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MICROMETRIC ALIGNMENT METROLOGY: MEANS, DEVELOPMENTS AND APPLICATIONS

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Abstract

In order to meet the ever-increasing drastic alignment tolerances concerning the future particle accelerators, a new generation of sensors has been developed. Whether they are based on ultrasonic, optical or capacitive technology, these sensors, of micrometric resolution, allow continuous measurements in an often hostile environment (strong radiations, strong electro-magnetic fields) and thereby revolutionize alignment possibilities. After a brief presentation of the different sensors tested, used and indeed developed by our group, we present the past, present and future applications linked to the particle accelerators – in the short term concerning micrometric alignment of the low-beta quadrupoles of the LHC, and in the long term concerning the prealignment of the CLIC – or linked to other applications.

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1 INTRODUCTION

The tight tolerances regarding the alignment of the next generation of accelerators have accelerated the development of new types of sensors, with the following requirements: micrometric resolution, resistance to radiation, a possible use within the stray field of the magnetic elements, allowing continuous measurements. Four types of sensors, answering to these characteristics, are described in this report:

- the Hydrostatic Levelling System (HLS)
- the Wire Positioning System (WPS)
- the Tilt Measuring System (TMS)
- the RASNIK-CDD (an optical offset measurement system)

This report deals with all these new sensors, tested and even sometimes developed in the Survey group, and gives examples of applications in accelerators (past examples with the vertical alignment of the LEP quadrupoles, the LEP spectrometer, "present" ones with the alignment of the LHC low-betas quadrupoles, and future ones with possible configuration for the initial alignment of CLIC).

2 INSTRUMENTS AND METHODS FOR MICROMETRIC REQUIREMENTS

2.1 HLS sensors

The free surface of a "water network" provides the reference frame. The system works according to the principle of the communicating vessels. The "water network" is composed of vessels connected to each other by pipes, partially filled with water, allowing water and air to circulate freely. To eliminate the effects of the differential variations of atmospheric pressure, the whole pipework system is only open to free air at one point. To avoid salt deposition and the growth of flora and micro fauna, demineralized water is used with a biocide additive [1].

A sensor is fitted to each vessel in order to determine the distance to the free surface of the liquid. Several technologies are possible: optical, capacitive, ultrasonic measurements. Regarding micrometric resolution, two technologies are valid: the capacitive technology, which is an experienced one, and the ultrasonic technology developed in the last years at DESY.

We are preparing the comparison of both types of sensors following a list of controls and tests. First results will be shown at IWAA2004 (International Workshop on Accelerator Alignment) to be held in October 2004 at CERN.

2.1.1. Capacitive HLS

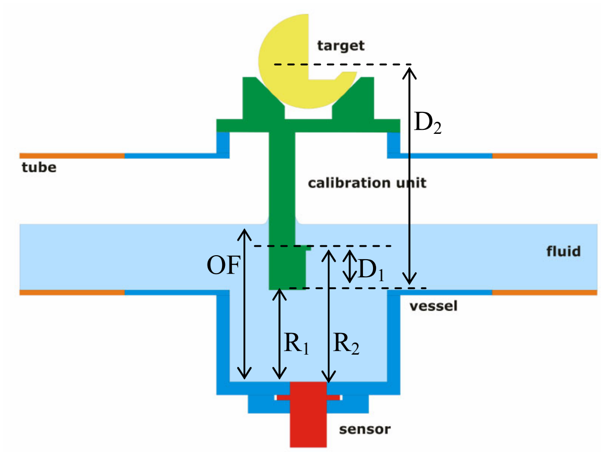
The most efficient devices are based on FOGALE-NANOTECH capacitive sensors and have been developed by ESRF in 1987, in order to perform the permanent vertical realignment of the magnetic elements distributed over the 1 km circumference of the storage ring [2]. Further improvements and refinements have then been made at CERN (where they are used intensively) and KEK.

Characteristics of the capacitive HLS :
- range: 5 mm
- resolution: 0.2 µm
- repeatability: 1 µm
- bandwidth: 0-10 Hz

Figure 1 : Capacitive HLS sensor

2.2 Ultrasonic HLS

These ultrasonic sensors have been developed for the alignment of TESLA at DESY, using a new concept of "in-situ" calibration which eliminates the drifts of the sensors and the temperature effects. Therefore a special measurement vessel has been developed, in which two reference distances D1 and D2 are calibrated and have to be kept constant over time. The reference is made of invar, to achieve maximum temperature invariance and stainlessness. During a measurement, three distances R1, R2 and OF are registered quasi simultaneously [3].

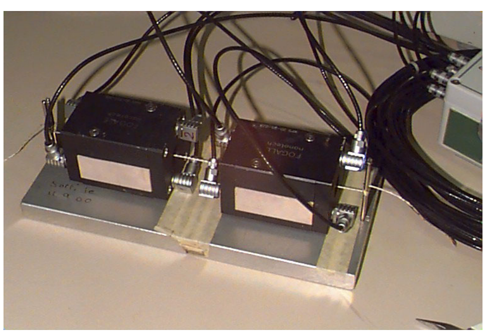


Characteristics of the ultrasonic HLS :
- resolution: 3 µm

Figure 2 : Ultrasonic HLS sensor [3]

2.3 WPS sensors

The WPS sensors adopted at CERN also use the capacitive measurement technique from FOGALE along two perpendicular axes, to measure the distance between its mechanical axis and a stretched wire which serves as a reference. On each measurement axis, the wire goes between two electrodes. The wire is made of carbon fibres and its geometry is maintained by a sheath of woven Peek (poly-ether-ether-cetone) filaments. It is held in tension by a frictionless pulley system and a counterweight, developed in the Survey Group [1].



Characteristics of the WPS :
- range: 10 mm on both axes
- resolution: 0.1 µm
- repeatability: 1 µm
- bandwidth: 0-100 Hz

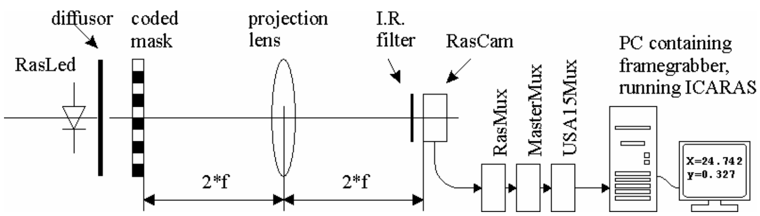
Figure 3 : Capacitive WPS sensor

2.4 Tilt Measurement System (TMS)

The reference frame for this instrument is the local vertical. Tilts are measured around two orthogonal horizontal axes. In the TMS, a mass is maintained in levitation by an electrostatic field. The displacements of the mass caused by the movements of the instrument are measured by FOGALE capacitive sensors and the values obtained are converted into angular units. From the outside, the instrument looks like a 40 mm cube; it does not include any electronic components [1].

2.5 Alignment system from NIKEF (RASNIK-CCD)

The RASNIK-CDD system consists of two opto-electronic components and one optical element. Part of the image of a coded mask, illuminated by a network of infrared diodes through a diffuser, is projected into a digital camera by means of a lens. In this application, the camera and lens are considered to form the optical reference axis and the movements of the mask are measured with respect to this axis (Y). The camera is connected to a computer and the image is analyzed and compared with the reference image to deduce the radial position (X, Z) of the mask with respect to the reference axis. The longitudinal movement (Y) can also be determined as well as the three angles of rotation about the X, Y and Z axes [1].



Characteristics of the RASNIK-CCD :
- range: 5 mm
- resolution: 0.01 µm
- precision with 2f=2.5m : 1 µm

Figure 4 : RASNIK system [1]

The RASNIK-CDD system was developed by the electronics department of the Dutch National Institute for Nuclear Physics and High Energy Physics (NIKEF). Making use of the same principle but in a different form, it has been used extensively to control the position of the detector elements of the L3 experiment in LEP [1].

3 EXEMPLES OF APPLICATIONS

3.1 In the field of accelerators

3.1.1 Past examples

- CLIC Test Facilities (CTF) [5]
  WPS and HLS have been first refined on test benches and finally set up on a real CLIC test facility, succeeding in monitoring automatically the position of the cells to within 3 micrometers.

- LEP spectrometer
  Another application regarding WPS is the LEP spectrometer designed for measuring very accurately some possible slight changes of the beam position monitors during operation of the accelerator, with the following features:
  - required accuracy for the relative movements of the BPMs: ± 1µm
  - reproducibility of WPS measurements: ± 0.2 µm; range:± 2.5 mm

  All elements were settled on 6 marble blocks. Both BPM and WPS reference instruments were in temperature-controlled containers, while wires were contained in a stainless steel pipe. All sensors and electronics were shielded against radiation [5].

- LEP low-beta inner triplets
  HLS systems were installed on the low-beta quadrupoles to measure the movements of the magnets continuously, leading to a feed-back system using these measurements for a correction of the vertical orbit. The precision of the HLS is limited by thermal-induced density differences of the water in the connecting tubes. For topological reasons, these pipes could not be kept horizontal in the environment, and the main problem was that the temperature conditions were not the same on each side – for several degrees – in this complicated path. The only solution was then to make the water circulate through a large tank in order to quickly homogenize the temperature measurements and then switch the system to its static configuration in order to perform coherent measurements [5, 7].

3.1.2 Present and future examples

- LHC low-betas
  Alignment tolerances for the LHC insertions are particularly stringent regarding the low-beta quadrupoles, i.e.:

- positioning of one inner triplet w.r.t left/right side :± 0.5 mm (3σ), and
- stability of the positioning of one quadrupole inside its triplet : a few microns.

The maintenance of this alignment involves the quadrupoles Q1, Q2 and Q3 equipped with permanent instrumentation. The position of each cryostat is monitored w.r.t. a reference position. When the deviations w.r.t. the reference positions become too big, it is possible to take back each cryostat to its reference position, using the motorized jacks.

Regarding the remote control of one inner triplet, the radial position of the quadrupole of one inner triplet is controlled with a wire stretched between D1 and Q1 and considered as a reference. The wire is fixed with a constant tension to elements that are independent from the quadrupoles to be controlled. This line is called the Inner Triplet Line. The Wire Positioning System sensors (WPS) are plugged to the fiducials dedicated to the remote control and located on the passage side of the cryostat. The vertical position and transversal tilt (roll angle) are controlled with the Hydrostatic Levelling System. All the fiducials dedicated to the remote control are equipped with a HLS sensor [6].

Regarding the relative positioning of the two inner triplets, in the horizontal plane, both Inner Triplet Line (ITL) on left and right side are linked continuously to the same Offset Reference Line (ORL) with 6 invar rods measuring with sensors the distance between ITL and ORL. The Offset Reference Line is a 126 m long stretched wire, crossing the galleries devoted to surveying and the experimental cavern [6].

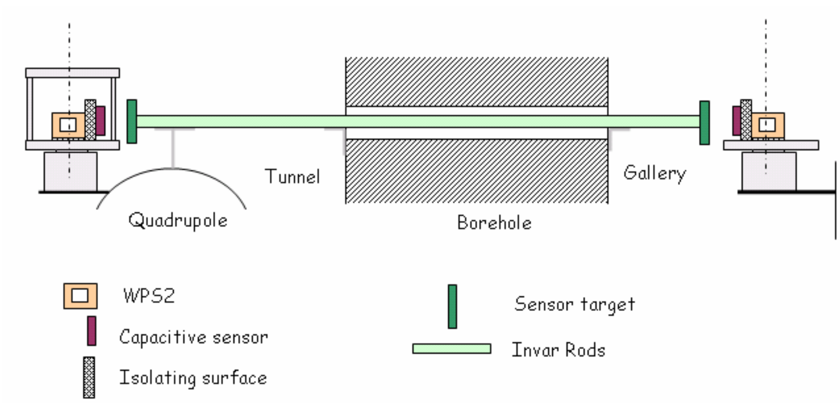


Figure 5 : Invar Rod system [6]

- CLIC
  The initial alignment tolerance of the transverse positions of the components of the CLIC linacs is typically 10 microns over a distance of 200 m and cannot be obtained by a static on-time alignment (because of seismic ground movement, and noise associated with human and industrial activity). Figure 6 contains one possible proposed solution.

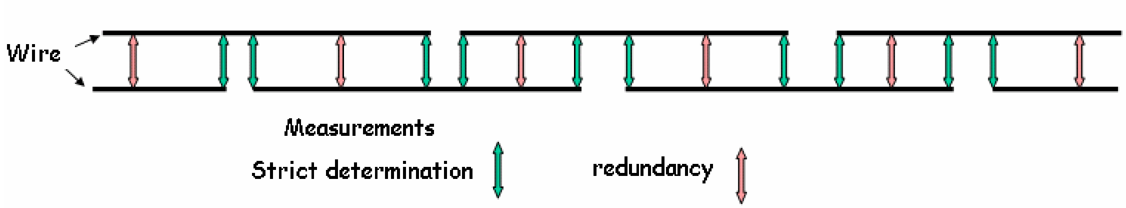


Figure 6 : Wires overlapping [1]

The accelerating or transfer cavities and the beam position monitors are laid on girders on pre-aligned Vs. The girders are supported by inter-girder articulation supports. The initial alignment consists of aligning the articulation points of the girders. Each articulation point is equipped with a RASNIK-

CDD transmitter, lens and sensor side by side. This allows the measurement of the misalignment of each articulation point w.r.t. the straight line joining the two adjacent articulation points. At regular intervals of approximately 49 m (22 modules), the articulation points are connected to a network of stretched wires by a combination of two offset and tilt monitor measurements. This network consists of two lines of wires about 98-m long, parallel to the linacs and overlapping by half their length [1].

3.2 Applications in other fields of activity

- SwissMetro / HISTAR

  Swissmetro is a new high speed transport system, able to carry passengers in full safety at speeds exceeding 400 and even 500 km/h. HISTAR project is a reduced-scale rig under construction in Lausanne with the purpose of analyzing the aerodynamic effects generated by the high-speed transport systems in general and the Swissmetro system in particular. The minimal requirements for the allowed difference between the track geometry and an ideal line are 1 mm overt 7 m, 0.1 mm over 2 m and 0.02 mm over 1 m. These requirements led to the following proposition: a train of 3 WPS sensors all along the 250 m track. Each measurement corresponds to the distance of the tightened wire w.r.t. the sensor. These observations allow computing the misalignment of the central sensor with respect to the other two [8].

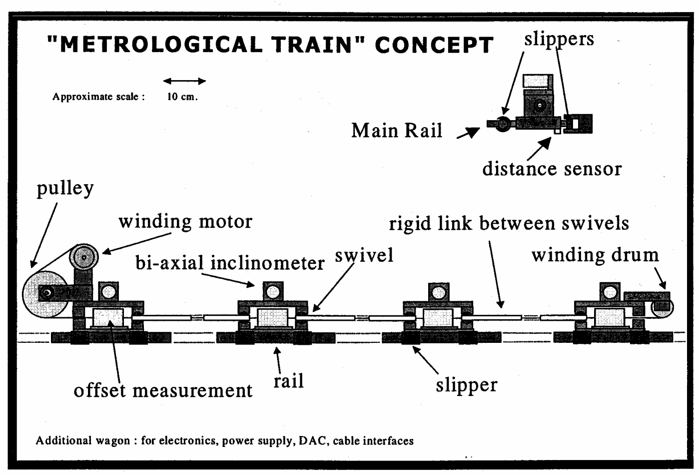


Figure 7 : The « metrological train » concept [5]

4 CONCLUSION

New techniques are being developped to achieve the stringent alignment tolerances needed for the next generation of accelerators: the sensors or systems like the HLS, the WPS, the TMS and the RASNKIK-CCD described in that report are revolutionizing survey measurements and methods, allowing thrilling possibilities. The introduction of such devices in the daily life of the surveyors is changing little by little their professional skills, opening the range of their competences in fields like precision mechanics, electronics, hydraulics, vibration measurements. What a great challenge!

5 ACKNOWLEDGEMENTS

All the developments, tests, improvements concerning HLS, WPS, TMS and RASNIK-CCD have been initiated and carried out by Williame Coosemans, who retired in 2003.

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