Identification of scanning errors using touch trigger probe head

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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 (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].

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.
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.

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

\[ ΔZ = R - R \cos α = R (1 - \cos α) \]  

(1)

According to the Fig. 2, error P and ΔZ are zero only at scanning flat surfaces (α = 0°), 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.

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:

$$
x_i = H
$$

$$
x_2 = \theta
$$

During scanning constant force $F$ is loaded on scanning ball tip. Knowing surface slope angle $\alpha$ (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.

$$
F_x = F \cdot \sin \alpha
$$

$$
F_z = F \cdot \cos \alpha
$$

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.

$$
\beta = 30' \quad S' = S \cdot \sin \beta
$$

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

At static condition, following equations can be written:

$$
\sum F_x = 0 \quad (5)
$$

$$
\sum F_z = -F + 3 \cdot k \cdot h = 0; \quad h \leq H \quad (6)
$$

$$
\sum F_z = -F \cdot L + k \cdot \sin \theta \cdot S^2 + 2 \cdot k \cdot \sin \theta \cdot S' = 0 \quad (7)
$$

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

$$
-F \cdot \cos \alpha + 3 \cdot k \cdot h = 0
$$

$$
F \cdot \sin \alpha \cdot L + k \cdot \sin \theta \cdot S^2 (1 + 2 \cdot \sin^2 \beta) = 0
$$

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

$$
X_o = -L \cdot \sin \theta
$$

$$
Y_o = -H - (L - L \cdot \sin \theta)
$$

To locate exact position (movement) of the centre of scanning ball according to the surface slope ($\alpha$), 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 $\theta = 0.573'$. Translational movement of the ball centre are in positive X-axis and positive Z-axis could be exactly defined, if surface slope $\alpha$ is known.

In our model, translational movements of the scanning ball centre on surface slope $\alpha$ are executed till contraction (value $h$) of the spring in the probe head do not reach maximal contraction.
Thus a 3D-graph can be plotted, which shows translational movement of the scanning ball centre according to surface slope degree $\alpha$ (in the paper only 2D-projection 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 $\alpha = 0^\circ$ (scanning flat surface) only contraction of springs in probe head ($\Delta z = -0.2$ mm) in Z-axis direction is presented, therefore, no translational movement in X-axis direction of the stylus ball centre, is perceived ($\Delta x = 0$ mm). At position, where stylus matching point with surface is 90 degrees ($\alpha = 90^\circ$), no translational movement in Z-axis direction is noticed in contrast to X-axis direction, where maximal translational movement occurs ($\Delta x = -0.7$ mm). Accordingly, a stylus tilt can be plotted with regard to matching point with surface ($\alpha$), Fig. 6. Stylus tilt is increasing in accordance with increasing surface slope angle $\alpha$, therefore, at scanning flat surfaces, stylus tilt does not exist. At $\alpha = 90^\circ$ stylus tilt is maximal ($\theta = 0.573^\circ$) and is (consequently) defined with maximal contraction of spring ($H = 0.2$ mm) in the probe head. Regarding to surface slope angle $\alpha$, dependence of the scanning force can be defined as well, Fig. 7. When matching point is $\alpha = 90^\circ$ only $F_z$ 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 ($\alpha = 0^\circ$) 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