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DETERMINATION OF THE MAGNETIC AXIS OF A CLIC DRIVE BEAM QUADRUPOLE WITH RESPECT TO EXTERNAL ALIGNMENT TARGETS USING A COMBINATION OF WPS, CMM AND LASER TRACKER MEASUREMENTS

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Abstract

CERN is currently studying the feasibility of building a high energy e+ e- linear collider: the CLIC (Compact LInear Collider). One of the engineering challenges is the pre-alignment precision and accuracy requirement on the alignment of the linac components. For example, the magnetic axis of a Drive Beam Quadrupole(DBQ) will need to be aligned within 20µm RMS with respect to a straight reference line of alignment over 200 m. The fiducialisation process which is the determination of the magnetic axis with respect to external alignment targets, that is part of this error budget, will have to be performed at an accuracy never reached before. This paper presents the strategy proposed for the fiducialisation of the Drive Beam Quadrupole, based on a combination of CMM measurements, WPS measurements and Laser tracker measurements. The results obtained on a dedicated test bench will be described as well.

INTRODUCTION

The fiducialisation is the determination of the axis of a component with respect to external alignment targets, named fiducials [1]. Since the beginning of the CLIC project, the fiducialisation process has been carried out by using only some CMM (Coordinate measuring machine) measurements used to determine the position of the mechanical axis of a component. While this fiducialisation is sufficient for testing the alignment procedure, but for the installation of the module in a real particle accelerator, it will be necessary to fiducialise the Drive Beam Quadrupoles (DBQ) with respect to their magnetic axis [2].

The method of using a vibrating stretched wire to determine the magnetic axis of a DBQ has been improved by the CERN magnetic measurements group for several years, reaching a precision of a few micrometers and an accuracy of a few tens of micrometers [3]. Throughout this paper, this measurement method will be called "traditional method". But for the CLIC project, the accuracy of the fiducialisation should be better than 10µm in the global budget of error concerning the alignment of the components [4] and this method is not accurate enough. A new method is proposed to improve the accuracy of the fiducialisation measurements keeping the method of vibrating wire [5] but using a fiducialisation bench combined with WPS (Wire Positioning Sensor) sensors [6] and AT401 laser trackers measurements [7]. This paper will introduce both traditional and new methods and will present the following results:

- Repeatability of the determination of the magnetic axis,
- Influence of different types of wire on the determination of the magnetic axis,
- Impact of the intensity of the magnetic field,
- Intercomparison between the two methods.

TRADITIONAL METHOD

The traditional method uses setup described below in figure1.

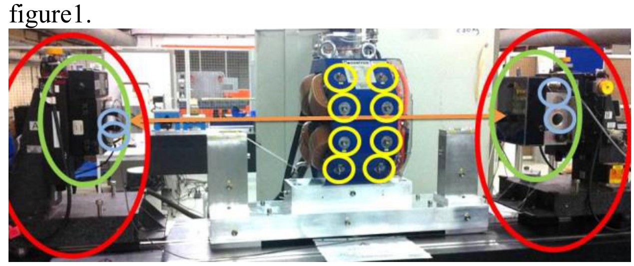

Figure 1: Traditional method

The vibrating wire system consists of a metallic wire, with a diameter of the order of a tenth of a millimetre. The wire passes through the magnet and is stretched by means of a motor coupled to a tension gauge. Referring to figure 1, the wire (orange arrow) is fed with a sinusoidal current. The wire supports are mounted on two translation stages (red circle) that allow the wire vertical and radial displacement with a 0.1µm resolution. The first harmonic mode is excited to find the radial and vertical position of the magnetic centre of the magnet. A parallel movement of the wire is then carried out where the oscillation of the wire takes the minimum amplitude. To find the correct orientation of the magnet (pitch and yaw), an anti-parallel movement of the wire is performed and this not changing the position of the centre of the magnet. This time, the second harmonic signal is analysed; the magnetic axis is found when the oscillations of the wire take the minimum amplitude.

Once the magnetic axis of the magnet is determined, the position of the wire with respect to the fiducials on the magnet must be measured. At CERN metrological lab, the position of the wire has been determined, with micrometric precision, with respect to the two fiducials fixed on each translation stages. The positions of the stages' fiducials (blue circle) and the magnet's fiducials (yellow circle) are then measured using the Leica 500 LTD. The position of the magnetic axis can then be deduced from the magnet fiducials.

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NEW METHOD

Introduction

The goal of this project is to develop a method to fiducialise the magnets as accurately as possible, changing the way of measuring the position of the stretched wire with respect to the magnet fiducials. In order to get the absolute position of the magnetic axis with respect to external fiducials, the use of fiducials fixed on marble does not seem optimal. For several years, the CERN has been working on the absolute position of the capacitive Wire Positioning Sensor (WPS) and more particularly in the implementation of a kinematic mount providing a referential frame for each sensor [8]. The absolute determination of the position of the wire is possible within 5µm along the two axes of the WPS sensor (radial, vertical). Such sensors could be used for the absolute determination of the position of the wire, combined with AT401 measurements to link the sensors readings and the external fiducials of the magnet. To perform these tasks, a bench equipped with WPS sensors was manufactured. The position of the fiducials and kinematic mount interfaces of sensors of the bench will be determined with micrometric precision at the CERN metrological lab.

The design of the bench is visible on figure 2.

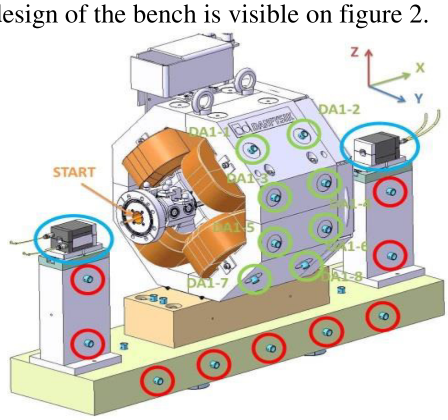

Figure 2: fiducialisation bench and its DBQ

The measurements process will consist in:

- The determination of the position of the magnetic axis using to the vibrating wire,
- The determination of the position of the wire using the WPS sensor (blue circles),
- The measurements of the fiducials of the magnet (green circles) and fiducials of the bench (red circles),
- The determination of the position of the fiducials of the DBQ with respect to the magnetic axis.

Error budget

A tentative errors budget has been set before the measurements taking into account:

- The position of vibrating wire on the magnetic axis ~1µm,
- The error opening and repositioning the sensors ~5µm,
- The uncertainty of measurements of the CMM ~1µm,
- The uncertainty on bench and DBQ fiducials measurement with the AT401 ~5µm,

As these sources of error are independent, a quadratic sum was performed to give an approximation of the overall error of the fiducialisation process. The global error budget is estimated at 7.2 µm.

MEASUREMENTS RESULTS

Two measurement campaigns have been made to validate this bench. During these two campaigns, the two measurement methods were compared.

First campaign

During the first campaign, three different wires of 0.1 mm diameter have been tested: Beryllium Copper 2013 (Cu-Be 2013), Beryllium Copper 2003 (Cu-Be 2003) and Niobium Copper (Cu-Nb). To test the repeatability of the magnetic axis determination, five different re-positioning of the DBQ have been made on the bench for the Cu-Nb wire and 4 for each Cu-Be wire, so 13 measurements in total. Best-fits have been performed on the fiducials of the DBQ measured with the AT401.

For the new method, the standard deviations AT401 are at micrometre level for x, y and z. The magnetic centres of the magnet are determined with a standard deviation of 2 µm in radial and 4 µm in vertical. For the longitudinal positions, a 6 µm standard deviation is obtained.

For the traditional method, the standard deviations on the fiducials measurements using AT401 are also at micron level for x, y and z. The magnetic centre of the magnet is determined with a standard deviation of 3µm in radial and 4 µm in vertical. For the longitudinal positions, a 6 µm standard deviation is obtained.

These initial results were very positive. A good repeatability of measurements was found for both methods. Some problems on repeatability were due to a non-optimal use of the laser tracker. The three wires give the same magnetic axis positions accuracy.

A best-fit was performed on the average positions of the external fiducials for the two methods to compare them. Table 1 shows the differences obtained between the average positions of the two methods:

Table 1: Differences between the two methods

Difference	X (µm)	Y (µm)	Z (µm)
Start	-2	26	3
Mid	-1	26	3
End	-1	27	1

The average positions of the magnetic axis in vertical for the two methods show a difference of less than 3µm. But in radial, the difference is of 26 µm. A systematic error was certainly present on one of the two fiducialisation methods. The goal of the second measurement campaign was to investigate this aspect

Second campaign

The second campaign of measurements has been realised in March on a different DBQ magnet. To try to understand the radial deviations obtained between the two methods, the DBQ fiducialisation was performed on both sides of the magnet. The objective is to see if the

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measurements made on the two sides of the magnet give the same position of the magnetic axis. The measurements have only been made with the Cu-Nb wire since, as mentioned, we checked that the type of wire utilized does not impact the measurement. The determination of the magnetic axis with the Cu-Nb wire was repeated 3 times (3 DBQ different re-positions on the bench) on each side of the magnet.

For the new method, the standard deviations on the fiducials measurements using AT401 are in micrometre range for x, y and z, on both sides of the magnet. Magnetic centre determination shows a standard deviation lower than 2 µm in radial and vertical. For the longitudinal positions, a 3 µm standard deviation is obtained. This time, the standard deviations are calculated only on a set of three measurements. In order to perform a best-fit between the two sides measured, a survey with the AT401 has been performed. This survey allows us to have the coordinates of the 16 fiducials on the same coordinate system. The deviations obtained on the magnetic axis when the two sides of the DBQ are compared with the new method are the following: for the magnetic centre, a radial deviation of less than 3 µm and a vertical deviation of less than 4 µm have been found. For the longitudinal, a 1.474 mm deviation between the two longitudinal positions is obtained. This difference is easily explainable. Indeed, the fiducials were fixed on both sides without being precisely positioned and the average longitudinal position is taken to determine the centre of the magnet. This offset between the longitudinal positions is not impacting the study. In fact, the determination of the longitudinal position could be easily improved by using the existing machined references holes in the magnet.

For the traditional method, the standard deviations are very close to the results of the new method but there is an offset of more than 60µm in radial. This error is maybe due to CMM measurements of the marbles fiducials used to determine the position of the vibrating wire or to the prisms used during measurements, but the problem has not been identified yet.

Intensity of the magnetic field

The nominal current for the operation of the magnets is 82.5A. Anyhow, in the Test Facility where the magnets will be installed, the magnet current will be much lower, of the order of 4 A. A measurement was therefore carried out to see how the position of the magnetic axis depends on the operating current, in figure 3.

Between 40 and 100 A, the magnetic axis is stable. But, at 4 A, the axis moves significantly (21µm vertical and 47µm radial). Repeated tests showed that the magnetic axis displacement is reproducible.

CONCLUSION

The new method shows an improved precision and accuracy in the fiducialisation; accuracy is close to what is needed for the CLIC DBQ magnets. Positive points are:

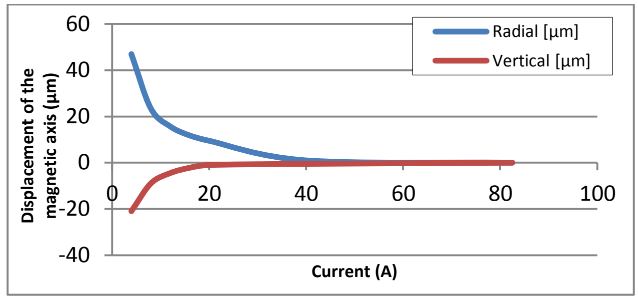

Figure 3: Position of the magnetic axis as a function of the current on the DBQ

good repeatability found and a measurement accuracy not depending on the type of wire utilized. A 27µm difference between the results obtained with the two methods for the radial reading was observed in the first series of measurements. The error seems to be coming from the traditional method. With the second series of measurements of the new method, the determination of the position of the magnetic centre, on both sides is found within a 3µm precision. For the traditional method, precision found was within a 60µm.

In conclusion, the two magnets must be fiducialised at 4A. The new method seems a very positive starting point for the PACMAN (Particle Accelerator Components Alignment and Metrology to the Nanometre scale) project [9] where the AT401 and the bench will be replaced by CMM measurements. Results will be certainly more accurate but measuring system less portable.

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