3D characteristics of triggering force of CNC machine tool probe

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Abstract. The triggering force of CNC machine tool probes has been tested using a dedicated setup. The measuring method out of CNC machine tool, based on a moving inner half-sphere master artefact is applied for tests. The executive part of the setup is the assembly of the PI NanoCube piezostage and the Kraftsensor K3D60 strain-gauge sensor. The paper describes the principle of operation of the setup. The experimental results are presented as polar plots for Renishaw OMP 40-2 machine tool probe. The 3-lobed 3D characteristics of triggering force of machine tool probe have been obtained.

1. Introduction
On-machine measurement (OMM) has become very popular among machine tool users. This approach decreases the time needed for the inspecting part between machining operations. So far, setting of the part on the machine table has been executed manually. The final part inspection used to require an additional measuring device or a measuring machine. All the mentioned actions affect the machine tool downtime which is undesirable. Thus, OMM allows to improve the manufacturing process [1-2]. Machine tool calibration is also possible by probing master balls artefact [3]. The most popular solutions regarding the construction of the machine tool probes are those with kinematic transducer which is similar as in probes used in coordinate measuring machines (CMM). In both cases their accuracy is seriously connected with their triggering force variation [4-7]. Moreover, the triggering force can cause deflections of flexible elements. Those deflections additionally decrease the measurement accuracy [8]. That is why the need for testing the triggering force of touch trigger probes exists. The popular method of the probes’ triggering force testing is using a Renishaw gram gauge [5]. This method is simple, but it cannot be automated. A novel setup for testing the triggering force was therefore proposed to overcome this limitation.
In this paper, description of the setup and its principle of operation are presented, as well as exemplary results – characteristics of the triggering force of OMP40-2 3-point kinematic probe for CNC machine tools.

2. Setup for examination of triggering force of probes of CNC machine tools

2.1. Triggering force of touch trigger probes
The triggering force is the force occurring at the time of triggering the probe due to the contact of the probe's stylus tip with the measured element. The most commonly used probes are those with kinematic transducer. For this type of probes, the triggering force has a great variation depending on
its operation direction. The level of triggering force for this kind of probes used in CMMs is in the range from sub-Newtons to several Newtons for axial directions. The triggering force increases with the increase of the angle between the force direction and XY plane of the probe. Therefore the biggest value of triggering force is reached for axial direction. As regards the machine tool probe, the maximum triggering force for Z direction can reach more than 10 N, which is very significant for the measurement accuracy.

2.2. The principle of the setup for examination of triggering force of touch trigger probes

The executive part of the setup for triggering force triggering testing has been described with reference to figure 1. A tested probe (1) is fixed firmly. Its stylus tip is located approximately centrally within the gauge in the shape of an inner half-sphere (2). The gauge is screwed to the force sensor (3) which is mounted on 3D piezoelectric translator (4). Before measurements begin, the stylus tip is in the neutral position, and there is a clearance between its surface and the inner half-sphere surface. The measurements are performed in the coordinate system of the master artifact, which has its origin in the center of the master artifact when it is located in the starting position, and the axes are parallel to the axes of the coordinate system of the piezoelectric translator. The control unit generates signals controlling the piezostage’s position and acquires signals from the force sensor and from the piezostage’s displacement sensors. To perform a measurement, the piezostage moves in a given direction. The master artefact’s surface contacts with the stylus tip and the probe gets triggered. The signals from the force sensor and from the probe are synchronised, so it is possible to find a value of the force in each of the 3 directions at the point of triggering. Basing on these values, the total triggering force’s value is calculated.

![Figure 1. The executive part of the setup for triggering force triggering testing.](image)

2.3. Practical implementation of the setup for examination of triggering force of touch trigger probes

The photo of the full setup for examination of triggering force of touch trigger probes is presented in figure 2. The developed device is based on a previous setup for probes’ triggering radius testing [9]. The executive part of the setup is the assembly of the Physik Instrumente P-615.3CD NanoCube piezostage (4) and the Kraftsensor K3D60 strain-gauge sensor (3) fixed together using a lightweight, fully portable, modular frame (5). The control unit is built on the basis of the National Instruments NI USB-6259 BNC data acquisition card (6). The signals from the force sensor are sent to this card by the multichannel amplifier (8). NanoCube works in a closed loop with the Physik Instrumente E-500 modular controller (7) with the E-509 and the E-802 modules. The triggering signal from the probe is received by a dedicated, wireless interface receiver (9). It is transferred to the data acquisition card via
additional electronic devices (10). All the components of the setup are fully portable and can be transported by one person, so it is possible to test the probes in the customer’s place of choice. The measuring range for the force measurement is 10 N in 3D and the extended uncertainty of the measurement in 3D has been calculated for 0.08 N for coverage factor k=2. Such setup allows to test the CNC machine tool probes of much higher triggering force than the probes for CMMs.

![Figure 2. The photo of the full setup for examination of triggering force of touch trigger probes.](image)

3. Experimental results and discussion

In order to demonstrate the feasibility of the described setup, 3D characteristics of triggering force of Renishaw OMP40-2 have been measured. The Renishaw OMP40-2 probe is a popular ultra-compact 3D touch-trigger probe with kinematic transducer and optical signal transmission. The tests were made for two measurement velocities: 0.5 and 0.05 mm/s. The second velocity reflects the quasi static operating conditions of the probe. To obtain the 3D characteristics of the triggering force of the probe, 3 measurement series were carried out for a horizontal angle $\alpha$ from 0 to 350° and of a vertical angle $\beta$ from 0 to 90°, with a step of 10°, as shown in figure 3.

![Figure 3. Definition of the measuring direction](image)

The obtained results are shown in figure 4. For the working directions placed on XY plane ($\beta = 0^\circ$ and near), the 3-lobed characteristics is visible which is typical for kinematic transducers. The triggering force increases with the increase of $\alpha$ and for $\beta$ close to 90° - the characteristics is smoothed. In case of velocity of 0.5 mm/s (Figure 4a), the maximum triggering force ($\beta = 90^\circ$) equals 5.5 N. In XY plane the triggering force variation is from 0.605 N to 1.215 N. Under the quasi-static conditions, the
maximum triggering force in the XY plane of 1.294 N, the minimum of 0.664, was obtained, while the switching force in the Z axis is 5.910 N.

The obtained results are close to the values specified by the probe manufacturer. As it can be seen, there is a visible influence of the measurement velocity on the triggering force. For quasi-static conditions, the highest values of the triggering force were obtained. This may be due to the increase in friction in the probe transducer.

**Figure 4.** Triggering force characteristic of the Renishaw OMP40-2 probe: a) 0.5 and b) 0.05 mm/s measurement velocities.

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