TWO DIMENSIONAL MODEL OF CMM PROBING SYSTEM

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Abstract:

A coordinate measuring machine (CMM) as an automation technology is playing the key role in the modern industry to improve the measurement accuracy. Accurate probing that is computer controlled is the current trend for the next generation of coordinate metrology. However, the CMM probing system is limited by its dynamic root errors that may markedly affect its response characteristics. In this paper, dynamic response errors of CMM measurements have been analyzed. The adopted probe stylus sizes throughout the course of measurements are found to cause some waviness errors during CMM operations due to each of the prescribed angle of the probe tip contact point with the specimen surface and the radius of the stylus tip. Variations in the geometry of the stylus have their consequent effects on its inherent intrinsic dynamic characteristics that in turn would cause relevant systematic root errors in the resulted measurements. Unforeseeable geometrical errors of a CMM using a ductile touch-trigger probing system have been characterized theoretically. These results are analyzed in order to investigate the effect of the dynamic root errors in the light of six probe stylus tip of the situation into account when assessing the accuracy of the CMM measurements. Analytical approaches have been applied on a developed two dimensional model (2DM) of stylus tip to demonstrate the capability of such approaches of emphasizing the root error concept using the strategy of CMM ductile trigger type of probe.

Keywords: *CMM, trigger probe, stylus tip, tip root errors, and two-dimensional-model (2DM).*

1. Introduction

One challenge for advanced coordinate metrology is the accurate dimensional measurements on modern engineering objects, especially in aerospace and automotive industries. The probe is one of the most important systems of CMM measurement accuracy. However, studies on CMMs cannot separate the characteristic performance of the probing system from other CMM error sources [1-9]. The stylus tip contact with the detected surface is the source of electronic signals that will develop the pattern on the working objects. So, the performance of the CMM overall system is very much dictated by the motion precision of the probe stylus tip and its actuator. Therefore, the probe stylus tip is literally at the center of the CMM operation and a key element of coordinate measurements.

A variety of probe designs in CMM are available today, although most probes are compatible with most CMMs [1, 10]. Metrology engineer should understand the behavior of each type of probe, where CMM probes are classified into two main categories; contact (tactile) probes and non-contact probes. As the name suggests, a contact probe gathers data by physically touching the artifact or specimen. CMM contacting probes are divided also into two specific families of hard probes and touch trigger or scanning probes, which maintain contact with the specimen surface during data collection [10]-[12]. The probing system in CMM machines includes stylus and stylus tip, which have their own dynamic characteristics during measuring processes [7], [13].

1.1. CMM hard probes

To use a hard probe, the CMM operator manually brings the probe into contact with the specimen, allows the machine to settle and manually signals of the CMM to record the probe position. The CMMs software treats the readings to compensate for the diameter of the probe stylus tip. CMM hard probes are available in a variety of configurations and continue to have a broad application in coordinate metrology. When used in conjunction with manual CMMs, they are most frequently used to measure curved surfaces, distances between specimen features, angles and the diameter and centerline location of bores in applications that require low to medium accuracy. Hard probes are simple in use and rugged also, but their repeatability quality depends upon his operator touch. Because every operator has a different touch when moving and bringing the probe into contact with the specimen, therefore this hard type probe is not commonly used in large mass production companies.

1.2. CMM touch trigger probe

Recently, the touch trigger (scanning) probe is the most common type of probes used in CMM. Ductile trigger probes are precision-built, touch-sensitive devices that generate an electronic digital signal each time the probe contacts a point on the specimen surface, which is usually indicated by an LED and an audible signal. The probe head itself is mounted at the end of one of the CMM's moving axes. It can be rotated automatically, and can accommodate many different probe stylus tips and attachments. These features make the CMM trigger probe a versatile and flexible data-gathering device. CMM touch trigger probes eliminate influence of operator touch on measuring results compared to hard probe type. It can be fitted on direct computer numerical control (CNC-CMMs) and manual CMMs [10]-[11]. An improvement on the basic touch trigger probe design incorporates piezo-based sensors to translate the deflection of the probe into a constant digital acoustic signal that is recorded by the CMM. This design improves the accuracy of measurements due to the elimination of the effect of stylus bending (caused by force variations when the touch trigger probe contacts the specimen) and inaccuracies caused by the probe's internal electromechanical parts. While, the last element in the probe styles is the tip.

In practice, the part measured waviness deviate from the desired value owing to many quasi-static systematic errors as inherited intrinsic are geometric error of measuring probe tip, thermally induced distortions of machine probe elements, errors arising from the static deflection or stiffness of machine-fixture-specimen-probe system under the touch force and other errors [1], [9]. Measurement accuracy is commonly determined by the kinematic accuracy of the CMM probe and a big portion of machines used with low kinematic accuracy. Software-based error compensation is a method for anticipating the combined effect of all of these above factors on standard precise and accurate spherical artifact and suitably modifying the conventionally designed probe tip scanning trajectory. Considerable research works have been reported to improve the kinematic accuracy of the CMM machine probe, which is too sophisticated to implement, there are few programs that focus on changing the CNC program to compensate the probe error [6], [14]. While, generating a cylindrical surface, its profile often concavely deviates from the ideal profile, which initiates the necessity of measuring the surface profile during the measuring process and suitable CMM strategy. Therefore, it is very difficult to separate and study these types of errors in practice clearly. In such cases, CMM is a reliable tool for verification, dimensional measurement and geometrical waviness form deviation accuracy for selected surface profile needs to be carried out theoretically. Probe stylus tip path is updated during measuring based on the parameters measured by the newly developed techniques. Thus, a high-quality inner cylindrical surface measurement has been successfully generated by process using software compensation. The geometrical form and undulation of spare parts for machinery and mechanical equipment is an important and active role in the technologies applications of industrial metrology. During the stages of assembly and operation of mechanical systems, the ruby ball tip of the stylus that used to measure deviations in geometrical feature always requires a thorough test to achieve high measurement accuracy, specially when measure the deviations of difficult forms and its waviness in the three directions (X, Y, and Z).

Recently, both theoretical analysis and experimental studies pointed at the triggering point being the main source of probe errors [1]-[6], [8], [12], [14-16]. But unfortunately, this area needs more dynamic analyses to understand stylus response error sources according to the design and construction of CMMs, especially new CMM machines [17]. The error caused by probe loping has become a significant component of the total system errors. However, most of the studies on scanning CMMs cannot separate the performance of the probing system from other error sources of the CMM [1], [8]. Since CMM trigger probes are precision equipments themselves, their performance should be studied separately from the rest of the components of the CMM in order to characterize its behavior to improve the measurement accuracy. This principle of operation effectively triggers the probe at a constant force regardless the contact area between the probe stylus tip and the measured specimen.

2. Mathematical Model

Since the influence of some unforeseeable factors affecting probe inaccuracy could be small, so it requires accurate analytical model during analysis. Thus, for this investigation a new two-dimensional-model (2DM) has been used to present the root error due to ball tip size of the CMM probe stylus at measurement operations.

2.1. Stylus ball tip error

During scanning all CMM touch probes in the coordinate measurement have a natural ball tip errors [14]. Supposing 2DM, where stylus ball is steady placed in horizontal position, thus only X-axis and Y-axis translation movement of the stylus is possible. Assuming no stylus tip ball deformation and no surface deformation under the test, following 2DM model can be presented in Figs. 1 and 2.

Figure 1 shows the measurement principle of the proposed system which include contact points 1, 2 and 3 that are indicated on the vertical and horizontal plans of the probe stylus tip with l stylus length and ball tip radius of R with predicate angle θ. Figure 2 presents that due to the finite size of the probe stylus ball tip, the contact point on a cylindrical surface will be along the stylus axis, but relatively at some point on the side of the ball where the test surface and the stylus tip ball slope angle match horizontally.

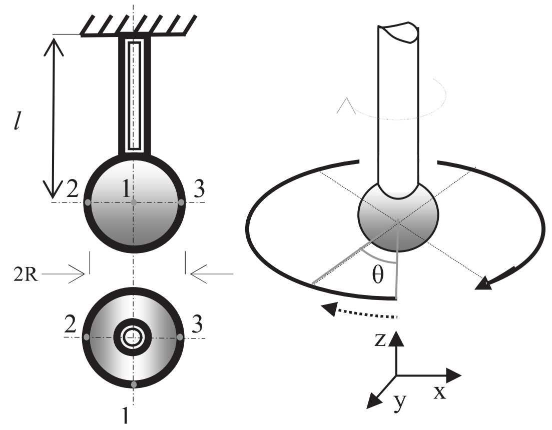

Fig. 1. Horizontal placed probe stylus ball tip radius (R).

Because of the ball does not touch the test artifact specimen along the same stylus slope angle, there will be an error E in the measured length for any measurement point where the test part surface slope angle (θ) is not zero degree. The error E and different possible positions of the ball tip are shown. Case d is at a higher surface slope (180°) and thus it has a larger measurement error E, while case a, is located at a lower surface slope and it has a smaller measurement error E. Therefore, to get exact location of n point on slope surface, an error E, reduced by value ΔY is made, due to fact, that position of point t on stylus tip ball every time is captured. From figure 2, values ΔY and E can be expressed as follows:

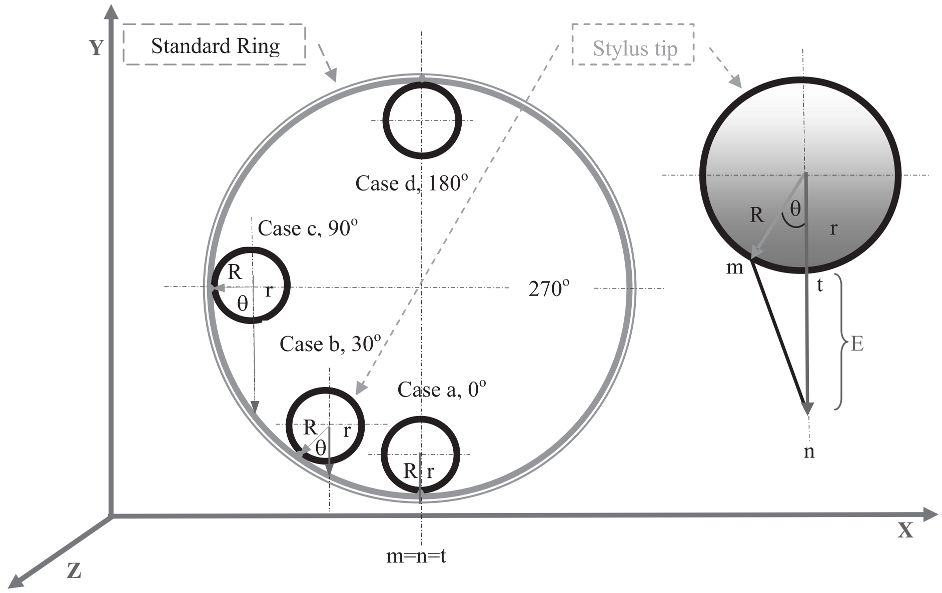

Fig. 2. Size of error E related to the probe tip ball radius (R) and surface slope degree (θ).

$$\Delta Y = R - r \quad (1)$$

$$\Delta Y = R - (R\cos\theta) = R\,(1 - \cos\theta) \quad (2)$$

Where the distance between two points t and n indicates the E in Y direction, while ΔY is the relative distance between points m and t in the Y-direction, the large scale of the tip ball in case b. From appointed 2DM can be stated that measurement error E and ΔY values are made only in Y-axis and is dependant on surface slope. In point 2 or 3 (according to figure 1, where is matching angle θ=180°) ΔY and error E would be maximal values, while error E and ΔY are equals zero only at scanning flat surfaces (θ=0, 360°) when all points m, n and t are overlaying each other ($m=n=t$), as shown in case a.

3. Results and Discussions

The root error due to CMM stylus ball tip cannot be neglected. Six different stylus balls with radii R=4.0, 3.0, 2.5, 2.0, 1.5 and 1.0 mm have been selected according to actually common using. A relative mutation in the Y-direction (ΔY) of the stylus ball can be observed according to the surface slope degree that called matching angle (θ), Fig. 3.

Through the application of accurate analytical 2DM proposed in the measurement of cylindrical parts using CMMs, emerged two types of systematic unforeseeable errors. The first error resulted when increasing surface slope angle while the second error resulted when increasing the radius of the stylus tip ball. Fig. 3 shows how margin of errors are calculated theoretically and the output of climate surface slope degree (θ) of the probe tip during contact through 360° at using complete cylindrical reference artifact for different six tips radii. It is observed that the amount of errors in the Y-direction starting from zero for each probe tip at the beginning of contact at 0°, while increasing incremental increase of inclination angle of a point contact of the tip with the artifact to reach its maximum relative value of 2R% at 180° and then come back to the decline to reach zero at 360°. It means that rotational motion that occurs during the probe tip scanning due to creeping of the tip at the base of the probe vibrates at the surface coming into contact with the cylindrical parts are also generate another error regularly.

Hence, it can be concluded from this mathematical-two-dimensional model is capable to appear two different systematic errors with the movement of the probe during CMM scanning. The first is consequence of the creeping tip while the second is a result of increasing the radius of the tip became increasingly error rate to a maximum value

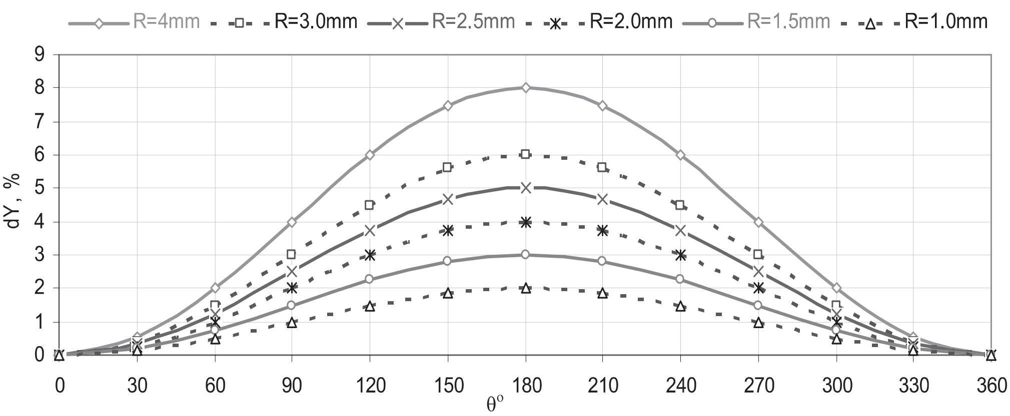

Fig. 3. Relative error of the probe ball tip at different surface slope angle.

of 2R% during the measurement at the point of orthogonal (180°) of the cylindrical artifact. The maximum relative amount of these root errors are ranged from 8, 6, 5, 4, 3 to 2% at the same matching point (180°) for the ball tip radius of 4.0, 3.0, 2.5, 2.0, 1.5 and 1.0mm in respectively as shown in Fig. 3.

In other words, figure 4 can help to conclude that; small probe tip of 1.0mm can be better used to diagnose the true state of the surface form of the specimens than that with bigger tip radius of 1.5, 2.0, 2.5, 3.0 and 4.0mm in reactively. This is because the probe tips of the large radii owing touch large contact area with the inner surface of the used standard artifact, and *vice versa*. In this case, the distortion of the measurement result using 1.0 mm probe tip become more visible and gives better estimate of the measured feature profile compared to the results of 4.0 mm probe tip.

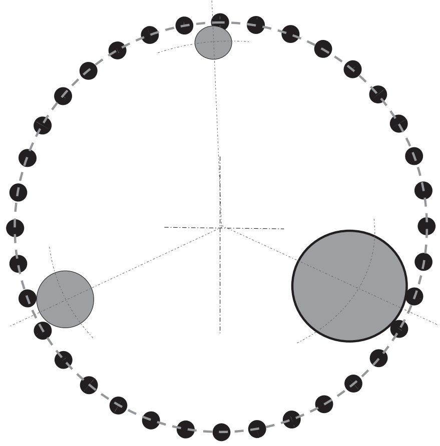

Fig. 4. Scheme of the probe tips scanning path during measuring process.

4. Conclusion

The application of the proposed accurate analytical two-dimensional-model (2DM) measurement technique can be used for its capability to present two types of systematic unforeseeable errors of the probe during CMM scanning process. The first error can be due to surface slope degree of the probe tip during contact with the detected surface of the cylindrical artifact in the Y-direction, with zero error value where the tip begin to start rotation and reach its maximum error value of 2R% at the point of orthogonal axis at 180°, then returns again to zero error at 360°. This error always occurs for the ball tip rotation during the scanning process as a result of creeping of the probe tip during touching the measured surface. The second error resulted at increased radius of the probe stylus tip ball. From carried out results analysis, are can conclude the following:

- Increasing the probe tip radius decreases the averaged measured error signals of surface waviness; it may be due to large number of contact points of small tip on the artifact during scanning trajectory. It has been cleared that the probe stylus tip at scanning have a significant influence in the accuracy of CMM measurements using the strategy of touch trigger probe independently.
- From results obtained, an easy calibration and correction technique for probe performance accuracy of CMMs measurements can be developed, which is can be built upon both of surface form and probe stylus characteristics experimentally.

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