Nuclear Instruments and Methods in Physics Research A 729 (2013) 14–18

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Simulations of axial B-dot monitors inside a groove in the beam pipe

Xiaozhong He [a,*], Jian Pang [a], Qin Li [a], Yingchao Du [b]

[a] Institute of Fluid Physics, Chinese Academy of Engineering Physics, Mianyang, Sichuan, China
[b] Department of Engineering Physics, Tsinghua University, Beijing, China

ARTICLE INFO

Article history:
Received 19 January 2013
Received in revised form
18 June 2013
Accepted 24 June 2013
Available online 29 June 2013

Keywords:
Axial B-dot
Beam tilt measurement
Groove
Simulation

ABSTRACT

Beam tilt measurement is important for understanding the beam dynamics. Our previous theoretical studies and simulations have shown that the axial B-dot in smooth beam pipe can be used to measure the beam tilt directly. Practical azimuthal B-dot loops typically are placed inside a groove in the beam pipe to avoid direct beam interception. For the same purpose, practical axial B-dot loops should also be placed inside such a groove. In this paper, responses of axial magnetic field to the beam tilt and to the beam offset, in the presence of the groove, are investigated by simulations. The simulation results show that the axial magnetic field in the central plane of the groove is proportional to the beam tilt and independent on the centroid position. The ratio between the axial magnetic field and the beam tilt depends on the position of the axial B-dot loop and the dimensions of the groove.

1. Introduction

Azimuthal B-dot monitors (commonly referred as B-dots) are used to measure the current and position of a pulsed beam by detecting the azimuthal magnetic field generated by the beam. Azimuthal B-dot monitors have been studied in detail and have been widely applied in the past [1–3]. Many types of beam position monitors have been developed to improve the measuring accuracy [4–5]. The development of beam position monitors which can provide information on more than two dimensional beam offsets is another noticeable trend in the research of beam position monitors [6]. Axial B-dots monitors can be used to measure the tilt of a pulsed beam directly by detecting the dipole term of the axial magnetic field generated by the beam. In addition, axial B-dots monitors can be easily combined with azimuthal B-dots monitors in a single device to provide information of beam current, beam position and beam tilt. Our earlier work has shown that the axial B-dots can be used to measure the beam tilt in a smooth beam pipe [7].

The arrangement of an axial B-dot is shown in Fig.1, where (a, φ) is the offset of beam centroid in cylindrical coordinate system, and b is the radius of the beam pipe. Four axial B-dot loops are placed near the beam pipe at $x+$, $x-$, $y+$, $y-$ direction respectively. Integral signals of these four axial B-dots are proportional to the axial magnetic field at their locations.

According to the theory of axial B-dots [7], the axial magnetic field at the inner surface of the beam pipe can be described by the following equations:

$$B_z(r=b,\theta=0)=2B_0\left(-y'-\frac{x'y+y'x}{b}\right) \tag{1}$$

$$B_z(r=b,\theta=\pi/2)=2B_0\left(x'+\frac{x'y+y'x}{b}\right) \tag{2}$$

$$B_z(r=b,\theta=\pi)=2B_0\left(y'-\frac{x'y+y'x}{b}\right) \tag{3}$$

$$B_z(r=b,\theta=3\pi/2)=2B_0\left(-x'+\frac{x'y+y'x}{b}\right) \tag{4}$$

where $B_0=\frac{\mu_0 I(s-\beta ct)}{2\pi b}$ is the azimuthal magnetic field at the inner wall of the beam pipe for a centered beam, (r,θ,s) is the position in cylindrical coordinates, (x, y) and (x', y') are the beam transversal displacement and the beam tilt respectively in Cartesian coordinates. Assuming that the deflection angle and the offset are small enough in Eqs. (1) and (4), the axial magnetic field, as well as the difference of axial magnetic field at the opposite direction, is proportional to the beam tilt.

In practical situation, B-dot monitors typically are placed inside a groove in the beam pipe to avoid the beam interception [8], as shown in Fig. 2. However, this structure may result in some drawbacks or constraints of the axial B-dot measuring beam tilt.

In this paper, we use the MAFIA code to analyze the response of the axial magnetic field to the beam tilt and beam offset inside a groove for different beam parameters and dimensions of the groove. The method is similar to what has been described in our

* Corresponding author. Tel.: +86 135 417 45496.
E-mail addresses: hexiaozhong@tsinghua.org.cn, siddel.he@gmail.com (X. He).

0168-9002/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.nima.2013.06.092

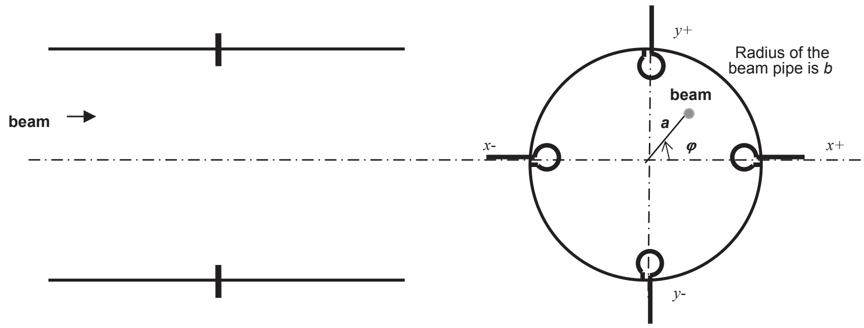

Fig. 1. Arrangement of axial B-dot measuring beam tilt [7].

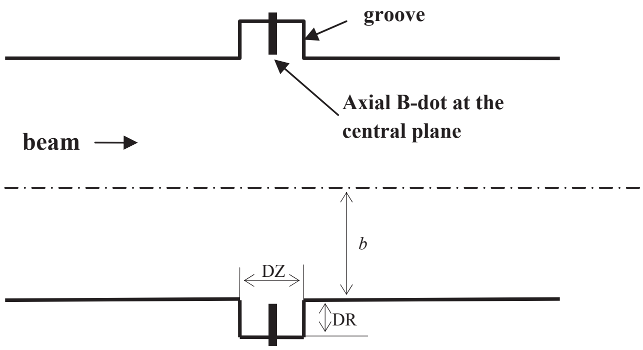

Fig. 2. Groove for practical axial B-dot.

previous paper [7]. The simulation geometry, beam parameters, and post-process method are described in the following section. The simulation results are shown in Section 3. The conclusion is presented in Section 4.

2. Simulation models and methods

2.1. Geometry

The simulation structure is illustrated in Fig. 3. The cylindrical beam pipe is 129 mm in diameter. The length of the structure (labeled with L) is 1 m or 4 m. Four steering magnets are located at $2L/7$, $3L/7$, $4L/7$, $5L/7$ from the beam entrance and labeled with C, D, E, F respectively. Four grooves with the same dimension are located at $2.5L/7$, $L/2$, $4.5L/7$, $6L/7$ from the beam entrance and labeled with G, H, I, J respectively. Solenoid is distributed between $L/5$ and $4L/5$ from the beam entrance. The axial and radial dimension of the groove is DZ and DR respectively (shown in Fig. 2).

2.2. Centroid trajectory

Three types of centroid trajectories are simulated. In the first case, the magnetic field of the steering magnets and the solenoid are turned off, and the beam is injected off-axis with zero beam tilt. In the second case, only the steering magnets are turned on, and the beam is injected on-axis with zero beam tilt. In this case the strength of the four steering magnets are properly set to make the beam offset at the plane H is zero. The purposes of the first and second cases are to compute the response of axial magnetic field in the groove to the beam centroid offset and to the beam tilt respectively. In the third case, the steering magnets and the solenoid are both turned on, and the beam travels along a complicated helical trajectory. The purpose of this case is to verify whether the axial B-dot can be used to measure the beam tilt in general beam trajectory with the existence of the groove. If the axial B-dot still works, the ratio between the axial magnetic field and the true beam tilt can be calculated in the third case.

2.3. Parameters of injected beam

The injected uniform beam with a radius of 5 mm has a Gaussian temporal profile with the FWHM width of 11.8 ns. The total charge is 2×10^{-15} C and the momentum is pc = 5 MeV.

2.4. Simulation software

The software used in our simulation is MAFIA. The S module is used to compute the magnetic fields of the steering coils and the solenoid. The TS3 module is used to self-consistently compute the field with the existence of the beam.

2.5. Boundary conditions

The boundary conditions in the axial direction (A and B plane in Fig. 3) are set to be waveguide. All modes with frequency less than 4 GHz are included, and can propagate through the waveguide boundary.

2.6. Data recording and post-process

Axial magnetic fields in x+, x-, y+, y− directions near the inner surface of the beam pipe and in the groove are recorded. The virtually measured beam tilt, is the beam tilt calculated by Eqs. (1) and (4) with the recorded axial magnetic field. Statistics of particle trajectories are performed to get the true beam tilt. Because the axial magnetic field is proportional to the convolution of the true beam tilt with the function $g(z, b)$ [7], for comparison, the convolution is also calculated and is called smoothed true beam tilt in the following sections of this paper.

3. Simulation results

3.1. The case of zero beam tilt and nonzero beam offset

The total length of the beamline is 1 m. DR and DZ are 9 mm and 11.4 mm respectively. The initial beam is offset 3 mm in the horizontal plane (x direction) from center of the beam-pipe. The virtually measured beam tilts in horizontal plane at various radius, are shown in Fig. 4 as a function of the longitudinal position z. In Fig. 4, the virtually measured beam tilt in horizontal plane is labeled with xp, and the radial coordinate of the observation point is labeled with R. We can see the axial magnetic field in the groove is an odd function of the longitudinal position relative to the central plane of the groove. If the beam is continuous and propagates along the axis, it is straightforward that the azimuthal magnetic field is symmetrical about the central plane of the