LASL ELECTRON LINAC WORKSHOP*

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Summary

An electron linac design workshop was held at the Los Alamos Scientific Laboratory (LASL) on July 12 and 13, 1979. The primary purpose of this workshop was to address the problems of attaining high single-pulse electron currents ($>$200 A) and concurrently maintaining good energy dispersion ($\leq$1%) and minimal beam emittance. Present and future applications of intense single micropulses include detector-response measurements, chemical photolysis and high-energy physics experiments. For the free electron laser application, a train of many ($\sim 10^4$) intense micropulses is required.

The workshop began with a brief review of existing accelerators capable of producing high current in a single micropulse. Next, future requirements and plans were discussed briefly. Most of the workshop covered presentations and discussions on electron injectors, space charge, energy compression and single-bunch beam loading.

Introduction

In the recent past electron accelerators have been developed that are capable of delivering an intense single micropulse with about 30-ps duration. These pulses with peak currents of about 100 A have been used in measurements of the time response of detectors of nuclear radiation and in chemical photolysis studies. Recently, new applications of intense single-electron bunches have developed. A single-pulse capability on the Stanford Linear Accelerator Center (SLAC) linac is desired for high-energy nuclear physics experiments and a long train of intense micropulses separated by a few rf cycles is required in the development of a high-power free electron laser at LASL.

An electron linac design workshop was held at LASL to study the possibility of improving the performance of present accelerators and to determine the ultimate performance to be expected from future machines. The workshop was organized as a small, informal meeting with the time divided nearly equally between presentation and discussion of the various pertinent subjects. The participants, who are actively working in this area, were: N. Norris and L. Detch, EG&G, Santa Barbara; G. Mavrogenes, Argonne National Laboratory (ANL); R. Miller and R. Koontz, SLAC; G. Saxon, Daresbury; S. Penner, National Bureau of Standards (NBS); W. Gallagher, Boller & Gallagher; J. Haimson, Haimson Research; T. Smith, High-Energy Physics Laboratory (HEPL). From LASL: R. Cooper, T. Boyd, K. Crandall, R. Hamm, E. Knapp, S. Schriber, and D. Swenson.

An abbreviated agenda indicating the topics covered is: Existing High-Current Linacs, Future High-Current Linacs, Electron Injector, Space Charge, Single-Bunch Beam Loading, Energy Compression.

A reasonably detailed report of this meeting is in preparation. At this time, I will cover what I consider to be the highlights of this workshop.

Present Performance and Future Requirements

Experimenters have recently requested shorter, more intense single micropulses for the detector response and chemical photolysis studies. Single bunches of 5 x 10^{10} electrons per pulse (8 nC/p) are contemplated for future high-energy physics experiments at SLAC.

A comparison between present linac performance and desired future capability for the free-electron laser application is given in Table I.

Clearly the emphasis in a new design will be on emittance and the number of micropulses while maintaining existing peak current and energy spread.

Single-Bunch Beam Loading

Beam loading in an accelerator by a single micropulse was a topic of much discussion. Electrons traversing an accelerator gap radiate rf power into the fundamental mode and a number of higher spatial modes. Even though the fields induced by this radiated power decay rapidly (a few ps), the electrons in the latter part of the micropulse experience a lower acceleration. Thus the earlier electrons have a higher energy than the latter electrons in the same bunch. A less accurate, but more transparent, approach to single-pulse loading is to consider the stored energy available to the electrons in the micropulse. Earlier electrons extract some of the stored energy from the cavities and the energy cannot be replaced in time for use by the latter electrons. This gives rise to a decreasing electron energy during the micropulse. Roger Miller described experimental work done previously at SLAC and the theoretical modal analysis by E. Keil.[1] Experimentally, the average decrease in energy for a micropulse containing 5 x 10^8 electrons in SLAC was about 50 MeV. Calculations by P. Wilson[2] using the modal analysis are in fair agreement with the

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TABLE I

LINAC PERFORMANCE AND REQUIREMENTS

	ARGONNE LINAC PERFORMANCE	FREE ELECTRON LASER REQUIREMENTS
Electron Energy (MeV)	20	20 to 100
Electron Energy Spread (%)	~1	±1
Peak Current (A)	100 to 400	25 to 250
Charge per pulse (nC)	3 to 12	1 to 10
Micropulse Length (ps)	30	>10
Emittance (mrad-mm)	to be measured	3π to 0.2π
Intense μ-pulses	single	Train, 10 to 50 μs long or cw

experiment. For the proposed charge per micropulse of 5 x 10^{10} electrons at SLAC the energy spread from this effect is expected to be about 7 GeV.

Compensation for this energy spread in the lower energy accelerators (ANL and EG&G linacs) is accomplished by proper phasing of the second accelerating section with respect to the first. For proper phase closure the electron pulse is injected into the second section ahead of the peak of the rf field. Thus the earlier, higher-energy electrons in the pulse experience a smaller electric field than the latter, lower-energy electrons. The excellent energy spectrum (<1%) for a 12-nC pulse from the ANL linac demonstrates the viability of phase closure. Without proper phasing of the second accelerator section a 5% energy spread would have been expected for a 12 nC per pulse. It was noted that an adequate phase spread is required to accomplish this energy compression.

Space Charge

Both longitudinal and transverse effects of space charge were presented by S. Penner. In the latter case, the equations of motion in the transverse direction were described. These equations included the electric and magnetic forces between the particles in the beam as well as external focusing forces.

A transverse beam instability caused by nonlinear space charge forces was predicted. The considerations were based on previous work on the stability of intense beams by L. J. Laslett and Lloyd Smith[3] and numerical simulations of I. Haber.[4] Estimates of the maximum electron current that can be transported without emittance growth was given as

$$I \text{ (Ampere)} \leqslant 5.2\beta\gamma\varepsilon_n B_z,$$

where B_z is the axial magnetic field in kilogauss and ε_n is the normalized emittance in units of milliradian-centimeters. Based on this prediction, the injector for the Argonne linac (25 A at 135 keV) is at the maximum limit when the beam is bunched to about 70 degrees. At higher injection energy, larger currents would be allowed.

The subject of injecting at higher electron energies was presented by J. Haimson. The advantages of these techniques were stressed and the excellent performance of accelerators using high-energy injection was described.

I wish to thank the participants for a very interesting and lively workshop.

References

1. E. Keil, "Diffraction Radiation of Charged Rings Moving in a Corrugated Cylindrical Pipe," Nuclear Instruments and Methods, 100, 419-427 (1972).
2. P. B. Wilson, J. B. Styles, K. L. F. Bane, "Comparison of Measured and Computed Loss to Parasitic Modes in Cylindrical Cavities with Beam Ports," IEEE Trans. Nucl. Sci., NS-24, No. 3, 1496 (1975).
3. L. J. Laslett and Lloyd Smith, "Stability of Intense Transported Beams," ibid., p. 3080.
4. I. Haber, "Space Charge Limited Transport and Bunching of Non K-V Beams," ibid., p. 3090.