Feasibility Study of Multipoint Based Laser Alignment System for CLIC

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IWAA 2012

Introduction and motivation

The Compact LInear Collider (CLIC) study is a feasibility study aiming at the development of a realistic technology at an affordable cost for an electron-positron linear collider. One of the important technical challenges is the critical **pre-alignment** requirements for the two main linear accelerators (linacs), especially the Beam Delivery System (BDS). The beam related components have to be actively pre-aligned within an **accuracy of 10 µm rms over a sliding window of at least 200 m** along the 20 km of linac.

A solution based on overlapping wires and Wire Positioning Sensors (WPS) has been proposed for the Conceptual Design Report (CDR). But this solution has some drawbacks and should be validated through inter-comparison with an alternative solution based on another technology. As currently no “off-the-shelf” solution exists, a **new metrological approach is proposed using a laser beam as alignment reference**.

This proposal is based on observing the laser diffraction pattern on targets oriented perpendicular to a laser beam and mechanically switched to intersect with the laser beam during the measurement. The technical concept is based on a high power laser source and an assembly of a lens with an optical sensor and image processing. This method would allow the implementation of N points in a sector length of about 200 m. Moreover, the straightness of the reference beam is not damaged by the use of shutters.

Alignment principle

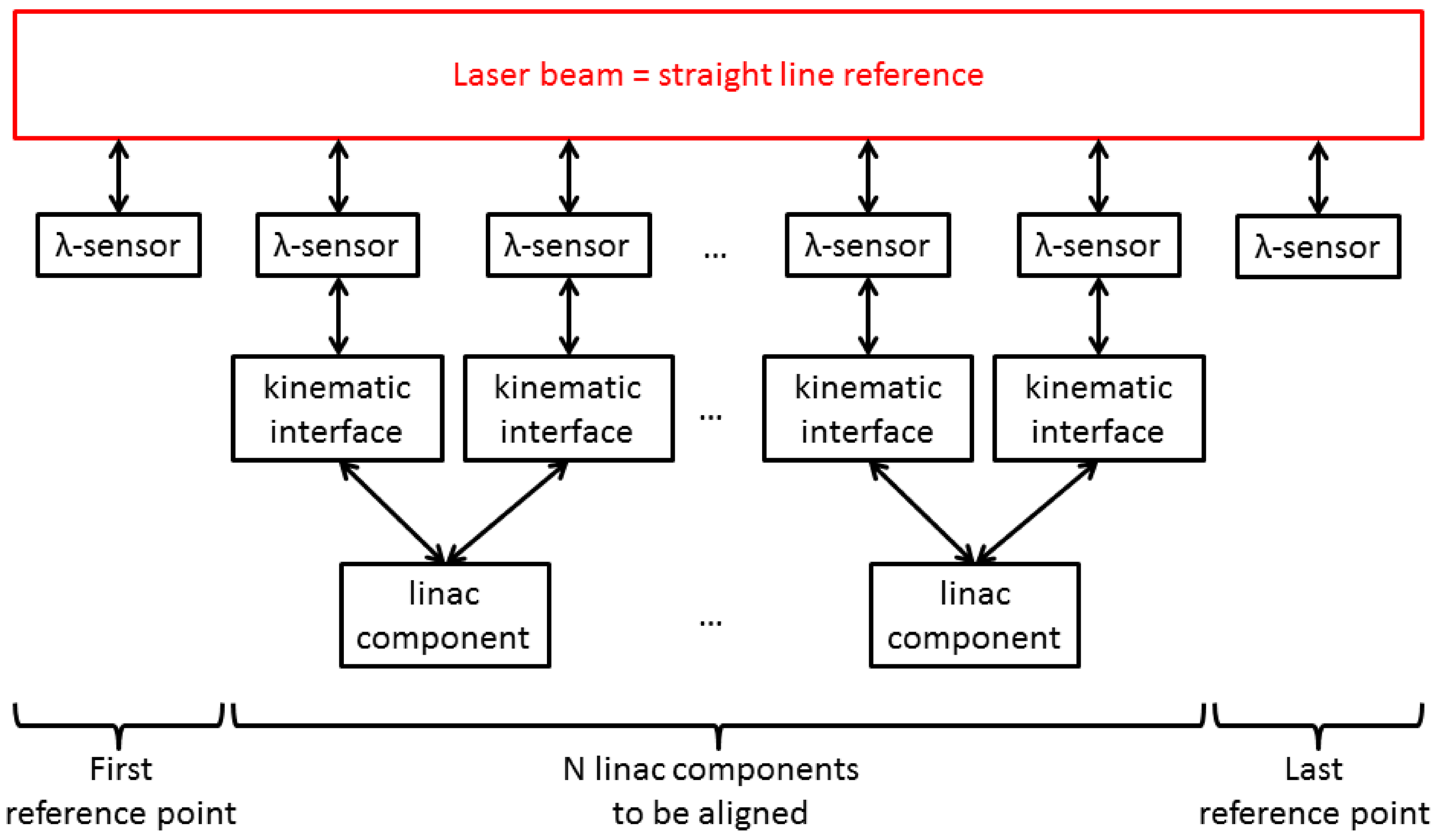

Figure 1: Alignment principle

The alignment is done by means of λ-sensors (LAMBDA stands for Laser Alignment Multipoint Based Design Approach). A λ-sensor is made of a shutter/lens/CCD assembly. In order to meet CLIC-project requirements, λ-sensors are subject to several constraints:

- -measurement repeatability: ≤ 1 µm,
- -measurement accuracy: ≤ 5 µm,
- -measurement range ± 3 mm,
- -sensor maximal size:10 cm × 10 cm × 10 cm,
- -distance sensor to laser beam small because of integration into the pipe.

Study of key-parameters

Parameters	Challenges	Solutions
Beam straightness	Air molecules or temperature gradient change refraction index and cause beam distortion	Use of vacuum pipe Use of stationary waves or continuous air flow in order to stabilise the beam
Shutter surface	If too flat, shutter like a mirror, if too rough, blurred image	Optimal order of magnitude for roughness: laser wavelength
Shutter orientation	Wrong orientation after opening/closing	Improve shutter stability after opening/closing
Spatial resolution	Limited by Rayleigh criterion (order of magnitude = $\left(\frac{0.61 \cdot \text{laser wavelength}}{\text{numerical aperture}}\right)$ and CCD resolution (order of magnitude = pixel size) Limited by Gaussian matching algorithm and target detection algorithm	Compromise between both factors (best spatial resolution achievable = half laser wavelength) Compromise between both algorithms

Table 1: System parameters, challenges and solutions

First experiments and results

Objective

Study of measurement repeatability and precision with a camera that moves perpendicular to the laser beam over a small distance (50 µm)

Hardware characteristics

Laser
-Type: HeNe
-Wavelength: 633 nm
-Power: 25 mW

Camera lens
-Focal length: 25.08 mm

CCD
-1/3’’ CMOS
-1280 x 1024 pixels
-Pixel size: 3.6 µm

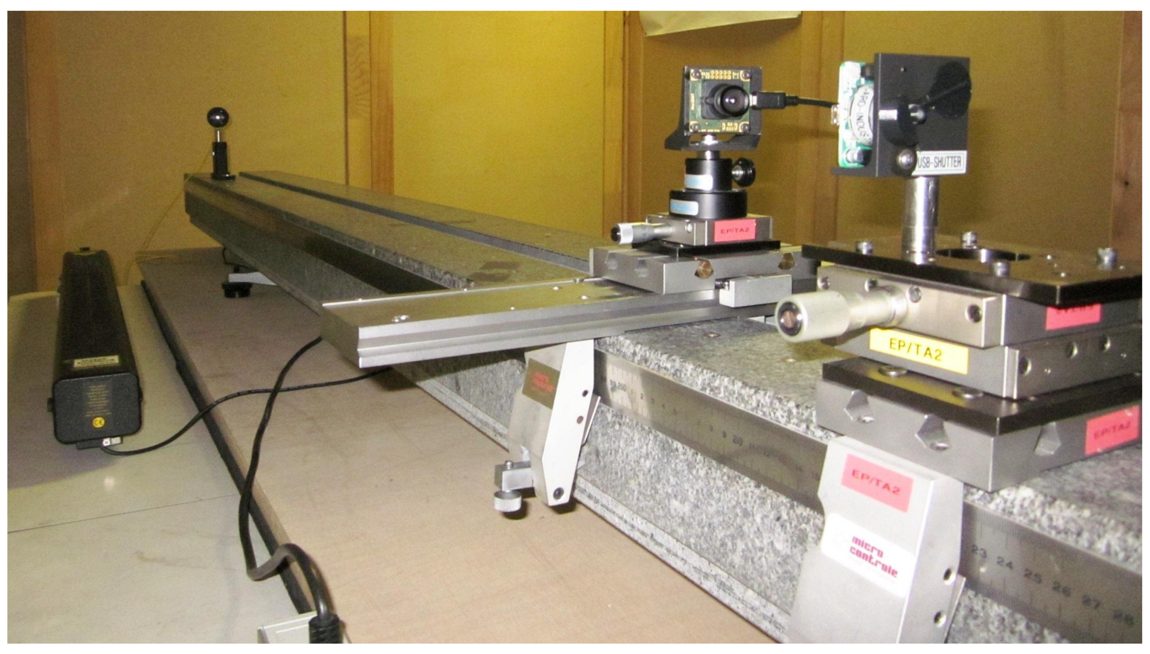

Figure 2: View of the experimental setup
(foreground: camera and shutter; background: laser, collimator)

Configuration

The experimental setup comprises 4 main steps:

- -beam production and orientation done by laser, optical fibre and collimator,
- -beam interruption done by shutter,
- -data acquisition done by camera,
- -data processing done by computer.

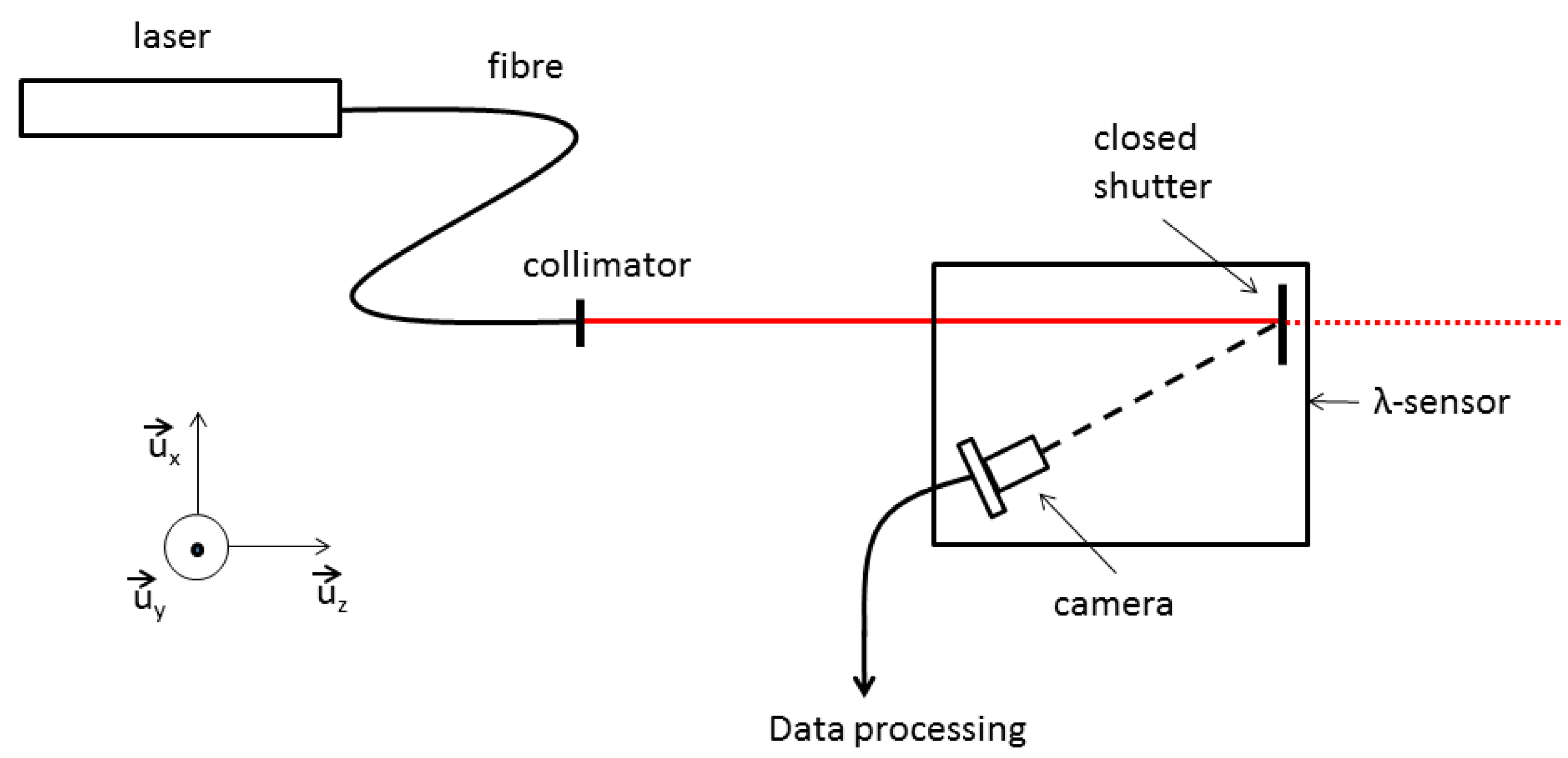

Figure 3: Schematic view of the experimental setup (from the top)

Results

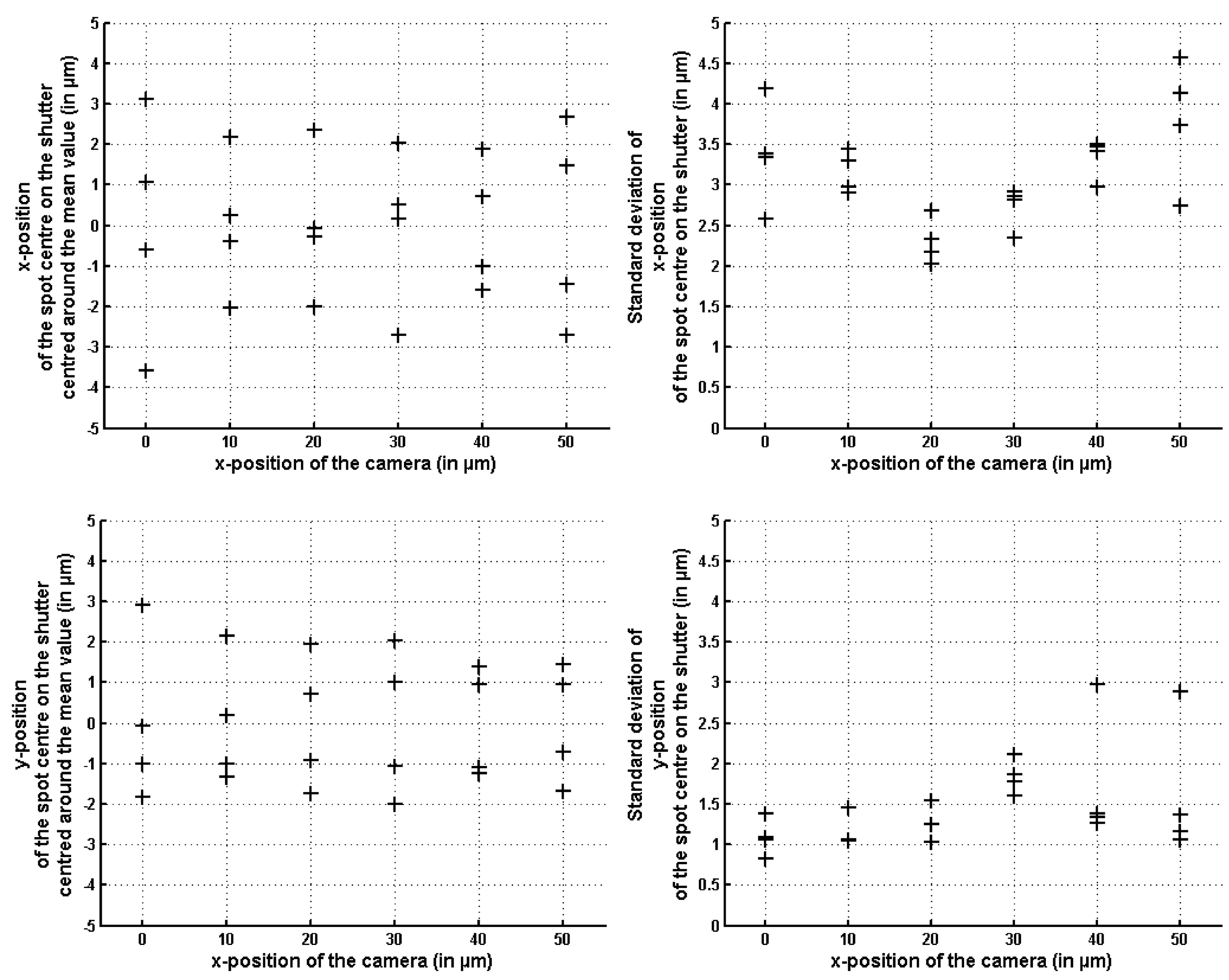

Figure 4: Repeatability and precision for radial and vertical positions

Conclusion

- -New alignment concept using laser beam as straight line reference
- -Basic laboratory experiments with low cost elements and simple methods done at short distance (about 2 m)
- -Measurement repeatability within an interval of [−4 µm,4 µm] around the mean values
- -Standard deviation less than 5 µm
- -Complementary tests scheduled in order to validate further system parameters with a higher level of detail (purchase of an automatised micrometric table)

12th International Workshop on Accelerator Alignment
Fermilab • United States • 10th – 14th September 2012

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