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Characteristic analysis of coupled transmission lines in stripline-type beam position monitor

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ABSTRACT

Signal transmission characteristics in stripline electrodes of a stripline-type beam position monitor (BPM) are discussed on the basis of a coupled-mode analysis in electromagnetically coupled transmission lines. The physical prospect in the calibration procedure of stripline electrodes is improved in terms of signal transmission characteristics in the frequency domain. It is demonstrated that in the signal transmission with electromagnetic coupling between the stripline electrodes, the magnetic- and electric-coupling parameters play an important role depending upon the spatial configuration and mechanical structure of the stripline electrodes. In this report, a theoretical analysis, and experimental investigation into signal transmission characteristics and performance in a standard stripline-type BPM are described in detail on the basis of a coupled-mode analysis in uniform transmission lines.

1. Introduction

A new stripline-type beam position monitor (BPM) system is under development at the KEK electron/positron injector linac in order to measure transverse beam positions with a high precision in the Super KEKB-factory (SKEKB) [1] at KEK. During previous KEKB operation [2,3], conventional stripline-type BPMs with a position resolution of ~ 0.1 mm have been working well for stable injection. A high-precision BPM system with a position resolution of ~ 10 μm is imperative for SKEKB operation in order to achieve further stable acceleration of single-bunch electron and positron beams with high-bunch charges of ~ 5 nC/bunch and to maintain beam stability with higher brightness. New stripline-type BPMs with a larger aperture than previous BPMs have been designed, which will be installed after the positron capture section.

A stripline-type BPM is a well-known beam diagnostics device used to measure transverse beam positions in a plane perpendicular to the beam axis. There are many excellent review articles on this subject (see, for example, [4,5]). In general, a stripline-type BPM has four stripline electrodes mounted on the inner surface of a circular pipe with $\pi/2$ rotational symmetry. The upstream port of the stripline electrode is a signal pickup port whereas the downstream one may be short- (or 50 Ω) terminated to the pipe ground or left open.

When a charged-particle beam passes through the BPM, a characteristic signal with a bipolar shape is induced in all the stripline electrodes due to electromagnetic coupling between the electrodes and the beam. The induced signals are fed into detection electronics through vacuum-feedthrough pickups for the measurement of their signal intensities. The transverse beam positions can be calculated using a weighted average of the four signal intensities based on algebraic calculations. This is a basic principle for measuring transverse beam positions with a stripline-type BPM.

The signal intensity induced in each stripline electrode can generally be analyzed based on the so-called wall-current model [4], in which the wall current is a mirror current induced in the stripline electrode. Based on this model, the signal intensity may be proportional to the intensity of the wall current, *i.e.*, the beam charges, and it may also be proportional to the angular width of the stripline electrode. Such an analysis may be fundamentally based on an electrostatic model that accounts only for the electrostatic coupling between the stripline electrodes and the beam.

In conventional stripline-type BPMs, there are some variations in the spatial configuration and mechanical structure of the stripline electrodes. The stripline electrode which has a finite angular width as viewed from the beam may be mounted with a certain gap between the electrode and the inner surface of the pipe. In such a mechanical spatial configuration, electromagnetic coupling may dynamically appear between the electrodes and also between the electrodes and the beam, and thus, the signal intensities may differ to some extent from those of the wall-current model.

From another point of view for a signal-gain calibration in a stripline-type BPM, it is important to analyze the electromagnetic coupling strengths between the stripline electrodes. An excellent calibration procedure has been implemented to stripline-type BPMs by Medvedko et al. of SLAC National Accelerator Laboratory (SLAC) [6]. In this calibration procedure, an on-board calibrator embedded in the

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detection electronics sends a calibration signal to one of the electrodes. When the calibration signal is fed into the electrode, similar bipolar signals are induced in the other electrodes due to electromagnetic coupling. The induced signal returns to the corresponding channel in the detection electronics where the signal intensity is precisely measured. Thus, in this calibration procedure, the signal gains in the detection electronics can be calibrated, and in addition, the transmission losses throughout the transmission lines including the stripline electrodes themselves can also be calibrated with high precision. This new calibration procedure uses the electromagnetic coupling between the stripline electrodes.

Although electromagnetic coupling between the stripline electrodes is an important physical phenomenon in a stripline-type BPM, only a few analyses have been performed to investigate the signal transmission characteristics while accounting for the electromagnetic coupling between the electrodes. A new analysis of the signal transmission characteristics in a stripline-type BPM is presented in this paper and the physical prospect in the calibration procedure for stripline electrodes is clearly improved. This new analysis exploits a similar method developed for microstripline circuits with electromagnetic coupling. Based on this new analysis, the signal transmission characteristics in a stripline-type BPM are systematically investigated in the frequency domain along with experimental verification.

2. Stripline-type beam position monitor

Mechanical drawings of two different stripline-type BPMs are shown in Fig. 1. The first is the previous BPM as shown in Fig. 1(a) and (b), and the second is the new prototype stripline-type BPM as shown in Fig. 1(c) and (d).

A new BPM with a large aperture is under development for the new positron beam line at the SKEKB to reduce the beam losses in the positron transmission to the extent possible. The mechanical structure of both the BPMs is a conventional stripline-type BPM with $\pi/2$ rotational symmetry. The development of the previously designed BPM is reported in detail elsewhere [7]. The requirements for the new BPM are that (i) the aperture diameter must be as large as possible and larger than 60 mm, and (ii) the outer diameter of the BPM must be 68 mm so that the BPM body can be precisely mounted inside the bore of a quadrupole magnet.

Based on these requirements, in order to enlarge the aperture diameter of the BPM, the four electrodes were mounted symmetrically on the inner surface of a pipe with the same diameter, while the electrodes of the previous BPM were designed to protrude away from the inner surface of a pipe with a different diameter. The electrode lengths in both cases are the same (132.5 mm) and the angular widths of the electrodes in the previous and new BPMs are 60° and 36°, respectively. The characteristic impedance of the stripline electrodes has been designed to be $\sim 50\,\Omega$ so as to match with a characteristic impedance of the signal transmission line. The upstream port of the electrode is a signal-pickup port comprising a 50-Ω SMA-type vacuum-feedthrough while the downstream port is short-terminated to the pipe ground. The main mechanical design parameters of the BPMs are summarized in Table 1.

3. Signal transmission characteristics

3.1. Electromagnetic coupling between the stripline electrodes

Fig. 2 illustrates the principal concept of electromagnetic coupling between the stripline electrodes.

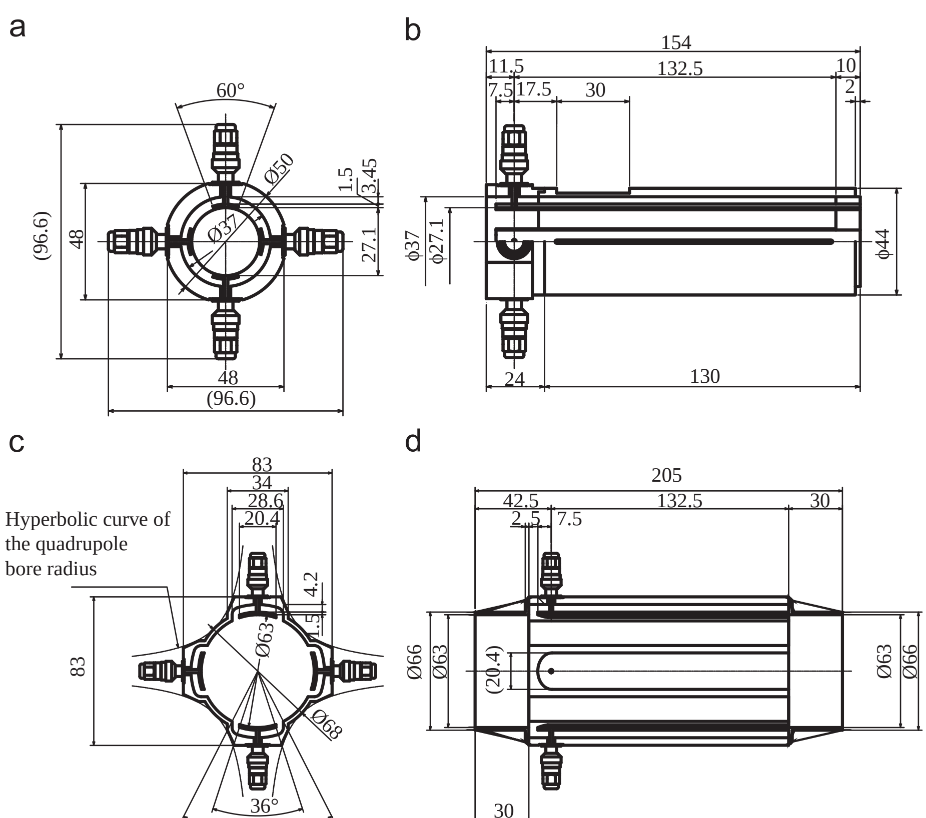

Fig. 1. Mechanical drawings of the previous and new prototype stripline-type BPMs, (a) front view, (b) side view of the previous BPM, (c) front view and (d) side view of the new BPM.