HIGH PRECISION CAVITY BEAM POSITION MONITOR

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Abstract

A cavity beam position monitor is proposed for measuring the beam deflection in the TESLA energy spectrometer. The precision of the measurement has to be better than 1 μm. A slotted cavity is applied in order to reject the background signals and enhance the precision and the dynamic range of the monitor. The paper gives the design overview for two prototypes with operating frequencies of 1.5 GHz and 5.5 GHz, respectively. The results obtained on the test bench with direct conversion electronics are presented. A resolution of about 100 nm was achieved.

INTRODUCTION

The magnetic spectrometer proposed for TESLA deflects the beam by means of strong magnets. This deflection depends on the magnetic field strength and the energy of the particles in the beam. Precise measurements of the magnetic field strength and the beam deflection have to provide the energy resolution of 10^{-4} or better. The integrated magnetic field can be measured with a precision of up to $2 \cdot 10^{-5}$. The beam deflection is supposed to be measured with a few beam position monitors (BPMs). These have to have a resolution of better than 200 nm in a range of a few mm (goal:±2.5 mm).

A cavity BPM with a novel slotted structure was proposed in order to satisfy the resolution demands. A cylindrical cavity is excited by the beam passing through the cavity. The excitation of the dipole mode TM_{110} is proportional to the beam position. The slots connected with output waveguides serve to couple the dipole mode (fig. 1). At the same time the monopole modes, TM_{010} and TM_{020}, that have the strongest excitation and produce strong background signals, are not coupled. This structure allows a strong dipole mode coupling without an influence of the monopole modes and as a result provides a high precision.

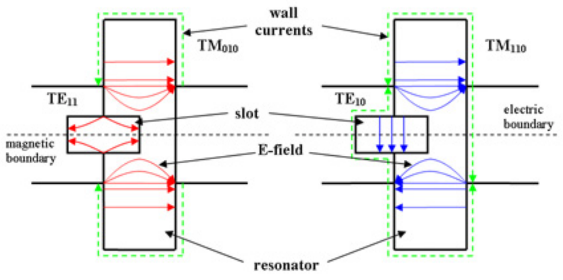

Figure 1: Monopole modes rejection in the slotted cavity.

Two designs of the cavity BPM for the frequencies 1.5 GHz and 5.5 GHz respectively are discussed below.

1.5 GHZ-MONITOR

The 1.5 GHz-cavity is a cylinder with a radius of about 114 mm and a length of 50 mm, fig. 2. The output waveguides are ridged in order to reduce their dimensions. The waveguides are coupled to a coaxial line using magnetic coupling. It was made out of stainless steel in order to reduce the lifetime of the uncoupled monopole modes. The dipole mode has a low Q_{ext} and therefore is not affected. A sensitivity of about 0.2 mV/100 nm together with a noise level of 9 μV gives an upper limit for the resolution of about 5 nm. The damping time of the dipole mode is 115 ns.

Figure 2: Prototype of the 1.5 GHz-monitor.

The read-out electronic for the BPM (fig. 3) is based on the homodyne principle. The signals coming from the monitor are down-converted using a signal with the frequency equal to the dipole mode frequency of the BPM. This signal comes from an additional smaller cavity (reference cavity) operating at the common mode. Filters at the front-end of the electronics select the dipole mode frequency and reduce the noise. The down-conversion is carried out by an I/Q-mixer (in-phase/quadrature), that provides a phase independent measurement and allows for the determination of the offset direction. The down-converted signals are amplified and delivered to the analog-to-digital converters. The reference cavity is also used for the charge measurement.

The resolution of the BPM was measured on a test bench where the beam was simulated by an antenna exciting the cavity. The antenna could be moved transversally using precision movers. The excited signals were measured with a power meter or processed with the elctronics and digitized. Fig. 4 shows the dependence of the monitor signals on the antenna position.

The measured characteristic has a non-linearity, much

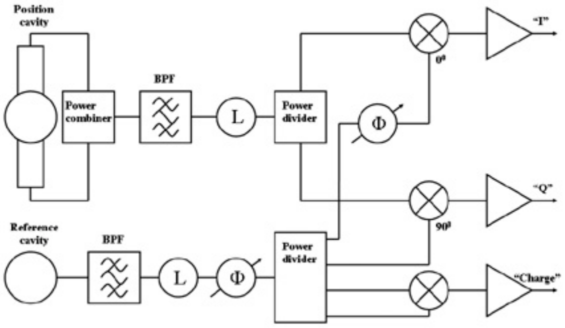

Figure 3: Block-scheme of the read-out electronics for the 1.5 GHz-monitor.

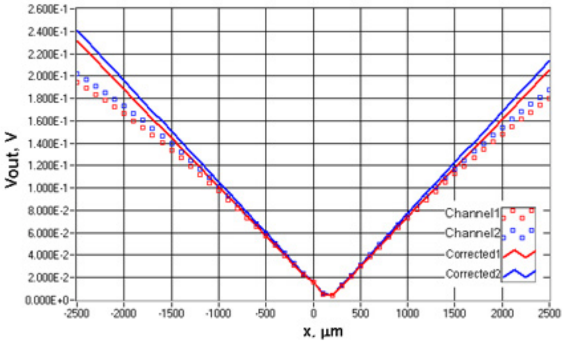

Figure 4: Dipole mode signal vs. antenna position.

higher than predicted by theory, because the excitation of the cavity by an antenna or by the beam is different. In the case of the antenna the characteristic is disturbed by the modes created in the feeding device. These effects are very hard to estimate, but the shift of the dipole mode resonance frequency, which occurs during the movement of the antenna, can be measured (fig. 5) and corrected for.

The correction coefficient follows from the resonant circuit theory: $k = \sqrt{1 + (2Q_L \Delta f/f)^2}$. The corrected data is also shown in fig. 4. This correction allows to estimate the range, where the resolution is better than 1 μm to about $\pm$1 mm.

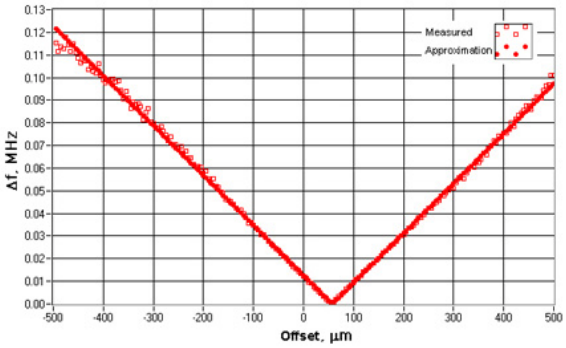

Figure 5: Shift of the dipole mode resonant frequency vs. antenna position.

The results obtained with the read-out electronics (fig. 6) give an information about the resolution and the dynamic range of the whole system. The resolution was calculated as an r.m.s. of a linear fit in a narrow range. The value obtained is 130 nm. The range of the offsets where the resolution is better than 1 μm is $\pm$0.9 mm.

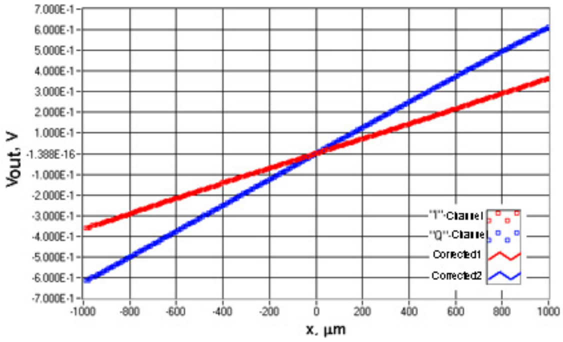

Figure 6: Signals at the outputs of the 1.5 GHz-electronics vs. antenna position.

5.5 GHZ-MONITOR

The 5.5 GHz-cavity is smaller, its radius is about 32 mm and the length is 9 mm. The reference cavity has a radius of 23 mm and a length of 4 mm. The output waveguides are realized in one block together with both cavities, (fig. 7). An aluminum model was used for the measurements in the laboratory and a prototype made of copper and brazed by hard brazing was used for tests with beam.

Figure 7: Prototype of the 5.5 GHz-monitor.

The characteristics were measured using a similar homodyne electronics as in the case of the 1.5 GHz-monitor. The data (fig. 8) give a value of 300 nm for the resolution and a value of about $\pm$0.7 mm for the dynamic range. These values are far from the design values, because broadband components and low-level mixers were not well suited for the application in the BPM electronics.

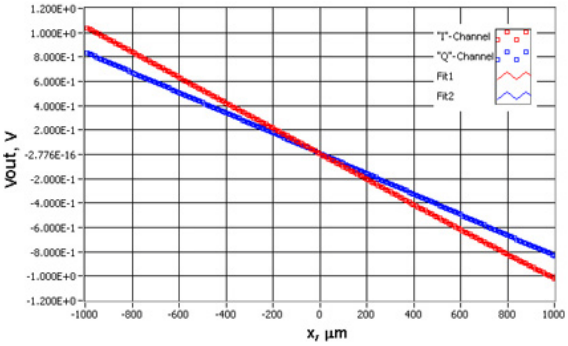

Figure 8: Signals at the output of the 5.5 GHz-electronics vs. antenna position.

TEST UNDER BEAM CONDITIONS

The 5.5 GHz copper prototype was tested with beam at the accelerator facility ELBE in Rossendorf (Dresden, Germany). The accelerator delivers an electron beam with an energy of up to 20 MeV, a beam charge of up to 80 pC at a repetition rate close to the parameters of TESLA. The monitor was installed into the test beamline of the accelerator (fig. 9) surrounded by viewscreens, so that the beam position could be observed visually. The beam could be deflected by steerers.

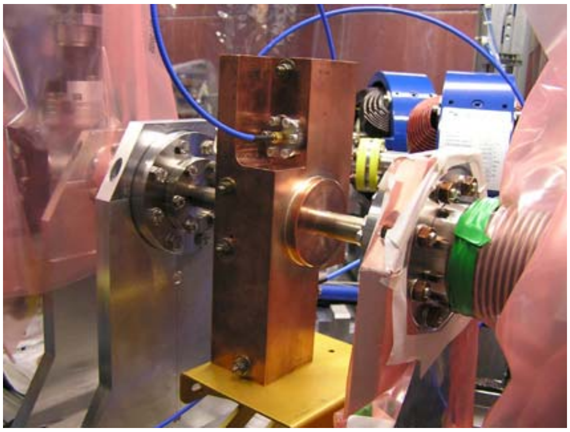

Figure 9: 5.5 GHz-prototype installed into the test beamline of ELBE.

During the first measurement the monitor signals were scanned in order to find common mode and dipole mode resonances. The dipole mode resonance was 5.555 GHz. No common mode resonance was found and is therefore below -70 dBm level (fig. 10). The expected value is about -80 dBm.

Unfortunately the signal delivered by the reference cavity was too weak to be used in the BPM electronics, although it was amplified. An external oscillator was taken instead. The signals at the output of the electronics were measured for different beam positions and values of the bunch charge (fig. 11). A position uncertainty of about 100 μm was measured. This value seems to come from the beam jitter and the uncertainty of the currents in the deflection magnets.

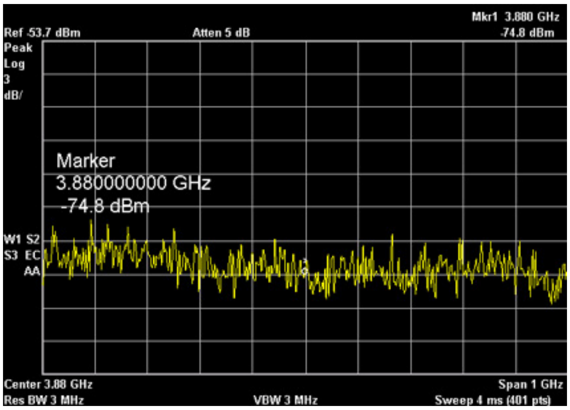

Figure 10: Scan in the region of the common mode.

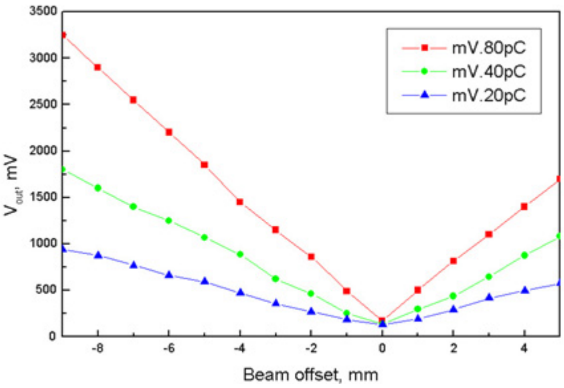

Figure 11: Signals at the output of the 5.5 GHz-electronics vs. beam offset.

CONCLUSION

Two prototypes of the slotted cavity BPM for the frequencies of 1.5 GHz and 5.5 GHz together with the readout electronics were designed, constructed and tested under laboratory conditions. Resolutions of 130 nm and 300 nm respectively were measured, while the dynamic range was close to ±1 mm. The 5.5 GHz-prototype was also tested with beam and showed a high common mode suppression. A position uncertainty of 100 μm was observed because of the test conditions. Further work on the 5.5 GHz-electronics has to be carried out in order to improve the resolution and, if possible, the dynamic range. A cross-check with three monitors is needed for the resolution measurement under beam conditions.