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Transverse beam envelope measurements and the limitations of the 3-screen emittance method for space-charge dominated beams

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Abstract

In its normal mode of operation, the Argonne Wakefield Accelerator Facility uses a high charge (10–100 nC), short pulse (3–5 ps) drive bunch to excite high-gradient accelerating fields in various slow-wave structures. To generate this bunch, we designed a 1.5 cell, L-band, rf photocathode gun with an emittance compensating solenoid to give optimal performance at high charge; it has recently completed commissioning. More recently, we have begun to investigate the possibility of using this gun in a high-brightness, low-charge operating mode, with charge equal to approximately 1 nC, for high-precision measurements of wakefields. Two related measurements are reported on in this paper: (1) measurements of the transverse beam envelope are compared to predictions from the beam dynamics code PARMELA; and (2) investigations into the use of a modified 3-screen emittance measurement method that uses a beam envelope model that includes both space-charge and emittance effects. Both measurements were made for the 1 nC, 8 MeV beam in the drift region directly following the rf photocathode gun.

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1. Introduction

The Argonne Wakefield Accelerator (AWA) facility [1] is used to investigate electron beam-driven, high-gradient wakefield acceleration techniques. The generation of high accelerating gradients (>100 MeV/m) in wakefield structures or plasmas requires a high charge (10–100 nC), short pulse (3–5 ps) electron drive bunch. While most rf photocathode gun designs are optimized for high-brightness, low-charge (~1 nC)

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applications, such as free electron lasers, the 1.5 cell, L-band AWA rf photocathode gun, or "Drive Gun," is optimized for high-charge operation mode. Recently, we have started to pursue a high-brightness application: a compact, high-precision wakefield measurement system for the purpose of characterizing slow-wave structures as described in the Ref. [2].

Motivated by the high-brightness application, we have begun an investigation to determine if the high-charge AWA Drive Gun can also be operated in a high-brightness operation mode. High-brightness rf photocathode guns routinely generate 1 nC beams with normalized transverse emittances in the neighborhood of 2–5 μm. Since the Drive Gun had already been optimized for high-charge operation, we realized that it might not be possible to generate such high-brightness beam with this gun. However, recent simulations [2] performed with PARMELA [3] indicate that high-brightness operation is possible provided that a sufficiently high accelerating gradient (peak field on-axis $= E_{z0} = 80\,\mathrm{MV/m}$) in the gun can be reached.

In this paper, we present the results of experiments to characterize the AWA Drive Gun operating in the high-brightness, low-charge mode. Spot size measurements were made of the 8 MeV, 1 nC beam at three locations in the drift region downstream of the Drive Gun as the rf launch phase of the gun was varied approximately from 30° to 70°. These measurements were then analyzed in two different ways: (1) the spot sizes were compared to predictions from the beam dynamics code PARMELA; and (2) the spot sizes were used to investigate the capabilities of a modified 3-screen emittance measurement method. This modified method differs from the standard method in that its beam envelope model includes space-charge effects, in addition to emittance effects, since it is well known that the standard method fails for space-charge dominated beams [4–6]. The outline for the remainder of this paper is as follows. We present: (i) the experimental setup and technique used to measure the beam envelope and emittance; (ii) the results of the experimental measurements; and (iii) a discussion of results.

2. The experimental setup and technique

In this section, we first describe the experimental setup including the main components of the beamline where the spot size measurements were made, the Drive Gun, and the photocathode laser system; and second the experimental technique of the modified 3-screen emittance measurement method.

2.1. The AWA Gun Test Stand

In Fig. 1, a highly simplified version of the AWA Gun Test Stand (GTS) beamline shows only the elements that were used during these measurements. The block labeled "Gun & Solenoids" consist of the Drive Gun and three solenoids as described in more detail below. The two diagnostics elements used are: (1) a single Bergoz integrating current transformer (ICT) for non-destructive measurement of the beam charge; and (2) three YAG:Ce (YAG) phosphor screens for beam profile measurements (YAG-1, YAG-2, and YAG-3). The YAG screens were mounted on pneumatic actuators, were purchased from Crytur Ltd., and have dimensions of 250 μm thick by 50 mm in diameter. It is known that the resolution of YAG scintillators can be severly limited by intensity dependent effects [7] when the charge density exceeds $6\,\mathrm{nC/mm^2}$ (different authors give slightly different estimates). However, since our charge density is approximately an order of magnitude below this threshold we do not

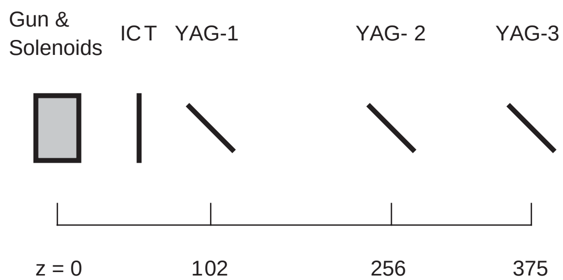

Fig. 1. A simplified diagram of the AWA Gun Test Stand beamline. Charge is measured by the ICT and beam images are measured by inserting the phosphor screens YAG-1, YAG-2, or YAG-3. ($z = 0$ is the location of the photocathode; all distances are in cm.)