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SLC POSITRON SOURCE STARTUP*

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The turnon experience and initial operating parameters of the SLAC Linear Collider positron source are described.

The SLAC Linear Collider (SLC) requires the collision of a high-intensity single bunch of electrons with a positron bunch of equal intensity, after the acceleration of each bunch to about 50 GeV in a common linac. The emittance and stability as well as the intensity and energy requirements for both bunch types are identical.[1] The old SLAC positron source, which had an in-line production target at the one-third point of the linac, typically had a yield of $\leq 10\%$ for the normally 7-GeV incident electron beam. Computer simulations indicated a production target with an incident electron energy of 33 GeV could result in a yield considerably greater than unity within a reasonable phase space.[2] Experimental tests of target materials with incident electron beams of up to 25 GeV indicated that some high-density targets would survive a reasonable number of pulses.[3] Subsequently, an off-axis positron source for the SLC was designed and built at the two-thirds point of the linac. The new source included a rotating target designed to survive an incident 0.6 mm radius beam of 33 GeV and 5×10^{10} e^-/pulse at up to 180 pps. Immediately following the target is a 1.5-m high-gradient (designed for 50 MeV/m) constant-impedance RF-capture section. Three conventional SLAC 3-m constant-gradient accelerator sections powered by a common klystron boost the energy of the captured positrons to 200 MeV. The 200 MeV positrons are then transported back to the beginning and reinjected into the linac where they are accelerated to 1.2 GeV, the energy of the damping ring. The large transverse emittance of the positron beam emerging from the target is transformed to match the capture section aperture with its 5-kG solenoidal field by a pseudoadiabatically changing solenoidal field consisting of a 5-T pulsed field from a flux concentrator superimposed on a 1-T tapered solenoidal field. The 5-kG solenoidal field extends to the end of the first booster section.[4]

The installation of the new source was completed in the summer of 1986. Unfortunately the caputure section failed[5] to achieve a gradient of more than about 15–20 MeV/m. The rotating target, although it had never been operated, was suspect (especially the ferromagnetic rotating seal) as a possible cause of contamination in the RF section. Consequently it was replaced by a water-cooled, W-26Re, stationary target about 6 mm in radius and six radiation lengths long (about 2 cm). A cross section of this target configuration and the associated target chamber is shown in Fig. 1.

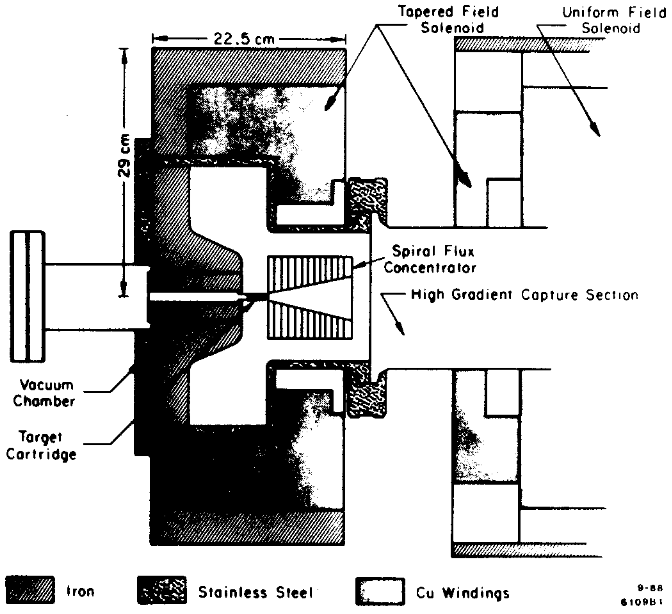

Fig. 1. Cross section of positron target assembly.

The commissioning of the source configured in this manner (and with the capture section limited to an accelerating gradient of 15-20 MeV/m) began in earnest in early September, 1986. The plan was to run the source a few shifts at a time in between high-energy physics experiments. The first couple weeks were taken up by extracting the 25-27 GeV electron beam (the two-thirds point of the linac was not yet capable of delivering 33 GeV electrons). This task was exacerbated by the large emittance of the electron beam since the electron damping ring was not yet delivering beam to the linac. Nonetheless a 3×10^9 e^-/pulse beam could be delivered almost routinely to the positron target by the latter half of September.

The instrumentation to analyze the positron beam is shown in Fig. 2. There is no room for instrumentation in the target chamber itself or in front of the capture section. A beam-induced RF signal, useful for timing the RF pulse, is available from couplers on the load end of each RF section. The capture and first booster section are so close together that only a button monitor[6] could be installed immediately following the capture section.

Not shown in Fig. 2 are the large number of stripline BPMs (beam position monitors) located in each of the quadrupoles in the instrument section and each of the quadrupoles shown downstream of the booster except Q609, Q619, Q745, and Q755, nor are any orbit correction magnets shown.

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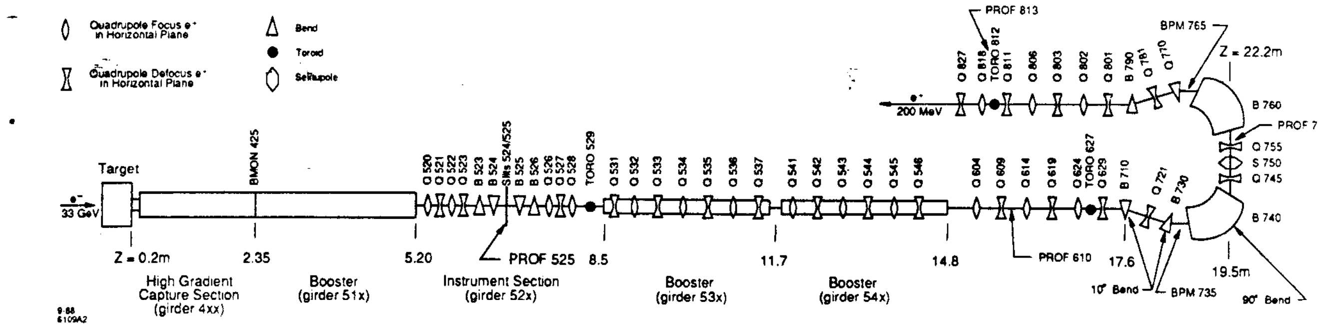

Fig. 2. Positron capture and booster transport system.

The mixed e^+ and e^- signal at the button monitor was quickly detected. The effect of the RF on the signal is illustrated in Fig. 3. Positrons are expected to give a positive pulse signal, so electrons here clearly dominate when the RF is turned off. Presumably the excess electrons are at very high energy. With the RF on, the maximum leading negative pulse is for a phase of 108° (these are relative phase values). Thus this phase is consistent with the prompt acceleration of electrons. Shifting the phase 180° resulted in a very small leading negative pulse as would be expected if prompt accelerated positrons are mixed with very high energy electrons. These results do not conclusively identify positrons.

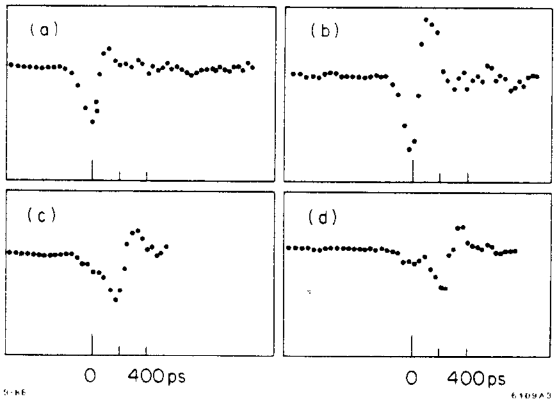

Fig. 3. Initial button monitor (BMON 425) signal: a) capture section off; b) capture RF phased (108°) for large leading negative pulse; and c) signal when RF phased about 180° away, viz., at −64° and d) at −94°.

The instrument section is equipped with a set of bends to form a chicane (B523, B524, B525, B526) and a pair of energy defining slits in order to select positrons only and a chosen energy. Since the RF sections were still being processed, the chicane slits (524/525) were set to the expected 100 MeV energy out of the booster. Positrons were then detected at BPM 721 with the signal amplified by 60 dB. These positrons turned out to be generated at the slits. Finally the RF was properly timed using a beam-induced signal from the load couplers.

Before the end of September, a low-energy, target-generated positron signal was detected at BPM 735. This initial signal is shown in Fig. 4. In this case positrons are expected to give a negative pulse signal.

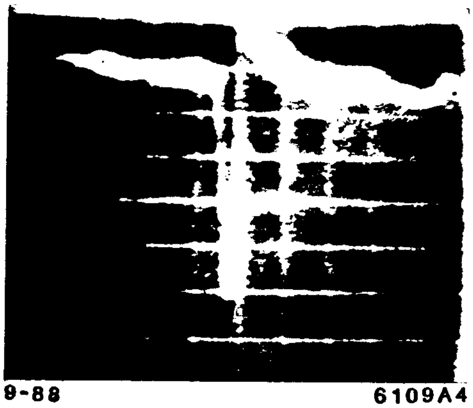

Fig. 4. Signal at BPM 735. First confirmed detection of low energy (80–100 MeV) positrons: about 2×10^7 e^+/pulse at BPM 735 with about 3×10^9 e^-/pulse (at 28 GeV) on the target. Scales are 100 mV and 5 ns/div. Raw signal is amplified by 60 dB; capture RF phase is −90°, booster RF phase is −107°.

The 524/525 slits are also used as profile monitors. The relative brightness of the e^- and e^+ spots, separated by the chicane magnetic fields, could be readily adjusted with the RF phase as shown in Fig. 5. The central spot in these figures is presumably gamma rays and/or high-energy electrons. Generally the chicane is left on and the electrons and gamma rays are blocked by running in the appropriate chicane slit past the centerline.

Having identified positrons, the rest of the target parameters—position of the e^- beam on the target, RF phase, chicane setting, orbits, etc. could be rapidly optimized. A yield of 100% at TORO 529 was achieved by October 11th with an incident e^- beam of about 3×10^9 e^-/pulse.

By mid-October the positron beam was in the return line (not shown in Fig. 2) and on its way to the damping ring. The

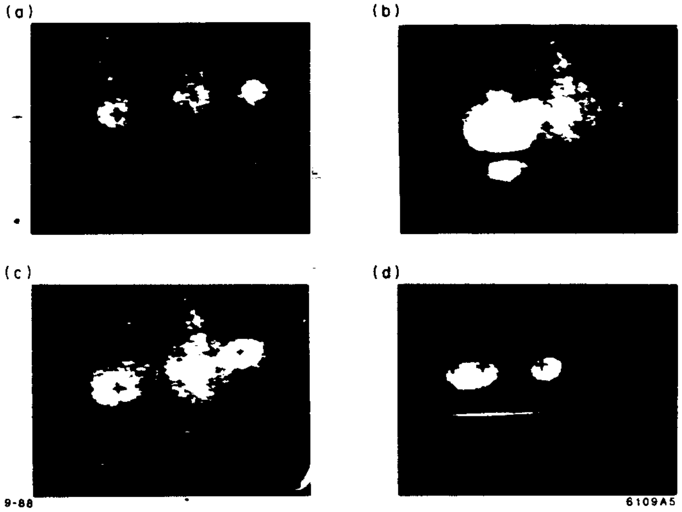

Fig. 5. Beam profile at PROF 525 for 3×10^9 e^-/pulse on target. Positrons appear on the right, electrons on the left. The chicane bends (B523 to B526) are held constant at 0.135 kG-m while the RF phase is varied. The phase for the capture/booster RF is: a) −34°/−168° for fairly equal e^+/e^- spots; b) −34°/−30° for bright e^- spot; and c) +150°/+146° for bright e^+ spot. d) Later, with 4×10^9 e^- on target and phases −63°/−27° giving 10^9 e^+/pulse at TORO 529. The scale for each profile is given by the 1-cm spacing of the graticule.

rapid improvement in beam quality is illustrated by the beam profile at PROF 610 at about this time, shown in Fig. 6. The energy profile from SPEC 756 between the two 90° magnets is shown in Fig. 7. The beam size, shape, and energy spread shown in these figures is about what is predicted by TRANSPORT.

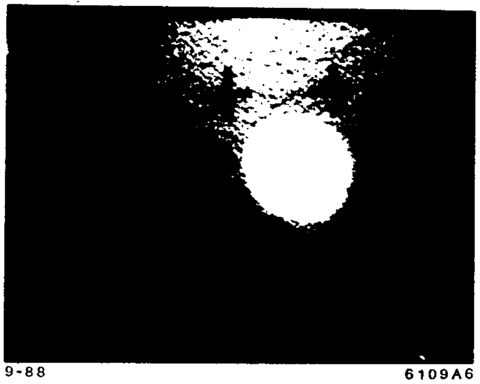

Fig. 6. Beam profile at PROF 610 with about 5×10^9 e^+/pulse at TORO 529. The graticule spacing is 1 cm.

Fig. 7. SPEC 756 signal corresponding to Fig. 6. The 90° bends are set to 152 MeV. The spectrometer has six pairs of strips, each pair separated by about 1.8%.

The source was rebuilt in the fall of 1987 with a new capture section and other improvements. So far the new capture section has been operationally limited to 18 MeV/m. The upgraded stationary target runs at 2 to 3×10^{10} e^-/pulse incident at 33 GeV on the target at up to 60 Hz. The 200-MeV positrons generated by the source are easily transported to the damping ring. The yield after the energy cut is typically 2.5, with no additional losses until reinjection into the linac. At present there remains a not well-understood loss of at least 30% in accelerating the positrons to 1.2 GeV. The phase cut once the accelerated beam is transported to the damping ring reduces the intensity another factor of 2. This latter factor will soon be mitigated by an RF compressor designed to match the energy spread of the accelerated positron beam to the acceptance of the damping ring. In addition, a new high-intensity, moving target (all bellows motion seals) will be installed in the summer of 1989 to allow up to 7×10^{10} e^-/pulse on the target at up to 120 Hz.

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