PRIMARY EXPERIMENTAL RESULTS OF AXIAL B-DOT MEASURING BEAM TILT DIRECTLY*

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Abstract

Beam monitors sensitive to the beam's azimuthal B-dot field (sometimes referred as B-dots) are widely used to measure the displacement of beam centroid, as the beam generates a dipole term of the azimuthal magnetic field. The authors have pointed out that the similar B-dots sensitive to axial magnetic field can be used to measure the beam tilt directly in earlier work. A monitor which consists of four azimuthal B-dots and four axial B-dots is designed and fabricated. The monitor was tested on a coaxial test stand, which has a character resistance of 50 Ohm. Two position tuners are installed on the test stand, to adjust the position and the tilt of the inner conductor. Experiments show that the axial B-dot monitor can be successfully used to measure the tilt of the inner conductor directly.

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 details and have been widely applied in the past [1-3]. Axial B-dots monitors can be used to directly measure the tilt of a pulsed beam by detecting the dipole term of the axial magnetic field generated by the beam traveling with nonzero beam tilt. And axial B-dots monitors can be easily composed with azimuthal B-dots monitors in a single device to provide beam current, beam position and beam tilt measurement (see Fig. 1) [4]. Our earlier theoretical and simulation studies have shown that the axial B-dots can be used to measure the beam tilt in a smooth beam pipe [4].

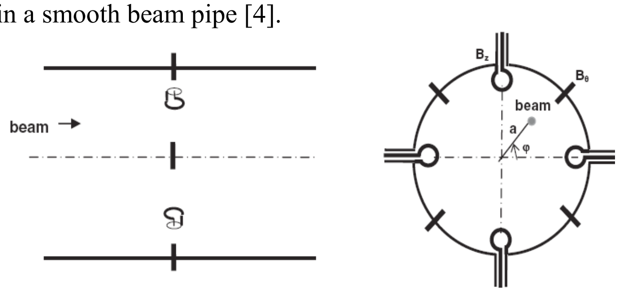

Figure 1: Azimuthal B dots and axial B dots are composed in a single device to measure beam current, displacement, and beam deflection angle.

For proving the principle of axial B dots monitors and developing practical axial B dots monitors, we established a coaxial test stand and a B dots monitor composed four azimuthal B dots and four axial B dots. The measurement results using a vector network analyzer was reported in this paper.

DESIGN OF THE COMPOSED B DOTS MONITOR

The picture of the composed B dots monitor is shown in Fig.2. The eight B dots are distributed in a single circuit board for mechanical robustness. Four B dots (at direction of π/4, -π/4, -3π/4, 3π/4) are designed to be sensitive to azimuthal magnetic field, and the other four (at direction of π/2, 0, -π/2, π) are designed to be sensitive to axial magnetic field. The circuit board is located in the central plane of a recessed groove in the beam pipe, to avoid direct beam interception. The existence of the recessed groove can influence the behavior of axial B dots monitors significantly [5]. Each azimuthal B loops consists of 20 turns of wire, and has a total area of about 10 square centimeters. Each axial B loops consists of 12 turns of wire, and has a total area of about 30 square centimeters. In the first composed B dot monitor, the area of the axial B dot loops is chosen to be as large as possible to increase the signals.

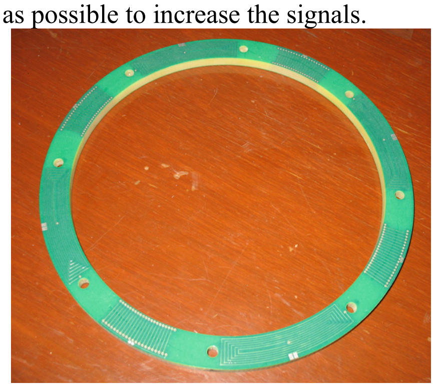

Figure 2: Picture of a composed B dots monitors.

COAXIAL TEST STAND

The coaxial test stand (see Fig. 3) utilize stainless-steel beam pipe with an inner diameter of about 140 millimeters. The impedance of the coaxial line was chosen to be 50 Ohm. The coaxial test stand consists of a coaxial, biconic input transition from a type-N connector to a coaxial transmission line, the monitor section, another transmission line, and finally a biconic exit transition back to a type-N connector. The coaxial test stand also consists of two independent two dimensional transverse position tuners, which can be used to adjust the position and the tilt of the inner conductor. The test stand can be driven either by a high voltage pulse source or by a vector network analyzer. When the test stand was

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driven by the high voltage pulser, the signals from the B dots monitor were read out by an oscilloscope with a bandwidth of 1 GHz. When the test stand was driven by the vector network analyzer, the signals were read out by the same vector network analyzer.

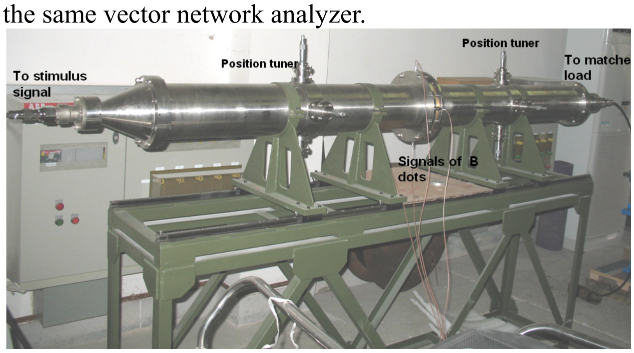

Figure 3: The coaxial test stand for the development of composed B dots monitors.

RESULTS OF THE AZIMUTHAL B DOTS

General Information

The inductance of the monitor loops were measured by using a vector network analyzer. The inductance of the axial loop is 2.6 µH, and the inductance of the azumuthal loop is 1.1 µH. The fairly large inductance leads to that the B dots work in self integration regime at the frequency of larger than several MHz. The isolation between arbitrary two B dot loops is larger than 60 dB.

On Axis Signals

The signals of azimuthal B dots when the inner conductor was adjusted to on axis are shown in Fig. 4. The magnitudes of the four signals from the four azimuthal B dots are shown in the left figure of Fig. 4. In the right half of Fig. 4, the phase of the four signals are shown. The difference between the four azimuthal B dots is less than 1% of the average signal. In Fig. 4 one can see the self integration behaviour of the signals from the azimuthal B dots. The self integration behaviour is consistent with the measured inductance of the azimuthal loops.

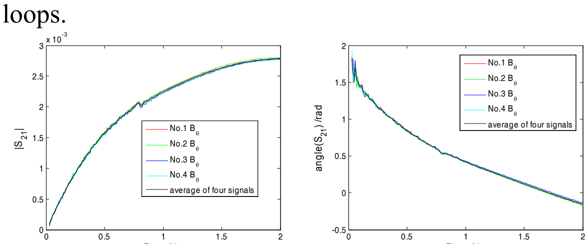

Figure 4: Signals of azimuthal B dots when the inner conductor is on axis.

Response on Transverse Displacement

When the inner conductor is transversely displaced (keep the transverse tilt to be zero), the signal amplitude varies linear with the displacement, see Fig. 5.

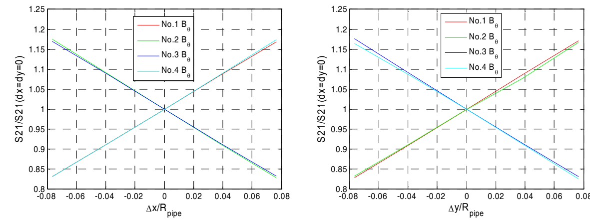

Figure 5: Ratio between the signal with transverse displacement and the signal on axis vs transverse displacement.

Response on Transverse Tilt

When the transverse tilt is less than 16 mrad (the maximum of the tuning range of the position tuners), no obvious signal change was observed.

SIGNALS OF AXIAL B DOTS

On Axis Signals

The signals of azimuthal B dots when the inner conductor was adjusted to on axis are shown in Fig. 6. The maximum difference between the four azimuthal B dots is about 3% of the average signal. We know from the theory of axial B dot monitors that, the axial magnetic field is zero when the beam tilt is zero. But we can see large signals (which are even comparable to azimuthal B dots) from axial B dots when both the offset and the tilt are zero. The phase of the signal at the low frequency end seems to be π. This result is quite out of our mind. After EM modelling of the axial B dot monitors using CST Studio [6], we can understand the signal as the capacitive coupling of the B dot loops to the electric field near the beam pipe.

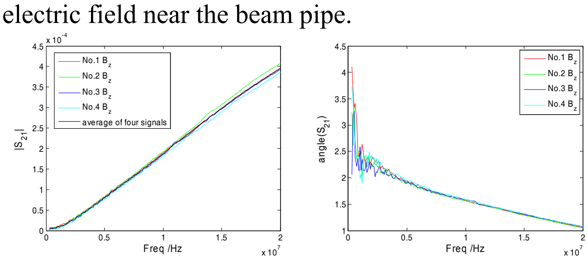

Figure 6: Signals of axial B dots when the inner conductor is on axis.

Response on Transverse Tilt

When the tilt of the inner conductor is set to several milliradian, the signals from axial B dots will be changed significantly, which shows the axial B dot is sensitive to the axial magnetic field. Signals of azimuthal B dots when the tilt of the inner conductor is 16mrad in y direction are shown in Fig. 7. We can see that the tilt leads to the increase of the amplitude of the signals in orthometric direction in low frequency range, and leads to large phase shift of the signals in the orthometric direction. The phase of the signal in orthometric direction at the low frequency end seems to be π/2 and 3π/2.

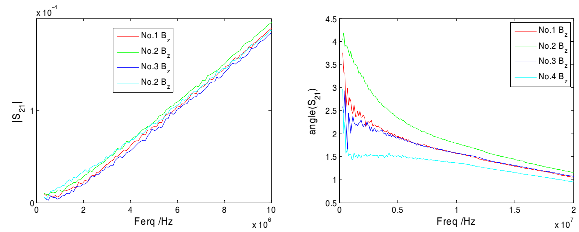

Figure 7: Signals of axial B dots when the tilt of the inner conductor is 16mrad in y direction.

The difference signal of axial B dot (at direction of $\pi/2$) with nonzero tilt in x direction and zero tilt is shown in Fig. 8. We can see that the magnitude of the difference signal is proportional to the tilt, and the phase of the difference signal varies corresponding to the sign of the tilt. The results agree with the theory of axial B dots, prove that the axial B dots can be used to measure beam tilt directly. In Fig. 8, we can also see the self-integration behaviour.

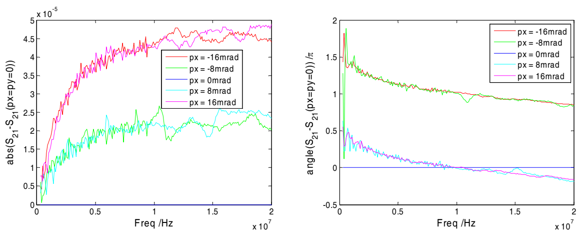

Figure 8: Signals of axial B dots at various transverse tilt.

Response on Transverse Displacement

The responses of the axial B dots on the transverse displacement were also measured on the coaxial test stand. In this case, the tilt of the inner conductor was set to be zero. The ratio of the signal with transverse displacement over the signal with zero transverse displacement was shown in Fig. 9. The ratio is linearly dependent on the transverse displacement. The amplitude of the signal with several mm transverse displacement, is comparable to the signal with several mrad transverse tilt even at frequency of several MHz. The response of the axial B dots on the transverse displacement will disturb tilt measurement significantly. The response of the axial B dots on the transverse displacement can also be understood as the capacitive coupling of the B dot loops to the electric field near the beam pipe.

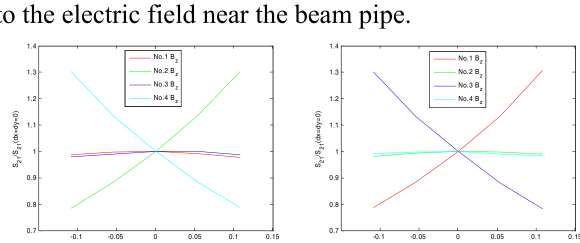

Figure 9: Response of the axial B dots to transverse offset.

REMARKS ON THE CURRENT MONITOR AND FUTURE IMPROVEMENT

The signal response of axial B dots on the transverse tilt was observed to be agreed with the theory of axial B dots. Unexpected response on transverse displacement which can significantly disturb the transverse tilt measurement was also observed. The first fabricated monitor can only be used in very low frequency (several MHz) by using some algorithm to eliminate the response on transverse displacement after transverse displacement has been measured by azimuthal B dots.

In near future, we will reduce the area and turns of the axial B dot loops to reduce the influence of the response on transverse displacement [6]. In this case, maybe an amplifier is needed in the experiments.

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