SCANNING WIRE BEAM POSITION MONITOR FOR ALIGNMENT OF A HIGH BRIGHTNESS INVERSE-COMPTON X-RAY SOURCE

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Abstract

The Free-Electron Laser Laboratory at the University of Hawai‘i has constructed and tested a scanning wire beam position monitor to aid the alignment and optimization of a high spectral brightness inverse-Compton scattering x-ray source. X-rays are produced by colliding the 40 MeV electron beam from a pulsed S-band linac with infrared laser pulses from a mode-locked free-electron laser driven by the same electron beam. The electron and laser beams are focused to 60 µm diameters at the interaction point to achieve high scattering efficiency. This wire-scanner allows for high resolution measurements of the size and position of both the laser and electron beams at the interaction point to verify spatial coincidence. Time resolved measurements of secondary emission current allow us to monitor the transverse spatial evolution of the e-beam throughout the duration of a 4 µs macro-pulse while the laser is simultaneously profiled by pyrometer measurement of the occulted infrared beam. Using this apparatus we have demonstrated that the electron and laser beams can be co-aligned with a precision better than 10 µm as required to maximize x-ray yield.

INTRODUCTION

A compact high brightness x-ray source is currently under development at the University of Hawai‘i Free-Electron Laser Laboratory, based on inverse-Compton scattering of 40 MeV electron bunches with synchronous laser pulses from an infrared free-electron laser (FEL) [1, 2]. One of the more challenging aspects of realizing a Compton backscatter x-ray source is co-alignment of the electron and laser beams. With high intensities, and spot sizes as small as 30 µm, it is not possible to align these beams without special diagnostic tools. The resolution of available beam position monitors (BPMs) and optical transition radiation (OTR) screens is limited to about 100 µm by the sampling electronics and video cameras used.

Wire scanners are commonly employed on accelerator beam-lines as alignment aides. The “flying wire” type scanners, such as those used at CERN, are too large for use in the space allocated on the Mk V beam-line at UH and are incompatible with the bunch structure of our accelerator. The x-ray interaction point is shared by two other insertable diagnostic devices in a crowded vacuum chamber, also housing the x-ray interaction point laser optics. The wire scanner described here is based on the designs used at NBS-LANL [3] and the SLC [4] and adapted to the constraints of our beamline configuration. This system also includes the capability to resolve the temporal evolution of the electron beam profile over the macropulse duration (approximately 4 µs).

HARDWARE

The wire scanner head shown in Fig. 1 consists of two 34 µm-diameter graphite fibers stretched across the 12.3 mm gap in an aluminum fork. The wires are oriented such that when the scanner insertion axis is inclined 45° above the beam plane, the two wires are oriented horizontally and vertically. In this way a single axis of motion allows the beam to be scanned in both axes.

Figure 1: The wire scanner fork electrically isolates the carbon fiber from the grounded fork. Fibers are soldered to the signal lead and clamped at the other end.

The secondary emission current from the wire is conducted via the scanner shaft to a vacuum feedthrough on the assembly shown in Fig. 2. The fork itself is grounded to avoid charge accumulation from the beam halo.

Most wire scanners in operation today utilize bremsstrahlung radiation detectors to measure beam interception of the wire. However, on a linear machine it is more difficult to position a PIN diode detector close to the source without substantial background radiation. Moving the detector to a suitably shielded location results in a large bremsstrahlung beam diameter, making efficient detection difficult and introducing errors due to diffraction.

Figure 3 shows the assembly integrated in the x-ray scattering chamber installed at the interaction point. The wire scanner assembly consists of a precision vacuum

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Figure 2: Beam profiler drive assembly with motor and LVDT with an early prototype fork. The support rod conducts the signal to the vacuum feedthrough on the far end.

Figure 3: The wire scanner installed with other diagnostic devices in the x-ray scattering chamber.

Figure 4: A PC acquires beam current, laser intensity, and scan position data and controls the drive motor.

The motor speed is controlled by software to achieve high resolution at the 5 Hz beam repetition rate. Position is measured with an LVDT attached to the translation stage; its resolution is limited by 12 bit readout electronics to 7.2 µm steps over a 14 mm range. The LVDT read-back is calibrated against the actual translation stage motion with calipers.

The GUI stripchart is only used as a rough guide for scan operation while detailed data analysis is performed using an offline tool, also implemented in Python. Figure 5 shows a sample wire scan analysis. The graphic in the upper part of the figure is a representation of the evolution of the beam current spatial distribution over a 4 µs macropulse. The vertical columns in the image are individual oscilloscope waveforms for each position along the horizontal axis; interpolation is applied to account for non-uniformly spaced positions. The lower plot shows the transmitted laser pulse energy compared to the wire current integrated over a particular duration of interest within the pulse. The integration region is typically chosen to overlap the laser pulse in the last µs of the macropulse.

RESULTS

Preliminary experiments have been conducted to measure the sizes, positions, and stability of the laser and elec-
Figure 5: The GUI displays the electron beam (yellow) and laser (purple) beam profiles in real time during a scan. Figure shows background data, not actual scan results.

Figure 6: Secondary emission current as a function of position and time within the macropulse. The lower plot compares the integrated current from 2 µs to 3 µs with the laser signal (axis inverted). This scan includes both the horizontal (right) and vertical (left) profiles.

electron beams. The wire scanner was initially commissioned with a 200 µm tungsten wire. This wire was operated successfully for several months with large beam diameters and limited resolution; however, a microfocused (sub 100 µm diameter) beam quickly severed the wire. Next, a 25 µm tungsten wire was chosen to reduce the absorption volume and to enhance the spatial resolution of the scans by a factor of eight. Again, however, a microfocused beam destroyed the wire on the first pass. Ultimately, 34 µm diameter carbon monofilament from Specialty Materials, Inc. has proven robust enough to endure the highly focused 150 mA electron beam and several mJ of infrared laser exposure. Since the carbon filament could not be wrapped in the same manner as the more flexible tungsten, it was necessary to modify the wire scanner fork. Figure 7 illustrates how the carbon fibers are clamped on one end between Vespel plastic discs while the other ends are soldered to a copper tab attached to the signal lead.

The scan data in Fig. 6 shows an electron beam focused to $w_x, w_y = 350 \mu m, 115 \mu m$, where the left feature is the evolution of the vertical beam profile and the right represents the horizontal. The total charge intercepted on each wire is the same, so the area under the beam profile curves is constant, resulting in lower peak signal for the horizontal scan. In this scan the laser is well aligned to the electron beam resulting in suppression of laser operation while the beam is intercepted by the wire.

Figure 7: Horizontal axis wire scan showing the laser displaced from the e-beam position. Interception of the e-beam by the wire inhibits lasing and results in a second co-aligned peak.

Figure 7 shows an example where the laser is misaligned from the electron beam. This horizontal scan (vertical wire only) gives an electron beam width of 175 µm and a laser beam width of 143 µm with a beam separation of 419 µm, correctable with a motorized mirror. The laser was intentionally defocused at the interaction point for this scan to preclude wire damage during these early experiments. It is interesting to note that while the laser size and position are measurable by transmission to the pyroelectric detector (red trace), a laser signal also appears distinctly in the wire current. We believe that this laser induced wire current is the result of thermionic emission from the wire due to heating from laser exposure. This hypothesis is supported by the observation that the laser induced current extends several hundred ns beyond both the end of the electron beam and laser macropulses while in fact the laser beam exposure of the wire begins a microsecond earlier and is there-
Figure 8: The Mark V FEL beamline at the University of Hawai‘i

CONCLUSION

A scanning wire beam position monitor has been successfully constructed and operated at the University of Hawaii Free-Electron Laser Laboratory. This custom design satisfies the tight space restrictions imposed by the need to share access to the interaction point of the inverse-Compton x-ray source with other diagnostic devices and laser optics. The use of a commercially available linear vacuum translator significantly reduces the engineering time and cost of the system. 34 µm carbon fiber has been selected as a suitable material for scans of a sub-100 µm microfocused electron beam operated at 40 MeV with 150 mA average current over 4 µs macropulses.

Further studies of the carbon filament damage threshold for both electron beam and laser exposure are necessary for effective optimization of the inverse-Compton scattering interaction point focus. The laser can easily be attenuated to avoid wire damage once this is known. However, the electron beam current cannot be varied and the damage threshold will impose a limit to the average current density allowed on the wire. In principle, the 7 µm width resolution is sufficient to achieve the 30 µm focal spot specification of the UH x-ray source. Alignment of the beams can be verified with a scan repeatability of better than 10 µm when the 30 µm hysteresis is accounted for.

Combining time-resolved wire scans with quadrupole magnet scans will give us the capability to perform time-resolved emittance measurements of the e-beam. This will be a vital capability for our continued efforts to improve extended pulse length thermionic electron gun technology.

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