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TESTING OF THE REPEATABILITY OF STYLUS CHANGE OF MODULAR PROBES USED IN COORDINATE MEASURING MACHINES

Adam WOŹNIAK

Warsaw University of Technology, Institute of Metrology and Biomedical Engineering
Warsaw, Poland, email wozniaka@mchtr.pw.edu.pl

Abstract − In this paper, a new method of testing of the repeatability of stylus change of modular probes used in coordinate measuring machines (CMMs) is proposed. The principle of the method is presented. The validity of the method is experimentally confirmed on a bridge Zeiss ACCURA CMM by testing positioning accuracy of magnetic joins the three popular probes: TP20 (Renishaw), VAST Gold (Zeiss) and VAST XXT (Zeiss).

Keywords: coordinate measuring machines, probing system, magnetic joint

1. INTRODUCTION

The constant progress in machine parts manufacturing, along with the necessity to increase the speed of dimensional and shape error checks, has caused a continuous increase in the use of coordinate measuring machines (CMMs) especially in automotive and aerospace industry. These measuring instruments are used in both laboratories and manufacturing plants. The advantages of these modern machines are measurement automation, graphic visualization of the results, numerical data archiving in electronic media, and capability for integration with computer-aided design/computer-aided manufacturing systems. Therefore, although they represent a substantial cost, these machines are utilized more and more frequently where speed and precision of measurements are required.

One of the fundamental elements that determine the precision of a CMM is the probe, which locates points on the surface of a measured part located within the machine's measurement volume. A magnetic joint is a component of the probe that is very important for the automation of the measuring process. It ensures quick and efficient replacement of styli, probe modules or whole probes. It largely diminishes the operator's involvement in the measuring process, reducing the time of consecutive measurement cycles that require stylus tip changing. Thus, instead of directly operating a measuring machine, which consists in replacement of its instrumentation, the operator can focus mainly on developing a measurement plan and, as the case may be, simply monitor its execution.

The replacement of CMM styli, probes or probe modules can be done in two ways. The first one is automatic, and the second one manual. Automatic replacement requires not only appropriate systems for automatic changing of styli and probes, but also a proper modular design of the probe head itself. To identify the location of the stylus in the probe holder or between probe modules, magnetic joints are usually used, which consist of electromagnets or permanent magnets. However, such an additional component of the probe assembly can be a major source of measurement errors for the coordinate measuring machine, especially that the manufacturers of such machines do not require the probe assembly to be calibrated after each stylus replacement.

Probes that are currently manufactured enable the replacement of the stylus tip together with the probe module, as shown in Fig. 1a) depicting a TP20 touch trigger probe made by Renishaw of England. However, definitely most often the magnetic joint is placed between the probe and the stylus tip. It is composed of a stylus holder and an adaptor plate in which the stylus tip is fitted, as shown in Fig. 1b) depicting a Vast XXT scanning probe made by Zeiss of Germany.

Each type of magnetic joint comes with a special magazine, which is usually placed in a rack on the measurement table. The magazine comprises two holders compatible with a particular probe module or adaptor plate. A magazine supporting Vast XXT scanning probes is shown in Fig. 1c).

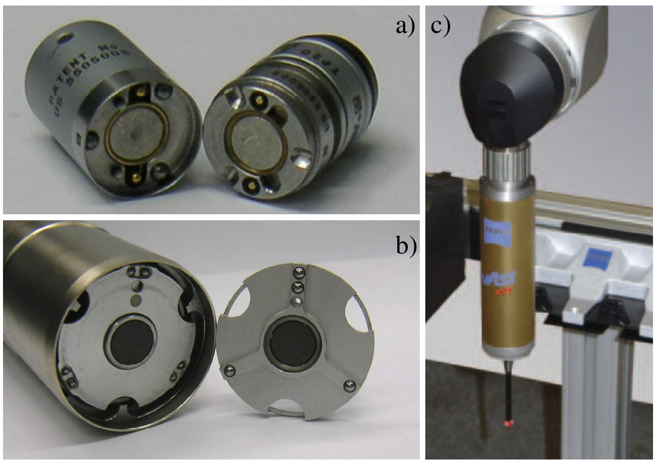

Fig. 1. a) Example magnetic joint of a modular TP20 touch trigger probe, b) example magnetic joint of a VAST XXT scanning probe, c) automatic module change magazine.

Proper embedding of the adaptor plate in the holder or coupling of probe modules is ensured by a magnet placed in the central part of the joint. In smaller probes, it is a permanent magnet, whereas in larger ones, the use of software-controlled electromagnets is a predominant solution. However, in all cases the structure of the joint is based on a pattern of three mounts evenly distributed every 120 degrees across the circumference of the holder, in which fixing elements are fitted, which, as with the holder, are also distributed every 120 degrees across the circumference of the adaptor plate. The mounts and fixing elements are both made in a different way, depending on the probe in which they are used. The joints of the TP20 and the Vast XXT probes shown in Fig. 1 are built using the principle of balls mating with, respectively, prisms, or mounts, each consisting of a pair of balls. However, in the Vast Gold scanning sensor made by Zeiss, the fixing elements are rollers mating with pairs of balls that constitute mounts, as shown in Fig. 2. Letters A, B and C in Fig. 2 indicate the fitting directions of the adaptor plates. Each direction was determined by two fixing elements that are coupled first so that the third one could be attracted by the magnet on the joint.

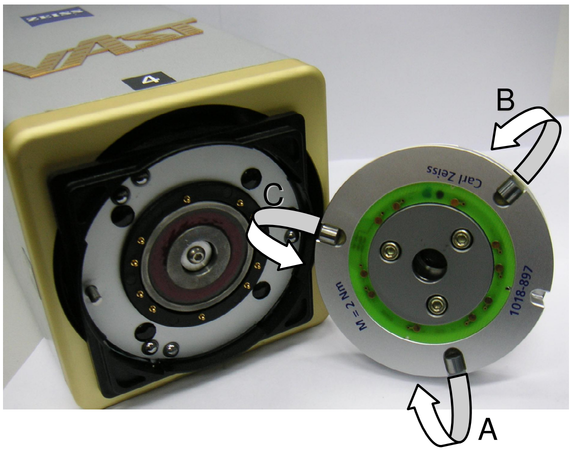

Fig. 2. Magnetic joint of the Vast Gold scanning probe and directions of connecting the magnetic joint during replacement.

The precisions of the CMM and probing system are closely interrelated [1, 2]. Users of CMMs who face the problem of testing the probes system accuracy use intermediate evaluation methods, e.g., checking simple master artifacts on the machine, which are usually certified spheres or rings [3-6]. These tests are recommended by the International Organization for Standardization (ISO 10360) [7]. In accordance with these recommendations, the scanning probe error *Tij* is calculated as an interspace of radial distances from the sphere center of all the measured points on the master sphere calculated according to the Gauss method. Scanning probe parameters are considered as verified as long as the value of *Tij* (the calculated error) is not superior to the maximum permissible scanning probing error MPE_{Tij}. The results of this check only reflect errors of the probe system, assuming that the shape errors of the masters and the errors of CMM scales and guides in the machine axes are negligible.

However, the ISO [8] and others standards like VDI/VDE 2617 [8] or ANSI/ASME B89.1.12M [9] do not recommends procedure and parameters for the evaluation of magnetic joint positioning error. It is therefore necessary to study such methods which have so far been unknown.

2. METHOD OF TESTING OF MAGNETIC JOIN POSITIONING ERROR

The method of testing the repeatability of magnetic joints is developed so that it is as consistent as possible with the existing guidelines of the ISO 10360 standard [11]. Accordingly, as it was the case with probing error parameter *P* as per [11], a test sphere measuring 25mm in nominal diameter and meeting the requirements [11] was used for examination, which was measured in 25 points evenly scattered across the half of the sphere in accordance with distribution as per [11]. The measuring points were used to determine the centre $[x_G, y_G, z_G]$ of the Gauss sphere. Subsequently, the magnetic joint was disconnected and reconnected, and 25 points of the test sphere were measured again to determine the centre of an associated sphere. In the case of automatic replacement as many as thirty repetitions were made. Replacement was repeated ten times for each of the three possible directions of connecting joints: A, B and C. Given that the test sphere is not displaced during measurement, an observable change in the location of the centre of the Gauss sphere provides a measure of magnetic joint positioning errors. The distance of observation *i* in relation to centre of concentration of points may be defined as

$$e_{Mi} = \sqrt{\left(x_{Gi} - \bar{x}_{Gi}\right)^2 + \left(y_{Gi} - \bar{y}_{Gi}\right)^2 \left(z_{Gi} - \bar{z}_{Gi}\right)^2}\,, \tag{1}$$

where: $\left[\bar{x}_{Gi}, \bar{y}_{Gi}, \bar{z}_{Gi}\right]$ is centre of concentration of points calculated as

$$\left[\bar{x}_{Gi}, \bar{y}_{Gi}, \bar{z}_{Gi}\right] = \left[\frac{\sum_{i=1}^{30} x_{Gi}}{30}, \frac{\sum_{i=1}^{30} y_{Gi}}{30}, \frac{\sum_{i=1}^{30} z_{Gi}}{30}\right]. \tag{2}$$

The maximum magnetic joint positioning error *M* may be defined to describe this dispersion as

$$M = \max\left(e_{Mi}\right). \tag{3}$$

3. EXPERIMENTAL SET-UP AND TESTED PROBES

The experimental tests were carried out on Zeiss's ACCURA coordinate measuring machine with CALYPSO measuring software. According to [11], the maximum permissible error of indication of this CMM for size measurement is MPE_E = (1.7+*L*/333) μm for scanning probes and MPE_E = (2.2+*L*/333) μm for touch trigger probes compatible with the RDS articulating system. *L* stands for the length measured in metres. Fig. 3 shows the measurement setup.

Fig. 3. View of the measurement of reference ball on CMM Zeiss ACCURA.

Tested was the positioning accuracy of magnetic joins the three popular probes: TP20 (Renishaw), VAST Gold (Zeiss) and VAST XXT (Zeiss).

The TP20 probe is a touch trigger probe. The probe has a modular design, composed of a main probe module and a stylus module in which transducers are fitted. The main probe module can be mounted in a permanent probe head or screwed to an articulating probe such as RDS (Zeiss) or PH10 (Renishaw). The magnetic joint consists of a permanent magnet located in the central parts of both probe modules. There are three 2mm wide balls distributed every 9.5 mm across the circumference of the probe module. The mounts are prisms extruded in the body of the probe holder. The joint of the TP20 probe is presented in Fig. 1a). The manufacturer specifies that the unidirectional repeatability of the probe ranges from ± 0.35 µm to ± 0.8 µm, and the pretravel variation from ± 0.6 µm to ± 2 µm, depending on the measurement module. The specified replacement repeatability of the probe module is ± 0,5 µm for automatic replacement and ± 1 µm for manual replacement. The manufacturer also informs that no re-calibration is needed after replacing a module with a stylus that has already been calibrated.

VAST Gold is an active scanning probe in which, according to [11], the maximum permissible scanning probing error is MPE_{Tij} = 2.7 µm and that of point to point probing error MPE_P = 1.7 µm. Its magnetic joint consists of an electromagnet and a permanent magnet. The permanent magnet is used to pre-fit the adaptor plate in the holder, whereas the electromagnet determines the final position of the rollers by pulling them towards the balls. Both magnets are centrally located in the probe head to ensure an even pressure force. The main probe module contains 5mm wide balls, and the adaptor plate rollers of the same diameter which are distributed every 62 mm across its circumference. An element determining the angle of the adaptor plate towards the main probe module is a pin mating with the corresponding groove in the adaptor plate. The joint of the VAST Gold probe is presented in Fig. 2.

VAST XXT is passive scanning probe. The magnetic joint is composed of a main probe module holder and an adaptor plate in which styluses are fitted. There are three 2 mm wide balls distributed every 120 degrees across the circumference of the adaptor plate. The fourth ball is used to orientate the adaptor plate in a certain angle to the mount. There is a permanent magnet in the central part of the adaptor plate and the main probe module. The joint of the VAST XXT probe is presented in Fig. 1b). The specifies maximum permissible errors similar to those of the VAST Gold probe. The manufacturer does not specify a separate parameter to describe the repeatability of the magnetic joint, neither for the VAST Gold nor for the VAST XXT probe.

4. EXPERIMENTAL RESULTS OF TESTING OF MAGNETIC JOINTS POSITIONING ERROR

Example results of the experimental tests of the TP20, VAST Gold and VAST XXT probes are presented in Fig. 4, 5 and 6, respectively. The test results were differentiated for each different direction of connecting the joint: A, B or C, as shown in Fig. 2.

The measuring points for a single direction of connection are identified with the same symbol: a square – data from direction A, star – from direction B or a circle – from direction C. For better comparison, all figures have the same scale.

The magnetic joint of the TP20 probe turned out to be very repeatable. The maximum magnetic joint positioning error *M*, as per (3) does not exceed 0.7 µm. This error completely fits into ± 1 µm of the manufacturer's specified interval of maximum repeatability errors for the replacement of measuring modules with a manually exchangeable stylus.

The maximum magnetic joint positioning error *M* of the VAST Gold probe is equal 1.4 µm. The manufacturer of this probe does not specify a separate parameter to describe the repeatability of the magnetic joint, either. The tests showed, however, that the percentage of errors related to the replacement of the stylus by means of a magnetic joint is considerably lower than the maximum permissible error of probing, which for the Vast Gold probe amounts to MPE_P = 1.7µm.

The Vast XXT probe has a significantly wider spread of results. In this case the maximum magnetic joint positioning error *M* reach 2.8 µm. The manufacturer of this probe does not specify a separate parameter for the repeatability of the magnetic joint, but any related errors should not exceed, in this case, the allowable threshold error, which amounts to MPE_P = 1.7 µm. This value was exceeded.

No obvious grouping of points depending on the direction of connection can be observed when analysing the test results presented in Fig. 4, 5 and 6. An analysis of variance was conducted to determine statistically whether the variability caused by a factor such as the direction of connecting the magnetic joint is significant against other operational errors of the tested probes. Statistical tests proves that at a confidence level of 95% the hypothesis that the direction of connection has a substantial effect on the repeatability of the magnetic joint can be rejected for all of tested probes.

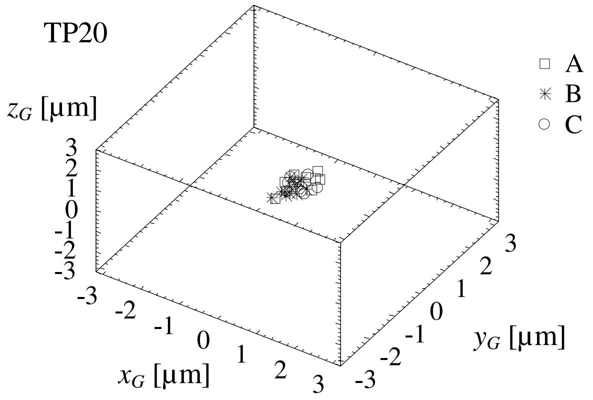

Fig. 4. Repeatability results for the magnetic joint of the TP20 touch trigger probe with a 40mm long stylus.

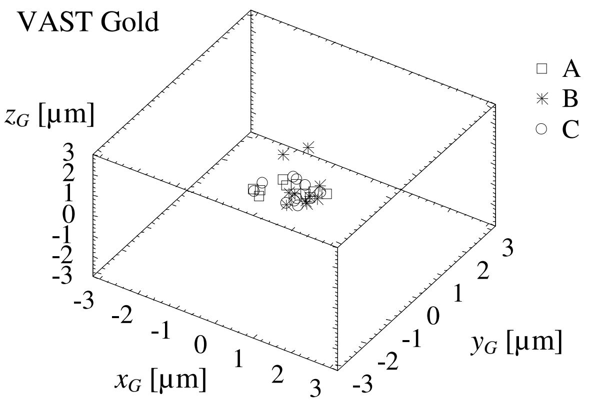

Fig. 5. Repeatability results for the magnetic joint of the VAST Gold scanning probe with a 110 mm long stylus.

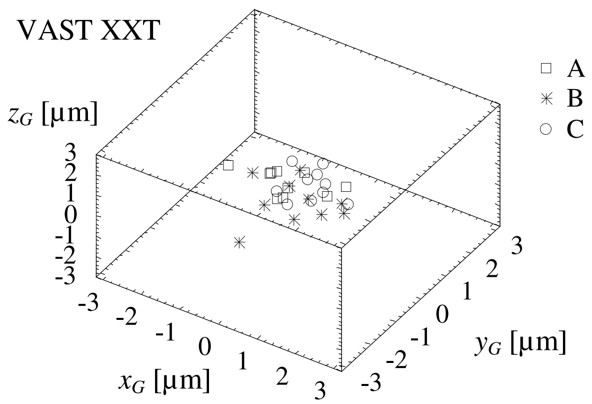

Fig. 6. Repeatability results for the magnetic joint of the VAST XXT scanning probe with a 80 mm long stylus.

5. CONCLUSIONS

The analysis of the results of tests performed to measure the repeatability of stylus change of modular CMM probes using the new testing method described above allows the following conclusions to be drawn.

• The developed method can be used for the testing of magnetic joint positioning error.

• Initial tests performed using the Renishaw TP20 and Zeiss VAST Gold and VAST XXT probes have shown that the magnetic joint positioning error range from approximately 0.7 μm up to 2.8 μm.

• The aim of this paper was not to present the magnetic joint positioning error of all types of probes but rather a new method for testing. This type of tool can be useful for operators of CMM machines, for service engineers, or for manufacturers of CMMs. To gain more knowledge of the metrological properties of magnetic joints of the probes and to optimize the proposed method, further research on the effect of various factors on probe operating accuracy is necessary.

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