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Machine tool probes testing using a moving inner hemispherical master artefact

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ABSTRACT

The growing popularity of usage of touch probes for CNC machine tools has created an increasing requirement to test their accuracy. Indirect methods used until now, based on the measurement of a material gauge with a machine tool equipped with a probe, made the separation of machine tool errors from probe errors impossible. In this article, a new method of testing the probe accuracy, which does not employ a machine tool, is presented. This method employs a moving master artefact in the form of an inner hemisphere. The standard uncertainty of the determination of triggering radius variation is 0.35 μm.

1. Introduction

Due to the development and increasing popularity of numerically controlled machine tools, a need for their further automation and of acceleration of the speed of quality control of processed elements has arisen. This was made possible by using measuring devices, which enabled automatic setting of the cutting tool, detection of its malfunctions, a precise location the processed element and its direct measurement on the measurement tool. The two latter tasks may be completed by using compact touch probes, mounted directly on the spindle of the CNC milling machine or of the machining centre, or in the CNC lathe turret. The use of such probe enables performance of a measurement in a way similar to a CMM measurement with a touch-trigger probe. The possibility of rotating the tool's spindle makes it necessary to use a wireless – either optical (infra-red) or radio – interface with the probe, but, on the other hand, it enables measurements with 2-axis or 3-axis probes, that is – with probes that work only in two or three main and in intermediate directions.

Touch-trigger kinematic probes are the most widely employed for CNC machine tools, but strain gauge and optoelectronic probes are also used, even if they are markedly fewer in number than kinematic probes. Due to their rising popularity in CNCs, a method of determining the parameters for determination their accuracy needed to be developed. Because the probes are interchangeable devices, it is essential to determine the accuracy of the probe and wireless interface itself, separately from the accuracy of the machine tool on which it is used.

2. Known methods of accuracy testing for CNC machine tools

The accuracy parameters of a complete measurement system, composed of a probe, an interface and a machine tool and the methods of their testing are described in the ISO 230-10:2011 standard [1]. Those methods are based on the measurement of material master artefacts, such as reference spheres, gauge rings and corners. They enable checking the utility of a complete system to given measurement task, but they do not enable separating probe errors from machine tool errors, which are of the same order or even an order greater than that of the probe errors. E.g. the positioning repeatability of an average CNC machine tool is several micrometres, while different probe errors vary from less than 1 μm to over a dozen micrometres.

It seems justified to apply similar parameters for testing the accuracy of the probe alone to those applied for testing the CMM touch-trigger probes – therefore, the unidirectional repeatability, the triggering radius variation and the pre-travel variation [2].

The unidirectional repeatability will be represented as UDR_i, where i stands for the successive directions of the probe. The unidirectional repeatability is defined as the spread of the positions of

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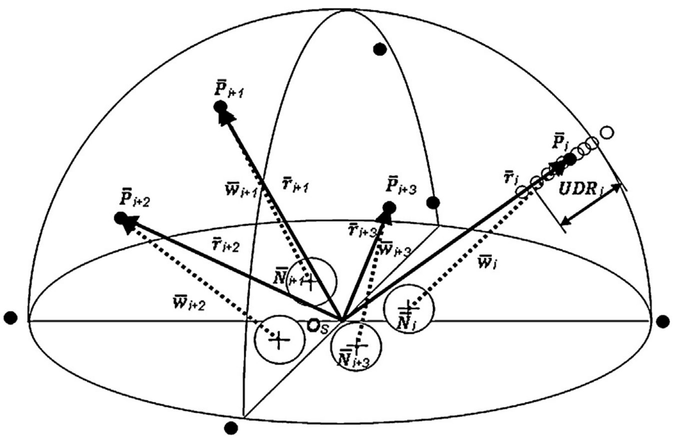

Fig. 1. Graphic interpretation of the parameters describing the accuracy of touch-trigger probes.

the probe's triggering points $P_{i,j}$ for single direction measurements, where j stands for successive measurement points for one given direction. The UDR_i value is defined by double standard deviation of obtained results in radial direction.

The best-fitted element may be determined based on the triggering points of all the working directions of the probe, by using the least square sum method.

The distance between the centre of this element O_S and the triggering point $P_{i,j}$ is defined as the triggering radius $r_{i,j}$, and the distance between the neutral position of the stylus tip and this given triggering point is the pre-travel $w_{i,j}$.

For each working direction of the probe it is possible to determine an average triggering point $\bar{P}_i$, average triggering radius $\bar{r}_i$, and an average pre-travel $\bar{w}_i$, which is defined as the distance between the average neutral tip position $\bar{N}_i$ and the average triggering point for a given direction. The neutral tip position of the probe has no importance for the measurement. The triggering radius variation is a more important parameter. The triggering radius variation V_r is defined as the difference between the maximum and the minimum average triggering radius values for all investigated directions:

$$V_r = \max\{\bar{r}_i\} - \min\{\bar{r}_i\}. \quad (1)$$

Often the pre-travel variation, V_p, defined as:

$$V_p = \max\{\bar{w}_i\} - \min\{\bar{w}_i\}, \quad (2)$$

is used as the triggering radius variation, and those two parameters are equal if one assumes that the average neutral position of the measurement tip is constant, and placed in the centre of the best fitted element. The graphic interpretation of those parameters is shown in Fig. 1.

Most probe producers provide the value of their probes unidirectional repeatability. The value of pre-travel variation or triggering radius variation is provided rarely and only for the most accurate probes (e.g. strain gauge ones). One producer also provides a value of probes "accuracy", but this parameter is not clearly defined.

In the case of determining the accuracy of machine tool probes, only the indirect methods are described. Those methods consist of measuring an appropriate standard, such as a reference sphere or a gauge ring, on the machine tool. They are often used because of their simplicity [3–7], but in their case it is necessary to use a highly accurate machine tool to obtain information about the accuracy of the probe itself, and not the probe joint with a machine tool. In the case of commonly used mediocre quality machine tools, this condition is not met.

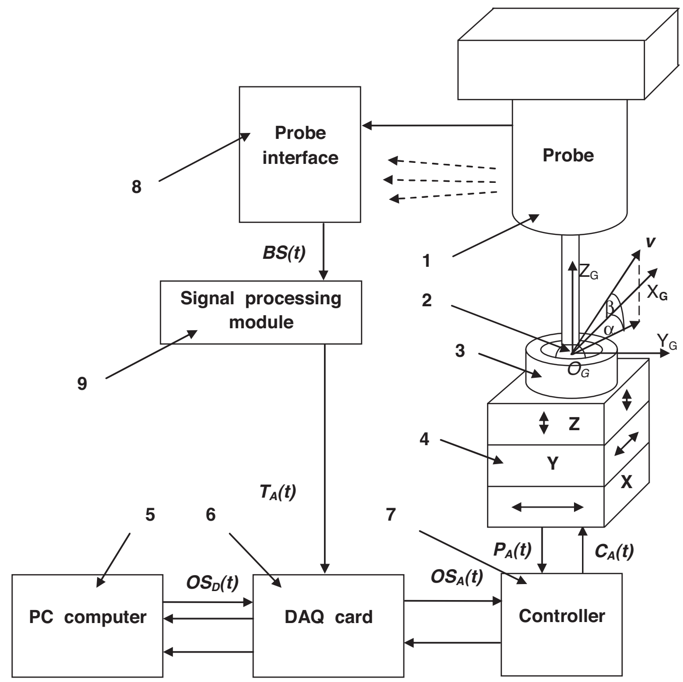

Fig. 2. The outline of a device equipped with a moving master artefact for testing touch-trigger probes.

Until now, the indirect methods described were only for probes used in coordinate measuring machines. They consist of investigating the accuracy of the probe mounted in a dedicated measurement setup. The noted indirect methods of testing the probes consist of employing gauge blocks and an interferometer [8], a low force displacement transducer [9] or a reference axis [10]. All above-mentioned methods require heavy and complex setups. That is why they are considered laboratory methods. The authors have attempted to adapt the already existing methods to be used for machine tool probes. Unfortunately, those attempts were unsuccessful, among all – because the triggering force of machine tool probes is much (several dozen times) greater in comparison to CMMs.

One of the probes manufacturers, Renishaw, built a setup for testing the probes performance using the method with the reference axis. This setup is called Portable Probe Test Rig and the uncertainty of repeatability of determination using this setup is equal to ±0.08 μm. However, this device is large and heavy, so using it in the production environment is problematic.

The testing of machine tool probes requires a portable device, which might be used directly on the machine tool, eliminating the time and trouble needed to dismantle the probe and its interface. Dismantling the probe is very onerous for its user, because remounting of the probe takes several hours and must be conducted by a qualified worker. The knowledge about the accuracy of the sensor in isolation permit independent study of the probe behaviour that is important, e.g. for probe manufacturers and scientists. That is why works were undertaken to develop a new, portable device for testing the accuracy of touch-trigger probes for CNC machine tools both in the laboratory and on the machine tool.

3. The principle of operation

The scheme of the developed setup is shown in Fig. 2. The probe (1) remains immobile during the test, placed either in a mount or directly on the machine tool's spindle. The stylus tip (2) is placed inside the ring or the inner hemisphere gauge (3). The gauge is mounted on a 3-axis piezoelectric positioner (4) equipped with