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UPDATE ON THE HIGH-CURRENT INJECTOR FOR THE STANFORD LINEAR COLLIDER*

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Abstract

The high current injector[1,2] has become operational. There are two crucial areas where improvements must be made to meet collider specifications:

1. While the injector can produce up to 10^{11} e^- in a single S-band bucket, initially much of this charge was captured in a low energy tail and was thus not suitable for transport through the accelerator and injection into the damping ring.
2. Pulse to pulse position jitter has been observed, resulting in transverse wake fields which increase beam emittance.

The problems described above contribute to substantial current loss during transport from the injector (40 MeV) to the SLC damping ring (1.2 GeV). Experimental studies are continuing with the aim of understanding and improving beam characteristics including bunch length, pulse to pulse stability and emittance. The present status of these studies is reported.

Specifications

The collider injector must provide two intense single RF bunches 59 ns apart with low emittance and reasonable spectrum. The design specifications for the collider injector are listed below

- Charge per bunch – $12nc = 7.5 \times 10^{10}$ e^- /bunch
- Bunch length – $15^o \simeq 15psec$
- Emittance – $.03\pi m_0 c - cm$
- Energy – 35 to 50 MeV
- Polarization – $\simeq 40\%$ longitudinal

Description

The collider injector (Fig. 1) consists of an electron gun, two 16th sub-harmonic bunchers, a 10 cm long S-band traveling wave buncher and a 3 meter long S-band traveling wave accelerator. The sub-harmonic bunchers (SHB's) bunch the 2.5 nsec gun pulse by about a factor of 10, so that the bunch entering the S-band buncher is about 250 psec long. The S-band buncher compresses the bunch about a factor of 3, and raises its energy slightly to about 250 kV. There is no drift between the buncher and the accelerator since space charge forces would cause the bunch to debunch rapidly in the absence of a compressing longitudinal electric field. The buncher is phased so that the bunch enters the accelerator centered on the phase focusing longitudinal electric field null. This causes the bunch to undergo an additional factor of 3 phase compression as it drifts back to the accelerating crest in the first meter of the 3 meter section. A cut-off iris between the buncher and accelerator section permits independent adjustment of phase and RF power level for each.

Operating Experience and Improvements

The collider injector has operated to date with a thermionic cathode triode gun.[3] In typical recent operation the gun pulse is 18 nanocoulombs, with 12 nanocoulombs captured and accelerated to 40 MeV. Full design intensity of 12 nanocoulombs ($7.5 \times 10^{10}e^-$) in a single RF bunch was achieved almost immediately and the beam was used for studies of wake field effects with intense single bunch beams traveling through the accelerator.[2] Initial operation was less than optimum due to wake field effects in the accelerator section, beam jitter, and poor spectrum. These problems and improvements to minimize them are discussed below.

Wakefield Effects and Beam Stability Mis-steering just upstream of the first 3 meter accelerator section has dramatic effects on the beam emittance. This is presumably due to excitation of dipole wake fields. When the bunch goes through the disk loaded waveguide off center, it excites a dipole wake field with transverse components which force the bunch farther off the center. If the beam were highly relativistic, we could prevent wake field emittance growth by centering the beam at the accelerator input and output. However, the beam enters the accelerator section at low energy, in the presence of solenoidal magnetic fields. Consequently we cannot avoid wake fields just by steering to center. Instead, we adjust the upstream steering to produce a round spot, not necessarily centered at the output of the accelerator section. We then steer to axis with the steering magnets downstream. For a given solenoidal field the steering required to produce a round spot seems to be repeatable. Altering the upstream steering produces a comet-like tail emenating from the central beam spot, as is characteristic of

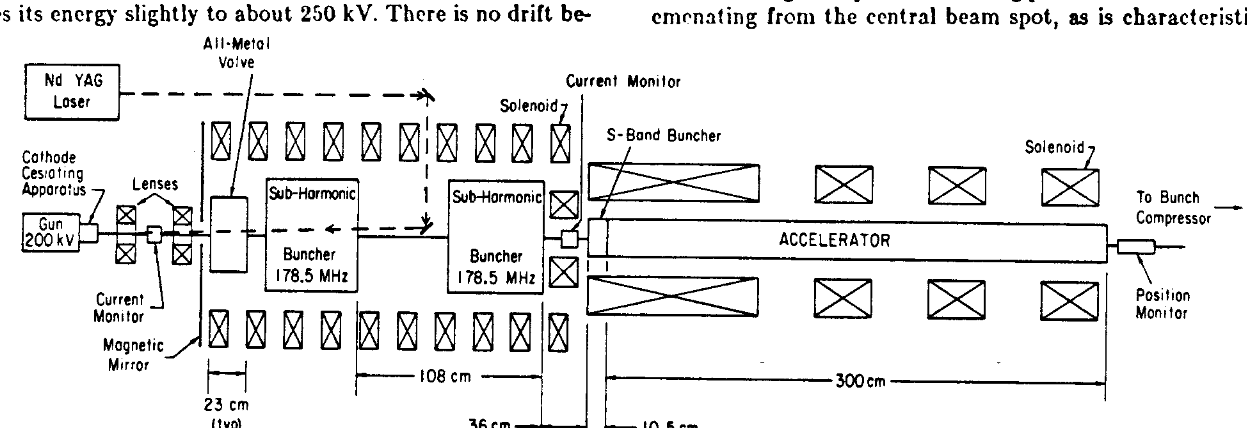

Fig. 1. The SLC Injector.

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wake field emittance growth. Beam energy and position jitter have been a problem on the new injector. The wake fields increase the effect of steering jitter at the injector by 2 orders of magnitude by the time the beam has traveled through 100 meters of accelerator.

We are making a number of improvements to reduce beam jitter. Initially we used many older, unregulated power supplies for steering and focusing. These have been replaced with well regulated DAC controlled power supplies interfaced to the VAX control computer. A new electronically regulated 200 kV power supply has just been installed on the gun. Recent operation has indicated greatly improved beam stability. The position monitor downstream of the injector indicates that the beam jitter is $\leq 30 \mu m$. The measurement is limited at that level by electronic noise in the position monitor. A program to improve the stability of the sub-harmonic buncher RF is in progress. Water temperatuare stabilized transmission lines have been installed, and an active phase control feedback loop is being installed around the amplifier and SHB cavity. We are working on an all-solid-state driver for the final stage which is a cavity oscillator.

Bunch Length and Spectrum During initial operation, the beam was characterized by a poor spectrum with about 50 percent of the charge outside the specified energy acceptance of the damping ring. At the end of the injector it is the bunch length, not the spectrum, which determines the spectrum at the damping ring. With our present equipment, a bunch measurement is too involved to be an effective tuning aid. (We do not yet own a streak camera.) Therefore we installed a momentum spectrometer in the 2 meter drift region between the collider injector and the main injector. The spectrum readout is obtained from a zinc sulphide screen placed in the dispersed beam. The screen is imaged onto a 128 element photo diode array which is interfaced to a micro processor. The microprocessor signal is displayed on an oscilloscope, giving a pulse to pulse beam spectrum. Using this spectrometer we tuned the injector to a new operating point at which the bunch rides on the RF crest in the accelerator section. For best spectrum, the klystron operates at 15 MW with the temperature of the accelerator section at 111.5 F. At 15 MW the calculated asymptotic phase is -90 (i.e., right on the accelerating crest) if $T = 113F$. The sub-harmonic buncher power is about 4 kW into each cavity. A spectrum is shown in Fig. 2 for a beam intensity of $5 \times 10^{10} e^-$.

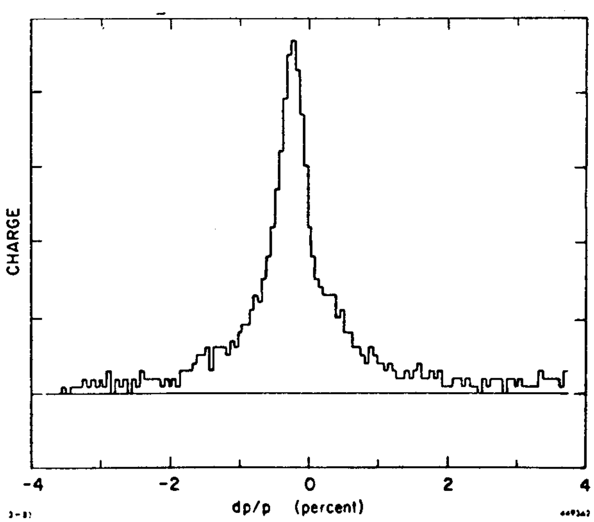

Fig. 2. Injector Momentum Spectrum.

The length of the bunch has been measured by a streak camera. The bunch passed through a quartz plate producing Cherenkov radiation that was detected by an Imacon 500 streak camera system provided by Hadlan Photonics Limited. At low repetition rates ($\sim$ 5 pps), this streak camera provides a pulse by pulse presentation of longitudinal charge distribution in the bunch. The camera has a 2 psec time resolution. At $1.5 \times 10^{10} e^-$ we measured the FWHM to be 15 psec (see Fig. 3a). At $5 \times 10^{10} e^-$ we measured a FWHM of 16 psec with rise time of 4 psec (Fig. 3b). Changing the streak camera to a slower sweep speed, we detected three small prebunches and one postbunch containing approximately 20 percent of the total charge (Fig. 3c).

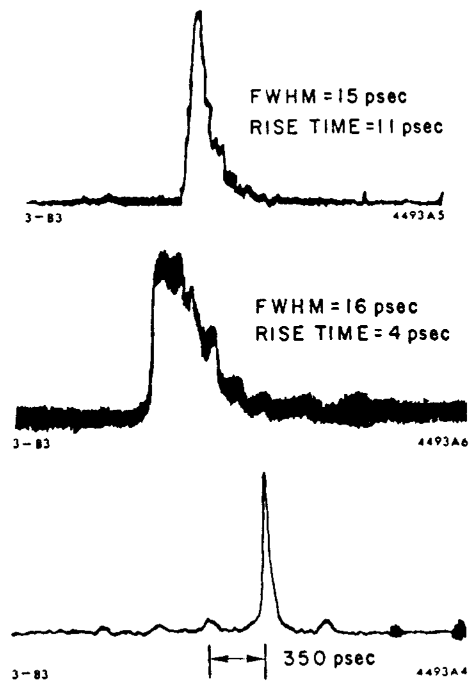

Fig. 3. Streak Camera Photos of Longitudinal Charge Distribution. a) At $1.5 \times 10^{10} e^-$/bunch. b) At $5 \times 10^{10} e^-$/bunch. c) Showing several cycles of S-band.

For comparison a calculated-charge distribution is shown in Fig. 4. (Note that time increases from right to left in this figure.) In the calculation the gun voltage was 200 kV rather than 150 kV and the bunch contains $7.5 \times 10^{10} e^-$.

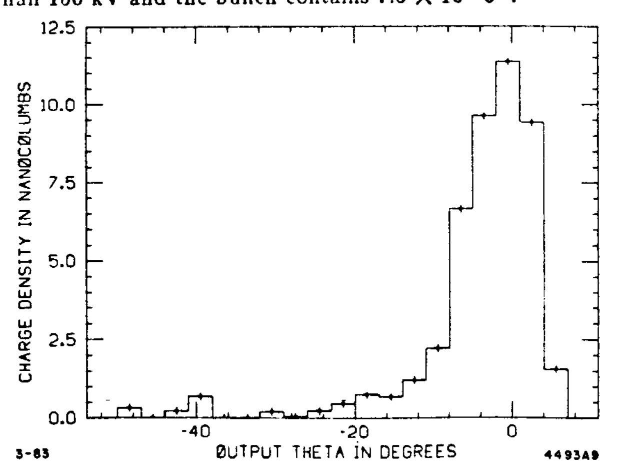

Fig. 4. Calculated Charge Distribution with $7.5 \times 10^{10} e^-$/bunch $\sigma_z = 7^o = 7$ psec.

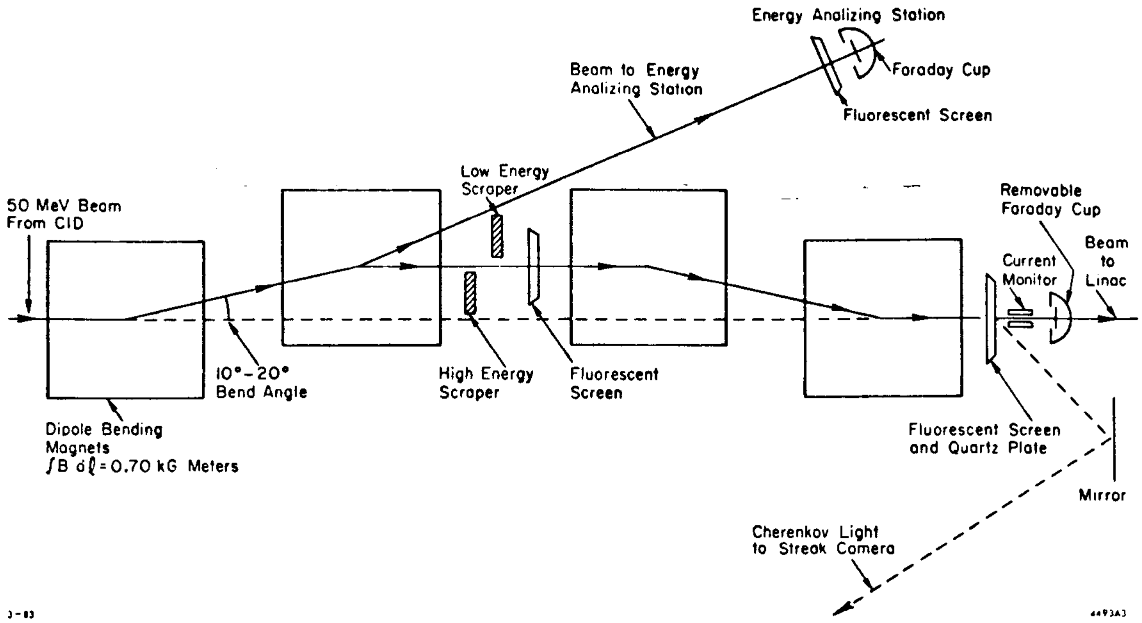

Fig. 5. Bunch Compressor.

The electron bunch from the collider injector must ultimately be injected into a small storage ring, where its transverse emittance is damped by a factor of 10 to $.003\pi\ m_0c$-cm. The acceptance of the 'damping ring' requires that the electron bunch contain $> 5 \times 10^{10}$ electrons with no greater than 2 percent energy spread at a mean energy of 1.2 GeV. Since a highly relativistic beam is not bunched by accelerating RF, the energy spread of the 1.2 GeV beam is determined by the bunch length at the end of the CID injector. For sinusoidal accelerating RF the energy spread as a function of bunch length is given by $\Delta E/E \approx \Delta\theta^2/8$. Thus for a 2 percent energy spectrum the electron bunch must be approximately 21° of the S-band RF. The bunch length at $5 \times 10^{10} e^-$ is 30° (see Fig. 3b) so it is desirable to decrease the bunch length by a factor of 1.5. A bunch compressor has been designed to accomplish this. The phase of the CID accelerator section is adjusted to create a strong correlation between energy and phase. The beam then passes through four dipole magnets (see Fig. 5). Electrons at the front of the bunch (lower energy) travel a longer path through the dipoles than those electrons behind (higher energy). We have calculated that the 30° bunch can be compressed to 8°, well within the damping ring spectrum requirements. Shortening the bunch decreases the effect of the dipole wake fields which cause emittance growth, but increases the higher mode beam loading. The compressor will provide a convenient bunch length control. While the deliberate energy spreading (13 percent for a 30° bunch) at CID is a negligible contribution to the energy spread at 1.2 GeV, it does complicate the transport of the low energy beam through the old injector region. A lattice that works well for peak energy electrons may not transport electrons whose energy is 13 percent lower. The compressor should be operational in early summer.

Emittance A summary of selected data from many emittance measurements made during the last year is presented in Fig. 6. The beam emittance is found by measuring the beam radius at a profile monitor as a function of the focal strength of a quadrupole lens.[4] The measured emittance as a function of beam intensity is reasonably fitted to a parabola given by $\epsilon = .007\sqrt{I}\ \pi\ m_0c$-cm, where I is the current in units of $10^{10}e^-$/pulse. The form $\epsilon = k\sqrt{I}$ is appropriate when the density in phase space remains constant as the current is varied.

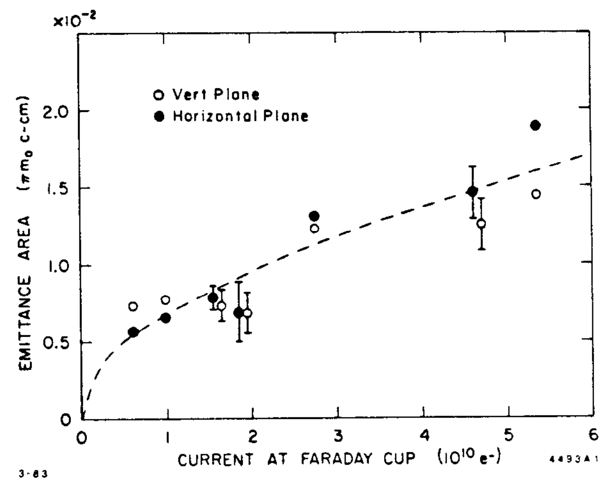

Fig. 6. Emittance versus Current. Error bars at $\pm\sigma$. Where no error bars are shown there is insufficient data to determine σ.

GaAs Photo-emission Gun A very important specification for the collider is the availability polarized electron beams. The development of a GaAs photoemission gun capable of producing polarized electrons is proceeding independently. The GaAs source will eventually replace the thermionic gun. This development will be discussed in an upcoming paper.

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