Validation of an optical WPS system

Abstract

For the Compact Linear Collider (CLIC) project an active pre-alignment system is planned to be used with over 90.000 wire position sensors (WPS). Therefore low cost solutions are studied. Open Source Instruments Inc provides a CCD camera based WPS.

This sensor has been tested for its different characteristics, such as resolution, stability, linearity, dynamic range and absolute calibration. A particular focus has been put on tests with different types of wires.

Parameters

The design of the optical wire position sensor has been specified with the following parameters, derived from the constraints of the CLIC prealignment system:

- ± 5 mm dynamic range in x and y axis
- 5 µm rms absolute accuracy
- 2 µm rms precision

Fig. 1: optical wire position sensor

Design

The sensor is made of two cameras that are taking pictures of the same section of a stretched wire from two different viewing directions. The calibration of each camera allows for each image the determination of a plane that contains the centre line of the wire.

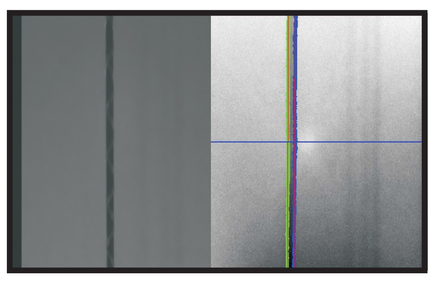

Fig. 2: image and edge detection of one camera

By intersecting these two planes, the centre line itself can be calculated. This centre line represents the wire. The intersecting plane concept is shown in Fig. 1 with the field of view of the camera, shown in blue. The cameras are installed on the vertical support of the sensor body and are mounted with an angle of plus and minus 31° each from the horizontal plane. This results in a slightly better configuration for the determination of the vertical direction and therefore the precision in vertical is about factor 0.6 better than the horizontal direction.

Electronics and flash light source are also installed on the sensor base plate. The flash used to illuminate the wire is an infrared light-emitting diode (LED) array.

Vectran wire

A new, high performance wire, called Vectran, is used in these tests. It is a fibre strand which has mechanical characteristics that are very interesting for the use in alignment systems. Thus its weight of only 0.133 g/m, the wire is more robust as presently used carbon-peek or fishing line wires. It has almost no creep and a very low moisture absorption rate. The wire is almost transparent to the used infrared illumination what makes this wire difficultly detectable on the CCD.

Equipment

A calibrated bench with supports for three optical wire position sensors was used for all measurements on a stretched wire. The calibration of each support on the bench is known to better than ± 3 µm. For stability tests, a static setup has been chosen and the bench has been fixed to a wire stretching unit with a fix end and a pulley with a weight of 10 kg.

A second setup has been used for all other configurations where the wire was moved in the field of view of the sensor. To control the wire movement, high resolution linear stages have been installed in order to move the wire independently in vertical and horizontal direction. The stages were mounted perpendicular on two granite tables allowing the precise positioning of the wire inside the sensor's field of view. Linear encoders on the stages gave the stage position in sub-µm resolution and with a bi-directional repeatability of 0.1 µm.

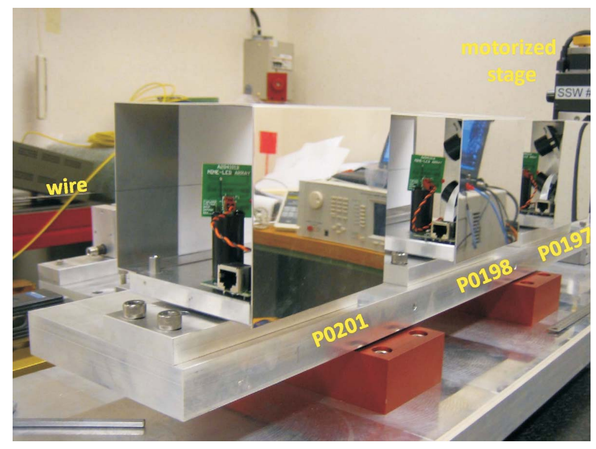

Fig. 3: sensor support plate for three sensors

Tests

Stability
stainless steel pin

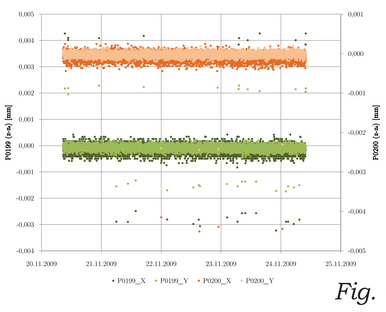

Fig. 4

The stability is measured on a stainless steel pin, as the calibration by Open Source Instruments is carried out with respect to a pin.

Result: Outliers are detected at steps of approximately 3 µm. This issue was identified as a problem of an insufficient number of decimal places in the software.

Stability
vectran wire

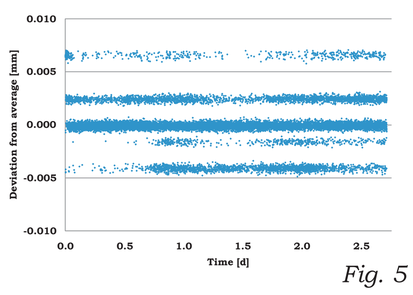

Fig. 5

Significantly more outliers are detected compared to the steel pin measurements. The observed steps have the same spacing as for the steel pin.

In the given three sensor configuration the wire position has been stable during the measurements.

Result: Problem in the edge detection algorithm was identified. The wire detection (as shown in Fig. 2) is not continuous along the image.

Calibration
vectran wire

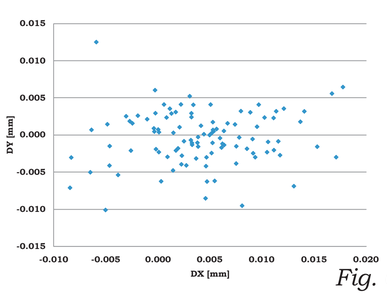

Fig. 6

Three sensors are installed during the calibration check on the calibrated support plate (Fig. 3). The position of the centre sensor is calculated by the position of the left and right sensor.

Result: All variation, DX and DY, shown in Fig. 6, are obtained from measurements in the dynamic range. Differences of ± 5 µm are observed in vertical direction and of ± 10 µm in horizontal direction.

Range
vectran wire

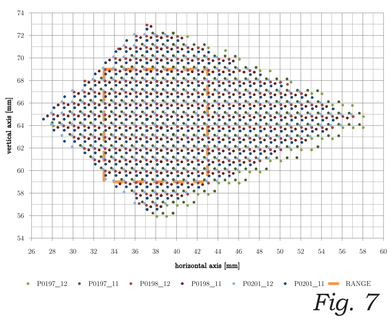

Fig. 7

The sensor's full range is shown in Fig.7 including the dynamic range of 10 mm by 10 mm shown in the orange frame.

Result: The sensor provides a larger field of view than specified. Though the edges of the dynamic range are close to the limit.

Final test
stability after modifications, vectran wire

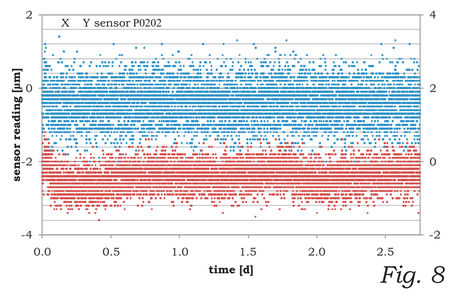

Fig. 8

Stability measurement on vectran wire with the modified resolution and edge detection show:

- a resolution of 0.1 µm for the sensor's coordinate output
- no more steps of some µm are observed
- complete detection failures have been reduced significantly to 1 out of 25.000

Future steps

The tests of the optical WPS have been completed. For a next generation of the sensor, the following main issues are under discussion:

- Modifying the characteristics of the vectran wire to allow a better detection of the wire and to make it conductive.
- Modifying the LED light source for better contrast on the vectran wire.
- Improvements in the data acquisition frequency in order to monitor the wire simultaniously.
- Applying changes to the mechanical design towards a compact sensor.
- Looking for a way to provide redundant measurements for the determination of the wire position of one sensor.
- Verification of the absolute calibration with an accuracy of 1µm in a dedicated setup.

Conclusion

The optical WPS from Open Source Instruments has been tested in several steps at CERN. The approach of a validation in the same conditions as at Open Source Instruments showed decimal propagation problems in the software which have been solved.

After validating measurement on carbon-peek wire, vectran wire has been used for further tests, as this fibre strain will be the reference wire in the future.

A robust edge detection interpretation has been implemented following detection problems at the beginning of vectran test. The failure rate of the wire detection is now at 1 out of 25.000 and the precision of the detection at 1 µm.

The implementation of a second sensor generation is planned for 2011 based on the results of the presented tests.

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Patrick Bestmann • Andreas Herty • CERN • 1211 Geneva 23 • Switzerland
James Bensinger • Kevan Hashemi • Open Source Instruments Inc. • Watertown MA • USA