PROBE RADIUS CORRECTION METHODS – REVIEW AND COMPARISON OF EXISTING METHODS

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Abstract:

Scanning technology has been becoming more common then ever. Scanning offers new and effective possibilities of measurement. Nowadays planning, production and assembling without high accurate metrology is impossible. Measurement of small, curved elements became much easier with great development of mechanical components of measure machines, such as: guideways, transducers, bearings, servomechanisms. All this improvement made possible to collect with good accuracy points in high density. Algorithms, and computer software were greatly improved as well. Especially, many efforts were put on probe radius correction algorithms development. In this paper a review and a comparison of probe radius correction methods are shown.

Keywords: *coordinate measuring machine (CMM), scanning probe, probe tip radius correction.*

1. Introduction

CMM scanning probes are used to locate and measure points, which will then form a three-dimension element. The measured points are being located by means of contact between a stylus tip and a surface of an element. Inductive transducers, located inside a probe, are registering a movement of stylus tip in X, Y, Z coordinates. As shown in Fig. 1, the data from transducers in addition with coordinates of scanning probe are actual position of stylus tip.

A scanning probe, in fact, acts as a small coordinate measuring device. During scanning on CMM the computer is registering a center of probe tip, which was calibrated before the process. The coordinates of measured points are registered during probing. The measured data, called indicated points, is not giving real information about shape and dimension of an element. Only, so-called corrected measured point is an approximation of a real point on the surface, which is described in [1]. 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. As many researches have shown, the biggest influence on measurement error in scanning process on CMM, has the correction of indicated points, particularly when a curved surface is being measured, which was described in [2]. There are many correction methods, which can be divided into three different groups: probe radius correction using information about position of indicated points, probe radius correction based on information from force generators in scanning probe, probe radius correction using information from CAD model. Many methods use a set of indicated measured points to estimate the correction direction. Such algorithm was described by Shuh-Ren Liang and Alan C. Lin in [3].

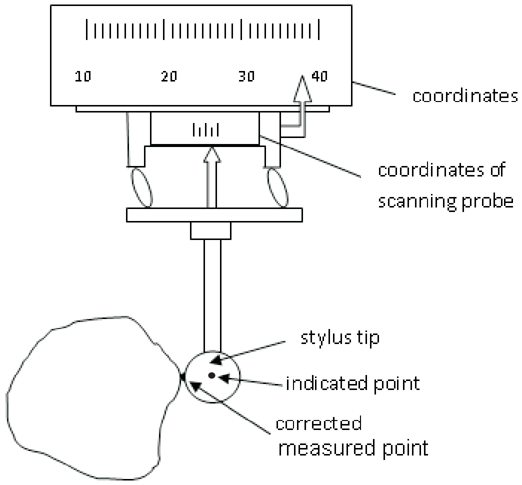

Fig. 1. Principle of scanning performance.

It was proposed to convert massive data points into numerous, connected triangular meshes and then calculate unit normal vector to each triangular mesh. The process starts with determining base and target trajectory. The one with fewer points is called base trajectory. Next step is to find corresponding points between each trajectory.Once the corresponding points are found, a connection between them is implemented and triangular meshes are formed. Trajectories cannot cross each others. After that, the program calculates unit normal vector to each mesh. Finally, each point is shifted in its normal direction with the value of probe radius.

Another simple method to calculate the correction direction is to connect successive points with a straight line and then calculate unit normal vector to determinate line. Alternative, it is possible to connect every second point of trajectory and calculate normal vector to the line. A big disadvantage of this method is that very often the corrected points are shifted in chaotic direction, which is not corresponding to measured surface, particularly curved or sharp shape, such as cutting edge. Much research was put on this problem, and as a result, a new correction method was proposed in [4]. Normal vector is not calculated in this algorithm, as well as the measured shape is not smoothed by any mathematical model, such as NURBS and the points are not manipulated to look more correct. It is also possible to perform validity check of corrected points. The principle of algorithm is that the profile is defined by an envelope of a family of circles formed by probe tips. The corrected measured points are situated somewhere on arcs of circles and are found by means of special mathematical equations and also fuzzy logic knowledge, which is described in [5].

Another method, proposed by Y. C. Lin and W. I. Sun in [6] is based on multi-cross-product method. The authors determine the directions of four normal vectors and their average for the compensated point from cross products of the four nearest tangential vectors. Tangential vectors are calculated from stylus tip centre and its four nearest points. Similar method, described by Jagoda and others in [7], determines eight normal vectors as cross product of stylus tip centre and eight nearest points. Normal vector of indicated point is the average of eight vectors calculated before.

Another approach for stylus tip radius correction was proposed by Jae-jun Park and others, whose idea was totally different from previous [8]. The authors designed a new measuring probe with an internal elastic structure equipped with strain gauges, so that the contact force between the tip and measured shape can be estimated and used for the calculation of the stylus tip correction vector.

Another example of new approach for stylus correction is an idea of Aoyama, Kawai, Kishinami, who proposed a potentiometric spherical tip, which is capable of detecting the point of contact with an electrically conducting object surface [9]. The touched point can be estimated by current flowing at electrodes distributed on a tip, which is covered with a thin resistance film.

2. Comparison of probe radius correction methods

The measurements were carried out on Accura Zeiss CMM, equipped with Vast Gold active scanning probe and Calypso software. Each point was recorded every 0,01 mm with measuring tip which radius was 2,001296 mm. Scanning speed was 1 mm/sec. There were two radius correction methods built in the machine. One method was based on information of contact force from scanning probe and is called VAST correction. The information about contact force generated in scanning probe, so that the tip was always in contact with the work piece, was used to determine the correction direction. Another method was using NURBS splines and the calculations were made by Calypso program - this method is called Calypso correction. Trajectories made by measure tip were transformed into splines, which enabled to calculate normal vector of each spline. Moreover, two simple programs for calculating corrected points were created and used for the comparison. To correct an indicated point, the first program was using next or previous point's coordinates to calculate the correction vector. Correction direction was perpendicular to a line created by connecting indicated point with next or previous point. The second program, for calculating the correction direction is using every second point's information. Additionally, the correction was carried out on STEM software for the stylus tip radius compensation in CMM scanning measurement, described in [10], according to the algorithm from [5].

The measured elements had free form surfaces and constant sections. Indicated points were corrected by five methods. The results are shown in Fig. 2 - 4. The indicated and corrected points are marked as follows: indicated points - black rectangle, VAST correction - white rectangles, STEM correction white circles, Calypso correction - white triangles, every another and every second point white stars and pentagons.

Measured profile, as well as corrected points was put on common chart, as shown in Fig. 2. Corrected profile is systematic, except for the edge, where the corrected points are irregular, which was shown in details in Fig. 3. VAST corrected points are put in wrong order, besides the scatter of corrected points is about 0,1 mm on the edge. When the profile is straight, VAST corrected points are given with smaller scatter. STEM, Calypso and correction based on previous or next or every second point position results are shown in Fig. 4. STEM and Calypso corrected points are close to each others, the distance is less then 1 μm. STEM corrected points are put in order, while Calypso, and correction based on previous or next or every second point position points are disordered. The scatter of Calypso and STEM corrected points is about 2 μm, while correction based on previous or next or every second point position has a scatter of about 4 μm.

3. Conclusion

In this paper a review and comparison of probe radius correction methods is shown. Each group of correction method has some characteristic results. Methods based on mathematical calculations, such as STEM or Calypso gives smooth profile without loops. The programs use some special algorithms to eliminate problems with incorrect point order. VAST correction results are irregular and scattered. The reason of such effect is the friction between measuring tip and the surface. An additional force component is added to the contact force and it results in big, irregular scatter and rough profile. Big influence on this effect has the speed of scanning, as well as material of measured work piece. The biggest differences between correction method results are on the edges of profile. The difference between VAST correction and STEM, Calypso, or correction based on previous or next or every second point is about 0,2 mm. Correction based on previous or next or every second point occasionally gives results, which are chaotic. Corrected profile may have loops or the points may be in wrong order, as shown in Fig. 4.

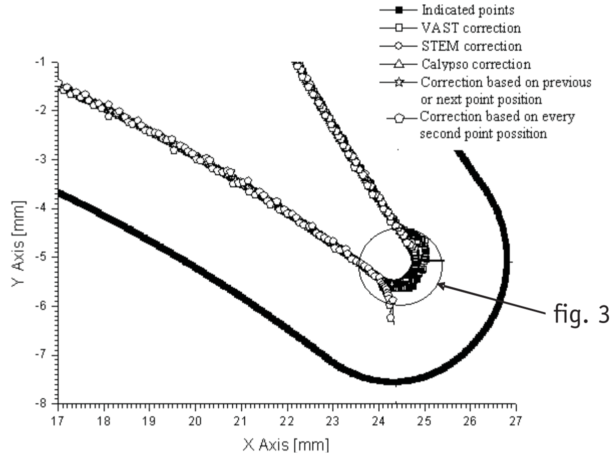

Fig. 2. Measured profile with indicated and corrected points.

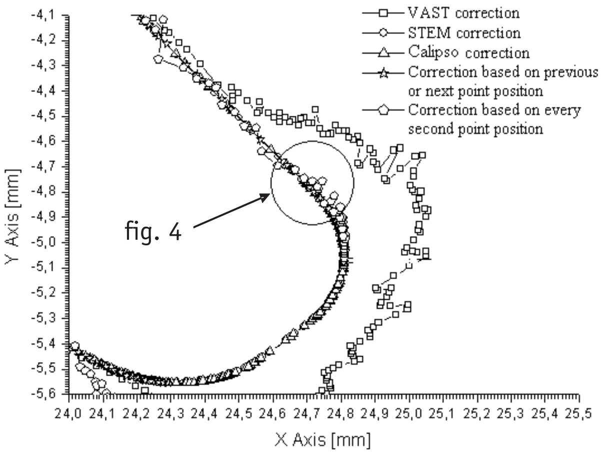

Fig. 3. Comparison of correction methods, an edge of measured element.

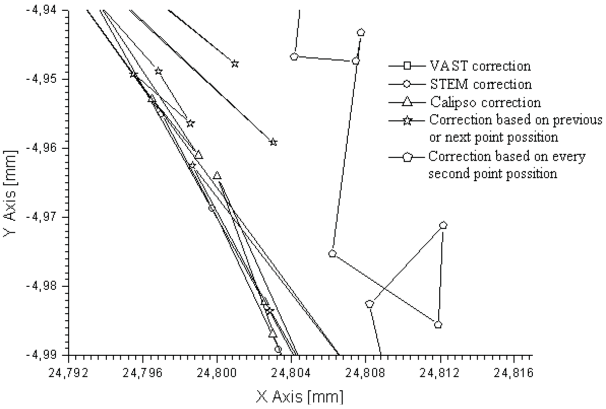

Fig. 4. Comparison of correction methods.

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References

[1] ISO 10360-6:2001 Geometrical Product Specifications (GPS) - Acceptance and reverification tests for coordinate measuring machines (CMM).

[2] Wozniak A., Mayer R., Bałazinski M., "Investigation into precise measurement of cutting tool edges using coordinate measuring machine". In: *CIRP 2nd International Conference on High Performance Cutting*, Vancouver, Canada, 12th-13th June, 2006, Proceedings.

[3] Shuh-Ren Liang, Alan C. Lin: "Probe radius Compensation for 3D data points in reverse engineering", *Computers in Industry*, no. 48, 2002, pp. 241 - 251.

[4] Woźniak A., Mayer R., Bałaziński M., "Stylus tip envelop method: corrected measured point determination in high definition coordinate metrology". *International Journal of Advanced Manufacturing Technology*, no. 42, 2009, pp. 505-514.

[5] Woźniak A., Bałaziński M., Mayer R., "Application of fuzzy knowledge base for corrected measured point determination in coordinate metrology". In: *Proceedings of North American Fuzzy Information Processing Society NAFIPS 2007*, San Diego, USA, 24th-27th June, 2007, pp. 135-139.

[6] Lin Y.C., Sun W.I., „Probe Radius Compensated by the Multi-Cross Product Method in Freeform Surface Measurement with Touch Trigger Probe CMM", *International Journal of Advanced Manufacturing Technology*, no. 21, 2003, pp. 902 - 909.

[7] Jagoda J., Karbowski K., Komenda Z., „Ocena dokładności wybranych metod korekcji promieniowej końcówki pomiarowej" - Master's thesis, Cracov University of Technology, 2006, in Polish.

[8] Park J., Kwon K.,Cho N., "Development of a coordinate measuring machine (CMM) touch probe using a multi-axis force sensor", *Meas. Sci. Technol.*, vol. 17, pp. 2380- 2386 doi: 10.1088/0957-0233/17/9/002.

[9] Aoyama H., Kawai M., Kishinami T., "A new method for detecting the contact point between a touch probe and a surface", *CIRP Ann.*, vol.38, pp. 517-520.

[10] Łoś A., Woźniak A., "STEM - program do obliczania punktów pomiarowych skorygowanych w pomiarach skaningowych na WMP", *Przegląd Elektrotechniczny*, ISSN 0033-2097. vol. 84, no. 5, 2008, pp. 208-211. (In Polish)