EXPERIENCE WITH WIRE SCANNERS AT SLC*

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ABSTRACT

Fifty wire scanners are in use at SLC for phase space and beam optics monitoring. A large number of failures of the 50 μm wire used in the scanners have occurred. Studies of these show strong electro-magnetic fields produced by the beam to be the probable cause. The problem has been cured with the adoption of a ceramic mounting scheme. Other improvements including very high dynamic range scans and scans of non-gaussian beams are described.

INTRODUCTION

Wire scanners at SLC are used for monitoring beam size for a number of purposes. In this paper we first review some of the scanner parameters and performance to date. Problems encountered during the operation of these devices will also be described with particular attention paid to wire failure. Finally we discuss some future plans for SLC wire scanners.

USES

SLC wire scanners are used for non-invasive or semi-invasive monitoring of beam phase space (emittance, optical functions, x - y coupling and energy spread). The terms non-invasive and semi-invasive refer here to the impact that the use of these scanners has on the routine operation of the SLC. Throughout the entire SLC linac and damping ring area, scans take place with barely detectable impact. Downstream of the collimation region at the end of the linac, care must be taken to avoid spraying the large amounts of radiation generated by the scan into the SLD detector at the SLC interaction point. In these cases the beam abort single beam dumper is used or the scans are performed on the outgoing beam downstream of the interaction region. In the latter case, the incoming beam must be stopped using its abort system for the duration of the scan. The semi-invasive scans stop collisions for about 2 seconds every 15 minutes and thus cause a 0.2% reduction in luminosity. Groups of scanners are used to acquire emittance data. Their results are used to control emittance reduction trajectory distortions in the SLC linac. The proper functioning of these devices has been a key factor in performance improvements seen at SLC.

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Table 1. SLC wire scanner functions, locations, and environment. Most scanners monitor either the emittance and related optical parameters or the energy spread of the beam. Scanners in the final focus region of the SLC have more specialized functions such as monitoring interaction point (IP) angular divergence and x -y coupling. Other final focus scanners are used for aberration suppression system performance monitoring.

Location	Num.	Wire diam. (μm)	Wire scan planes	Typical beam size (mm sigma)	Drive screw pitch (mm)	Purpose	Radiation near scanner (R/hr)
Injector							
100 KeV	1	200	x,y	2	2	Beam size	small
50 MeV	4	200	x,y	2	2	Emittance	300
1 GeV	4	2x75	x,y	1 (3e+)	2	Emittance	300
1 GeV	1	500	x,y	3	2	Energy spread	300
e+ injector 1 GeV	1	500	x,y	5	2	Energy spread	300
Ring extraction							
e-	1	40	x,y,u	0.3	2	Quad scan emit	10
e+	1	40	x,y,u	0.3	2	Quad scan emit	10
Linac entrance	7	40	x,y,u	0.3	1.27	Emittance	50
7 GeV	1	40	x,y,u	0.3	2	Quad scan emit	10
17 GeV	4	40	x,y,u	0.2	2	Emittance	10
46 GeV	4	40	x,y,u	0.1	1.27	Emittance	10
30 GeV target transfer line	1	120	x,y,u	0.3	2	Energy spread	500
e+ injector							
250 MeV	4	1000	x,y	3	2	Emittance	100
Linac end	2	75	x,y,u	0.2	1.27	Energy spread	1000
	1	50	x,y	0.1	0.635	Prototype	300
Final focus	2	75	x,y,u	0.3	1.27	Quad scan emit	100
	2	75	x,y,u	0.5	1.27	IP Divergence and skew	50
	4	10	x,y,u	0.05	2	FF Optics	100
	4	50	x,u,v	0.5	2	dispersion corr	100
Total	49						

PERFORMANCE

Table 1 lists some of the beam conditions at the scanner locations. The most significant one, from the view of the designer, is the ambient radiation. In these locations, the scattered particle detector must be adequately shielded.

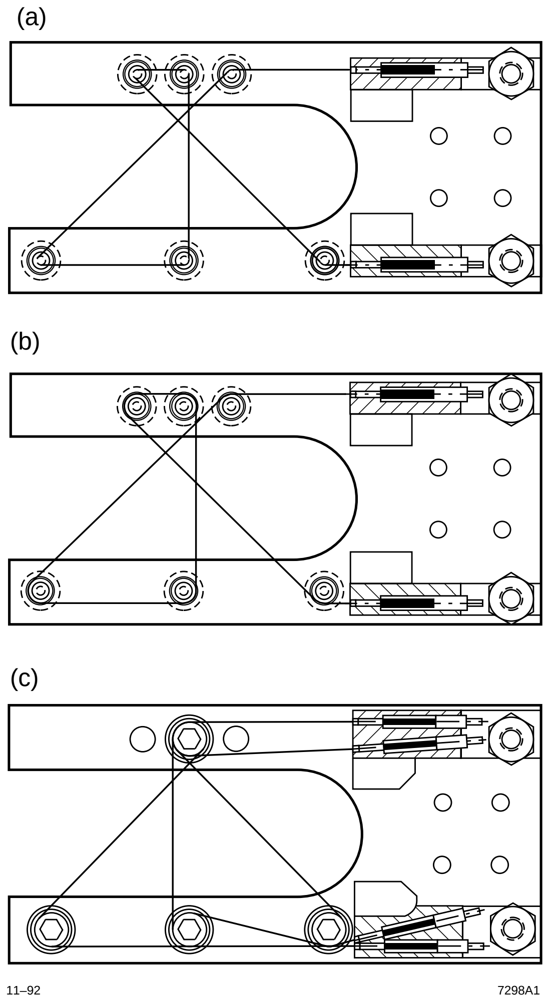

Figure 1. Evolution of wire mounting schemes. The drawing shows the alumina wire support card that is moved across the beam in the scanner vacuum chamber. The wire positioning support studs, mounted in the card, were changed twice. The earliest design, shown in a) shows the 2 mm diameter stainless steel studs. In b) the stud diameter was increased to 8 mm in order to reduce the stress generated in the wire from the tight bend. The final mounting scheme, c) shows the 8 mm ceramic studs and the independent wires.

WIRE FAILURES - BRIEF CHRONOLOGY

During the last two years, about 90% of the 40 μm diameter wires have broken during routine use. While we have been unable to break wires in the laboratory with the same mechanism, we have some idea of the causes of these failures. Chronologically, the failures occurred in two groups, around the SLC startup of 1991 and around the startup of 1992. During the bulk of the running period there were few failures. In the interval between these two runs some modifications were made to the wire mounting system. Figure 1 shows the evolution of the wire mounting schemes. Some important design considerations are as follows: 1) all materials used in the mounting scheme must adhere to strict ultra-high 10^{-9} Torr vacuum rules, 2) the wire must be under constant tension in order to keep it taut during scans when there may be significant heating, 3) the wire must be easily replaceable, 4) the coordinate system defined by the wires must be rolled by no more than 3 mrad with respect to the alignment grid, 5) the wires must be electrically isolated and connected to an external test point for secondary emission operation and general testing, and 6) the wire mechanical resonances must be above 500 Hz.

TESTS

Figure 2 shows an electron microscope picture of the broken end of a wire after failure. Failures always occur at a tangent to one of the support studs one the wire card. It is important to note that the wire appears to have undergone local melting. Figure 3 shows the stainless steel support stud at the contact point. Tests were performed in the laboratory to try and recreate this kind of fracture under more controlled conditions. All purely mechanical failures, such as those that come from prolonged vibration or working, give rise to clean fractures with no sign of local melting. On the other hand, all breaks that come from steady heating show evidence of heating over longer sections of wire. Vacuum arcing from a very high voltage was the only type of break that looked like the ones from the accelerator. Figure 5 shows the wire fractures studied in these tests.

Contact author for these figures.

Figure 2. Electron microscope picture of a 40 μm tungsten wire break. This wire was installed in an SLC linac wire scanner.

Figure 3. Electron microscope picture of the stainless steel support stud at the point where the wire broke. A short piece of tungsten is clearly visible.

Figure 4. Small pit marks seen near the end of the wire are further evidence for arcing.

Figure 5. Wire ends produced in high voltage arc tests. They are somewhat similar to those produced in the beam.

The chronology of these failures and the machine operating mode during that time has lead to the conclusion that they had more than one cause. In 1991 we determined that the failure was due to beam loss in the vicinity of the scanners. The large electromagnetic showers caused during beam loss charged up the uncoated ceramic of the wire support card. At some point a small arc will occur in order for the charge to more uniformly distribute itself. The arc will break the wire if it occurs nearby. In 1991, the beam losses were brought under control and the wire support cards were coated with titanium nitride to provide a several 100 KΩ path to ground. No further failures were seen during the remainder of the run. These initial failures had occurred in some cases without any scans having taken place.

The most significant modification that took place in the interval between the two runs was the replacement of the support studs with studs of much larger diameter. The reason for this was to decrease the yielding of the wire around the stud. After a short period of use, most of the wires that had been remounted in this fashion failed. Beam tests showed that the failure was proportional to the amount of time that the wire was actually in the beam and that there was a threshold maximum beam current and minimum beam size that, if not exceeded, would not lead to any failures. The threshold was 3 x 10^{10} particles at a beam size $\sigma = 100\ \mu$m. The failures appear to have been caused by arcing between the wire and the stud. Since the stud is mounted in a coated ceramic card and both are grounded a few centimeters away there can be no static potential between them. Arcing due to microwave fields induced by either the beam or the nearby S-band sources was ruled out by simple tests. The tests showed that the wire would survive indefinitely when placed a fraction of a millimeter from the beam but would break within a minute if parked in a beam with intensity and size beyond the threshold.

Failures occurred at both ends of the wire at about the same time. When the wires and their support cards were removed for examination with the electron microscope, the wires looked similar to the previous set of failures and the support stud showed strong signs of arcing (Figures 2-4). This was fixed by installing ceramic support studs. At this time no further failures have occured.

NEW DEVELOPMENTS

The SLC wire scanners are also used to monitor the extremes of the charge distribution. This is done by measuring scattered radiation from the wire using a very high signal to noise detector. Figure 6 shows a scan obtained in this manner. Typical scanners use radiation scattered at 90° to the beam path. This is usually done when it is not possible to monitor forward angle radiation because of constraints in the beamline geometry. In some cases, however, the particle beam is bent away from the forward direction and bremstrahlung photons can be used.

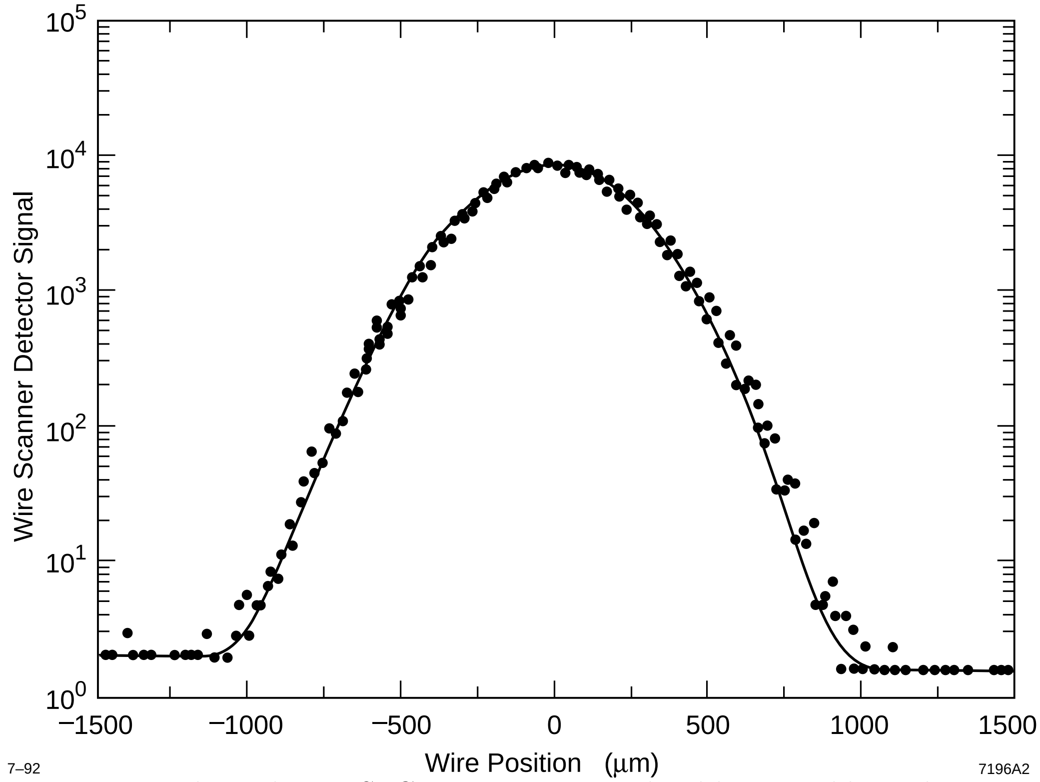

Figure 6. High-resolution SLC wire scan using hard-bremstrahlung detector. This device has an 80 dB signal to noise and can effectively measure the beam distribution to 5σ.

USE OF SCANNERS TO MONITOR NON-GAUSSIAN BEAMS

An example of a non-gaussian beam shape which must be determined in detail is the energy profile of a single collider bunch emerging from the linac. Because of the strong dependence of the energy-spread distribution, especially the extremes of the distribution, on the bunch shape, it is important to measure the shape carefully. Figure 7 shows SLC linac energy-spread wire scan data.

FUTURE PLANS

Future developments will be directed along two paths: 1) improving the reach of high resolution scans and 2) providing scans of smaller beams. Beams in the SLC have improved to the point where in some cases, they are smaller than can be reliably measured using the existing scanners. Upgrades must be implemented to provide smoother motion and thinner wire. In the final focus, careful placement of new scanners will allow more accurate monitoring of the optical aberration correction systems.

High resolution scans of the high energy beam at the end of the linac and in the final focus system can provide information about the effectiveness of the background collimation system employed to protect the users detector. The most accurate estimate of this now comes from the detector itself. While this is a crucial signal that must be used for the control of the backgrounds, it gives little

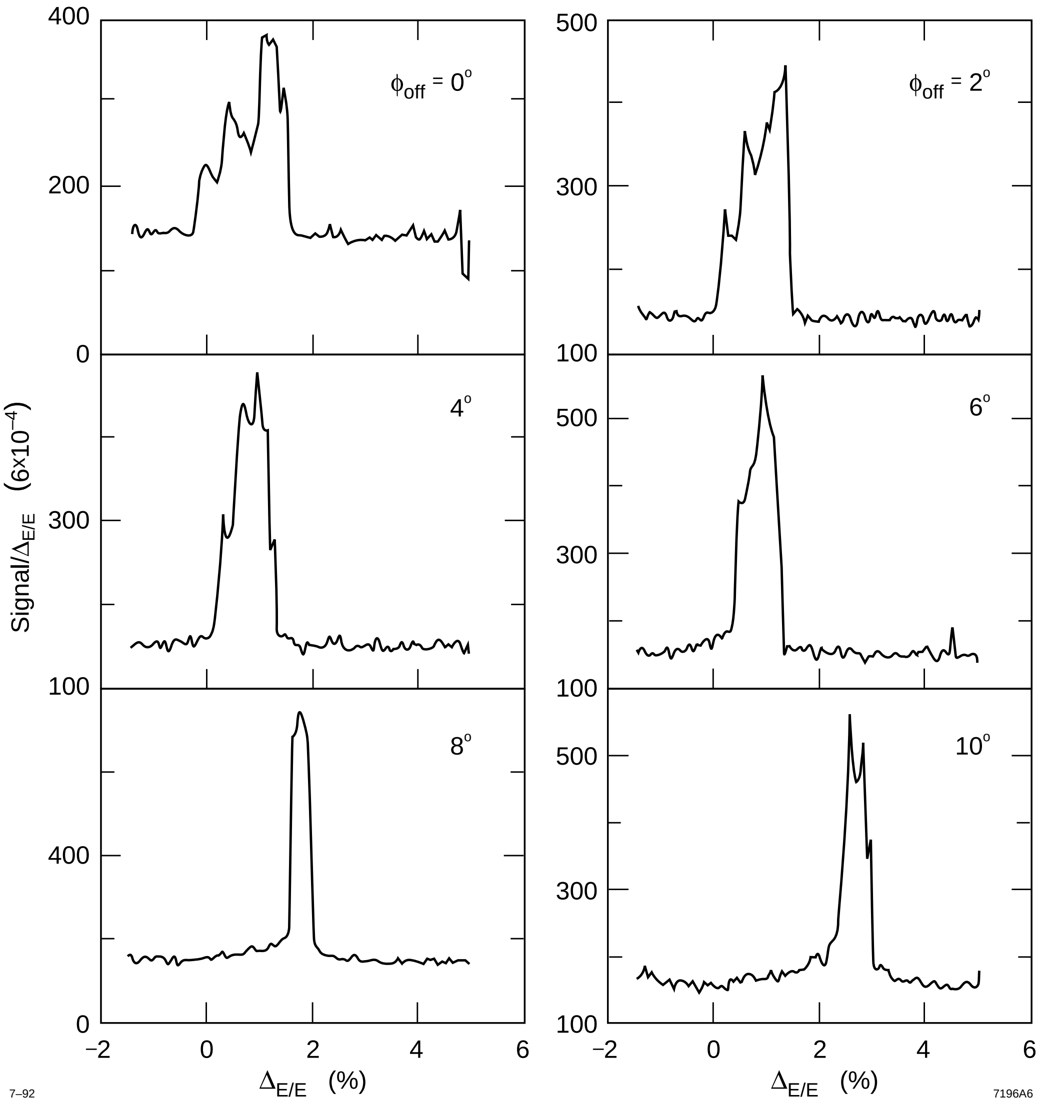

Figure 7. SLC linac energy-spread distributions. These data were produced from wire scans taken as the overall phase of the linac was varied. The data agree with simulations that assume a gaussian, longitudinal bunch distribution, and use a computed higher-order waveguide mode distribution.

information about the structure of the beam and source of the background. In order to improve the resolution of these scanners, a scanner detector must be developed that can be inserted near the forward beam direction.

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