HIGH-GRADIENT THZ-SCALE TWO-CHANNEL COAXIAL DIELECTRIC-LINED WAKE FIELD ACCELERATOR*

S.V. Shchelkunov[1], T.C. Marshall[2], G. Sotnikov[3], J.L. Hirshfield[1,2], M.A. LaPointe[1]
[1]Yale University, New Haven, CT, 06520, USA; [2]Omega-P, Inc, New Haven, CT 06511, USA;
[3]NSC Kharkov Institute of Physics and Technology, 61108, Kharkov, Ukraine

Abstract

A mm-scale THz coaxial dielectric-lined two-beam wakefield accelerator concept is currently under study by Yale University Beam Physics Lab and collaborators. Performance of this structure is based on use of annular drive bunches. The structure has the attractive feature that the drive and accelerated bunches both have good focusing and stability properties, and also exhibits a large transformer ratio. We have had recent successful experiments at AWA/Argonne National Lab with a cm-scale GHz rectangular dielectric-lined two-beam accelerator module, and plan further activity there with a cm-scale GHz coaxial structure. The research reported here has two objectives. The first is to design a structure to produce acceleration gradients on a scale of 0.35 GeV/m per each nC of annular drive charge. The second goal is to build and test the structure at FACET/SLAC. At FACET the structure can be excited only with the available pencil-like drive bunch, but a reciprocity principle allows one to infer some of the properties that would be seen if the excitation were to be by an annular drive bunch. This presentation shows our latest findings, discusses related issues, and discusses our plans for experiments.

INTRODUCTION

In [1], a new scheme for a two-beam dielectric wakefield accelerator was proposed that uses two hollow concentric dielectric tubes with vacuum channels for drive and accelerated bunches. This two-channel coaxial dielectric accelerator (CDWA) appears to be a promising candidate for a future TeV-scale collider [2].

The CDWA structure consists of two coaxial dielectric tubes enclosed one inside the other, thereby forming two vacuum channels, the outer for the annular drive bunches and the inner for accelerated witness bunches. It could provide a high acceleration gradient, in the GeV/m range for mm-scale structures, while demonstrating a larger transformer ratio (TR) than would a single-channel structure. The transverse forces acting upon the accelerated bunch can be focusing, while the annular drive bunch has been shown to move an appreciable distance without undergoing distortion or deflection [2].

An experiment is now underway at FACET (SLAC) to test a mm-scale THz CDWA using their point-like drive bunch. It might appear that only an annular bunch could be used to set up the desired wakefields in this structure. However it can be shown that the point drive bunch will establish the fields one wishes to study; furthermore, it will be shown how one may obtain information from this study whereby the data can be compared with theoretical simulations obtained with the CST STUDIO code.

Experience with this THz structure, together with information obtained from a larger GHz structure now under study at the Argonne Wakefield Accelerator facility (ANL), could provide the necessary stimulus for further development of this type of DWA structure for a collider-type accelerator.

DESIGN OVERVIEW

The basic configuration for this type of DWFA is shown in Fig.1.

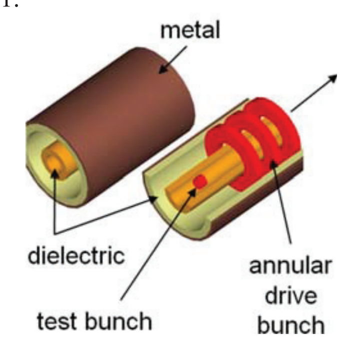

Figure 1: coaxial CDWA schematic.

One or a few annular drive bunches can be used to produce the wakefield. When several drive bunches are used, the ratio of drive bunch charges and the distances between bunches should be adjusted to constitute a ramp bunch train with constructive wake fields [3].

The structure and related parameters are presented in Table 1; it is instructive to also show in Table 2 the parameters of the cm-scale coaxial structure that is being tested at AWA/Argonne. Both structures are to be driven by a single drive bunch; the THz structure will be excited by the ~3-nC 23-GeV bunch available at FACET, and the GHz structure is to be excited by a 14-MeV AWA annular bunch with charge up to 50 nC.

There are several modes excited in each structure; the design mode for the THz structure is E_{04} at 472 THz, while the design mode for the GHz version is E_{02} at 18.8 GHz. The test bunch should lag the drive bunch by ~700 microns to experience acceleration in the THz structure, and by ~17 mm in the GHz structure. Figs. 2-3 present some drawings/photos of these structures.

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#sergey.shchelkunov@gmail.com

Table 1: THz (mm-scale) coaxial structure parameters

OD of outer dielectric tube (mm)	2.0
ID of outer dielectric tube (mm)	1.0
OD of inner dielectric tube (microns)	360
ID of inner dielectric tube (microns)	100-150
Length (mm)	21
Dielectric constant (quartz)	3.75
Acceleration Gradient (MV/m/nC)	310-138
Transformer Ratio (1 drive bunch)	8:1 - 7:1

Table 2: GHz (cm-scale) coaxial structure parameters

OD of outer dielectric tube (mm)	30.15
ID of outer dielectric tube (mm)	27
OD of inner dielectric tube (mm)	8
ID of inner dielectric tube (mm)	4.8
Length (mm)	100
Dielectric constant (Al_2O_3)	9.8
Acceleration Gradient (MV/m/nC)	0.4
Transformer Ratio (1 drive bunch)	6.5:1

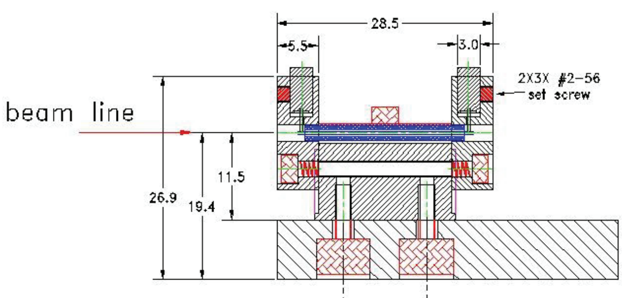

Figure 2: cross-section view of the THz structure to be tested at FACET (dielectric tubes are in blue)

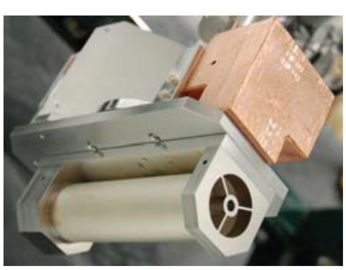

Figure 3: photo of the GHz structure being tested at AWA/Argonne.

PLANNED EXPERIMENTS

The experiment with the THz-structure at FACET will use a point-like beam to probe the structure. We will show later that this allows us to obtain information sufficient to draw conclusions about the structure's behaviour when excited by an annular bunch.

The experiment at AWA/Argonne uses a ring-like bunch. Fig.4 shows results of our first attempt to produce such a bunch.

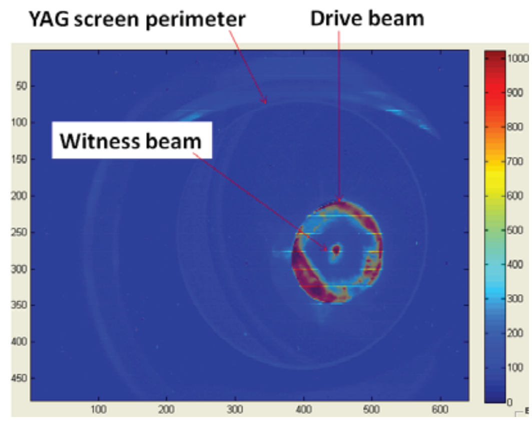

Figure 4: Frame-grabber snapshot of the annular-like beam at AWA (screen calibrated in pixels). Further efforts are under way to form a more uniform ring distribution. The ring shown has 20 nC of total charge.

In the initial stage of the experiments at FACET, the plan is to direct the e-beam to either the outer, annular channel or the inner channel, and to compare the amount of THz radiation produced (see Fig 5). The amount of radiation yields the ratio of drag forces acting on the drive bunch when it goes through each channel. This ratio is computed to be ~ 3.8.

In the second stage of the FACET experiment, the plan is to map the fields produced by a point-like bunch in the inner channel by measuring the energy changes of the drive bunch itself, to yield the deceleration gradient. Together with information obtained at the first stage, this will allow us to infer the transformer ratio and the acceleration gradient that would occur in this structure when it is driven by an annular-like beam as described in [1,3 and 4].

The experiment at AWA will use a test bunch to probe the fields; if this test bunch is situated ~56 ps behind the drive bunch, it should undergo acceleration. The probing technique and measurement procedures will be the same as used before when investigating the rectangular two-channel GHz-scale DWFA [5].

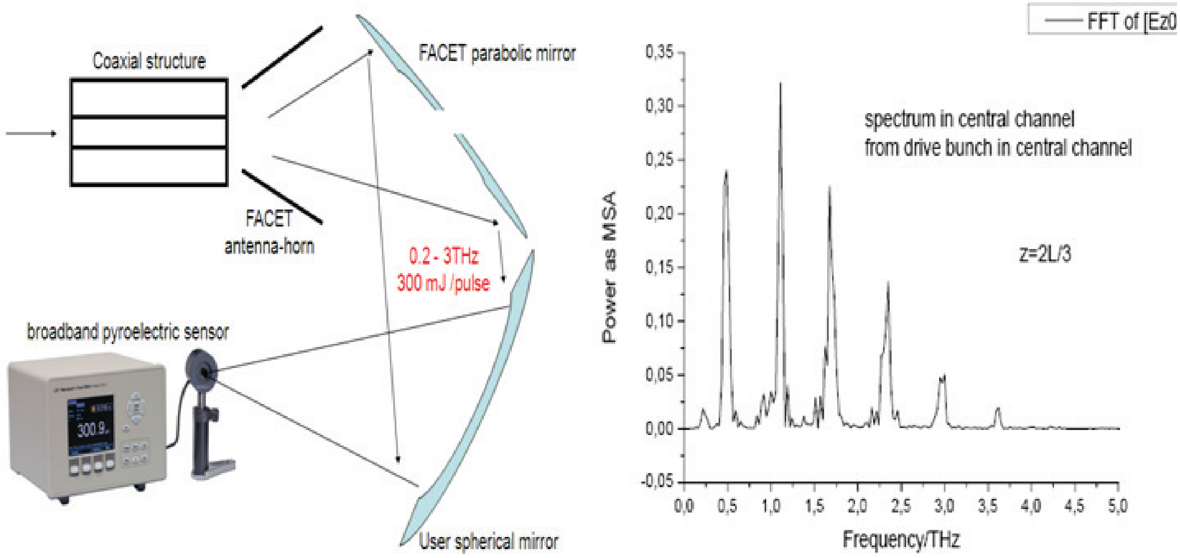

Figure 5: at FACET, the plan is to direct the e-beam to either the outer, annular channel, or inner channel and compare the amount of THz radiation produced (the right-hand side shows an example of spectrum expected when the e-beam goes through the inner channel)

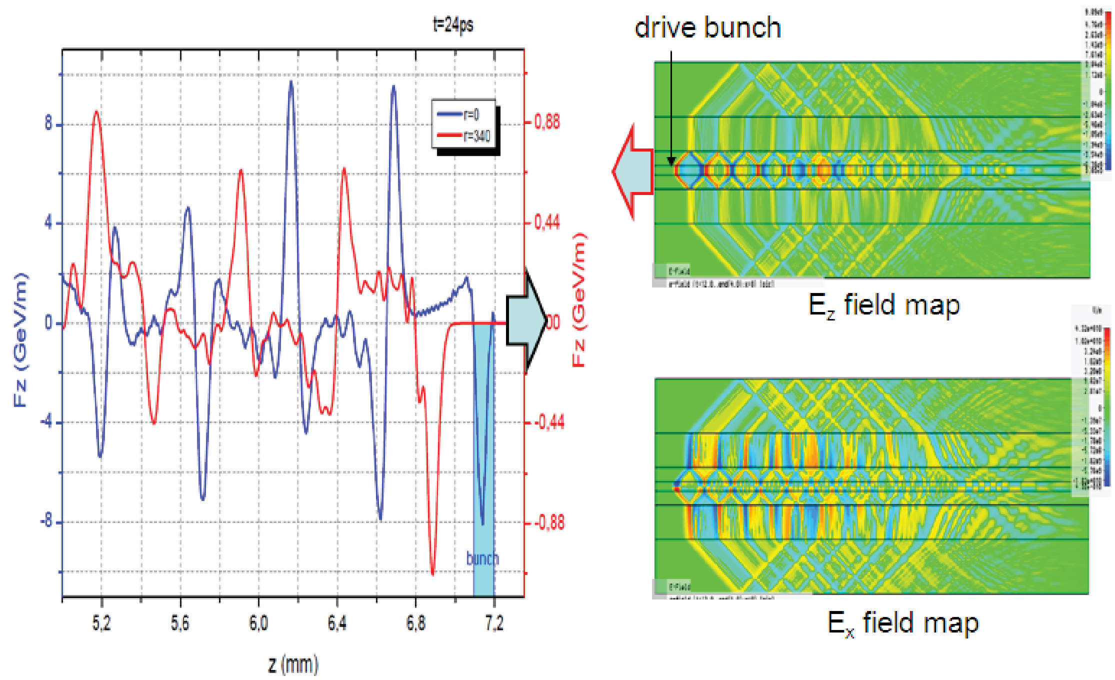

Figure 6: Prediction of the fields produced by a bunch propagating in the inner channel (FACET experiment). The drive bunch propagates in the direction shown by the arrows. On the left-hand side, the blue curve presents the composite F_z force along the axis of the structure (in the inner, tube-like channel), and the red curve presents the composite F_z in the annular channel as setup by a 3nC point-like drive bunch moving along the axis of the structure (in the inner channel)

REFERENCES

[1] G.V. Sotnikov, T.C. Marshall, and J.L. Hirshfield, *Phys. Rev. ST-AB* **12**, 061302, (2009)

[2] T.C. Marshall, G.V. Sotnikov, and J.L. Hirshfield, *AAC: Fourteenth Workshop*, edited by S. Gold and G.Nusinovich, AIP Conf. Proc. 1299, 336 (2010)

[3] G. V. Sotnikov and T. C. Marshall, Phys. Rev. ST Accel. Beams 14, 031302 (2011)

[4] G. V. Sotnikov, et al., WEPPP004, these proceedings

[5] S. V. Shchelkunov, et al., Phys. Rev. ST Accel. Beams 15, 031301 (2012)

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