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# Mechanical model of errors of probes for numerical controlled machine tools

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ABSTRACT

CNC machine tool probes are not only used to set up the workpiece before machining and to control it after machining, but also to determine volumetric errors of the machine tool. That's why there is a necessity not only for knowledge of the complete on-machine measurement system errors, but also for the knowledge about probe's errors in separation from machine tools. This paper presents a theoretical model of errors of probes for CNC machine tools. It takes into account such unique features of the machine tool probes as the transducer with support on the whole circumference and as wireless communication. 3 probes: RMP60, MP700 and IRP32.00-MINI were tested using moving master artifact method, out of machine tool, to verify the model described. The triggering radius values obtained experimentally were compared with values calculated using theoretical model, resulting with a compliance up to 92%.



## 1. Introduction

Touch-trigger probes for CNC machine tools are mounted in place of the tool, and allow to take measurements on a CNC machine tool in a similar way to a coordinate measuring machine (CMM). The primary application of probes is an automatic workpiece setup. The probes also allow to perform dimensional control of parts after or during machining, and to determine kinematic errors of the machine.

The accuracy of the on-the-CNC machine tool measurement, which is performed using a probe, influences quality of parts machined on the machine tool. In order to verify if a complete measurement system composed of a probe and machine tool adheres to an accuracy required by the user, indirect methods of testing probe accuracy, basing on a material gauge measurement on a machine tool using a probe are used. The ISO 230-10 standard [1] introduces $P_{FTU,3D}$ and $P_{FTU,2D}$ parameters which are form errors obtained in on-machine measurement of, respectively, a test sphere and a gauge ring. In [2] and [3] on-machine measurement of a 25 mm master ball was used to determine pre-travel variation errors – spatial, systematic errors – of Renishaw probe. In [4] errors of the probe in plane perpendicular to its axis were determined basing on the measurement of 150 mm ring gauge. Also in [5] the results of on-machine measurement of gauge ring (diameter of 29,998 mm) were used to determine systematic errors of the probe (Renishaw MP10). In [6] the same test sphere was measured using 2 different probes – m&h TX/RX 40.00 and Renishaw OMP400 – and the measured form deviations were attributed to probes' errors. This approach allows to determine errors of the machine tool measuring system, but it does not allow to separate probe errors from machine tool errors. Nevertheless, many applications require knowledge about probe errors characteristics. En example of such application is, described in [7], determination of kinematic errors of machine tool basing on on-machine measurement of artifact, in this case build of

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multiple master balls. In [8] the abovementioned method is extended by using an additional 2-ball scale bar. Similar method of machine tool errors determination using another artifacts – 3 square columns – is described in [9]. The same application is also presented in [10]. For this application, the various master artifacts are measured on the machine tool. It's assumed that obtained deviations are caused by the kinematic errors of the machine. But if there was no possibility to separate the errors of the probe and the errors of the machine tool, the errors of the probe would be accounted for errors of the machine tool, which have to be determined. That is why a study of probes' accuracy outside of the machine tool [11] is currently carried out.

The accuracy of measurements using probes for CNC machine tools can be increased with digital compensation of their errors. Its application require a probe error mapping or theoretical model of its operation.

Probe error characteristics depend on type of used transducer. A 3-point kinematic transducer is commonly used in probes for CNC machine tools, and in probes for coordinate measuring machines (CMMs). A scheme of such transducer is shown on Fig. 1a. In this type of a transducer a mobile element with three arms is pressed with a spring against three points of support. Each of these points of support is a break in the electrical circuit. When the stylus connected with the moving element is tilted or moved, the electrical circuit opens.

Probes with 3-point kinematic transducer are characterized by triangular characteristics of errors of considerable values, reaching up to several dozen micrometers [8]. Probes with strain-gauge transducer do not have this flaw. A scheme of such transducer is shown on Fig. 1b. In a transducer of this type contact of the stylus tip with measured surface is detected by the strain-gauge located between the moving element of the transducer and the stylus. Similarly to probes with a 3-point kinematic transducer, probes with a strain-gauge transducer are commonly used in CNC machine tools as well as in CMMs.

Another method of elimination of probe's systematic errors' triangular characteristic is application of a transducer with support on the whole circumference, for example of a 1-point kinematic transducer. It is shown in Fig. 1c.

In a transducer of this type, the support of a half-spherical moving element is implemented on the whole circumference. When the stylus connected to the half-spherical moving element is tilted or moved, the half-spherical moving element pushes the cylindrical element, which opens the electrical contact. Probes with this type of transducers are commonly used in probes for CNC machine tools.

The error models of 3-point kinematic probes for CMMs are well known. In [12] a virtual CMM based on Monte Carlo Method is described. One of this virtual CMM's modules is module responsible for modeling probing errors. In [13] the description of using neural networks, Fourier transformation and, as in [12], of the Monte Carlo Method to model errors of the probes is presented. But most probe models takes into account elastic deflections of the stylus, which vary depending on the value of a triggering force, which is the force necessary to trigger the probe, in a given direction. For example in [14] a model of a 3-point kinematic probe which takes into account both the elastic bending of the stylus and the displacement required to break an electric contact is described. This model is extended in [15]. In another model, presented in [16], both the abovementioned factors and, additionally, the Hertz deflections are taken into account. A similar model for strain-gauge probes is also described in this paper. The measured-object-related part of model considering Hertz deflations is wider presented in [17].

Nevertheless, none of these models is verified for machine tool probes, and in particular there is no operation model for a 1-point kinematic transducer. Additionally, probes for CNC machine tools use a wireless communication, which results in a delay of the triggering signal between the probe and the machine tool controller.

This article presents an error model for three most popular types of probe transducers for CNC machine tools. The models were verified experimentally on a dedicated experimental setup.

## 2. A theoretical model of CNC machine tool probes performance

Most models [12–16] of CMMs probes performance refer the pretravel $w$ of a probe that is defined as a distance

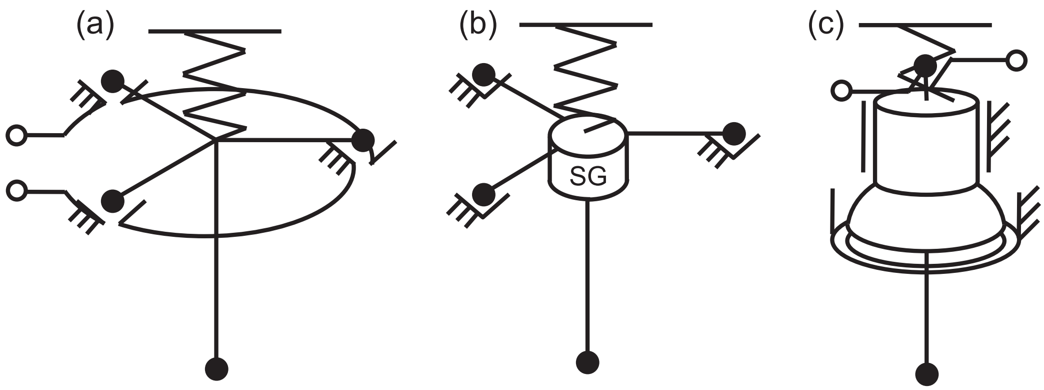


**Fig. 1.** (a) Scheme of 1-point kinematic transducer; (b) scheme of strain-gauge transducer; (c) scheme of 1-point kinematic transducer. SG – strain-gauge.