Automation of the process of determining the errors of the installation of blanks for CNC machines in unmanned industries

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Abstract. In article an analysis of the errors, which are determining by the cycle of position’s monitoring of workpiece, was done. The usage of this cycles and details was described. Proposed the technique of using the cycle and adding new user elements. Illustrated the application of the cycle in the NC program when installing workpiece on the table of a machine tool.

1. Introduction
Today, unmanned and semi-automated technologies occupy more and more space in industry. As the entire technological process is automated, in the framework of the operation it becomes important to automatically ensure the accuracy of the installation of the workpiece on the table of CNC machine [1-3]. In the manufacture of precision parts, monitoring of the actual position of the workpiece in the machine coordinate system is required, and, if necessary, measures should be taken to compensate errors that occurred during installation and fixing the workpiece. Monitoring of the workpiece installation accuracy for CNC machines is carried out using special measuring cycles.

According to the measurement results, a real reinstalling or virtual correction of the workpiece position should be performed [4]. Measuring cycles are software applications of CNC systems and, like CNC systems themselves, are closed products which are purchased for a fee and does not always correspond to the tasks of a particular enterprise. In order to import substitution and expand the functionality of domestic control systems, measuring cycles are being developed in the domestic CNC system “AxiOMA Control” [5, 6]. These cycles are used to determining position and monitoring accuracy of the workpiece installation.

2. The errors determined by the cycle position’s monitoring of the workpieces
When using the workpiece position’s monitoring cycle on the machine table, various types of errors should be taken into account. They can be divided into compensable and non-compensable. The cycle of workpiece position’s monitoring determines the errors of its installation on the machine table, the data about which are used for adjustments in the NC control program. The structure of compensated
errors, in turn, includes the errors of the machine drives and the errors of the probe calibration. Data of these errors should be determined and used when monitoring the position of the workpieces.

Non-compensable errors include errors that occur during measurement. They include the delay in transmitting the probe triggering coordinates to the CNC system and the probe triggering speed (the transmission speed of the probe-triggering signal and its registration in the CNC system).

The errors of the feed drives and the errors of the geometric parameters of the probe, as well as uncompensated errors, are characteristics of the measuring system itself [7]. And depend on its design features, kinematics, layout of executive bodies, structural rigidity, etc.

The errors of the feed drives are gaps or clearances in the gear, the screw pitch error, deviations from the straightness of the guides, etc. They are determined using a laser interferometer, after which their values are entered into a special error table of the CNC system and then they are automatically taken into account when performing the cycle.

The errors of the geometric parameters of the probe are the deviation of the position of the probe axis from the spindle axis, the radius of the probe ball and the length of the probe. These parameters are determined using calibration cycles. The errors of the probe calibration calculated by the CNC are written to the CNC memory (persistent system variables) and automatically are taken into account when performing the workpiece position’s monitoring cycle.

Different CNC systems have their own set of calibration cycles, which basically consists of three: determining the actual radius of the probe ball, determining the actual probe length, and determining the amount of deviation of the probe axis from the spindle axis. The CNC system "AxiOMA Control" also implemented a set of these calibration cycles [8]:

- «Axis deviation measurement» - determines the deviation of the spindle axis from the axis of the probe along the X and Y axes. This parameter can be both positive and negative;
- «Ball radius measurement» - determines the radius in the positive and negative direction along the X, Y axes;
- «Probe length measurement» - determines the actual length of the probe.

The measured and calculated values of the errors of the probe are recorded in persistent system variables of the CNC and taken into account during subsequent of measurements of workpieces.

The errors of the installation of the workpiece are determined using the cycle of position’s monitoring of the workpiece on the table of the CNC machine. This determines the error vector, the parameters of which are entered into the offset table of the coordinate system of the workpiece and are automatically taken into account in the further processing of it.

The errors of the size and shape of the workpiece are determined by specialized cycles to more accurately determine the parameters of the workpiece to comply with the processing parameters. For example, if the machining plane has a convex shape for the constancy of layer’s thickness to be removed, it is necessary to adjust the initial machining point in height (from the machined plane) by the value of the convexity.

3. Using workpiece position’s monitoring cycles on a table of CNC machine

Workpiece position’s monitoring cycles on a table of CNC machine is used to determine the deviation of the workpiece position relative to the coordinate system in which the workpiece is installed. Usually this coordinate system is tied to the auxiliary bases of the device in which the workpiece is installed and fixed.

In the General case, the installation error vector of the workpiece on the machine can be represented as [9]:

$$\omega = (x, y, z, \phi, \theta, \psi)$$

(1)

where x, y, z - are offsets parameters of the workpiece coordinate system (OXYZ) relative to the coordinate system of the fixture or machine (oxyz);
\( \phi, \theta, \psi \) – are parameters of the rotation of system OXYZ workpiece relative to the axes of the coordinate system oxyz of the fixture (machine).

In order to eliminate the installation errors of each subsequent workpiece on the machine, it is necessary to monitor and compensate for them, which is done with the help of special measuring cycles [10].

In the CNC system «AxiOMA Control» [11], cycles of control of the position of the workpieces are used to determine the real position (presence or absence of a shift or rotation) of the workpiece relative to the axes of the machine coordinate system and, if necessary, to correct its position. Determining the actual position of the workpiece on the machine involves three steps: 1) measuring in a plane parallel to the plane of the mounting base - coordinates of three points are measured, 2) measuring in a plane parallel to the plane of the guide base - coordinates of two points, 3) measuring in a plane parallel the planes of the support base, the coordinates of one point are measured (Fig. 1). Further, having the coordinates of six points of the workpiece, you can determine the real position of the workpiece in the machine coordinate system and, if necessary, make a correction.

Below is the implementation of the described actions using the developed measuring cycles that are included in the cycle of controlling the position of the workpieces on the table of the CNC machine.

### 3.1. Measurement cycle parallel to installation plane

First cycle – measurement parallel to the installation plane (in most cases, it is the XOY plane). Measurement is carried out parallel to this plane, that is, in this case along the OZ axis, at 3 points on the surface of the workpiece. This determines the shift of the workpiece along the axis OZ (parameter \( Z \)) and also the rotation around the axes OX (parameter \( \phi \)) and OY (parameter \( \theta \)).

To calculate these parameters use the following matrix (formula 2) [9]:

\[
\begin{bmatrix}
Z \\
\theta \\
\phi
\end{bmatrix} = \frac{1}{C} \begin{bmatrix}
(X2Y3 - X2Y3) & (Y1X3 - Y3X1) & (Y2X1 - Y1X2) \\
(Y3 - Y2) & (Y1 - Y3) & (Y2 - Y1) \\
(X3 - X2) & (X1 - X3) & (X2 - X1)
\end{bmatrix} \begin{bmatrix}
Z11 \\
Z22 \\
Z33
\end{bmatrix}
\]

Were \( X1, X2, X3, Y1, Y2, Y3 \) - are coordinates of points relative to the axes OX and OY, \( Z11, Z22, Z33 \) - are offsets values of the position of the workpiece relative to the axis OZ, are calculated after measuring points 1-3.

\( C \) – is the determinant of the system.

### 3.2. Measurement cycle parallel to the guide plane

Second cycle – measurement parallel to the guide plane (in the article, the guide plane is parallel to the XOZ plane). Measurement is carried out at 2 points (points 4 and 5), and determining the shift relative to the axis OY (Y) and the angle of rotation around the axis OZ (\( \psi \)).
The components of the installation error vector for the guide base are calculated by the formula 3 [9]:

\[
\begin{bmatrix}
Y' \\
\psi
\end{bmatrix} = \begin{bmatrix}
\frac{X_5 - X_4}{X_5 - X_4} & \frac{X_4}{X_5 - X_4} \\
1 & 1 \\
\frac{X_5 - X_4}{X_5 - X_4} & \frac{X_4}{X_5 - X_4}
\end{bmatrix} \begin{bmatrix}
Y_{44} \\
Y_{55}
\end{bmatrix}
\]

(3)

where \(X_4, X_5\)– coordinates of control points relative to the axis \(OX\);

\(Y_{44}, Y_{55}\)– offset the position of the workpiece relative to the axis \(OY\), which are calculated after measuring points 4 and 5.

3.3. Measurement cycle parallel to the reference plane

Third cycle – measurement parallel to the reference plane (in the article the reference plane is located parallel to the \(YZ\) plane). Measurement is carried out at point 6, and a shift relative to the \(OX\) axis is determined (parameter \(X\)). For the reference base formula is used 4 [9]:

\[X = X_{66}\]

(4)

\(X_{66}\) – the deviation of the position of the workpiece relative to the axis \(X\), which is calculated after measuring the point 6 [5, 6].

In the general case, when it is necessary to know the errors in the shifts and turns around all the axes (that is, the full vector of errors), all 3 cycles are used.

After determining the coordinates of the touch points, these values are entered into the memory cells of the CNC system, and the error vector is calculated. After its calculation, the data is automatically entered in the table of offset of the workpiece zero point.

So, the measuring cycle for determining and controlling the position of the workpiece involves 3 stages: 1. call cycle to measure points on the surface of the workpiece; 2. calculation of the error vector based on measurement results; 3. deciding on the need to correct the position of the workpiece and further correction.

4. Basic elements of cycles for position’s monitoring of workpiece in the user interface

The cycle for the position’s monitoring of workpiece uses the following input and output parameters (see Table. 1).

| #  | Parameter of cycle | Description                                                                 |
|----|--------------------|----------------------------------------------------------------------------|
| Input parameters |                    |                                                                            |
| 1.  | Work plane         | The choice of the plane, which is parallel to the installation plane (G17 (XY), G18 (XZ), G19 (YZ)) |
| 2.  | Measurement plane  | Plane selection to determine the number of measurement points (installation (3 pnt.), the guide (2 pnt.), or reference point (1 pnt.)) |
| 3.  | Tool number        | The position of the probe in the revolver of tool changer                   |
| 4.  | Safety height      | The height over the workpiece                                              |
| 5.  | Feed rate          | Feed rate during measurement                                               |
| 6.  | Overrun            | The value of overrun                                                       |
| 7.  | X1-X6, Y1-Y6, Z1-Z6 | Approximate coordinates of 6 points of measurement                        |
| Output parameters |                    |                                                                            |
| 1.  | X1-X6, Y1-Y6, Z1-Z6 | The measured values of the coordinates of 6 points of measurement         |
| 2.  | X, Y, Z            | Workpiece offset along axes \(OX, OY, OZ\)                                |
| 3.  | \(\phi, \theta, \psi\) | The angles of rotation of the workpiece relative to the axis of the machine |

The concept of the basic elements of the operator screen of the cycle for position monitoring of workpiece on the machine was developed using the Microsoft Visio graphical editor (Figure 2).
The basic elements of the screen consist of two parts: a table of parameters (on left side) and a measurement scheme (on the right). The parameter table provides the ability to set, adjust the values of input parameters and display the measurement results. Measurement scheme is a graphic representation of the layout of the axes of the machine, the axes of the workpiece, their relative displacement, rotation and measurement points. For a more visual graphical representation, the measurement scheme can be animated (depending on the development environment toolkit) by adding an image of the probe and moving it during the measurements [12-14].

| Parameter       | Value | Parameter       | Value |
|-----------------|-------|-----------------|-------|
| Work plane      | G17   | Safety height   | 10    |
| Meas. plane     | Guide | Feed rate      | 500   |
| Tool num.       | 99    | Overrun        | 5     |
| X1              | 15    | X2             | 85    |
| Y1              | 100   | Y2             | 100   |
| Z1              | 20    | Z2             | 20    |
| Meas. results   |       |                |       |
| X1              | 15    | X2             | 85    |
| Y1              | 89.85 | Y2             | 87.15 |
| Z1              | 20    | Z2             | 20    |

Figure 2. Basic controls of the cycles for position monitoring of workpiece

5. Methods of adding new custom elements in the cycle of position’s monitoring of the workpiece

The presented cycles demonstrate the way to perform the control in the automatic mode, and, as it can be seen, it is composite. The control technology can provide other measurement options (for example, there is a method for measuring the angle of rotation and displacement not by two points, but by the centers of two holes) [10], for such cases, a variant of connecting new (user) cycles is provided [15, 16].

This method includes the following steps (Figure 3).

1. Analysis of input parameters. It determines the input data: the type of the workpiece, the method of its measurement (by points, hole centers, etc.), the number of unknown elements (turns and shifts around the axes that need to be controlled), the type of planes (installation, guide or reference) and so on.

2. Creating or updating a mathematical model and pour over the measurement scheme. It identifies the need to use existing measurement cycles and changes in them to obtain a new cycle.

3. Creating or updating NC programs for a new cycle. The program code is developed on the basis (using the elements) of the previously developed cycles, taking into account the specifics of the new cycle.

4.1. Creating of user screen for the new cycle. Based on the typical arrangement of controls for the measuring cycle, controls are created to integrate them into the application of the NC system terminal [17-20].

4.2. Testing NC-program of new cycle on the Emulator. In parallel with the development process of the user's screen, testing of the program operation is performed using emulator functions to operate the probe.

5. Testing the measuring cycle on the machine. It implements a full check of the development results on the machine, the results of the check are drawn up, and the documentation for the operator.
The presented method of expanding the functions of measuring cycles summarizes and systematizes the development process, determines the main stages and the data set involved in the implementation of these stages. As a result, the development time of new measurement cycles is reduced, including on the end-user side.

6. The usage of workpiece position’s control cycles in NC programm

After the measurement, the parameters of error vector calculated by the measuring cycle are recorded in the corresponding memory cells in the table of the position of the coordinate system of the part of the CNC system "AxiOMA Control".

Next, the position of the coordinate system of the part is corrected by calling the function G154, the values of which are on page P2 in the Zero Offset window in the table of the position of the coordinate system of the part, inserting a frame (G154 P2) into the control program. Below is the program code.

```
// Security string
G00 G15 G17 G40 G49 G53 G71 G80 G90 G94 G97 G153 G191 G193
// Position correction
G154 P2
N10 G17 T3 M6 G00 X0 Y0
N20 G1 Y50 F1500
N30 G2 X0 Y50 I0 J-50
N40 G1 X0 Y0
...```

7. Conclusions

Automating the workpiece position monitoring on the table of the CNC machine allows to increase the efficiency and accuracy of processing, as well as to minimize the monitoring time and reduce the influence of the human factor. Today, many leaders on the market of CNC systems are developing software to monitoring parts positioning, but these cycles are often closed products and are not flexible enough to solve all the tasks of the end user. In this regard, as part of the domestic CNC system “AxiOMA Control” development, a set of measurement cycles is being implemented, including cycles for determining and monitoring the position of workpieces on the tables of CNC machines. These cycles are expandable software applications.
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