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EXPERIMENTAL EVALUATION OF CMM TOUCH PROBING SYSTEM

Adam Wozniak

Warsaw University of Technology, Poland,
8 sw. A. Boboli St., 02-525 Warsaw, Poland
e-mail: wozniaka@mchtr.pw.edu.pl

Abstract: The accuracy of touch probes of coordinate measuring machines (CMM) will be analyzed, taking into consideration identification of respective sources of errors.

Keywords: coordinate measuring machines (CMM), probing system

1. INTRODUCTION

One of the most important factors influencing CMM accuracy is the probing system (trigger or scanning) [1-5], which locates points on the surface of a measured part in the machine's measurement volume. All results coming from coordinate measurements are obtained using calculation algorithms, which take under account the coordinates of individual measurement points. The measurements of each of the points are also indirect, because to calculate them, the radius of the tip of the styli determined by measuring a reference sphere is rectified by the average value of the probe error is used, and by the indications of the machine scales. Often also the coordinate system is transformed, by translation and rotation of the global frame relevant to the coordinate measuring machine geometry to the local coordinate system relative to the measured object. Because the orientation of the coordinate system of the object is calculated according to the measurements, such operation affects also the result of the measurement of a single measurement point.

2. TOUCH PROBING SYSTEM

The system which locates the points of a measured object in the measurement space of a coordinate measuring machine equipped with a touch probe might be represented by a scheme, as shown in fig. 1. When the tip of the styli enters in contact with the measured object, it is detected by a probe transducer, through the stylus, usually fixed with a magnetic joint. The information about the occurring contact is sent to the displacement measurement and control system of a coordinate measuring machine, where an indicated measured point – that is, the point which is usually the centre of the tip of the stylus- is measured by the machine's scales. In this procedure, information previously obtained during the probe and stylus calibration procedures and during the transformation of the coordinate system (if such was executed) is used. Than the coordinates of a corrected measured point (the most accurate approximation of the point of the measured surface) will be calculated. This procedure requires information about the diameter of the probe tip (obtained during the calibration procedure) and about the correction vector. Direction of this vector should be normal for the measured surface in the particular measurement point.

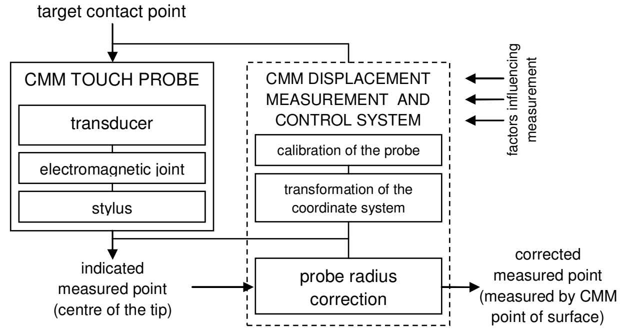

Fig. 1. Scheme of the system of measured point location in the measurement space of a CMM

Errors occur during all of the above mentioned stages of detection of the measured object points in the measurement space of CMM. These errors may result from imperfections in the construction of the probe's transducer as well as from calculation algorithms. Analysis of the accuracy of CMM probes system therefore requires a detailed identification of respective sources of errors. The principal sources of errors are represented in fig. 2.

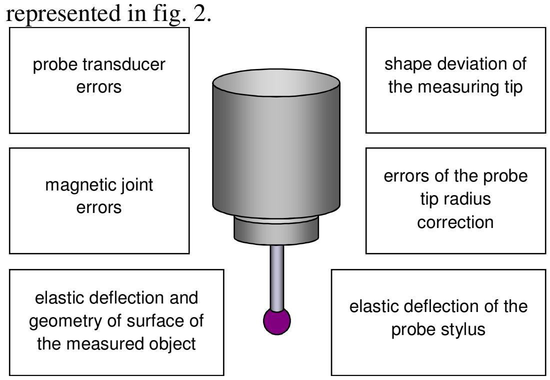

Fig.2. Principal error sources of measurement points localization for CMM touch probe

Six groups of errors were specified: probe transducer errors, errors caused by elastic deflection of the measured object or by the micro- or macro geometry of its surface, errors caused by the form deviation of the probe tip, magnetic joint positioning errors, and errors caused by correction of the tip radius. Detecting those respective errors and determining their value is crucial for determining the precision of the probing system, the optimum choice of the styli's length and of the diameter of the tip, and for determination of methods of compensating systematic errors.

3. ERRORS OF PROBE TRANSDUCER

Contact probes are categorized into tough trigger and measuring (scanning) probes. All CMM touch trigger probes contain a three-base spring-tighten setting mechanism (a six point kinematic mechanism) by which the stylus is electrically fixed in five or six spatial degrees of freedom. In the basic version this mechanism is designed as a group of electrical contacts. When the stylus touches a work piece, the electrical contact is opened, a trigger pulse is generated and sent to the computer resulting in a coordinate reading. Although there are many different designs of this kind of probes, generating of the trigger is always strictly connected with a triploid structure of the settings. Setting points are always displaced by 120^{o}, and for this reason the probing force is not constant. Additionally, different values of stylus displacement from the neutral position to the triggering position are observed, depending on probing direction. As a result, a triangular form error will occur while measuring a circle (see fig. 3).

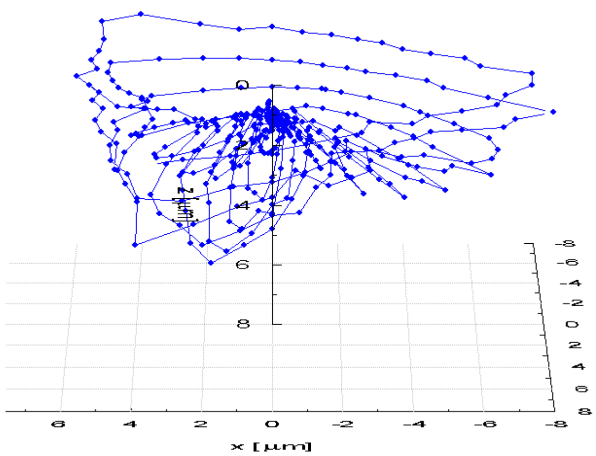

Fig. 3. Example of spatial distributions of the average pretravel of the electro-switching probe TP6 plotted in Cartesian coordinates

To avoid above mentioned lobbing error of kinematic probes, supplement wire resistance strain gages or piezoelectric elements are employed in addition to mechanical/electrical contacts. This provides constant sensitivity in all probing directions in the plane perpendicular to the stylus, and effectively reduces probing errors. In the two stage probe, a very sensitive transducer acts as an actual position sensor (first stage), and the electro-mechanical (second stage) only serves to confirm the workpiece probing action. As a result, quasi-circular shape of probe error characteristic will occur (fig. 4). Characteristics of probes error presented in fig 3 and 4 have been obtained using method and reference set-up described in [6].

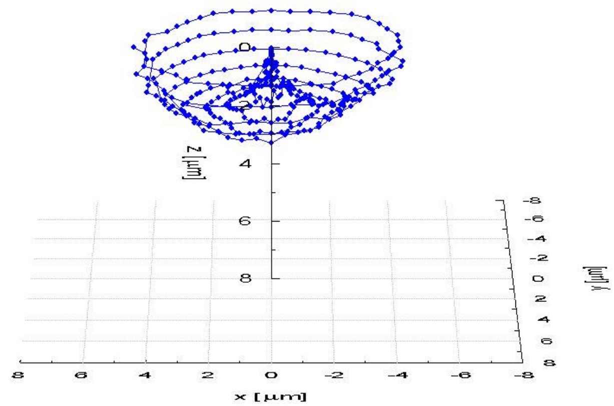

Fig. 4. Example of spatial distributions of the average pretravel of the electronic TP200 probe plotted in Cartesian coordinates

A scanning probe is, in fact, a small coordinate measuring device. It usually consists of three Cartesian length-measuring systems that are parallel to the main axes of the coordinate measuring machine. The probe's length transducers measure probe tip displacement along axes X, Y and Z. The scanning probe readings and the results comes from CMM length measurement scales are added in all measuring axes. Thus, the probe does not have to be in a zero position of transducer readings during probing. If an analog signal of the scanning probe system is digitized and added to the length measurement value of the CMM, the result should be the same as that obtained with the probe in the zero position. There are several types of probe measuring transducers. However, the most popular are inductive and optoelectronic incremental transducers.

Users of coordinate measuring machines who face the problem of testing the probe accuracy use intermediate evaluation methods; such as checking simple master artifacts on the machine, usually certified spheres or rings. These tests are recommended by ISO 10360 international standards [7]. In accordance with these recommendations, the scanning probe error T_{ij} is calculated as an inter-space of radial distances from the sphere centre of all measured points on the master sphere calculated according to a least-squares method. In effect, by testing the probe on a CMM we in fact are checking not only the probe, but also the overall CMM inaccuracy. Information about the errors of the scanning probe is difficult to evaluate.

However, a new method that employs a piezoelectric translator to test the dynamic accuracy of scanning probes for coordinate measuring machines (CMMs) have been proposed by author [8]. The obtained exemplary e_i error characteristics of y-axis of C. Zeiss VAST XT scanning probe has been shown in fig. 5. The errors are of the order of several micrometres appearing at maximum deflection of the probe tip. Existing differences in the characteristics are caused by accidental probe errors. Hysteresis is revealed as well.

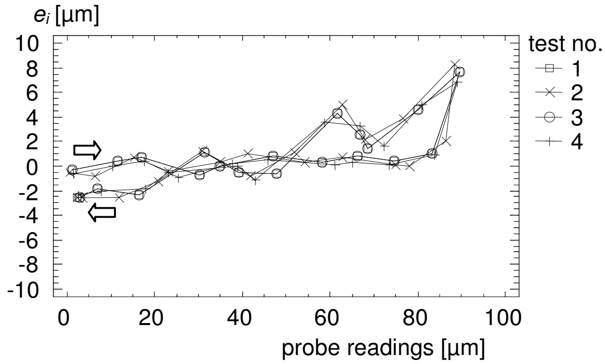

Fig.5. The VAST XT scanning probe errors e_i as a function of its readings

4. ERRORS RELATED TO ELASTIC DEFLECTIONS OF THE PROBE STYLUS

The material, the length of the styli, and the measurement force has the largest influence on the change of the probe system accuracy [9]. Because of the variety of measurement tasks (measuring objects of various shapes and made of various materials) the head parameters that change the most often are: the measurement force (usually adjusted by tightening of the head transducer's spring), the material the stylus is made of, and its length. Examples of results of research of the accuracy of touch-trigger probes for different values of measurement force and different lengths of styli are shown on fig. 6.

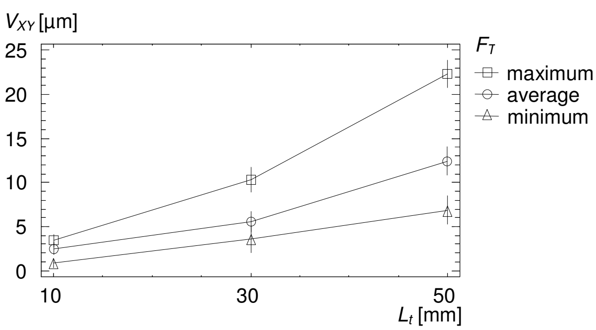

Fig. 6. The result of the testing of the influence of length of the styli L_t and measurement force F_T on the TP6 probe errors.

The average values obtained from five repetitions of the measurement of pretravel variation. Vertical bars mark two standard deviations. Three levels of measurement force F_T were assumed: the strongest, average pressure – the centre of adjustment, and the lowest measurement force. Three straight styli of the same diameter (D_t=2mm) and lengths L_t of 10 mm, 30 mm and 50 mm, made of tungsten carbide, with ruby ball of 4mm of diameter D, were used in the tests.

The presented results confirm that increased stem length increases measurement error of the probe. This effect is greater for greater preload force of measurement.

5. ERROR OF THE PROBE TIP RADIUS CORRECTION

The accuracy of the scanning probe obtained according ISO10360 tests is usually of several to tens of micrometers, but this degree of accuracy is generally only achieved for the measurement of well-known shapes, or when the feature size largely exceeds probe tip radius because of the algorithms used for stylus tip radius correction [10]. For instance, freeform profiles of surfaces, which are not sections of a known geometric primitive such as a plane, circle, sphere, cone, torus etc., present particular difficulties in establishing the normal correction vector. Freeform surfaces are now very common (car bodies, consumer products ergonomic shapes, turbine blades etc.). Furthermore, small features are becoming common place and although measurements can be performed by scanning, the correction may result in the introduction of unacceptable errors.

The stylus tip radius correction is an offset vector of norm equal to the effective stylus tip radius, which is added to the indicated measured point (i.e. the measured stylus tip center point) to estimate the actual contact or measured point on the profile (i.e. the stylus tip actual contact point on the real surface). The nature of the tangential contact between a sphere and a surface results in the offset vector being normal to the surface at the point of contact, so the primary task for correction is to estimate this vector for each data point. In the case of a freeform surface or for a contour, the measuring surface normal vector is unknown. Thus, because of inherent measuring machine inaccuracy, small deviations of centre point coordinates can cause big deviations in the direction of the normal vector calculated by the CMM software. As a result, we observe incoherently connected corrected measured point patterns as shown in fig. 7.

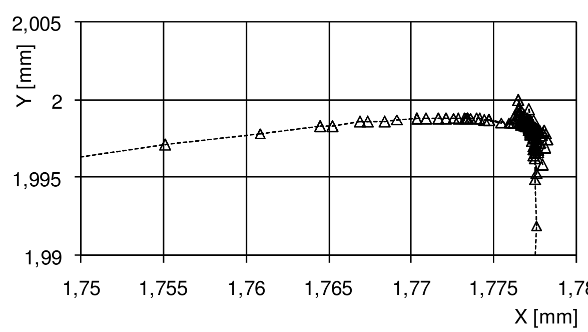

Fig. 7. Measurements of a plane section of the cutting edge of a Minicut® cutting tool using the CMM built-in method of probe radius correction

Some CMM manufacturers manipulate the measured points (such as re-ordering them) to make the results look consistent [11]. Unfortunately, in the case of measurement of freeform surfaces and 2D contours this is not adequate. Problems may also arise from the size of stylus tip and, generally, during the measurement of freeform surfaces. There are many examples of such surfaces: edges (for example cutting tools edges), gear toothed wheels, turbine blades and their leading and trailing edges, screw threads and many type of machined features in manufacturing.

6. MAGNETIC JOIN POSITIONING ERROR

The magnetic joint is a very important probe component for the automation of the measuring process. Construction of the magnetic joint is based on the pattern of three slots spaced at 120 degrees on the circumference of the joint, which cooperate with fixing elements arranged on the circumference of stylus plate - also at 120 degrees.

This ensures quick and efficient replacement of styli, probe modules or of entire 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. 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. Example results of the experimental tests of the VAST XXT probe is presented in fig. 8.

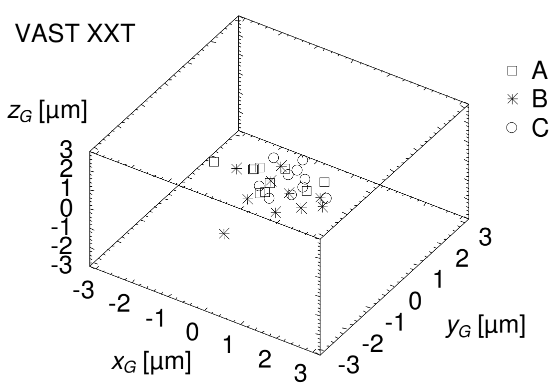

Fig. 8. Repeatability results for the magnetic joint of the VAST XXT scanning probe with an 80 mm long stylus.

The proposed in [12] new method for determination of the accuracy magnetic joint positioning constitutes the extension of the method for the research of *P* probing error in accordance with the recommendations of the ISO 10360 [7]. The research procedure encompasses the measurement of 25 points distributed in accordance to the determinants upon the test sphere. Based upon the measurement points the following coordinates are determined: [x_G, y_G, z_G], which represent the centre point of the Gauss sphere. What follows is the further disconnecting and connecting of the magnetic joint and the measurement of the 25 points of the test sphere is being conveyed with the determination of the centre of the associated sphere. On the condition that the research sphere did not change its location during the measurement process, the observed change of location of the Gauss sphere is the measure of the errors of the magnetic joint. The test results were differentiated for each different direction of connecting the joint: A, B or C. In this case, the maximum magnetic joint positioning error defined as the largest deviation reaches 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.

7. CONCLUSION

CMM are devices that enable to measure not only linear dimensions, but also deviations of the shape and position of parts which often have complex geometry. Errors occur during all stages of point location of the measured object in a measurement space of a CMM, due to the imperfections in the probe construction, as well as to the imperfections in functioning of the calculation algorithms. In the article, the accuracy of CMM touch probing system has be analysed, taking into consideration identification of all respective sources of errors.

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