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# A METHOD FOR POSITION MEASUREMENT OF ACCELERATED CHARGED PARTICLE CONTINUOUS BEAM

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**Abstract.** A non-intercepting method for accelerated continuous beam position measurements is proposed. This method uses the influence of the electric field of charged particle continuous beam on the space charge emitted by an electrode positioned in the high vacuum of the accelerator chamber. The sensitivity of a position monitor designed by using this method is estimated.

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## 1. Introduction

The effective work of the accelerators of charged particles is critically dependent on the quality of the diagnostics of the accelerated beams. The monitoring of the beam position in the vacuum chamber is one of the most important tasks of that diagnostics.

Many methods for beam position measurement have been in use [1–6]. They can be classified into two groups, i. e. intercepting and non-intercepting methods according to the type of the interaction with the beam. The intercepting methods use the direct interaction of the measuring probe with the particles of the beam. The second group of methods is based on the interaction with the electromagnetic fields of the beam. The known methods performing continuous beams position diagnostics belong mainly to the first group. They use scrapers, diaphragms, wire or gas targets, etc. positioned in the beam area. Another way to measure the position of the DC beams is to change the structure of the beam by modulation (bunching) in order to put in action the known methods for non-intercepting diagnostics of bunched beams [2]. There are some more sophisticated methods as is the method based on the particle structure of the beams. This method uses the so-called Schottky signal from the beam [3]. Other methods "observe" the main beam by thin low intensity and low energy electron beam [4, 5].

The intercepting methods partially or completely damage the beam and the non-intercepting methods need complex devices and sophisticated electronics.

 

## 2. Method Description

The present paper offers a proposal for a novel non-intercepting method. This diagnostics method can be a base for the design of different beam position monitors (BPM). As in the other non-intercepting methods, the method uses the electromagnetic field created by the beam in the metal accelerator chamber. The difference comes from the element proposed to register this field. In the method offered an electron emitter positioned in the accelerator vacuum chamber creates space charges. The influence of the beam on these space charges can be measured by different types of monitors. Here we shall discuss the possibility to include the emitter as a cathode in the electrode system of an electron valve, i. e. a diode. As a matter of fact the presence of the beam controlling the diode characteristics makes that system a triode one.

The paper aims at giving a rough estimation of the possibilities of this kind of BPM that is why we shall use some simplifying conditions. First, the particle structure of the beam can be neglected because the standard accelerator beam has sufficient density for that. Second, we shall not consider the relativistic nature of the fields and we shall estimate the effect of the minimum value of the radial component of the electric field. Thus, the estimation is based on the case of pure electrostatic field generated by the space charge of a circular beam with radius $r_0$, positioned on the axis of a cylinder accelerator chamber with radius $r_c$. When the space charge has density (and the acceleration is in high vacuum ($\varepsilon_0$ — electrical permittivity of vacuum) the values of the radial electric field $B_r$ and potential are given by [2]

$$E_r = \sigma \frac{r_0^2}{2\varepsilon_0 r}, \tag{1}$$

$$U = \sigma \frac{r_0^2 \ln(r_c/r)}{2\varepsilon_0}. \tag{2}$$

Off-centre beam in circular chamber is discussed elsewhere [6]. The induced charge distribution $q$ on the circumference of the chamber where the chamber radius is normalized to 1 is expressed by

$$q(r,\varphi) = \frac{1-r^2}{1+r^2-2r\cos\varphi} \tag{3}$$

where $r$ is the distance between the beam and the axis of the chamber and $\varphi$ is the angle of this direction to the point of interest. The transversal electric field distribution coincide with this charge distribution.

The use of analytical expressions for our purposes can be substituted by calculations of computer code with extreme commodities for flexible change of the input data and the graphic presentation of the results. We use the code POISSON/SUPERFISH code, freely distributed by Los Alamos National Laboratory Accelerator Group of Codes [7], version 96.

The input data must be composed in a file and should contain full information about charge and material geometry and properties as well as the type of boundary conditions.

We consider that the domain of use for the proposed BPM is limited by the minimum intensity of the diagnosed beam. The estimation of this limit should be made for a standard configuration. In the input data file a circular accelerator chamber is fixed ($r_C = 5$ cm) with infinite conductivity wall and a beam with charge density $10^{-10}$ C/cm$^3$ passing through the chamber along a trajectory parallel to the chamber axis.

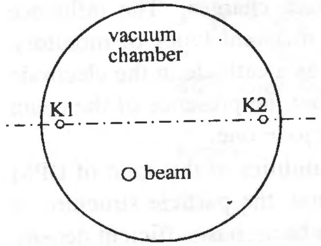


**Fig. 1.** The positions of K1 and K2 in the vacuum chamber

Two cathodes K1 and K2 positioned as shown in Fig. 1 can be used to get information about the position of the beam along the first co-ordinate. The difference of the induced potentials on K1 and K2 serves as a signal, proportional to the displacement of the beam along the axis coinciding with the (K1, K2) diagonal. A second similar pair of electrodes on an orthogonal diagonal can measure the second co-ordinate of the beam and the sum of four signals can be used to calculate the exact position of the beam. The anode of these diodes is the grounded metal wall of the vacuum chamber. For the electron/positron accelerators the cathodes must not be in the median plane to avoid the strong influence of the synchrotron radiation. Nowadays, a large choice of emitters design exists: from simple tungsten heated wire to GaAs photo cathode driven by a laser beam [4, 5]. The regime of diode systems can be biased by external cathode voltage to match the cases of different signs and densities of the beam charge. The characteristics of the proposed BPM are obviously nonlinear that is why the measurement procedure must be performed as in the case of "button" type BPM [1]. First, the potentials of the cathodes are measured by standard electronics and the obtained values are decreased by the zero-intensity beam values. The corrected signals from the four cathodes V1–V4 can be combined by one of the known methods [1] for the calculation of the co-ordinates $x$ and $y$ along the isolevel curves. The electrical signals $X$ and $Y$ can be transferred in the real position $(x, y)$ by the use of a calibration table or a polynomial fit with calibrating coefficients.

On this basis we consider the diode with standard volt-ampere characteristics with slope 1 mA/V and registering electronics with opportunities to measure currents as low as $10^{-8}$ A. This results in minimum measurable potential difference on K1 and K2 in a range of $10^{-5}$ V. To these limiting values of the proposed BPM device we add the requirement for accuracy of position observation. The best sensitivity level reported by other methods is 0.3 mm for a similar geometry and beam currents [5].

In the input data file the emitters K1 and K2 are described as dielectric regions with very high electric permittivity (FIXEPS = 9999) what makes it possible to calculate floating potentials for surfaces with Neuman boundary condition [7]. Our choice of the mesh size is shown in Fig. 2 in the vicinity of K1. This choice gives a good boundary description of the problem.

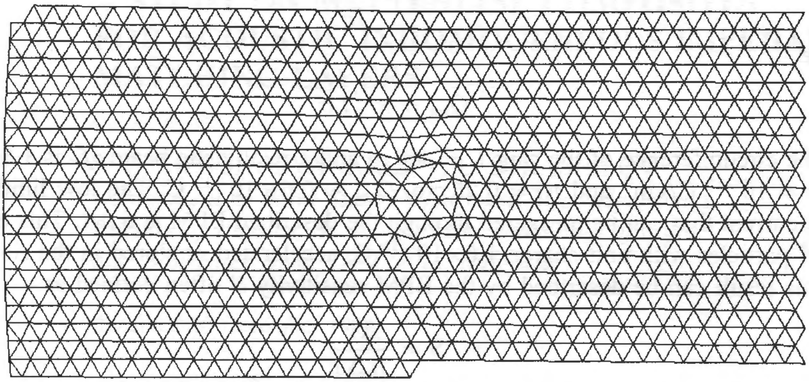

**Fig. 2.** The mesh for the potential calculations in the vicinity of K1

The picture of the calculated potential lines for a significant deviation of the beam is shown in Fig. 3.

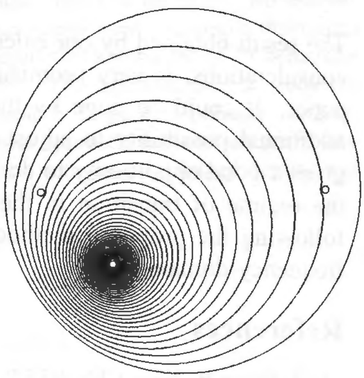

**Fig. 3.** Calculated potential lines of the electric field of off-centred beam

The calculated values of the potential differences of K1 and K2 are linearly dependent on different charge density in the range of computing accuracy. The calculations were made for two positions of the beam and 1 $\mu$m deviation of the beam from these positions. The 1 mm shift from central beam position results in 0.634 V potential difference. The same shift in beam position for the maximum off-centred beam by 2 cm on each of the co-ordinates provides 0.600 V change of the potential difference between K1 and K2.

According to these potential differences and the accepted values of the registering device accuracy we obtain the value $10^{-15}$ C/cm$^3$ for the low limit charge density.

The accelerator physics describes the beam properties through the beam current $I_b$. For circular accelerators (rings) the beam current and charge density of the beam are transferred into each other by revolution frequency $f_r$:

$$Q_{tot} = \frac{I_b}{f_r}, \tag{4}$$

where

$$Q_{tot} = \pi r_0^2 L \sigma . \tag{5}$$

For the circumference of the ring $L = 300$ m and a relativistic beam, $f_r$ is 1 MHz and for $\sigma = 10^{-15}$ C/cm$^3$ and $r_0 = 0.25$ cm, $Q_{tot} \approx 0.6\times10^{-11}$ C. The low limit for the beam current that can be measured through the described BPM is 6 $\mu$A. This equals to $\approx 10^8$ particles with unit charge $1.6\times10^{-19}$ C, accelerated or stored in the ring.

This result can be described by the BPM sensitivity $S$ often defined as

$$S = \frac{\Delta V}{I_b \Delta x} \tag{6}$$

where $\Delta V$ is the output potential difference (in $\mu$V), $I_b$ — the beam current (in mA) and $\Delta x$ — its displacement (in mm) [1, 4]. For the proposed BPM this parameter has a value in the range of $10^3$.

## 3. Conclusion

The result obtained by our calculations based on rough and minimizing the interaction considerations, is very promising. The calibration procedure is not discussed in this paper. It could be done by the same methods as for the split pickups [1] with the additional possibility to adjust the parameters by the external voltages. The method gives a good opportunity to design BPM for measuring the beam position, e. g. during the regime of transition in the storage rings. Those who wish to construct a BPM following the proposed method can design it with better characteristics, e. g. in the frequency domain.

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