A COAXIAL BEAM POSITION MONITOR FOR THE TESLA-FEL AND SOME ERROR ESTIMATIONS

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Abstract

For the TESLA-FEL project a number of beam position monitors are needed in the undulator and at the interaction point. For these tasks a monitor based on a coaxial resonator is being developed. Using the appropriate dipole mode, which couples with the TEM-field of the beam magnetically, such a monitor can be designed very flat requiring only little space. Also some universal error estimations concerning the beam pipe shape as well as the coupling slots are described.

1 INTRODUCTION

First a design for a space-saving resonant monitor is presented, which is based on a coaxial resonator. The principal function is explained and first measurements are shown. Thereupon some error estimations due to deformations of the beam tube as well as slight variations of the coupling slots are carried out. The momentum method and Bethe hole coupling applied for this are explained shortly.

2 COAXIAL MONITOR

2.1 Principal mode of operation

Figure 1 shows the principal mode of operation. The coaxial resonator picking up the signal magnetically through the coupling slots is a rectangular resonator wrapped around the beam tube. The magnitude of excitation of the TE_{021}-mode depends on the transverse shift of the beam. The power is coupled out from the resonator with inductive loops. Coupling slots are a possible alternative. The positions of the coupling devices for maximum power transfer are shown in figure 1. A longitudinal and transverse cut of the two used prototypes are depicted in figure 2. The length of the resonators is choosen in order to get a good separation of the resonances. In table 1 the first three calculated and measured resonance frequencies for the two prototypes are compared.

	monitor A		monitor B	
mode	calculat.	measurem.	calculat.	measurem.
	[GHz]	[GHz]	[GHz]	[GHz]
TE_{011}	0.944	1.000	1.171	1.147
TE_{021}	1.372	1.520	1.949	1.936
TE_{012}	1.605	1.677	1.748	1.729

Table 1: Calculated and measured resonance frequencies for the two monitor prototypes A and B.

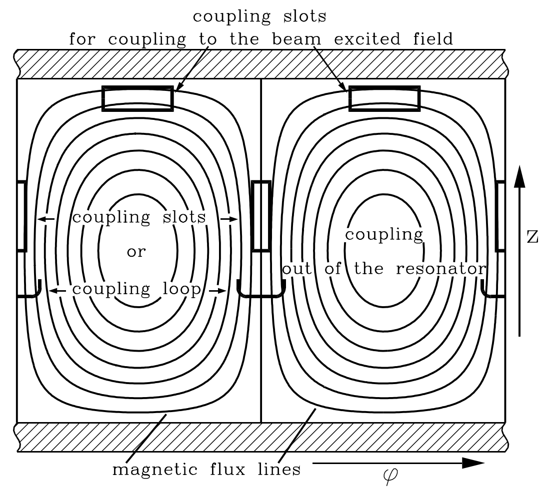

Figure 1: Principal mode of operation of the resonant BPM.

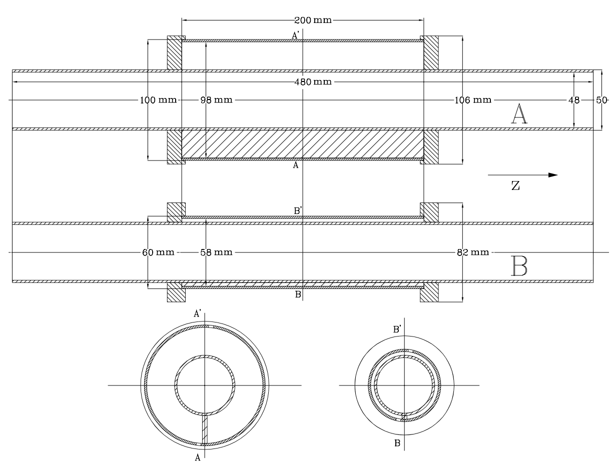

Figure 2: Longitudinal and transverse cut of the two prototypes.

2.2 Measurements

For testing the sensitivity and linearity of the monitors as a function of the beam position the prototypes are measured in a test assembly. The beam is simulated with a tightened 0.4 mm thin wire, which is shifted by a micrometer screw. The amplitude of the transmission resonance is scanned with a network analyser.

Figure 3 shows the transmission signal of monitor A versus the excursion of the wire for three different rectangular coupling slots. In figure 4 the same is depicted for monitor B. A good linearity can be seen. Due to reflections caused by the termination of the beam tube with metal caps the

signals do not reach zero for the centered wire. A careful absorbing termination has to be installed.
Figure 5 and 6 show some details concerning the sensitivity. Due to deviation from the linear trace one can say that the sensivity is limited to about 5 μm wire shift, for the largest 24x5 mm slot a little lower.
The magnitude of the signal has to be inversely proportional to the root of the quality factor of the dipole resonance according to transformer theory. The measured quality factor is about 5600 for monitor A and 850 for monitor B. The root of this ratio is 0.39. This corresponds with theory, taking as a rough approximation for quality factor relation the proportion of the ratios of inner resonator surface to the volume, which results in 0.20 / 1.13 = 0.18. The root reveals 0.42. This tallies with measured signals plotted in figure 3 and 4. So, if space is large enough, high resolution prefers a larger outer radius.

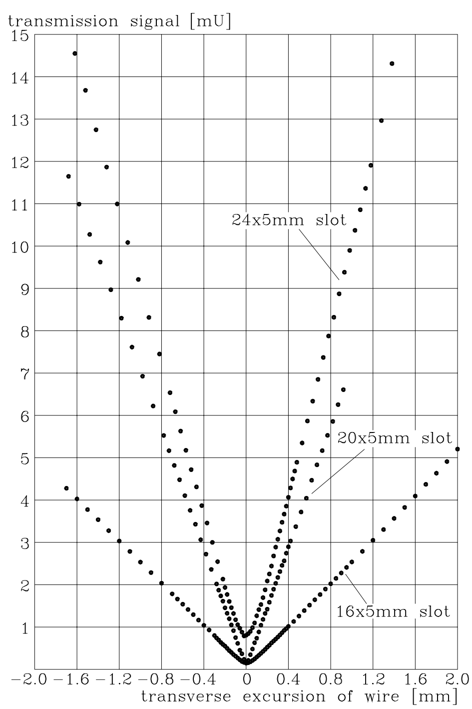

Figure 3: Measured transmission coefficient versus the wire shift for three different slot lengths for prototype A.

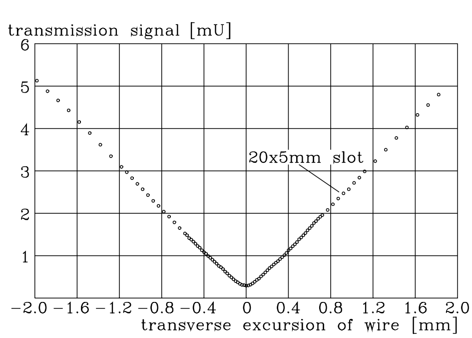

Figure 4: Measured transmission coefficient versus the wire shift for one slot length for prototype B.

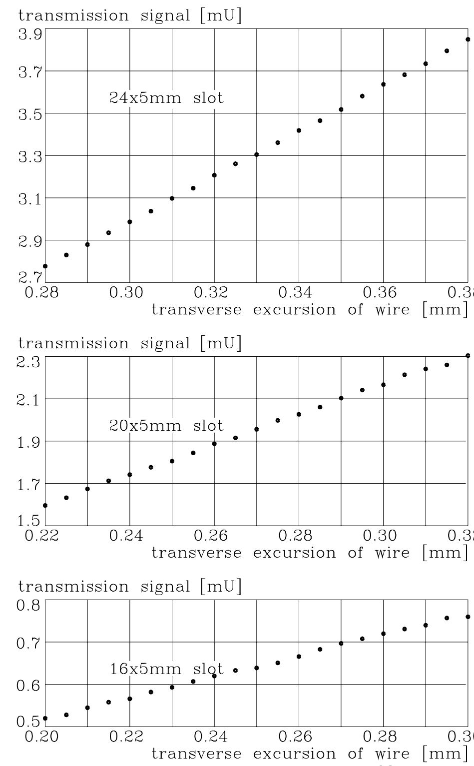

Figure 5: Measured transmission coefficient versus the wire shift for three different slot lengths for prototype A.

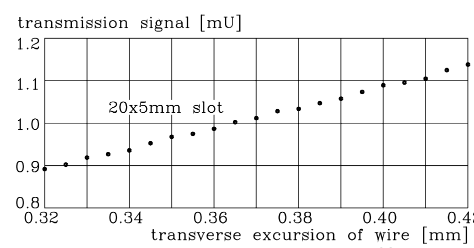

Figure 6: Measured transmission coefficient versus the wire shift for one slot length for prototype B.

3 ESTIMATION OF ERRORS

The purpose of this chapter is to point out a method and examples of their results to estimate the influence of several inaccuracies of the BPM geometry.

3.1 Method of moments applied to deformations of the beam tube

In the beam pipe mainly TEM-fields are present. So for dealing with shape deviations one can fall back upon a static method for estimation of errors. For the reason of simplification the discussion is restricted to two dimensions. The method of moments is based on substitution of metal walls by arbitrary charges. Their quantities are determined by fulfilment of boundary conditions resulting in a system of linear equations. The beam is represented by a line charge perpendicular to the calculation plane.
The calculations are done here with a beam pipe radius of 6 mm, which is valid for the waveguide monitor in the undulator. They can be applied to any other configuration.

Figure 7 shows the relative difference of field strength between two scanning points shifted 180^o (see detailed sketch) versus the beam shift in an exact round beam tube.

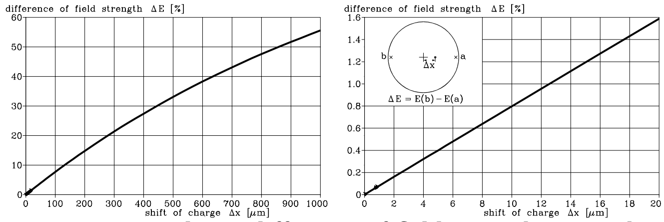

Figure 7: Relative difference of field strength versus the shift of the beam in an exact round beam tube.

A possible fabricational error is an ellipticity of the beam tube. Therefore in Figure 8 and 9 the difference signals versus the ellipticity using a centered beam are traced, once with constant scanning radius, once with constant distance from the beam tube wall. The real occuring variations are in between.

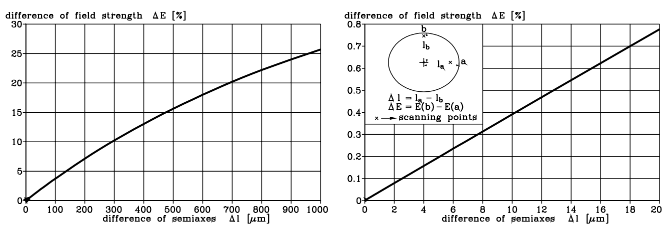

Figure 8: Relative difference of the field strength versus the ellipticity of the beam tube with a centered beam, taken at constant distance from the center of the ellipse.

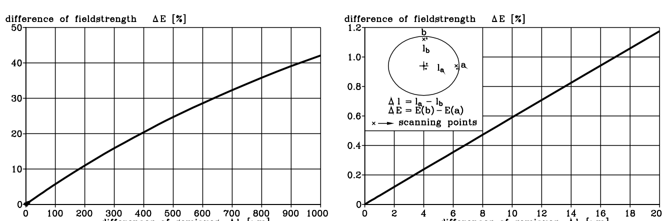

Figure 9: Relative difference of the field strength versus the ellipticity of the beam tube with a centered beam, taken at constant distance from the wall of the beam tube.

3.2 *Bethe hole coupling applied to variations of the coupling slot*

Coupling slots small compared to the wavelength are replaced by electric and magnetic dipols. Using the reciprocity theorem combined with suitable dipols for the shape of the rectangular slots the coupling coefficient can be evaluated [1, 2]. Under consideration is the coupling from a TEM-line corresponding to the TEM-field of the beam pipe into a perpendicular rectangular waveguide.
We assume a coupling coefficient of about 2 %. The dimensions again are based on the waveguide monitor. In figure 10 the width and length of the slot are changed in the way that the area remains constant. The width is in the same direction as the magnetic field, the length perpendicular with that. Figure 11 gives some information of the sole change in width for different lengths of slots.

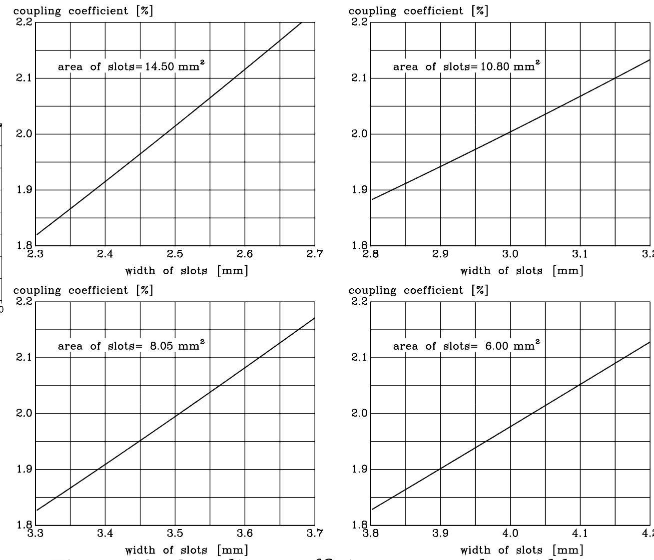

Figure 10: Coupling coefficient versus slot width at constant area. Dimension of TEM-line is 5x15 mm, of X-band rectangular waveguide 22.86x10.16 mm at 12 GHz.

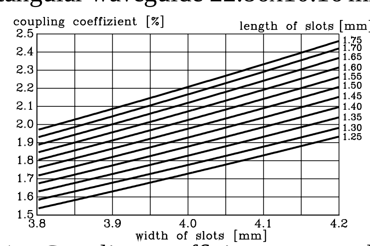

Figure 11: Coupling coefficient versus slot width for some slot lengths. Geometry is as in figure 10 at 12 GHz.

4 CONCLUSION

The proposed resonator BPM has been proved satifactory in terms of sensitivity and linearity. Further efforts are directed in enlargement of the signal as well as the improvement of measurement setup with regard to signal noise.
A good evaluation can be achieved concerning the BPM signal by using the easy manageable two dimensional momentum method. Further estimations, such as crosstalking between the two transverse pickup directions in presence of lost circular symmetry or a light angle deviation of the coupling slots, are in progress.
Bethe's theory is suitable to estimate roughly the radiation through small holes compared with the wavelength.

5 ACKNOWLEDGEMENT

I would like to thank M. Filtz for helpful theoretical discussion concerning the momentum method and H. Henke for general support.

6 REFERENCES

[1] H. Henke, *Bethe's Theory of Diffraction by Small Holes*, TETNOTE 96/04, TU-Berlin, internal note

[2] S. Kurennoy, *Pumping Slots: Coupling Impedance Calculations and Estimates*, SSCL-636, August 1993