Assessment of the impact of the articulated probe head angular orientation on the probe head errors distribution

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Abstract

The probe head is an essential part of any coordinate measuring system. In the case of Coordinate Measuring Machines the best accuracy is achieved using tactile probe heads. The articulated probe heads provide easier access to the measured object from different directions. In this article, authors try to assess the impact of the angular orientation of the probe head, on the distribution of measurement errors.

Keywords

Coordinate Measuring Systems, probing systems, measurement accuracy.

1. Introduction

Modern measuring systems have to fulfil demands formulated by the industry which include: measurement automation, short measurement duration and probably the most important, appropriate accuracy. The Coordinate Measuring Technique (CMT) met all mentioned requirements. In CMT the dimensions and information about object geometrical features are obtained on the basis of measured points coordinates. Such approach guarantees high versatility of Coordinate Measuring Systems, because the same measured points can be utilized during evaluation of different features. Thus, it can be said that point coordinates measurement is the only direct measurement in case of CMT, and that probing process is crucial for any Coordinate Measuring System. The CMT offers variety of devices which differ among themselves in terms of application and working principle. The main tool of CMT is a Coordinate Measuring Machine. Such machines allow measurement automation and also achieves the best accuracy, up to tenths of micron. They use different probing systems for coordinates acquisition process. The most popular classification divides probing systems into: tactile and contactless. The first group is considered to be more precise, in the other hand contactless probe heads allow to measure thousands of points in a very short time. The data obtained in such a way (in form of cloud of points), are used for instance in reverse engineering or directly in quality control of free form objects. Both groups are constantly developed. The recent trend in the field of tactile probe heads are so-called 5-axis measuring systems (in literature also known as articulated probe heads). These systems are able to shorten the measurement duration, without deteriorating its accuracy. Of course, as a relatively new system, the 5-axis probe heads requires detailed studies, primarily in terms of measurement uncertainty. Generally, the estimation of coordinate measurement uncertainty is a challenging task. Due to the complexity of measuring devices, large number of possible measurement tasks and the high cost of coordinate measurements, the methodology for uncertainty estimation must be established in a very thoughtful way. The standard methods for CMM uncertainty estimation (such as calibrated workpiece method) usually involve multiple repetition of measuring tasks, they also require special standards and experienced staff. Another approach is represented by the simulation methods, especially the method of the Virtual Machine. However, application of this solution must be each time preceded by extensive studies on the individual CMM model, in order to determine the impact of the main measurement uncertainty contributors on the measurement. The issue of coordinate measurement uncertainty has been studied for many years at the Laboratory of Coordinate Metrology (LCM) which is a part of Cracow University of Technology. The research projects undertaken by LCM resulted in development of number of methods for uncertainty estimation [1,2,3]. In this paper authors try to estimate impact of angular orientation of articulated probe head, which is one of the measurement errors contributor, on the measurement accuracy. The methodology shown in the paper involves measurements of standard element. The results and conclusions are presented at the end.

2. The conventional Coordinate Measuring Machines

The CMMs are usually described as a machines which movable units move in certain directions and at least one of kinematic pairs realizes shift. Most often machine units move along mutually perpendicular axes which defines a machine basic coordinate system. The movements in each axis are measured with linear transducers, however most accurate machines utilize even laser interferometry for that purpose. Normally, the machines are constructed using materials characterized by high resistance to the environmental conditions changes, like granite or ceramics. Especially in the first case, this involves the necessity of moving the elements of large masses. That is why CMMs usually use air-bearings. The CMM construction solutions include: fixed bridge, moving bridge, cantilever, horizontal arm and gantry type. The CMMs with fixed bridge offer the best accuracy. In such a solution the movements in two machine axes are separated from movements of machine's table with mounted object. They are characterised by high rigidity, however the weight of the measured object that can be mounted, is limited. In second group the table remain fixed when the whole bridge moves. Usually the drive is attached only to one of the columns what may cause the yawning phenomenon (the sides of the bridge are moving with different speeds)[4]. The accuracy in such machines depends strongly on the location of the measured object in the measuring volume. The next possible construction type is a cantilever. Usually, in machines of this type the cantilever is a support for a moving vertical arm. Probably the biggest advantage of cantilever CMMs is the accessibility to the measured object. The gratest drawback is their medium accuracy. The horizontal arm machines are popular particularly in automotive industry. Horizontal arm machines can work simultaneously in DUPLEX mode (mirror-image set) measuring the both sides of a car body or other elements. They usually have big measuring volume, with one axis range substantially greater than the other two. The low rigidity of such solution make it prone to the so-called elastic errors. The gantry machines are designed for large scale measurements. They can achieve good accuracy even measuring over large distances, however they are very expensive and difficult to maintain. As can be seen the chosen construction type strongly affects the machine behaviour and its accuracy. The errors associated with machine geometry are described by different models. The most popular one include 21 components [5] related to positioning errors of each machine axis; errors of mutual perpendicularity; translation errors and rotation errors.

Of course all CMMs must be equipeed with adequate probing system. This paper refers to the tactile probes, so only they will be further described. Probe heads can be generally divided into touch-trigger probes and measuring heads[6]. In fisrt case the deflection of the probe is only a signal for machines drive unit to read the indications from the scales, but the deflection itselfs is not measured. The construction of the touch-trigger probes is rather straightforward. The stylus is connected with three spherically ended arms which are oriented by 120 degrees relative to each other. They are pressed by the spring so that each arm rely on the prism. When the stylus deflects during probing process, the arms lose contact with the prisms, the electrical circuit brakes and the signal is produced. The supporting arm distribution affects the

probe accuracy, and makes its functioning strongly dependent on the probing direction. The second mentioned group has an additional ability to measure the stylus defection, using different phenomena (among others: inductive transducers and optics). The measuring probe heads are considered to be more accurate however, they much more complex and more expensive than the touch-trigger probes.
Ideally, the coordinates of probing points indicated by the machine should be the same as the actual point of tip ball contact with measuring surface. However, in reality the probing process can be interfered by number of errors. Same of them can be determined, but others are difficult to measure. Thus, the total probe head error can be defined as the difference between the coordinates indicated by the machine and actual coordinates of contact point[7]. The total probe head error (PE) is a sum of all individual errors, and can be expressed using following equation:

$$PE = x_r + x_{cd} + x_{sd} + x_s + x_i + x_c + x_n + x_{zk} \quad (1)$$

The probe head error will be different depending on the approach direction. The total probe head error can be summarized using function of probe head errors (FPE), which links the probe head errors with probe deflection angle α.

$$FPE = (\alpha, PE) \quad (2)$$

This function is used for probe head characteristic determination. The methodology is further described in [7], and is based on the measurements of standard object.

3. 5 axis measuring systems

The 5-axis measuring system can be obtained by adding the two rotations around the reference axes of probe head (horizontal and vertical), to the displacements along the three axes of the Cartesian coordinate system of CMM. The probe head revolute movements are measured by encoders. The additional movements of probe head can be utilized during probing process, what changes its nature. The probing process consist of four main stages: the tip ball approach to the measuring surface with constant speed, the contact occurrence, determination of contact point coordinates, retract from measured surface [8]. Between measured points, machine moves with high speed and decelerates before point coordinates are measured. The changes in machine velocity may cause the vibrations of the machine elements which may affect the measurements results. In 5-axis measuring systems before the coordinates are measured the machine stops entirely and measurement is performed only using probe head rotational movements.
In 5 axis measuring mode the machine movements in three main directions of its coordinate system are a basis for the probe head displacement, while an additional two rotations, makes the resulting system become redundant one (Fig.1). Thus, the measurement of the coordinates of a given point, can be performed for infinitely many configurations of the CMM kinematics. The measurement strategy optimization became the key issue in case of such systems.
The accuracy of 5 axis measuring systems is strongly dependant on the probe head proper functioning. The sources of errors include: the encoders scale errors, misalignments in probe head assembly (non-orthogonality axes, non-intersection axes), used probe characteristic. Another important factor which influences the accuracy of 5 axis measuring systems is angular orientation of probe head because the changes in orientation cause the droop of probe head elements under the gravity force.

Fig. 1. *The same tip ball position obtained with three different orientations of machine elements*

4. Experiment and results

Authors try to estimate the impact of angular orientation of articulated probe head on probe head error distribution. The experiment involved multiple measurements of standard element in different positions. The chosen element was a standard ring of 20 mm diameter, characterised by form deviation less than 0.2 * P_{FTU} defined according to [9]. The standard was mounted on the special holder which allows object rotational movements.

All measurements were performed on the Zeiss WMM850S machine, located in the LCM at the Cracow University of Technology. This machine has moving bridge, and an measuring volume of 800\1200\700 mm. It is placed in the air-conditioned room. During whole experiment the ambient conditions were monitored and the temperature varied between 19,3°C – 20,3 °C. The machine was equipped with PH20 probe head, with touch trigger TP20 probe. The FPE was determined in reference to the best-fitted circle constructed from 25 measured points. The measuring sequence consist of 10 measurements in one position of the standard. The ring was set in 4 different orientations which can be defined by the angle between the main axis of the ring and the Z-axis of machine coordinate system. In the Fig.2 the measuring station was shown.

Fig. 2. *The experiment setup, the standard mounted in a holder in first position, PH20 probe head*

The following orientations were included: 0° , 30°, 60° and 90°. The results obtained for each position are showed in Fig. 3, Fig. 4, Fig. 5, Fig. 6. The angular values expressed in ° are associated with the approach direction. The values of PE arithmetic mean calculated in each point are given in mm.

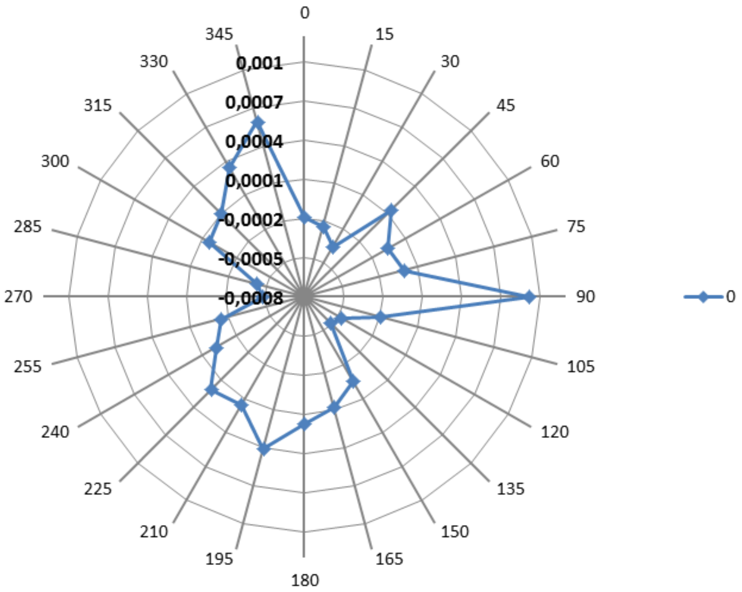

Fig. 3. *The results obtained for first standard orientation - 0°*

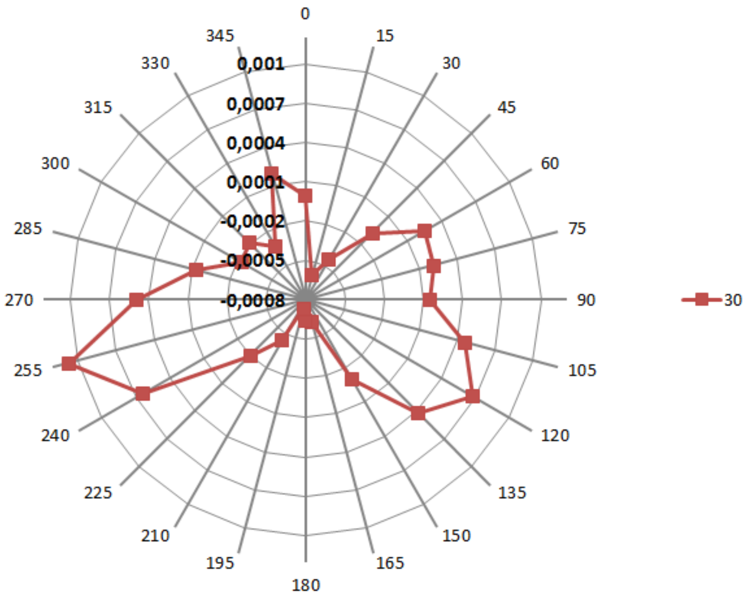

Fig. 4. *The results obtained for standard orientation - 30°*

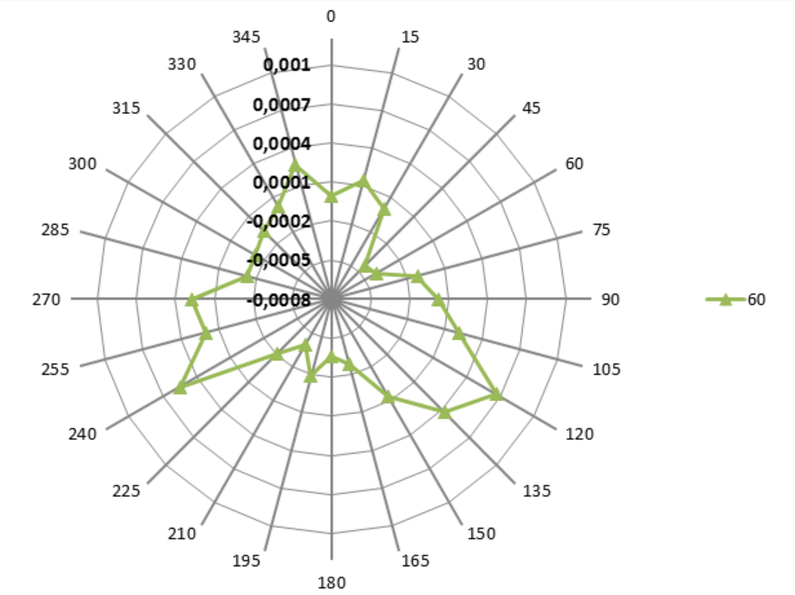

Fig. 5. *The results obtained for standard orientation - 60°*

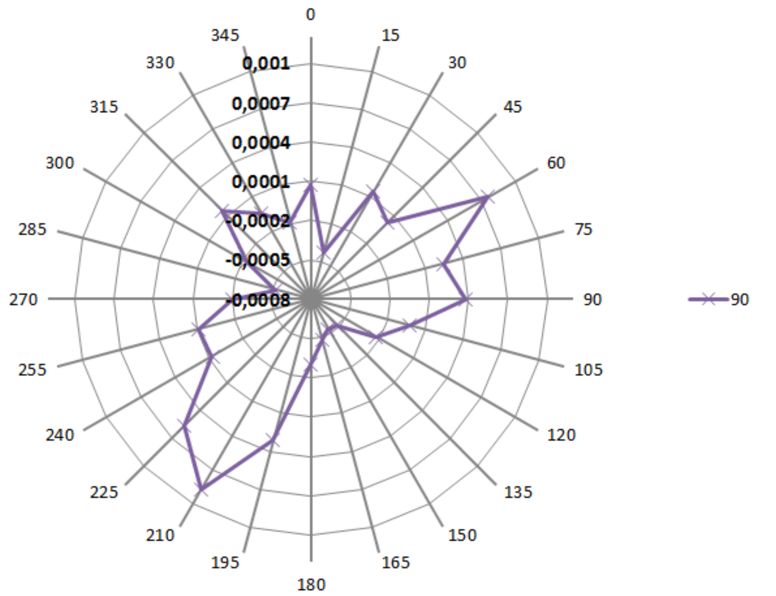

Fig. 6. *The results obtained for standard orientation - 90°*

In the Fig. 7 all obtained results are presented in one graph.

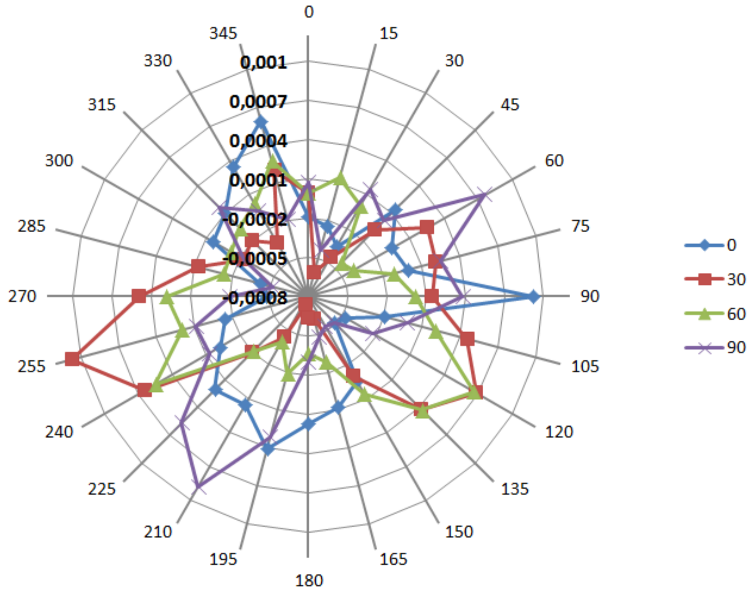

Fig. 7. *The results obtained for all standard orientations*

5. Conclusions

The obtained results confirm that measurement result strongly depend on the angular orientation of the articulated probe head. Such results affirm the authors assumption that the orientation of the probe head during measurements, would have a major impact on the measurement uncertainty. In all cases the distinctive triangular probe head characteristic was obtained. That may indicate that one of the biggest errors contributors is a TP20 probe which was mounted during experiment. Changes in the distribution of the error between the standard settings do not show linearity. However, the standard was rotated between measurements sequences only around one axis. The another experiment should be undertaken in order to determine how changes in standard orientation which cover whole probe head range, affect the error distribution. The final goal of such research would be a probe head errors map which would cover the entire measuring volume of 5-axis probing system.

Symbols

x_r – the measured surface condition (roughness and form errors)
x_{cd} – deformations of tip ball during contact process
x_d – stylus deformation under the measurement force
x_{sd} – errors related to the tip ball shape deviations
x_s – the pretravel
x_i –differences in characteristics of inductive transducers, in relation to the direction of probing
x_c – differences in sensitivity of the transducers
x_n – errors caused by probe heads balancing system
x_{zk} – errors associated with the change of probe head operation direction

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