

A Possible Experiment at LEUTL to Characterize Surface Roughness Wakefield Effects

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Abstract. Wakefield effects due to internal vacuum chamber roughness may increase the electron beam energy spread and so have become an immediate concern for future x-ray free-electron laser (FEL) project developments such as the SLAC Linac Coherent Light Source (LCLS) and the DESY TESLA x-ray FEL. We describe a possible experiment to characterize the effects of surface roughness on an FEL driven by self-amplified spontaneous emission (SASE) operation. Although the specific system described is not completely identical to the above-proposed projects, much useful scaling information could be obtained and applied to shorter wavelength systems.

INTRODUCTION

Although the effects of internal vacuum chamber roughness have been predicted by analytical methods [1-6] and simulation [7], there is currently no experimental confirmation. Furthermore, the results are strongly dependent upon the details of the theoretical surface roughness model used. The effects may be important for future x-ray free-electron laser (FEL) projects such as the SLAC Linac Coherent Light Source (LCLS) [8] and the DESY TESLA x-ray FEL [9] that are based on the self-amplified spontaneous emission (SASE) process, as the induced energy spread could cause significant lengthening of the gain length. Currently, there are plans to test roughness effects at the SLAC Gun Test Facility (GTF) at an electron beam energy of 30 MeV [10] and between ~240-390 MeV at the TESLA Test Facility (TTF) [11-13]. In addition, we describe yet another possible experiment that could be attempted to further our understanding of surface-roughness-induced wakefields and their effect on the electron beam. To be concrete, we will consider the Low-Energy Undulator Test Line (LEUTL) at the Advanced Photon Source (APS) at Argonne National Laboratory

[14]; however, the experiment can obviously be done elsewhere. This note outlines some of the technical considerations for a roughness experiment at LEUTL.

POSSIBLE EXPERIMENTAL LAYOUT

The first LEUTL experiment examines SASE gain and saturation in three wavelength regions: the visible, ultraviolet, and vacuum ultraviolet [15-17]. This first LEUTL experiment is often referred to as the APS SASE FEL and utilizes a string of undulators that are similar to those found in the APS storage ring, each having an undulator parameter K of 3.1, a period of 3.3 cm, and a length of 2.4 m. LEUTL presently (Fall 2000) employs nine identical undulators spaced by ≈ 0.38 m. This space contains a combined function dipole-corrector and quadrupole magnet, electron beam diagnostics, and optical beam diagnostics [18]. LEUTL uses a photocathode-rf gun [19] and drive-laser system [20] to generate electrons that are further accelerated through the APS linear accelerator (linac) [21]. (Note: this linac is also used as part of the injector system to the APS storage ring.) The APS linac is capable of operation up to 650 MeV, corresponding to a SASE FEL output wavelength down to 59 nm. Peak currents up to 650 A have been achieved using a recently installed bunch compressor system [22], allowing a variety of experimental measurements to be obtained.

With regard to a beamline region appropriate for surface roughness wakefield effects investigations, we point out that a transfer line lies between the exit of the linac and the LEUTL tunnel proper. This line has numerous electron beam diagnostics, the necessary corrector and quadrupole magnets to insure a proper transport to and match into the LEUTL tunnel, and a high-resolution electron beam spectrometer capable of resolving one part in a thousand. There is sufficient space upstream of this spectrometer to install various vacuum chambers with a variety of induced surface roughnesses. These would be mounted on an actuator allowing the insertion or removal of the chamber under study. Furthermore, there will be an identical spectrometer installed at the exit of the linac within a year, thus allowing one to measure the electron beam energy and energy spread both before and after traversing the chamber in question. The existence of two spectrometers is the essence of this proposal in that it would allow a clean subtraction of all other wakefield effects that might arise in the transport between the two identical spectrometers. Also, there is a high-resolution energy spectrometer after the exit of the undulator line, so the system can also test the effect of the wakefields from the test pipe on the SASE output. The general layout is shown in Figure 1.

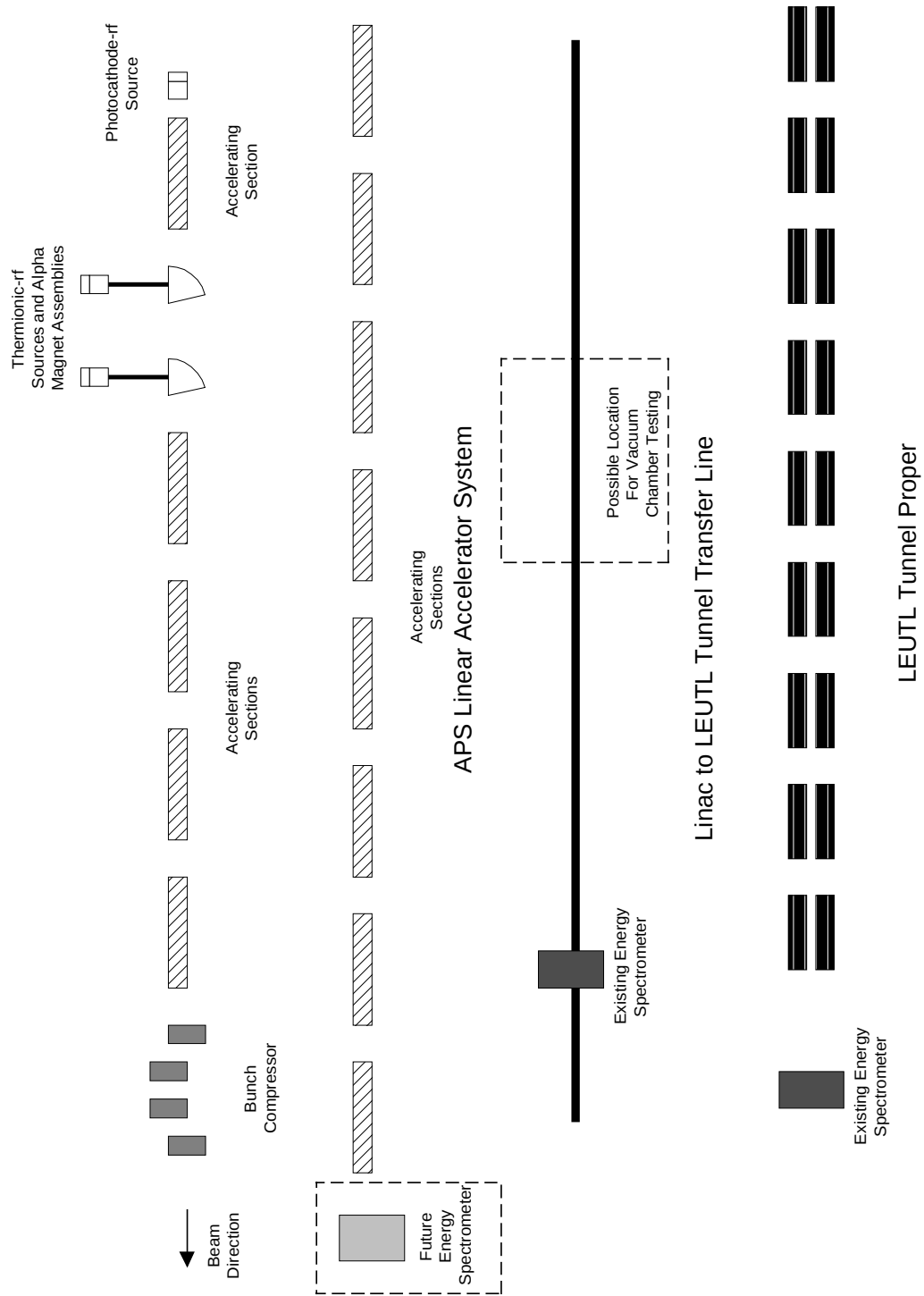


FIGURE 1. LEUTL layout with notation of place for future spectrometer and possible place for test chamber installation.

WHAT ROUGHNESS TO IMPOSE?

A number of different roughness models have been developed and published by authors such as K. Bane, G. Stupakov, A. Novokhatski, A. V. Agafonov, L. Palumbo, and others [1-6]. The effects depend upon the bunch length, the radius, and the length of the vacuum pipe as well as details of the surface roughness.

Surface roughness experiments are not likely to realize either the bunch length (about 100 fs or less) or the length of the vacuum pipes (100 m or more) that are proposed for the LCLS and the TESLA FEL. With longer bunches and shorter vacuum chambers, the effects from realistic surfaces would be too small to be measured in a test experiment. It will therefore be necessary to prepare a special beam pipe with artificially produced large-scale roughness structures on the inside.

The roughness models, discussed in the literature, are based on two types of geometrical structures: small bumps with heights that are equal to the distance between them or grooves that are longitudinally elongated with respect to their depth. The structures that can be purposely created on the inside surface of a long, narrow vacuum tube (typically 5 mm to 1 cm in diameter) are limited. The GTF group decided, therefore, to restrict their test to a surface structure with a periodicity on the order of the bunch length and transverse groove lengths of about half that. Theory predicts that for such an arrangement the induced energy spread scales proportionally to the length of the pipe and inversely to the square of the pipe radius.

An experiment at LEUTL could use a similar strategy but would have access to a wider range of bunch lengths due to the existence of the bunch compressor. A scanning electron probe, with a resolution on the atomic scale horizontally and 5 Å vertically, is available at the Advanced Photon Source and could be used to accurately measure the surface roughness of the sample pipes. Also, to achieve a more capable method of producing the artificial roughness as well as to properly measure it, there is some thought of splitting the chamber in two 180 degrees apart with fitting grooves. This entire assembly would be placed on an actuator inside a larger vacuum chamber. Different chambers could then be inserted and removed frequently without disruption of the vacuum system. As stated earlier, a direct measurement of SASE degradation as a function of different test chambers could be made at LEUTL, as it is presently configured as an operating SASE FEL.

CONCLUSION

An experiment could be constructed to clearly show the effect of surface roughness on an electron beam. The LEUTL at the APS was used as an example. Since this experiment relies upon the successful installation of a high-resolution electron beam spectrometer, the earliest this experiment could be scheduled at the LEUTL facility is the summer of 2001. Experimental comparisons of the theoretical models and a scaled

prototype chamber would determine if the predictions are strongly model dependent and help in the design of upcoming x-ray free-electron laser systems. At present, we are awaiting input from our theoretical colleagues. With their assistance, proper scaling of the effects to our lower energy, longer bunch length systems could be done to determine the types of vacuum chambers we should be testing. This information could then be used to directly predict the effect on projects such as the LCLS and TTF x-ray facilities.

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