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AND POSITION OF A RELATIVISTIC
ELECTRON BEAM**

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**A NOVEL PROBE FOR DETERMINING THE SIZE AND POSITION
OF A RELATIVISTIC ELECTRON BEAM***

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ABSTRACT

In order to determine the size and position of a relativistic electron beam inside the wiggler magnetic field of a Free Electron Laser (FEL), we have developed a new probe which intercepts the electron beam on a high Z target and monitors the resulting bremsstrahlung radiation. The probe is designed to move along the entire three meters of the wiggler.¹ This FEL is designed to operate in the microwave region (2 - 8 mm) and the interaction region is an oversized waveguide with a cross section 3 cm x 9.8 cm. The axial probe moves inside this waveguide. The probe stops the electron beam on a Tantalum target and the resulting x-rays are scattered in the forward direction. A scintillator behind the beam stop reacts to the x-rays and emits visible light in the region where the x-rays strike. An array of fiber optics behind the scintillator transmits the visible light to a Reticon camera system which images the visible pattern from the scintillator. Processing the optical image is done by digitizing and storing the image and/or recording the image on video tape. Resolution and performance of this probe will be discussed.

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A Free Electron Laser (FEL)¹ experiment is now operating at the Lawrence Livermore National Laboratory. The wiggler magnetic field is plane polarized and only provides focusing in the vertical direction. Focusing in the horizontal (wiggle plane) direction is provided by quadrupoles which surround the wiggler magnets. Since the FEL is operating in the microwave frequency regime, the interaction region of the laser is an overmoded waveguide (cross-section dimensions are 3 cm by 10 cm). The period of the wiggler field is 9.8 cm while the length of the interaction region is 3 meters. The wiggler magnet with horizontal focusing quadrupoles is shown in Figure 1. Due to the compact construction of the magnets, as well as the fact that the waveguide interaction region cannot be easily penetrated for electron beam or radiation probes, a special probe was constructed to monitor the beam size and position in the interaction region.

The electron beam used in this FEL has a beam energy of 3.5 MeV and a current of 100 to 1000 Amps. The pulse length of the beam is approximately 15 ns. The FEL operates at 0.5 Hz (one pulse every 2 seconds). During the initial experiments, we could not propagate the beam through the wiggler. Subsequent computer modeling indicated that unless the beam is properly matched into the wiggler, it will not propagate through the interaction region. Since there were no beam diagnostics once the beam entered the wiggler, it was impossible to determine where the electrons were being lost or what were the reasons for their loss. The probe developed to monitor the electron beam takes advantage of the fact that the electrons are relativistic. The electron beam strikes the Tantalum (Ta) target which is located on the face of the axial probe. This target attaches to the front of a thin-walled, stainless steel, vacuum-tight housing which contains an NE 108

scintillator followed by a 4 x 9 array of fiber optics that monitor the light emitted by the scintillator in response to the x-rays produced in the Ta target.² This detector scheme is illustrated in Figure 2. Two 3-meter long stainless steel tubes house the fibers as well as air cooling channels for the scintillator and fiber optics. An additional 15 meters of fiber optics bring the light signals to a camera located outside the shielded accelerator wall. This camera images the 4 x 9 array of fiber optics onto a Reticon photodiode array camera. The output of the Reticon camera is digitized and the signal displayed on an xy-monitor.

The detector is illustrated in Figure 3; Figure 4 shows the actual probe head. The probe is designed to monitor the size and position of the electron beam over the entire length of the interaction region. The face of the probe consists of a 3 mm thick Tantalum plate which serves as the beam stop. This Ta plate is approximately one range thick for the 3.5 MeV electrons.³ This target is fixed onto the front of the probe housing which contains the scintillator and fiber optics. Since the interaction region is at vacuum (10^{-5} Torr) and the fiber optics communicate with the outside world, the interior of the housing is at atmospheric pressure. The cross-sectional area of the housing is 2.8 cm high and 9.8 cm wide. The housing makes contact with the wall of the waveguide interaction region via Copper-Beryllium finger stock which provides a return current path for the electron beam striking the probe face. The thin-walled construction of the probe housing ensures both a close coupling of the scintillator to the target and maximum area for detection (thicker walls would reduce the usable area of the scintillator which is inside the probe housing).

A 1 mm thick slab of NE108 scintillator is located at the front of the inside of the probe housing. A 1 mm gap between the inside of the front wall and the scintillator provides a path for air cooling the face of the scintillator. The fiber optics which detect the response of the scintillator are located directly behind the scintillator. The array of fiber optics is embedded in a 2.54 cm thick lead block. The 36 fibers are arranged in nine columns separated 9.4 mm apart and 4 rows separated 5 mm apart. The QSF-AS fibers have a core diameter of 163 microns (the glass outside diameter is 200 microns). The lead block serves to position the fibers in the array and to stop the x-rays that pass through the scintillator before reaching the fiber optics bundle at the back of the probe housing. The range of a 3.5 MeV photon in lead is approximately 2 cm.⁴

We can crudely estimate the spatial resolution of the probe as follows: an electron which is stopped in the Ta target (one range thick) emits x-rays in a forward cone with a half angle $1/\gamma$. If this x-ray pattern originates at the middle of the target and propagates through the housing wall (1 mm), air gap (1 mm), and scintillator (1 mm), the half width of the radiation pattern will be $r \approx d \times \tan (1/\gamma) = 4.5 \tan (1/\gamma) \text{ mm}$. For $\gamma = 8$, the radius of the image will be approximately 0.6 mm. For an electron beam with a 5 mm radius, this resolution is quite adequate for our purpose. The fiber optics, which are close coupled to the scintillator, have a numerical aperture of 0.25. This implies that the fiber optics can view a spot with a diameter of 0.7 mm at a distance of 1 mm. Thus, the minimum spot size we should be able to resolve has a 0.9 diameter.

The fiber optics are brought out of the probe head and interaction region through a 320 cm, 1.27 cm O.D. stainless steel tube. An identical tube is

used as the input channel for the air cooling for the scintillator. The return path for the air flow is through the tube housing the fiber optics (see Figure 3). These two tubes come out of the vacuum interaction region through sliding O-ring seals. The ends of the tubes are connected to a drive unit which moves the probe along the entire length of the interaction region. A precision potentiometer on the drive unit allows continuous monitoring of the probe position. The probe drive speed is adjustable but was typically set to 0.5 cm/sec which corresponded to a probe motion of 1 cm between electron beam pulses.

The 36 fibers are brought out to a camera located outside the radiation shield (a distance of approximately 20 meters). The fibers are arranged in a 2-dimensional array pattern corresponding to their location inside the probe housing. This array is imaged through a cross polarizer and band pass filter onto an 18 mm diameter ITT Multi channel Plate Intensifier (MCPI) using a 50 mm focal length, F1.4 Nikon camera lens. The cross-polarizer serves as a variable attenuator. The optional band pass filter (20 nm band centered at 570.0 nm) selects only the 576 nm signal from the NE108 scintillator while rejecting fluorescence at other wavelengths. The MCPI has an S20 photocathode input and a P20R phosphor output.^{5,6} The P20R output is used to provide a better match to the spectral sensitivity of the Silicon photodiode array of the Reticon camera. A variable width gated shutter is used on the input of the MCPI to improve the S/N ratio by collecting signals only when the beam is striking the target. Typically, a 40 ns gate is used and is triggered from the master-timing of the accelerator. The signal from the output of the MCPI is imaged onto the photodiode array of the Reticon camera through an 18 mm to 10 mm fiber optic image reducer.

The signal amplification due to the MCPI is approximately 300 times the system gain, which is about one. That is, without the MCPI, the loss through the system due to expanding the image and absorption in the optics is balanced by the 4x increase in intensity due to the image reducer; thus, N photons/cm² at the input results in N photons/cm² at the diode array on the camera.

The diode array consists of 100 x 100 pixels located on a 0.6 cm x 0.6 cm silicon wafer. This implies that there are three pixels per fiber. The camera system was calibrated with an Optoliner at 570 nm. The dynamic range of 200:1 is limited by the Reticon camera digitizer.

The digitized output of the reticon camera is read into a Lecroy memory unit processed by an RCI TRAPIX system and displayed on a monitor. The timing and data collection scheme is illustrated in Figure 6. The digitized data collection is initiated by a trigger pulse from the master timing chain.

Figure 7 shows a typical beam image. The beam spot appears to be well centered on the probe. The beam is between .5 and 1 cm high and between 1 and 2 cm wide. The uncertainty in beam size is determined by the number of fibers illuminated and the distance between fibers. By studying the beam pattern and position as a function of probe position in the wiggler, we were able to optimize the beam matching into the wiggler as well as correct some problems associated with the wiggler magnetic field (i.e., a wiggler period was wired backwards). With proper matching, virtually all of the electron beam can be transported through the wiggler.

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Fig. 1. One meter section of wiggler showing wiggler coils, quadrupoles, and interaction region.

Fig. 2. Electron beam detection scheme. The beam is stopped in a Tantalum target. The resulting x-rays are emitted in a cone in the forward direction and strike an NE108 scintillator. The optical emission from the scintillator is transmitted to a Reticon camera system via an optical fiber array.

Fig. 3. Schematic of the probe head showing placement of target, scintillator and optical fiber array.

Fig. 4. Photograph of the axial probe.

Fig. 5. Reticon camera system used to image the array of fiber optics onto the photodiode array of the camera.

Fig. 6. Data collection and processing scheme used with the axial probe.

Fig. 7. Sample data showing the electron beam centered on the probe. The spacing between columns is 9.4 mm while the spacing between rows is 5 mm.