CAVITY BEAM POSITION MONITOR FOR THE TESLA ENERGY SPECTROMETER

A.Liapine, TU-Berlin, Germany

Abstract

In order to measure the beam position with a precision of better than $1\mu m$ in the TESLA energy spectrometer a cavity beam position monitor is proposed. A slotted cavity with a waveguide coupling is used to achieve a good common mode rejection and therefore a better precision. The paper gives a short overview of the monitor functionality and describes resolution measurements which were made on a $1.5GHz$ cavity prototype with homodyne electronics.The estimation based on this measurements shows about $100nm$ of spatial resolution.

INTRODUCTION

A magnetic chicane spectrometer is foreseen for the beam energy measurements in TESLA (TeV Energy Superconducting Linear Collider) (Fig.1) [1]. This type of spectrometer realizes a simple principle - the beam is deflected from its original direction by a magnet and the deflection angle is determined measuring the beam position in a few points after the magnet. Mapping the magnetic field with high accuracy one can obtain the average beam energy as:

$$E_{beam} = \frac{ec\int B\mathrm{d}l}{\theta} \quad (1)$$

The problem is that the beam energy at the end of the linac is so high that the deflection angle is small and can not be increased because the sychrothron radiation rises drastically. Therefore the beam position has to be measured with a very high precision, a few $100nm$, in order to get the demanded accuracy of a few 10^{-5}.

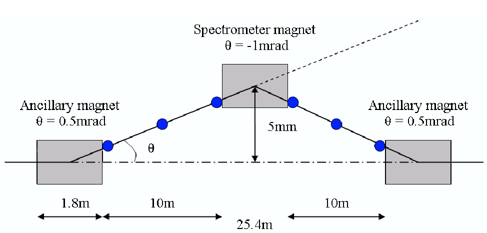

Figure 1: The forseen spectrometer layout

SLOTTED CAVITY BPM

A slotted cavity beam position monitor (BPM) was proposed for the application in the spectrometer [2]. The goal of the slotted cavity structure (Fig.2,4) is a strong rejection of the first monopole modes [3], which deliver strong noise signals at the frequencies close to the frequency of the dipole mode of the cavity (Fig.3).

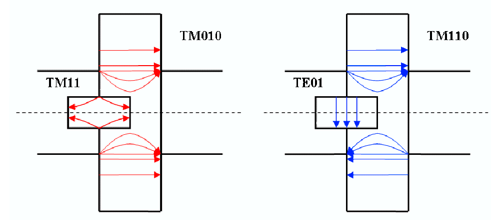

Figure 2: Mode selection in a slotted cavity

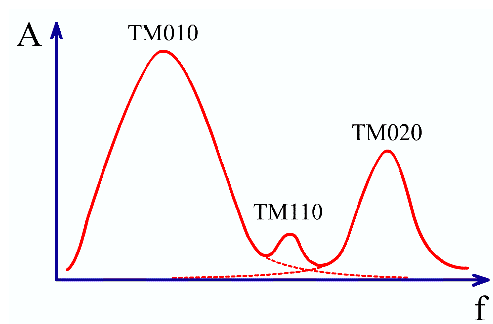

Figure 3: The influence of the monopole modes

A prototype of the slotted cavity for the laboratory measurements was designed and built for the frequency of $1.5GHz$ (Fig.4, 5). Results of the estimations and simulations done for the prototype are listed in the Table1.

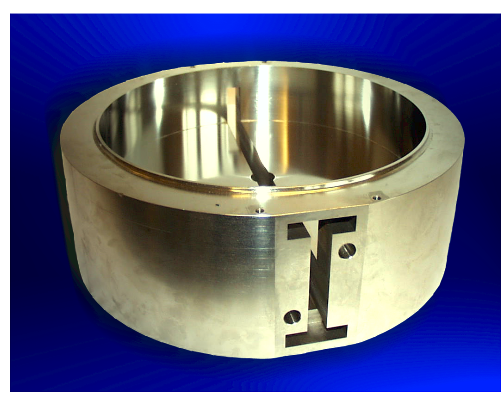

Figure 4: Cavity prototype inside

The resonance frequency of the common mode is $1.0GHz$. The common mode is practically uncoupled that is why the cavity was made from stainless steel in order to make the quality factor of the common mode smaller.

The common mode voltage V_{in} excited in the cavity is about $130dB$ higher as the voltage of the dipole mode. At the cavity output this difference is already at $45dB$ because

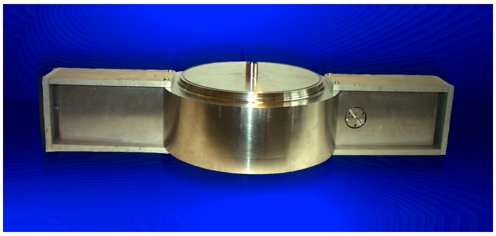

Figure 5: Cavity prototype with coupling waveguides

Table 1: Parameters of the prototype

Parameter	TM010	TM110
f, MHz	1010	1518
Q_0	2110	1680
Q_{ext}	$\rightarrow \infty$	820
$\frac{R}{Q}, Ohm$	144	$2 \cdot 10^{-5}/100nm$
BW, MHz	0.5	2.8
Decay time, ns	662	115
$V_{in}, V/3.2nC$	1450	$4 \cdot 10^{-4}/100nm$
$V_{out}, mV/3.2nC$	9.3/100μm of slot shift (5μV at f_{110})	0.056/100nm of beam offset
V_{angle}/V_{offset}	—	34
$V_{noise}, \mu V$	—	1.6

of the mode selective coupling. The part of the common mode which lies at the frequency of the dipole mode resonance is than 10 times weaker as the dipole mode signal of $100nm$ offset because of the frequency discrimination. The rest of the common mode signal is suppressed in the output waveguides with a higher cutoff frequency and filtered out in the electronics, so that it does not affect the measurement. The same happens with the second monopole mode except the suppression in the waveguides, but it is weaker excited.

SIGNAL PROCESSING

Signal processing electronics is based on the homodyne principle. The dipole mode signal is mixed down using a reference signal with nearly the same frequency coming from an additional reference cavity (Fig.6). This signal is also used for the charge measurement which is needed in order to exclude the charge dependence of the dipole mode signal.

The advantage of the homodyne principle (also called direct conversion) is simplification of the electronics because it contains only one conversion stage and the output signal frequency is very low, so that no expensive analog-to-digital converters (ADCs) are needed. Another point - this electronics consists of only a few components. This means that a low self-noise of the electronics is achievable.

A prototype electronics was constructed and tested (Fig.7). The tests show the upper limit of the input signal

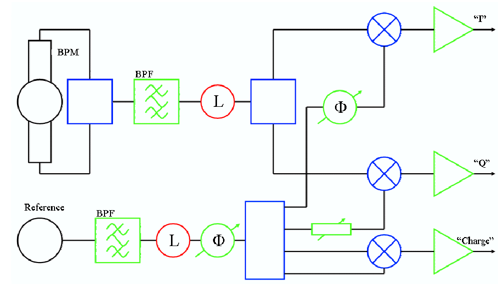

Figure 6: Electronics scheme

to be $0dB$. This limit is extendable to at least $15dB$ by a modification of amplifiers. This gives together with a noise floor of about $80dB$ a very wide dynamic range, which is enough to cover the the range of -1..+1mm of the offset.

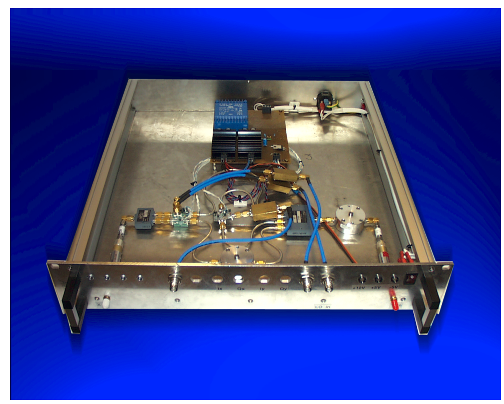

Figure 7: Prototype electronics

This type of the electronics can be also used for the suppression of the angle-dependent component of the dipole mode. The angle-dependent component is excited if a bunch passes through the cavity with some slope to the z-axis (Fig.8) and can essentially reduce the resolution. Provided the frequency of the reference signal and of the monitor are exactly the same it is possible to split angle- and position-dependent components with I/Q-mixer because of their 90^0 difference in phase. Unfortunately up to now it is not clear how to make a stable reference signal with exactly the same frequency. Therefore a simple tilt of the cavity is preserved as a solution of this problem.

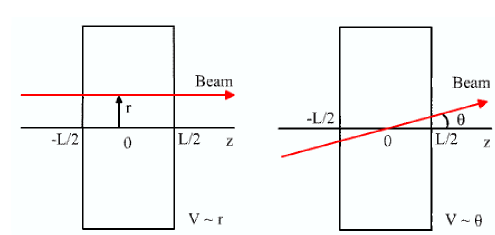

Figure 8: Dipole mode excitation

MEASUREMENTS

Cavity and electronics tests were made with a measurement setup consisting of a voltage controlled oscillator, an antenna for the cavity excitation, precision movers, a powermeter, ADCs and a control software written with LabVIEW. The cavity is excited with the antenna driven by the voltage controlled oscillator. The frequency of the excited signal and the antenna position are controlled by software.

The cavity response at the dipole mode frequency is measured with the powermeter while the antenna is moved. The response characteristic was at first measured without electronics in the range from $-1mm$ to $+1mm$ in order to check the resolution of the monitor itself (Fig.9). A linear fit was applied in order to find the r.m.s resolution. The measured value scaled to the nominal bunch charge is $\sigma = 400nm$. But it includes the curvature of the measured characteristic around zero which causes an additional nonlinearity (Fig.10). The nature of this feature is not completely clear. It can be caused by self-noise of the powermeter but it can also be caused by a dipole mode resonance slide while the antenna is moving.

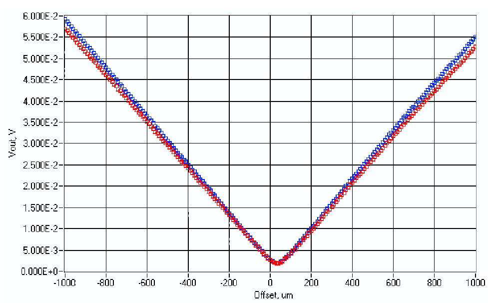

Figure 9: Cavity response for the two outputs. R.m.s resolution is $\sigma = 400nm$

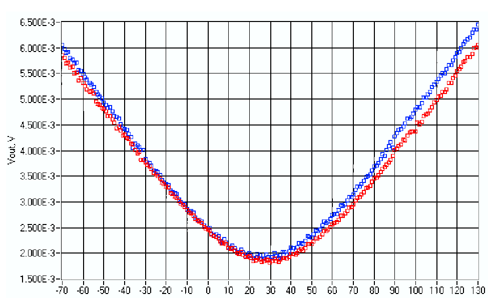

Figure 10: Cavity response around zero offset. R.m.s. resolution is $\sigma = 60nm$

Tests with the signal processing electronics show better results. The r.m.s. of the fit is still about $400nm$ (Fig.11) but the signal is linear around zero and the r.m.s. resolution around zero (Fig.12) is around $40nm$.

The measured common mode rejection well coincides the estimation and is about $100dB$.

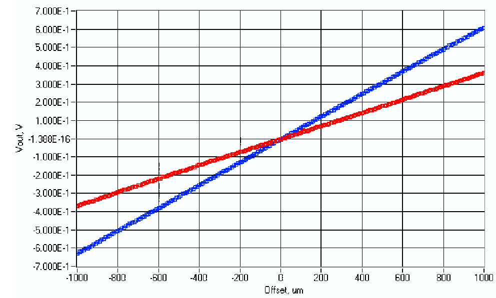

Figure 11: Cavity response measured with electronics. Resolution $\sigma = 400nm$. Red curve represents the ”I”-channel and the blue one the ”Q”-channel

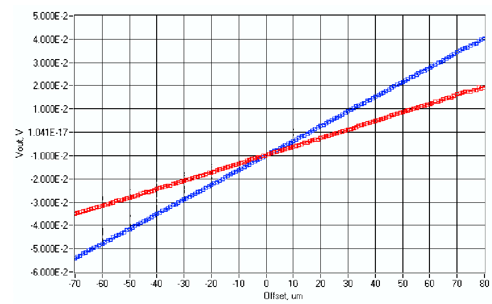

Figure 12: Cavity response measured with electronics around zero. Resolution $\sigma = 40nm$

CONCLUSION

A prototype of the high precision slotted cavity beam position monitor for the TESLA energy spectrometer was designed, tested and precision measurements were made with the prototype and a homodyne type down-conversion electronics. Precision measurements show a resolution about $100nm$. Further work will be concentrated on a smaller $5.5GHz$ prototype which should have a lower angle-dependent component excitation.

ACKNOWLEDGEMENTS

The author would like to thank H.Henke, H.J.Schreiber and V.Sargsyan for helpful advices and precise questions and H.Thom and J.Krueger for helping to construct the prototype.

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