HIGH-RESOLUTION BEAM PROFILE MONITOR R&D AT THE BNL ATF

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Abstract

Beam profile monitor (BPM) is widely used at the Brookhaven accelerator test facility (ATF) for machine operation and beam studies. BPM is also critical for many ATF experiments, such as laser acceleration and single-pass FEL experiments where both laser and electron beams profiles and positions measurements are required. We will first describe the ATF video and BPM system, the performance of the BPM is presented. The two-lens telescope optics was adopted for the most ATF BPM optics, the experimental data for a variable resolution BPM is presented from laser acceleration experiment Stella. We will also present two special BPM, one is the BPM and Faraday combination for photocathode RF gun injection system, and other is dual arm OTR BPM.

1 INTRODUCTION

The BNL ATF is a dedicated laser linac user facility for beam physics research, one of the most important, and also most frequently used beam diagnostic tools at the ATF are beam profile monitor (BPM). BPM is critical not only for ATF operation, also for high brightness electron beam R&D and many ATF experiments. The BPM performance requirement for the ATF covers wide range, resolution as good as μm, sensitivity as low as a tenth of pico-coulomb are required. We will first describe the basic design of the ATF BPM in the following section, then we will discuss several special purpose BPMs, such as Faraday cup BPM combination.

2 THE BNL ATF BPM SYSTEM

2.1 The ATF Video System

The ATF video system consists cameras, video switcher and connection with the ATF control system. There are more than 70 CCD cameras distributed around the ATF for both electron beam and laser beam diagnostics. The cameras and eight display monitors are connected through a matrix video switcher, which can be control either local, or by the ATF control system. Video switch also provides time stamped title for each video signal. Since the title display is synchronised with incoming video signal, it is also often used for simple camera diagnostics. For more than 20 critical cameras, such as laser beam profile monitor on the cathode, and cameras for emittance and tomography studies, external synchronisation TTL signals are provided.

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One of those 8 display units is a PC-based frame grabber system was built using components from the MVC 150/40 family, manufactured by Imaging Technology, Inc. By combining their IM-PCI card (video motherboard) and several plug-in modules, a complete, high-performance, pipelined video image processor occupying 2 PCI slots was constructed. The plug-ins includes an AM-VS module (variable scan video acquisition and 8-bit digitizer) and a series of computation modules: a CM-ALU (arithmetic unit), a CM-CLU (convolution and logic unit), a CM-HF (histogram, projection and feature extraction) and a CM-MEM (video memory). Most computations and projections are developed locally in this dedicated arithmetic hardware where all modules can communicate over their own local bus, thus placing no serious burden on the host PC. Frame grabbing, digitisation and display are all completely synchronous with each pulse of the electron beam. Programming to control this subsystem was done using Microsoft Visual C++ under Windows NT. It can operate either as a stand-alone instrument (set-up and results displayed on a local monitor) or as a slave device where commands and data are exchanged over a network TCP socket connection. The frame grabber is capable of provide real-time information of the image analysed, such as image centroid and size, in 10 Hz. Another stand-alone PC based frame grabber, a Spiricon PC-500, installed PC for single-shot, laser beams diagnostics and 12-bit digital camera applications. It was used for energy spectrum recording for both bunched laser accelerator experiment (Stella) and high gain harmonic generation (HGHG) FEL.

There are almost 10 different types of camera used at the ATF. There are special cameras for 10 μm CO_2 laser, and window less camera for UV laser beam monitoring. The CCD camera used for e-beam diagnostics cover spectral range from 400 nm to 1100 nm, the sensitivity covers from 0.5 lux to 0.009 lux. For interline frame transfer camera, synchronisation is very critical.

2.2 The ATF BPM

Image source, image optics, CCD camera and frame grabber make up a complete BPM system. Fig.1 is the schematic of the ATF beam profile monitor. The image screen usually placed perpendicularly to the electron beam, a 45 ° mirror placed behind the screen. Phosphor screen [1], YAG crystal [2] and thin OTR foil have been used at the ATF for image source. The main advantage of phosphor screen is the sensitivity and large dynamic range [1]; it is more than an order of magnitude more sensitive than YAG screen. The resolution for both phosphor and YAG screen is measured to be on the order of 100 μm [3]. Further more, YAG screen could easily be saturated for high intensity beam. YAG screen is primarily used where HeNe laser and electron beam co-alignment is required while resolution is not major concern, such as HGHG radiator BPM. OTR is widely used at the ATF for beam diagnostics. For the charge routinely used at the ATF (100 pC to 1nC), more sensitive cameras were used (better than 0.05 lux). The measured resolution for an OTR screen at the ATF is about 30 um [3].

The most commonly used image optics for the ATF BPM is a two-lens telescope image system (Fig.1) [1]. Such imaging system has several advantages; one is the large light collection angle due to the short focal length of the first lens. The image amplification for such system is the ratio of the focal lengths f_1/f_2. Fig.3 is the BPM of electron beam energy spectrometer for bunched laser acceleration experiment STELLA. The motorised zoom lens used for the second lens (F1) allows variation of the image amplification by a factor of two. Further more, a Peltier cooled CCD camera was to reduce the noise and improve the dynamic range of the images. The energy resolution of the spectrometer is $5x10^{-4}$. Fig.3 is the energy spectrum of femto-second bunch train acceleration phase is about 45 degree from crest.

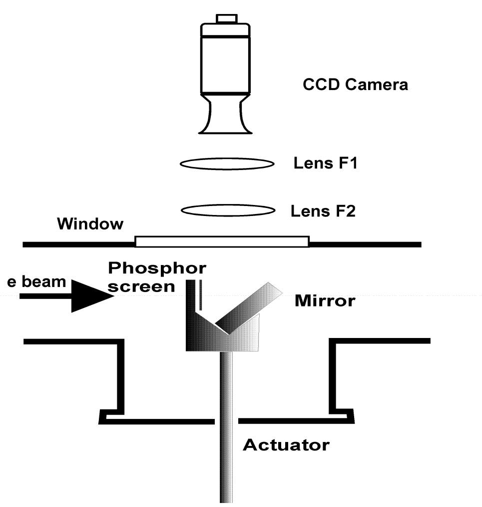

Figure 1: The schematic of the ATF BPM.

3 SPECIAL PURPOSE BPM AT THE ATF

We have developed many special BPM at the ATF for photocathode RF gun injector operation and other ATF experiments, here are two examples:

3.1 The Photocathode Injector BPM

To be able successfully operating a photocathode RF gun injection system, the photoelectron beam charge, RF gun phase and beam energy must be measured reliable [4]. The limited space available for beam diagnostics

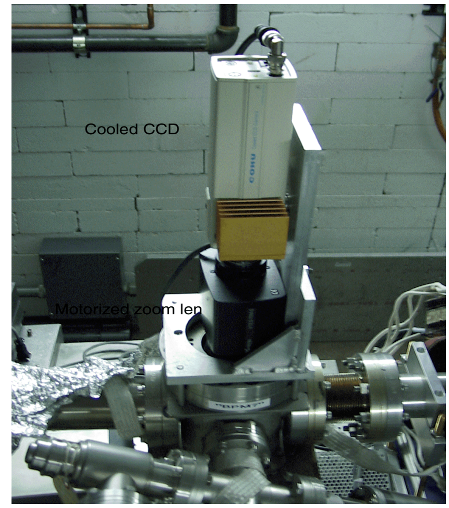

Figure 2: High-resolution BPM for Stellar

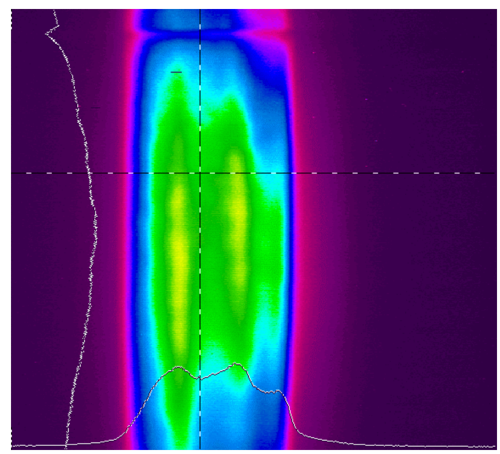

Figure 3: Femto-second bunch train energy spectrum at acceleration phase 45 degrees from the crest.

forced us came to a design of BPM and Faraday cup combination (Fig.4); a phosphor screen is followed by a 45° mirror, which was polished, from solid Tungsten. The metal foil support of the phosphor and mirror formed Faraday cage. Using a steering magnet mounted inside the emittance compensation solenoid magnet and measuring the centroid of the beam, the energy of photoelectron beam, hence the field of the RF gun cavity can be measured (Fig.5). By measuring the photoelectron beam charge as a function of the RF gun phase (Fig.6), the absolute laser arrives phase and laser pulse length information can be obtained [4].

3.2 The OTR BPM

We have developed several versions of OTR BPM. The simplest one is just a 45 ° copper mirror with Cleartran window, this type of BPM was used to align the CO_2 laser with electron beam for both STELLA and High-Gain Harmonic Generation (HGHG) experiments. A HeNe laser was used as a reference for both electron beam and

CO2 laser. CO_2 was first aligned to HeNe laser, and OTR from $_{\text{electron}}$ beam was used aligned to HeNe during the experiments (Fig.7).

We have built a dual-arms OTR BPM (Fig.8), one arm is just a 45° mirror; while other arm is an OTR foil, perpendicular to the e-beam followed by a 45 ° mirror. Second configuration has several advantages over the first one. One is the depth of the field problem is less severe; other is the symmetry of the image.

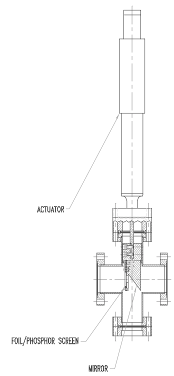

Figure 4: BPM and Faraday cup schematic.

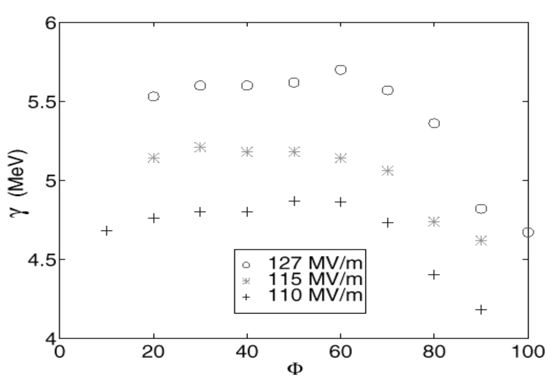

Figure 5: Photoelectron beam energy as function of the RF gun phase. measured using beam centroid and steering magnet.

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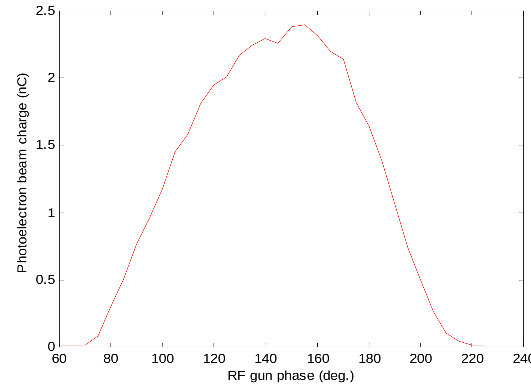

Figure 6: Charge as function of the RF gun phase.

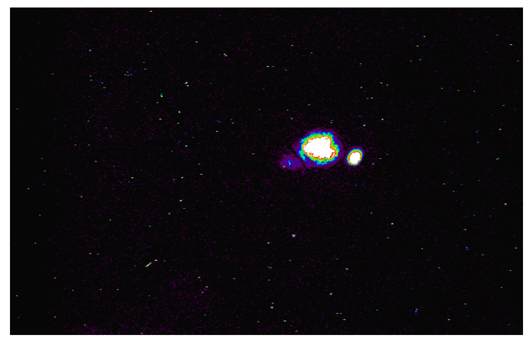

Figure 7: 0.5 mm HeNe laser (large one) and OTR image of electron beam for 0.3 nC charge.

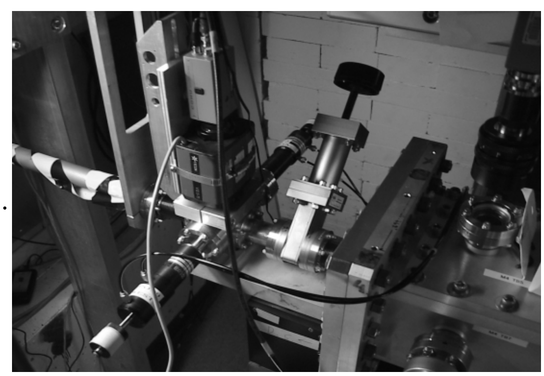

Figure 8: OTR test BPM.

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