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COMPENSATION OF SYSTEMATIC ERRORS OF DAMAGED PROBE FOR ON-MACHINE MEASUREMENT

Spatial characteristic of triggering radius of the damaged probe for the CNC machine tools has been presented. In such case a clear distortion of the probe performance characteristic and a significant increase in probe errors have been observed. Then, to such a damaged probe, a variable speed correction method of systematic errors was used. By setting proper measurement speeds, varying for different measurement directions, errors of the probe can be significantly reduced.

1. INTRODUCTION

Touch trigger probes for the CNC machine tools are widely used for component set up and on-machine measurement of produced part. Also they can be used for determination of machine tools' errors [1-5]. Measuring probes are mounted in the spindle of machining centers, using a machine taper, and in turning centers – in the revolver head. Communication between the probe and machine tool controller is most often carried out by using an optical machine interface working in the IR bandwidth or by a radio machine interface.

The accuracy of an on-machine measurement, which is executed using the probe, influences the accuracy of parts machined on the machine tool. 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.

The most popular are simple, kinematic probes, which have significant probing errors [6-8]. Fortunately, systematic component of these errors can be compensated [9-11] The other issue is what is a accuracy of damaged kinematic probe and is it possible to reduce the systematic errors of such probe by application of error compensation?

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In the paper a spatial characteristic of triggering radius of the damaged probe for the CNC machine tools is presented. Then, to such a damaged probe, a variable speed correction method, of systematic errors, was used. By setting proper measurement speeds, varying for different measurement directions, significantly reduced errors of the probe were obtained.

2. RANDOM AND SYSTEMATIC ERRORS OF PROBE

The accuracy of a touch trigger probe can be described using two parameters: the average uni-directional repeatability $\overline{UDR}$ as well as the triggering radius variation V_r [12].

These parameters can be defined as the following: let index i represent the tested direction of operation of the probe, index j – the number of the measurement in the given direction, and point $P_{i,j}$ – the point where the probe was triggered during the j-th measurement in the i-th direction. Additionally, let the measurement count be the same for each direction, while the tested directions are distributed uniformly. Then point O_S will be the center of the element fitted to all points $P_{i,j}$ using the least square sums method, and the triggering radius $r_{i,j}$ – the distance between point O_S and point $P_{i,j}$. The uni-directional repeatability for each direction UDR_i, is the spread of all radii $r_{i,j}$ obtained for a given direction expressed as two standard deviations, and the average value of uni-directional repeatability $\overline{UDR}$ is the arithmetic mean of the value of uni-directional repeatability for all directions.

In order to determine the triggering radius variation, the average triggering radius for each direction $\bar{r}_i$ must be calculated. The value of the triggering radius variation V_r is given by formula (1):

$$V_r = \max\{\bar{r}_i\} - \min\{\bar{r}_i\} \tag{1}$$

Figure 1 displays the graphical interpretation of uni-directional repeatability UDR as well as the triggering radius variation V_r.

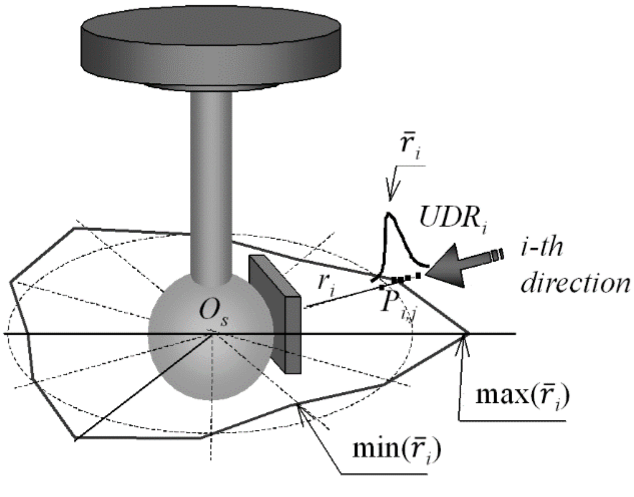

Fig. 1. Graphical interpretation of random and systematic errors of probe

3. SETUP FOR PROBES EXAMINATION

To determine the errors of probe itself, withought taking into account errors of the machine tools, a test setup built by the authors implementing the method with a moving master artifact described in [12] was used. Photo of a mechanical part of the test setup is shown on the Fig. 2.

Tested probe (1) is fixed firmly. Its stylus tip (2) is located approximately centrally within the gauge in shape of an inner half-sphere (3), attached to the triaxial 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. 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 axes are parallel to axes of the coordinate system of the piezoelectric translator. In order to examine operation of the probe in *i*-th direction (see Fig. 1), the piezoelectric translator moves in that direction. As a result of this displacement the surface of the master artifact touch the surface of the stylus tip, and then the stylus tip also moves in the set direction. When the probe triggers, the readings of current position of the piezoelectric translator are recorded. After measurements are taken for all examined directions, a sphere is fitted to the obtained triggering points using the least squares method. Next the uni-directional repeatability *UDR* as well as the triggering radius variation V_r can be calculated as described before.

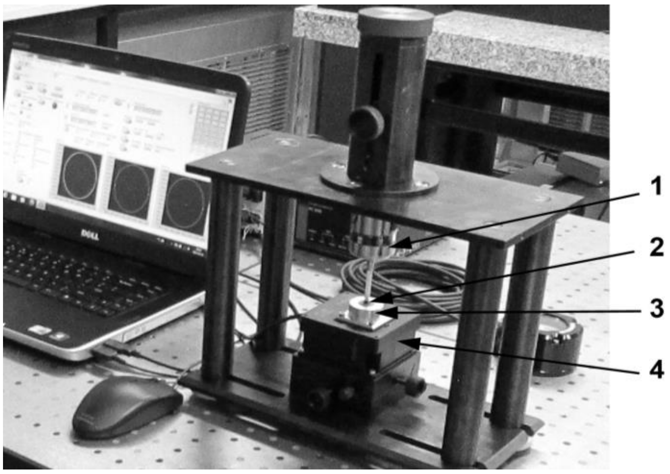

Fig. 2. Photo of a mechanical part of the test setup for examination of probes

4. PRINCIPLE OF THE PROBE ERRORS COMPENSATION METHOD

Previous researches by authors showed that the triggering radius in a given direction is proportional to the measurement speed [13] and equals:

$$r_i = r_{Ti} + r_{Ii} = r_{Ti} + v\tau \tag{2}$$

where: r_{Ti} – triggering radius component related to the probe's transducer, r_{Ii} – triggering radius component related to the measurement speed, v – measurement speed, τ – delay between the triggering of the transducer and the change of the probe's controller output.

In order to compensate the variability of probe's error systematic component related to the probe's transducer, the triggering radius component related to the measurement speed has to decrease with an increase of the transducer-related triggering radius component according to the equation:

$$r_{Ii} = \bar{r} - r_{Ti} \tag{3}$$

where $\bar{r}$ is an average value of triggering radius for all directions. If this condition is met, the probe's systematic errors are compensated. To achieve this goal, measurement speed values should be calculated as follows:

$$v_i = v_N + \frac{\bar{r}_0 - r_{0i}}{\tau} \tag{4}$$

where: v_i – measurement speed applied to compensate the probe errors, v_N – nominal measurement speed before applying error compensation, $\bar{r}_0$ is an average value of triggering radius for all directions before compensation, r_{0i} – triggering radius for i-th direction before applying error compensation. This method, ruffle presented here, is described in the paper [11].

5. EXPERIMENTAL RESULTS

In order to check the possibility of using the systematic error compensation method in the case of a damaged probe, it was used for a damaged Renishaw OMP40-2 probe with a 50 mm length measuring stylus. To obtain the triggering radius characteristics of the probe r_i, 10 measurement series were carried out for an horizontal angle α from 0 to 350° and of vertical angle β from 0 to 90°, with a step of 10°. The measurements were carried out using the set-up shown in the Fig. 2. The filtering of the signal transmission between the probe and receiver has been turned on. The results obtained are shown in Fig. 3.

The three-lobed shape of the characteristic is clearly visible. The observed value of probe triggering radius variation V_r is equal approximately 20 μm. In the case of a probe in a technically good condition (not damaged), the triggering radius variation of this type of probe should be about 2 times smaller and equal about 10 μm.

Fig. 3 also shows that three-lobed shape of error characteristics is not symmetrical, i.e. one of the three arms is elongated. In the case of undamaged probes, the characteristic is a three-lobed shape regularly [14].

The delay value τ was measured between the operation of the probe transducer and the appearance of the triggering signal at the output of its interface. It is 13.2 ms for this type of probe (with the filter on). The values of the measuring speed for the each of individual directions of measurement were calculated, the use of which allows compensation of systematic errors of the probe. The characteristics of the probe triggering radius were then tested again, this time using a variable measuring speed. This operation was repeated three times, each time correcting the measurement speed values used in the previous repetition. The characteristic of the triggering radius obtained after the third iteration is shown in Fig. 4.

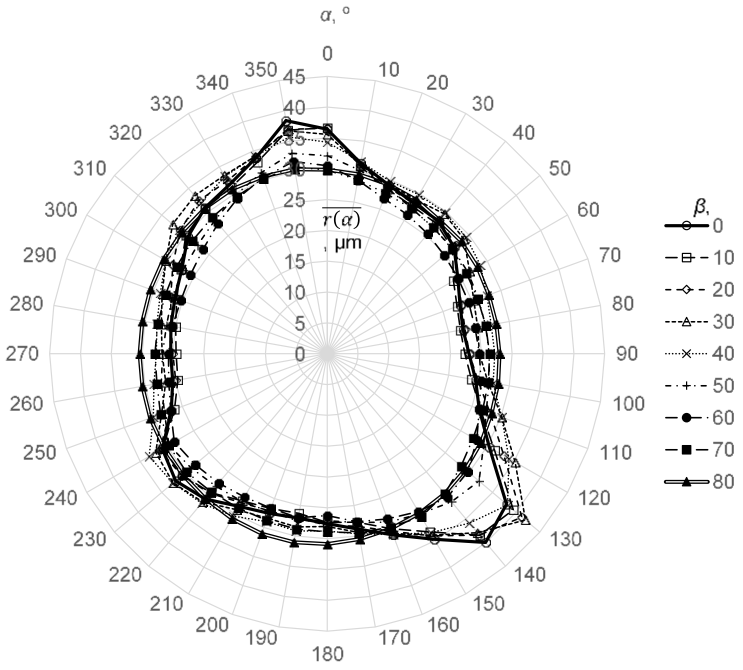

Fig. 3. The triggering radius characteristics of the defective OMP40-2 probe for individual values of the β angle before applying the systematic error compensation

The obtained value of instability of the triggering radius variation V_r is equal 1.3 μm. This confirms that the tested method of error compensation for systematic probes for CNC machine tools is also effective in the case of damaged probes.

It was doubtful whether the changes in the measuring speed would not have a negative impact on random errors of the probe. However, it has been shown that there is no such effect. The unidirectional repeatability UDR: maximum value for all directions UDR_{max}, average for all directions $\overline{UDR}$ and the minimum value for all directions UDR_{min}, before and after applying probe error compensation, are summarized in Table 1.

Table 1. Unidirectional repeatability values before and after applying compensation

	UDR_{max}, μm	$\overline{UDR}$, μm	UDR_{min}, μm
Before compensation	1.94	0.55	0.14
After compensation	1.28	0.50	0.12

As can be seen, unidirectional repeatability of the probe has not increased. For this both before and after error compensation of the probe’s systematic errors, maximal values of random errors UDR_{max} are much smaller than before error compensation.

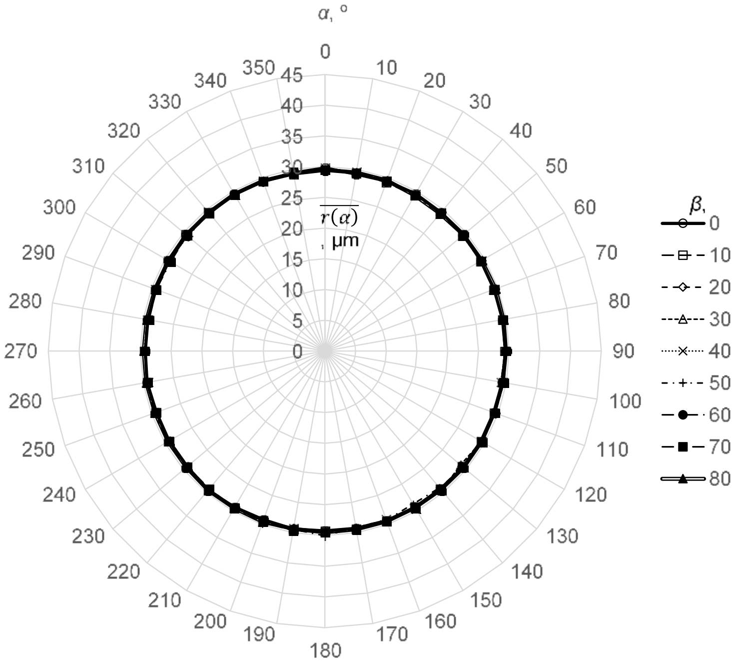

Fig. 4. The triggering radius characteristics of the defective OMP40-2 probe for individual values of the *β* angle obtained after applying the systematic error compensation

6. CONCLUSION

Spatial characteristic of triggering radius of the exemplary damaged probe for the CNC machine tools has been presented. In such case a visible distortion of the probe error characteristic have been observed, as well as a significant increase in probe errors. This article presented a principle of the probe errors compensation method employed variable measuring speed. Then, this method was applied to compensate a systematic errors of a damaged probe. Basing of the tests results it was concluded that by setting proper measurement speeds, varying for different measurement directions, errors of the damaged probe can be significantly reduced.

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