IEEE Transactions on Nuclear Science, Vol. NS-32, No. 5, October 1985

MEASUREMENT FACILITY FOR NEW ACCELERATION TECHNIQUES

J. Simpson, J. Norem, P. Schoessow, F. Cole, A.G. Ruggiero
Argonne National Laboratory, Argonne, IL 60439

Summary

Interest in developing new, high gradient acceleration techniques is growing rapidly.[1,2] Experimental investigation of new concepts, however, lags noticeably behind the ideas. To a large extent this situation arises simply because the very specialized beams and diagnostics required to make the necessary measurements are not available.

A facility is being constructed at ANL which will permit the direct measurement of wake fields for a variety of experimental conditions. A single, short bunch of 22 MeV electrons from an existing linac is manipulated to form two separate pulses which can be set to specified time and space separations. Normally, the leading pulse will be an intense, full energy pulse of a few times 10^{10} electrons less than 10 psec in length. The trailing "witness" pulse will be at roughly 3/4 the energy of the leading pulse, will contain fewer electrons, and will have the same pulse length as the leading "driver" pulse. Energy gain/loss and deflections of each pulse will be measured after the bunch doublet has passed through the wake structure under test. Design specifications and project status are presented.

The facility will provide a continuous 800 Hz sequence of two beams with adjustable intensity, pulse shape, and separation between pulses. Pulse widths can be selected from 100 picoseconds down to 6 picoseconds, and pulse separation from 0 to over 2000 picoseconds. A well-instrumented spectrometer situated downstream of the test section will permit accurate analysis of beam energies and trajectories.

Experiments on wake field effects are especially well suited for the facility because the leading pulse will contain approximately 10 nanocoulombs of charge. Either pulse, however, may be used separately for experiments which require only one pulse (e.g. non wake field experiments).

Description of the Facility

Formation of short pulses

The facility is being built in existing space in the experimental areas of an existing 20 MeV electron linac operated by the Argonne Chemistry Division.[3] This linac has unique properties which have been exploited in the past for beam signal pickup calibration[4]. Its present parameters are given in Table I.

Table I

rf system	1300	MHz
Energy	22	MeV
Intensity	>10	nC/pulse
Repetition	<800	Hz
Pulse width	30	ps (fw 10% max)
Emittance	7	pi-mm-mrad
Energy spread	±150	KeV

An upgrade is being made to the linac by the Chemistry Division which will reduce the pulse length to 6 picoseconds while retaining the high charge per pulse. This is to be accomplished by the bunch rotation system shown in Fig. 1. The longitudinal dispersion of the double 90 degree bend section of the beam transport produces the desired bunch rotation of the 30 picosecond pulse after it has passed through the buncher cavity. This transport system has been designed taking electromagnetic self-forces into account.

In situations in which the wake causing pulse is colinear with the trailing pulse there have been several methods proposed to circumvent the so called wake field theorem. All are based on having extended length, specially time-shaped leading pulses.

The systems described above will permit the pulse shape to be adjusted to some extent. For example, it is easy to see how positioning the beam at the voltage "zero" 180 degrees from that used for bunch compression will produce bunch lengthening. Of more interest is the capability of adjusting the crossing phase to values near the maximum buncher cavity voltage. Here, the resulting pulse after the double 90 deg section will have a triangular shape. This capability will be especially useful in plasma wake field experiments as a method of controlling the effective wake effect transformer ratio[5,6,7].

It is also possible to modify the pulse shape by making beam line 1 to not be isochronous and installing momentum tapering slits. This maps a momentum distribution into a time distribution. Not as attractive as the technique described above which uses rf manipulation, it nevertheless points out the flexibility of the design.

Description of beam manipulations

Figure 2 depicts the beam handling system which produces the double pulse and the variable pulse separation. A single linac pulse arrives at the target T, where a rod target intercepts the core of the beam. The beam, now consisting of a mixture of the scattered "spray" from the target and non-interacting beam, is split in bending magnet B1. The non-interacted full-energy component of the beam travels down beam line 1 as shown, while the "spray" is collimated and momentum selected by a slit system as it travels down beam line 2. A trombone system consisting of bending magnets B2, B3, and B4 permits the path length of beam line 2 to be varied by approximately 70 cm. After the two beams have been recombined in bending magnet B5, beam pulse 2 trails beam pulse 1 by 0 to 2000 picoseconds.

Beam line 1 is designed to be isochronous. This is necessary because the energy spread of beam pulse 1 will be about ± 3% dp/p. Part of the spread comes from the "natural" spread of the rotated linac pulse and some from longitudinal self-forces in the intense pulse. Fortunately, the shear and enlarged beam envelope in beam line 1 is sufficient to make the self force effects small for all but short portions of the transport system.

Beam line 2 is not isochronous for all delays. However, the momentum spread of beam pulse 2 is selected by the slit system to be only ± 1% and self forces are negligible. Thus the small longitudinal dispersion of beam line 2 will not produce significant pulse lengthening. As the path length of beam line 2 is varied, only the currents of two quadrupole families require adjustment to maintain nearly constant beam properties beyond B4. Figure 3 indicates the variation of the quadrupole currents and of the transverse dispersion as the path length varies. Calculations predict the intensity of beam pulse 2 to be about 1.E7 electrons. This is quite sufficient to permit the use of straightforward instrumentation techniques.

Beyond the recombining magnet B5 there will be considerable space for the accelerator test section. A well instrumented spectrometer downstream of the test section will be used to measure deflections and energy changes of the two beams.

Controls and diagnostics

For the initial experiments, we are designing a spectrometer system capable of measuring longitudinal and transverse accelerations of the lower energy, low intensity "witness" beam. For initial experiments this spectrometer will have a momentum acceptance of ± 20% and a solid angle of 0.01 sr. Separation of the two beams is done in the spectrometer. The high intensity beam will be appropriately dumped.

For this to be an effective, widely used facility it is imparitive that it have well thought out, reliable, and "user friendly" diagnostics and controls. Plans include the utilization of a dedicated mini-computer and off the shelf equipment as much as practical. Because there is no need for extremely rapid data acquisition and control we propose that programming be in a high level language such as BASIC.

Modes of operation

This facility will be uniquely well suited for wake field experiments. The extremely large current of pulse 1, about 5 KA, plus the adjustable delayed witness pulse 2 present near ideal conditions for such experiments. It will also be possible to not have pulse 2 be co-linear with pulse 1 but have it displaced relative to it. Coupling impedances (parallel and transverse) of various devices may then be obtained by frequency analysis of the measured wake potentials.

Reducing the emittance of beam pulse 1 by a large factor, 100 or more, will permit extremely small diameter beam pulses which can be of use in probing the small spaces described in some of the new acceleration techniques being proposed.[2]

Initial Experimental Program

As examples of the types of experiments which can be conducted with the facility, consider three specific ones which are being planned.

*) A plasma wake field[5,8], test- An experiment is planned by a group at the University of Wisconsin[9] to measure the characteristics of the wake field in a cold, relatively low density plasma.

*) Wakeatron[6] - Many of the concepts incorporated in the idea of a proton bunch driven electron accelerator can be tested in the facility.

*) Periodic plasma waveguide[10] - A plasma of varying density can act as a low-loss slow-wave medium somewhat analogous to conventional disc loaded linac structures or to travelling wave tubes.

*) Investigation of pulse shape dependence for the effective transformer ratio.[7]

References

1 ECFA Workshop on High Gradient Accelerators, Frascati (1984).

2 Second Workshop on Laser Accelerators, Los Angeles, Calif., (Jan. 1985).

3 G. Mavrogenes, W. Gallagher, T. Khoe, and D. Ficht, IEEE Trans. Nucl. Sci, NS-30, 2989 (1983).

4 J. Simpson, R. Konecny, S.L. Kramer, and D. Suddeth, IEEE Trans. Nucl. Sci., NS-30, 3648 (1983).

5 R.D. Ruth, A.W. Chao, P.L. Morton and P.B. Wilson, SLAC-PUB-3374 (July 1984).

6 A. Ruggiero, "The Wakatron: Acceleration of Electronics in the Wake Field of a Proton Bunch", 2nd Workshop on Laser Accelerators, Los Angeles, Calif. (1985).

7 P. Chen and J.M. Dawson, SLAC-PUB-3601 (March 1985)

8 P. Chen, J.M. Dawson, R.W. Huff and T. Katsouleas, SLAC-PUB-3387 (Nov. 1984).

9 D.B. Cline, University of Wisconsin, Private Communication

10 F. Cole, 1985 Particle Accelerator Conference, Vancouver, BC, Canada, (May, 1985)

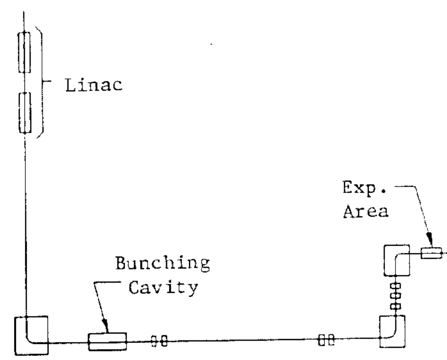

Fig. 1 Acceleration and Bunch Rotation Apparatus.

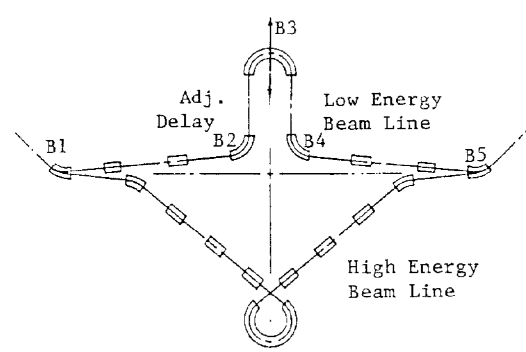

Fig. 2 Low and High Energy Beam Lines.

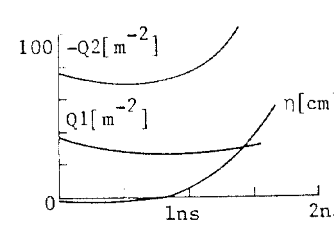

Fig. 3 Quadrupole Gradients and Dispersion as a Function of Delay, Assuming only Q1 and Q2 are Varied.