We have developed a reliable procedure for multicycle filling of the Cambridge Electron Accelerator ring with positrons and electrons. The positron fill rate is determined by the intensity, spectrum, and emittance provided by the 125-MeV positron linac and also by the available phase-space and momentum acceptance aperture of the synchrotron for off-axis injection. This aperture in turn depends on the width of the already stored beam. Losses of newly injected particles in subsequent acceleration cycles depend on the extent of radiation damping provided by special damping magnets. After measuring and optimizing the main parameters, we have achieved a positron fill rate of 0.4 mA peak per second.

The control system used in rapid change over from 125-MeV positron injection to 250-MeV electron injection is sufficiently stable, automatic, and fast acting that filling the ring with countertraveling positron and electron beams takes less than five minutes.

Electron-Positron Linac

The injector is a Varian S-band electron-positron linac. It consists of a Mark IV gun, three SLAC-type accelerating guides, each three meters long, a Frascati-type converter, and two additional accelerating guides, each five meters long. Each of the five accelerating guides operates at 20 MW peak RF providing a total unloaded energy gain (\( V_0 \)) of 260 MeV. The electron beam is chopped at the gun by a 475.790 MHz transverse chopper cavity for operation at one bunch in six. There are two modes of operating the linac: positron mode and electron mode. See Fig. 1 for a schematic view of the linac and its beam transport.

Positron Mode

The gun and the first three accelerating guides are tuned for maximum beam current (250 mA peak) at an energy of about 100 MeV. The positron converter (1 radiation length of tungsten) is inserted, and the electron beam is focussed onto it by a quadrupole doublet. A high field solenoid (17.6 kG max) at the converter and a low field solenoid (2.5 kG max) for the last two accelerating guides are turned on, and these guides are RF phased to accelerate positrons. The beam transport allows tuning of the linac through adjustable slits. Positron currents of 250 mA in a 2k energy bin at 125 MeV have been achieved. A spectrum of the positrons is shown in Fig. 2.

Switching System

The set of controls for the linac operation and injection system (in total, about 50 parameters) have been duplicated and can be independently adjusted for \( e^- \) and \( e^+ \) operation. A system of T-bar relays, operated by a single push button, transfers the control from one set to the other. The complete transfer from positron injection to electron injection takes about twenty seconds. A drift in electron
energy caused by the large change in beam loading and its effect on the slow water temperature control systems of the linac requires a few minutes to stabilize electron injection. By adjusting the pulse length of the accelerated beam so as to keep the charge accelerated per pulse approximately constant, this drift has been reduced somewhat. The system for rapid refilling from positron injection to electron injection has been in operation for about one year. Reliability of the switching system has been good. Future effort will be made to improve the response times of the linac water systems and to track down parameters that cause small drifts during runs. The linac is kept pulsing during the time the e⁺ and e⁻ beams are stored in the synchrotron so that refilling is available on demand.

**Multicycle Filling**

First, the synchrotron is filled with a positron beam. Positrons are injected off-axis in a single turn injection mode (see Fig. 3). After accelerating these positrons to an energy of 2 GeV and decelerating them again to the injection energy of 125 MeV, radiation damping has decreased the horizontal beam size to 0.92 of injection size. This allows more positrons to be injected without elimination of those that are already stored. Optimum positron injection efficiency is reached as a compromise between many conflicting requirements and conditions. Damping of betatron and synchrotron oscillations increases with the third power of the peak energy during the cycle. This favors use of high peak energies. The horizontal equilibrium beam size of the stored beam at injection, on the other hand, also increases approximately with the 3/2 power of the peak energy, leaving less phase space for injection at higher peak energies. The resulting compromise depends on the available horizontal aperture at injection time. This aperture was found to be about 1.6" in the Cambridge Electron Accelerator. The resulting optimum peak energy is then about 2 GeV during multicycle filling. The equilibrium beam size of the stored beam (7.2 standard deviations) is 1" in this case. The aperture of 1.6" is considerably smaller than originally expected (2.7") . It is presently assumed that crosscoupling between horizontal and vertical betatron oscillations is the cause for this horizontal aperture restriction.

As a result of this relatively small aperture, positron injection efficiency in the Cambridge Electron Accelerator is considerably below original expectations.

It is found that positron currents of 40 μA can be injected and accelerated. Of these, about 15 μA survive the deceleration through the synchrotron energy minimum, which is 3 to 4 MeV below injection energy. Moving the beam with the kicker system towards the off-axis inflector for injection in the following cycles causes further intensity losses. As a result, the peak current accumulation proceeds at a rate of 6 μA per cycle or 0.4 mA/sec.

Fortunately, the lifetime of stored beams in this cycling mode is considerably longer (200 seconds or more) than originally expected (16 sec.), such that reduction in injection efficiency is compensated for by the possibility of longer accumulation times. Total accumulation of positron currents (up to 25 mA peak and 8 mA average) is, for this reason, not limited by positron injection efficiency together with the lifetime of particles in the cycling mode, but the limit is given by the onset of beam instabilities.

When the positron filling is completed, the dc of the synchrotron magnets is raised ("ramped up") to increase the lifetime of the cycling beam (see Fig. 4). The energy of the cycling beam then varies between 0.75 and 2.45 GeV and the lifetime is about 3000 seconds. Then the linac is switched to the electron mode and after about three minutes is sufficiently stabilized for electron injection.

An electrostatic plate system is turned on to separate electron and positron beams. The dc of the synchrotron magnets is then lowered so that injection of 250 MeV electrons can commence. The fill rate of electrons is very large (about 10 mA peak/second) and is generally slowed by inserting a foil in the transport system to get a smooth controlled fill. Again, instabilities limit the nautrated current achievable but 40 mA peak of e⁻ has been achieved. After electron filling is complete, the dc of the synchrotron magnets is ramped up and the beams are ready for dc storage and subsequent switching into the bypass.

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**References**

4. Anderson, B. C., Proceedings this Conference.
5. Hofmann, A., Proceedings this Conference.

222
RING TUNNEL, a Mt Itltb IUNb /
QUADRUPOLE ELECTRON LINAC MAGNETS
EAGi GUIDE 5 METERS LONG 0 F ACCELERATING CAVITY
SEPTUM INFLECTOR

Figure 1. Injection layout.

POSITRON SPEdTRUM
IN 1.2 % TEC
lmax = 200 mA
1° ON CONVERTER = 200 MeV pulse
3.4 % FR-VFIM

Figure 2.

SYNCHROTRON ENERGY VARIATION DURING MULTICYCLE FILLING SEQUENCE

Figure 4.

Figure 3.