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DESIGN OF A ULTRAFAST STRIPLINE KICKER FOR BUNCH-BY-BUNCH FEEDBACK*

J. Wang[1†], P. Li, D. Wu, D. Xiao, L. Yan, Institute of Applied Electronics,
China Academy of Engineering Physics (CAEP/IAE), Mianyang, 621900, P. R. China
[1]also at Graduate School of China Academy of Engineering Physics, Beijing, 100088, P. R. China

Abstract

Lorentz force detuning and beam loading effect of the RF cavities will induce a slope of the cavity gradient. Combed with the cavity misalignments, transverse position of subsequent bunches will differ from each other. The CAEP THz Free Electron Laser facility (CTFEL) will have a fast transverse bunch-by-bunch feedback system on its test beamline, which is used to correct the beam position differences of individual bunches in the macro-pulses. The time response of the kicker is rigid for the interval of the micro-pulses is 18.5 ns and will upgrade to about 2 ns, requiring impedance matching of the kicker with the power source and transmission system in a high bandwidth. Also, the electromagnetic field must reach the requirements of the beam parameters. In this paper, the structure design and the optimization of the geometric parameters of the ultrafast stripline kicker is presented. The characteristic impedance, transmission characteristics, field consistency are analyzed and optimized. And the feedback signal generation scheme for continuous bunch trains was proposed.

INTRODUCTION

China Academy of Engineering Physics (CAEP) has developed a terahertz free electron laser (CTFEL) facility with Peking University and Tsinghua University, which is the first high average power FEL user facility in China [1]. CTFEL is a kind of oscillator type FEL and mainly consists of a GaAs photocathode high-voltage DC gun, a 1.3 GHz 2x4-cell superconducting RF linac, a planar undulator and a quasi-concentric optical resonator. The first saturated lasing of CTFEL was obtained in 2017 [2]. Since then, CTFEL has realized stable operation and some user experiments have been done. The repetition rate of THz beams is 54.17 MHz and the THz frequency can be adjusted from 1.87 THz to 3.8 THz continuously. The average output power in macro pulse is more than 10 W and the peak power is beyond 0.5 MW [3]. Now, fast machine protection system is under developed and CW operation will be realized soon. Moreover, CTFEL is expected to upgrade to cover the THz band from 1 THz to 10 THz and greatly promote the development of THz science as well as many other cutting-edge fields in the future. The CTFEL will have a test beam line behind the 90 degree analysis magnet, a fast transverse intra-bunch train feedback system to stabilize the beam position will be developed. The time interval of the micro-pulse will set to be about 2ns. Several beam elements and diagnostics device will be installed in the test beam line. Figure 1 shows the location of the CTFEL diagnostics device. This paper gives an overview of the design and analysis of the strip-line kicker and the scheme of the feedback signal generation.

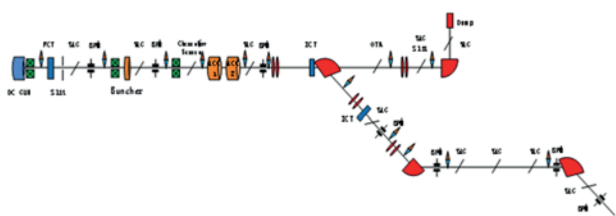

Figure 1: Location of CTFEL diagnostics device.

DESIGN STUDY OF THE STRIPLINE KICKER CROSS SECTION

A stripline kicker consists of two parallel electrodes housed in a conducting vacuum pipe: each of the electrodes is driven by an equal but opposite polarity pulse. The most technology challenges are the following: first, good power transmission by achieving good impedance matching to the electrical circuit; second, the excellent field homogeneity was need in the center region of the vacuum pipe. The stripline design has been carried out by using CST Microwave Studio and CST EM Studio [4].

In order to avoid reflections when exciting the electrodes, the geometry design of the stripline kickers should be adapted to 50 ohm to match the characteristics impedance of feedthroughs and coaxial cables [5,6]. The stripline kicker has 2 electrodes connected to electrical feedthrough at both ends. The cross section of the stripline defines the characteristic impedance and homogeneity of the electromagnetic field in the center region. The geometry of the cross section is showed in Fig. 2.

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The model is parameterized as shown in Table 1, for changing and optimizing the shape of the electrode. The distance between the electrodes was chosen.

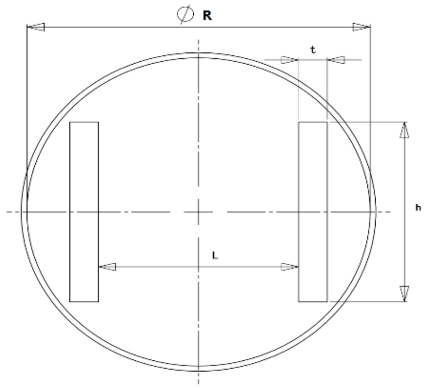

Figure 2: Geometry of the cross section.

Table 1: Parameters of the Stripline Kicker

Parameter	Symbol	Value [mm]
diameter of the vacuum pipe	R	60
distance between the electrodes	L	35
thickness of the electrodes	t	5
width of the electrode	h	35

A feedthrough is needed to transfer the power to the strip-line electrode. The characteristic impedance of the connection from the feedthrough to the stripline electrode is not 50 ohm. This impedance mismatching will introduce reflection to the transmission of the pulse power. So a 3D model (see in Fig. 3) with 4 feedthroughs is studied to analyze the influence of the geometries on the reflection.

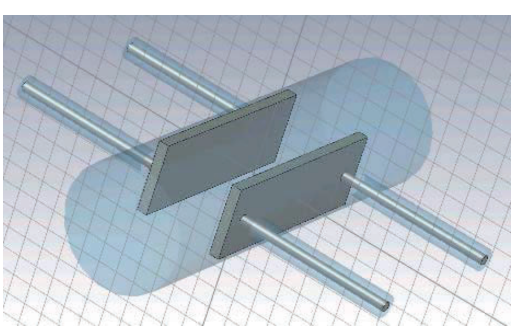
Figure 3: 3D model of the stripline with 4 feedthroughs.

Set the input side of feedthroughs as waveguide port 1, port 2, port 3 and port 4. The plot of S11 parameter for strip-line kicker is showed in Fig. 4. It presents the reflection coefficient vs the frequency. The S11 is small than -20 dB in 500 MHz, so the reflected power can be estimated less than 1%.

The feedthrough position refer to the stripline and the inner radius of the feedthrough were studied to analyze the influence on the reflection parameter magnitude, but no significant differences were found through parameters sweep.

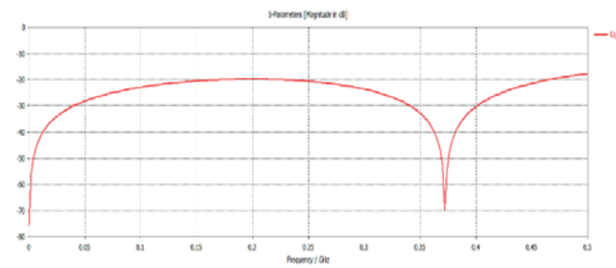
Figure 4: S11 plot for strip-line kicker.

The field homogeneity was analyzed using the CST EM Studio. The same magnitude but opposite polarity voltages were imposed on the two striplines as the excitation. The E-Field distribution of the working space was got using the E-Field solver which is showed in Fig. 5.

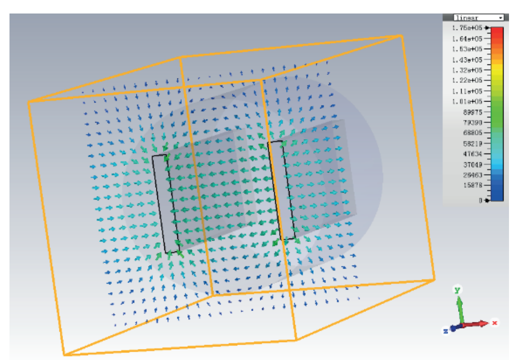
Figure 5: E-Field distribution of the kicker.

The E-Field strength vector of any point in the working space can be got through post-processing of the CST EM Studio data. The X direction field strength of the region ‘z=0, x(-5,5), y(-5,5)’ was used to analyze the field homogeneity. The field homogeneity is about 3% in this region with the step of the region is 1mm.

FEEDBACK SIGNAL GENERATION

Since CTFEL has bunch trains with the interval of the micro-pulses is 18.5ns and will upgrade to about 2 ns. Special waveform of the RF power supply output is need for arbitrary kicks to each bunch not to disturb neighboring bunches. It is difficult to generate a train of

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square pulses with flat top of several 10s ps and about 2ns bunch spacing as in Fig. 6.

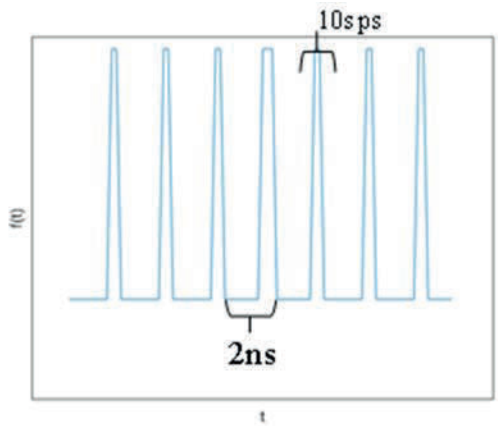

Figure 6: Square pulse trains.

The parameter fitting method is proposed to generate the input signal of the RF amplifier. The input signal must conform to the kicker strength of every individual bunches and regardless of the gap of the bunches. By adding infinite sine (and cosine) waves we can make the any functions f(t) theoretically as shows in the following equation.

$$f(t) = \sum_{0}^{\infty} A_n(n\pi t / L) + \sum_{1}^{\infty} B_n(n\pi t / L).$$

Parameter fitting method is using the combination of fourier sine and fourier cosine series to represent the input signal. The input signal is the target function, and the sine (and cosine) series must in the bandwidth of the system. Through parameter fitting, we can calculate all the coefficients An and Bn, and then got the function of the input signal. Figure 7 shows an example of an input signal generation, a train of four pulses with different peaks was generated though parameter fitting method.

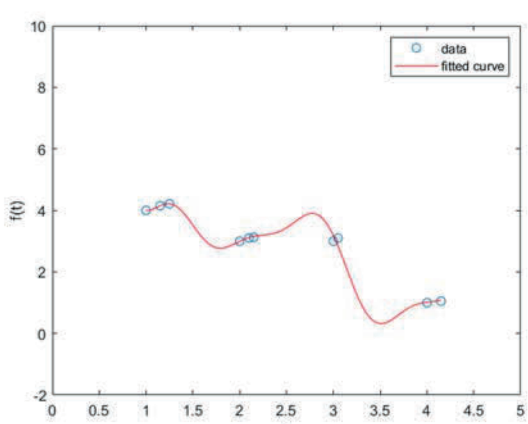

Figure 7: Parameter fitting method.

CONCLUSION

The preliminary geometry design of the stripline kicker for the CTFEL is presented. The cross section optimization of the stripline kicker is almost complete. The 50 ohm characteristics impedance and less than 1% reflection coefficient from the port, the field inhomogeneity of about 3% was realized. The parameter fitting method is proposed to generate the input signal of the RF amplifier.

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