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Electrodes for Beam Position Monitors for Fourth Generation Synchrotron Radiation Source

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Abstract—Fourth-generation synchrotron radiation sources demand new quality for the electron beam diagnostic systems. Some of diagnostic system elements have to be accurately developed or redeveloped due to match the new requirements. Beam position monitor (BPM) is a most used detector and tens (even hundreds) BPMs are installed in numerous positions along beam transfer lines, booster and storage rings. Modern approach to this device development assumes such features as short transient time, wide bandwidth, high sampling rate, low noise architecture and reasonable production and maintenance price. As a part of the system, the BPM electrodes should meet all those requirements. In this article we describe a development procedure for high quality capacitive electrodes for the BPM. 3D electromagnetic model allows estimation of the sensitivity, frequency response and tolerance requirements for the manufacturing of hundreds of monitors. Presented here equivalent scheme for the electrodes is a basis for the BPM electronics design.

Keywords: synchrotron radiation, light source, beam position monitor

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INTRODUCTION

Nowadays, synchrotron radiation is a powerful tool for studying the properties of materials of a crystalline and polymorphic structure, as well as studying surfaces and the dynamics of surface processes [1], [2], [3]. The requirements imposed on the quality of radiation and, through it, on electron beams in fourth-generation sources, also determine new parameters for diagnostic systems and stabilization of orbits [4]. The most widely used diagnostic instrument are beam position sensors [5]. Its importance increases with the use of alignment technologies of the synchrotron elements from measurements of the beam position. The system of electrodes could be quite complicated depending on application and beam properties [6]. The design of the position sensor for electron ring accelerator is shown in fig. 1. It must meet several basic criteria. In order to be able to separate the individual bunches of electrons, following with a frequency of up to 700 megahertz, sensors and electronics must have the appropriate bandwidth. In the past few years, progress has also been noticeable in the field of electronics, in particular, in the area used in the signal processing system from the position sensor. Commercially available are now wideband amplifiers, high performance analog-to-digital converters ADCs [7], fast field-programmable gate arrays FPGAs. As a result, a broadband version of a position sensor that enables the coordinates measurements for each of several hundreds individual bunches circulating in the light source storage ring can be implemented. The narrowing of the band leads to a lengthening of the transient process and the propagation of a signal from the bunch to the region of signals from subsequent bunches, distorting for them the readings of the position sensor. The sensor should also not affect the beam, creating conditions for unwanted resonances at the harmonics of the electron bunches repetition rate. Therefore the longitudinal and transverse impedances spectra for the electron guide sections with the position detectors should not have pikes in the frequency range up to ten gigahertz. Following the frequency requirements, the electrode geometry was maximally simplified, reducing the number and size of irregularities in the signal path (see the left image in Fig. 1).

Also for comparison, this figure shows the image of the electrode constructed and modeled of detector used for new light source in European synchrotron radiation facility (ESRF, Grenoble, France) [8].

VOLUME ELECTRODYNAMIC MODEL

Modern modeling tools allow us to determine the properties of devices before they are implemented in

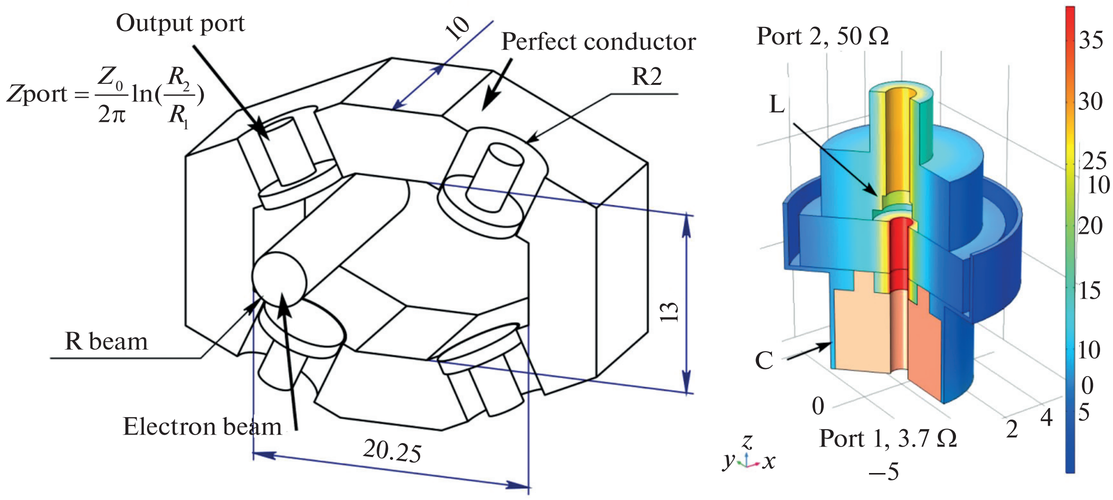

Fig. 1. Construction of the beam position monitor.

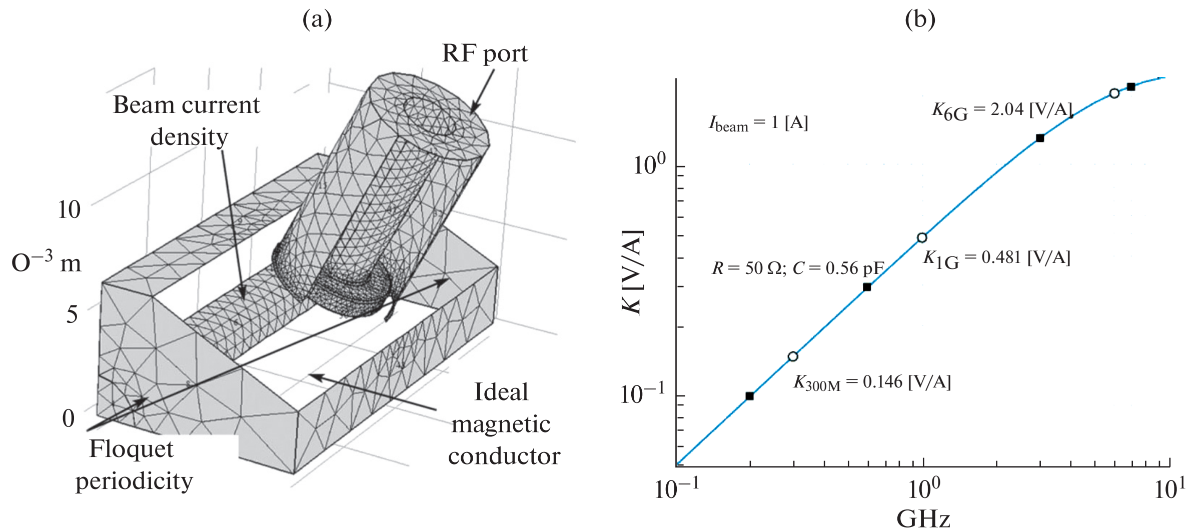

Fig. 2. Partitioning of the region into finite elements and amplitude-frequency characteristic of the electrode.

the form of full-scale samples. In particular, COMSOL™ computer development code [9] was used to study and optimize the design of the position sensor. The three-dimensional model for determining the sensitivity of the electrodes to the magnitude of the beam current is shown in Fig. 2. The decomposition of the current into frequency harmonics was used, therefore the calculations were carried out mainly in the frequency domain. The current was set by the density distribution over the cross section of the cylinder (Fig. 2), the frequency of the harmonic and the velocity of the particles in the longitudinal direction. To facilitate the formulation of boundary conditions at the ends of the model, they were defined as periodicity conditions with a phase shift in accordance with the particle velocity, which for electron energy of 6 GeV almost coincides with the velocity of light. When determining the transmission coefficient between the beam current and the signal at the output of the high-frequency port, the beam was located in the center of the chamber, which allowed using two planes of symmetry.

The results of the simulations were used to simplify the model. The resulting replacement circuit is shown in Fig. 3. The parameters of the coupling capacitance C6 and the voltage source controlled by the current H1 are selected based on the correspondence of the amplitude-frequency characteristic from Fig. 2. To find the values of C6 and the transmission coefficient of a controlled voltage source, three-dimensional simulation data and a specially developed MATLAB [10] code *bpm_equivalent* was used. It determines the

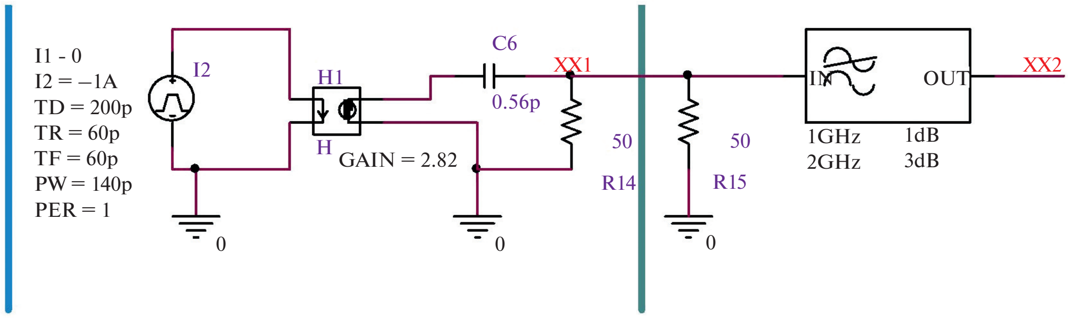

Fig. 3. Substitution diagram of the beam position sensor electrode.

parameters of the equivalent circuit by the least squares method. In order to compare the models, the amplitude-frequency characteristic of the replacement chain is shown in Fig. 2 by black square markers. One can see very good agreement between the three-dimensional model and the substitution scheme. Subsequently, the circuit from Fig. 3 was used to design the electronic part of the position sensor, including frequency analysis, pulse transmission, and noise level estimation in the created device.

WORK AREA OF THE POSITION SENSOR

Geometry with "button" electrodes has much lower linearity of coordinate transformation than, for example, split electrodes used in heavy ion accelerators. In the case of an electron synchrotron, the most important parameter is the frequency properties characterizing the electrodes geometry of the position sensor. Nevertheless, it is important to assess the performance of the position sensor when the beam passes at a considerable distance from the axis of the device. The simulated grid of equal deflection lines, shown in Fig. 4, gives a complete picture of the nonlinear properties of the structure under consideration.

Simulation has shown that for the distance between the electrodes of about 20 millimeters the coordinates of the beam can be transmitted without critical distortion inside the axial cylinder with a diameter of 5 millimeters. Since the projected synchrotron is supposed to use the binding of the magnetic optics elements to the beam trajectory, it is necessary to first bind the position sensor coordinates to the magnetic element ones. At the same time, again from Fig. 4 it follows that the installation of the beam position meter at the magnetic lens axis can be performed with a tolerance of one millimeter. Nevertheless it is absolutely necessary to determine the position of the BPM electrical axis and the lens magnetic axis with a tolerance of ten micrometers.

MANUFACTURING ACCURACY

The excessively stringent requirements for the manufacturing precision of the electrode-vacuum connector assembly lead to an increase in the cost for this part of the position sensor. At the same time, it is often difficult to control electrodes made according to strict specifications when installing, usually by welding, on the seat in the electron guide. Figure 5 shows the sensitivity of the readings from the electrode to the degree of the electrode penetration into the chamber volume. According to the specification, the sensor has to determine the position of the beam with an accuracy better than one percent of the full scale of displacements. It can be seen from the figure that an attempt to ensure such accuracy due to tight mechanical tolerances would lead to the requirements of the micrometer range when elements are fixed by vacuum-tight welding. This, with exact observance, will lead to a marked increase in the cost of the system, multiplied by several hundred instances of position

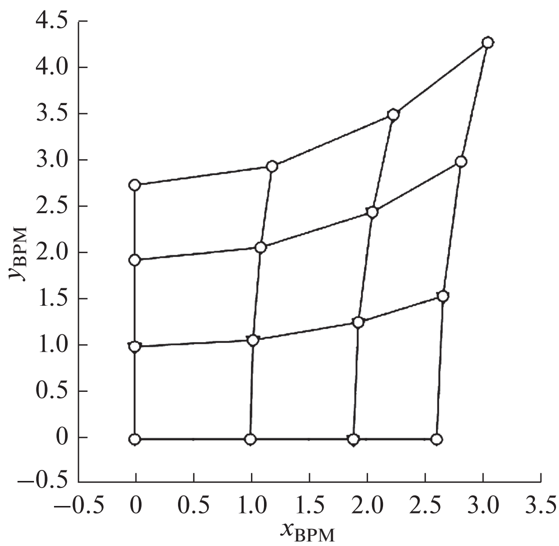

Fig. 4. Distortion of the apparent position of the beam in the 'button' sensor.

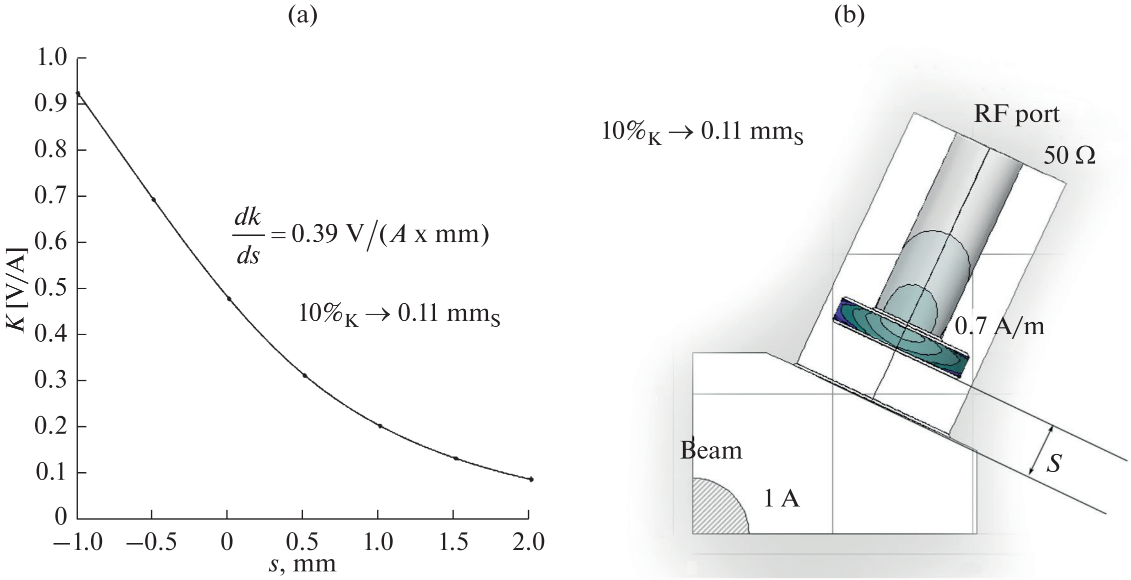

Fig. 5. Signal sensitivity depending on the position of the electrode.

sensors. As result one can conclude that the approach with electronic calibration of the assembled instruments seems more reasonable.

CONCLUSION

Modern electronics can significantly improve the performance of the elements of electron beam diagnostics in ring-type synchrotron radiation sources. There is also a counter-trend: fourth-generation light sources require a corresponding improvement in diagnostics, in particular, beam position sensors. Preliminary design of the position sensor described here provides improved performance of feedback systems due to a better signal-to-noise ratio when measuring coordinates. It will allow to measure the position of each individual bunch with micron-precision for one measurement.

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