RASCLIC: A LONG-BASELINE 3-POINT ALIGNMENT SYSTEM FOR PARTICLE ACCELERATORS

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Abstract

RasClic is a new optical alignment system for large objects like linear accelerators, based on the RASNIK alignment system. The system is a 3-point straightness monitor consisting of a monochromatic light source, a diffraction plate and a pixel image sensor. By monitoring the position of a diffraction pattern on the image sensor, a measure for the relative positions of the three components is obtained. It has been shown that such a system has an adequate alignment resolution for use as an alignment system for the Compact Linear Collider (CLIC). By its principle of static deformation measurement, RasClic is a potentially superior seismometer for very slow oscillations like the Earth' Hum.
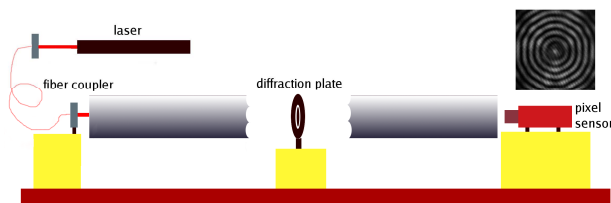
Fig. 1 Experimental setup of RasClic. The distance between the image sensor and the laser is 140 m.

INTRODUCTION

In experimental particle physics charged particles are made to collide after being accelerated. The product of the collision is a set of elementary particles, which are detected and studied. Circular shaped colliders, like the Large Hadron Collider (LHC), are often used, but have limitations for accelerating light particles to high energies [1]. The Compact Linear Collider (CLIC) is a future 2 x 22 km linear electron-positron collider, which will access a high centre-of-mass energy regime of several TeV. Linear colliders require an accurate alignment of the accelerator beam (10 μm per 200 m) and several alignment methods are studied (e.g. stretched wire systems).

In this paper an optical alignment system based on the RASNIK system [2] is proposed. RasClic is a 3-point alignment system consisting of a monochromatic light source, a diffraction plate and a CCD camera. The laser illuminates the diffraction plate, which produces a diffraction pattern on the camera. Calculating the displacement of the image results in a measure for the alignment [3].

DEVICE SETUP

A 140 m test setup was built in a former accelerator tunnel at CERN. Monochromatic light is guided from the He-Ne laser through an optical fiber to the vacuum tube in order to decouple the position of the light source from position of the beam in the laser. Heating effects of the laser, resulting in variations of the beam position and beam angle, are diminished in this way. The fiber-beam coupler also offers a stiff mechanical reference to the optical centre of the light emitting point. The tube is evacuated ($<10^{-3}$ mbar) to eliminate the effects of air turbulence and air density gradients. At 70 m distance a plate made of a concentric cut-away is placed in a section of vacuum tube firmly attached to the ground, creating a diffraction pattern in the geometrical shadow along the optical axis. An image (pixel) sensor is placed at the end of the vacuum tube, recording images with a rate of 62.5 Hz controlled by a quartz-stabilized external trigger. At several positions in the vacuum tube, field stops are placed reducing the amount of background light.

The shift of the images with respect to a reference image, taken at the beginning of the measurement, is determined using a Fourier analysis. Taking the Fast Fourier Transform (FFT) of the images and by calculating the relative phase for each spatial frequency component (wx, wy) gives a phase plane. This is fitted in the two dimensions, giving the relative position shifts in the x and y directions.

PERFORMANCE AND NOISE

A linearity test was performed by varying a force on the diffraction plate holder in steps up to 50 N in the vertical direction; see Fig. 2. This test shows linearity as expected, and an excellent position resolution at nm level. Some elastic deformation observed in the vertical direction may be due to the non-uniform distribution of weights during the experiment. From the analysis of simulated images

we conclude that the linearity error may be much better than 1 µm.

Fourier analysis was done on data collected over a number of hours. The spectrum is dominated by 1/f noise in the low-frequency domain (< 100 mHz). In the high-frequency domain (> 5 Hz) white noise dominates, with some resonances superimposed; the dashed line indicates the white noise level prior to the latest upgrade.

The recent improvements on the RasClic system (laser fiber coupler [4], 50 % increased length, fivefold increase of measurement rate, weighed fits) have led to reductions in the error of individual image positions which is now down to 20 nm. Together with the increase in repetition rate this reduces the intrinsic (white) noise by a factor of > 20 (see Fig. 3).

The extension increased the sensitivity by 2.25 (proportional to the square of length), with a resulting total improvement of the signal-to-noise ratio of 50.

This improvement only fully materializes at f > 5 Hz due to a large 1/f noise background in the signal. This can be explained by temperature variations causing deformations of the tunnel and of the setup; a system of sensors is set up to closely monitor the temperatures and to correct for their effects. Further investigation is needed to determine if there is an instrument-noise contribution in the 1/f noise.
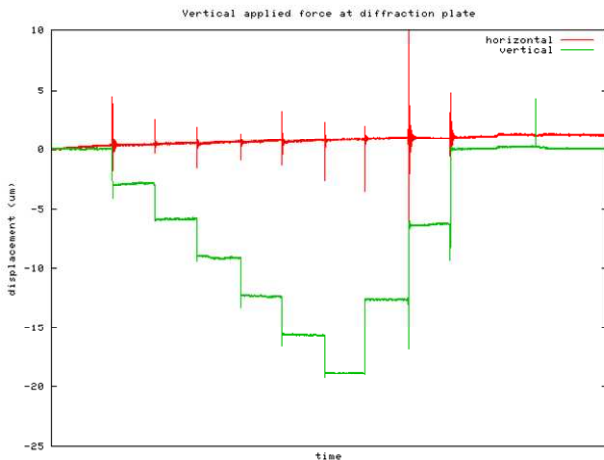

Fig. 2 Linearity test in the vertical direction at the diffraction plate

RASCLIC AS A SEISMOMETER

The results of the noise and sensitivity studies show that RasClic could be used as a low-frequency seismograph. Due to its potential sensitivity to low-frequency, long wavelength movement RasClic could be suited to study the Earth' Hum [5] or slow and silent earthquakes [6]. A better understanding of the latter could improve the efficiency of earthquake early warning systems. An interesting application of RasClic is as an instrument to monitor the slow deformation of the earth's crust across a fault line.

Noise behavior of an ideal RasClic compared to the STS-1 and STS-2 seismographs used by the Royal Dutch Institute for Meteorology (KNMI) [7] is shown in fig. 4. The NHNM and NLNM envelopes are the New High- and New Low Noise Models; these are models for the background noise in seismic measurements due to actual movements in the Earth's crust, during periods of high and low seismic activity, respectively.
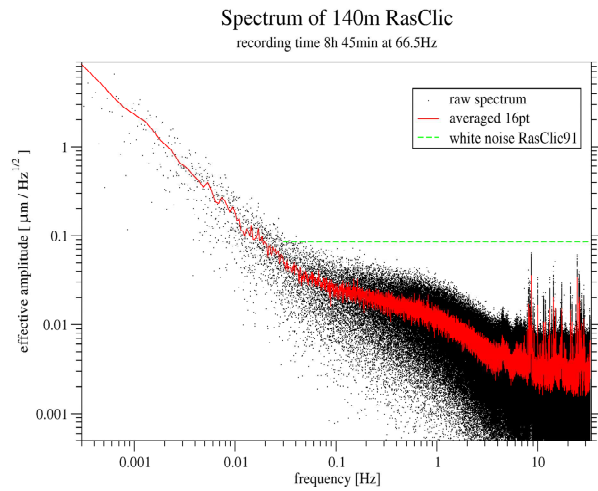

Fig. 3 Noise spectrum of RasClic data.

By extending the length l of RasClic the sensitivity at low frequencies increases with l^2 [5]. The main practical limitation in this ideal situation is the need for a long vacuum system. The relatively cheap laser, diffraction plate and pixel sensor can work in principle at any distance, provided they are individually well coupled to the earth crust.

Model predictions show that a 20 km RasClic system with an image position resolution of 1 nm could surpass the performance of current seismographs in the low frequency domain (see Fig. 4).
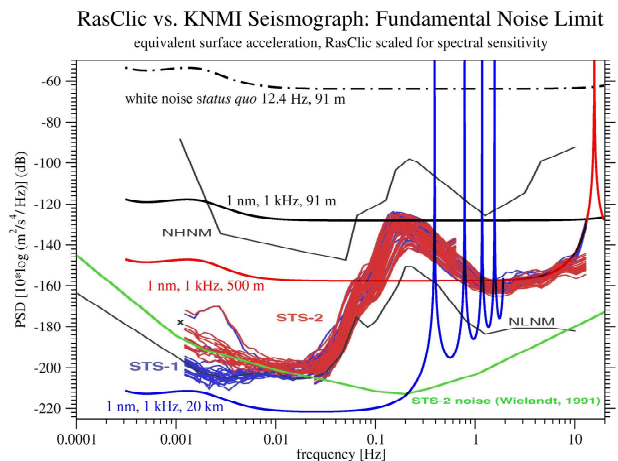

Fig. 4. Comparison of Ideal RasClic seismograph systems compared to current seismographs.

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