EG&G ELECTRON LINAC MODIFICATIONS*

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Introduction

The electron linear accelerator at EG&G/EM, Santa Barbara Operations, installed in 1963, has been subsequently modified to produce short, intense beam pulses used in the test, calibration and development of many types of fast radiation detectors and systems. The first practical use of the single RF pulse operation, now used in many accelerators, was demonstrated on this accelerator in the late 60s.[1]

A major three-year modification, to replace obsolete equipment and bring all the subsystems up to the current state of the art, has increased the beam intensity, stability and reliability.

We designed, constructed and tested components and subsystems off-line, and installed them on the linac with minimum downtime on the facility. This approach permitted experiments to continue with minimum interruption, one of the primary objectives.

The block diagram of major subsystems is shown in Figure 1, and the accelerator, as it is now configured, is shown in plan view in Figure 2. The performance characteristics are given in Table 1, in which the major improvement is the higher peak beam current, approximately 10 times the intensity attainable before the start of the project.

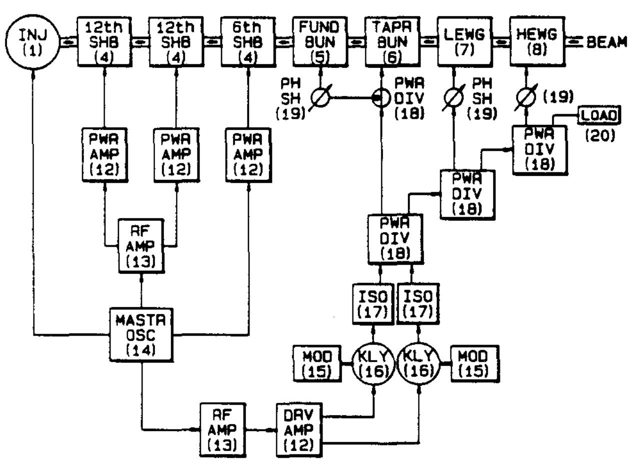

Figure 1. Linear accelerator block diagram.

Table 1. Performance characteristics.

Electron energy	1-32 MeV
Peak beam current	
Long (1-4.5 μs) pulse	0.5 A
Short (5-50 ns) pulse	2.0 A
Ultra-short (50 ps) pulse	500 A
Repetition rate (max), long pulse	200 Hz
Repetition rate (max), short pulse	400 Hz
Beam diameter (min)	2 mm
Electron charge (max) (per 50 ps pulse)	25 nC
Charge density (max) (50 ps pulse)	500 nC/cm^2

Electron Gun

We had previously been using the ARCO Model 12 electron gun, a gridded 20 cm^2 concave cathode and grid gun, capable of more than 30 A peak beam current at 120 kV. However, we and several other users have found that this gun had a large emittance, due to nonuniform grid-cathode space and the grid lens effect from a rather coarse grid, especially at grid-cathode voltages lower than the design value.

Stanford Linear Accelerator Center (SLAC) has developed a gun with a demountable grid-cathode assembly for their SLC program.[2] Their gun uses a flat, 2 cm^2 cathode and a fine-mesh, closely-spaced grid, which has proven to be reliable and having good emittance. We designed a similar gun, Figure 3, differing from the

Item Number Key, Figures 1 and 2.

1. Injector
2. Lens
3. Solenoids
4. Subharmonic Buncher
5. Fundamental Buncher
6. Tapered Buncher
7. Low Energy Waveguide
8. High Energy Waveguide
9. Quadrupole
10. Dipole
11. Beam Exit Ports
12. Power Amplifier
13. RF Amplifier
14. Master Oscillator
15. Modulator - Power Supply
16. Klystron
17. Isolator
18. Power Divider
19. Phase Shifter
20. Dummy Load

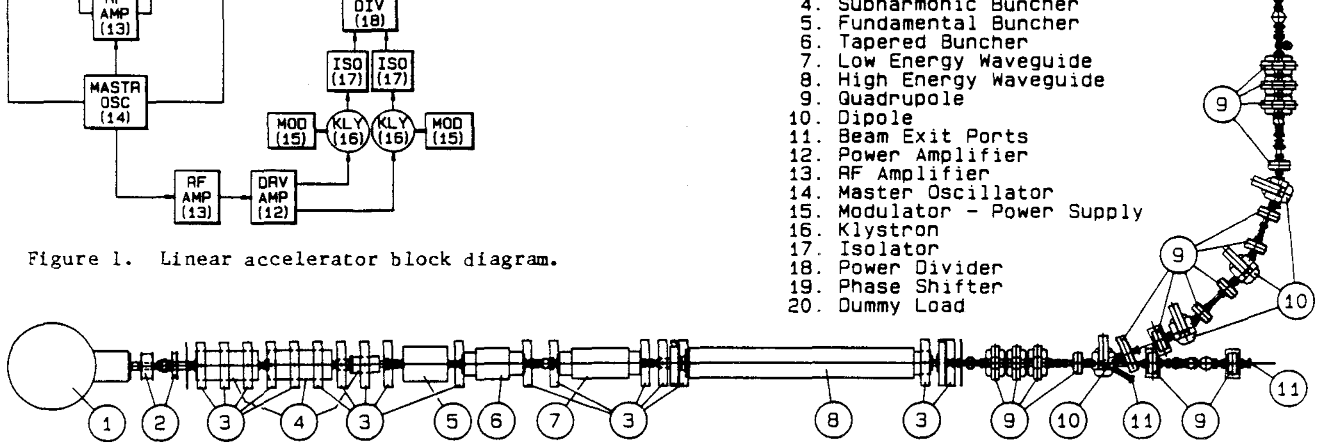

Figure 2. Major beam line components.

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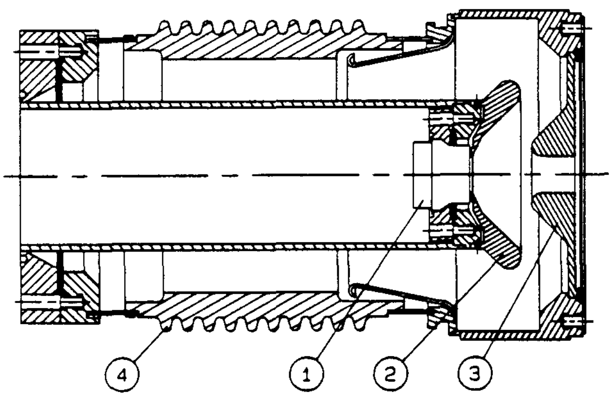

Figure 3. KM gun layout.

SLAC gun only in the mechanical design, which makes it interchangeable with the Model 12 gun. In our application, we inject up to 15 A peak current at 120 kV, with pulse length of 3 ns or less. The beam quality has definitely improved as a result of the gun change and the performance of this gun has been reliable, following a significant improvement in the vacuum in the gun region.

Solenoid Focusing System

Relatively small original solenoid coils wound on the accelerating guides had made it impossible to maintain a continuous field over the entire accelerator, due to the physical space required for the RF couplers and supports. Computer programs were written to calculate the fields and the electron trajectories from the injector gun to the accelerator output, allowing us to design an improved focusing system. Additional large-diameter tape-wound solenoids were installed along the accelerator, such that a continuous field of about 500 gauss could be maintained for the entire accelerating length. A pair of Glaser lenses were installed immediately after the gun, to match the beam into the solenoid field.

Although the fields were adjustable to the values calculated for Brillouin flow and to satisfy the trajectory calculations, the actual performance of the accelerator was not optimized by these conditions. We now attribute this to the radial RF fields, especially near the input couplers of the tapered buncher and the low energy waveguide, which have not yet been included in the computer trajectory calculation.

Subharmonic Bunchers

A major objective of the upgrade modifications was to increase the charge in a single RF pulse of the accelerated beam to 25 nC or more. Recent calculations[3,4,5] have shown that this can best be achieved by using a set of several subharmonic cavities to velocity-modulate the charge from the gun into a small fraction of a single RF cycle. Furthermore, the power and the relative RF phase for each cavity need to be individually adjusted for optimum bunching. We have chosen to use two 12th (108 MHz) and one existing 6th (216 MHz)[6] subharmonic cavities. The new cavities are completely evacuated. The low Q thus obtained has made them insensitive to beam excitation, and we have not experienced any problem with multipactor or breakdown. Their resonant frequency is temperature-sensitive however, so we have added slug tuners that are remotely adjustable by the operator. Individual amplifiers, adjustable in power and phase, were procured to supply the buncher power.

The beam from the subharmonic bunchers is further bunched in a 10-cavity, 1.3-GHz, travelling wave buncher and a tapered phase velocity buncher, both driven by adjustable power dividers from the klystrons. These bunchers were unchanged from the previous operation.

Accelerating System

The L-Band accelerator operates at a frequency of 1.3005 GHz, and has a 0.65-m tapered phase velocity accelerating section, a short (0.85 m) constant gradient section, and a long (2.5 m) constant attenuation section, relocated to optimize the focusing field. They operate in the travelling-wave, $2\pi/3$ mode with matched input and output couplers and external dummy loads. Table 2 gives the acceleration parameters A, B; which are constants of the simplified beam loading equation,

$$V = A\sqrt{P} - B\ i$$

where: V = electron energy gain (MeV)
P = peak power (MW)
i = peak beam current (A).

Table 2. Acceleration parameters.

	A	B
Tapered buncher	0.95	0.5
Low energy waveguide	2.80	1.9
High energy waveguide	6.50	14.0

RF System

The three accelerating sections are driven by two 10-MW, 15-kW klystrons, which were not replaced. We have been using a power divider to deliver the desired proportion of RF power from one of the klystrons to the two short sections, and the other klystron supplies the long section. We are modifying this system to combine the power from both klystrons and controllably redivide it among the three accelerating sections to improve the operational flexibility. The klystrons are driven from a driver amplifier, replaced to improve stability, and a master oscillator.

Klystron Modulators and Power Supplies

The pulse shape and stability of the klystron cathode pulse had been limiting the energy spectra and stability, so we replaced the modulators and their power supplies with new units. They are still pulse forming networks, discharged through a pulse transformer by a thyratron, but the charging voltages are regulated by a series triode regulator tube. The PFNs and pulse transformers are operated at a higher voltage and higher impedance than the previous units. Both the power supply and the modulator are enclosed in an oil-filled steel tank, which reduces the radiated noise considerably. These units have been in operation for more than a year and the improved stability and reliability has improved the linac operation significantly.

Control System

The accelerator parameters are controlled by 85 separate control signals and the resulting conditions are monitored by approximately 250 monitors. We have replaced the previously used manual controls by a computer-based system, in which the CAMAC modules form an interface between the computer and the equipment, as shown in Figure 4. The operator console consists of four color video monitors, two of which have touch

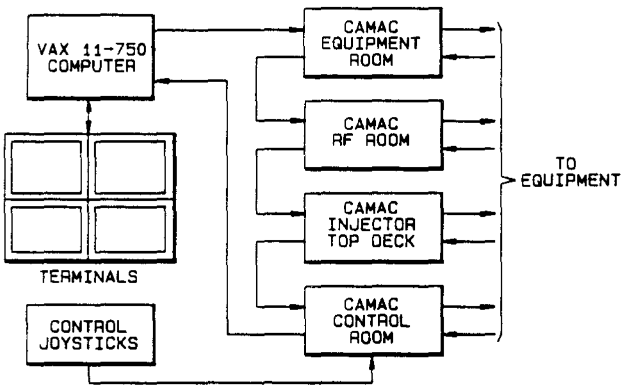

Figure 4. Control system block diagram.

screens which allow on-off control and the control selection. The operator controls the system using four joysticks, which can be assigned to any of the controlled devices using the touch screens. The screen displays are divided into a rectangular set of 48 or more cells, each of which contains control and monitor information for a particular device, such as a magnet power supply or an RF power divider. Each cell contains the value of the set point and the actual read value.

Once a set of linac parameters has been adjusted to obtain a particular beam condition, it can be saved to be recalled later, considerably reducing the tedious "tweaking" of the individual controls.

The control system uses a set of tables which are continually updated from the data source. Raw values tables store the information in digital form, as read by the CAMAC modules. Engineering values tables are maintained by using conversion tables to convert the raw values to appropriate engineering units. These engineering values tables are used in the operator interface to give information to the display and to generate the control data.

Each channel of each device is assigned appropriate two-level limits in engineering units, indicated to the operator by changes in color of the affected cell on the display. Green indicates OK, yellow indicates CAUTION, and red indicates that the DANGER limit has been exceeded. Audible signals can also be used for special devices.

One of the monitors is convertible to other displays by using a menu, selectable from the operator's console. The menu items allow the operator to change the values in any of the assignment or conversion tables, call up other display programs, or use the computer in its normal computational mode. The control system operates in semiautomatic mode, similar to the manual system it replaced. We have not yet tried to develop any "models," such as using TRANSPORT or other programs to automatically adjust many parameters to a specific beam condition, but we can incorporate such programs in the future, if desired.

Beam Handling System

Experimenters often require the beam to be transported to an analyzed port, so that the energy and the energy spread of the beam reaching the experiment is known. We have used an achromatic 90° port consisting of two 45° magnets and a quadrupole, but we found that the small vertical aperture of the vacuum envelope was limiting the peak current transmitted through the system. A new beam handling system, which also gives a 90° bend from the accelerator beam line (Figure 1), was installed on the accelerator in April 1986, and has shown the expected improvement in beam transmission, especially at energies of about 5 MeV, where the space charge spreading caused the beam dimensions to exceed the aperture of the old system. The new system consists of 4 identical sectors, each a quad, bend, quad for a total phase advance of 2π. This design makes the beam handling system "transparent," reproducing the input beam parameters at the output port. Then, by using the quadrupole triplets at the input and output, the beam can be controlled over the desired range of spot size and shape. The beam can also be transported to the 0° port, which also has quadrupole focusing, and to the right 30° analyzer port when desired.

Vacuum System

We had been using seven 50 ℓ/s ion pumps to maintain the linac vacuum in the 200 nTorr range. However, since the KM gun has a smaller cathode area than the Model 12 gun and higher current density is required, we found that the gun emission and life was severely limited. We replaced several pumps and their power supplies and added a Cryopump near the injector gun flange. These changes, with more care to eliminate all organic material, has improved the vacuum to less than 20 nTorr everywhere and less than 10 nTorr in the injector. The improvement in the gun performance was dramatic, and the gun life has been extended to more than a year, compared to a few months.

Beam Current Monitors

Fast, nonintercepting beam monitors were designed 15 years ago[7] and have been used with good results. However, that design had a limited aperture and a long insertion length, which prevented its use at intermediate points in the accelerator and beam line. A new monitor has been designed and installed which has an aperture of 2.7 cm and an insertion length of 10 cm. Although it is not as fast as the previous design, it is adequate for measuring and optimizing the single RF beam pulse and will be used in several locations.

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