Wire Breakage in SLC Wire Profile Monitors[*]

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Abstract. Wire-scanning beam profile monitors are used at the Stanford Linear Collider (SLC) for emittance preservation control and beam optics optimization. Twenty such scanners have proven most useful for this purpose and have performed a total of 1.5 million scans in the 4 to 6 years since their installation. Most of the essential scanners are equipped with 20 to 40 μm tungsten wires. SLC bunch intensities and sizes often exceed 2×10^7 particles/μm^2 ($3C/m^2$). We believe that this has caused a number of tungsten wire failures that appear at the ends of the wire, near the wire support points, after a few hundred scans are accumulated. Carbon fibers, also widely used at SLAC (1), have been substituted in several scanners and have performed well. In this paper, we present theories for the wire failure mechanism and techniques learned in reducing the failures.

SCANNER OPERATION

Wire-scanning beam profile monitors (or wire scanners) are used throughout the SLC for beam size monitoring and optimization (2). A typical scan takes about 1 second, with the wire actually within the beam envelope for about 20% of the pulses that occur during that time. Two million scans have been done during the roughly 40 months of SLC operating time elapsed since most of the scanners were installed, averaging about 1 scan/minute. Approximately 0.3% of all SLC pulses have intercepted a wire, illustrating the utility of such phase space monitors in the linear collider.

The SLC is a prototype linear collider and our ability to control emittance propagation has developed as both the beam size monitors and the tools to effectively use them have developed. Four groups of wire scanners have proven most useful: 1) at the exit of the damping ring, 2) following the bunch length compressor at the entrance of the linac (RTL – S2), 3) near the end of the linac (S28), and 4) at the entrance to the final focus (FF), following the SLC arcs about 100 m from the IP. The 10 FF wires, installed as part of an FF upgrade (3) in 1994, are different from the others since they

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are located in a complex beamline close to the high-energy physics' detector, the SLD. Since the other scanners are located upstream of the collimation sections, the optimum wire size is determined by the expected beam size and limits on the scattered beam power. The FF scanner wire sizes are further constrained so that the scattered radiation produced during the scan does not harm sensitive SLD detector components, resulting in thinner, weaker wires. Several attempts were made to determine the optimum wire size and material that would allow both operation of the SLD and provide a signal strong enough for accurate emittance estimates.

TABLE 1. Parameters and locations for the critical SLC emittance scanners. The scanners are listed in roughly the order that the beam passes them during routine operation. Typical SLC beam intensities for 1994–1998 operation are 3.5×10^{10} particles/bunch with a bunch length of 1± 0.5 mm resulting in peak currents of 2 kAmp. The wire material is tungsten, except as noted. The units shown in *italics* are critical for emittance preservation control.

Location	**Number**	**Wire diameter (μm)**	**Wires**	**expected beam size**	**Number of scans/ device**	**Purpose**
RTL - ε	*2*	*40*	*x, y, u*	*200×50 μm*	*80000*	*Beam size*
Linac begin	*4*	*40(20y)*	*x, y, u*	*300×30 μm*	*140000*	*Emittance*
Linac end	*4*	*40(20y)*	*x, y, u*	*200×40 μm*	*150000*	*Emittance*
FF (e^+/e^-)	*10*	*15–40 & 34 C*	*x, y*	*10 – 200 μm*	*15000*	*Emittance*
Other	36	50–500		3mm – 3mm	430000 (total)	Emittance, energy spread and optical parameters
Total	56			Total no. scans	1930000	(age varies 3 to 7 yr.)

TUNGSTEN WIRES

Wire failures in the SLC scanners were reported in 1992 (2). The failure frequency was greatly reduced at that time with the introduction of a purely ceramic support mechanism. Since 1992, SLC peak beam intensities have increased 30% and beam sizes have dropped 10%. Wire failures, somewhat similar to those originally observed, have again become a concern. The rate is about 2% of that seen with the initial support mechanism but can be as low as 10% in the FF locations with smaller beam sizes and thinner wires. Figure 1 shows the number of scans before failure as a function of the beam charge density.

The thin tungsten wires always fail at the point of tangency to the cylindrical support stud. Figure 2 shows the mounting scheme. We have concluded that the failure must arise from a large number of high voltage discharges between the wire and the titanium-nitride (Ti-N) coated alumina support stud. The wires have always been eroded at both ends. Close examination of the wires prior to failure show weakening begins after the first few scans. Figure 3 shows a typical end of a failed wire. Each discharge displaces a small piece of tungsten. A small stripe is clearly visible on the stud under the wire tangent point. Since the capacitance of the wire must be quite small, we think that the high-voltage pulse must be quite high.

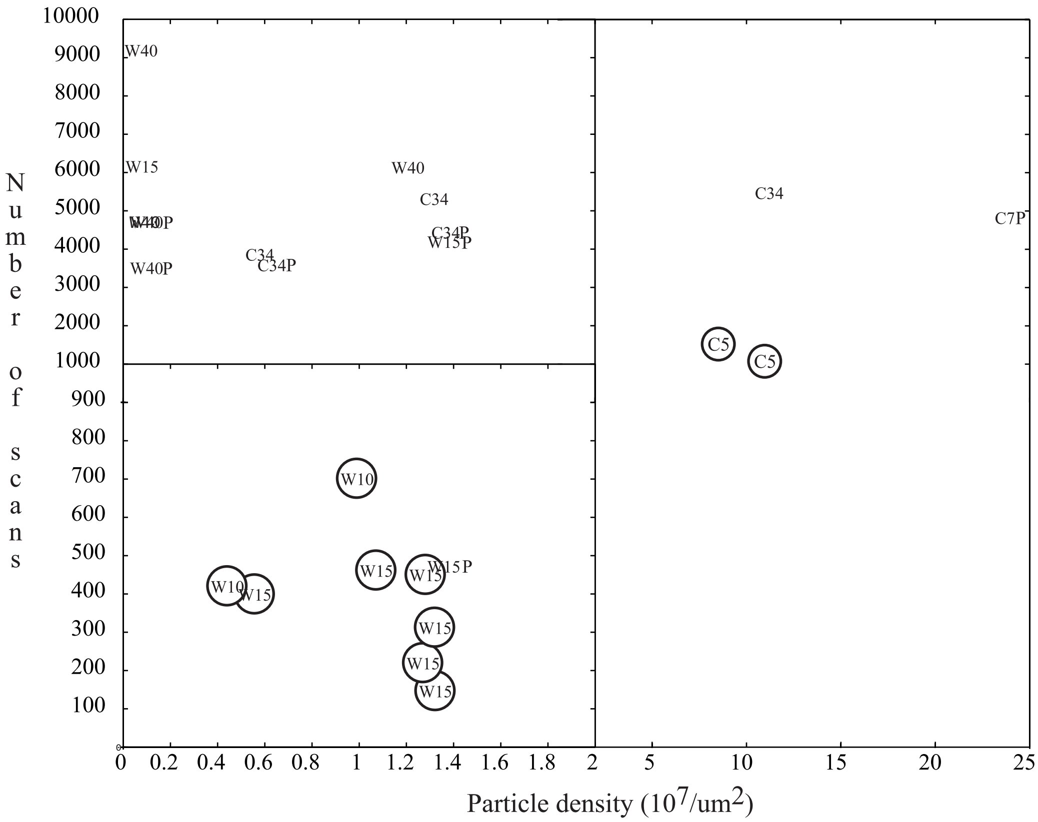

FIGURE 1. Number of scans performed with FF scanners vs. beam density. The symbol indicates the wire type and size in µm. Circles indicate failed wires. The plot shows roughly three regions: 1) failure prone wire sizes with low (1×10^7) particle density, 2) wires that survive indefinitely at lower charge density and 3) carbon wires that survive the highest charge density. The 'P' indicates scanners used only for positrons. These wires evidently fail much less often.

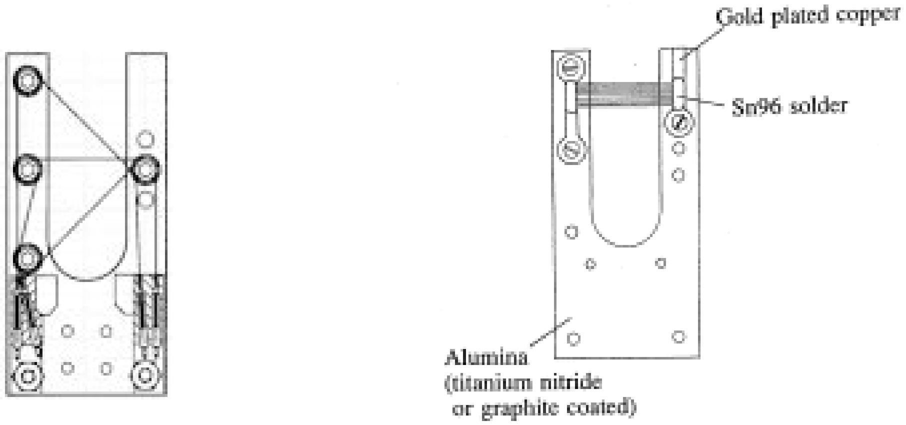

FIGURE 2. Wire mounting scheme for tungsten and carbon wires. The tungsten wire mounting scheme used on most scanners is shown at the left. In this figure, the beam passes into the page, roughly centered between the tines of the alumina fork. The wires are accurately positioned by the four ceramic alignment pins and tensioned by springs shown at the bottom of the figure. Ti-N coating provides a drain path for charges that may collect on the fork and alignment pins. The right side of the figure shows the carbon wire support scheme used when the tungsten wires were replaced. No tensioning springs or alignment pins are used. The separation between the fork tines is 1 inch.

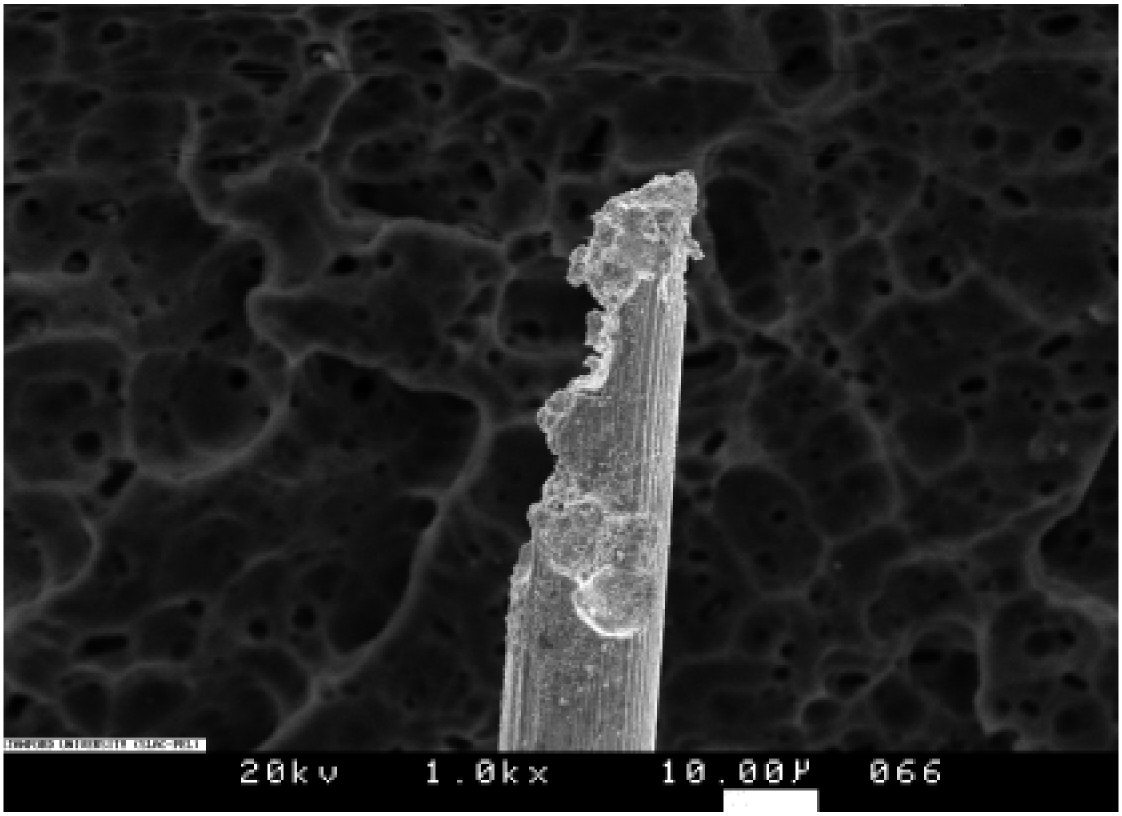

FIGURE 3. Failed 15 µm diameter tungsten wire showing the rough surface resulting from many discharges.

A reasonable estimate for charge depletion in a 10 µm tungsten wire, caused by secondary emission, is 7.5×10^{8} charges (2% of the beam population). Assuming this occurs in a 10 µm length of the wire, its capacitance of about 10^{-15} farads means this has a potential energy of 10^{-6} Joules.

This depletion is made up by recharging through the wire. Since we are looking for a mechanism that causes damage at the ceramic roller pins which position the wires, it seems necessary that a fast recharge via the tensioning springs is inhibited. If the springs were not shorted, this would occur naturally because of their large inductance. Somehow we have to hypothesize that the back of the center pin does not make good enough contact with the tension block, or that some mutual inductance is enough to do the job.

For damage of the type observed to occur, it seems necessary also to assume that the wire does not make good contact with the alignment pin, at least in vacuum. Good contact in this case means electrical resistance less than that of the tungsten wire, a few ohms for a 10 µm example. In this case the surface of the alignment pin forms a relatively large capacitance which will drain the charge on the wire through the contact resistance.

The heat that is available from the flow of charge, through a constriction of a few tens of ohms, is enough to raise the temperature of a 10 µm length of the wire by 3000°C, or to melt perhaps a 7 µm length. Evaporation requires much more energy. There would be enough energy to remove about 1.5 µm length. However, it would indeed be hard to generate and transfer the heat efficiently, so the sites of melting/ evaporation, if any, would be expected to be much smaller.

The Ti-N coating provides a drain path to ground of about 100 kΩ which should prevent the accumulation of high charge between pulses.

As seen in Figure 1, the 10–15 µm tungsten wire is most prone to failure. In most instances, we have replaced it with 34 µm carbon wire. At this time, we have not observed any failures of the carbon wire. Some signal loss and resolution loss results from the lower *Z*, higher diameter wire.

CARBON FIBERS

Carbon fibers have been used at SLC since its inception. They are able to handle greater intensity than tungsten wire by roughly an order of magnitude. They are themselves limited, however, at bunch densities of about 3×10^9 for $\sigma_x\times\sigma_y = 1\ \mu\text{m}^2$. Their disadvantage lies in the weaker wire-scan signal, 1.8% of that of tungsten. Diameters of 34 µm, 7 µm and 4 µm have been used. Obviously the smallest diameter is used for the smallest beam spots, and encounters the most hostile conditions.

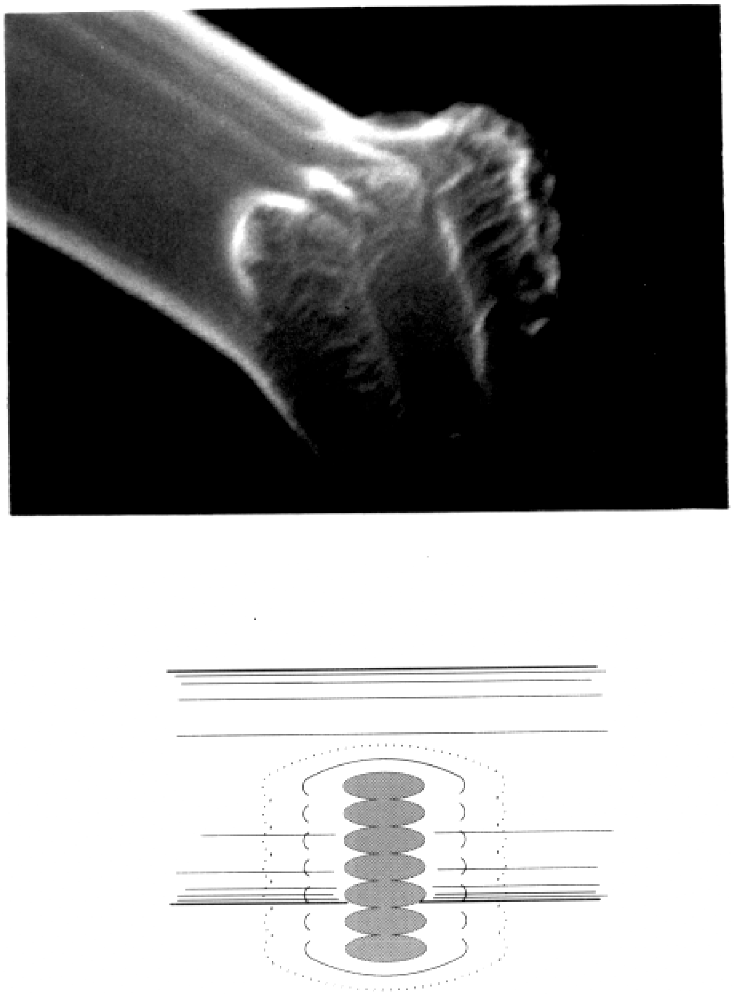

FIGURE 4. Failed 4 µm carbon wire with inset showing the progression of successive beam pulses scanning across the wire. This wire was broken at the point of intersection with a beam of 3×10^9 particles/µm^2.

Figure 4 shows a failed 4 μm carbon wire. All failures that can be associated with the beam have been directly at the beam impact point, and occurred after no more than a few pulses. From the remains that have been recovered, severe distortion of the carbon is observed. This is evidence for strong forces caused, perhaps, by shock thermal expansion somehow interacting with a softening of the material at temperature >2500 C.

The forks that hold the carbon fibers have, in most cases been made of MACOR ceramic. In a few cases aluminum was used. The fibers were positioned by laying them over a ledge or in a groove in the fork material and then holding them in tension by encapsulating the ends in SN96 flux-free solder. This, in turn, was connected to electrical ground. The thinnest fibers form a resistance of 10^4 ohm to ground for the (positive) secondary emission depletion charge at the beam collision point. No failures associated with beam scanning have been documented at the solder joint, or at the position where the fiber runs over the fork material. Tungsten wires mounted with this technique were observed to fail in a fashion similar to the pin-mounted wires.

CONCLUSION

Wire scanners have proven the most effective beam size monitor for linear collider operation. Recent SLC parameters and optimization challenges have forced us to develop scanners with thin wires or with low *Z* wires. This, in turn, has caused wire failure problems. While the hypotheses listed above may not prove to be the primary cause of the failures, they have helped us to develop useful solutions.

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REFERENCES

[1] Field, Clive, “The Wire Scanner System of the Final Focus Test Beam,” *Nucl. Instrum. Meth. A,* **360**, pp. 467–475, (1995).
[2] Ross, M. C., E. Bong, L. Hendrickson, D. McCormick, M. Zolotorev, “Experience With Wire Scanners at SLC 1992,” presented at the Accelerator Instrumentation Fourth Annual Workshop, Berkeley, CA, October, 1992 (in proceedings pp. 264–270).
[3] Zimmermann, F., T. Barklow, S. Ecklund, P. Emma, D. McCormick, N. Phinney, P. Raimondi, M. Ross, T. Slaton, F. Tian, J. Turner, M. Woodley (SLAC), M. Placidi, N. Toge, N. Walker, “Performance of the 1994/1995 SLC Final Focus System,” *Proceedings of the IEEE Particle Accelerator Conference,* 1995, pp. 656–658.