EVALUATION OF NEW, FAST WIRE SCANNER DESIGNS FOR THE LCLS*

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Abstract

Transverse beam size measurement for emittance tuning of the LCLS electron beam relies on wire scanners strategically placed on the beam line. It was originally intended to use Optical Transition Radiation (OTR) screens to obtain single shot measurements of the transverse beam size but it was soon discovered that the Coherent OTR that is a feature of ultra-short bunch length operation in linac FELs swamped the signal and rendered this diagnostic unusable. The original SLAC wire scanners that have been in operation for about 20 years are fairly slow and not optimized for the rapid measurements needed to monitor and fine tune the very small LCLS beam emittances, taking over a minute to complete a measurement in both planes. Two new wire scanner designs are being tested at LCLS that make use of state-of-the-art mechanical slides and position read-back systems to make fast, vibration-free measurements of the beam size. One uses an in-vacuum piezo-controlled linear slide and the other uses a dc linear servo motor coupled through a pair of vacuum bellows. The merits of the two designs are compared to the original SLAC design that relies on a ball screw driven by a stepping motor.

INTRODUCTION

The wire scanner diagnostic system at SLAC was originally intended as a backup to confirm the performance of the profile monitor screens using optical transition radiation (OTR) to image the transverse beam profiles. Profile monitor images have the advantage of capturing the full 2D transverse intensity profile of the beam on a single shot but unfortunately the signal at the Linac Coherent Light Source (LCLS) [1] is swamped by coherent optical transition radiation (COTR) [2]. The COTR is the result of a microbunching instability resulting from the very short bunches with very high peak currents that are necessary for FEL operation [3].

A wire scanner measures the average, projected beam profile in one plane over several successive beam pulses. Good agreement in the measured beam size can be found with profile monitor measurements providing the beam does not change significantly from pulse to pulse. Motion of the beam centroid during a wire scan can be compensated by measuring the beam position at adjacent BPMs on each beam pulse and calculating the actual position of the wire with respect to the centroid. The beam intensity signal at each wire position comes from a downstream radiation monitor detecting the Bremstrahlung from the wire and is therefore not influenced by the COTR that spoils the OTR screen measurement.

The existing wire scanner design [4] is based on technology available at the time when the scanners were first introduced on the accelerator some 20 years ago. The fine wires are mounted on a fork that traverses the beamline at 45° so that a vertically and a horizontally strung wire could scan both the x- and y-profiles of the beam, as shown in Fig. 1. Reference [4] describes the mechanism - “The carriage motion is actuated by a stepping motor through a 2mm pitch ball screw, chosen because of the expected large number of cycles. Some difficulty was experienced obtaining the small pitch, high quality ball screw with no plastic parts. Both the cantilever nature of the wire support and the stepping motor contribute to wire vibration.”

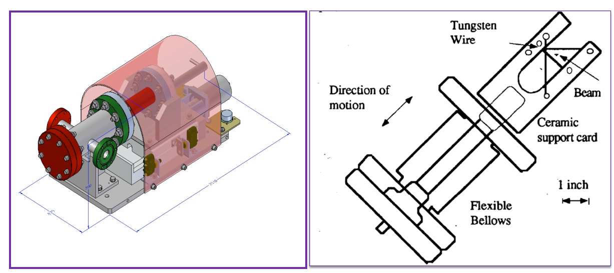

Figure 1: Original SLC design of the wire scanner from Ref. [4] uses a fork moving at 45° to the beamline to measure both x- and y-profiles of the beam.

Stepping motors were an obvious choice at the time because they could be controlled by simply applying electrical pulses through the control system to the motor windings. A rotary motor dictates the use of a screw drive, which does introduce its own set of problems such as backlash. On the plus side, stepping motors are readily available with enough power to counter the vacuum force on the motion bellows. The screw drive does have enough friction that a modest holding force can be applied to the motor to keep the scanner stationary when not in use. The position of the wire during the scan can be calculated by counting the number of pulses (steps) applied to the motor. This was an important consideration in the original design since no position monitor could be found with sufficient resolution, large dynamic range and radiation hardness compatible with the beam losses encountered during SLC operation. The system still needs calibration to determine the number of steps per mm of wire motion and this is done with a linear variable differential

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transformer (LVDT) that can typically measure 50 mm of motion with a resolution of 10^{-3}.

DESIGN GOALS

Since the LCLS is now reliant on wire scans for routine tuning of the beam we are striving to achieve the following with our new design:

- Reduce the scan time from minutes to a few seconds
- Minimize vibration during the scan to the point that it is not observable in the scan data
- Improve the position resolution of the wire scanner motion to 1 μm or better.
- Incorporate real-time readback of the wire position into the data acquisition system.
- Integrate the wire scanner into the LCLS EPICS control system
    - Incorporate the real-time beam position data into the existing Beam Synchronous Acquisition system so that it merges with BPM data.

Two prototype designs are currently being evaluated for the LCLS.

DESIGN 1: EXTERNAL ACTUATOR

In the external actuator design the motor mechanism remains outside the vacuum and is transmitted to the wire carriage through a linear bellows. A simple analysis of the cantilever design in the original SLAC wire scanner shows that a factor 8 reduction in vibration amplitude is achieved by supporting the scanner carriage at both ends. The deflection, δ, of a cantilever length L from a force F is given by

$$\delta = FL^3/3EI \quad (1)$$

where E = Young's Modulus and I = moment of inertia of the beam.

And that of a beam held at both ends is

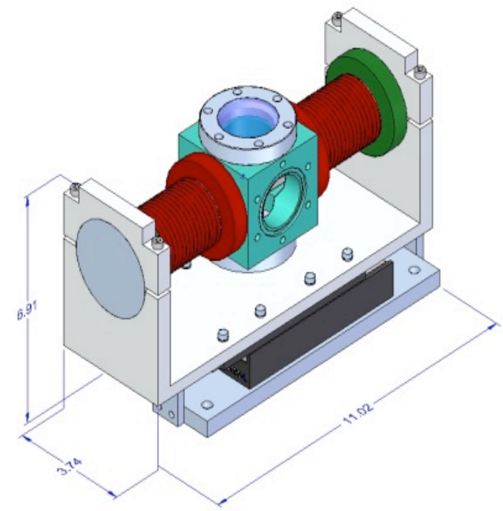
$$\delta = FL^3/192EI \quad (2)$$

All things being equal, the deflection of the supported beam is 8 times less than a cantilever.

The effects of any remaining vibration are further negated by using one wire scanner per plane and mounting the wires perpendicular to the direction of motion. The vibration direction is along the axis of the wire and does not displace the wire transverse to the beam.

Supporting the wire scanner at both ends through two linear bellows has the added advantage that the vacuum forces on the bellows are cancelled and a less powerful motor is required. The motor is a driving term for some of the vibrations so reducing its size should be beneficial for vibrations.

With a smaller motor requirement and there no longer being a static holding force required against the vacuum it becomes possible to consider linear dc servo motors rather than a stepping motor and rotary screw. A linear motor combined with a linear stage is a simpler design than the rotary screw design and also does away with the discrete motor steps that add to the vibration. The final design appears in Figure 2, and is built around a 3” cube.



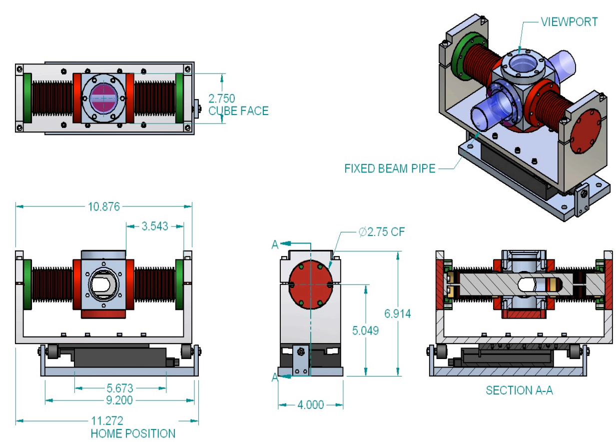


Figure 2: New design with external linear motor actuator.

The linear dc servo motor will accelerate from the park position where the wire is fully retracted, over to a position at the edge of the beam where it then moves at constant speed to cross the beam during approximately 100 beam passes. At completion of the scan the motor accelerates back to the retracted park position.

A consequence of this “minimum vibration” design is that two separate scanners are now required for vertical and horizontal beam measurements. The compact size of the new scanner design does allow two scanners to be mounted side by side without occupying too much space.

DESIGN 2: INTERNAL ACTUATORS

The second design approach is to use a small in-vacuum linear stage and actuator to move the wire without any external motion components. The linear motion stage is once more a cantileverd design but the vibration issue is addressed by making the length, L, of the arm very short, and as we see in equation (1) the vibration amplitude scales with L^3.

The stage is mounted inside the same standard 3.38” standard cube, as shown in Figure 3. One linear stage is used per plane, as in the external actuator design, to

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minimize the effect of vibration. The stages are small enough that both X and Y stages can be mounted in the same cube, offset slightly from one another.

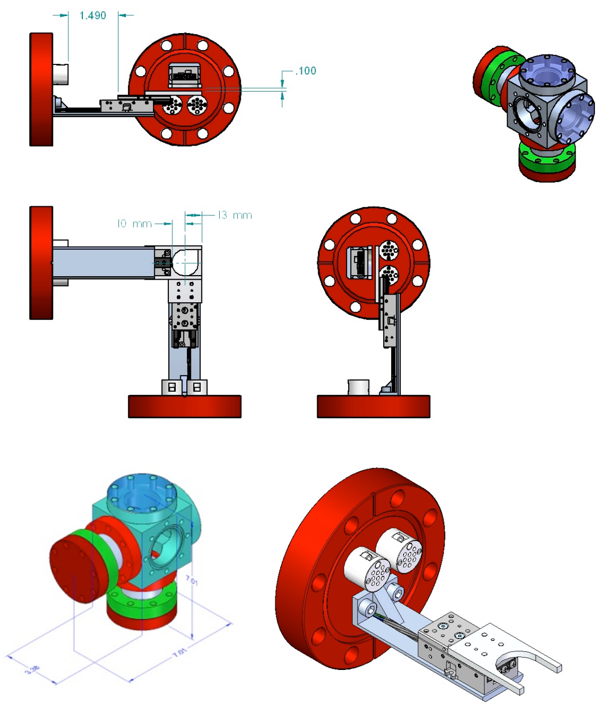

Figure 3: New design with internal linear motor actuator.

The stage is a Micos PPS-20 using a piezoelectric actuator. Each stage has 26 mm of travel and uses cross roller bearings, ceramic balls and no lubrication so that it can be used in vacuum. Vacuum RGA testing has been done to confirm this. One concern with the internal actuator design is the susceptibility of the stage to radiation damage from stray particles close to the beam. We have estimated the expected dose that a stage may be exposed to over a life of several years installed at the LCLS. Beam losses in a low current machine like the LCLS can be quite low, especially after the linac in the undulator beam lines. The stage has been tested with radiation exposure up to 25 krad without any ill effects. We are continuing with higher radiation exposure tests and will also put the device on the beamline.

POSITION MEASUREMENT AND CONTROLS INTEGRATION

In both designs the linear stage incorporates an optical position encoder with submicron resolution. In the internal actuator design a Numerik Jena encoder with Kapton insulated wires is used. The position encoders can combine a precision optical scale together with a coarser magnetic scale that gives absolute position. This is useful for the control system to establish the absolute position when the system is initialized. Limit switches and a hard mechanical stop establish the home position for the controls.

The wire position must be read back into the control system synchronously with the beam pulses where it is correlated with downstream detectors and adjacent BPMs. The synchronously acquired data is processed to calculate the transverse beam profile and rms width. High level software takes several beam size measurements to calculate the transverse emittances. The positioning controls for the wire scanners will be made backwards compatible with the high level application software so that the high degree of automation in the present emittance measurement software can be preserved.

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