A ROTARY MOUNT FOR POSITIONING A STRETCHED WIRE AXIS WITHIN A COORDINATE MEASUREMENT MACHINE

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Abstract

The European Organisation for Nuclear Research (CERN) is studying future colliders for increasing the chances of new discoveries. Among them there is the Compact Linear Collider (CLIC). This electron-positron collider with a sub-micrometric beam size would require a pre-alignment of its thousands of elements within tolerances at the micron level. For this, a test bench where the pre-alignment is performed in one single series of measurements using a stretched wire as a reference is being considered. This study is the focus of the PACMAN project, a study on Particle Accelerator Components' Metrology and Alignment to the Nanometre scale. This project is a Marie-Skłodowska Curie Program supported by the European Commission (FP7 Program) [1].

This series of measurements consists in the alignment of a stretched wire at the theoretical position of the beam in each collider element, followed by its location with respect to references positioned outside the element. The challenge is to measure the form error of this wire with 0.1 µm accuracy and its position with 0.5 µm precision on a Coordinate Measuring Machine (CMM). For this purpose, a non-contact sensor is being mounted on a support so that it can rotate. This paper introduces the requirements for this support and the sensor: no magnetic fields created, high accuracy on the positioning, low error motion, open on the side; and it describes and discusses the technical solutions: from the material to use to the bearings, including the kind of sensor.

INTRODUCTION

The scientific community wants to deeper understand the particles composing the Universe and the bounds between them. The aim of the Compact Linear Collider is to increase the possibilities of such discoveries.

The pre-alignment of this electron-positron accelerator is a technical challenge on which the PACMAN team is working, using a stretched wire as a reference. This wire is a copper-beryllium wire with a diameter of 0.1 mm. As this reference is not perfect, its form must be measured in order to reach the expected accuracy for the positioning of its axis.

Despite that non-contact form error measurements can be done within dedicated environments as well as within a CMM on samples with limited slopes, currently no sensor has been designed to measure the form error of a small element such as a stretched wire within a CMM. The study on the design and the requirements of such a system are described in this paper.

CONTEXT: WHY USE A ROTARY MOUNT FOR ADAPTING A NON-CONTACT SENSOR TO A CMM?

The pre-alignment of the particle accelerator is done first by materialising the functional axis of an element with a stretched wire, second by measuring the axis position with respect to external reference markers, third by using these references in the tunnel. For the second step, the dedicated CMM at CERN for the CLIC study is the Hexagon Manufacturing Intelligence Leitz Infinity. Currently, it does not have any rotary measuring part despite that a rotary sensor would be optimised for accurate non-contact measurements of some samples. The design discussed in this paper has the purpose of providing this accurate rotary connexion.

This mount will be able to measure different objects, nevertheless is has been optimised to measure the PACMAN project's reference stretched wire. A stator part will be rigidly linked to the CMM clamped head, whereas a rotary part will be performing the measurements with the sensitive element. Due to the accuracy required on the positioning of the wire axis and the form error measurement, the motion error of the mount after mapping is expected to be smaller than 0.1 µm. This implies:

• high accuracy guiding bearings
• a stiff material for both the stator and the rotor
• a high accuracy form error measurement sensor, which will be fixed on the rotor
• an encoder system to know the sensor's position with the best possible accuracy during the measurements
• a motor to master the rotor's move during the measurement

Furthermore, as one of the elements to be aligned is a quadrupole magnet, the assembly must withstand strong magnetic fields without creating any field strong enough to disturb the quadrupole's magnetic field. Finally, as the measurement is performed on the CMM in a stabilised metrology room, a low heat emission of the mount and a weight fitting with the machine's head limit are additional requirements. The last requirement is on the size, which should fit with the application: the PACMAN bench (width < 100 mm, see Figure 1).

Tolerances for the rotary mount assembly have been defined and a study on the commercialised components which could fit with them is done. They created new

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requirements or amended the first ones. The selected components were ordered and tests will be performed to characterise them before the assembly will be assessed as a whole. The next chapter focuses on the details of the definition of the requirements and the study of existing solutions.

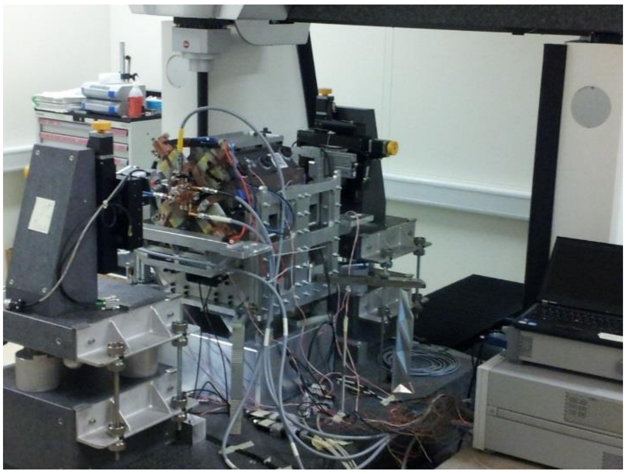

Figure 1: PACMAN quadrupole magnet on the CMM.

THE ROTARY MOUNT'S PARTS REQUIREMENTS AND CONSIDERED SOLUTIONS

The sensor

The sensor must:

• be able to measure the form error of 0.1 mm diameter cylindrical features with the best possible repeatability (< 0.1 µm)
• be as light and small as possible
• be regulated in temperature by the CMM environment
• withstand medium to strong magnetic fields (15 mT)

Additionally, the cables linked to the sensor should not add to the rotor's weight a force greater than the stiffness of the rotor's guiding.

The evaluation of the existing technologies [2] led to the conclusion that the chromatic confocal technique [3] fulfils these requirements.

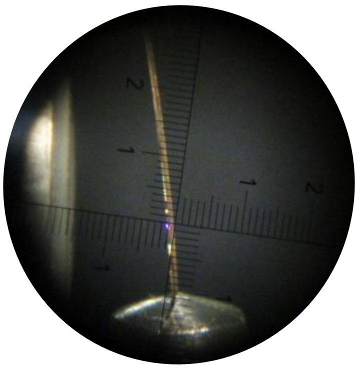

Figure 2: Chromatic confocal sensor's purple spot on a 0.1 mm wire seen through a magnifier.

The encoder system

The encoder has a key role in the accuracy of the final rotary sensor as the measurement accuracy relies on the high quality of the sensor's positioning during the measurement. To obtain this, synchronisation between the reading of the position and the reading of the distance provided by the sensor is essential, as well as high accuracy position reading. In addition, the scale should fit with the opening and the limited space available on the CMM. This means that the encoder must:

• be positioned so that it is reducing the Abbe error
• be fast in reading and sending the information
• have the highest number of graduations enabling high angular resolution (< 2.10^{-6} degree)
• not be a complete ring
• be adapted to a surface with a small radius of curvature •
• have a frequency match with the controller of the CMM (which limits the displacement speed)

A linear scale with a reading pitch of 20 µm, wrapped around the rotor, could fit with the application, with an adapted reader. Nonetheless, this implies a limitation in the rotor's radius which should be greater than the minimum bending radius of the encoder, and the tightening elements of the scale reduce the coverage of the rotation.

Figure 3: The encoder scale and reader.

The motor

The motor must:

• be as light and small as possible
• withstand strong magnetic fields
• not create any magnetic field
• have a low power loss since passive cooling by the air stream of the CERN Metrology laboratory is required
• have a sub-micrometric resolution in displacements
• have a torque large enough to master the rotor's move

These requirements eliminate most of the existing motors, nevertheless, a piezo motor fits them. This kind of motor is based on the friction force between two small piezo legs and a ceramic surface. It is capable of bidirectional action. The leg is extended when the motor stops, which means that it blocks the rotation without any power consumption and without any vibration similar to what a servo would create. Furthermore, the electronics controlling the motor is deported on a rack with a five-meter-long cable, which makes possible an optimised cooling of the electronics.

The guiding bearings

Despite the opening in the rotor eliminating most of the possibilities for high precision guiding systems, the new air-pad technologies makes possible the guiding of this rotor. Indeed, the design is based on the use of air-pads composed of a porous medium which allows working on a perforated surface without affecting dramatically the behaviour of the system.

In order to increase the stiffness necessary for the motion error targeted (< 0.1 µm after the correction of systematic errors), the air pads will be opposite each other (see Figure 4) and loaded as much as possible, namely between 111 N for the larger ones and 23 N for the smaller ones. Moreover, simulations and tests are being performed to predict the behaviour of the pads so that any risk of collision between the rotor's bearing areas and the air pads due to the opening in the rotor will be eliminated.

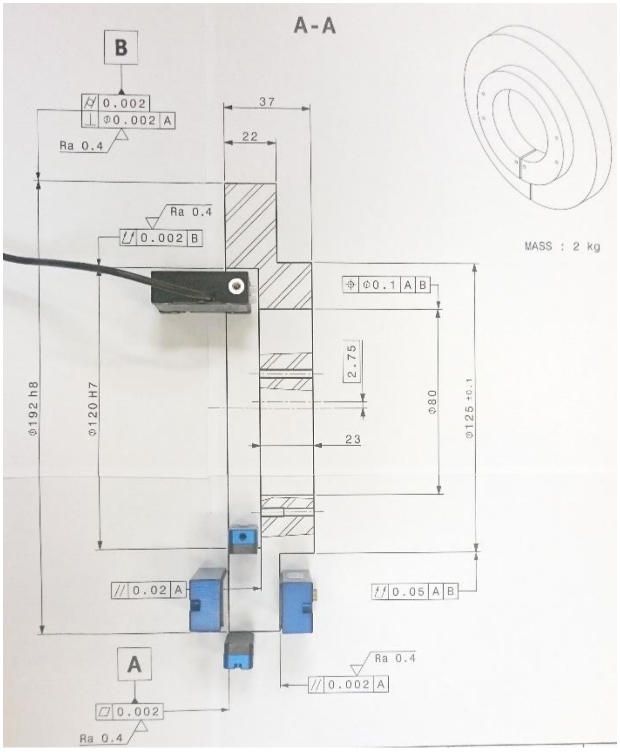

Figure 4: Photo of the technical drawing showing the positioning of the air pads (blue) and the piezo motor (black) as well as the tight tolerances linked to them on the ceramic rotor.

The material

The material of the rotor must be:

• light and stiff
• non-magnetic
• possible to be machined to the required tolerances (< 2 µm radial and axial runout on the bearing surfaces) with as little internal stresses as possible

The path for the motor should be a flat surface (< 20 µm axial runout) made out of alumina ceramic or a harder material to prevent abrasion by the motor's ceramic legs.

As the alumina ceramic is fulfilling all the rotor's requirements apart from lightness, this material has been chosen for the prototype used for the proof of concept. Nevertheless, the best option for the rotor is still under study.

Concerning the stator, the material must be light and stiff for the final version so that it can be carried by the coordinate measuring machine. Nevertheless, for the sensor's preliminary tests, the stator is made out of aluminium as it will be standing on a granite table (see Figure 5). A next version is being optimised: it may be made out of titanium, with a weight reduction compared to the aluminium stator thanks to the use of the shape freedom brought by the additive manufacturing technology.

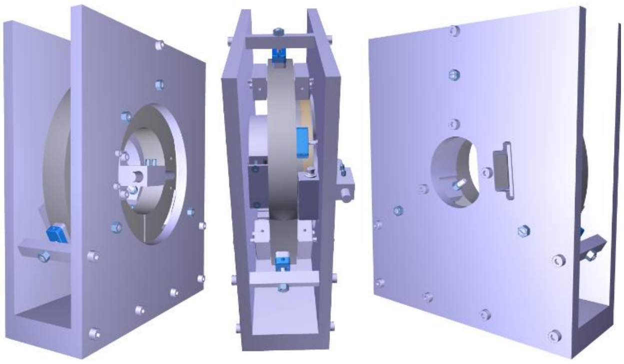

Figure 5: Computer assisted drawings of the test version of the sensor mount, to be standing on a table

SUMMARY, CONCLUSION AND FUTURE WORK

A rotary mount is being designed by a Ph.D. student from Cranfield University within the CERN Metrology Laboratory. The aim is to make possible the form error measurement and sub-micrometric positioning of small cylindrical features such as a stretched wire. The requirements for its different parts have been described and existing solutions have been considered.

The design of this mount is in progress and the simulations as well as the validating tests are to be undertaken. A non-negligible part of the future work will be the integration on the CMM and the calibration process of the sensor.

REFERENCES

[1] N. Catalán Lasheras et al., "Measuring and aligning accelerator components to the nanometer scale", IPAC 2014, Dresden, Germany, 2014

[2] C.Sanz et al.,"Characterisation and measurement to the sub-micron scale of a reference wire position", CIM, Paris, France, September 2015

[3] C.Pruss et al., "Diffractive Elements for Chromatic Confocal Sensors", DGaO Proceedings 2005, ISSN:1614-8436