows the schematics of the delay-lines. They are situated very close to the BPM pickups and are easy to recognize by their black 3/8" heliax cable. The short connections between pickup electrodes and delay-line circuit is realized by four RG223 cables of equal length. On the patch panels the inputs are ordered from *right* to *left*(!) to the pickup electrodes in the following way (in beam direction):

*1* (top), *2* (bottom), *3* (left), *4* (right).

For each passing bunch 4 pulse signals, spaced by 22 ns, appear at the output of the delay line, corresponding to the up, down, left and right BPM electrodes. The output signals of the 5 BPM's are connected by black colored 1/2" heliax cables to a patch panel outside the cave. It is located on top of the second 19" rack which also keeps the BPM readout electronics.

Inside this rack short pieces of RG 58 cable are used to feed the signals into the inputs of the BPM electronics. These cables have N-type connectors on the patch-panel side, and SMA connectors to connect to the BPM electronics.

The individual BPM pickup electrodes are called *1*, *2* (top, bottom) and *3*, *4* (left, right in beam direction). All signal cables are labeled accordingly.

### 3 Readout Electronics

The readout electronics is housed in a so-called *SEDAC* crate, which has NIM-size dimensions but a different backplane. The power supplies are installed in a separate 19" crate. The DC output levels are:

$$+5.0 \text{ V}, -5.2 \text{ V}, +15.0 \text{ V}, -15.0 \text{ V}.$$

They have sense terminals on the front panel and a potentiometer that allows to adjust the output voltage. Sufficient air cooling is provided by crate fans mounted between the SEDAC crate and the power crate.

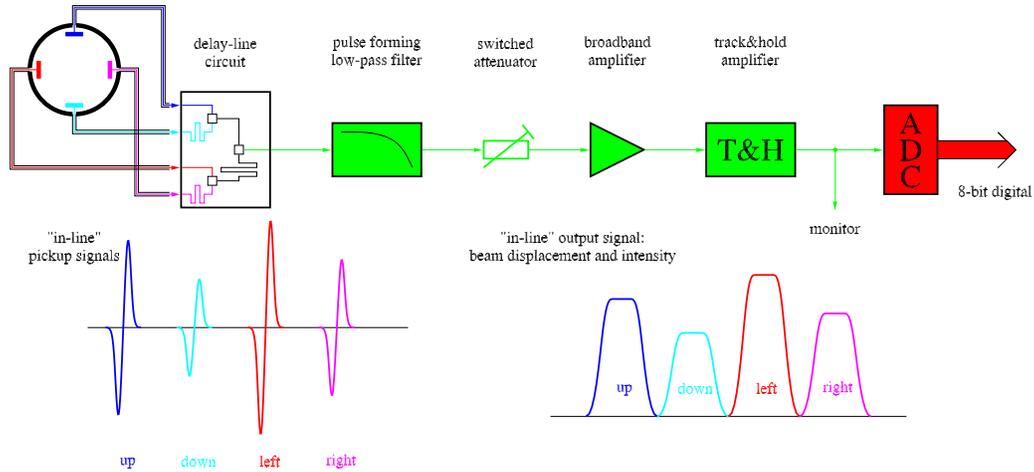


Figure 3: Schematics of BPM readout electronics

The SEDAC crate can accommodate up to 12 modules. The leftmost module is the controller. It has a green colored frontplate and interfaces the backplane to the serial data BNC plug at the front panel. The next 5 pairs of modules are the readout electronics for five BPM's. The left module of each pair is equipped with analog- and ADC-electronics, while the right one

is the so-called *adder* module. The function principle of the analog module is shown in the diagram in Figure 3.

An SMA output at the front panel of the ADC module can optionally be used to monitor the sampled analog signals. A flat ribbon cable on the front panel feeds the 8-bit digitized electrode data from the analog to the adder module which is used for real-time averaging.

The 8-bit ADC of the analog module generates integer values in the range:

$$0 \leq E_k \leq 255$$

for each pickup electrode  $E_k$  ( $k=1, 2, 3, 4$ ). The adder module adds the values of a number of  $n$  consecutive bunches (selectable:  $1 \dots n \dots 63$ ), separately for each electrode. Consequently, four adders are required for each BPM. The latency of the adder is  $5 \mu\text{s}$ , thus bunches separated by less than  $5 \mu\text{s}$  – although getting digitized – are being ignored by the adder modules.

For test purposes, one so-called *burst* module is connected with BPM pickup # 1. This unit allows to acquire and store the individual beam displacement of each bunch in the same macropulse.

Figure 3 does not show details on triggering, digitizing and the following data treatment, so here are some brief hints:

The readout electronics does not require an external trigger or clock signals since it is fully self-triggered by the incoming signals. Therefore, all 4 electrode signals at the input have to be above a minimum level to ensure correct operation. A flag in the readout program will be raised in case an input level is too low.

Data processing in the adder module is done individually for each electrode. The signal levels of all 4 electrodes are sent to the computer. A normalized (beam intensity independent) horizontal and vertical beam displacement is then computed from the four pickup signals by applying calibration constants.

## 4 Computer and Readout Programs

The BPM hardware is connected to the Windows PC via a serial link (SEDAC). An interface unit (SEDPC) is used to adapt the serial SEDAC line to the par-

allel port of the PC. *Visual Basic* routines are used to control the hardware, take data, manipulate the data, and visualize and store the data.

## 4.1 PC Parameters

Most important parameters of the Windows NT PC are (not complete):

```
IP address   : 131.225.122.31
gateway     : 131.225.122.200
domain nameserver : mstnta0bpm.fnal.gov
login       : mstnt_a0bpm
password    : mst4bpm
```

At boot time the PC automatically starts an FTP and a VNC server for maintenance purposes. These functions have been tested and work from DESY.

## 4.2 Calibration

The 4 signal values  $E_k$  of the electrodes have to be normalized and calibrated to compute the horizontal and vertical beam displacement  $\Delta_h$  and  $\Delta_v$ :

$$\begin{aligned}\Delta_h &= k_h \frac{\tilde{E}_4 - \tilde{E}_3}{\tilde{E}_4 + \tilde{E}_3} \\ \Delta_v &= k_v \frac{\tilde{E}_1 - \tilde{E}_2}{\tilde{E}_1 + \tilde{E}_2}\end{aligned}$$

A positive horizontal and vertical beam displacement corresponds to the upper, right-hand quadrant of the beam pipe cross-section (viewed in direction of the electron beam).

To compute the beam displacement, as a first step, the digitized signals have to be corrected to take the influence of the attenuation of the individual signal cables into account. The digitized values of the down (2), left (3) and right (4) electrodes of each BPM are increased by appropriate factors. These calibration factors are stored in an initialization file.

Before the normalized values are computed the mean values  $\tilde{E}_x$  are calculated:

$$\tilde{E}_x = \frac{\sum E_k}{n} + 10$$

The numerical value 10 adds an offset to the signal sum to ensure that the analog electronics is operated at levels where its response is known to be linear.

The so-called *monitor constants* ( $k_h, k_v$ ) are derived from the cross-section geometry of the BPM chamber using a linear approximation of the mirror charge model or a numerical analysis (see Appendix A). For a circular vacuum chamber of 48 mm diameter (BPM's 0 through 5) the monitor constants are:

$$k_h = k_v \approx 12.1 \text{ mm.}$$

This parameter is kept, together with other values, in the already mentioned initialization file:

```
L:>\server\BPMininit.ini
```

### 4.3 Read-out Routines and Operational Aspects

The PC is configured to start all required routines automatically during startup. The most important program for the orbit display is called *Injorb*. Double clicking the *Injorb* icon on the Desktop display of the PC launches the main window of the *Beam Position* routine. Most parts of this program are self-explanatory.

Here are some remarks:

- The upper part of the panel is used to display the signal of an individual BPM versus time (Single-Mode).
- The lower part is used to display the data of all BPM's simultaneously as an orbit (Orbit-Mode).
- All values changed in the fields have to be *entered* by pressing the corresponding button next to the input field.
- In both parts the data can be transferred once on request (by pressing a button) or continuously at selectable time intervals.

- Also, in both subpanels data can be stored in a file on the computer's harddisk.
- During continuous data acquisition parameters should be NOT changed; instead, stop the continuous BPM measurements, change the parameters and then restart the continuous operation.
- The orbit display allows the storage of a *reference orbit*.

Starting *Injorb* sets the attenuators in the analog front-end electronics according to a start value read from the init file. Subsequent readouts are used to optimize the setting of the attenuators such that a good signal-to-noise ratio is achieved. By default this automatic feature is enabled upon start-up. Although the attenuator automatic works fine in most situations, unstable or exotic beam conditions may require a manual setting of the input attenuator. This can be accomplished by switching to Single-Mode, unchecking *dB Automatic*, and change the attenuator value for each BPM channel individually. Minimum and maximum attenuator settings for the dB automatic are provided by the init file. They may be changed by the user to cheat the feedback and fix the addressed problems. However, test runs with electron beam at A0 have shown that the gain automatic works reliable.

A *Burst* module is currently connected to *BPM 1*. The burst display allows monitoring the intensity and displacement of individual bunches in the bunch train. The display can be terminated using the *End* button in the right section of the display.

## 4.4 Simulated Beam

A fast pulse generator is available to simulate a bunched beam with a bunch spacing of 1  $\mu$ s. To use it in the current configuration this SEDAC module can be installed instead of the *Burst* module. One of the four output signals of the pulse generator is cabled into the cave where it splits into four signals. These can be connected to the delay line input of one BPM pickup. Then the test pulse operation allows a complete functional test of the BPM system. Normally, it should return a zero displacement reading. Inserting RF attenuators in the signal path allow simulation of a displaced beam.

To start the pulse generator one has to use a low-level interface routine on the PC:

- double-click on the *SEDAC Read-Write* button in the *Bpms* window.
- In the *Write* section enter the following values:  
*Li*: 1, *Cr*: 14, *Sub*: 176, *Reg*: 0, *SedacValue(Hex)*: 2  
All values have to be entered using the **Enter** key (not Return!).
- Press *Sedac Write* and exit the program (use the checkbox at the upper right-hand corner).

Now the pulse generator has to be switched on (an LED on the frontpanel has to light up!) and, if connected, the readout routine *Injorb* will display a simulated orbit.

Feel free to change, improve the PC routines, the BPM hardware, the cabling, etc. – at your own risk, and/or this description – with no risk. For hints and comments, please contact:

**wendt@ux-bello.desy.de** or **rudolf.neumann@desy.de**

## A Appendix: Evaluating the monitor constant from the wall-current model

For a circular vacuum chamber the monitor constant can be resolved analytically from the wall-current model approach:

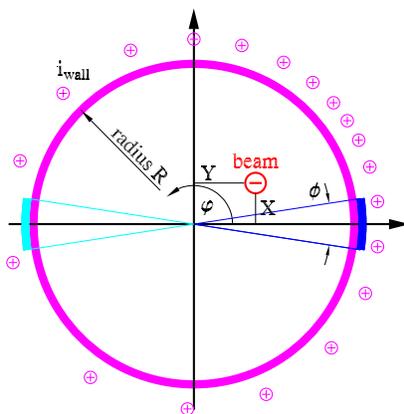


Figure 4: Mirror charges in a circular beam pipe.

Figure 4 sketches the *mirror charges* (wall-current) on the beam pipe surface for an infinitely thin beam, with horizontal ( $X$ ) and vertical ( $Y$ ) displacement. The wall-current is:

$$i_{\text{wall}}(\varphi) = -\frac{i_{\text{beam}}}{2\pi} \frac{1 - x^2 - y^2}{1 + x^2 + y^2 - 2x \cos \varphi - 2y \sin \varphi}.$$

Integration over an angle  $\phi$ , corresponding to the BPM electrode, yields:

$$i_{\text{elec}} = -i_{\text{beam}} \frac{2}{\pi} f(x, y, \phi),$$

$$f(x, y, \phi) = \arctan \frac{[(1+x)^2 + y^2] \tan(\phi/4) - 2y}{1 - x^2 - y^2}.$$

The beam displacement is given as normalized horizontal/vertical offset  $x = X/R$ ,  $y = Y/R$ .

For the  $R=24$  mm radius beam pipe of A0 the *Metaceram* button electrodes ( $\approx 11$  mm dia.) span about  $\phi \approx 0.45$  of the chamber, which translates

into 7% coupling. The normalized horizontal position characteristic of the A0 pickups can be computed as follows:

$$\text{horizontal(norm.)} = \frac{f(x, 0, 0.45) - f(-x, 0, 0.45)}{f(x, 0, 0.45) + f(-x, 0, 0.45)}.$$

Here, we are neglecting the vertical influence. The inverse of the derivative at  $x = 0$  gives the monitor constant:

$$k_h = k_v \approx 12.1 \text{ mm.}$$

The errors due to the linearization are small (of the order of a few percent) for beam displacements less than half the aperture of the beam pipe. For more complex beam-pipe apertures a numerical analysis (electrostatic) has to be used.