TIME-RESOLVED ELECTRON BEAM DIAGNOSTICS FOR THE LOS ALAMOS FREE-ELECTRON LASER OSCILLATOR EXPERIMENT*

A.H. Lumpkin, J.S. Fraser, R.W. Warren, and C.A. Brau
Los Alamos National Laboratory, University of California
P.O. Box 1663, Los Alamos, New Mexico 87545 USA

SUMMARY

Measurement of the time-dependent electron beam energy distributions in the Los Alamos Free-Electron Laser (FEL) Oscillator Experiment will be accomplished by employing gated proximity-focussed microchannel-plate intensified vidicon cameras, an electron spectrometer employing a fluorescent target, and synchronized electron beam deflection techniques. General diagnostic system design features are described that provide information in the 30-ps, 50-ns, 10 μs, and 100-μs time regimes. These techniques provide a real-time electron micropulse optimization diagnostic and an on-line, time resolved measurement of the energy lost by the electrons within the optical cavity.

Introduction

The Los Alamos Free-Electron Laser (FEL) Oscillator Experiment involves the transport of a 20-MeV electron beam through a "wiggler" magnetic field so that coherent radiation at ∿ 10.6 μm is emitted within an optical cavity. In contrast to the earlier Los Alamos FEL amplifier experiment,[1,2] where steady state electron-light interactions were studied, the time-dependent evolution of the energy release in the optical cavity is of primary interest. As a complement to optical measurements, detailed time-resolved diagnostics of the electron beam energy distribution are required. The capability of obtaining data on a single micropulse out of a 2000-pulse train exists. This is accomplished by the application of an electrical gate having a 50-ns pulse width to the intensified vidicon camera viewing a scintillator in the focal plane of the electron spectrometer. These shuttered camera techniques are extended by employing electron beam deflection techniques.

Objectives and Approach

The characteristics of the electron beam pulse structure dictate many of the specifications of the diagnostics. The 20-MeV electrons are bunched to provide a peak current of 50 amps and have a resultant micropulse width of ∿ 30 ps.[3] The electron gun provides a pulse train of 2000 micropulses in a 100 μs interval, i.e., the micropulses are separated by about 50 ns. The repetition rate of the pulse train is to be 1 to 10 Hz.

The two principal requirements of the electron beam distribution measurements are:

A. Optimization of the Micropulse

The system must be capable of selecting a single micropulse out of the pulse train and of providing data in real-time to maximize the peak current and achieve the anticipated 30-ps long electron intensity profile.

B. FEL Oscillator Operation

The system must select a single micropulse and provide data on its energy distribution. Because of the nature of the electron pulse train, time resolution of ∿ 50 ns is needed to select individual micropulses, the on/off shutter ratio should be better than 10^4, a spatial resolution at the focal plane of ∿ 1% in a field-of-view (FOV) of 300 mm is needed, and a variable time window for selecting the first to the 2000th micropulse or some time-averaged sample is desirable.

An extension of the techniques employed in the Los Alamos FEL amplifier experiment provides the present diagnostic approach. The magnetic field of an electron spectrometer was utilized to analyze the electron momentum spectrum. The electron distribution displayed on a ZnS screen in the focal plane was viewed by a standard television camera with 32-ms frame rates. Figure 1 illustrates a portion of the accelerator beam line for the present experiment with the spectrometer, a scintillator screen, and television cameras indicated. In order to provide the required time resolution, the old fluorescent screen is changed to one with <50 ns decay constant and a microchannel plate (MCP)-intensified vidicon camera is employed that can be shuttered "on" for only 50 ns. In addition the 20-MeV electron beam is subjected to vertical beam deflections that transform a spatial direction on the screen into a time axis of 30 ps or 100 μs extent. The deflection rate and the effective spatial resolution of the camera system determine the time resolution. Technical details are provided in the next section.

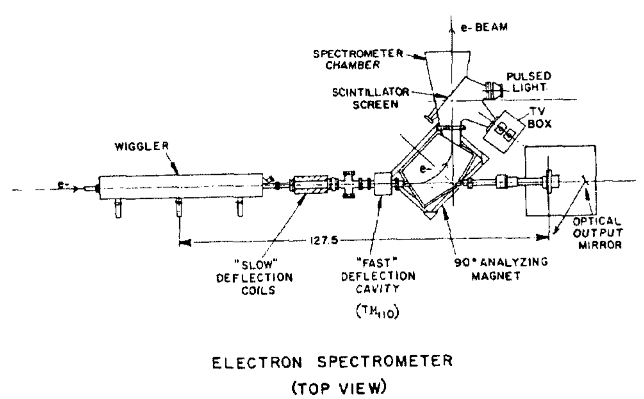

Fig. 1. Diagram of the final portion of the FEL Oscillator Experiment beamline. The relative positions of the "wiggler" section, beam deflectors, electron spectrometer, and television cameras are indicated.

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Technical Aspects

Intensifier Tube

The proximity focussed intensifier tubes are of a standard design[4] employed by a diagnostics group at Los Alamos for many years.[5,6] Their basic structure, as shown in Fig. 2, consists of a photocathode for conversion of visible photon energy into photoelectrons, a microchannel plate (in proximity with the photocathode) for electron multiplication or gain, and a phosphor for conversion of the electronic image to a visible image again. This tube is fiber optically coupled to the vidicon tube of the television camera. The photocathode (PC) and phosphor (P) are selectable to some extent but in this experiment, S20 (PC) and P20 (P) materials are used. This PC choice provides good sensitivity in the visible wavelength region and the P20 phosphor's spectral output is peaked in the middle of the visible wavelength regime where the human eye has maximum sensitivity. The intensifier tube is shuttered by forward-biasing the PC to MCP interface for the time interval desired for data accumulation. The shortest time interval possible with these particular 25-mm diameter intensifiers was determined to be 20-25 ns, well below the 50-ns requirement. The electrical gate can also be selected for DC operation. By back-biasing the PC to MCP interface, photoelectrons are prevented from reaching the MCP and rejection ratios of about 10^6 were measured. The inset of Fig. 2 schematically shows how the microchannels are set at a slight angle to the PC surface to ensure that the electrons will have a limited penetration depth into the tube for the first encounter with the wall. The tube then acts like a photomultiplier with successive electron-wall encounters multiplying the electron number. This gain parameter is controlled by varying the potential difference across the MCP, giving gains from 1 to 10^4 for the tube by itself. The output electronic image is converted by the phosphor and fiber optically coupled to the vidicon tube for subsequent standard television raster readout.

It should be noted that there is some degradation in the effective spatial resolution of the coupled system versus the components. The coupled system may exhibit a limiting resolution of 9-11 lp/mm as compared to the 20 lp/mm of the intensifier tube and 40 lp/mm of the silicon vidicon tube alone. However, since the optical mapping of the object onto the vidicon tube still gives the required resolution, this is an acceptable compromise to obtain the fast time shutter and variable gain in the system in a manner which can be remotely controlled.

Deflection Techniques

Deflections of the electron beam at variable rates by electromagnetic fields can be used to extend the diagnostic capabilities. A referral to Fig. 1 shows the location of the deflecting systems. The more difficult problem involves the application of the deflectors to the micropulse tune-up. In this case time scales of less than 40 ps with $\sim$ 10 ps resolution are required. The vertical direction on the screen (y-axis) is transformed into a time axis. A RF-cavity operating in

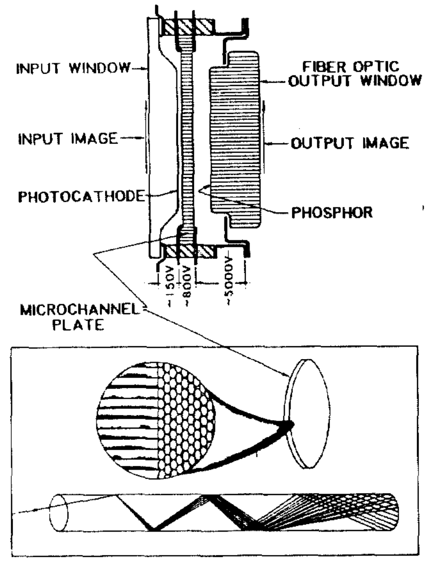

Fig. 2. Schematic of a proximity-focussed microchannel plate intensifier tube.

the TM_{110} mode at $\sim$ 1.3 GHz and 200 kW RF power is calculated to provide a beam deflection rate of 4mm/30 ps. With the deflection cavity off, an unperturbed electron intensity profile will be observed. A nominal 1-mm diameter vertical beam spot with a basewidth W is expected and using the camera system with sub-millimeter spatial resolution should result in $\sim$ 10 ps effective time resolution. With the fast deflection cavity turned on, the electron profile will be swept vertically and the resulting deflected width, W_D, will be directly related to the sharpness of the electron pulse in time as was shown in the Stanford FEL experiment.[7] On-line inspection of the TV images will guide the operator in minimizing W_D, i.e., optimizing the micropulse intensity profile. A novel application of this same technique involves the measurement of the synchronization of the electron micropulse with the optical field in the oscillator cavity. It is anticipated that discrimination of the interactions at the leading and trailing edge of a single micropulse (selected by the MCP shutter) will be possible, and this would facilitate the fine-tuning of the FEL oscillator.

The main aspect of FEL oscillator evaluation involves the mapping of the growth of the optical field strength and the concomitant increase in the number of electrons which lose energy. The evolution of the electron energy and momentum losses can be tracked by gating the MCP for 50 ns or even 10 μs and stepping the shutter window through the time profile with appropriate time delays in successive runs. Some normalization would be needed to compare the results. Alternatively, we can operate the cameras in the DC-mode, but again transform the vertical direction (y-axis) into a time axis with the slow deflection coil. Full-scale ranges of 10 or 100 μs are envisioned to map from 1-2 cm spatial deflections. This technique is schematically represented in Fig. 3. The upper portion of the figure recalls the analogy with the amplifier experiment's laser on-off conditions, the extremes anticipated in the oscillator experiment. The

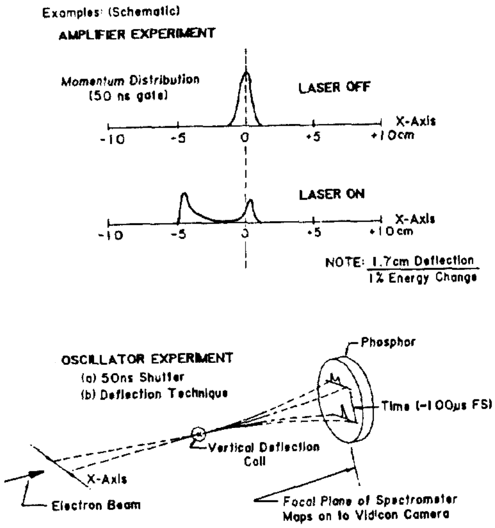

Fig. 3. Schematic of the electron momentum distribution diagnostic.

lower portion of the figure indicates how the x-axis provides electron energy information and the y-axis provides time information. The two-dimensional representation will be recorded on the television raster. Each raster line would then correlate with a time slice of the energy distribution. One anticipates a readout of effectively 20-40 slices in each field of the 256 line raster.

Experimental Layout

Referring to Fig. 1 again, we now summarize the general layout of the equipment. The complete beamline was presented in another paper in this conference.[3] After the wiggler section, the electron beam encounters the slow deflection coils, the 1.3 GHz deflection cavity, the 90 degree analysing magnet, and then the focal plane of the spectrometer and its fluorescent screen. As shown in Fig. 4 the focal plane is viewed by two intensified cameras by means of the beam-splitting mirror (M1). From this side view it is seen that the 90 degree bend in the image path provided by the mirrors allows the intensifiers (MCP's) to be shielded from the strong bremsstrahlung background generated by the beam. Camera B is as close to the object as possible with the right-angle constraint so that a full 300-mm FOV is possible, horizontally. The vertical direction is constrained by the chamber and the viewing path. The deflection yoke in camera B is rotated 90 degrees so that the raster line scan is approximately parallel to the object (image) horizontal plane. Camera A views the scene with greater magnification (and hence better effective object resolution) with a reduced FOV of $\sim$ 150 mm. Its raster scan runs parallel to the vertical direction of the object. The analog outputs of the cameras may be viewed directly on a monitor and recorded in parallel on a video tape recorder or a video digitizer.

Conclusions

In principle, the combined techniques of shuttering the camera and deflecting the beam provide a flexible diagnostic system for electron momentum and energy analysis in the time

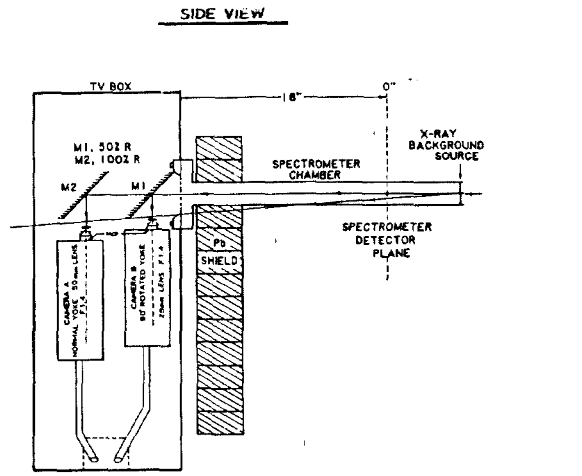

Fig. 4. Schematic side view of the electron spectrometer chamber, the intensified vidicon cameras, and the focal plane detector position.

regimes of 30 ps, 50 ns, 10 μs and 100 μs. A complete mapping of the time-evolution of the oscillator buildup during the FEL oscillator experiment is planned as well as for the eventual energy recovery experiments at Los Alamos in the future.

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