Proc. 13th International Beam Instrumentation Conference,Beijing JACoW Publishing
ISBN: 978-3-95450-249-3 ISSN: 2673-5350 doi: 10.18429/JACoW-IBIC2024-TUP41

TEST OF BPM CABLES VS TEMPERATURE AND HUMIDITY*

Chongyang Liang†,1, Jun He
Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China
[1]also at University of Chinese Academy of Sciences, Beijing, China

Abstract

Measuring the absolute position of the beam in the intensifier and storage ring of a high energy photon source (HEPS) requires measuring the offset between the electrical and mechanical centers of the beam position monitor (BPM). In the HEPS project, a four-electrode BPM is used, and the signals from each of the four electrodes of the BPM probe are led out by a cable. During the operation of the intensifier and storage ring, the influence of ambient temperature and humidity on the BPM cable and the difference between the four channels will directly lead to changes in the BPM measurement results. In this paper, vector network analyzer (VNA) is used to test the data of signal amplitude change of two BPM cables within ten hours when temperature and humidity change. The conclusion is that the influence of temperature on the signal is about 0.01 dB/℃, the influence of humidity on the signal is about 0.05 dB/10%, and the relative change between channels is about 5%.

INTRODUCTION

The High Energy Photon Source (HEPS), a fourth-generation high-performance synchrotron radiation source under construction in China, is designed with an electron energy of 6 GeV and boasts an ultra-low emittance of 34.2 pm·rad and a brightness reaching $5 \times 10^{22}\ \mathrm{s^{-1}mm^{-2}mrad^{-2}}$. Composed of a 500 MeV linear accelerator, a booster, a storage ring with a circumference of 1360.4 meters, a low-energy transport line, two high-energy transport lines, and a beam dump line, the schematic of the device is shown in Fig. 1 [1]. Upon completion, HEPS is expected to alleviate the tight supply and demand situation for experiments, providing a higher level platform for scientific research.

The beam position monitoring system is an essential component of particle accelerators, capable of directly measuring beam position information as well as indirectly calculating critical parameters such as working points, dispersion, and chromaticity. The various data obtained through the beam position monitoring system are employed to optimize the operational state of the device, ensuring the stable functioning of the accelerator.

Submicron-level stability requirements for the beam trajectory at the High Energy Photon Source (HEPS) necessitate a precise beam position measurement system along with a trajectory feedback system. The vertical dimension of the beam in the HEPS storage ring reaches a minimum size of approximately 1 μm, demanding a beam position monitor (BPM) resolution on the order of 0.1 μm and trajectory control accuracy around 0.3 μm [2]. To meet such stringent criteria, strict quality control of the BPMs used in HEPS is essential, and the performance of the cables under environmental influences must also be considered. This study has tested the signal amplitude of BPM cables for the high-energy synchrotron radiation source under varying temperature and humidity conditions using a vector network analyzer.

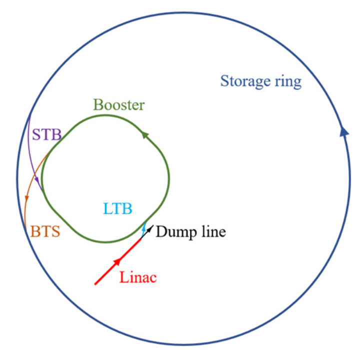

Figure 1: Schematic diagram of the HEPS.

BPM SYSTEM

A complete beam position measurement system is typically comprised of two main components: BPM probes and BPM signal processing electronics, often connected by coaxial cables, with the basic structural framework illustrated in Fig. 2. The BPM probes are designed to detect electromagnetic field signals produced as the beam passes, thereby acquiring information on the beam's position. Each BPM probe consists of a cavity with two or four symmetrically arranged electrodes, depicted in the left section of Fig. 2. The signals captured by the BPM probes are transmitted via coaxial cables to the BPM signal processing electronics, where they first undergo processing by the Analog Front End (AFE) circuitry to handle the analog signals. Subsequently, these signals are converted into digital signals by the Digital Front End (DFE), and after algorithmic processing, the final beam position information is obtained.

BPM probes consist of a cavity that mirrors the shape of the vacuum pipe and four symmetrically arranged electrodes. These electrodes capture electromagnetic field signals generated by the beam, which are then converted into electrical signals and transmitted through the output port to the connecting cable. BPM probes are typically situated near the quadrupole magnets of the accelerator. There are various types of BPMs, with button and stripline types being the most commonly utilized.

* Chongyang Liang. Work for accelerator beam measurement and control.
† liangcy@ihep.ac.cn

ISBN: 978-3-95450-249-3 ISSN: 2673-5350 doi: 10.18429/JACoW-IBIC2024-TUP41

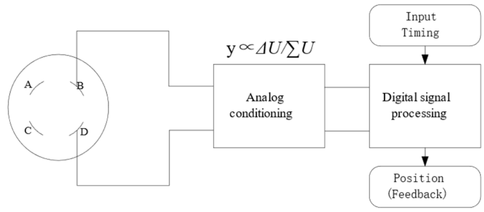

Figure 2: Basic structure of BPM system.

The button type BPM is the most widely used BPM probe due to its simple structure, compact design, and low production cost. Typically, a button type BPM comprises a cavity and four symmetrically arranged button-type feedthroughs. Each button-type feedthrough integrates a button electrode, a coaxial connector (inner core of the electrode), and an isolation support structure into a single component. The shape of the electrode resembles a button, and each electrode is located at the end of a coaxial transmission line connector with a characteristic impedance of $Z_0 = 50\ \Omega$.

The stripline BPM model is depicted in Figs. 3 and 4., requires an optimized design of various parameters such as the spread angle α, thickness t, and the distance h between the electrode and the probe. To maximize the signal, the spread angle of the stripline electrodes is generally designed to be as large as possible. However, an excessively large α can lead to inter-electrode coupling, thereby affecting the resolution of the BPM system. The thickness t of the electrode is primarily considered with respect to the cavity space and to ensure mechanical strength of the electrodes. Additionally, to minimize signal reflection impacting the electrode output signal, the characteristic impedance of the electrode should match the characteristic impedance of the coaxial cable, typically 50 Ω. The characteristic impedance Zstrip of a single stripline electrode can be calculated using the following formula, where rin represents the distance from the inner side of the stripline electrode to the center of the cavity [3].

$$\begin{aligned} Z_{\text{strip}} &= 60\frac{2\pi}{\varphi}\ln\frac{r_{\text{in}}+h+t}{r_{\text{in}}+t}, \\ \varphi &= \frac{w}{r_{\text{in}}} + \frac{2\pi h}{2\times(r_{\text{in}}+h+t)-h}, \\ w &= \alpha\times\left(r_{\text{in}}+\frac{1}{2}t\right) \end{aligned} \tag{1}$$

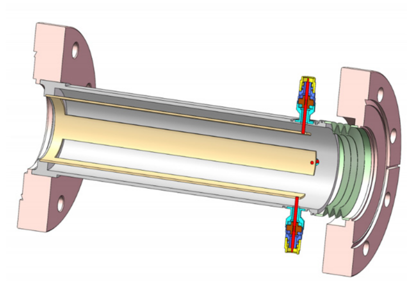

Figure 3: Schematic diagram of the stripline BPM.

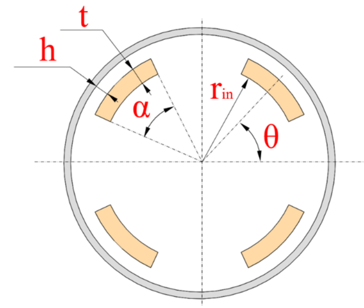

Figure 4: Strip line BPM cross-section diagram.

In an ideal scenario, the output signal from the electrodes can be represented as follows:

$$U_{\text{strip}}(t) = \frac{Z_{\text{strip}}}{2}\cdot\frac{\alpha}{2\pi}\cdot\left[e^{-t^2/2\sigma_t^2} - e^{-(t-2l/c)^2/2\sigma_t^2}\right]\cdot I_0, \tag{2}$$

Compared to button-type BPMs, stripline BPMs require a larger longitudinal installation space. However, stripline electrodes also offer numerous advantages. The characteristics of button-type BPMs and stripline BPMs are shown in Table 1.

Signal processing electronics are utilized to adjust and process signals originating from BPM probes, providing beam position information in digital form for acquisition by the accelerator control system.

The output signals from BPM probes require conditioning through appropriate radio frequency circuits and a digital processing unit, after which beam position information is calculated. The most commonly used processing methods are: the logarithmic ratio method, amplitude to phase conversion (AM/PM) method, and the difference and ratio method.

Table 1: Comparison Between Button-type BPM and Stripline BPM

	Button-type BPM	**Stripline BPM**
Coupling mode	Capacitance	Capacitance, inductance
Signal strength	Lesser	Larger, depending on azimuth
Signal quality	Because of the limited size and capacitance, the signal may be distorted	Less distortion
Mechanical structure	Easy	Complex
Installation position	Small size, can be installed in many places	Generally located in the linear accelerator, requires a large installation space
Directional coupling	No	Yes

ISBN: 978-3-95450-249-3 ISSN: 2673-5350 doi: 10.18429/JACoW-IBIC2024-TUP41

In the logarithmic ratio (Log-Ratio) signal processing method for beam position monitors (BPM), the signals induced by the electrodes of the BPM probes are subjected to band-pass filtering through the RF link. Subsequently, these signals are fed into a logarithmic amplifier. The output from the logarithmic amplifier is then processed through a differential amplifier for the computation of the ratio of the data, facilitating the normalization of the BPM signals. Ultimately, this process yields the amplitude of the BPM signal. The output of the logarithmic ratio circuit is given as:

$$V_{out} = k_y \log\frac{A}{B} = k_y(\log A - \log B) \approx k_y \cdot r, \quad (3)$$

The Amplitude-to-Phase Conversion (AM/PM) method operates in the frequency domain. Its principle involves splitting signals from two BPM electrodes, which have the same phase but different amplitudes, into four channels. Subsequent quadrature synthesis, which introduces a 90-degree phase difference at the processing frequency, results in signals of equal amplitude but different phases. The phase difference between these two signals correlates with the amplitude difference of the original input signals.

The difference and ratio processing method allows for the real-time processing of signals in both the time and frequency domains. Typically, this method handles carrier frequencies exceeding 1 GHz and achieves a bandwidth greater than 100 MHz. It exhibits a relatively low input dynamic range and moderate linearity in offset response, without achieving normalized response. The noise figure of its amplifiers is extremely low, and the results are influenced by the phase characteristics of the cables. The output of the logarithmic ratio circuit is as follows:

$$V_{out} = k_y \frac{A - B}{A + B}, \quad (4)$$

A comparison of the transmission equations for the three position processing methods is presented in Table 2.

Table 2: Comparison of Transmission Equations of Three Position Algorithms

Property	Log-Radio	AM/PM	The division of the difference by the sum
Carrier frequency range	~2.7GHz	~500MHz	>200MHz
bandwidth	<100MHz	<10MHz	>100MHz
Dynamic range	large	large	small
Complexity	medium	high	low
Cost	medium	high	low

TEST OF BPM CABLES

Signal attenuation occurs during the transmission from the probe to the electronics via cables. This study aims to investigate how variations in humidity and temperature affect the amplitude of signals transmitted through BPM cables, with a particular focus on testing the relative drift among multiple cables, as common drift across all cables does not impact position measurement.

To meet the performance requirements of HEPS, environmental conditions similar to those of the HEPS storage ring BPM installation and operational environment were simulated in the laboratory. The constant temperature inside the HEPS storage ring tunnel is maintained at 25 °C ± 0.1 °C, with humidity ranging from 20 % in winter to 70 % in summer. This study utilized a temperature-controlled chamber with a volume of 400 L, capable of adjusting temperatures from 0 °C to 50 °C. The experimental setup constructed is depicted in Fig. 5, featuring a radio frequency signal generator on the left, the SMC 100 A (Rohde & Schwarz), which provides a continuous wave at 499.8 MHz. In the center, a four-channel power splitter, the ZFSC-4-1-S+, with a bandwidth of 10-2000 MHz, is used. On the right, a four-channel vector network analyzer (VNA), the ZNB4 (Rohde & Schwarz), is positioned. Additionally, a temperature and humidity data logger was placed inside and outside the temperature-controlled chamber. The experiment tested two types of cables: PWB480 (30 m) and LMR240 (30 m).

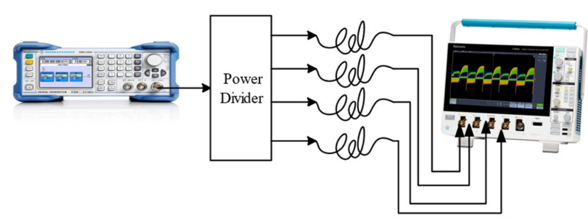

Figure 5: Experimental platform structure diagram.

In the experiment, two temperature and humidity data loggers were employed to record the variations within and outside the temperature-controlled chamber. Due to the slow rate of change in temperature and humidity, measurements were set to be recorded every 10 seconds. The radio frequency signal generator was configured to output a continuous wave of 499.8 MHz (with signal amplitude set at -20 dBm), which was then divided into four identical signals by a four-channel power splitter, and transmitted through the test cables to the vector network analyzer. The vector network analyzer was set to continuous wave (CW) mode, recording the amplitude of the signals from all four channels every 10 seconds. The initial temperature of the temperature-controlled chamber was set at 25 °C with a humidity of 50 %, and upon heating for four hours, the target temperature of 30 °C was reached, with a humidity level adjusting to 39 %. After stabilizing the temperature, the heating was turned off, and over the next six hours, the temperature and humidity returned to their initial states.

ISBN: 978-3-95450-249-3 ISSN: 2673-5350 doi: 10.18429/JACoW-IBIC2024-TUP41

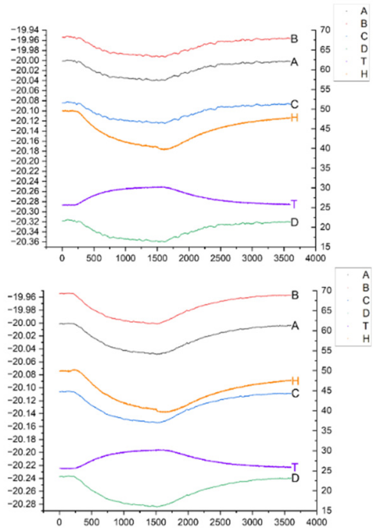

Figure 6: PWB480 (up) and LMR240 (down) test results.

The changes in signal amplitude over a ten-hour period due to variations in temperature and humidity for two types of cables are illustrated in Fig. 6, where A, B, C, and D represent the signal amplitudes of the four channels, T represents temperature, and H represents humidity. It is observed that for every 1 °C increase in temperature, the signal amplitude decreases by approximately 0.01 dB; similarly, for every 10 % decrease in humidity, the signal amplitude decreases by approximately 0.05 dB, while the relative change in signal amplitude among the four channels is about 5 %. Compared between the two types of cables, LMR240 is more sensitive to changes in external temperature and humidity than PWB480.

CONCLUSION

The beam tuning work for the High Energy Photon Source is being vigorously carried out, and as an integral component of particle accelerators, the precise detection by the beam position measurement system is crucial for achieving the beam trajectory stability required by HEPS. This study primarily investigates how environmental temperature and humidity variations affect the amplitude of signals transmitted through BPM cables. The experimental findings indicate that an increase in temperature impacts the signal amplitude by approximately -0.01 dB/°C, a decrease in humidity affects the signal by about -0.05 dB/10%, and the relative change among the channels is around 5%.

REFERENCES

[1] Y. Jiao *et al.*, “The HEPS project,” *J. Synchrotron Radiat.*, vol. 25, no. 6, pp. 1611–1618, Sep. 2018. doi:10.1107/S1600577518012110

[2] P. He *et al.*, “Progress of HEPS Accelerator System Design,” in *Proc. IPAC2019*, Melbourne, Australia, May 2019, pp. 633-635. doi:10.18429/JACoW-IPAC2019-MOPRB027

[3] J. He *et al.*, "Beam Position Monitor Design for the High Energy Photon Source," *Meas. Sci. Technol.*, vol. 33, p. 115106, Aug. 2022. doi:10.1088/1361-6501/ac8277