DESIGN AND DEVELOPMENT OF THE DIAGNOSTIC SYSTEM FOR 75 MeV ELECTRON DRIVE BEAM FOR THE AWA UPGRADE*

J.G. Power[#], M.E. Conde, D.S. Doran, W. Gai, R. Konecny, W. Liu,
E. Wisniewski, and Z. Yusof ANL, Argonne, IL 60439, USA
S. Antipov and C. Jing, Euclid Techlabs, LLC, Solon, OH, USA

Abstract

We report on the development of the diagnostic system for the on-going upgrade to the Argonne Wakefield Accelerator (AWA) facility where the electron drive beam energy will be increased from 15 to 75 MeV. The facility will produce a wide dynamic range of drive bunch train formats ranging from a single microbunch of 100 pC to bunch trains of up to 32 bunches spaced by 769 ps with up to 100 nC per bunch. In addition to standard diagnostics, this drive bunch train format poses two challenges for the diagnostic system: (i) the close spacing of the drive bunches, 769 ps, makes resolving the individual pulses difficult and (ii) the dynamic range of the bunch charge varies by x1000. A critical parameter of the drive bunch train for the wakefield accelerator is the charge along the train. To measure this, we are planning to use a 15 GHz digital oscilloscope to read either a BPM or Bergoz FCT. To handle the large dynamic range of charge, the imaging system will make use of GigE Vision cameras and a distributed system of motorized lenses, with remote control of focus, zoom, and aperture, which are operated through terminal servers and RS232 controllers.

AWA FACILTY

The Argonne Wakefield Accelerator (AWA) facility is dedicated to the development of new rf accelerating structures capable of producing gradients in excess of 100 MV/m, on the basis of electron-beam-driven wakefield acceleration [1]. The current facility uses a 1.3-GHz rf photocathode gun and rf cavity to produce 15-MeV single bunches of 100 nC or bunch trains of up to 4 × 30 nC. The maximum gradient generated at the current facility, 100 MV/m, was achieved in a short dielectric structure. In order to reach higher acceleration gradients (up to 300 MV/m), a facility upgrade is under way to increase the drive beam kinetic energy to 75 MeV and the total charge in the drive bunch train to 1000 nC.

An upgrade to the AWA facility diagnostic and control system is underway to support the upgrade to the AWA facility. The format of the drive bunch train for the AWA upgrade is driven by our current understanding high-gradient breakdown and is detailed elsewhere [2]. In the remainder of the paper we start by stating the goals of the diagnostic system motivated by the wide range of drive beam parameters that the AWA facility will generate. We then present the overall facility layout and finally list the choices made for each of the major diagnostic systems.

*Work supported by the Office of HEP, US DOE
#jp@anl.gov

DIAGNOSTIC OBJECTIVES

The primary challenge for the AWA diagnostic system (Fig. 1) is to cover the wide dynamic range of charge in which the AWA drive beam is operated. The secondary challenge is due to the wide variety of bunch train formats that are required for the AWA upgrade. These challenges are summarized in Table 1.

Table 1: Dynamic Range of the AWA Drive Beam

Parameter	Minimum	Maximum
Charge	100 pC	100 nC
Microbunches in Drive Train	1	32

The High Charge Limit

The application that requires the highest total charge drive beam is for the generation of RF power on the GW scale [1]. The required drive beam is an extremely high-charge, short-pulse bunch train. Approximately a 1000nC of charge is distributed in bunch trains ranging from 6 ns to 24 ns (8 – 32 bunches separated by 0.769 ns) will be accelerated up to 75 MeV. While this obviously impacts the charge measurement systems (e.g. current transformers) it also impacts the other systems such as the transverse profile measurements based on fluorescent screens and cameras.

The Low Charge Limit

Applications that require low charge drive beams are primarily phase space manipulation schemes. This includes longitudinal pulse shaping schemes used for both the exploration of enhanced transformer ratio [3] and THz generation, as well emittance exchange [4]. While high charge is beneficial in these applications, the collective effects tend to limit these intricate manipulation schemes to charge on the order of a nC, with risetime of the shaped pulses in the sub-ps range. The lowest charge we envision running with is about 100 pC.

Drive Bunch Train Format

In addition to the wide dynamic range of charge required for the various applications, the drive bunch train format can be varied from a single microbunch to a pulse train of up to 32 bunches spaced by 769 ps. In addition, some applications require a flat bunch train, where all

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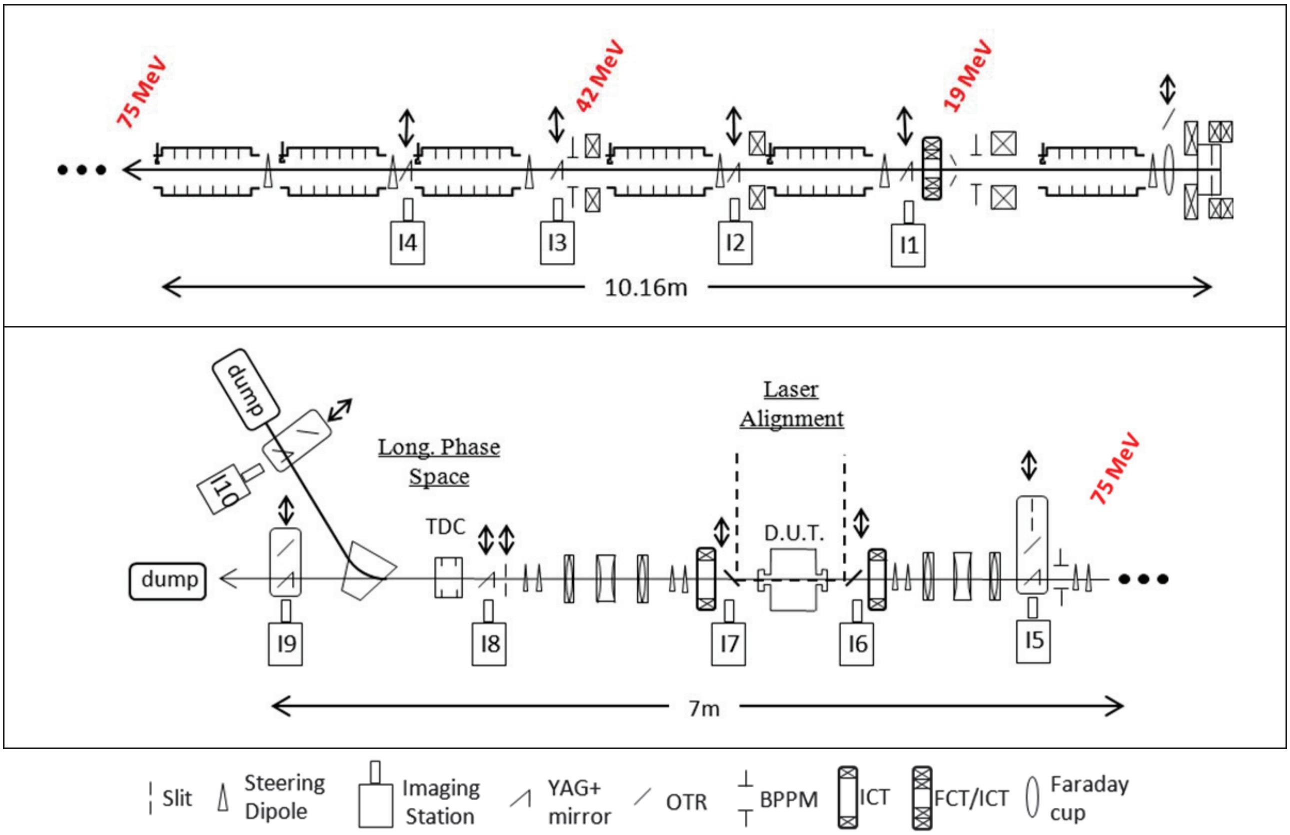

Figure 1: Block diagram of the AWA beamline (top) from the cathode to the end of 6th 1300 MHz rf cavity and (bottom) primary test area (D.U.T.) where wakefield measurements are made.

bunches have the same charge, while other applications [5] require a ramped bunch train, where the charge is intentionally varied along the length of the train. The diagnostic system must be capable of measuring both the total charge in the train as well as the individual charges along the train. The close spacing of the drive bunches, 769 ps, makes resolving the individual pulses difficult.

CHARGE MEASUREMENT

The requirements for charge measurement are set by the two modes of operation of the AWA facility. In the single bunch mode of operation, the microbunch charge of the AWA drive beam will range from approximately 100 pC to 100 nC. In the bunch train mode of operation trains of 2-32 bunches are generated at a spacing of 769 ps. Measurement of the total charge (either microbunch or bunch train) is straight forward using an off-the-shelf ICT [6] and a homemade, Faraday Cup installed directly

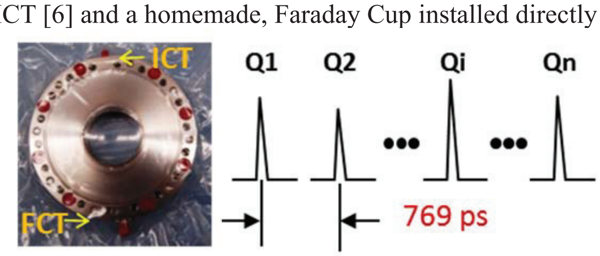

Figure 2: Combined FCT/ICT.

after the gun. To measure the intensity along the bunch train (Qi, Fig. 2) we purchased a custom, in-flange, combination FCT/ICT equipped with 6.75" conflat flanges and 60.4 mm ID [6]. The FCT has a rise time of approximately 175ps according to the vendor. By directly measuring the output of the FCT with a 15 GHz digitizing scope [40 GS/sec, Tektronix] we should be able to resolve the intensity along the bunch train. The measurement is a delicate balance between the FCT pulse not being too long to overlap with adjacent bunches while not being too short to be under sampled near the peak.

BEAM POSITION AND PHASE MONITOR (BPPM)

Due to the relative simplicity of the current AWA facility (rf gun followed a single rf cavity powered by 1 klystron) it has been run with a single, open loop klystron and no BPM's. To address the needs of the more complex AWA upgrade facility, the control system has been upgraded to phase lock the 4 klystron together using commercial electronics [7]. However, as an RF photoinjector based facility, the phase of the beam can drift relative to the rf if the laser timing drifts which means that the beam phase must also be monitored. To do this, we are implementing a BPPM system (in collaboration with Euclid Concepts, LLC) modelled after the system used at APS [8] with some cost-saving modifications. The BPPM consists (Fig. 3) of two major

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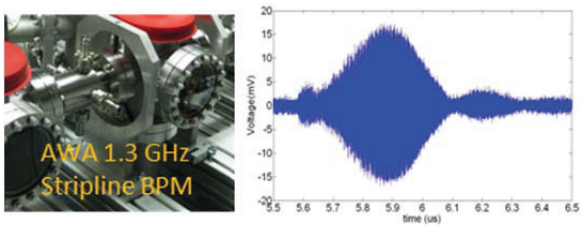

Figure 3: (left) 1/4-wave, 50 Ω stripline BPM and (right) the BPM output signal after the BPF.

items. A 1/4-wave, 50 Ω stripline BPM has been designed and tested at the current AWA facility (Fig. 3). The signals from the 4 striplines are first sent through high-Q, 1.3 GHz, bandpass filters (BPF) [MFC Inc.] resulting in a 1.3 GHz signal with a rise time of a few hundred ns (Fig. 3) that is sent into the second item, an rf based front end which sends the *rf sum signal* to the phase comparator, IC AD8302 [Analog Devices] and the *individual rf signals* to four log amplitude detectors, IC AD8317. As a cost savings we replaced the standard high speed digitizer with a triggerable Sample & Hold circuit. The subtraction and summation of these four logarithmic signals, done on a PC for now, give the basic information of the beam position and charge.

IMAGING STATIONS

The requirements of the image acquisition system are set by the large variation in intensity (4 orders of magnitude) and transverse spot size of the beam (from sub to 50mm). To achieve excellent resolution and capture large spots, normal incidence, 50 mm dia x 0.1 mm, YAG:Ce screens are used with a homemade Si-wafer based Al mirror. To handle the intensity and size variation of the images (Fig. 4) all cameras are equipped with motorized Computar lenses that allow remote control zoom, focus, and iris via a motorized controller [8]. As a cost savings a single controller can be used to control 16 lenses when used in conjunction with a DB25 switch. At the moment we plan to stay with the inexpensive RS-170 cameras but may switch to GigE Vision cameras in the future.

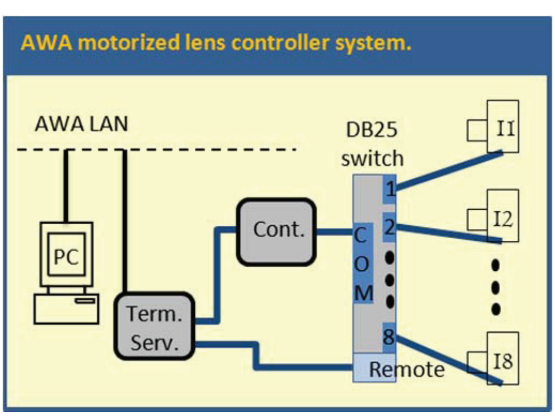

Figure 4: PC based control of multiple camera lenses.

TRANSVERSE EMITTANCE

Many transverse emittance diagnostics are especially limited in dynamic range. For instance, a pepper pot's dynamic range is only about a factor of 2 [9]. Therefore, we plan to use a thin scanning slit (located in station I5 of Fig. 1). A tungsten plate of only 0.5 mm will scatter the unwanted electron by the amount,

$$\theta_{\mathrm{rms}} = \frac{13.6MeV}{\beta pc} z\sqrt{x/X_0}\left[1+0.038\ln\left(x/X_0\right)\right] \tag{1}$$

or θ=64 mrad. For a beamlet imaged in a downstream imaging station, I8 or I9, L=~=5m and the scattered electrons are scattered into a background spot with σx = 320 mm. In addition, studies are underway to use the TDC to measure the slice emittance of the bunch.

LONGITUDINAL DIAGNOSTICS

Bunch length measurements can be made in two ways. Using the recently commissioned transverse deflecting cavity (TDC, Fig. 1) [10] and the YAG screen in I9 *or* using the OTR screen in station I5 and Hamamatsu 2-ps resolution streak camera. Momentum and momentum-spread measurements will be made with an imaging spectrometer that images a slit just upstream of I8, through a dipole magnet, onto the YAG screen in I10. In addition, studies are underway to use the TDC and spectrometer together measures the longitudinal phase.

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