A 7MEV S-BAND 2998MHZ VARIABLE PULSE LENGTH LINEAR ACCELERATOR SYSTEM

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Abstract

An S-band (2998MHz) linear accelerator system capable of producing a range of pulse lengths and currents for radiation chemistry research has been designed and commissioned by American Science and Engineering High Energy Systems Division (AS&E HESD.) The system allows samples to be exposed to electron beam pulses as short as 8nS FWHM (Full Width Half Maximum) with 1.1A peak current and pulses as long as 3uS with .12A peak current. The available electron pulse durations are 3uS, 400nS, 200nS 100nS, 40nS, 18nS and 8nS. FWHM. The pulse repetition rate is variable from 50 to 250pps. The beam centerline consists of a pulsed electron gun (3A 15kV 1.5-3uS pulse duration), an electrostatic deflector ($\pm$1.5kV), a side coupled standing wave linear accelerator fed by a 2.6MW magnetron, beam focusing optics and a Bergoz FCT current monitor. In this paper a discussion of the beam centerline construction, deflector design and experimental data are presented.

INTRODUCTION

The accelerator system utilizes an L3 (Litton) M754 grided electron gun combined with an AS&E designed gun drive system that is capable of producing in excess of 3A at beam energies from 10 to 15kV with pulse lengths of 1.5 to 4uS. The beam from the gun is focused by a Stangeness lens coil and is then sent into the electro-static deflector. The un-deflected beam enters an S-band (2998MHz) standing wave side coupled linear accelerator section with 17 cavities that is 80.8 cm in length. This section is fed by a 2.6MW magnetron with a circulator providing isolation. The beam is accelerated to 7.5MeV nominal or higher depending on the magnetron power utilized.

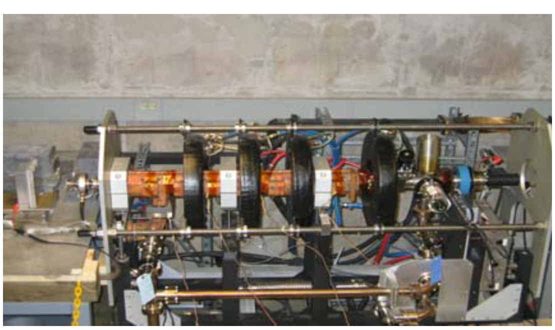

Figure 1: Accelerator system electron gun is on the right and beam exit is on the left.

The beam is confined in the accelerator section using four large Helmholtz coils that surround the linac. After the beam exits the linac it passes through a ceramic break combined with a Bergoz FCT that providers for beam current monitoring. The end of the ceramic break contains a .6 mil thick Ti window that allows the electron beam to exit the vacuum system and interact with samples located outside of the vacuum envelope. A 75l/s MidiVac ion pump that is connected to the linac and deflector and a .5 l/s MiniVac ion pump on the gun maintain vacuum for the system.

DEFLECTOR DESIGN

In order to produce the desired pulse lengths of 3uS, 400nS, 200nS, 100nS, 50nS, 20ns and 10nS an electro-static deflector system was chosen. Another option is to pulse the grid of the electron gun. This would require a pulser capable of producing 15kV and an electron gun with a cathode and grid capable of producing currents of 3A and short pulse duration. While requiring no major modification to the gun drive electronics, there were challenges with deflection of the electron beam in magnetic solenoidal fields from the lens and Helmholtz coils in the system. These magnets produce longitudinal magnetic fields that force the deflected beam back to the un-deflected beam axis.

The relation for deflection of charged particles in a static electric field only is [1]:

$$x_d = \left[{(eE)} \big/ {(2mv^2)} \right] z^2 \qquad (1)$$

where x_d is the deflection of the beam from the axis at the distance z which is the length of the electric field region, E is the electric field which is perpendicular to the beam axis, v is the beam velocity (here v<<c.) Now E=Vd where V is the potential difference between the plates and d is the gap or separation of the plates. One can see that the amount of deflection increases linearly with voltage and gap and quadradically with plate length. Decreasing the gap can reduce beam transmission as can lengthening the plates since the radial beam size must be kept small for a longer distance. Additionally if the beam strikes the deflector plate this can "load" down the power supply that produces the deflection. Thus reducing the voltage from the supply and reducing the deflection of the beam. While the relation above does not contain magnetic field effects (both radial and longitudinal are present) it is useful for understanding the basic deflector properties.

A prototype deflector system was built with a gap of 2mm and length of 20mm. The system was tested with the electron gun, lens, and two of the four Helmholtz coils. An aperture and copper target served to simulate the linac

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entrance and allow the determination of the transmission of the deflector system. In order to determine the approximate magnetic field strengths required for the Helmholtz coils, simulations using the particle pushing code PARMELA were performed.

All of the effects discussed above were found to occur in the system including the loading effect on the deflector power supply. The 2mm gap produced about 40% transmission and the subsequent loading of the deflector supply prevented the beam from being fully deflected. Enlarging the gap to 5mm increased the transmission and reduced loading of the supply but the beam could not be deflected completely deflected for the desired 1kV range that could be produced by a commercially available pulser.

Based on the experience gained from the prototype deflector system a new deflector design was created. This design consists of 105mm long copper plates 15mm wide separated by 14mm. The gap of the plates is adjustable. These dimensions were chosen so that the beam could be fully deflected with the Helmholtz coils at maximum strength using a commercially available pulser system to drive the deflector. And the dimensions also allowed the plates to be mounted in a standard six-way 2.75" flange vacuum cross. Additionally the gap is large enough to allow greater than 95% transmission, measured with the system installed on the complete accelerator.

The deflection voltage is provided by a high voltage pulser (±1.5kV) system from Directed Energy Inc (DEI.) The system consists of a TTL level pulser that triggers a high voltage pulser capable of producing a pulse with 25nS rise time, with a duration as short as ~50nS FWHM and with a maximum voltage differential of 3kV. The pulser utilizes two high voltage supplies, one positive (+1.5kV) and one negative (–1.5kV.) When the TTL input to the high voltage pulser is low the –1.5kV supply is connected to the output. When the TTL input becomes high the +1.5kV supply is connected to the output. Intermediate voltages can be set by remotely adjusting the high voltage supplies. One plate of the deflector is connecter to the high voltage pulser output and the other tied to ground.

To produce the electron beam pulses of 3uS, 400nS, 200nS, 100nS and 50nS the deflector is pulsed. In this mode the high voltage plate of the deflector is held at a value of -1.5kV to deflect the beam from entering the linac entrance. When the TTL pulse becomes high the plate connected to the pulser is released to the positive high voltage supply that is set to ground. When the TTL pulse returns low the plate connected to the pulser returns to -1.5kV deflecting the beam from the linac entrance.

In order to produce pulses shorter than 50nS, the 25nS rise time of the pulser is utilized. The beam is deflected by the –1.5kV and the positive high voltage supply is now set to +1.5kV. The TTL pulse duration is set to 10uS and with this configuration the beam is swept across the linac entrance. Using this method pulses as short as 8nS FWHM with peak currents of 1.1A have been produced. To produce the 20nS (18nS FWHM measured) an external capacitance is switched into the high voltage output to slow down the rise time of the pulser. Additional steering coils were necessary to obtain the desired transmission for the sweep mode and the short pulses. A smaller aperture for the linac entrance could be produced with an additional diaphragm, however this would limit the available system transmission.

In sweep mode a small amount of "dark current" or beam from the deflector during beam off time, <1% of the peak beam current is present. This additional current is present for a temporal duration 3 orders of magnitude longer than the desired pulse. Dark current is detrimental for integrated dose measurements since it exposes the sample when the desired beam pulse is not present. This does not occur in the pulse mode since the beam was pulsed on and off with no additional steering. To reduce the dark current the gun pulse was made as short as possible with existing gun electronics (1.5uS FWHM) and shifted to occur as late in the RF macropulse as possible. The beam from the gun is then only on for a short period at the end of the RF pulse.

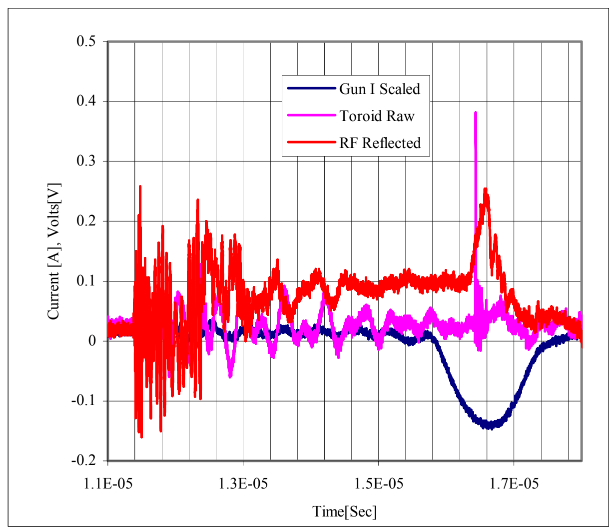

Figure 2: Scaled gun current pulse, reflected RF signal and raw toroid for 8nS FWHM electron pulse.

The additional steering, rise time lengthening capacitance, gun pulse width reduction and timing shift are done automatically. The user can select the desired pulse length, number of pulses or time interval for pulses to be produced and the pulse repetition rate (50 to 250 pps.) An additional feature is a single shot mode in which the system starts, issues one pulse and shuts off or remains on and issues additional pulses only upon use of a fire button. In order to produce a stable shot-to-shot beam, the beam is deflected until the gun is at full current and the RF has fully stabilized.

With this method a peak-to-peak variation in the beam current of ±1% was achieved running the system in single shot mode for a series of ten measurements. The pulse-to-pulse timing jitter measured with this method was determined to be ±1nS peak-to-peak.

RESULTS

Plots of the signals from the toroid for the long and short pulses are presented below.

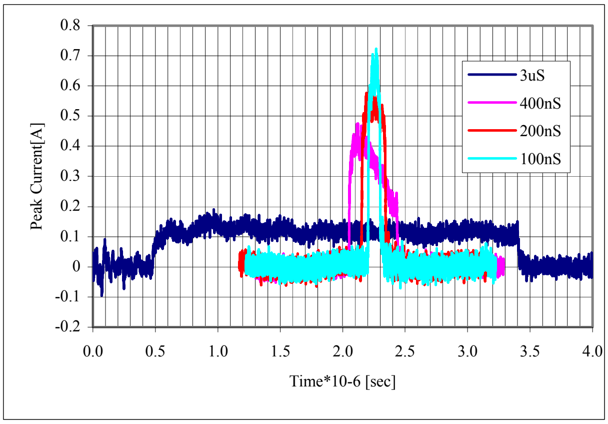

Figure 3: Toroid output for the 3uS, 400nS, 200nS and 100nS FWHM electron beam pulses.

The data in these plots is background subtracted. The toroid signal with the gun grid off (no beam from the gun) is subtracted from the live signal. The data demonstrate the sharp 25nS rise time of the deflector. The rounded shape of the 400nS pulse is due to a combination of variation in the gun current distribution and beam loading effects. With slight adjustments of the lens coil the distribution can be made flat.

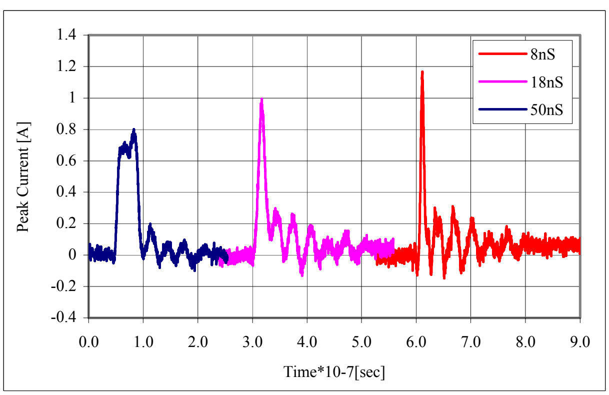

Figure 4: Toroid output for the 40nS, 18nS, and 8nS FWHM electron beam pulses.

There is noticeable "ringing" on the toroid pulses for the shorter beam pulses. This is due to impedance mismatch in the system. Efforts to reduce the noise by surrounding the toroid with a shielding system have been attempted but no substantial reduction has been achieved.

Table 1: Linear accelerator system parameters.

Pulse Length FWHM [nS]	**Peak Current [A]**
3000	.12
400	.41
200	.52
100	.63
40	.68
18	.97
8	1.12
System Parameters	
Beam Energy	7.5MeV Nominal
Pulse-to-Pulse Jitter:	
Timing	±1nS Peak-to-Peak
Current	±1% Peak-to-Peak
Beam Diameter at E-Beam Window	2mm FWHM

CONCLUSION

The accelerator system has been designed, commissioned and has successfully met all of the design specifications. The system is now installed and in use at the University of Pune in India.

REFERENCES

[1] L.D. Landau and E.M. Lifshitz, "The Classical Theory of Fields," Pergamon Press, New York, 1975.

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