Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 20 ISSUES 1-2 January-February 2007

Identification of scanning errors using touch trigger probe head

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Received 17.10.2006; accepted in revised form 15.11.2006

Analysis and modelling

ABSTRACT

Purpose: Creation of a mathematical model, which combine ball tip radius error and small tilt of the stylus to determine translational motion (in two directions) of the stylus ball centre, due to the surface slope.
Design/methodology/approach: First error is described on two dimensional model, thus is very simple. Second model is based on 3D-mathematical model, which is a basis to determine (and plot) translational movement of the stylus ball according to surface slope.
Findings: Accurate scanning process on freeform surface with touch trigger probe head could not be performed, due to number of reasons connected to the stylus ball and trigger probe head errors.
Research limitations/implications: According to nature of this problem, 4D, 5D and 6D-graphs could not be plotted, which would define translational motion of the stylus ball centre at any slope surface.
Practical implications: Understanding the physical model for described error is a basis to create mathematical compensation error model.
Originality/value: No such mathematical model to determine translational motion (in two directions) of the stylus ball centre was published in any paper before.
Keywords: Engineering design; Scanning; Touch trigger probe; Stylus-tilt and ball-tip errors

1. Introduction

The reverse engineering process is unavoidably connected with scanning devices, which were extensively developed in last decade. Numbers of various scanning techniques are known, however, a major part of scanning process is still done on scanning devices with touch trigger probes. Employment of touch techniques with trigger probes is even more present on coordinate measuring machines for accurate dimensional verifying of machined parts. Thus, is necessary to look at the errors which occur during scanning process with touch trigger probes. All described errors in the paper are categorized as *systematic errors* caused mainly by measurement uncertainty of the elements in the system. These errors could be in some manner measured or identified, in contrary to the second big group of errors united under the name *random errors*, which are caused by random external factors. These errors are not in the scope of this paper [1,2 and 3].

2. Touch trigger probe head

Touch trigger probes are widely used on scanning or coordinate measuring machines (CMM's). Usually the stylus is attached to a tripod structure whose three cylindrical legs are kinematically located by three pairs of crossed cylinders. A spring, co-axial with the stylus, supplies a seating preload (Fig. 1). The trigger signal for this type of probe is caused by displacement of one or more of the tripod legs, when the stylus ball pushed away, one or more of the tripod legs, due to surface contact [4, 5 and 6] .

In the paper we firstly want to show ball tip error, secondly we want to describe our mathematical model, which combine ball tip radius error and small inclination of the stylus in order to get translational motion (in two directions in graphical mode) of the stylus ball regarding to the matching point of the scanning ball on the surface slope.

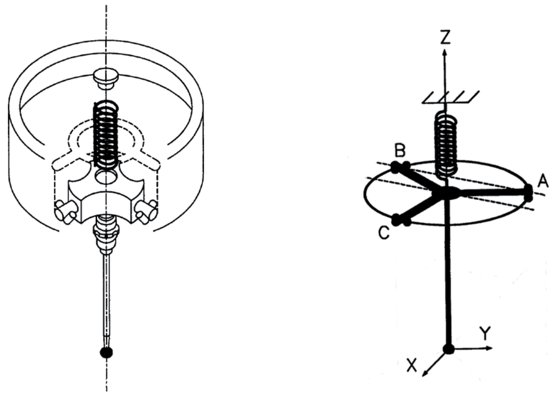


Fig. 1. Sketch and a model of a touch trigger probe head

3. Ball tip error

All vertical touch probes on touch scanning or coordinate measuring machines have an inherent ball tip error. Supposing two-dimensional model, where stylus ball is steady placed in vertical position, thus only X-axis and Z-axis translation movement of the stylus is possible. Considering no stylus ball deformation and no surface deformation under the test, following model can be presented, Fig. 2. Figure shows that due to the finite size of the stylus probe ball, the contact point on a curved surface will not be along the stylus axis, but rather at some point on the side of the ball where the test physical surface and the probe ball slope match. Because the ball does not touch the test part along the stylus axis, there will be an error P in the measured height for any measurement point where the test part surface slope (α) is not zero degree [6, 7]. On Fig. 2 error P and three possible positions of the stylus ball are shown. Example A is at a higher surface slope and thus has a larger measurement error P, while example B is located at a lower surface slope and has a smaller measurement error P [7]. If we want to get exact location of N point on slope surface, an error P, reduced by value ΔZ is made, due to fact, that position of point T on stylus ball every time is captured.

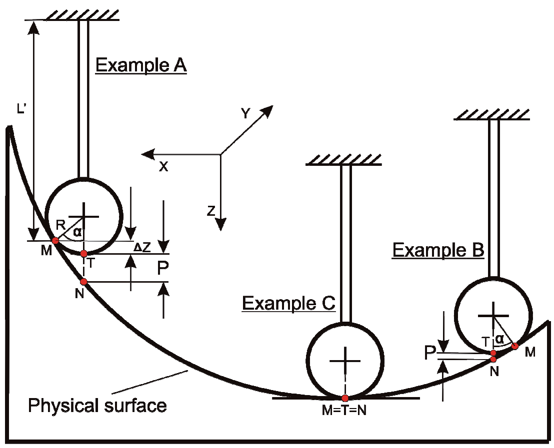


Fig. 2. Vertically placed stylus ball with length L and ball radius R

From the Fig. 2, value ΔZ can be expressed:

$$\Delta Z = R - R\cos\alpha = R\,(1 - \cos\alpha) \tag{1}$$

According to the Fig. 2, error P and ΔZ are zero only at scanning flat surfaces ($\alpha = 0^o$), when all points M,N and T are overlaying each other (M = N = T), Example C.

4. Stylus tilt error and ball tip error

At scanning process with touch trigger probe head on scanning machine or CMM's, the stylus incline for limited angle. Stylus tilt is a misalignment of the stylus motion relative to the X and Y measurement plane of the system, due to stylus axis (Z) is not perpendicular to that plane. Thus, to improve mathematical model from section 3, a stylus tilt error along ball tip error must be also taken into consideration. This misalignment of the stylus causes a systematic error in the measured data for the surface. Combination of errors leads to a skewed coordinate system. The error therefore cannot be corrected by a simple rotation of the part to the stylus shaft tilt angle [7]. As Fig. 3a and 3b shows, the magnitude of probe ball tip error is dependent not only on the stylus tilt angle but also the surface slope angle. Comparison of mathematical model shown on Fig. 2 and model shown on Fig. 3a indicate, that error P decreases in conjunction with stylus tilt angle.

a) b)

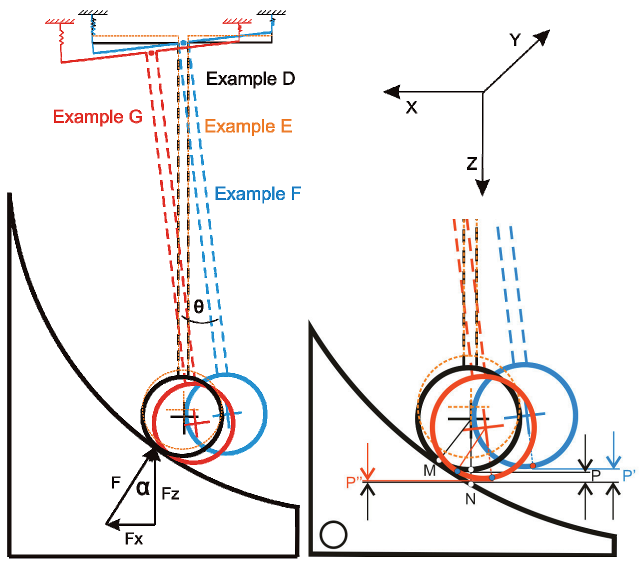


Fig. 3. (a) Mathematical model considering stylus tilt, ball radius and translational movement in (minus) Z-axis, due to contraction of spring coil in probe head; (b) Changing of error P regarding stylus tilt error and ball tip radius.

Examples D,E,F and G (Fig. 3b) present four possible positions (frozen states) of stylus according to permitted stylus tilt angle and load of scanning force F. Example D in Fig 3b present basic vertical model with error P, which was described in section 3. Example F (frozen state) shows permitted stylus tilt, consequently error P increases to value P'. Together with stylus tilt and considering translational movement of stylus in positive X-axis and Z-axis (according to coordinate system in Fig. 3b), a different stylus position is reached, example G. Accordingly, in this position error P decreases to value P''. Example E shows position of stylus regarding to scanning process of flat surfaces, where stylus saves its vertical position. In this particular example E, force F is acting only in Z-axis direction, causing spring coil contraction for maximal value H [6].

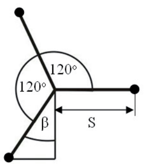
Regarding to the mathematical model shown on Fig. 3a, following variables exist:

$$x_1 = H$$
$$x_2 = \theta$$

During scanning constant force F is loaded on scanning ball tip. Knowing surface slope angle α (or matching point), force F can be divided on F_x and F_z force, accordingly to coordinate system, defined in mathematical model, Fig. 3a.

$$F_x = F \cdot \sin\alpha \tag{2}$$
$$F_z = F \cdot \cos\alpha \tag{3}$$

Regarding to the tripod structure of a touch trigger probe head (see Fig. 4), a following position of cylindrical legs in the touch trigger probe head must be taken into consideration.



$$\beta = 30^o$$
$$S' = S * \sin\beta \tag{4}$$

Fig. 4: Position of cylindrical legs in probe head (bird's-eye view)

At static condition, following equations can be written:

$$\sum_i F_{ix} = 0 \tag{5}$$
$$\sum_i F_{iz} = -F_z + 3 \cdot k \cdot h = 0; \qquad \mathrm{h} \leq \mathrm{H} \tag{6}$$
$$\sum_i F_{io} = -F_x \cdot L + k \cdot \sin\theta \cdot S^2 + 2 \cdot k \cdot \sin\theta \cdot S'^2 = 0 \tag{7}$$

From equations 5, 6 and 7, we get equations 8 and 9

$$-F \cdot \cos\alpha + 3 \cdot k \cdot h = 0 \tag{8}$$
$$F \cdot \sin\alpha \cdot L + k \cdot \sin\theta \cdot S^2 (1 + 2 \cdot \sin^2\beta) = 0 \tag{9}$$

Assuming load F on surface slope angle α, centre of the scanning ball is moved to point T_o.

$$X_o = -L \cdot \sin\theta \tag{10}$$
$$Y_o = -H - (L - L \cdot \sin\theta) \tag{11}$$

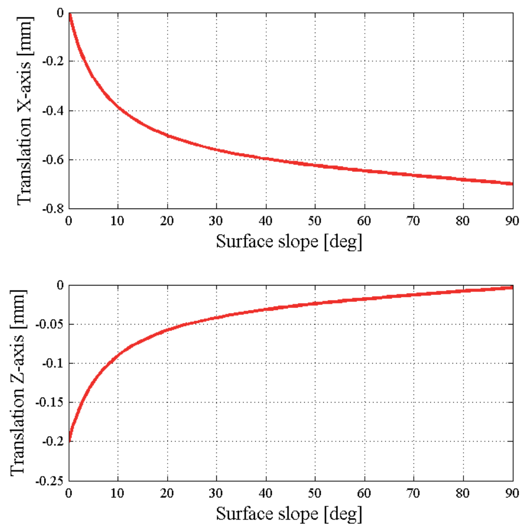


Fig. 5. Translational movement of the scanning ball centre according to surface slope degree α

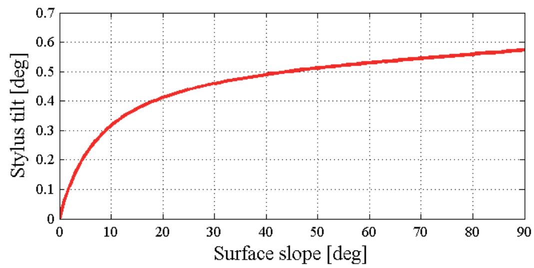


Fig. 6. Stylus tilt regarding to surface slope angle α

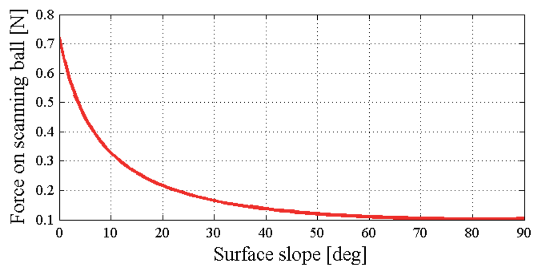


Fig. 7. Force on scanning ball according to surface slope angle α

To locate exact position (movement) of the centre of scanning ball according to the surface slope (α), we set following variables; spring rate k = 1,2 N/mm, max. contraction of spring H = 0,2 mm, stylus length L = 100 mm and max. stylus tilt angle θ = 0,573°. Translational movement of the ball centre are in positive X-axis and positive Z-axis could be exactly defined, if surface slope α is known.

In our model, translational movements of the scanning ball centre on surface slope α are executed till contraction (value h) of the spring in the probe head do not reach maximal contraction (value H). Thus a 3D-graph can be plotted, which shows translational movement of the scanning ball centre according to surface slope degree α (in the paper only 2D-projetion image is shown, Fig. 5). When condition h = H = 0,2 mm is fulfilled, a program inscribe a new location of the scanning ball centre.

From the plots shown on the Fig. 5 principal condition is confirmed. At surface slope degree $\alpha = 0^o$ (scanning flat surface) only contraction of springs in probe head (Δz = -0,2 mm) in Z-axis direction is presented, therefore, no translational movement in X-axis direction of the stylus ball centre, is perceived (Δx = 0 mm). At position, where stylus matching point with surface is 90 degrees ($\alpha = 90^o$), no translational movement in Z-axis direction is noticed in contrast to X-axis direction, where maximal translational movement occurs (Δx = -0,7 mm). Accordingly, a stylus tilt can be plotted with regard to matching point with surface (α), Fig. 6. Stylus tilt is increasing in accordance with increasing surface slope angle α, therefore, at scanning flat surfaces, stylus tilt does not exist. At $\alpha = 90^o$ stylus tilt is maximal ($\theta = 0{,}573^o$) and is (consequently) defined with maximal contraction of spring (H = 0,2 mm) in the probe head. Regarding to surface slope angle α, dependence of the scanning force can be defined as well, Fig. 7. When matching point is $\alpha = 90^o$ only F_x force is present on the scanning ball. F_x force in conjunction with stylus length L forming momentum on springs in probe head, thus the minimal F_x force is needed. When scanning flat surfaces ($\alpha = 0^o$) only F_z force is loaded on scanning ball, therefore, only force F_z is loaded on springs in the touch trigger probe head. Because of that, the biggest load is needed for maximal contraction of springs in probe head (h = H = 0,2 mm) [6]. Mathematical model and presented results are in accordance with our expectations. In the same manner translational movement of the scanning ball centre could be appointed also in other two planes (XY-plane and YZ-plane). Thus, translational movement of the scanning ball centre can be exactly appointed if surface slope angle in each plane are known. Graphically, these results can not be presented, because four- and more-dimensional graphs could not be plotted [6].

5. Conclusions

In the paper we want to present one of the possible mathematical model for error identification originated during scanning process with touch trigger probe head. On the model presented in section 4 we want to expose error identification problem complexity, thus we made a presumption of knowing surface slope angle in advance. Taking into account surface slope angle (in each plane in 3D-space), translational movement of the stylus ball centre can be exactly appointed. But, normally scanning process is carrying out on surfaces with unknown surface slope angle, thus errors occur during scanning process. However, presented model describes some error origin problems, which occur during scanning and as is, might be good basis for further improvement considering additional errors incorporation in the model.

References

[1] M. Sokovic, J. Kopac, RE (reverse engineering) as necessary phase by rapid development, Journal of Materials Processing Technology 175 (2006) 398-403.

[2] I. Budak, J. Hodolic, M. Sokovic: Development of a programme system for data-point pre-processing in reverse engineering, Journal of Materials Processing Technology 162-163, (2005) 730-735.

[3] B. Acko, Method for measurement uncertainty analysis of CMM’s; PhD thesis, University of Maribor, Faculty of Mechanical Engineering, Maribor 1997 (in Slovene).

[4] W.T. Estler, S.D. Philips, B. Borchardt, T. Hoop, C. Witzgall, M. Levenson, K. Eberhardt, M. McClain, Y. Shen, X. Zhang, Error compensation for CMM touch trigger probes, J. of the Int. Societies for Precision Engineering and Nanotechnology 19 (1996) 85-97.

[5] P.A. Cauchick-Miguel, T.G. King, Factors which inflenece CMM touch trigger probe performance, Int. J. Mach. Tools Manufact. Vol. 38, No. 4 (1998) 363-374.

[6] M. Cedilnik, A. Sluga, M. Sokovic, J. Kopac, Identification of stylus errors on Renishaw scanning device Cyclone 2, Seminar on postgraduate study, Faculty of Mechanical Engineering, University of Ljubljana, 2006.

[7] R.S. Clark, E.J. Greivenkamp, Ball tip-stylus correction for a stylus profilometer, J. of the Int. Societies for Precision Engineering and Nanotechnology 26 (2002) 405-411.

[8] Y.C. Lin, W.I. Sun, Probe radius compensated by the multi-cross product method in freedom surface measurement with touch trigger probe CMM, J. of Advan. Manufact. Techn., Vol. 21, No. 10-11 (2003).

[9] Y.L. Shen, X. Zhang, Modelling of pretravel for touch trigger probes on indexable probe heads on CMMs, J. of Advan. Manufact. Techn., Vol. 13, No. 3 (1997).

[10] W.P. van Vliet, P.H. Schellekens, Accuracy limitations of fast mechanical probing, Vol. 45, No. 1 (1996) 483-486.