BEAM-BASED METHODS OF BPM CENTER OFFSET AND RESOLUTION MEASUREMENTS

A.Kalinin, Bergoz Instrumentation, Espace Allondon Ouest, Saint Genis Pouilly 01630, France

Abstract

Beam-based methods to measure BPM's center offset with reference to the pickup center and BPM's resolution are proposed. Being built in a BPM, the methods provide a BPM verification by its own means. Use of the same beam signals which are used for the position measurement, for verification at any present beam intensity provides reliability and accuracy of the methods. The methods can be used for measurement of rms amplitude of beam vibrations as well. A device is developed for subnanosecond bunches to measure BPM's center offset and resolution. It has accuracy close to 10^{-3} and can be used either in a four parallel channel BPM or in a BPM with multiplexing the pickup signals. These devices are used in Bergoz Instrumentation Log-Ratio BPMs. The circuit and characteristics of the device are described. The accuracy is discussed. Test results are presented. A resolution measurement method for both difference-by-sum and log-ratio algorithms is considered. By this digital method, resolution/vibration measurements can be done continuously providing exhibiting the noise bars on the BPM position readings.

1 INTRODUCTION

The center offset and resolution are main measures of the performance of a Beam Position Monitor. The center offset is an error of the measurement when the beam is on the longitudinal axis of the focusing quadrupoles. The resolution represents scattering caused by a noise inherent to the BPM, and can be defined as a rms variation of this error. The offset may vary with beam intensity. Scattering with increase of beam intensity comes to some floor level characteristic for BPM's demodulator. An extra scattering of BPM's readings may be caused by some noise-like beam position vibrations.

In most of the accelerator physics tasks, an offset error and its rms variation can be considered individually because a tolerable offset is usually much more than its rms variation. The offset error is important in beam dynamics tasks. It should be kept less than the position uncertainty of the quadrupole axis itself. The scattering decides the ultimate fluctuation of some beam positioning and is to be less than the beam transverse characteristic size. One more BPM's error, an absolute error of the BPM's sensitivity to beam displacement is less important. It is usually sufficient to have low relative sensitivity errors of the BPM's used in a system.

To verify a BPM, to determine its center offset and resolution and sensitivity as well, a beam-based technique is widely used. A beam-based method of center offset determination by variation of quadrupole strength [1] uses the quadrupole axis itself as an ultimate reference. Same variation of the strength is also used in a method of sensitivity calibration [2]. Some general verification method is described in [3]. A statistical method using a model-independent analysis is developed to identify the malfunctioning BPMs and measure BPM's resolution and beam vibrations [4]. Though these methods are powerful, they are quite work-consuming and need a beam time.

As for a BPM itself, a beam-based technique, in opposition to a technique based on test or pilot signals is ultimate. In this report, a beam-based method and an instrument are described to measure BPM's center offset with reference to the pickup center. BPM's resolution and beam vibration can be measured as well. Another beam-based method, a digital method of resolution/vibration measurement proposed in [5] for difference-by-sum algorithm is extended to log-ratio algorithm.

The center offset measurements can be done routinely to check stability and repeatability of the BPMs and confirm that the center offsets obtained with, for instance, the method given in [1] are still valid. The digital resolution/vibration measurements can be done continuously providing exhibiting the noise bars on the position readings.

2 CENTER OFFSET

To identify some typical causes of the center offset, let's consider two general types of BPM: a BPM with four parallel channels and a single channel BPM with multiplexing the pickup signals. In a four channel BPM, a difference of the channel gains results in the center offset. Compression of the gains which is used to provide high dynamic range of the BPM, makes the center offset changing with beam intensity as well. In both the BPMs, reflection of the pickup signals in the input cables causes also a center offset [6,7].

To enhance BPM's accuracy by neutralising numerous and sometimes uncertain factors as described above, a beam-based method of eliminating BPM's offset is proposed. When the beam is on the pickup center, the pickup signals are equal each to other and the BPM reading is just the BPM offset. Let's assume that with the beam displaced, the output pickup signals are equalised by some means. Then the offset can be measured and subtracted from the position calculated, to be eliminated from the BPM reading.

This procedure can be done with any present beam intensity in a full BPM dynamic range. For an intensity, offset's rms variation represents the resolution of the BPM.

Let's assume that a residual offset should be less than the position uncertainty of the quadrupole axis. Taking the uncertainty ±0.1mm and the residual offset few times less, for a pickup with radius several tens mm, one can estimate an acceptable error of equalising as close to 10^{-3}.

Fot the position measurement, the equalising device is to pass the pickup signals with a relative error of the same order as above. This error manifests itself as a pickup center shift.

A pickup own coordinate system is two axes of two pairs of opposite electrodes. Each axis can be defined as a population of such beam positions where the signals of the other pair are equal each to other. The axes intersect in the pickup center. With the same position of the center, the pairs may not have the same but different sensitivities to beam displacement. The effect of difference manifests itself far from the center and is usually neglected. Thus, it is acceptable to equalise the signals by pairs and allow some relative error between the pairs.

The equalising device may have crosstalk of the passing signals. Crosstalk $\eta<<1$ reduces BPM's sensitivity to displacement as $K(1-\eta)$, where K is sensitivity of the pickup.

A device is developed to equalise a pair of signals. To measure both X,Y-components of BPM's offset, two devices are to be used. The devices are inserted in a BPM close to the pickup.

The device is intended for subnanosecond bunches. It consists of a pair of irregular directional couplers and a switch between their outputs. To measure the offset, the output signals, i.e. the BPM input signals, are made equal by the switch short. The position is measured when the switch is open.

Representing the output signals as combinations of common and differential modes $(1-\Delta)$ and $(1+\Delta)$ and noting that the differential mode reflected from a short diode is absorbed on the upstream end, a residual differential mode signal on an output can be written as $\delta=\Delta\cdot(r/2Z)$, where r is diode resistance, Z is line impedance. The error of equalising is 2δ. It increases linearly with beam displacement. With $Z=50\Omega$, $r=0.8\Omega$, $2\delta=\Delta/60$. For displacement $(1+\Delta)/(1-\Delta)=6$dB, $2\delta=5\cdot10^{-3}$.

The device has other functions as well. It loads the pickup electrodes on resistive impedance in the bandwidth of the pickup signals. It conditions the signals to have them suitable for a BPM. It has 50Ω output impedances and it absorbs signals reflected from the BPM inputs. It has two optional lossless outputs of the primary signals and can be used as a precise splitter of the signals to another BPM.

The device is made as a PCB $160*70\text{mm}^2$ with two outside conducting surfaces. A directional coupler is made as two strip transmission lines between the surfaces. As a switch, a pin-diode is used. It is controlled by an external bias current/voltage via the pair of the BPM input cables. The circuit is shown in Figure 1. A pin-diode is installed between the vertexes of the ticks of the output lines. On the opposite ends of the lines, DC-blocking capacitors and 50Ω-resistors are installed.

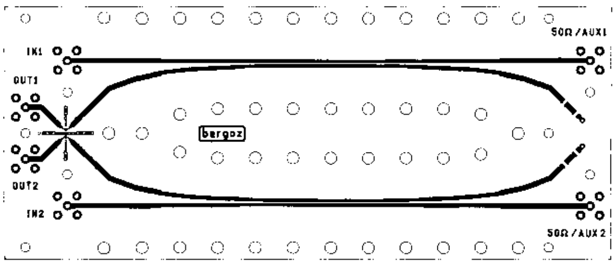

Figure 1: Circuit of the equalising device.

In the range 30MHz-2.8GHz, the input/output SWR is less than 1.4/1.3 correspondingly. Crosstalk through capacitance of the open diode is (−28)dB on 500MHz.

An irregular coupler is used to convert a short pulse to a comparatively narrow-band signal as a single sine wave, with amplitude independent on bunch duration. For a weak coupling $W\cdot f(z)$, $W<<1$, where $f(0)=f_{max}=1$ and $f(L/2)=f(-L/2)=0$, a signal on the upstream end (−L/2) is [8]:

$$V(-L/2;t)=jvW\cdot(Z/2)\cdot F(vt/2-L/2), \qquad (2.1)$$

where $F(z)=df(z)/dz$, $J=jv\delta(vt-z)$ is a δ-function current in the input line, Z is impedance and v is wave velocity in the lines. Thus, a single sine wave as an output signal is provided by coupling $f(z)=(1/2)\cdot[1+\cos2\pi(z/L)]$. Coupler's frequency-domain and time-domain responses measured with a network analyzer are shown in Figure 2.

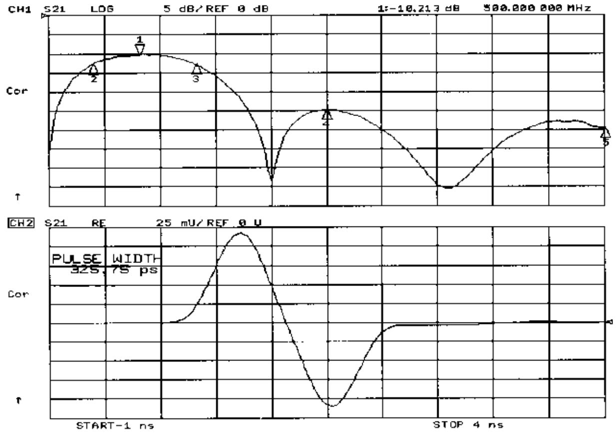

Figure 2: Frequency-domain and time-domain responses of the coupler. CH1 markers: 2: 250MHz, (−12.8)dB; 3: 800MHz, (−12.8)dB; 4: 1.5GHz, (−24.8)dB; 5: 3GHz.

The central frequency is 500MHz, insertion loss 10dB, bandwidth is (250-800)MHz, attenuation in the range (1-3)GHz is more than 15dB.

With the signal above, device's dynamic range is independent on bunch duration. The range can be found from the condition that a differential signal $V\cdot 2\Delta$ applied to the open diode is not to exceed the bias voltage V_b. With displacement 1/3 of radius and $V_b=V_{rev}=50$V where V_{rev} is diode reverse voltage, the upper end of the dynamic range is around 70nC of bunch charge.

The device is developed for enhancement of the center accuracy of the Log-Ratio BPMs manufactured by Bergoz Instrumentation [6]. 80 devices were tested using Network Analyzer HP8753D and precise 50Ω-terminals. As Analyzer's errors are comparable with device's errors, the errors of an individual device can not be directly measured. On 500MHz, an average error of pickup center shift is $(-2)\cdot 10^{-3}$ with rms variation $(\pm 5)\cdot 10^{-3}$. For beam displacement 6dB, an average error of equalising is $5\cdot 10^{-3}$ with rms variation $(\pm 6)\cdot 10^{-3}$.

3 RESOLUTION

BPM's resolution as rms variation σ_{bpm} of the center offset measured with the instrument described above can be determined as well. Position rms variation σ_{pos} is $(\sigma_{pos})^2=(\sigma_{vbr})^2+(\sigma_{bpm})^2$ where σ_{vbr} is rms amplitude of a beam vibration. Thus, the fact that $\sigma_{pos}>\sigma_{bpm}$ means that some vibration has been there. Its rms amplitude can be calculated as

$$\sigma_{vbr}=\mathrm{sqrt}[(\sigma_{pos})^2-(\sigma_{bpm})^2]. \qquad (3.1)$$

Another beam-based method of resolution/vibration measurement [5] can be used when all four BPM's output signals A,B,C,D are available for digitizing and then applying either difference-by-sum algorithm or log-ratio algorithm. Let's consider first the difference-by-sum case. The position is calculated as $X=M_x\cdot(A-B-C+D)/(A+B+C+D)$, $Y=M_y\cdot(A+B-C-D)/(A+B+C+D)$. In [5], a "quadrupole pickup" combination is proposed for determination of resolution:

$$Q=M_q\cdot[(A+C)-(B+D)]/(A+B+C+D). \qquad (3.2)$$

(3.2) is a quite weak function of beam displacement, if it is not far from the pickup center, and dependence can be neglected when a beam vibration is considered. Assuming for simplicity $A\cong B\cong C\cong D$, one can obtain: $\sigma_x,\sigma_y=\sigma_q$, if $M_q=M_x$, M_y. Thus, BPM's resolution can be calculated as

$$\sigma_q=\mathrm{sqrt}\{[\Sigma_i(Q_i-\langle Q\rangle)^2]/n\}. \qquad (3.3)$$

Rms amplitude of vibration can be calculated using (3.1).

This method can be extended to log-ratio algorithm. The BPM output signals are a=lgA, b=lgB, c=lgC, d=lgD. The position is calculated as $X=m_x\cdot[\lg(A/C)-\lg(B/D)]$ and $Y=m_y\cdot[\lg(A/C)+\lg(B/D)]$ [6], or $X=m_x\cdot\lg(AD/BC)$ and $Y=m_y\cdot\lg(AB/CD)$. A combination similar to (3.2) is:

$$q=m_q\cdot[(\lg A+\lg C)-(\lg B+\lg D)]=m_q\cdot\lg(AC/BD), \qquad (3.4)$$

and with the same assumption, $\sigma_x,\sigma_y=\sigma_q$, if $m_q=m_x$, m_y. The BPM resolution and rms amplitude are calculated as (3.3) and (3.1) accordingly.

4 SUMMARY

Beam-based methods to measure BPM's center offset with reference to the pickup center and BPM's resolution have been proposed. Being built in a BPM, the methods provide a reliable and accurate BPM verification. The methods can be used for measurement of rms amplitude of beam vibrations as well.

A device has been developed for subnanosecond bunches to measure BPM's center offset and resolution. It has accuracy close to 10^{-3} and is used in Bergoz Instrumentation Log-Ratio BPMs.

5 ACKNOWLEDGEMENT

I would like to thank J.Bergoz and K.Unser for useful discussions, R.Lubes and M.Buffou for their collaboration

6 REFERENCES

[1] P.Rojsel, "A Beam Position Measurement System Using Quadrupole Magnets Magnetic Centra As The Position Reference", NIM A343, 1994, p.374-382.

[2] S.Sasaki, K.Soutome and H.Tanaka, "Beam-Based Calibration Of BPM Position Sensitivity At SPring-8 Storage Ring", The 10-th Beam Instrumentation Workshop (BIW02), BNL, May 2002, to be published.

[3] J.Safranek, "Beam-Based Modelling And Control Of Storage Ring", PAC'97, Vancouver, May 1997, p.708-712.

[4] C.-X.Wang, M.Borland, V.Sajaev at al, "BPM System Evaluation Using Model-Independent Analysis", PAC'01, Chicago, June 2001, p.1354-1356.

[5] A.Kalinin, V.Smaluk, "Analysis Of Transverse Beam Motion", was presented at HEACC'98, Dubna, 1998.

[6] A.Kalinin, "The Log-Ratio Beam Position Monitor", The 10-th Beam Instrumentation Workshop (BIW02), BNL, May 2002, to be published.

[7] P.S.Prieto, a communication on Discussion on the 10-th Beam Instrumentation Workshop (BIW02), BNL, May 2002.

[8] A.S.Kalinin, M.M.Karliner, "Strip Line Monitor: Theory And Experimental Results", HEACC'92, Hamburg, July 1992, p.266-268.