euspen's 15th International Conference & Exhibition, Leuven, Belgium, June 2015
www.euspen.eu

New potential for the Leitz Infinity Coordinate Measuring Machine

C.SANZ[1], A.CHERIF[1], H.MAINAUD-DURAND[1], J.SCHNEIDER[2], N.STEFFENS[2], P.MORANTZ[3], P.SHORE[3]

[1] CERN, Meyrin (Switzerland) *[2]HEXAGON Metrology, Wetzlar (Germany)* *[3]Cranfield University (United Kingdom)*

Claude.Sanz@cern.ch

Abstract

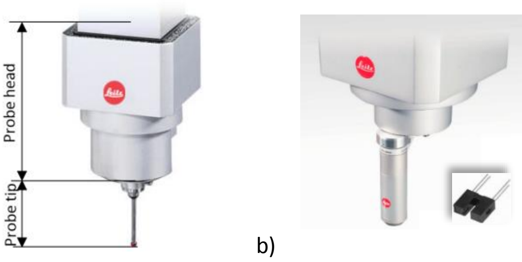
The following study is realised within the frame of the PACMAN project: a study on Particle Accelerator Components Metrology and Alignment to the Nanometre scale, which is a Marie Curie program supported by the European commission and hosted by CERN (European Organisation for Nuclear Research). The aim of this program is to develop and build a pre-alignment bench on which each component is aligned to the required level in one single step using a stretched wire. During the operation, the centre of the stretched wire is aligned with the magnetic axis of the magnet. Then, the position of the wire is measured to the highest possible accuracy using a 3D Coordinate Measuring Machine (CMM) Leitz PMM-C Infinity from HEXAGON Metrology. The research described in this paper is two-fold: on one hand we apply a strong magnetic field to the head of the CMM and evaluate its influence on the measurement accuracy; on the other hand we measure the position of the wire using different non-contact probes to assess their capability to determine it with a sub-micrometre accuracy.

Metrology, Coordinate Measuring Machine, Magnetic measurements, Non-contact probing

1. Introduction

The request for high energy colliding particles is increasing as the knowledge about the universe is broadening. In the world of particle accelerators, the alignment of the different elements to the required precision is a complicated and time consuming task; the PACMAN project aims at automatize this procedure using a wire as a reference. The wire is already used efficiently to fiducialize magnets [1] and the accuracy of this process should be increased by the use of a Coordinate Measuring Machine (CMM) to perform the measurements, as it is usually [2]. Indeed, this study is about the adaptation of the Leitz PMM-C Infinity CMM to the high accuracy measurements needed for the PACMAN project: first its behaviour in a magnetic field is assessed, and then non-contact probe tips used for measuring the position of the wire without touching it are evaluated.

2. Influence of a magnetic field on the LSP-S4 probe head



a) b)

Figure 1: a) The probing parts
b) The Precitec LR sensor and the SHARP optical switch

The LSP-S4 probe head of the Leitz Infinity CMM (see figure 1a) is a complex assembly which changes its shape when a force is applied on the extremity of the probe tip during a contact measurement. This change in shape provides part of the information about the position of a measured point. A magnetic field may induce a force on some parts of the probe head (for instance if a 2,54 cm in diameter disk of iron was brought close to the pole of the magnet used in the PACMAN project it would undergo a strength of ~130N≈13,4Kg). The behaviour of the mechanical parts of the probe head is very well-known when used in usual conditions, nevertheless it had never been assessed within a strong magnetic field. The magnetic field remaining around the magnet used for the PACMAN project is not pulsed, this is why for the tests a strong permanent magnet has been used to create a similar environment around the head.

2.1. Protocol for the magnetic measurements

The magnetic measurements have been performed directly on a PMM-C Infinity CMM at HEXAGON Metrology in Wetzlar. Actually, to measure the impact of a strong magnetic field on the behaviour of the head, a probe tip made of weakly magnetic hard metal was used. It has been calibrated first without any magnetic field to give a reference, and then several measurements of the calibration sphere were done within magnetic fields of different strength at the height of the probe tip first, and then at the height of the probe head. All the magnetic fields have been measured using a Metrolab Hall probe [3].

2.2. Results

No change is visible when the magnet is at the probe tip height for a magnetic field increased up to 20mT.

PACMAN is funded under the European Union's 7th Framework Programe Marie Curie Actions, grant PITN-GA-2013-606839

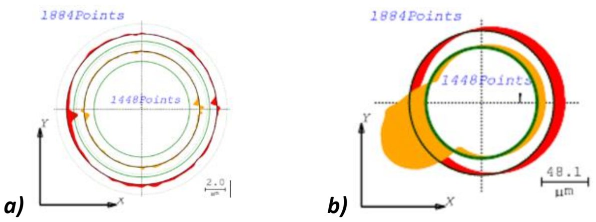


Figure 2: Deviation plot of the sphere: a) at 0mT; b) at 3mT

On the contrary, when the magnet is at the head height there is a big impact from the magnetic field on the measurements: ~55µm as can be seen on figure 2. Further investigations will aim at understanding in detail this phenomenon which will be the object of another paper.

3. Non-contact probe tips for wire measurements

The wire used for the PACMAN project will be a copper-beryllium wire with a diameter between 100µm and 500µm. For all these measurements, the diameter was chosen equal to 100µm. The first trials were to measure the wire position with a contact probe tip: for 25 measurements, the repeatability was $3\sigma_Y$=12,6µm & $3\sigma_Z$=14,4µm for a wire along the Z-axis, and the diameter of the measured circle was found negative as the wire was pushed during the probing. These results imply the need for a non-contact probing. Several possibilities exist and are under test for this project: namely LASER sensors such as the KEYENCE 9006 [4], capacitive sensors such as the Wire Positioning Sensors, and optical sensors such as the ones described below.

An optical probe-tip has already been integrated by Leitz to the Infinity CMM, namely the Precitec Lateral Resolution sensor (see figure 1b) [5]; the measurements were started with this one. Then the second series of measurements were performed with a white light Precitec sensor, and finally a completely different type of sensor was tested: an optical switch from SHARP (see figure 1b) [6]. The Precitec sensors are based on the chromatic confocal technique [7] monitored by the CHrocodile controller [8], whereas the optical switch is composed by an infrared light beam going from a source to a phototransistor -- a drop in the light intensity is observable on a voltmeter when the wire enters the light beam.

3.1. Protocol for the assessment of the repeatability of non-contact probe tips

The first characteristic evaluated for the different sensors was the repeatability. For the PACMAN project, the aim is to achieve a measurement of the position of the centre of the copper-beryllium wire with a repeatability 3σ<0.5µm. In order to evaluate this statistical result, the position of the centre of the wire has been evaluated 100 times. Two measurements are needed for defining the position of one centre: one vertical and one horizontal (see figure 3a).

With the Precitec sensor, for each measurement, two scans are performed: the first scan is to give a good estimation of the position of the centre of the circle going to be measured by the second scan, so that the latter is performed at the optimised distance. With the SHARP optical switch probe, the wire is translated through all the infrared beam while the controller of the coordinate measuring machine records the position of the sensor and the voltage corresponding to the detected intensity. The maximum of the recorded voltage gives the vertical (see figure 3b) or the horizontal position of the centre of the wire.

3.2. Results

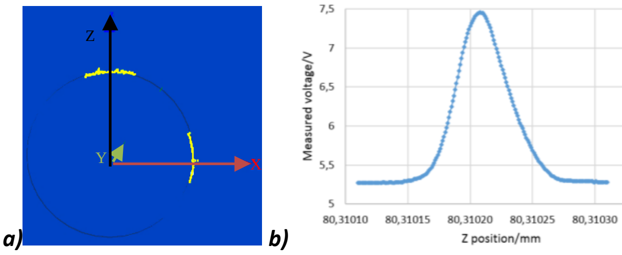


Figure 3. Typical results: a) for the Precitec LR sensor
b) for the SHARP optical switch

The coordinate system is with the Y-axis along the wire, so that the centre is positioned in the XZ-plane, as shown on figure 3a.

Table 1

Repeatability measurements	**Number of samples**	**3σ/µm**
Lateral Resolution Precitec	100 circles	$3\sigma_X$=0.9 $3\sigma_Z$=0.6
White light Precitec	100 circles	$3\sigma_X$=1.45 $3\sigma_Z$=1.88
SHARP optical switch	30 measurements	3σ=1.5

4. Summary, conclusion and future work

4.1. Summary

The behaviour of the probe head has been assessed within a strong stable magnetic environment, and no changes could be noticed for a magnetic field up to 20mT at the probe tips height. Nevertheless, when the magnetic field is at the probe head height, important changes are occurring.

Concerning the non-contact measurements of a wire, different types of probe heads have been evaluated and despite the slopes of the wire due to its smallness, the repeatability of the positioning of the centre has reached $3\sigma_X$=0.9µm & $3\sigma_Z$=0.6µm for the Precitec sensors, and 3σ=1.5µm for the SHARP optical switch.

4.2. Conclusion

As the magnetic field at the probe head height has an impact on the measurements, further studies will be necessary to deeply understand it and to attempt to correct it.

The repeatability of the different sensors assessed in this study does not fulfil the PACMAN project requirements, so more investigation on what could be improved to reduce the uncertainty is needed.

4.3. Future work

The optical switch will undergo other tests as this setup was not optimised: the resolution of the acquisition system should be improved and the sources more stabilised. For the PACMAN project, other sensors will be qualified and when the repeatability will fit its requirements, the next step will be to assess the trueness of the sensors.

More investigations focused on the behaviour of the probe head are to be performed in order to discover which parts are reacting to the magnetic field, and how they can be replaced or adapted to this environment.

The wire is the reference of the alignment, which is why different measurements will be performed to evaluate its characteristics, namely its roundness, its form, the regularity of its diameter along its length…

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Sanz, Claude

2015-06-01

Sanz C, Cherif A, Mainaud-Durand H, Schneider J, Steffens N, Morantz P, Shore P, New potential for the Leitz Infinity Coordinate Measuring Machine, Proceedings of 15th International Conference of the European Society for Precision Engineering and Nanotechnology, EUSPEN 2015, 1-5 June 2015, Leuven, Belgium

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