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Recent Improvements in the SLC Positron System Performance*

P.Krejcik, J.Corbett[1], S.Ecklund, P.Emma, T.Fieguth, R.Helm, A.Kulikov, T.Limberg, H.Moshammer, M.Ross, R.Siemann, W.Spence, M.Woodley,
Stanford Linear Accelerator Center, Stanford University, California 94305

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1. THE POSITRON SYSTEM

The positron system is very specific to the SLC in that the positrons are accelerated in the same linac as the electrons that produced them and the electrons with which they collide, as shown in fig. 1. Some of the difficulties in tuning this system to peak performance are thus unlikely to be encountered in future linear colliders, but many of the lessons learned in beam matching are useful for future machines. The design and commissioning of this system has been previously reported [1] so we only briefly describe the major subsystems before detailing the tuning and diagnostics involved in optimizing the performance of the overall system.

Electrons are extracted from the 50 GeV linac at about the 30 GeV point and deflected into a transport line that focuses them onto the positron production target.

The positrons are produced in a moving target [2] and captured in a high gradient accelerating section and solenoid field. The yield of positrons captured is largely determined by the maximum attainable field gradients and transverse acceptance in this space charge dominated transport. A precise simulation with space charge of this process is very difficult and up to now the empirically determined positron yields at the end of the capture section have been used to calculate the expected yields of positrons in downstream transport systems [3]. The acceleration to 200 MeV follows in a structure with more modest gradients.

The 180° turnarounds are isochronous to preserve the bunch length of the positrons [4].Their energy acceptance is controlled by collimators at a high dispersion point and this feature is used in the East Turn Around (ETA) to make the principle energy selection from the broader spectrum of positrons. The ETA is also at the start of the 2 km long periodic focusing Positron Return Line (PRL) so the quadrupoles in this area must also correctly match the beam. The West Turn Around (WTA) likewise acts to match the beam into the Sector 1 linac (S1). In S1 the positrons are co-accelerated with electrons from the injector, from 200 MeV to 1.15 GeV in a structure with strong quadrupole focusing.

At the end of S1 the positron bunches are deflected into the South Linac-To-Ring (SLTR) beam line. The SLTR sets limits on the longitudinal and transverse phase space of the beam that can be accepted from the upstream systems. In view of this, several recent upgrades have been made to enlarge the SLTR aperture and improve the ability to steer the beam through the limiting apertures. The SLTR also serves to match the beam into the damping ring and this tuning process has benefited from recent improvements in beam diagnostics, described further below.

The positrons are damped in the South Damping Ring (SDR). Two bunches are present in the ring but their damping cycles are interleaved so that at a machine rate of 120 Hz the bunches remain in the ring for 1/60 second. The 3.5 ms damping time is thus adequate to damp the bunches from nominally 300×10^{-5} to less than 3×10^{-5} m rad normalized emittance.

The South Ring-To-Linac (SRTL) beam line compresses the bunch and matches it to the high energy linac.

2. POSITRON YIELD DIAGNOSTICS

The tuning strategy adopted is to begin tuning the system upstream since failing to optimize an upstream system adversely effects the settings of downstream systems and results in endless retuning exercises. A loss in performance of just a few percent in the individual subsystems can accumulate into a substantial downgrading of the overall system. Precise diagnostics of the yield in each system have been essential in improving the overall performance.

A recent innovation in the SLC controls and software system allowed us to read back the intensity monitoring toroids throughout the entire system simultaneously on a single machine pulse. The positron yields display now shows both graphically and numerically the yield on a pulse by pulse basis of each subsystem, fig. 2. Previously, yields were often erroneously calculated by normalizing to an electron beam intensity from a different machine pulse.. The yields shown in fig. 2 are at each of the strategic locations discussed below in tuning of the subsystems.

3. DIAGNOSING AND TUNING OF SUBSYSTEMS

The diagnostics and tuning techniques used in the positron system are largely part of generic diagnostic and control system used throughout the SLC and which have been described in more detail in other publications. We concentrate here on their implementation in the positron system.

3.1 *Electron Extraction Line*

The extraction line should provide stable, focused beams to the target. An upgrade in the optics that reduced the dispersion by 40% has made the line less sensitive to energy fluctuations in the beam. A beam phase monitor has been installed to help us understand the nature of phase fluctuations of the electrons hitting the target which in turn produce energy fluctuations and hence intensity variations in the positrons.

The transverse position of the beam hitting the target is kept stable by the implementation of an SLC beam orbit feedback system [5]. The transverse size of the beam hitting the target determines the brightness of the positron beam. The core of the electron beam is intentionally kept larger than 0.6 mm to prevent damaging the target. In practice we find that if any tails are present in the beam they can change the effective beam size on a pulse by pulse basis making it very

* Work supported by Department of Energy Contract DEAC03-76SF00515.
[1]. present address SSRL, Stanford California 94305

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POSITRON SUBSYSTEMS

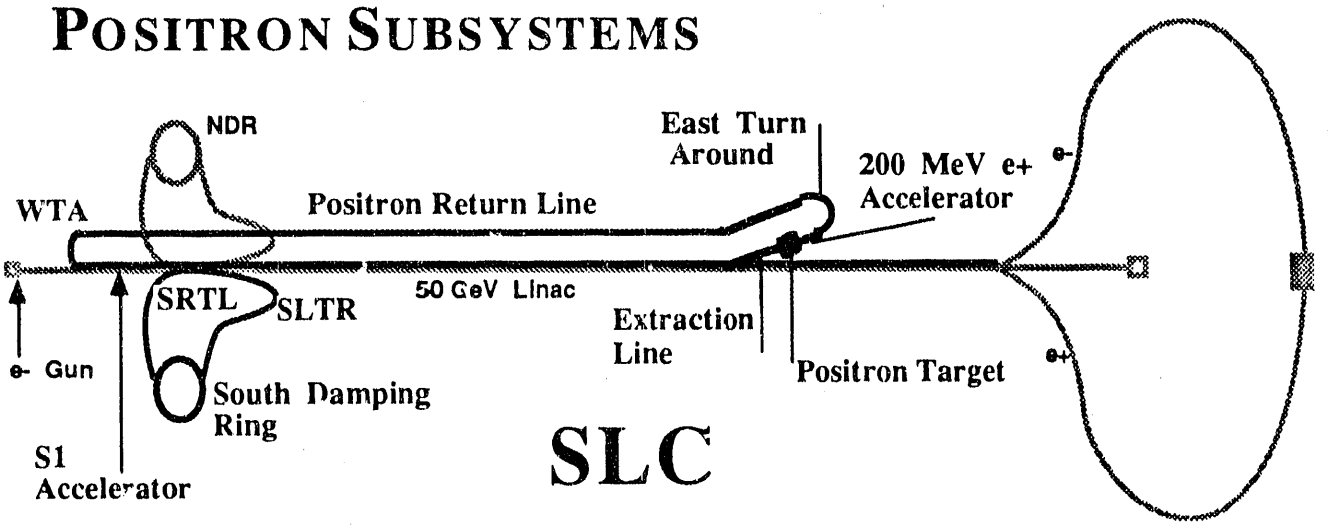

Figure 1: Schematic of the major subsystems in the SLC positron system.

difficult to tune the downstream systems. The tails result from wakefields generated when the electron orbit in the linac deviates from ideal. The orbit of the electrons is in our case influenced by the wakefields of the leading positron bunch produced in the previous machine pulse. An SLC flying wire scanner [6] monitors this behavior. A video camera on a screen immediately in front of the target provides a qualitative view of the beam condition.

3.2 Positron Capture and Acceleration Section

The section is operated at maximum gradient before breakdown in response to space charge limitations of the current. The yield of captured positrons is ~4 positrons for each electron on the target. The rf phase of the capture and accelerating section determines the energy and energy spread of the positrons and hence influences the capture efficiency of downstream systems.

3.3 East Turnaround and Positron Return Line

The dispersion generated in the turnaround allows the energy and energy spread of positrons from the acceleration section to be diagnosed with a segmented beam position monitor (BPM). The primary energy defining aperture of the ETA reduces the yield of positrons down to ~ 2.8.

The beam line of the turnaround is an adjustable path-length "trombone" that determines the phase of the positrons as they are re-injected into the S1 linac.

A transition region to the periodic focusing PRL serves to beta match the beam. This can be done by dead reckoning using the modeled optics of the section. However, earlier problems with false read-backs from quadrupole supplies misled us. For some time we looked instead at effects such as phase advance in the PRL [7], but our experience now is that correct beta matching is more critical. The success of the beta match is judged by the emittance measured on the wire scanners in the next downstream section.

The launch into the PRL is feedback controlled, as is the launch at the end of the PRL into the WTA. The losses over the length of the PRL are small so that the yield at the end is ~2.6.

3.4 West Turnaround and Linac Re-injection

The wire scanners at the end of the WTA diagnose the amount of emittance growth resulting from filamentation if the beam is mismatched into the PRL. We have observed that the beam does not filament in S1 and that we are able to correct any mismatch from the WTA by measuring with the wire scanners at the end of S1. Our on-line beta matching software [8] takes the measured beam functions and predicts the necessary change in the WTA quadrupoles to optimally match the beam. Confirmation of a successful match comes from repeating the wire scan measurement.

In addition to wire scans and BPM measurements of orbits a very useful tool proves to be the PLIC (Panofsky Long Ion Chamber Cable) system [9] for measuring beam loss along the beam line. This is used to diagnose the transmission of beam through the system as well as reduce backgrounds at the wire scanner detectors in order to make clean scans for beta matching.

The most serious beam loss in the WTA occurs where the positrons are inflected vertically through a chicane bend together with the electrons from the injector into S1. The tight placement of elements and the difficulty in finding and aligning the limiting apertures means the positron yield drops to at best 2 and often runs below this value. Typically the steering correctors for the launch into S1 are set at a compromise value between getting the maximum intensity in to the beginning of S1 and obtaining good transmission through S1. In other words, the problems in S1 force us to scrape some of the positron beam in order to launch onto an orbit that reduces the losses within S1.

3.5 Sector 1 Linac

The S1 accelerating structure does not allow for installation of an adequate number of BPMs nor steering correctors that would allow both electron and positron bunches to be independently steered. Consequently only launch correctors are used to optimize the orbit of the beam in S1 and the degradation of the orbit then becomes a function of how well the S1 quadrupoles are aligned. Reproducibility of mechanical alignment techniques has not proved adequate in this system.

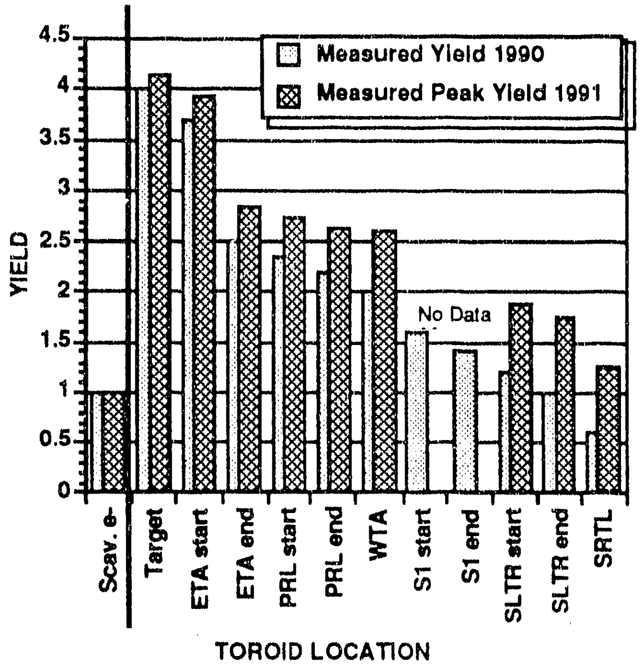

Figure 2: Positron yields measured for each subsystem normalized to the electron intensity hitting the target. The earlier 1990 data are chosen as typical rather than the best achieved.

Greater success has recently been had with a beam based alignment technique [10] in which many orbits are measured and correlated as the strength of pairs of quadrupoles in the region is varied.

The transport in S1 is further complicated when we run at the full repetition rate of 120 Hz as the electron and positron bunches are then co-accelerated. The exact orbit of the bunches, their energy and energy spread is influenced strongly by the wakefields of the leading electron bunch. The configuration of this section therefore differs greatly when the machine drops back to a rate limited mode and the bunches are not co accelerated.

The injection phase and energy are tuning parameters for the longitudinal dynamics in S1 which for the positrons are determined by settings of the phase and amplitude in the capture section and the setting of the trombone in the ETA.

3.6 Linac To Ring Transport

The energy and energy spread first become critical in the SLTR because of its finite energy aperture. A new wire scanner at a high dispersion point in the SLTR gives a quick and reliable measure of the energy spread. A video camera and profile monitor still provide real-time, qualitative information on the distribution and tails in the beam. The energy aperture of the SLTR has been measured with an electron beam while the polarity of the magnets is reversed. The energy acceptance is found to be ±2%, which is adequate for the positrons.

The transverse acceptance of the SLTR has also been probed experimentally with an electron beam. This proved to be a useful way of finding aperture restrictions in the system all the way through to the damping ring. As a result of these studies several improvements were made to widen the aperture in the SLTR in the critical regions. Enhancements to the beam steering system also made it easier to direct the orbit around obstructions in the beam line. We have found that the alignment of the vacuum chambers is equally serious as the alignment of magnetic elements. Aperture restrictions, particularly in the injection region into the ring, were often found to be due to misaligned or distorted vacuum chambers.

Following these various improvements the positron yield at the end of the SLTR was raised as high as 1.8. The beta matching within the SLTR does not critically effect the yield within the SLTR but does have a measurable effect on the ring throughput.

3.7 Positron Damping Ring

The SDR has been the major bottleneck in the positron system yield. We have been able to gradually raise the throughput to 70%. Probing the aperture with electrons, as described above, shows the ring has little tolerance for orbit and misalignment errors. Careful steering in the injection region and around the kickers and septa is necessary to achieve good transmission.

A beta mismatch at injection results in filamentation. Since the aperture is already fully illuminated, any emittance growth results in beam loss. The matching procedure we adopt is to match beam at the end of S1 using the WTA quadrupoles, as described above, and to set the SLTR optics to the design matching value. Only minor deviations from this setting are found experimentally to improve transmission, presumably to compensate for optical errors located at the septum region of injection.

4. CONCLUSIONS

As a result of systematic improvements throughout the positron system the positron yield has been raised to 1.25 at the exit of the damping rings. It is routinely kept above 1 during daily operation. This represents a factor 2 improvement over the previous year and has been a major contribution to the increase in SLC luminosity in the last running cycle. The robustness of the tuning of the system was demonstrated by the rapid return to yields>1 after the last extended down time.

5. ACKNOWLEDGMENTS

The operations staff play a key role in achieving and maintaining the positron yield. Many of the excellent diagnostics and tuning procedures used were developed by the control and software group as generic tools for the SLC.

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