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A Method of Correcting the Beam Transverse Offset for the Cavity Bunch Length Monitor*

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Abstract

Cavity bunch length monitor uses monopole modes excited by bunches within the cavities to measure the bunch longitudinal root mean square (rms) length. It can provide a very high accuracy and high resolution. However, when the bunch passes through the cavities with transverse offset (that is, the bunch moves off the cavity axis), the amplitude of the monopole modes will change and cannot reflect the bunch length precisely. In this paper, a method of correcting the beam transverse offset is proposed. Simulation results show that the method can reduce the error of the bunch length measurement significantly.

BACKGROUND

When a bunch passes through the cavity, many monopole modes such as TM010 mode and TM020 mode are excited. The output voltage of a monopole mode can be written as

$$V = \frac{1}{2}\omega q\sqrt{\frac{Z(R/Q_0)}{Q_{ext}}}\exp\left(-\frac{\omega^2\sigma^2}{2}\right) \quad (1)$$

We need at least two monopole modes in different frequencies, and the bunch charge q and the bunch length σ can be obtained by solving the simultaneous equations

$$\begin{cases} V_1 = \frac{1}{2}\omega_1\sqrt{\frac{Z(R/Q_0)_1}{Q_{ext1}}}q\ \exp\left(-\frac{\omega_1^2\sigma^2}{2}\right) \\ V_2 = \frac{1}{2}\omega_2\sqrt{\frac{Z(R/Q_0)_2}{Q_{ext2}}}q\ \exp\left(-\frac{\omega_2^2\sigma^2}{2}\right) \end{cases} \quad (2)$$

It follows that the bunch length can be described as

$$\sigma = \sqrt{2\ln[k_2V_1/(k_1V_2)]/(\omega_2^2-\omega_1^2)} \quad (3)$$

According to the requirements of FELiChEM, the cavity bunch length monitor has been designed. It is shown in Fig.1. This monitor is composed of two cavities. The TM010 mode in the first cavity and the TM020 mode in the second cavity are used to measure the bunch length. The two modes resonate at 0.9515 GHz and 6.1847 GHz, respectively. The signal coupler consists of two coaxial probes with axial symmetry.

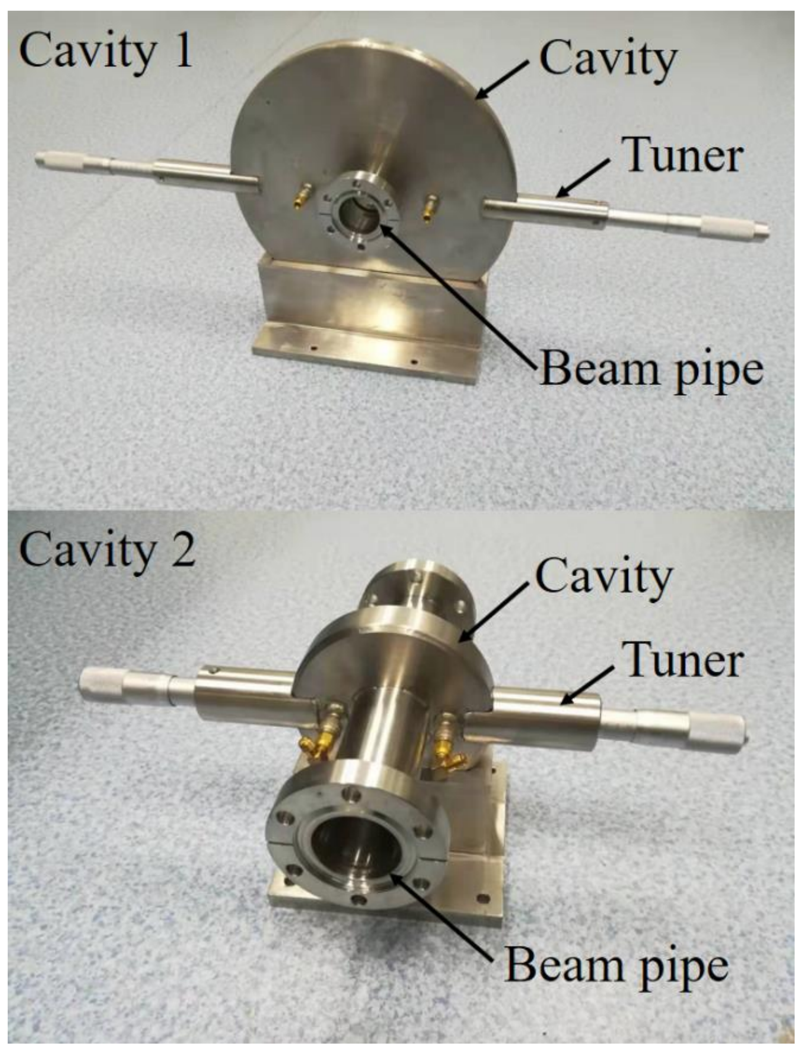

Figure 1: The cavity bunch length monitor.

ERROR OF BEAM OFFSET

Compared with moving on axis, the beam passes the cavity with a small offset leads to the electric field intensity of the two modes decrease slightly on the beam orbit, witch means the output voltages decline. Although the amplitude of the signal of the TM010 mode is insensible to the beam offset, it is still changing with the position. Meanwhile, when a bunch passes off axis of the cavity, a series of dipole modes such as TM110 are excited. The dipole modes have effect on the monopole modes. This interference is still exist even through the TM110 mode is narrow-band. According to Eq. (3), any small changes of V_1/V_2 will bring about great impact on the measuring results. Therefore, the influence of beam transverse offset on the bunch length measurement must be taken into account.

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ERROR CORRECTION

In Eq. (1), (R/Q_0) is the normalized shunt impedance, which can be described as

$$\frac{R}{Q_0} = \frac{\left|\int \mathbf{E}ds\right|^2}{\omega U} \quad (4)$$

Where U is the stored energy of the mode in the cavity, and the numerator indicates integration of the electric field of the mode along the beam orbit. The longitudinal electric field of the TM_{0n0} mode in a cylindrical cavity can be described as

$$E_z = E_0 J_0\left(\frac{y}{r}u_{0n}\right)e^{-j\beta z} \quad (5)$$

Where E_0 is a constant, $J_0(x)$ is zero order Bessel function, y is the beam transverse offset, r is the cavity radius, u_{0n} is the nth root of zero order Bessel function, and the exponential term represents vibration. According to Eq. (3), it can be seen that the amplitude of the monopole mode depends on the Bessel function term. The correction coefficient η can be defined as

$$\eta = \frac{E_{z,axis}}{E_{z,offset}} = \frac{J_0(0)}{J_0(\frac{y}{r}u_{0n})} = \frac{1}{J_0(\frac{y}{r}u_{0n})} \quad (6)$$

Specific correction method is as follows. First, according to the cavity dimension and the beam position obtained from BPMs, calculate the correction coefficient η. Then, multiply the output voltages of the monopole modes by η. Finally, take the output voltages revised into Eq. (3) and calculate the bunch length.

- *Simulation Results*

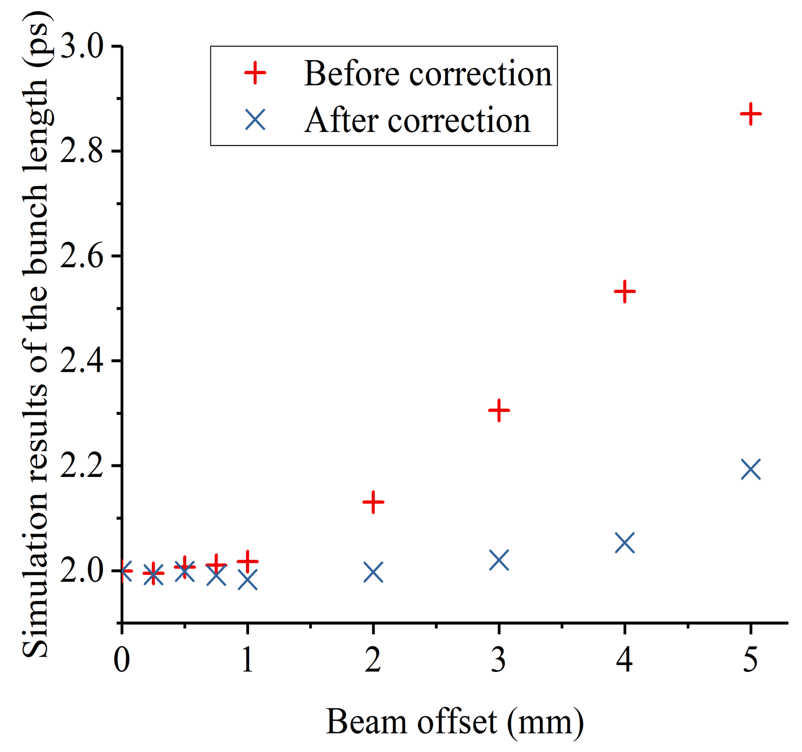

Figure 2: Simulation results of two-picosecond bunch length measurement.

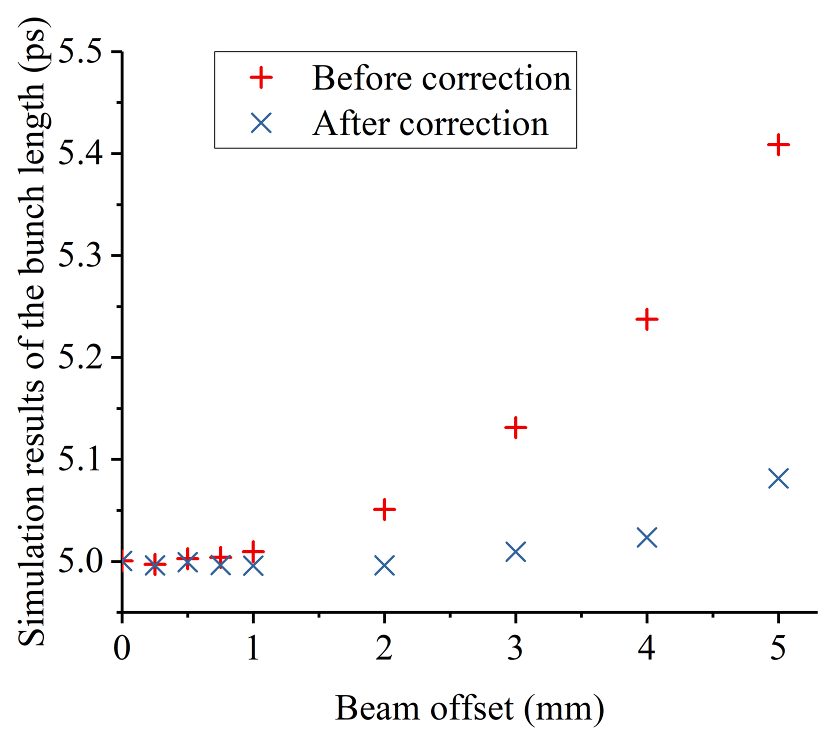

Figure3: Simulation results of five-picosecond bunch length measurement.

It can be seen that the relative errors of the bunch length measurements brought by the beam transverse offset reduce significantly after correction. For large offset, this error correction effect is more obvious.

However, this method can only correct the errors brought by the beam offset. For the interference from dipole modes, it can do nothing. In addition, this correction method depends on the information of the beam position obtained from BPM. As an improvement, the cavity itself can also be used to evaluate the beam transverse position roughly, because the different signal of the coaxial probes with axial symmetry only contain the dipole modes. Although this kind of simple "BPM" cannot provide a high resolution, it is enough for the error correction.