BEAM SIZE EFFECTS ON BEAM POSITION MEASUREMENTS IN PROTON SYNCHROTRON

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Abstract

Three-dimensional surface electric charge method has been applied to calculate the effects of the beam size on the beam position measurements. We confirmed that the change of the beam size led to beam position errors. The calculated results were compared with experimental data, indicating the validity of the simulation. The output signal ratio of beam position monitor was smaller when the beam size was large in the horizontal direction. The proposed method can estimate the effects of the beam size when a beam cross section is given.

1 INTRODUCTION

The electrostatic beam position monitor (BPM) is used to measure a closed orbit distortion (COD) produced by the misalignment of magnets in accelerators. BPM is usually calibrated using a straight wire antenna that models an accelerated pencil beam. The relationship between the antenna position and an output signal ratio of the electrodes of BPM is measured[1]. The beam position is estimated using the above relationship. However, the measured data contains significant errors when the cross section of a real proton beam is much larger than that of the calibration antenna; and therefore, it is important to estimate the effects of the beam size on the measurement beforehand.

The author estimated the influence of the beam size in case of a button type BPM for an electron synchrotron using two-dimensional boundary element method, and showed that the measurement error was produced by a large-sized beam[2]. However, a three-dimensional analysis is required for the BPM in a proton synchrotron because of its complicated geometry. We compare the calculated results with experimental results to confirm the validity of the proposed method.

2 BEAM POSITION MONITOR

Figure 1 shows the schematic drawing of the structure of the BPM that is used in the proton synchrotron having a low accelerated current.

The BPM consists of two separated triangular electrodes that are closely located with each other. The electrode size is 190 mm wide and 200 mm long. They are surrounded with the ground board. When the beam deviates from the center of the BPM, the distance from the center is given as a function of an output signal ratio, $(V_L - V_R)/(V_L + V_R)$, where V_L and V_R are output voltages on the two electrodes. The relationship between the output signal ratio and the horizontal beam position is usually measured using the antenna in advance. An actual beam's position is determined using the calibration curve.

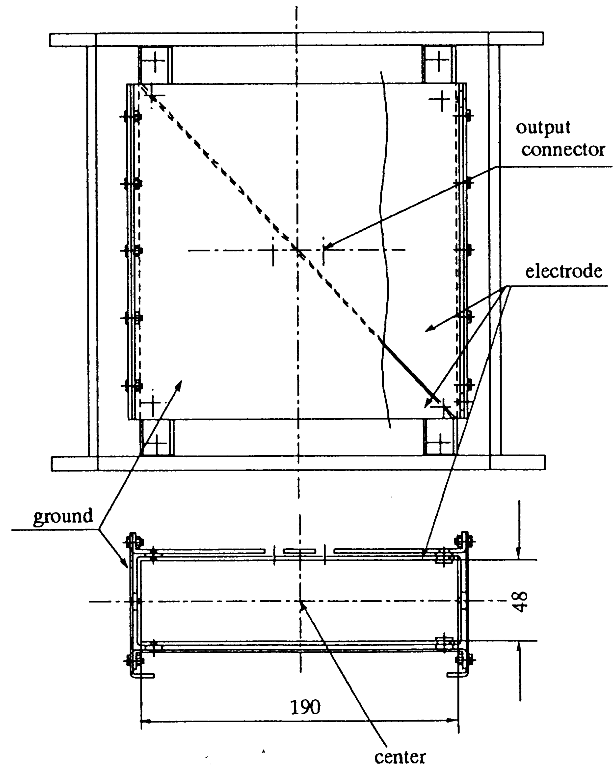

Figure 1: Schematic drawing of the structure of a BPM.

3 NUMERICAL CALCULATION

3.1 Method

The potentials generated by the beam on the electrode is calculated using the three dimensional surface electric charge method. The potential, V_p, at an observation point is given by the following equation:

$$V_p = \sum_{k=1}^{n} \frac{1}{4\pi\epsilon_0} \int_{S_k} \frac{\sigma_k}{r}\, dS \qquad (1)$$

where σ is the surface electric charge density on a triangular element, r represents the distance between the center of the triangular element and the observation point, n denotes the total number of triangular elements. The boundary condition, total charges become zero on the conductor surface, is required because the electrodes are isolated from the ground shown in Figure 1. After discretization, the resulting equations are given as follows:

$$\sum_{i=1}^{n} P_{ij}\,\sigma_j = V_c \qquad (2)$$

$$\sum_{j=1}^{n} C_{n+1,j}\,\sigma_j = 0 \qquad (3)$$

where V_c is the known potential on the electrode and P_{ij} represents the integration in equation (1). The unknown electric potentials on the two electrodes are calculated when the electric potential on the beam is given. The change of the output signal ratio is calculated with the obtained voltages, V_L and V_R.

3.2 Calculation

The effects of the beam size is calculated for two different beam models. One is a pencil beam having a diameter of 2 mm. The other is a rectangular beam having a cross section of 70 mm $\times$ 9 mm. The pencil beam models the calibration antenna and the rectangular beam shows the multiturn injection beam having the large beam size horizontally. The beam length is much longer than the BPM length. The ground position is adjusted so that the calculated output signal ratio equals to the measured one using the pencil beam model. We calculated the output signal ratio for the rectangular beam model with the same condition. The calculation is done with an upper half model for the fast calculation.

4 RESULTS AND DISCUSSION

Figures 2 shows the upper half model with the rectangular beam, its surface being subdivided into small triangular elements.

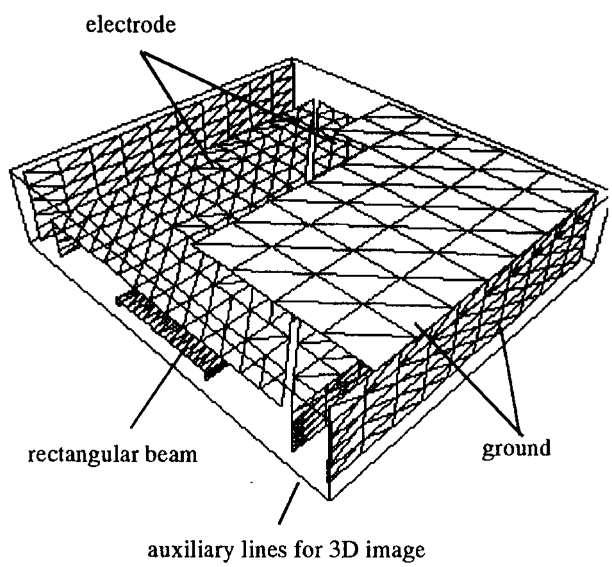

Figure 2: Upper half model subdivided on the surface of BPM with a rectangular beam.

The calculated and measured relationship between the positions and the output signal ratios are shown in Figure 3. The solid line refers to the pencil beam calculation, while the dashed line shows the rectangular beam calculation. The open circles indicate measured values for the pencil beam model, and the dots show those for the rectangular beam model. The wire with 2 mm diameter and an aluminum block with a cross section of 70 mm $\times$ 9 mm are used as the beam models in the measurement.

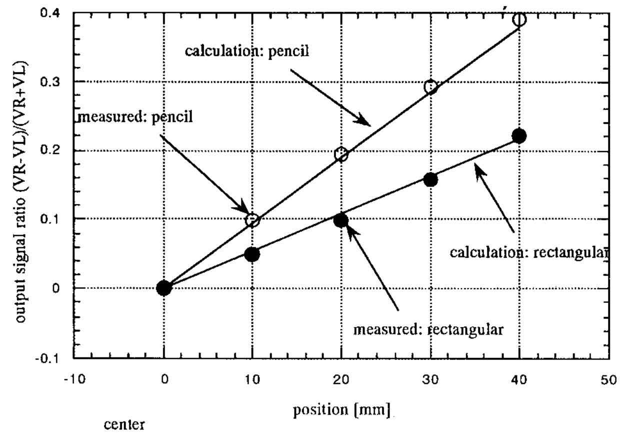

Figure 3: The calculated and measured relationship between the positions and the output signal ratio.

The calculated values for the rectangular beam agree well with the measured one. The figure also suggests a larger-sized beam results in a smaller difference signal-to-sum signal ratio. The reason is that the surface electric charge on the two electrodes is not changed significantly according to the displacement of the beam when the beam size becomes large. Therefore, the estimated deviation is smaller than the true position when the beam size is large in the horizontal direction, indicating that the beam cross section should be evaluated for a precious position measurement.

5 CONCLUSION

Three-dimensional surface electric charge method was applied to calculate the effects of the beam size on the beam position measurements. We have confirmed that the change of the beam size led to beam position errors. It is found that the output signal ratio decreases and the measurement errors increases when the beam cross section became large horizontally. The proposed method can estimate the effects of the beam size when a beam cross section is given.

The relationship between the beam cross section and the beam sized effect will be studied in detail including the vertical displacement of the beam.

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7 REFERENCES

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