SENSITIVITY AND TOLERANCE ANALYSIS OF A NEW BUNCH ARRIVAL TIME MONITOR PICKUP DESIGN FOR FLASH AND XFEL#

A. Kuhl*, S. Schnepp, Graduate School CE, Technische Universität Darmstadt, Germany
A. Angelovski, A. Penirschke, R. Jakoby,
Institut für Mikrowellentechnik und Photonik, Technische Universität Darmstadt, Germany
T. Weiland, TEMF, Technische Universität Darmstadt, Germany
H. Schlarb, M. Bousonville, DESY, Hamburg, Germany

Abstract

New pickup designs for a Bunch Arrival time Monitor (BAM) at the Free Electron Laser in Hamburg (FLASH) have been developed and simulated [1, 2] with CST PARTICLE STUDIO ®. With regard to the signal characteristics and manufacturability a cone-shaped pickup was selected as a prospective candidate. At high frequencies, small manufacturing tolerances might have great influence on the pickup signal. A sensitivity analysis considering several manufacturing tolerances regarding their influence on the output signal was carried out. It shows that the output signal is insensitive with respect to manufacturing tolerances of most geometrical parameters.

INTRODUCTION

The Free Electron Laser in Hamburg (FLASH) is equipped with Bunch Arrival time Monitors (BAM) [3], which provide for a time resolution of less than 10 fs for bunch charges higher than 0.2 nC [4]. The timing information is obtained by mixing the pickup signal with pulses of a reference laser in an Electro Optical Modulator (EOM) [5]. This information is coupled back to the first accelerating module, for stabilizing the arrival time jitter of the electron bunches to less than 25 fs. The sensitivity of the measurement system is defined by the slope of the pickup signal at the zero crossing and scales close to linear with the bunch charge. For future experiments lower bunch charges down to 10 pC are of interest. In this case the requirements on the time resolution will no longer be fulfilled. The slope can be increased either by increasing the output signal voltage or its frequency. Due to a technical limitation of the maximum signal voltage the new pickup should have a bandwidth of 40 GHz. Some new designs fulfilling these requirements are developed and simulated [1, 2].

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* kuhl@gsc.tu-darmstadt.de

CONE-SHAPED DESIGN

The development of new pickups focuses mainly on achieving a steep slope at the zero crossing and reducing the ringing of the voltage signal. With consideration of the signal characteristics and manufacturability a cone-shaped pickup [1] was selected as a prospective candidate. The feedthroughs are commercially available from the Advanced Technology Group, Inc. The length is 1.4 mm. The glass bead diameter is 1.625 mm and the diameter of the inner conductor is 0.305 mm. The relative permittivity (ϵ_r) was set to 4.6. The pickup has been designed to house four separate plug-in units. Since the housing needs to be slightly larger in diameter than the plug-in units a small gap remains to fulfill vacuum requirements. The gap and all other dimensions are shown in Figure 1.

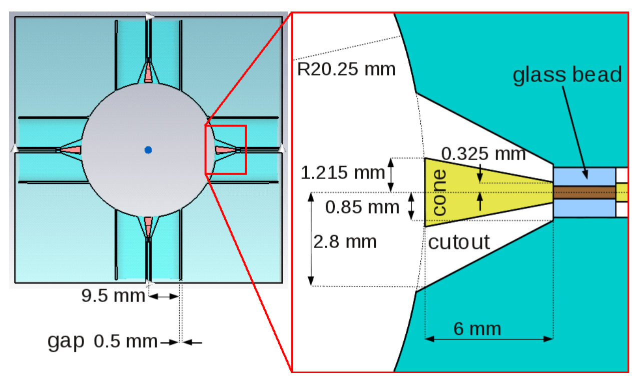

Figure 1: Reference dimensions of the cone-shaped design.

SIMULATION

For the design and simulation of the new cone-shaped pickup we used the CST PARTICLE STUDIO ® software package, which allows for computing the time dependent voltage along user defined paths as one feature. To determine the voltage gradient at the zero crossing (slope) and the amplitude of the ringing an automatic analysis has been developed and implemented as a postprocessing step by means of Visual Basic for Applications macro scripts. In order to distinguish whether the slope is influenced by the amplitude or by the frequency bandwidth, considering its value alone is not sufficient. Therefore, additionally an equivalent frequency f_e is calculated by using the slope and the peak-to-peak voltage [2]

$$f_e := \frac{|S|}{\pi \cdot U_{\text{peak to peak}}} \quad \text{with the slope S.}$$

The ringing is calculated with the maximum absolute voltage in the time window between 0.3 ns after the zero crossing up to the end of the simulated time. In the following, all simulations are carried out using Gaussian bunches with a longitudinal standard deviation of $\sigma = 1$ mm and 20 pC bunch charge.

SENSITIVITY ANALYSIS

Varying the geometry parameters of the pickup leads to small changes in the model which in turn may lead to changes of the computational grid. To minimize the influence of changing computational grids on the results, only one of the four pickup components was varied for the tolerance analysis. The three unmodified pickup components are used as reference inside the same simulation. A list of the varied parameters and the variation range are shown in Table 1. The tiltings and the position offset have been considered parallel and perpendicular to the beam axis.

Table 1: List of Varied Parameters

Parameter	Range of variation
cutout small radius	± 0.1 mm
cutout big radius	± 0.2 mm
cutout length	± 0.3 mm
cone small radius	± 0.1 mm
cone big radius	± 0.2 mm
cone length	± 0.3 mm
tilting[1] of the cutout	± 0.2 mm
tilting[1] of the cone	± 0.3 mm
position offset of the glass bead	± 0.1 mm
variation of ϵ_r of the glass	± 0.4
tilting of the plug-in unit	± 2°
rotation of the plug-in unit	± 2°

RESULTS

Figures 2 - 6 show results and a quadratic fit for slope, peak-to-peak voltage, ringing and equivalent frequency. Based on this step of the tolerance analysis, we performed a worst case scenario simulation using $\pm 20\,\mu$m and $\pm 50\,\mu$m as the maximum manufacturing tolerances. The worst case settings for a tolerance of $\pm 20\,\mu$m provides a decrease of the slope of (4.3±3) % and for tolerances of $\pm 50\,\mu$m we obtain a decrease of the slope of (9.7±3.6) %, where the ± means the simulation inaccuracy.

[1]Tiltings are approximated with shears.

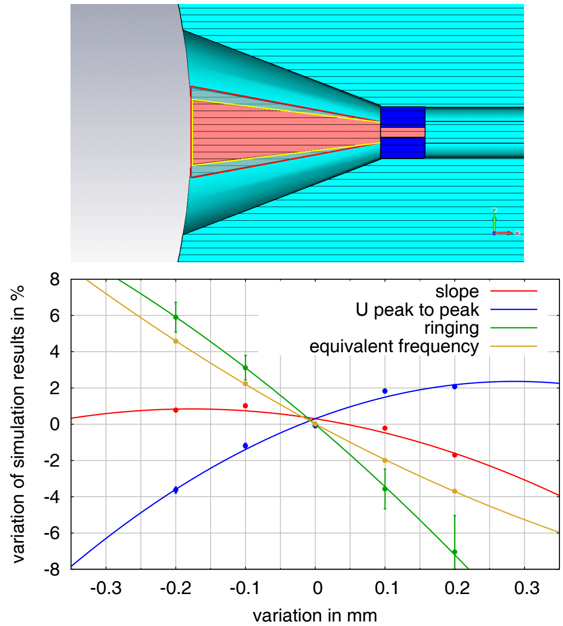

Figure 2: Variation of the big cone radius and quadratic fit.

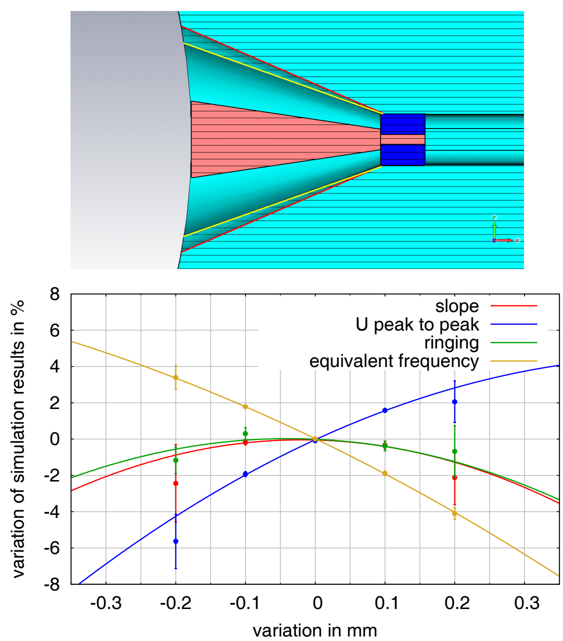

Figure 3: Variation of the big cutout radius and quadratic fit.

CONCLUSIONS

The most sensitive parameters are the small cone radius and the position of the glass bead parallel to the beam axis (see Fig. 6). If single parameter tolerances are considered the glass bead position and the small radius of the cone have to be manufactured with a precision of $\pm 20\,\mu$m for ensuring the signal slope to change by less than 1 %. The other parameters are not as sensitive and can be manufactured with a tolerance of $\pm 50\,\mu$m. The rotation and tilt of

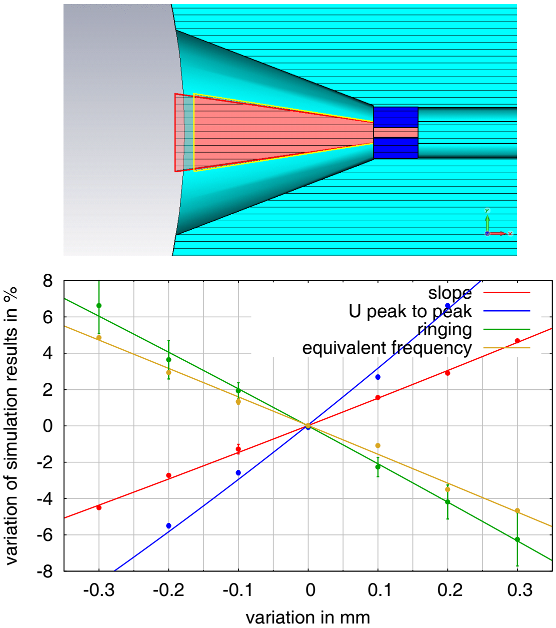

Figure 4: Variation of the big cone length and quadratic fit.

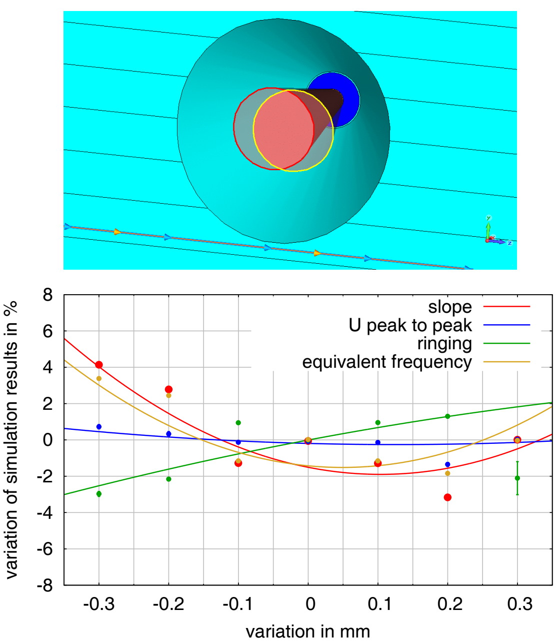

Figure 5: Tilting of the cone parallel to the beam axis and quadratic fit.

the plug-in unit should be less than 0.5°. For the worst case scenario regarding multi-parameter tolerances the signal slope changes by less than 10 % for the above described manufacturing tolerances. In the next step, a vacuum compatible prototype will be built and installed in the FLASH facility.

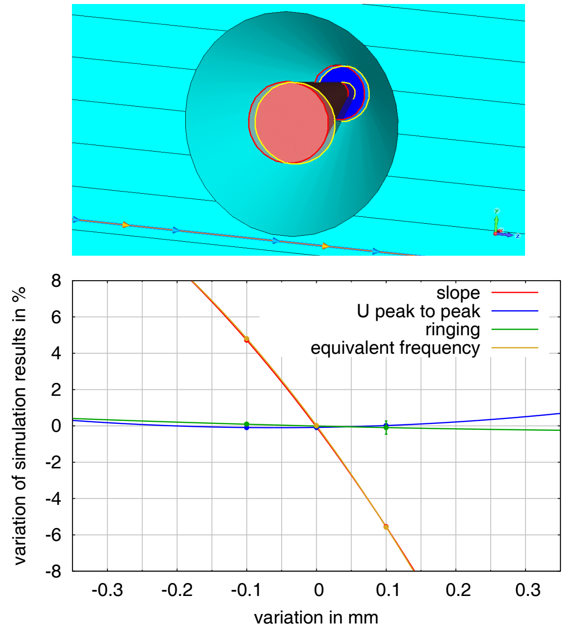

Figure 6: Variation of the position of the glass bead parallel to the beam axis and quadratic fit.

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