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Measuring Micron Size Beams in the SLC Final Focus*

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Abstract

A pair of high resolution wire scanners have been built and installed in the SLC final focus. The final focus optics uses a set of de-magnifying telescopes, and an ideal location for a beam size monitor is at one of the magnified image points of the interaction point. The image point chosen for these scanners is in the middle of a large bend magnet. The design beam spots here are about 2 microns in the vertical and 20 microns in the horizontal plane. The scanners presented a number of design challenges. In this paper we discuss the mechanical design of the scanner, and fabrication techniques of its ceramic wire support card which holds many 4 and 7 um carbon wires. Accurate motion of the wire during a scan is critical. In this paper we describe tests of stepper motors, gear combinations, and radiation hardened encoders needed to produce the required motion with a step resolution of 80 nanometers. Also presented here are the results of scattered radiation detector placement studies carried out to optimize the signal from the 4 micron wires. Finally, we present measurements from the scanner.

INTRODUCTION

Wire scanner beam size monitors are used throughout the Stanford Linear Collider (SLC) to make beam profile and emittance measurements.[1,2]. After the conclusion of the 1993 SLC run, the final focus optics were upgraded to provide improved chromatic correction. As part of this upgrade, five new scanners were added to both the north and south final focus.

One of these scanners is located at an image of the interaction point (IP), and it provides a direct estimate of the vertical beam size at the IP. Because of its location, this scanner plays a particularly important role in measuring the properties of the incoming beam and the performance of the final focus optics. At this wire scanner, the design βx and βy are small, and the horizontal dispersion is a few centimeters. The aspect ratio of the beam at this scanner is ten to one. The primary goal of this scanner is to measure the vertical beam size and the x-y coupling to within 5% at the full SLC repetition rate and current.

MECHANICAL DESIGN

The location of the IP image is at the center of a large bend magnet. Two types of scanner installations were considered. One design required cutting the steel of the magnet in half, moving the sections apart and building separate coils for each of the resulting halves. A standard SLC wire scanner design, [1] which moves at 45° with respect to the horizontal, would have been used. Another option required boring a vertical hole through the middle of the magnet. A wire scanner with a

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vertical motion was needed for this design. The impact of the magnet modifications, the perfonnance required of the wire scanner, and the costs of each design were considered. Given that a scanner with vertical motion can make all the required measurements, and that calculations of the effects from the hole in the magnet indicated only minor field distortion, the scanner with the vertical motion was chosen. Measuring the vertical beam size is done using a horizontal wire. The x-y coupling and the x beam size measurements are obtained by using two sets of wires; one at ±5 degrees and another at ±15 degrees with respect to the horizontal wire. The angles of theses wires with respect to the beam must be known to ±3.0 milli radians in order to maintain the required measurement accuracy. The scanner is built so that the angle of the wires with respect to the beam could be measured and adjusted after the scanner installation. The wires are accurately fixed to a ceramic fork which was indexed to surveyor tooling balls on the top of the scanner. Adjusting the angle of the wires is accomplished by having the slide and shaft assemhly mounted on a circular saddle. The scanner can be rolled until the wires are at the correct angle with respect to the beam.

WIRE CARD FABRICATION

The wire scanner card is fabricated from a 4.50 x 2.75 x 0.27 inch thick 99.5% alumina substrate (a herman). Machining the herman is done using a CO_2 laser. Parts of the herman are cut away to reveal the outline of the wire card, a two tine fork. The wire card is left attached to the herman at several locations. This provides a means of handling the card without risk of contamination and aids in the installation of the carbon wires. Tooling holes in the card are ground to exact tolerances using a diamond jig grinding machine. These holes are used to mate the wire card precisely to the shaft of the wire scanner. After the wires are attached, the card is scored along the attachment points and broken out of the herman.

V-shaped grooves shown in Fig. 1 were machined into the surface of the card to precisely locate the carbon wires. The grooves are approximately 14 microns wide and 20 microns deep. The machining was performed using a excimer laser with a high precision X-Y table. Since the location of the grooves are referenced to the card's tooling holes, the position of each wire on the wire scanner is known.

Figure 1. A seven micron carbon wire is positioned in a V groove cut in an alumina substrate.

Attaching the wires to the fork proved to be difficult. The initial approach was to place a mask over the card leaving only the tines exposed. Titanium and then palladium was sputtered over the wire filled grooves. It was believed that this would seal the wires in place with a "blanket" of metalization. Two problems prevented this technique from working. The metalization did not adhere to the tines in the areas where the excimer laser machining was performed. This was found to be caused by a fine non-adhering alumina particulate[3] left behind after the excimer laser machining. This problem was solved by refiring the card at 1400 °C before the wires were placed in the grooves. The particulates were sintered to the card, providing a solid substrate for the metalization process. The metallization adhered to the wires and the tines, but cracks developed between them, and the wires still pulled easily out of the grooves. To solve this, the wires were soldered into the grooves using a 48.5% Sn / 51.5% In solder preform. The solder was reflowed in a nitrogen belt furnace using no flux. A finished wire card is shown in Fig. 2.

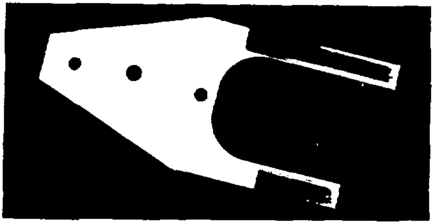

Figure 2. A finished wire card is shown above. The ±15, ±5, and 0 degree wires, and the diamond ground holes which precisely position the card on the shaft the wire scanner are shown.

WIRE SCANNER MOTION

Standard SLC wire scanners use a stepper motor with 200 full steps per revolution. The motor drives a ball screw with a lead of 2mm per revolution, producing a linear motion of 10 microns per full step. The 2 micron vertical spots at the scanner require a much finer step resolution. Microstepping divides full steps of a stepping motor into 125 smaller microsteps. For this scanner, microstepping improved the step resolution to 80 nanometers. A test facility was constructed to measure the uniformity of the motion. A linear optical encoder with a resolution of 50 nanometers was used to measure slide motion.[4]. A least squares linear fit to the encoder data was performed and the residual from the fit to the data is shown in Fig.3. Depending on which part of a normal step a two micron beam sampled, the measurement error could be as large as 30%. These errors were too large to meet the measurement goals for these scanners.

Three attempts were made to reduce this error. The microstepping module used for the tests has a feature that resets the motor to the nearest full step. This forces the scan to begin from the start of a full step. It was hoped that the error would be similar enough from one scan to the next to allow a correction. Unfortunately, the motion varied at different motor speeds and different slide positions and the corrected data had an error equal or larger to the original. Another attempt at

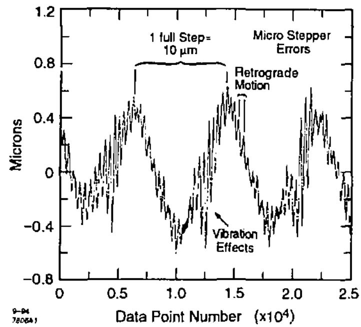

Figure 3. This plot shows the residual of the difference between the position of the scanner recorded by the optical encoder and a linear fit to the data. The stepper motor was using microstepping. The residual clearly shows the microstepper error over a single full step.

reducing the measurement error consisted of using reduction gears instead of microstepping to achieve the required step resolution. Two different types of gear systems were tried. One was a nested set of gears that produced an 80:1 reduction and the other was a rotary index table with a reduction of 180:1. The residuals from both these systems were unacceptable.

These results indicated that it would be unsatisfactory to build a system that relied on the motor step count to determine the position since the motion is uneven. Therefore we decided to measure the actual position of the scanner during the scan. A magnetic linear encoder and interpolating unit was tested [5]. The magnetic encoder was appealing because of its resolution (100nm) and radiation hardness. It has no electronics in the sampling head. It was compared to the optical linear encoder. The residual from the magnetic encoder was about ± 5microns. In spite of the 100nm resolution, the accuracy of the magnetic encoder was insufficient and we decided to install the optical linear encoder on the wire scanner. Radiation dosimetry was installed on the gauge. At present the north final focus encoder has an integrated dose of over 100 kilorads with no observable decrease in performance. It is expected that the semiconductor components in the optical encoder will fail and the unit will have to be replaced after about a year of operation.

At certain motor speeds there is a considerable amount of vibration imparted to the scanner structure. Some tests were done with a laser doppler vibrometer [6] to study the actual motion of the wire during a wire scan. Data from the vibrometer was compared with the data from the optical encoder. The two sets of data showed similar structure but weren't exactly the same. This result prompted an investigation to quantify the amplitude of the vibration and develop techniques to reduce it. In these tests, the scanner was moved at constant speed while the optical encoder sampled the position of the slide. The RMS of the residual to the linear fit was tabulated over all the motor speeds. Various damping mechanisms were fitted to the motor and the scanner and another set of data was taken. Figure 4 shows a plot of the dramatic reduction in the vibration of a damped and undamped wire scanner.

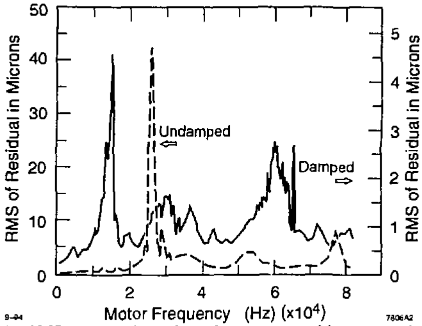

Figure 4. The RMS of the residual from the scanner position data and a linear fit to the data is plotted against the frequency of the stepper motor microsteps. The vertical axis on the left reflects the vibration of the scanner before a damper is added. The axis on the right reflects the reduction of vibration after a rotary damper [7] is attached to the shaft of the motor.

DETECTORS AND SIGNALS

Outside of the IP, these are the first SLC wire scanners to use carbon wires instead of tungsten. In general scanners using tungsten wires have an excellent signal to noise ratio. It was expected that the signal from carbon wires would be about two orders of magnitude less than the signal from the tungsten wires. It was clear that detectors with a gain of at least a factor of 100 would be required. Proportional tube detectors were chosen for their low cost, compact size and rugged construction. The proportional tubes are constructed from a tube 15 cm long with an inside diameter of 1.5 cm and a 40μm sense wire. A mixture of 89% Ar, 10% CO_2 and 1% methane is passed through the tubes at a rate of 0.05 ft^3/hour.

The detectors are placed to intercept bremsstrahlung or lower energy particles scattered from the wire. Since the scanner is in a bend magnet, an excellent location is downstream where the bremsstrahlung from the wire exits the beam pipe. Other detectors were placed on the opposite side of the vacuum chamber from these tubes to detect degraded electrons scattered off the wire. Placing these detectors in the ideal locations has been difficult because of the many beam line components already installed. Background levels in these detectors can be problematic. Proportional tubes used to detect bremsstrahlung from the wires are also sensitive to synchrotron radiation produced by the bend magnet. The tubes placed to intercept the scattered electrons from the wire are also in the path of particles scattered from upstream collimators. Figure 5 shows an example of the signal to noise for good beam conditions. If the beam is unstable or has large emittances, the background in the proportional tubes can increase to a point where accurate beam size measurements are difficult. Figure 6 shows a plot of a skew scan made by scanning all the wires of the scanner. The display also includes: 1) The beam size (WNAMS) and error, for each wire. 2) The beam intensity (TMIT) for each scan. 3) An asymmetry (ASYM) term and error, that indicates the presence of a tail on the beam.

Carbon wires do have an advantage over tungsten wires. Because the signal from the carbon wires is small, wire scans can be done with out turning off the central drift chamber high voltage of the physics detector.

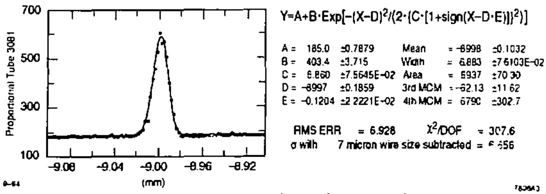

Figure 5. Wire scan using a 7um carbon wire. The elevated background is believed to be due to synchrotron radiation.

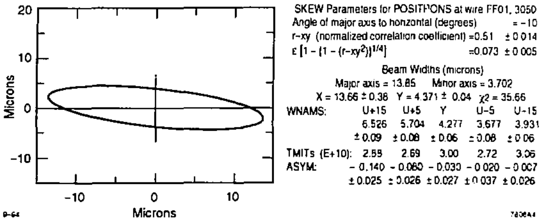

Figure 6. Plot of a skew scan. Results from five separate scans using one wire at each of the five angles are combined to produce measurements of the vertical and horizontal beam size, and the x-y coupling.

PROBLEMS

After operating the scanners for about two months, a number of the 4 micron wires were found to be broken. The wire card was removed and placed in a scanning electron microscope and the broken ends were observed in detail. Figure 7 shows the end of one of the broken wires. The hemispherical shape observed on the broken ends was surprising. It has been proposed that a similar effect to radiation enhanced sublimation [8] of graphite in fusion reactors is responsible for the destruction of the carbon wires.

CONCLUSIONS

This scanner has successfully met its goals and measured spot sizes below three microns and the x-y coupling of the beam. Readout of scanner position during scans is working well and the life time of the electronics in the encoder has been better than expected. The unexpected failure of the carbon wires has caused concern and possible solutions are being examined.

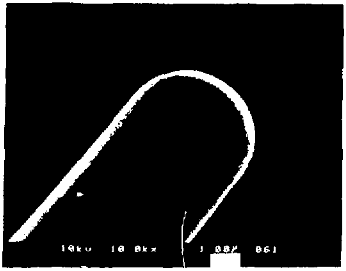

Figure 7. The end of a broken carbon wire is shown under an electron microscope. The wire failed after approximately 2500 scans. For scale, note the 1 micron wide rectangle along the bottom of the picture.

ACKNOWLEDGMENTS

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