Alignment Tools Used To Locate A Wire And A Laser Beam In The VISA Undulator Project

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1. INTRODUCTION

The Stanford Linear Accelerator Center is evaluating the feasibility of placing a free electron laser (FEL) at the end of the linear accelerator. The proposal is to inject electrons two thirds of the way down the linac, accelerate the electrons for the last one third of the linac, and then send the electrons into the FEL. This project is known as the LCLS (Linac Coherent Light Source). To test the feasibility of the LCLS, a smaller experiment VISA (Visual to Infrared SASE (Self Amplified Stimulated Emission) Amplifier) is being performed at Brookhaven National Laboratory. VISA consists of four wiggler segments, each 0.99 m long. The four segments are required to be aligned to the beam axis with an rms error less than 50 µm [1]. This very demanding alignment is carried out in two steps [2]. First the segments are fiducialized using a pulsed wire system. Then the wiggler segments are placed along a reference laser beam which coincides with the electron beam axis.

In the wiggler segment fiducialization, a wire is stretched through a wiggler segment and a current pulse is sent down the wire. The deflection of the wire is monitored. The deflection gives information about the electron beam trajectory. The wire is moved until its x position, the coordinate without wire sag, is on the ideal beam trajectory. (The y position is obtained by rotating the wiggler 90°.) Once the wire is on the ideal beam trajectory, the wire's location is measured relative to tooling balls on the wiggler segment. To locate the wire, a device was constructed which measures the wire position relative to tooling balls on the device. The device is called the wire finder. It will be discussed in this paper.

To place the magnets along the reference laser beam, the position of the laser beam must be determined. A device which can locate the laser beam relative to tooling balls was constructed and is also discussed in this paper. This device is called the laser finder.

With a total alignment error budget less than 50 µm, both the fiducialization and magnet placement must be performed with errors much smaller than 50 µm. It is desired to keep the errors from the wire finder and laser finder at the few µm level.

2. WIRE FINDER

The wire finder contains a detector assembly consisting of a laser shining through a slit onto a photodiode detector (see figure 1). When the detector assembly moves past the wire, the wire casts a shadow and the signal from the detector decreases. The signal goes from a couple volts to nearly zero as the detector assembly moves a distance corresponding to the slit width. This gives the wire finder very high sensitivity to the position of the edges of the wire. The laser, slit, detector assembly is mounted on a stage with a micrometer drive. The stage is mounted on a frame with tooling balls. The wire's position can be obtained relative to the tooling balls. Note that no physical contact of the wire is made.

Figure 1- Wire Finder In Its Calibration Stand

The laser we used is a Melles Griot 0.9 mW compact visible diode laser, model 06 DAL 001. The slit is a Melles Griot 50 µm precision air slit, model 04 PAS 005. The silicon detector, model 13 DSI 007, and its amplifier, model 13 AMP 005, were also from Melles Griot. The gain of the amplifier was set to give roughly 3 Volts output when no wire was in front of the slit. The signal went to nearly zero as the detector assembly moved 50 µm so the wire obscured the slit. This gives a sensitivity of roughly 60 mV per µm of detector motion. 60 mV is far above the noise, giving us precision at the µm level.

The procedure for locating a wire is to first set a reference voltage near the center of the detector output range. The micrometer moves the laser, slit, detector assembly to the first edge of the wire until the output is at the reference voltage. The micrometer position is recorded. The detector assembly is then moved to the other edge of the wire until the output is at the reference voltage and the micrometer position is again recorded. The average of the two micrometer readings gives the position of the center of the wire, independent of the wire diameter. The position is given relative to the micrometer zero position. A calibration is needed to find the micrometer zero position relative to the tooling balls.

A special fixture was constructed to calibrate the wire finder. The fixture had a fixed stretched wire and allowed the wire finder to locate the wire in both a standard configuration and a ‘flipped’ configuration where the wire finder was rotated 180° about its vertical axis.

These two measurements allow the micrometer zero position relative to the tooling balls to be determined.

In the standard configuration (see figure 2), the wire position is given by

$$X_w = X_0 + X_{mic1} \tag{1}$$

X_w is the position of the wire relative to the reference tooling ball (ball R). X_0, the zero offset relative to the reference tooling ball, is the position of a wire which would be found with the micrometer reading zero. X_0 is what we are trying to determine. X_{mic1} is the position of the wire relative to the micrometer zero position. X_{mic1} is found by averaging the micrometer readings of the left edge and right edge of the wire.

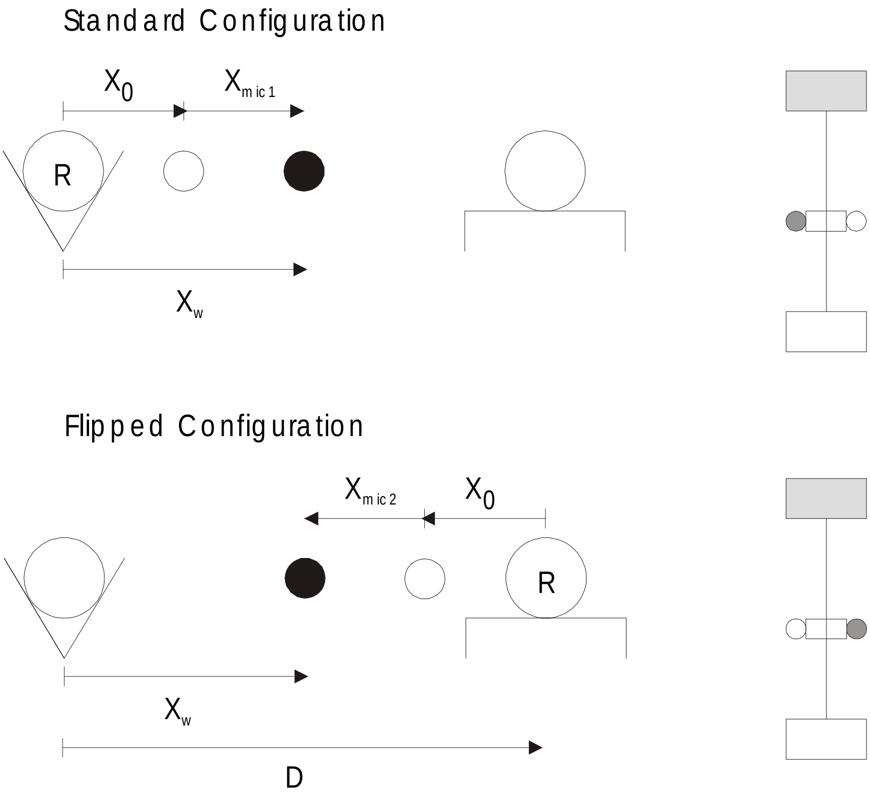

Figure 2 – Wire Finder Zero Offset Calibration

When the wire finder is flipped, the wire position is given by

$$X_w = D - X_0 - X_{mic2} \tag{2}$$

D is the distance between the tooling balls. X_{mic2} is the position of the wire as given by the micrometer. Note that X_w is the same in (1) and (2). We can solve (1) and (2) for X_0:

$$X_0 = D/2 - (X_{mic1} + X_{mic2})/2 \tag{3}$$

The zero offset we obtain by this procedure is very repeatable. In a test, the zero offset was determined five times throughout the day. The rms variation of the measurements was 1.5 µm.

In operation, the standard configuration is used and the zero offset is added to the micrometer reading to find the position of the wire relative to the reference tooling ball.

3. LASER FINDER

The laser finder consists of a quadrant detector mounted on an x-y stage (see figure 3). The stage is mounted on a support with tooling balls. The output current of each quadrant of the detector goes to a transimpedance amplifier board which converts the current to an output voltage. The four voltages then go to an A/D card in a laptop PC. The laptop, running LabWindows/CVI software, then measures the four voltages, calculates the laser beam position relative to the quadrant cell, and displays the position. The quadrant cell is used as a nulling device. The micrometers are used to move the cell until the laptop displays the beam position as x = 0, y = 0. The micrometer readings are then recorded. They give the laser beam position relative to the micrometer zero positions. The micrometer zero positions relative to the tooling balls are required to locate the laser beam relative to the tooling balls. The micrometer zero positions are determined in a calibration fixture.

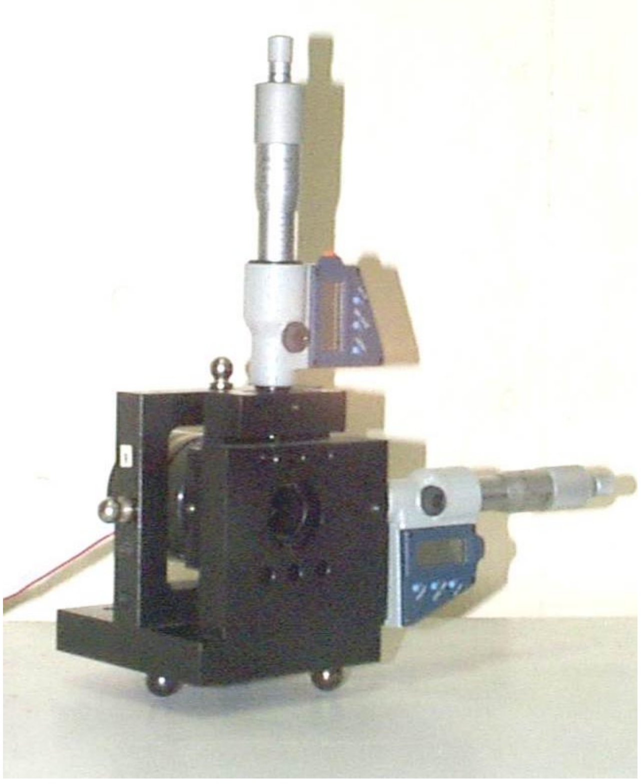

Figure 3- Laser Finder

The quadrant detector we used is a UDT Sensors SPOT-9DMI. The laser is a Melles Griot 21 mW, 780 nm, collimated diode laser with a 4mm beam. The model number is 06 DLS 407. The transimpedance amplifiers have a gain of roughly 600 V/A. The micrometers which move the x-y stage are Mitotoyo model 350-714-30. The A/D card is a National Instruments DAQCard-516. The computer program samples each of the four quadrant voltages 80 times and averages for noise rejection. It then uses the average voltages to compute the position of the laser beam relative to the quadrant detector. The software displays the laser beam position relative to the quadrant detector three times per second. The software also has a history plot. A dot showing the x-y position of the beam relative to the quadrant detector for each measurement is placed in the history plot. The average x and y positions of the points in the history plot are displayed. The history plot allows one to find the average beam position in case of turbulent air refraction. In operation, the micrometers are used to move the quadrant detector. The history plot is reset. The average x and y positions of the beam are noted and the process is repeated until the laser beam is at the center of the quadrant detector. At this point, the micrometer readings are recorded. The micrometers give the laser beam position relative to the micrometer zero positions. The zero offset is added to the micrometer readings to get the laser beam position relative to the tooling balls.

The zero offset is determined in a calibration fixture using a flipping technique. The position of a fixed laser beam is found relative to a reference tooling ball both with the laser finder in a standard configuration and with the laser finder rotated 180° about its horizontal axis. From these two measurements, both the x and y zero offsets are determined.

The procedure for finding the x direction zero offset is shown in figure 4. In the standard configuration, the laser beam position is given by

$$X_b = X_0 + X_{mic1} \tag{4}$$

X_b is the position of the laser beam relative to the reference tooling ball (ball R). X_0, the zero offset relative to the reference tooling ball, is the position of a laser beam which would be found with the x micrometer reading zero. X_0 is what we are trying to determine. X_{mic1} is the reading of the x micrometer when the laser beam is centered on the quadrant detector.

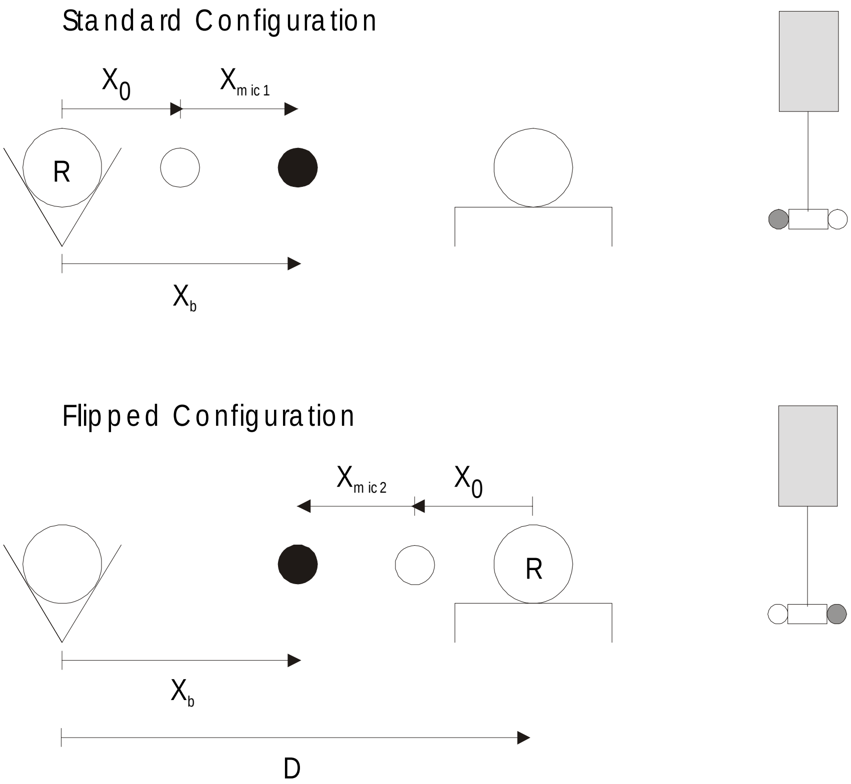

Figure 4 – Laser Finder X Zero Offset Calibration

When the laser finder is flipped, the laser beam position is given by

$$X_b = D - X_0 - X_{mic2} \tag{5}$$

D is the distance between the tooling balls. X_{mic2} is the position of the laser beam given by the micrometer. (4) and (5) can be solved for X_0:

$$X_0 = D/2 - (X_{mic1} + X_{mic2})/2 \tag{6}$$

This determines the zero offset for the x micrometer.

The procedure for finding the y direction zero offset is shown in figure 5. In the standard configuration, the laser beam position is given by

$$Y_b = Y_0 + Y_{mic1} \tag{7}$$

Y_b is the height of the laser beam above the line joining the two tooling balls. Y_0, the zero offset relative to the line joining the two tooling balls, is the position of a laser beam which would be found at the y micrometer zero position. Y_0 is what we are trying to determine. Y_{mic1} is the reading of the y micrometer when the laser beam is centered on the quadrant detector.

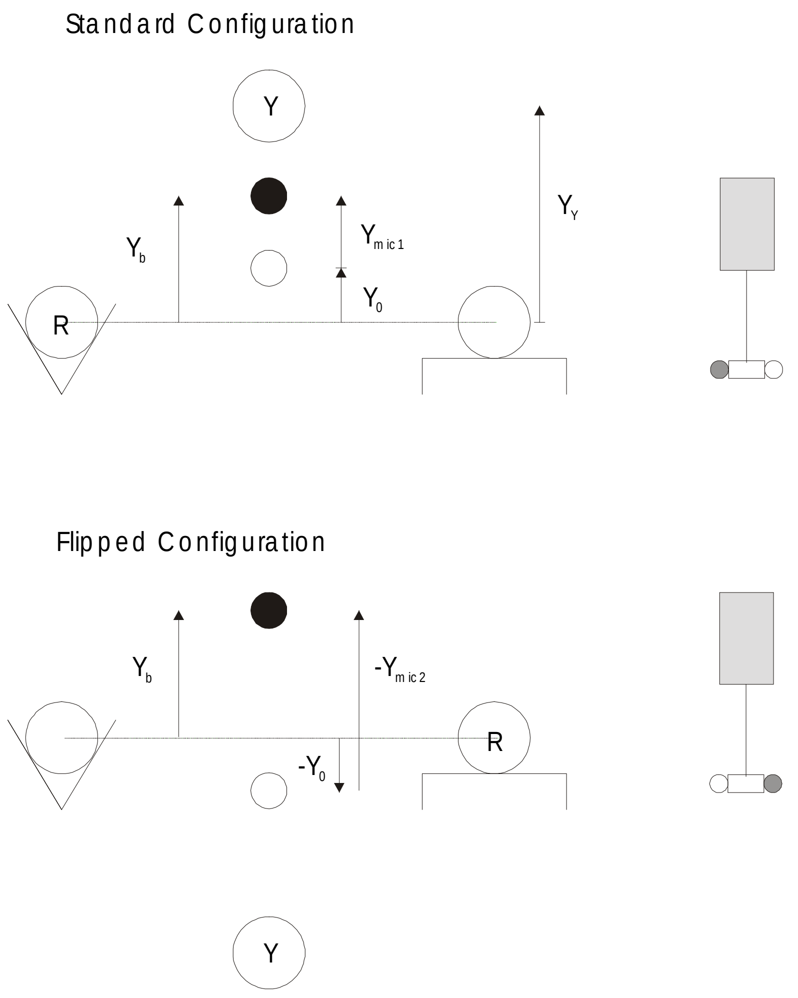

Figure 5 – Laser Finder Y Zero Offset Calibration

When the laser finder is flipped, the laser beam y position is given by

$$Y_b = -Y_0 - Y_{mic2} \tag{8}$$

Equations (7) and (8) can be used to determine Y_0:

$$Y_0 = -(Y_{mic1} + Y_{mic2})/2 \tag{9}$$

This determines the zero offset for the y micrometer.

We wish to make y measurements in the vertical plane to minimize possible errors. To do this, a third tooling ball, ball Y, is added to the laser finder. Its position relative to the other two tooling balls is accurately determined in a coordinate measuring machine. In particular, ball Y's height above the line joining the other two tooling balls is determined and is given by Y_Y. In the standard configuration, the vertical distance of the laser beam below ball Y is given by

$$Y_{bY} = Y_Y - (Y_0 + Y_{mic1}) \tag{10}$$

To test the laser finder, we found the position of a laser beam (x = 50.525 mm, y = - 0.208 mm measured from the line joining the two horizontal tooling balls). We then precisely moved the laser up by 0.208 mm. We measured a beam position of (50.525 mm, 0.001 mm). We then flipped the laser finder and measured a y position of zero, as desired. Other tests have also indicated the laser finder working at the μm level.

4. CONCLUSION

A wire finder and a laser finder were constructed for the VISA project. The wire finder consists of a laser, slit, detector assembly which moves past the wire. The wire makes a shadow which causes the detector signal to drop by several volts as the detector assembly moves the slit width (50 μm in our case) past the wire edge. The center of the wire is given by the mean of the two edge positions. A calibration allows the micrometer readings to give the wire position relative to tooling balls.

The laser finder consists of a quadrant detector on an x-y stage. The detector is moved until it is centered on the laser beam. The x and y micrometer readings are then recorded. A calibration allows the micrometer readings to give the laser beam position relative to tooling balls.

5. References

[1] P. Emma and H. D. Nuhn, ‘FEL Trajectory Analysis for the VISA Experiment’, SLAC-PUB-7913, 1998.
[2] R. Ruland et al., ‘Alignment of the VISA Undulator’, SLAC-PUB-8086, 1999.