SIMULATION OF A BEAM ANGLE MONITOR USING AXIAL B-DOT FIELD*

Jian Pang#, Xiaozhong He, Qin Li, Chaofan Ma, IFP, CAEP, Mianyang, Sichuan, China

Abstract

A beam angle monitor using axial b-dot field was published recently, while the monitor using azimuthal B-dot field have been employed to measure beam positions for more than ten years. Basing on the principle of proportionality between deflection angle and difference of axial B field between the axially symmetrical positions, the axial B-dot probe has a potential use for beam deflection angle measurement. A test stand was built to test and improve the beam angle monitor, which was fabricated as a PCB structure. Meanwhile, simulations using CST MWS codes have been performed, demonstrating a good agreement with test results and giving some advices to suppress the disturbance of position deviation of beam.

INTRODUCTION

Accurate measurements of beam transverse displacement and tilt angles are very important for understanding the underlying beam physics of the transverse particle motion. Azimuthal B-dot probes (commonly referred as B-dots) are used to measure the current and position of a pulsed beam by detecting azimuthal magnetic field generated by the beam [1-2].

Axial B-dots probes can be used to directly measure the tilt angle of a pulsed beam by detecting the dipole term of axial magnetic field generated by the beam traveling with nonzero beam tilt. In the case of smooth beam pipe, simulations show that differential term of axial magnetic field at the opposite direction is proportional to the beam deflection angle of perpendicular direction by assuming that the deflection angle and transverse position deviation (referred blow as deviation) is quite small[3]. Axial B-dots probes can be easily composed with azimuthal B-dots probes in a single device to measure the beam displacement, current and deflection angle, as shown in Fig. 1.

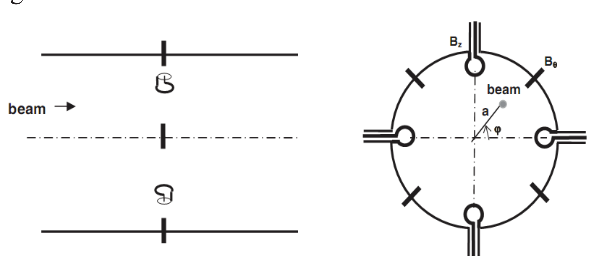

Figure 1: Composition of azimuthal B-dots and axial B-dots.

In actual use, B-dot probes typically are placed into a groove in the beam pipe to avoid the beam interception, as shown in Fig. 2. However, this structure may result in some drawbacks or constraints of the axial B-dot measuring beam tilt angle. Our earlier simulations show that in the central plane of the groove, the axial magnetic field is proportional to beam tilt angle and does not depend on centroid position [4]. But the proportion between them is sensitive to the dimensions of the groove and much smaller than that in a smooth pipe.

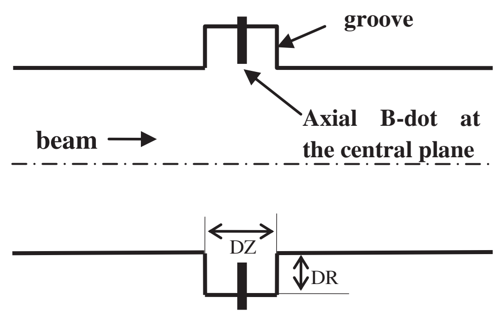

Figure 2: Grooved pipe for actual axial B-dot.

A simple way to improve the proportion (referred blow as the sensitivity of axial B-dots) is enlarge the coil area of B-dot ring. An annular PCB, printed with several loops referred in different radial directions, was employed to guarantee the central plane of PCB is aligned in the centre of the groove and perpendicular to the pipe axis. Meanwhile, a test stand, composed of an approximately 50-Ohm coaxial line and vector net analyzer, was built to test the frequency response of the PCB probes. The test results are discussed in another paper in this conference [5]. In this paper, simulations using CST MWS codes were performed to analyse the frequency response of the probes in the grooved pipe and reduce the interference signal caused by beam centroid displacement.

FABRICATION AND MODELING

A two-layer PCB was fabricated to demonstrate the feasibility of the beam angle monitor. The dimensions of PCB were determined by the size of beam pipe of the linear induction accelerator located in our institute. There are 8 B-dot coils (probes) printed on the PCB, four of them are axial B-dots and the others are azimuthal ones, as shown in Fig. 3. The thickness of the PCB was 6±0.3 mm aiming for good sensitivity of the azimuthal B-dot probes, also providing a good verticality between the PCB center plane and the pipe axis.

The B-dot probes were modelled with CST MWS codes, as shown in Fig. 4. About 190,000 tetrahedron grids were used. The transmission line tube, similar to a 50-Ohm coaxial line, had uniform dimensions as the test stand tube. We chose DR as 17 mm and DZ as 27 mm. The

*Work supported by National Science Foundation of China (NSFC), Grant 11175166
#jpang@mail.ustc.edu.cn

inner conductor, transverse deviation or tilt of which could be adjusted to simulate the beam centroid deviation or tilt, was inserted in the grooved pipe. The differential frequency response function at vertical directions (S31(f)-S41(f)) with displacements or tilt angles at vertical and horizontal directions were calculated to analyse the frequency limit for actual use: a narrow, rapid-rising pulse will contain more weight in high frequency region and may excite larger signals with a certain beam deviation than that with a certain beam tilt angle.

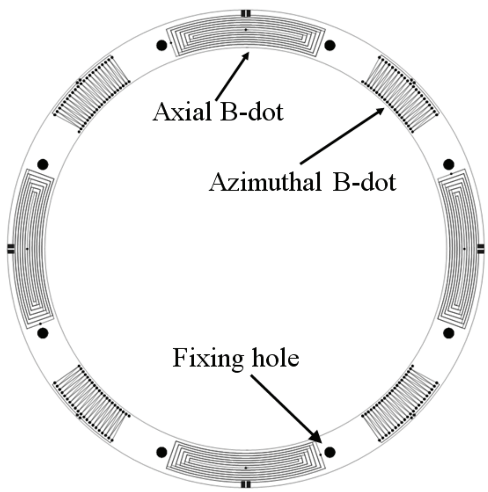

Figure 3: Sketch of the PCB probes.

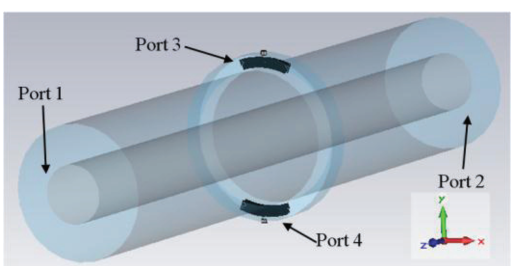

Figure 4: Model of test stand with CST MWS.

FREQUENCY RESPONSE OF AXIAL B-DOT PROBES

The differential frequency response function at vertical directions ($S_{31}(f)$-$S_{41}(f)$) was recorded at different inner conductor transverse displacements and tilt angles. With no inner conductor deviation, the differential output of axial B-dot probes in opposite directions grows proportionally with the tilt angle of inner conductor approximately, as shown in Fig. 5. With the same tilt angle, the differential outputs have the same magnitude but reversed phase, as shown in Fig. 6. As the frequency grows, the response to inner conductor tilt shows good self-integration behaviour.

The comparison of differential response of axial B-dot probes in case of only inner conductor tilt or deviation in different directions have been done as shown in Fig. 7. First, the output differential signal with a certain tilt angle (as the chart in case of x'=30 mrad) is significantly larger than that with the same tilt angle in the perpendicular direction (as the chart in case of y'=30 mrad), but above a certain frequency (about 29 MHz in Fig. 7), the chart indicating y' as 30 mrad grows above that indicating no tile and deviation. It is clear that under a certain frequency, isolation occurs between the responses of axial B-dots in two perpendicular directions. Second, as the frequency grows, disturbance of displacement of the inner conductor in the same direction with the axial B-dot become significant and will be a fatal cause of failure in the measurement of beam deflection angle above a certain frequency (labelled as fc in Fig. 7 and about 8.2 MHz). In this case, when monitoring a Gaussian pulse with FWHM less than about (1.3/fc), the response to a displacement of 20 mm would be accidentally identified as that to a tilt angle of 30 mrad.

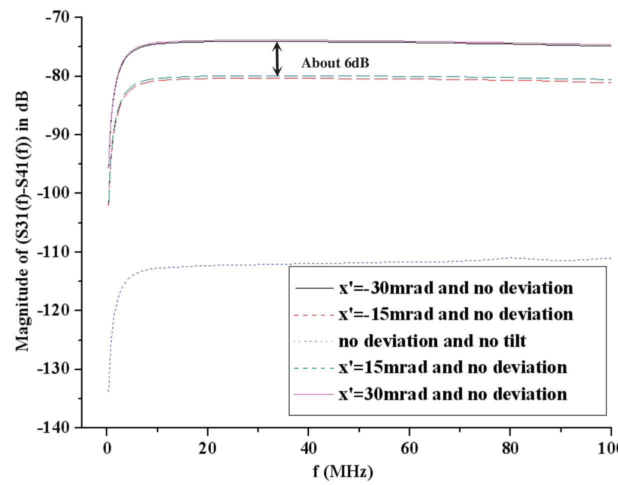

Figure 5: Magnitude of ($S_{31}(f)$-$S_{41}(f)$) in dB at various inner conductor tilt angles.

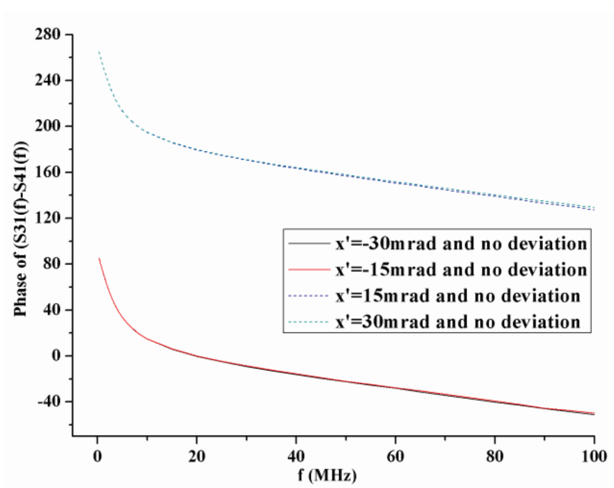

Figure 6: Phase of ($S_{31}(f)$-$S_{41}(f)$) in degrees at various inner conductor tilt angles.

Simulation results were compared with the test results as shown in Fig. 8, both of which presented approximately consistent in the same case of tilt angle or displacement. The disagreement of charts of x'=16 mrad

ISBN 978-3-95450-122-9

in high frequency region may be caused by a little deviation of the inner conductor when under test.

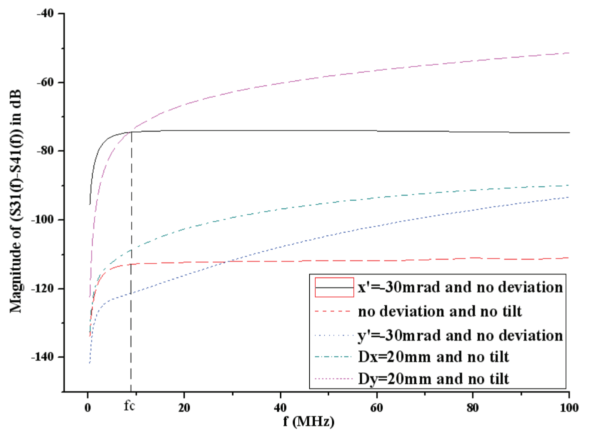

Figure 7: Magnitude of $(S_{31}(f)\text{-}S_{41}(f))$ in dB in cases of only inner conductor tilts or deviations in different directions.

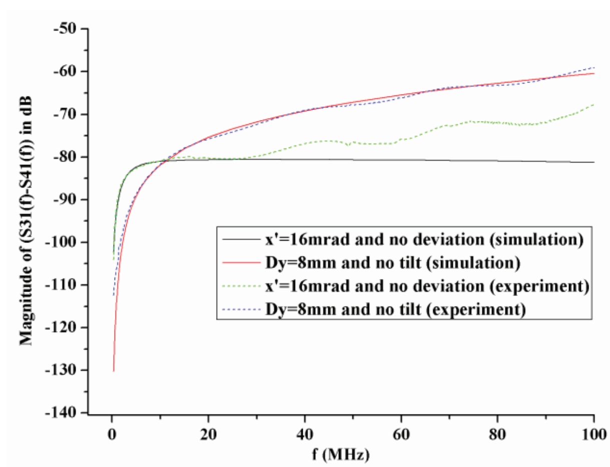

Figure 8: The comparison of simulation and test results.

ATTEMPT TO SUPPRESS DISTURBANCE OF TRANSVERSE DEVIATION

In actual use, the frequency range fc, determined also by the transverse beam displacement and minimum deflection angle measurement sensitivity, is limited by the existence of electric field in the groove which is concomitant with the beam propagation and proportional to the beam transverse displacement. In order to improve the scope of applications in measurement of beams with various transient characteristics, two routes could be carried out as follows:

- Improve the sensitivity to the Bz, or increase the inductor sensitive to the Bz.
- Suppress the sensitivity to E-field, or decrease the coupling capacitance of the probe.

One attempt is to increase the number of PCB layers from 2 to 4 and reduce the coil area in a single layer. Simulation results show that the cross point of frequency (fc) of charts indicating x'=30 mrad and Dy=20 mm could be improved to about one and a half times than that with the 2-layer PCB.

Another attempt is to use single-layer and single-loop probe. Some simulation results are present in Fig. 9. Comparing to Fig. 6, the sensitivity to inner conductor tilts decreases obviously especially in low frequency region; meanwhile, the difference of sensitivity to the same magnitude of tilt but in reversed directions could be also observed. But inspiringly, the cross frequency (fc) could be improved a lot to reduce the influence of response on transverse displacement of inner conductor. This type of probe may be used in beam tilt angle measurement in case of short or fast beam longitudinal profile with help of an amplifier.

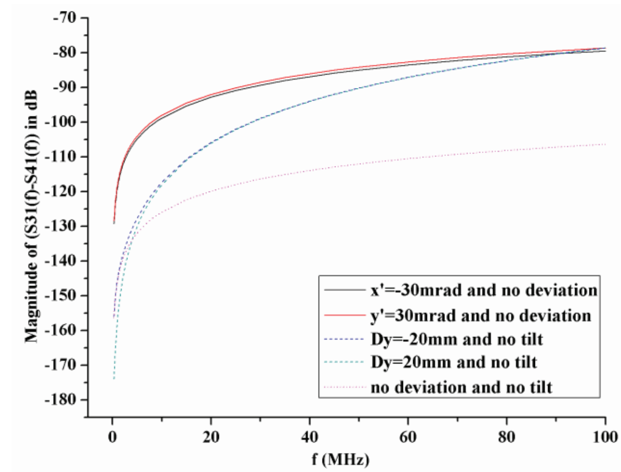

Figure 9: Magnitude of $(S_{31}(f)\text{-}S_{41}(f))$ in dB when changing the probe to a single loop.

CONCLUSIONS

The axial B-dot probe printed on a PCB was simulated using CST MWS codes. Simulation results indicated a good agreement with test results and insulation of the response to tilts in perpendicular directions. Unexpected response on transverse displacement, which significantly disturbs the transverse tilt measurement, will limit the frequency scope in actual use. Several attempts were done to suppress the disturbance of transverse deviation and other ones would be tried in further studies.

REFERENCES

[1] Isaac R. Shokair. Review of Scientific Instruments. 60(1989) p. 2969.
[2] W. W. Rienstra and M. D. Haworth. Review of Scientific Instruments. 62(1991) p. 2363.
[3] X.-Z. He, K.-Z. Zhang, Q. Li. Physical Review Special Topics on Accelerators and Beams. 14(2011), 052804.
[4] X.-Z. He, J. Pang, Q. Li. Nuclear Instruments and Methods in Physics Research Section A. In revision.
[5] X.-Z. He, J. Pang, Q. Li, et al. "Primary experimental results of Axial B-dot measuring beam tilt directly" MOPME046, these proceedings.