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THE HIGH-GRADIENT S-BAND LINAC FOR INITIAL ACCELERATION OF THE SLC INTENSE POSITRON BUNCH*

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Abstract Although short lengths of S-band standing-wave, disk-loaded waveguide have been successfully RF-processed to accelerating gradients equivalent to about 175 MeV/m in a traveling-wave structure, the 20 MeV/m gradient of the SLC 50 GeV linac has been the highest gradient S-band accelerator in operation. However, the 1.5 m traveling-wave constant impedance capture section for the SLC positron source, operating with a dedicated 60 MW klystron, is now routinely accelerating single-bunch beams of more than 7×10^{10} e^+/pulse at rates of up to 60 Hz with an accelerating gradient of 40 MeV/m. Design, processing techniques, and operation of the high-gradient section are described.

DESCRIPTION OF SYSTEM

Rapid acceleration of positrons produced by the $\geq$ 30 GeV electrons which are directed to the positron production target of the SLAC linear collider (SLC) is crucial in order to avoid phase lag and, consequently, bunch lengthening of the positrons.[1] This acceleration is provided by a 1.5 m constant impedance, disk-loaded waveguide (DLWG) operating in the traveling-wave mode. As shown in Fig. 1, the DLWG section is placed within about 13.5 cm of the positron production target, which subjects it to a great deal of radiation. The entire area is immersed in strong solenoidal fields. The tapered field solenoid (TFS) surrounds the target with a 1 T field, while the uniform field solenoid (UFS) provides 0.5 T for the high-gradient section. An additional pulsed 5 T field is added to the target region alone. No special radiation barrier is placed between the target and the DLWG.[2]

RF power is provided by a SLAC 5045 klystron using a SLED pulse-compression system and driven by a dedicated solid-state subbooster. The 5045 klystrons produce a peak power of $\sim$ 60 MW and have been tested in the SLC at 120 Hz. The RF waveguide loss to the high-gradient section is 0.97 dB. With the klystron generating a 3.5 μsec RF pulse, the peak power into the section is multiplied by a factor

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of 5.5, which, as indicated in Table 1, will double the accelerating gradient for a single-bunch beam.

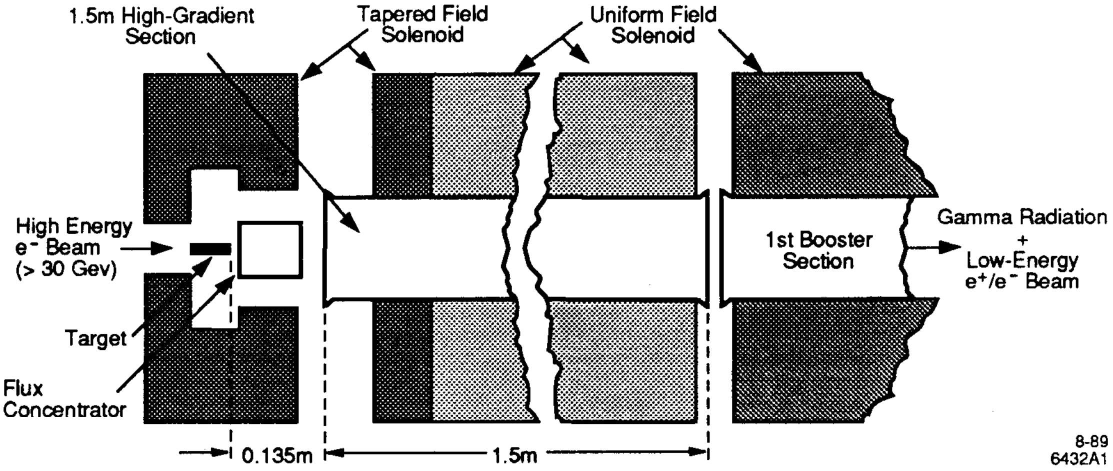

FIGURE 1 Layout of the SLC positron source showing the relative locations of the high-gradient section, the target, and the solenoids.

TABLE I Characteristics of RF source.

Parameter	Value
Klystron type	5045
Present repetition rate	60 Hz
Pulse width	3.5 μsec
Beam voltage	350 kV
Peak klystron power, P_k	60 MW
Energy gain (SLED Detuned)	5.3 $(P_k)^{1/2}$ MeV
Energy gain (SLED tuned)	10.9 $(P_k)^{1/2}$ MeV

The design of the 1.5 m section is described in detail in Ref. 3. This design makes use of many of the techniques developed for manufacturing the standard SLAC 3 m constant gradient sections. The SLC linac now routinely accelerates at 60 Hz (later 120 Hz) up to two bunches (later three), each of several times 10^{10} particles, within a single RF pulse with gradients of about 20 MeV/m. This gradient has been the highest for an operating high-energy electron linac—although in the original SLAC linac, single 3 m sections driven by dedicated klystrons (i.e., one klystron per section) were routinely operated with gradients of $\sim$ 17 MeV/m.

Studies of RF breakdown in S-band structures have been conducted at SLAC and Varian using short sections of resonant standing-wave structures. In these studies, the structures were RF processed to accelerating gradients equivalent to about 175 MeV/m in a traveling-wave structure.[4] The question then remains as to the operating gradient that can be achieved routinely by a linac operating in a high radiation environment.

RF PROCESSING OF INITIAL SECTION

As described in Ref. 3, the high-gradient section alone[5] was initially processed without incident to a peak power of about 170 MW within a few hours, spread out over several days. In the summer of 1986, the section was assembled with the target and solenoids. RF processing (alternating between SLED being detuned and tuned) resumed with no e^- beam at the target. A maximum power into the section of 60 MW, with high fault rate, was achieved before turning on the solenoidal fields. At this point a sudden drop in the breakdown level to 7 MW occurred which appeared to be correlated with the turning-on of the TFS. After several more days of effort, a stable operating level of 20 MW (SLED detuned) was achieved, and this power level was used for the next year during the SLC positron source startup.[6] No conclusive evidence for the cause of the power limitation was ever found, but the ferromagnetic vacuum rotary feedthrough which was integral to and just upstream of the rotating target was highly suspect, although the target itself had not been rotated since installation. This rotating target was replaced with a stationary model for the final processing to a 20 MeV/m gradient.

RF PROCESSING OF REPLACEMENT SECTION

In the Fall of 1987, a new 1.5 m DLWG section of identical design was installed. For RF processing, the section, as before, was equipped with RF couplers at the input and output of the DLWG. Several new safeguards were provided, including:

1. the reflected RF energy trip point was initially reduced to 0.5 MW, then eventually raised to 1.25 MW[7];
2. the difference between the forward RF signal out of the section and the forward RF signal into the section (attenuated and delayed, so the difference normally gave a zero signal) was added to the usual reflected RF signal out of the klystron, by which the klystron control system trips off the klystron modulator[8];

3. the reflected RF signal out of the section was also added to the usual reflected RF signal out of the klystron;
4. the vacuum trip level was set to 8×10^{-8} Torr at the entrance to the section[9] (this will limit the pressure in the center of the section to 10^{-5} Torr);
5. a thin Al window was installed between the target and the capture section to separate the two vacuum systems; and
6. the klystron control system was programmed to require the RF drive to be attenuated to zero and ramped back up after each RF trip.[10]

In addition, the following procedures were used:

1. the RF processing was not begun until the pressure at the entrance to the section was less than 10^{-8} Torr (at this pressure, the vacuum in the center of the section is calculated to be $\leq 10^{-6}$ Torr[11];
2. the klystron fault rate was not allowed to exceed one per minute; and
3. at the end of any stage in the processing, the fault rate was required to be less than one per 15 minutes before proceeding to the next stage; e.g., before increasing the pulse width.

The RF processing with the new high-gradient section was started in mid-December 1987. It began at a power level (SLED detuned) of 1 MW with a 400 nsec pulse width at 60 Hz (but no beam). About 20 hrs of processing were required to reach saturation (which, for a beam voltage of 300 kV, is about 30 MW); the rate of processing was limited only by the conditions described above. Vacuum and Reflected Energy (RE) trips were the common types of faults observed. The usual multipactoring was observed over limited power ranges.

The power was then returned to a low level and the pulse width increased to 600 ns, afterwhich 16 hrs of processing were required to reach 30 MW. Again returning to low power, 7 hrs of processing were required to return to saturation with an 800 nsec pulse width.

After the new year, the surrounding solenoidal fields were turned on; this necessitated an additional 12 hrs of RF processing.

During the next eight months, the station ran continuously at 30 MW (SLED detuned) and 60 Hz (the beam at 10 Hz) with a 700 nsec pulse width, providing an accelerating gradient of almost 30 MeV/m. The high-gradient section was once for 4 hrs with dry N_2, after which the section processed back up to 30 MW within 2 hrs.

During the Fall of 1988, when the SLC was recovering from its initial high-energy physics run, the DLWG section was processed up to a gradient of 50 MeV/m. This was done in stages as follows. First, with SLED still detuned, the beam voltage was increased to 350 kV and the station saturated (60 MW), using a 700 nsec pulse width. This took about 13 hrs over a three-day period. SLED was then tuned and the pulse width increased to the final 3.5 μsec. About 70 hrs of processing over 11 days were required to reach the final gradient.

All the processing of the replacement section followed a common pattern: at the beginning of a processing period, an hour or so was required to reach previous power levels, after which progress was increasingly slower. Progress was governed by the rate of vacuum and/or RE faults originating primarily in the section itself. Whenever a fault occurred immediately on removal of the drive attenuator, the drive level was temporarily lowered a small amount.

CONCLUSION

At 50 MeV/m the fault rate still exceeds 10/hr, whereas at 40 MeV/m the rate is about 0.4/hr. In February 1989, the SLC resumed high-energy physics with the positron source linac at 60 Hz (the beam at 30 Hz), and a gradient of 40 MeV/m. About 10^{11} e^+ and an equal number of e^- are accelerated through the high-gradient section each beam pulse, resulting in more than 7×10^{10} e^+ per pulse at 200 MeV. After damping, as many as 1.8×10^{10} e^+ per pulse are available for reinjection into the 50 GeV linac. This intensity is limited primarily by the thermal stresses expected in the fixed target. A new bellows-sealed rotating target will be ready for installation in the Fall of 1989, after which the beam through the high-gradient section will be doubled (for a given bream rate).

Although the klystron is not fully saturated, no serious effort has been made to increase the accelerating gradient. The beam rate was increased to 60 Hz a few months ago. Lately some inconclusive evidence has been accumulated which indicates that the presence of the beam affects the RF fault rate. This possibility is being investigated.

REFERENCES

1. F. Bulos *et al.,* IEEE Trans. Nucl. Sci. **NS-32** (1985) 1832.
2. J. E. Clendenin, SLAC–PUB–4743 (1989).
3. H. A. Hoag *et al.,* 1986 Linear Accelerator Conference (1986) 437.
4. J. W. Wang and G. A. Loew, SLAC–PUB–4866 (1989).
5. The target, TFS, UFS, etc., were not yet installed.
6. J. E. Clendenin *et al.,* SLAC–PUB–4704 (1988).
7. A normal klystron station has the reflected energy trip point set to 3.5 MW and has an additional 6 dB attenuation between the DLWG section and the fault detector.
8. R. K. Jobe *et al.,* IEEE Trans. Nucl. Sci. (1985) 2107.
9. There is a 270 l/sec ion pump at the entrance and another at the exit of the high-gradient section. The pressure at the entrance and the trip point is established by a Bayard-Alpert ion guage with a Granville-Phillips Series 271 controller.
10. A single fault at a normal klystron station will simply remove, and then a few seconds later restore, the modulator trigger. Only after a rapid succession of faults (ten or more in a one-minute interval) will the drive be attenuated to zero and then ramped back up. Whenever the drive is attenuated to zero in response to a fault or series of faults, the modulator trigger is also removed in order to immediately prevent even one additional RF pulse.
11. The pressure in the center of the section due to outgassing of clean Cu alone is calculated to be about 10^{-8} Torr.