A 10 MHZ PULSED LASER WIRE SCANNER FOR ENERGY RECOVERY LINACS*

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Abstract

For high average current electron accelerators, such as Energy Recovery Linacs (ERL), the characterization of basic electron beam properties requires non-interceptive diagnostics. RadiaBeam Technologies is developing an inexpensive, stand-alone laser wire scanner (LWS) system specifically adapted to ERL parameters. The proposed system utilizes distinctive features of ERL beams, such as a relatively long bunch length and ultra-high repetition rate, to maximize photon count while using off the shelf laser technology. The RadiaBeam LWS prototype presently under development will be installed and commissioned at the Brookhaven National Laboratory (BNL) ERL facility. This system's design and projected performance are discussed herein.

INTRODUCTION

In high average current electron accelerators, such as the Energy Recovery Linac (ERL) [1,2], the determination of basic electron beam properties including a transverse profile, emittance, and bunch length is non-trivial. The standard methods, such as OTR screens, scintillation beam profile monitors and conventional wire scanners are inapplicable, as the impact of a MW-grade electron beam would destroy any target. One promising non-degradable approach for a high average current beam diagnostic is a laser wire scanner (LWS), which operates by intercepting an electron beam with a laser beam and counts the Compton scattered photons as a function of the laser position [3]. This technique was initially developed in the context of multi-GeV colliders [4,5,6], but has also found practical applications in the Thomson regime at softer energies [7]. The two LWS methods employed to date utilize either a continuous wave (CW) mode [8,9] for storage rings, or a high power single pulse interaction [10] for linacs. However, a direct application of either one of these approaches is not optimal for the diagnostics of short bunch length electron beams with MHz repetition rate, such as in ERLs [11,12]. In CW LWS regime, most of the laser power would be lost in the intervals between the bunches. A single-pulse operating mode mandates special care in handling the optical components to endure high energy density laser pulses, introducing an unnecessary complexity into the LWS system. To address these limitations, RadiaBeam Technologies is developing a stand alone, flange-to-flange, 3-D LWS system that is relatively inexpensive and optimized for ERL diagnostic needs. The technical design of such system is complete and discussed in this manuscript. The near term experimental plans include building, installation and commissioning of the prototype LWS system at Brookhaven National Laboratory (BNL) ERL, a facility presently under construction with the mission to perform electron cooling of the Relativistic Heavy Ion Collider (RHIC) [13,14]. Eventually, the goal of this effort is to develop an LWS system available for a variety of high duty cycle electron beam facilities as a commercial product with a minor amount of custom modifications.

LWS SYSTEM LAYOUT

A schematic diagram of the LWS measurement system is illustrated in Fig. 1 An electron beam is intercepted by a laser beam, and then deflected with bending magnets, while the scattered photons propagate from the interaction point downstream into the X-ray detector. The laser beam can be scanned across the electron beam horizontally, vertically and longitudinally to obtain a projected transverse beam profile in two planes, and a current profile, respectively (the latter is meaningful only when the electron beam bunch length is significantly longer than the duration of the laser pulse). Following Ref. [15], the LWS system's components can be separated into the following four subsystems:

- the laser source;
- an optical transport and manipulation system;
- the interaction region, including optics and the vacuum chamber;
- and a scattered X-ray detector system.

To maximize Compton photons count, a laser beam must always temporally overlap with the electron beam, and thus be externally mode locked to the RF clock, to synchronize the laser pulse to the electron beam over many pulses, with the minimal shot-to-shot temporal jitter. The optical transport system has to offer fast feedback and dynamic correction on the laser beam's position and envelope properties to allow for a 3-D scan that is fast enough to obtain single axis measurements within a one-minute time frame. The interaction region has to include electron beam position diagnostics and an impedance-shielding cage to reduce wakefields and avoid mode trapping. Finally, for the soft electron energies, the X-ray detector has to be in-vacuum, and offer the means of achieving a good signal over noise ratio in the environment of a significant bremsstrahlung X-ray background.

* work supported by the U.S. DOE SBIR grant DE-SC0000864
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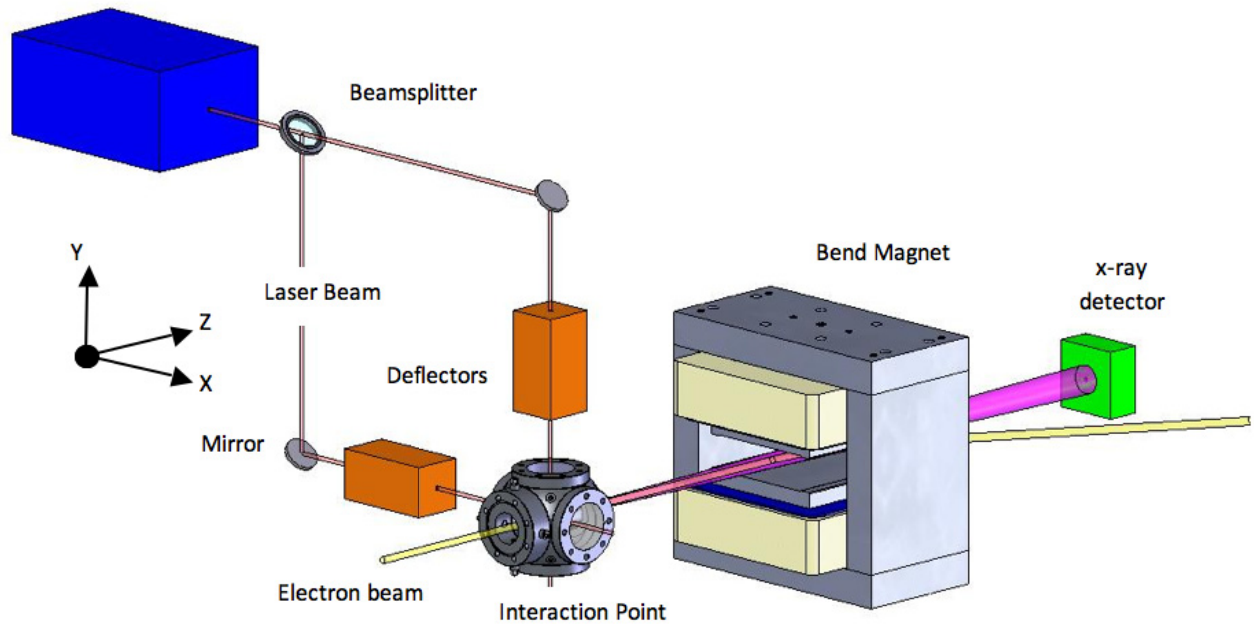

Figure 1: A schematics of LWS measurement system.

PRACTICAL ADVANTAGES SPECIFIC TO ERL TYPE LWS APPLICATIONS

Most of the LWS systems to date have been designed towards pushing the limits of spatial resolution [5,16] into single microns and below. This is consistent with collider requirements – to obtain profile measurements of very dense, multi-GeV electron and positron beams. With such design targets, there is a significant amount of complexity in handling a very intense and structurally complex laser pulse that is forced towards a hard focus at the interaction point [15,17].

On the other hand, for the ERL-type diagnostics applications, the electron bunches are relatively large in both the transverse size (> 100 µm RMS spot size), and pulse duration (> 20 ps FWHM); and also have a high repetition rate (> 10 MHz), with very small shot-to-shot fluctuations. RadiaBeam design takes a full advantage of the unique electron beam properties at ERLs to design practical and cost efficient LWS diagnostics.

In particular, the noteworthy feature of the LWS system for ERL applications is due to a relatively loose requirement for a beam resolution, which not need to be much better than 10-30 µm range. Such large spot size significantly simplifies the LWS system design, as the system become much less sensitive to laser and electron beam jitter in transverse and longitudinal domain. In addition, soft focus of the laser beam insures nearly invariable laser beam envelope throughout the interaction region, which substantially simplifies the data analysis of the measured profile.

DESIGN LWS SYSTEM PARAMETERS FOR BNL ERL FACILITY

Another advantage of ERL LWS diagnostics is due to very high beam current at the ERL facilities. With the 100 mA class electron beam one can obtain a sufficient Compton-scattered photon flux for a well resolved measurement, while maintaining relatively low peak and average laser beam powers at the transport and focusing optics. As a result, a relatively inexpensive off the shelf externally mode locked laser can have sufficient power to generate a well resolved Compton-scattered photons flux for LWS measurement (i.e. Table 1).

Quantitatively, a rough estimate for ERL parameters is that it takes about 1 Watt of interacting laser power, in order to generate about 1 million Compton photons.

Table 1: LWS parameters for BNL ERL.

Electron Beam	
Maximum beam energy	20 MeV
Charge per bunch,	5 nC
Maximum average current	50 mA
Bunch repetition rate	9.38 MHz
RMS bunch length	30 ps
Anticipated RMS beam size	~ 200 µm
Laser Beam	
Wavelength	1045 nm
Waste size, RMS	~ 20 µm
Effective repetition rate	9.38 MHz
Pulsed energy at interaction point	200 nJ
Pulse duration	1.0 ps
Compton photons	
Maximum photon energy	3.8 KeV
Maximum photon flux	1.0 MHz
Detector distance/area	~ 1 m/ 1 cm^2
Photon flux at the detector	140 KHz

CONCLUSION

RadiaBeam Technologies is developing an inexpensive laser wire scanner as a non-degradable diagnostics for high average power electron beams. The design of the system has been completed, and a prototype commissioning is planned at BNL ERL facility in H1'2011.

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