Results of work with the BPM system in Wide Band and requirements for BPMs in MI-31

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1. Introduction

The current BPM system works better that we have expected and satisfies our current needs. The system is used in most of our measurements, including the initial beam alignment, measurements of differential trajectories, beam size, and beam stability. The system in MI-31 will be used in the same ways as now with an addition of pbar beam position measurements. Performance identical to the present one with an addition of a low offsets between DC and pbar modes should satisfy our basic needs; a better understanding of BPM linearity and adding some new features may be desirable.

2. Resolution

Currently the resolution of averaged beam positions is determined by the beam's oscillations and drifts (Fig.1). The electronics noise is at the level of 1-3 microns with an exception of BYR03S. The structure of the "electronics" (i.e. determined by the measurement system) noise is repeatable from day to day while the beam noise depends on settings. In the best positions the deviations of the beam position readings are equal to the electronics noise.

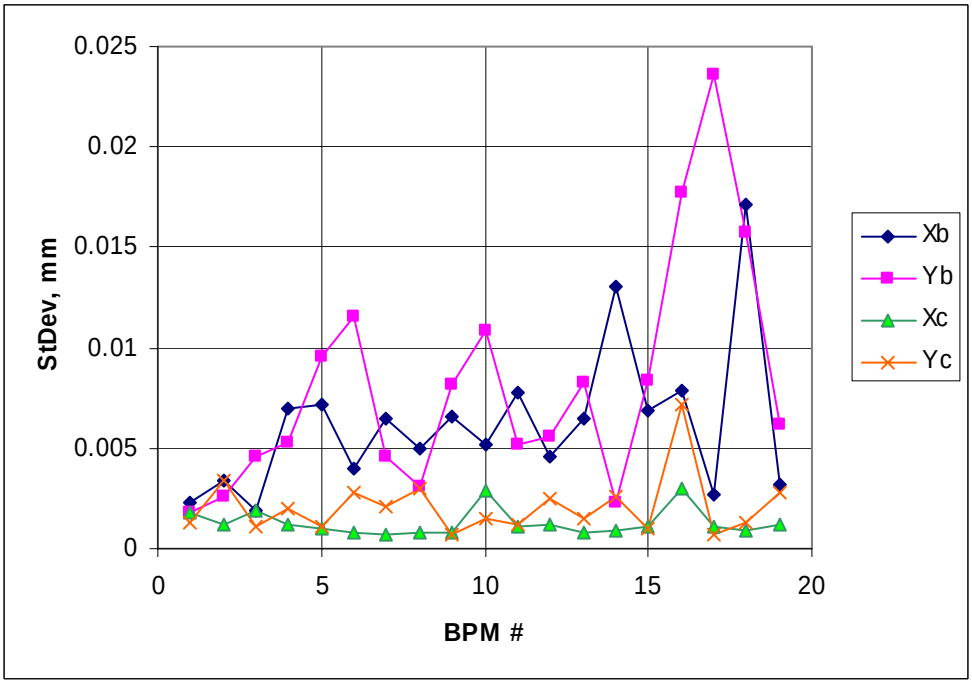


Figure 1. Comparison of standard deviations of BPM readings measured with a DC beam (Xb, Yb) and with calibration signal (Xc, Yc). Beam measurements: I = 0.17 A, modulation voltage is 100 V. Calibration: 0.115 V modulation at 89 kHz. In both cases the intensity ~ 1500; high gain (G=1). Deviations are calculated from 20 "slow" measurements taken with 10 sec intervals. 3-Feb-04.

In the pulse mode noise, a beam – related structure is not distinguishable (Fig.2). The noise level, 60 -120 microns in the "fast" measurements, is most likely determined by electronics. The noise decreases significantly, down to 20- 40 3 μm in the case of "slow" date, when 10 "fast" measurements are averaged. The decrease by $N^{1/2}$, where N is the number of measurements is in a good agreement with an assumption that the noise is random. Note that the decrease like that is found only in "good" times, when beam drifts are comparatively low.

The second set of curves in the plot shows the noise of "fast" readings of the calibration signal. The noise level is significantly higher than corresponding noise in the "slow" mode.

The only possible improvement for the resolution might be to make the electronics noise in all channels identical, $\sigma \leq 3$ μm. The resolution for pbar beam positions should be at least 20 μm to be able to use it as a reference line for aligning the electron beam.

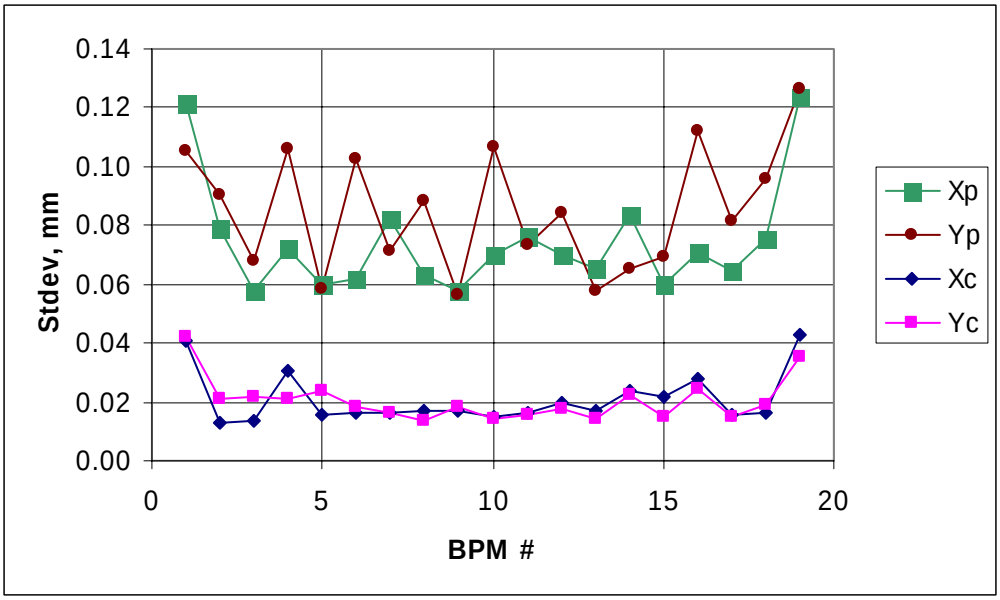


Figure 2. Comparison of standard deviations of BPM readings measured with a pulsed beam (Xp, Yp) and with calibration signal (Xc, Yc). The intensity is about 73 in the beam measurements, pulse duration is 2 μs, repetion rate is 1 Hz. Calibration signal voltage is 0.4 V. In both cases the gain is high. Deviations were calculated from 200 "fast" measurements taken with 1 sec intervals. 27-Feb-04.

3. Different modes

The BPMs are used in three modes: pulsed mode, DC + sinusoidal modulation at 32 kHz, and DC + negative pulsing. Comparison of readings in different modes show that the observed difference is beam-related, is linear with DC current, and generally increases from the entrance of the beam line to its exit. At low DC currents in the beginning of the beam line, the difference of readings in pulsed and in DC + modulation modes is within the measurement errors (Fig. 3).

Providing a good agreement between pbar position measurement mode and DC + modulation mode is critically important. The discrepancy between the modes should not exceed 20 μm at beam shifts from the BPM centers of 4 mm.

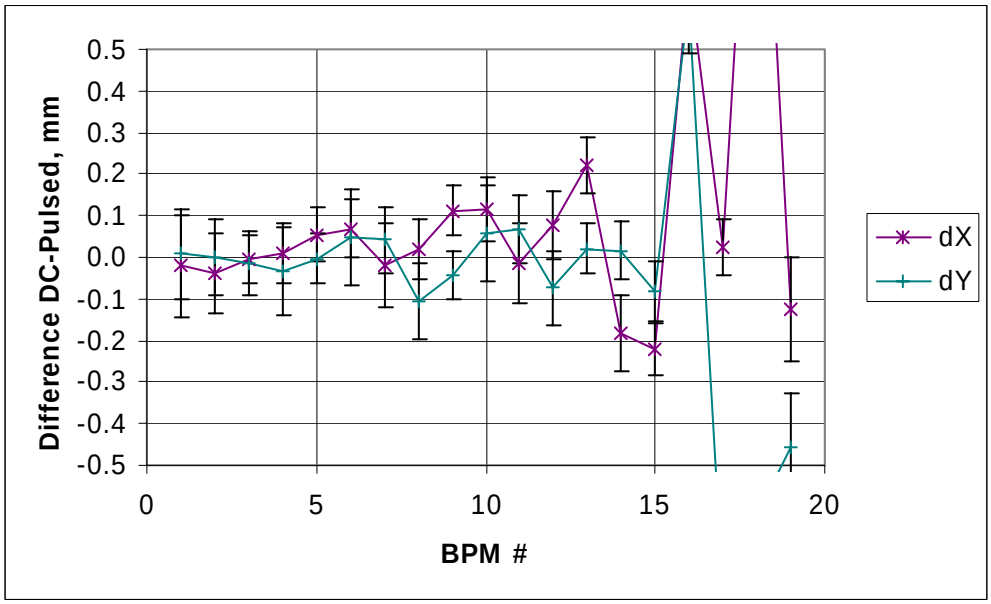


Figure 3. Difference in BPM readings in the pulse and DC+modulation modes. DC beam: 0.17 A, modulation is at 32 kHz and 32 V. Pulse mode: intensity is ~73. In both cases the gain is high; 200 "fast" measurements are taken. Error bars show values of standard deviations. 27-Feb-04

4. Offsets

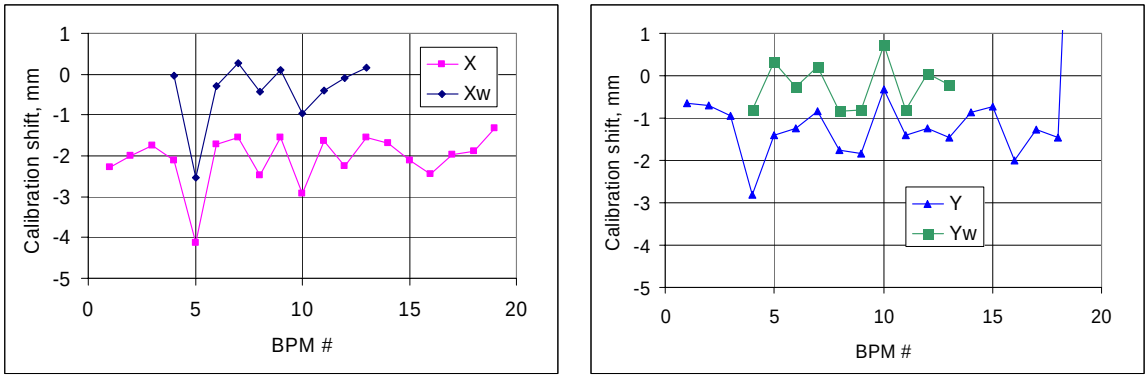


Figure 4. BPM offsets found in stretched wire measurements (Xw, Yw) and BPM readings (X, Y) with a calibration signal. Frequency in the stretched wire measurements and of the calibration signal is 32 kHz. Calibration signal amplitude is 0.115 V; voltage on the stretched wire was 8 V. 3-Feb-04.

Offsets were set by P. Joireman according to measurements of BPMs on a test bench (A. Semenov) and measurements with a wire stretched inside the cooling section (C. Schmidt). The results of measurements with the wire are shown in Fig.4. They are

compared in the plots with readings of “positions” when a calibration signal is sent to the inputs of preamplifiers. The calibration signal corresponds to a shift of about 2 mm, and variation of this value from BPM to BPM is caused by taking into account variations of sensitivities and offsets found in the test bench measurements.

It is desirable to decrease the offsets in MI-31 to work in the most linear part of BPMs. It means that a preliminary mechanical alignment of BPMs to 1 mm of concentricity will be useful.

5. Linearity

The linearity of BPM readings versus the beam position is important primarily for optics measurements with differential trajectories. An example of such measurement, changes in the beam positions in the cooling section as a result of changing the current in a corrector near the entrance of the cooling section. The measurement is used to calibrate the electron energy by a known value of the longitudinal magnetic field. Precision of the calibration is estimated to be 1% presumably because interaction of the DC beam with image charges is not taken into account.

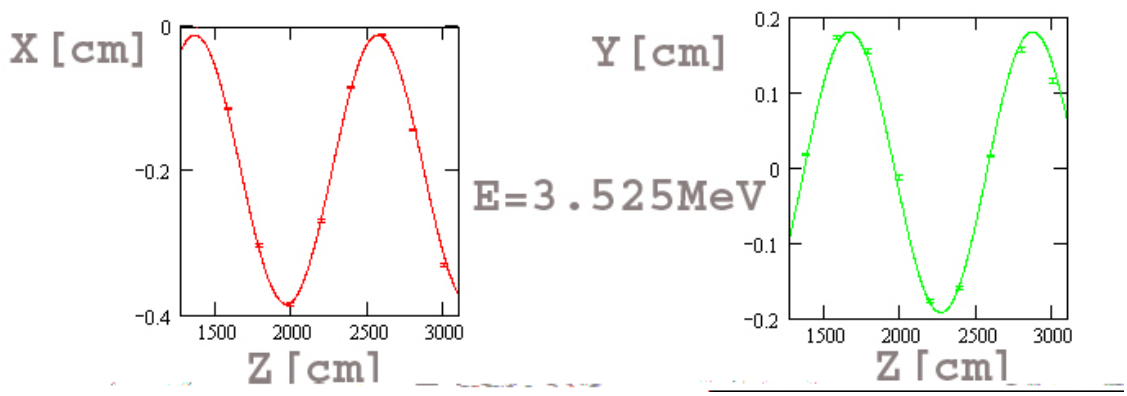


Figure 4. Shifts in the beam position after a change of CXS04 corrector. Cooling section magnetic field is 70 G. Measurements are made with DC, 0.17 A beam and modulation at 32 kHz and 100 V. Averaging is made over 20 “slow” readings. Error bars show a standard deviation. 15-Mar-04.

According to S. Seletskiy, an uncertainty in energy calibration dE/E caused by errors in BPM measurements dX/X is linear with the latter:

$$dE/E = 0.25 * dX/X$$

for typically used parameters. To make this source of errors insignificant for the desired dE/E ~ 0.3%, dX/X should be less than 0.4%. Assuming resolution of 10 μm, it requires the amplitude of the trajectory scalloping of 2.5 mm. Hence, taking into account possible mechanical shifts of BPMs, the non-linearity should not exceed 10 μm at deviations of 4 mm, or 0.25%. Estimations for precisions of measurements analyzing the rotational invariance give a similar value.

An experimental estimation of the present linearity was made from differential trajectory measurements with a parallel shift of the beam in the cooling section. Figure 5 shows a difference between measured beam positions and a linear fit to the end points,

plotted against BPM readings. While the plot shows clearly a non-linearity, it is difficult to judge whether it is caused by the BPM system or by the beam-shifting system, which includes two pairs of correctors, 4 solenoidal lenses and two 45° bends. There are two indications that the main effect is the latter: changes of the sign of the non-linearity in BXR01S readings and the fact that the non-linearity is closer to a second-order than to the third one. Note that BPM offsets are not taken into consideration. Most likely the BPM non-linearity do not exceed 20 microns at deviations of 1.5 mm.

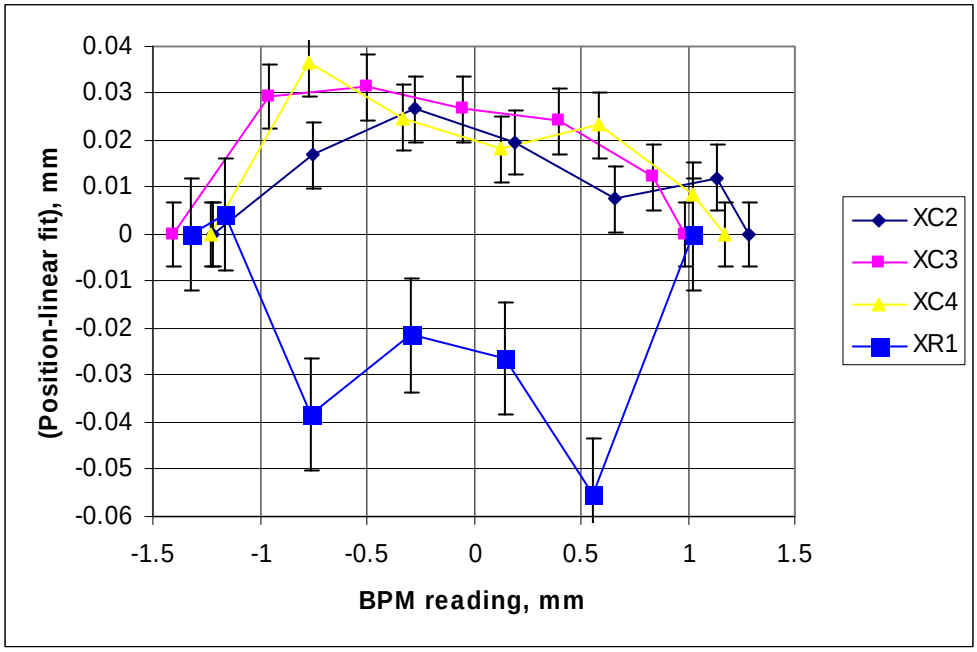


Figure 5. Difference between measured beam positions and a linear fit to the end points versus BPM position. 20 "slow" readings are made in each point. Measurements are made with DC, 0.17 A beam and modulation at 32 kHz and 32 V. Error bars show standard deviations divided by $N^{1/2}$, where N =20 is the number of measurements in each point. 9-Mar-04.

6. Amplitude and frequency dependence

The frequency dependence has not been measured yet. An estimation of the amplitude dependence can be done from plots Figures 6 and 7 for DC and pulse modes, correspondingly. In both cases the positions stay unchanged within scatter of the data points. For the case of the pulsed beam, Fig.7, it is correct only for normal operation conditions, when the control electrode is negatively biased with respect to the cathode in the time of a pulse. In a wide range of intensities, the readings change by less than 50 μm in DC mode and less than 150 μm in the pulsed mode.

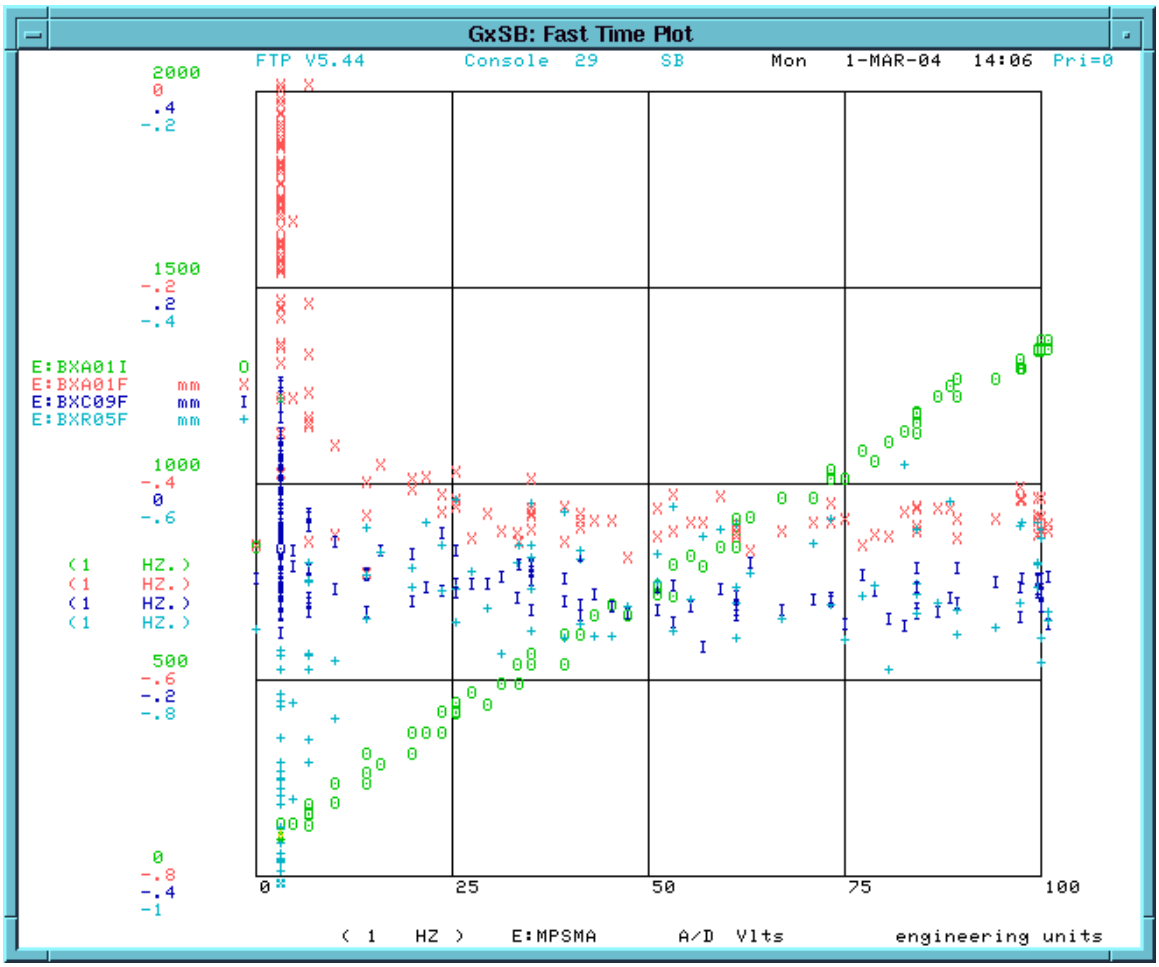


Figure 6. BPM readings as functions of the modulation voltage in the DC mode. Position readings (red, dark blue, and blue curves) are shown in mm, 0.8 mm full scale; the green curve is the intensity reading (similar in all BPM channels). The beam current is 0.17 A; the modulation frequency is 32 kHz. 1-Mar-04.

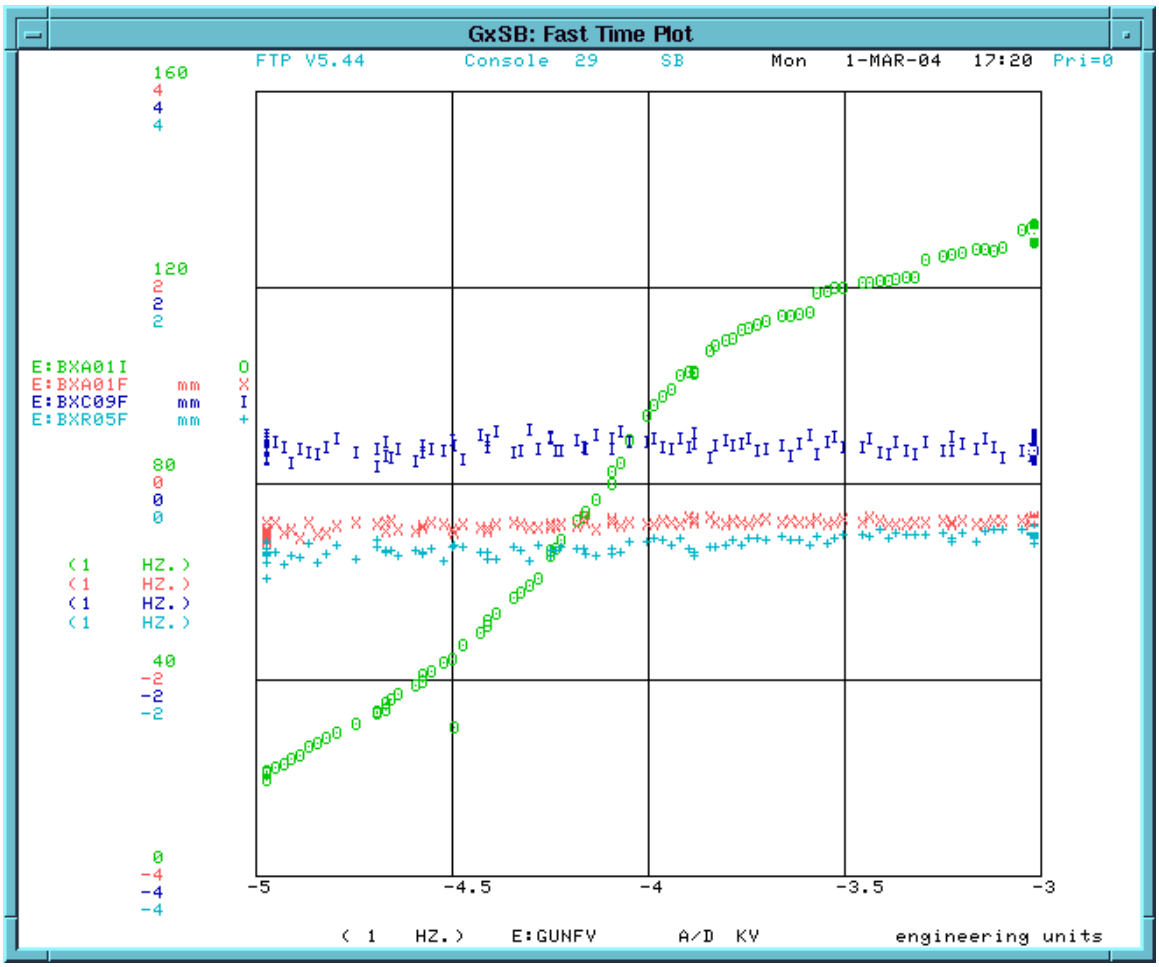
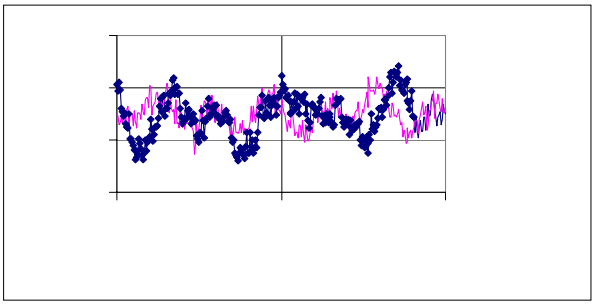


Figure 7. BPM readings as functions of the control electrode voltage in the pulse mode. Position readings (red, dark blue, and blue curves) are shown in mm, 8 mm full scale; the green curve is the intensity reading (similar in all BPM channels). The control electrode pulse amplitude is 4 kV (corresponds to 3 kV reading of E:MPSPA). The gun is completely closed at the total control electrode voltage of – 2.6 kV. The preamplifier gain is low. A knee at -4 kV corresponds to a fully open gun during the pulse, when the total control electrode voltage becomes positive. 1-Mar-04.

7. Reliability

After a lot of efforts that G. Saewert and the DSR team put into improving of reliability of the system, BPMs cause not too many problems. The most problematic

Another usage of the BPM system was made in the time of initial beam line commissioning, when changes the intensity of the signal were heavily used as an indication of beam scraping. Typically, several percents of the intensity change can be resolved.



The results shown in the paper are summarized in the Table 1.

Table 1. Summary of results of measurements in Wide Band in comparison with changes desirable for MI-31.

Parameter	**Measured in Wide Band**	**Needed in MI-31**	**Comments**
Noise, σ(μm)	3(DC + mod.) 100 (pulse)	Same+20 in pbar mode	Can be decreased by averaging
Difference between modes, μm	≤ 40 (DC vs pulse)	20 (DC vs pbar)	Very difficult to check by beam measurements
Linearity, μm	< 20 at shifts of 1.5 mm	10 at shifts of 4 mm	For optics measurements
Amplitude dependence	< 50 μm (DC, 300-1300 int.)	20	For DC vs pbar comparison
Position vs time	1 Hz all; 5-500 Hz single channel	1Hz – 500 kHz	Optional output for oscilloscope
Mechanical BPM alignment	2.5 mm	1 mm	