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DESIGN AND TEST PLAN FOR A PROTOTYPE CORRUGATED WAVE-GUIDE*

G. Waldschmidt†, S. Doran, R. Kustom, A. Nassiri, J. G. Power, and A. Zholents
Argonne National Laboratory, Lemont, IL 60439, USA
G. Ha, Nam-gu Pohang, Gyeongbuk, South Korea, S. Siy
University of Wisconsin, Madison, WI 53715, USA

Abstract

A cylindrical, corrugated wakefield accelerating structure with a 1 mm radius bore is being designed to facilitate sub-terahertz Čerenkov radiation produced by an electron bunch propagating along the waveguide. A 220 GHz axial mode for the wakefield is being considered. The waveguide is being optimized to maximize the trailing wakefield potential while maintaining a ratio of the trailing potential to the peak decelerating voltage in the bunch, or transformer ratio, of approximately 5 for the door step peak current distribution [1]. In order to evaluate the manufacturing tolerances and perform rf and electron beam testing of the waveguide, a 21 GHz prototype waveguide structure will be built consisting of re-configurable parts allowing modelling of various fabrication errors. Measurements with an electron beam will be performed at the Argonne Wakefield Accelerator (AWA) test facility. Analysis of the experimental layout has been performed.

Introduction

Due to limitations of the effective gradient in current accelerator structures, a number of options are being investigated including plasma accelerators, structure-based accelerators and laser-driven accelerators. Structure-based accelerators incorporating dielectric layers or corrugations [2-5] have produced promising results. Corrugated structure-based waveguides are being explored in this paper due to positive attributes such as the elimination of the dielectric / metal interface and the absence of issues regarding beam charging.

The corrugated waveguide is intended to accelerate a witness bunch of ~0.3 nC using a high charge drive bunch on the order of 10 nC with gradients of ~100 MV/m in a collinear wakefield accelerator (CWA) [6]. In order to achieve high gradients, the corrugated structure will be designed between 200 – 300 GHz which presents challenges for the manufacture of the structure. The impact of manufacturing errors is significant especially due to beam instabilities.

In order to understand the effect of errors and determine tolerances, rf tests will be performed as well as beam tests at the Argonne Wakefield Accelerator (AWA) in Argonne [7]. AWA is capable of producing a high charge bunch of ~10 nC with a bunch length of ~0.6 mm. The corrugated waveguide test structure will be scaled from 220 GHz to 21 GHz in order to facilitate setup and testing. It also facilitates the ability to precisely incorporate scaled manufacturing errors in the structure to reproduce the expected relative tolerances of the waveguide at 220 GHz.

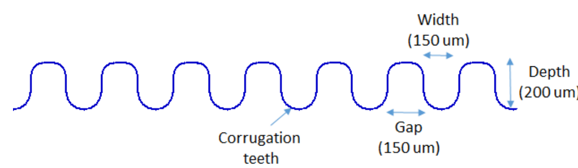
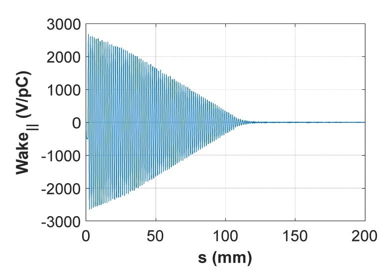


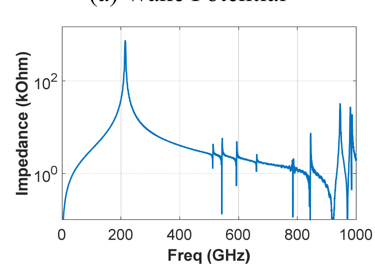
Figure 1: Corrugated waveguide cross-sectional input geometry for ECHO.

MANUFACTURING ERROR

A typical corrugated waveguide cross-section is shown in Fig. 1. The waveguide dimensional parameters were adjusted to modify the frequency and various properties of the wakefield including loss factor and peak wakefield. The wake potential and the shunt impedance calculated by the code ECHO [8] are shown in Fig. 2 for a corrugated waveguide with a highly asymmetrical door step – style drive bunch [1]. The rato of the peak accelerating wakefield to the peak decelerating wakefield within the bunch, or transformer ratio, was designed at ~5 as a compromise between the maximum accelerating gradient within the corrugated waveguide of ~100 MV/m and the overall length of the accelerator to achieve a final energy of 5 GeV [6].



(a) Wake Potential



(b) Shunt Impedance

Figure 2: Results from ECHO with a 200 μm bunch in a 300 mm long matched corrugated waveguide structure.

*Work supported by US DOE under contract DE-AC02-06CH11357
†waldschm@anl.gov

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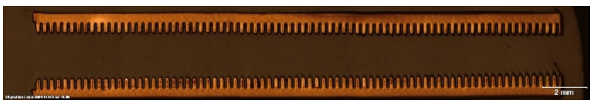
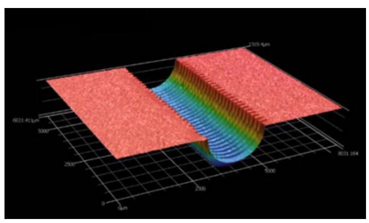
Various prototype corrugated waveguides were fabricated and measured to determine the range of expected manufacturing errors and to determine the most reliable fabrication techniques for producing the structures. Fig. 3 shows a typical cross-sectional view of a 25 mm corrugated waveguide, as well as measurement results with a color-coded scale of the relative transverse depths of the structure.



(a) 25 mm waveguide cross-section



(b) Profile of corrugated waveguide measurement

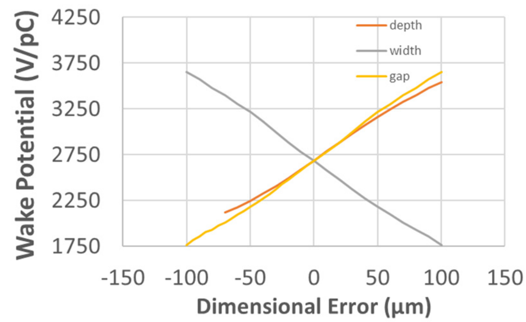
Figure 3: Prototype corrugated waveguide structure and measurement results.

Effects of manufacturing errors on the depth, width, and gap defined in Fig. 1 are plotted in Fig. 4. In order to determine fabrication tolerances, the dependence of the wake potential, frequency, and transformer ratio on these dimensional errors are shown in the plots. The manufacturing errors are varied around the nominal values shown in Fig. 1 where the length of each period is held constant along the structure.

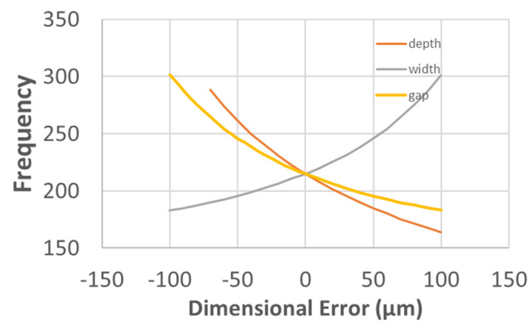
RF tests are being developed to detect and locate errors to quantify the magnitude of the errors and to create specifications for acceptance testing of these structures. The phase advance of the structure will be re-constructed from an rf signal reflected at periodic intervals along the waveguide. Variations of the phase advance from their nominal value will be evaluated and a correction factor calculated. The magnitude of the correction factor will be related to the local manufacturing error within that period. As a result, the location and relative severity of the error may be determined.

AWA EXPERIMENT

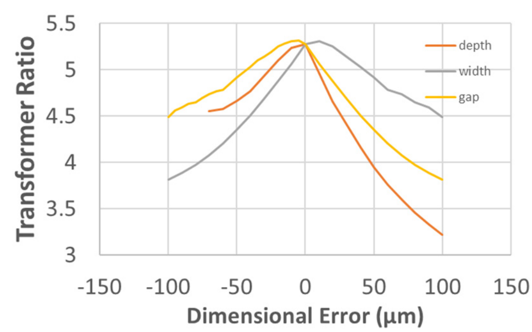
Beam experiments will be performed at the AWA to perform tolerance studies on a scaled version of the corrugated waveguide at a resonant frequency of 21 GHz and an inner radius of 6 mm. A schematic of the lattice near the experimental interaction region is shown in Fig. 5. A Be window is used to separate the high-vacuum linac region from the interaction region to facilitate ease of replacement of the structure being testing. It is located at a waist in the lattice in a high divergence region in order to reduce the window impact on the beam emittance.



(a) Wake potential



(b) Frequency



(c) Transformer ratio

Figure 4: Dependence of corrugated waveguide parameters on dimensional variations of corrugation depth, width, and gap length.

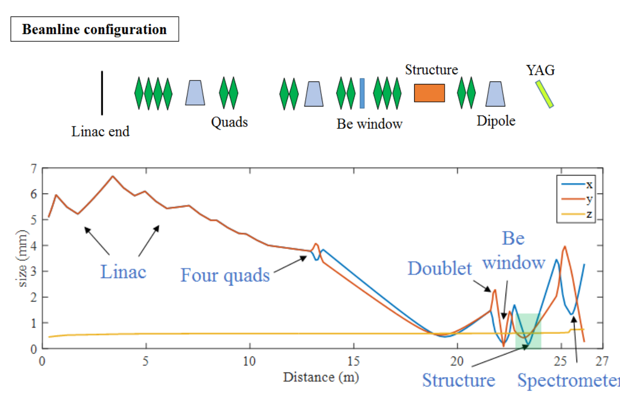


Figure 5: Argonne Wakefield Accelerator lattice layout.

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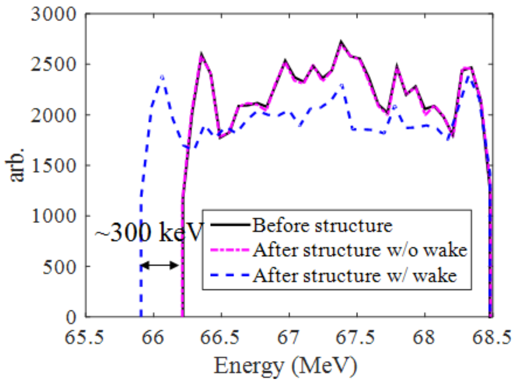

Figure 6: Energy of the beam at simulated spectrometer with and without corrugated waveguide.

The initial set of tests on the scaled structure will compare the longitudinal wake function of structures with and without dimensional errors. The beam will be directed through a test structure and into a spectrometer where the energy dispersion of the beam will be measured to infer the longitudinal wake. For the initial test, a control structure consisting of a smooth cylindrical pipe with no corrugations will be compared to the corrugated structure without dimensional errors. Simulation results of the longitudinal energy dispersion from GPT [9] are shown in Fig. 6 where a 300 keV energy modulation is expected due to the 300 mm long corrugated waveguide. Fig. 7 shows the energy spread of the beam on a simulated spectrometer in GPT for the cases of corrugated structure (upper) and no structure (lower). The next steps are to simulate several structures with intentionally machined errors and misalignments to study tolerance.

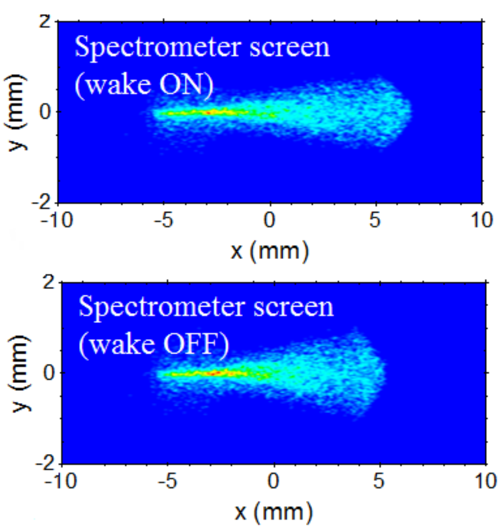

Figure 7: Simulation results of beam spread at spectrometer with and without corrugated waveguide.

Fabrication of the waveguide may consist of brazing or welding from two halves. In that case, additional errors will be produced due to the misalignment in both the longitudinal and transverse planes. Simulations in CST [10] are being performed to evaluate the effect on the longitudinal energy dispersion as well as the kick of the beam. This will be validated with further testing performed at the AWA.

CONCLUSION

A cylindrical corrugated waveguide with 1 mm inner radius has been designed. It will operate at 220 GHz with a transformer ratio of ~5 in order to balance the competing requirements of peak accelerating gradient and accelerator length. Quantifying fabrication errors are critical for achieving the required performance from the corrugated waveguide, as well as in determining the acceptance criteria and in reducing beam instabilities caused by them.

In order to quantify errors in the high-frequency structure, rf and beam tests are being planned for a lower frequency prototype operating at 21 GHz. Beam tests are being prepared at the Argonne Wakefield Accelerator which is capable of producing 10 nC charge with a 0.6 mm bunch length. These tests will evaluate both longitudinal and transverse beam parameters in order to help determine any fabrication errors or misalignment.

REFERENCES

[1] K.L.F. Bane, P. Chen, and P.W. Wilson, "On collinear wakefield acceleration", *IEEE Trans. on Nucl. Science*, vol. NS-32, No. 5, p.3524, 1985.

[2] W. Gai, M. E. Conde, R. Konecny, J. G. Power, P. Schoessow, J. Simpson, X. Sun, and P. Zou, "Experimental demonstration of two beam acceleration using dielectric step-up transformer," *PAC'01,* Chicago, IL, pp. 1880–1882. http://www.JACoW.org

[3] M. Conde, Survey of advanced dielectric wakefield accelerators, in *Proceedings of the 22nd Particle Accelerator Conference, PAC-2007*, Albuquerque, NM (IEEE, New York, 2007), pp. 1899–1903.

[4] A. Zholents et al., "A preliminary design of the collinear dielectric wakefield accelerator", *Nucl. Instr. Meth.*, vol. A829, pp. 190-193, 2016.

[5] K.L.F. Bane, G. Stupakov, Corrugated pipe as a beam dechirper, *Nuclear Instruments and Methods in Physics Research* A 690 (2012) 106.

[6] A. Zholents, et. al., "A Conceptual Design of a Compact Wakefield Accelerator for a High Repetition Rate Multi-User X-Ray Free-Electron Laser Facility", presented at the 9th Int.Particle Accelerator Conf. (IPAC'18), Vancouver, Canada, May 2018.

[7] M. Conde, et. al., "The Argonne Wakefield Accelerator Facility: Capabilities and Experiments," AIP Conference Proceedings 737, 657 (2004); https://doi.org/10.1063/1.1842605

[8] I. Zagorodnov, K. L. F. Bane, and G. Stupakov, "Calculation of wakefields in 2D rectangular structures", Phys. Rev. ST Accel. Beams 18, 104401 (2015).

[9] GPT User Manual, Pulsar Physics, Flamingostraat 24, 3582 SX Utrecht, The Netherlands.

[10] CST STUDIO, Computer Simulation Technology AG, Darmstadt, Germany.