EXPERIENCE WITH A RADIO FREQUENCY GUN ON THE SSRL INJECTOR LINAC*

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Abstract

A-SSRL/Varian-Associates-built, one-and-a-half cavity, microwave, thermionic-cathode gun has operated on the SSRL Injector Linac reliably without changing the cathode for over 10,000 hours, with no significant decrease in emission. Thus, for a pulsed electron beam, with a maximum of 0.5 A peak at 2 to 3 MeV from a 3.5 MW peak rf pulse of 2 μs pulse width at 10 pps, the apparent but small amount of back bombardment of the cathode has been tolerable. Use of a bunch-compression alpha magnet and a stripline chopper after the gun produces the required S-band 3 to 5 microbunches of electrons for injection into a standard 10-m-long linac and on into a booster synchrotron, which in turn is used to fill SPEAR. Component limitations and operating characteristics of the gun and the linac's rf system are discussed.

I. INTRODUCTION

There are four thermionic-cathode, microwave guns of the SSRL/VA/AET type [1,2,3] in existence, designated by the following model numbers: SSRL 1, SSRL 2, MG–200, and MG–300, and listed here in the order in which they were built. SSRL 1 is being used as the source for SSRL's injector for SPEAR, and has logged over 10,000 hours of operation on the linac. SSRL 2 has been operating for over 1000 hours as the source for a couple of experiments at HEPL on the Stanford campus [4]. Both MG–200 and MG–300 were built for ANL's new APS facility that is still under construction, and have not been tested yet. After testing, one is expected to serve as a secondary source [5]. Some discussion of the operating characteristics of SSRL 1 follows. The complete layout of the SSRL linac's rf system has been described elsewhere [6,7]. This system has behaved reasonable well, with the exception of some modulator reliability problems, and some outgassing and arcing problems. The arcing problems, described below, seem mainly to have been associated with one particular accelerator section and load.

II. THE LINAC'S RADIO FREQUENCY GUN PERFORMANCE

The linac receives nominally three 120 MeV bunches of 4×10^8 electrons each, with a bunch spacing of 350 ps, at a repetition rate of 10 Hz from a chopper, alpha magnet and rf gun source. Thus, the gun only has to produce a steady beam for a relatively short time during its
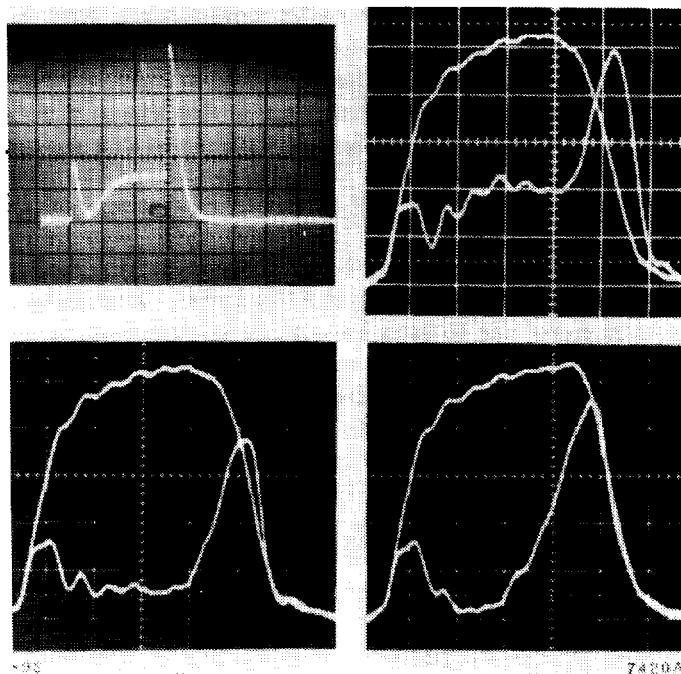
Figure 1. Incident (full pulse) and reflected (with a porch) rf power pulses from the rf gun, 0.5 μs/div, (a) [upper left] with the heater off and a 10 mW peak pulse from a signal generator (the incident pulse is not shown in the oscillograph), (b) [upper right] with the heater off and a 3.5 MW peak incident pulse, (c) [lower left] with the heater on at its normal, 9.0 W, operating level and a 3.5 MW peak incident pulse and (d) [lower right] with the heater at 10 W and a 3.5 MW incident pulse.

pulsed time on. The rf gun and accelerator section fill times are factors that have to be coordinated, since the same klystrons and modulators supply the whole rf network. Five time constants for the rf gun standing-wave cavities are about 1.5 μs, and the linear fill time of the travelling-wave accelerator sections is about 0.8 μs, so a 2-μs-long rf pulse with a nominal 1.5 μs flat top is sufficient for operation. The gun cavity $Q_o = 14,000$, as calculated from a slotted line measurement of $\beta = 4.4$ and from determining the pulse decay time from Fig. 1(a), which shows the reflected signal from the rf gun with the heater off and a square, signal-generator-level, incident pulse. Within measurement accuracy, the values of Q_o and β are the same after 10,000 hours of operation as when built. Figure 1(b) shows the incident and the reflected signals from the gun, also with the heater off, but with a high-power incident pulse. The reflected signal is much less

ideal with the much-less-than-square incident pulse from a modulator pulse forming network. Figure 1(c) shows the same signals with the heater set at its normal operating point, which result in a beam-loaded reflected signal. It should be noted here that the cathode is run temperature-limited in order to obtain the desired current from rf accelerating fields that allow the alpha magnet-to-bunch length compress a few microbunches most effectively for injection into the linac [2],[3]. If the heater power is increased by 10%, the same signals are as shown in Fig. 1(d).

It seems that the heavier the beam-loading, the earlier the beginning of the rise in the reflected signal (from a steady, beam-loaded state to the cavity discharging state that accompanies turn off of the incident pulse). This phenomenon, together with the continually rising shape of the gun output current pulse, as seen in Fig. 2(a), may be an indication of the effects of back bombardment [8], and/or off-resonance-rf driving, or something else. The SSRL 1 gun has never had to use a bias or deflecting magnet to divert the back-bombarding beam away from the cathode to prevent overheating. The SSRL 2 gun, which is being run at higher power and is being studied extensively for such effects, is operated with a deflecting magnet [8], as was one of the earliest rf guns [9].
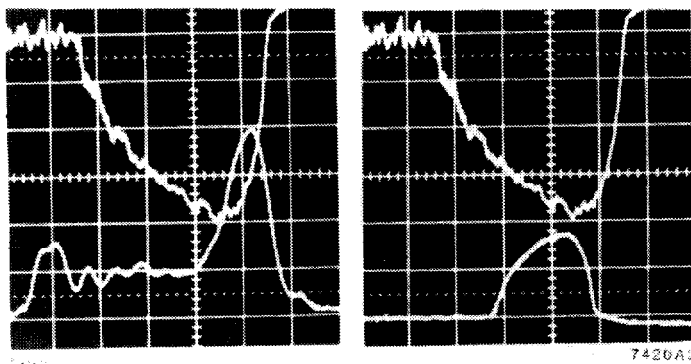

Figure 2. Current pulse (upper and inverted) directly out of the rf gun as compared in time, 0.5 µs/div, to (a) [left] the gun reflected rf power pulse (lower), and (b) [right] the current pulse (lower) after being scraped and compressed by the alpha magnet.

Another complication occurs with the timing of the compressed current pulse out of the alpha magnet, in comparison with current directly out of the gun, as seen in Fig. 2(b). The amplitude of the former is reduced from that of the latter by a low-energy tail scraper. Computer calculations undoubtly predict that the maximum in the high energy portion of the current pulse occurs before full beam loading. However, since measurements of the rf field levels in the two cells of the gun during operation is only possible with MG–200 and MG–300 (which have coupling loops built into them), this will have to wait for computer model verification. It turns out that, for 3.75 MW of incident power some component (a faulty vacuum window?)

in the gun's drive, rectangular waveguide network arcs occasionally, abruptly dropping the incident signal's amplitude. As a result, the reflected signal (actually only an emitted signal from the cavity remains) rises sharply, then decays with the cavity's time constant, as the theory says. Thus, there is reason to believe that the unexplained pulse shapes of some of the previous figures are real.

The gun's first cathode died at an early age while undergoing initial beam tests in one of Varian Associates' Clinac test cells under high rf fields and a long pulse length (close to 6 MW for 6 µs). The initial test setup was not fully instrumented with vacuum interlocks, so the apparent cause of failure was from poor vacuum during excessive processing discharges and excessive heating of the cathode due to back bombardment. The gun's rectangular-waveguide ceramic window cracked and the poisoned cathode was found to be severely crevassed in some areas. Before the failure, the heater power supply could be completely turned off once emission was established, which is a good indication of self-heating from back bombardment. With a long pulse and high fields, the current out of the gun was found to increase exponentially after about 3 or 4 µs into the pulse. Thus the initial plateau value that was reached some 2 to 3 µs into the pulse would rise to triple or quadruple the current before pulse breakup occurred at about 4 to 5 µs, from yet some other undiagnosed instability. Subsequent tests of the gun on the linac have resulted in relatively stable operation with less than 4 MW of peak rf drive power to the gun at 10 pps and a 2 µs pulse width. The more than 10,000 hours now logged on the second cathode have been under these less strenuous running conditions. It seems that rf guns with thermionic-cathodes do have some interesting quirks that could bear further study.

III. ACCELERATOR SECTION AND RADIO FREQUENCY LOAD PERFORMANCE

The linac's three, 3-m-long, accelerator sections and rf loads were purchased from IHEP in Beijing, PRC. They have performed very well, with the exception of a not-very-well understood arcing and outgassing problem that occurred almost exclusively with one load. This problem manifested itself in terms of high reflected power signals from either within the guide or from the kanthal-coated, vacuum, rectangular-waveguide load of the SLAC-type. Most kanthal loads of this type are notorious sources of prolonged outgassing and multipactoring. Thus, to be safe after exposure to air and before rf processing, all the loads are treated with a 160°C dry nitrogen bake for 24 hours and then with a 160°C vacuum bake for several days. The duration of the vacuum bake depends upon the pump down rate.

Some tests of a load on a SLAC klyston test stand indicated a VSWR that increased from 1.05:1 at signal generator power levels to 1.26:1 at 0.1 MW peak, and to over 4:1 at 8 MW peak. A permanent magnet passed along the length of the load could change the VSWR and the outgassing rate considerably, suggesting some sort of discharge

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phenomenon. The high reflected power signals could be processed away, but they have also occasionally returned, so the problem load has been replaced by a water load with double ceramic windows with a "guard vacuum" in between. The guard vacuum is instrumented to hopefully give an early warning of any impending water-to-vacuum leaks. An improved, high peak power, high vacuum load with external water cooling is being sought. Some ideas and designs are on the horizon [10]; currently, they are in the process of being incorporated into a readily available proven product [11].

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The dogged and intuitive efforts of the SSRL operators to get and to keep the rf gun going in the face of only a little enlightened instruction is to be praised, especially since the gun is still running!

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