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Generation and Acceleration of High Intensity Beams in the SLC Injector*

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ABSTRACT

A new gun pulser and substantially increased focusing have been added to the first 100 m of the SLAC linac in order to provide a pair of intense electron bunches to the SLC damping ring. Each bunch from this injector must have 5×10^{10} electrons, an invariant emittance $\gamma\epsilon \leq 1.8 \times 10^{-3}$ m-rad and the pair must have an energy spread of less than 2% . Wakefield instabilities present in earlier versions of this injector [1] have been controlled by reducing the transverse beam dimension by a factor of 3.

SLC REQUIREMENTS

On each machine pulse the SLC electron damping ring must receive a pair of 1.21 GeV electron bunches, each approximately 3mm long and spaced by 61.06 ns which is about 1/2 of the damping ring circumference. The injector provides this pair of bunches with an energy distribution in each bunch of less than 2% full width. In addition the mean energy of both bunches must be the same. In order for the beam to damp sufficiently during the inter-pulse period, the input invariant emittance $\gamma\epsilon < 1.8 \times 10^{-3}$ m-rad. This ensures that for 120 Hz operation, the emittance at the time of extraction from the damping ring is not larger than 3×10^{-5} m-rad, as specified for the SLC[2].

SYSTEM DESCRIPTION

Previous attempts to satisfy these requirements have not succeeded because of several difficulties. Pulse to pulse jitter from a variety of sources combined with transverse wakefield instabilities kept the maximum intensity at the end of the injector below $2 \times 10^{10} e^-$/pulse. Because of the need to operate the older off-axis guns compatibly with the new injector, the focusing at the 50 MeV point was limited, leading to large beam losses in that region. Improvements to the injector included the addition of 4 focusing magnets to the old gun region. Upstream, in the bunching system, few changes were made. That part of the injector has been previously reported[3]. From the 50 MeV point to the positron insertion point (190 MeV), 7 quadrupoles have been added and existing magnets have been relocated in order to establish a regular FODO lattice. From the e^+ insertion point to the end of the injector, 71 quadrupoles have been added. The primary purpose of these magnets is to focus the large emittance ($\gamma\epsilon \approx .01$ m-rad) positrons as needed to transport them through the 19.1 mm minimum aperture of the accelerator irises. Of course, they also stabilize the electron bunches.

Figure 1 shows the layout of the focusing magnets and diagnostic devices in the injector. After 2 sets of doublets, the beam is matched into the regular array. Four different magnet designs were used, as summarized in Table 1. Notable among these are the QW magnets which are the bulk of the installation. These magnets (Fig. 2) wrap around the accelerator disk-loaded waveguide (DLWG).

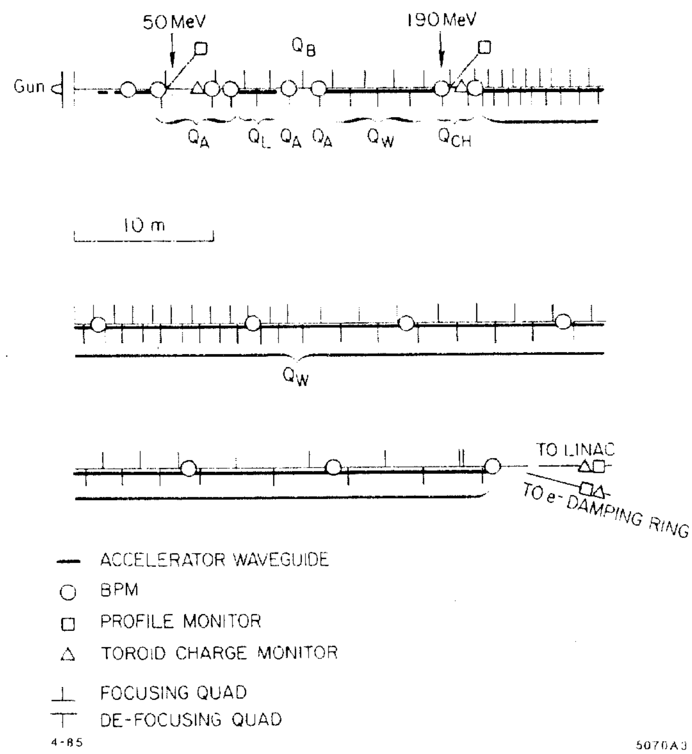

Fig. 1. SLC 1.2 GeV high current injector showing waveguide, focusing magnet and diagnostic instrument locations.

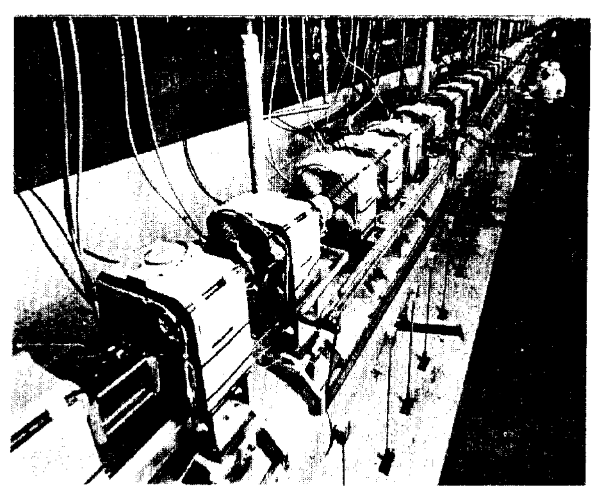

Fig. 2. QW magnet installation around 12 cm diameter disk loaded waveguide.

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TABLE 1

Sector 1 Quads	QA	QB	QCH	QL	QW
Maximum $\int g d\ell$ (kG)	14.5	29.0	22.0	5.8	15.0
ℓ_{eff} (cm)	10.2	20.4	8.3	38.1	24.8
Aperture Radius (cm)	1.5	1.5	1.4	11.1	5.9
Maximum Current (Amps)	8	8	12	50	50
Cooling Mechanism	Air	Air	Air	H_2O	H_2O
Total # in Injector	9	1	4	3	79

Figure 3 shows the horizontal and vertical beam sizes throughout the injector. The beam is deflected toward the damping ring at the 120 m point and this is also where the damped beam is re-injected. The beam sizes are shown for both the high emittance input electron beam and the low emittance extracted beam.

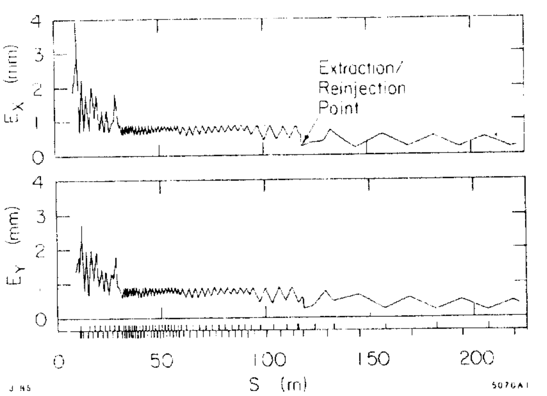

Fig. 3. Horizontal and vertical beam size throughout the injector shown with the extracted, damped beam size in the following 100m of accelerator. The quadrupole magnet locations are also shown. Injector emittance $\gamma\epsilon_{x,y} = 15 \times 10^{-5}$ $m - rad$

PERFORMANCE

The general performance of the injector was much improved due to the increased focusing. Some pulse to pulse energy fluctuation was observed and traced to fluctuations in the gun trigger timing. Gun timing jitter must be kept less than $\sigma_t < 15$ ps to keep energy jitter at the end of the injector $< .1\%$. Development efforts are underway to limit and monitor this. Present operation has $\sigma_t < 30$ ps.

Intensity, emittance and energy spread measurements were made at several places in the injector. Intensity is monitored using both the faraday cup at the 50 MeV point and a set of 4 recently installed resonant toroids. These devices resonate at 50 kHz when shock excited by the beam pulse and can monitor the beam intensity with 1% accuracy. Because of the slow response time these toroids cannot be used to determine the intensity of each bunch of the pair. This can be done, with lower resolution (10%), using the beam position monitor (BPM) striplines installed throughout the injector.

The specified intensity of 5×10^{10} particles in a single bunch was reached and surpassed without difficulty. Peak bunch intensities up to 7.5×10^{10} were observed at the end of the injector. Bunch pairs with intensity up to 1.1×10^{11} were observed.

Figure 4 summarizes the emittance measurements made at the end of the injector at different intensities. The measurement technique[4] used a fine-grained fluorescent screen and a video camera along with a transient digitizer. Slices of the image are fit to a gaussian in order to extract the width. Each fit is performed on data from a single pulse. At intensities above $3 \times 10^{10} e^-$ some distortion and movement of the beam spot is seen due to wakefield effects. Thus with the image slice processing technique, a broad distribution of widths is seen. This is reflected in the error bars for these points in Fig. 4.

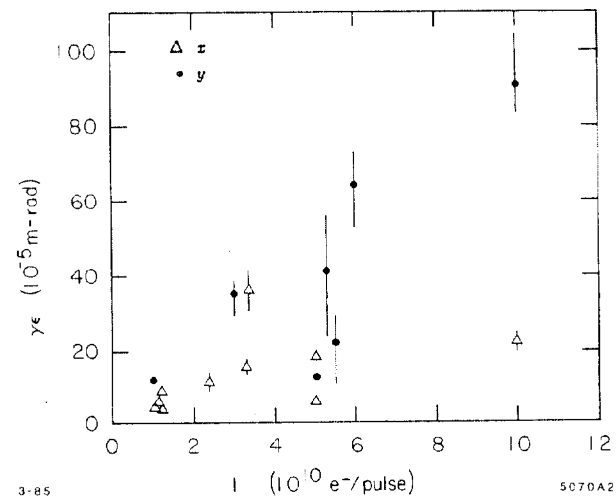

Fig. 4. Horizontal and vertical emittance data at the end of the SLC injector for different beam currents. The points at $10^{11} e^-$/pulse represent the superimposed emittance of the bunch pair.

The sweep speed of the camera as well as the decay time of the phosphor preclude separate measurements of the emittance of each pulse when both are present. The data shown at a beam intensity of $10^{11} e^-$ represents the superimposed emittance of the pulse pair.

Because the first bunch extracts 20 MeV/$10^{10} e^-$, so-called beam loading of the RF fundamental, the power input to the DLWG must rise in the interval between pulses to make the mean energy of each bunch equal. This is conveniently accomplished with the SLED RF. If the first pulse is placed 100 ns before the time of maximum energy, the second pulse, 62 ns later, will have equal energy. Each bunch has a mean energy which is 2.5% below the peak (unloaded) energy.

The minimum energy spread is achieved when the bunch is short enough to occupy only 20° of the S-band RF yet long enough to prevent rapid blow up due to space charge forces. The bunch length is set early in the injector, since it does not change once the beam becomes relativisitic. In order to monitor this, a quartz radiator which produces pulses of Cerenkov light can be inserted at the 50 MeV point. These light pulses retain the longitudinal intensity structure of the beam and are viewed by a streak camera. The system resolution is 2 ps.

We observe a minimum energy spread of 1.4% at $5 \times 10^{10} e^-$ with a bunch length of 3 mm. The combined energy spread of the bunch pair was 2% at the full intensity of $10^{11} e^-$, within the energy acceptance of the damping ring complex. It is broader than the one bunch spectrum, not because of any separation of the mean energy of each bunch, but because the second bunch has a larger energy spread. This is due in part to the way the second bunch is tuned. Since the phase of the 16th sub-harmonic bunchers cannot be changed in the time between the two bunches, the bunching of one is optimized using the buncher phase and the second is adjusted using a vernier to delay the gun trigger. The granularity of this computer controlled vernier is 100 ps which is not fine enough to allow optimum adjustment of the bunching. Some of the increased spread, however, may be due to fields remaining in the sub-harmonic bunchers from the passage of the first bunch.

CONCLUSIONS

Strong focussing has improved the performance of the SLC injector so that it now meets all of the requirements. Planned improvements include fine pulse timing monitoring and control and a series of diagnostic devices near the damping ring takeoff point.

REFERENCES

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4. M. C. Ross, these proceedings.