Entering the operative correction machining processes CNC

R Yu Nekrasov¹, A I Starikov¹ and A A Lasukov²
¹Tyumen State Oil and Gas University, 38, Volodarskogo street, Tyumen, 625000, Russia
²Yurga Institute of Technology, TPU affiliate 26, Leningradskaya street, Yurga, 652050, Russia

E-mail: syncler@mail.ru

Abstract. The article describes the solution to the problem of compensation of errors occurring during machining on CNC machines. We propose a method of mathematical modeling of processes diagnostics and control of technological equipment. The results of the diagnosis of the CNC machine, as well as the mathematical model describing the dependence of the positioning error of the executive bodies of operating component of cutting force $P_z$, in the range of movement $OX$.

Introduction.
The problem of improving the accuracy of process equipment associated with the cutting force caused by the deformation is solved for many years, but it is still not completely solved.

Errors, inaccuracies predefined positioning of the cutting tool in the operating space of the machine are determined or eliminated by CNC systems, where the bodies of stepper drives constantly monitor the position of the working elements of the technological system. However, attempts to solve the problem of occurrence of errors associated with strains did not find their wide application. So the use of adaptive control systems invented B.S. Balakshin not widely used due their improper conditions of modern market economy. After all, in order to stabilize the individual parameters of the cutting process had understated modes, despite the fact that she did not meet the stabilization of optimal performance.

Path to the maximum optimization of cutting process was found only in the 21st century. Scientists from the Tyumen State Oil and Gas University have proposed to introduce corrections in the work process equipment directly in the processing, based on operative diagnostic [1, 2, 3]. So for the regulation of the cutting conditions, it was decided to base, the defined directly in the process of machining, deformation coefficient of the shear layer, and to enter corrections to compensate for deformation in the process system data on power strain on the servo drive of the machine.

Figure 1 shows a diagram of the transformation commands required linear movement into control signals supplied to drive the technological systems that provide real displacement of technological system elements. In modern CNC systems installed better interpolators [4, 5], which provide an estimate on several coordinates and allow you to enter correction to compensate for the errors of single steps and accumulated leadscrew errors. However, the verification of accuracy of positioning is done periodically, and the error is determined by the entire length of the movement of the body of the machine.

Massive use of operative diagnostics and correction is not possible without the of the
universalization of process, which in turn requires the use of mathematical modeling techniques [6, 7]. So for process modeling, it was decided to use the language of mathematical logic, the possibility of having a clear description of the patterns of interaction of elements of technological system.

Figure 1. Linear interpolation of movement

To derive a mathematical model, by the language of predicate logic, necessary to draw the alphabet of its operands. The operands may include elements of the technological system and thereof parts. In addition, alphabet must include all occurring in the process of diagnosis and management of processes and their parameters.

| Table 1. The alphabet of operands of mathematical models of processes of diagnostics and management |
|-----------------------------------------------|
| Technological system elements |
| A | Machine tool |
| A1 | Bed |
| A11 | Guide |
| A2 | Headstock |
| A21 | Spindle |
| A3 | Caliper |
| A31 | Instrumental head |
| A4 | Tailstock |
| A5 | Power elements |
| A51 | Longitudinal feed drive |
| A52 | Cross feed drive |
| A53 | Maine drive |
| A6 | Table |
| A61 | Rails |
| B | Instrument |
| Bn | Instrumental element |
| C | Workpiece |
| Cn | Workpiece element |
| D | Load device |
| D1 | Simulating the cutting force P |
| D2 | Simulating the component of cutting force Px |
| D3 | Simulating the component of cutting force Pz |
| E | Measuring device |
| E1 | Measuring device probe |
| E2  | Instrumental measuring device |
|-----|--------------------------------|
| E3  | Measuring ruler               |
| E4  | Cutting layer deformation meter|
| F   | Auxiliary tool                |
| F1  | Holder                        |
| F2  | Front center                  |
| F3  | Rear center                   |
| G   | Information system (CNC)      |
| G1  | Diagnostic data registration system |
| G2  | Correction calculation system |
| G3  | Lathe management system       |

### Processes

L   | Diagnostic system
---|---------------------
L1  | Technological system cutting force deformation process
L11 | Cutting force workpiece deformation process
L12 | Caliper deformation diagnostic process
L13 | Instrumental head shift diagnostic process
L14 | Temperature deformation diagnostic process
L15 | Straightforwardness rails deviations process
L16 | Cutting layer deformation diagnostic process
L17 | Feed drive load characteristics diagnostic process

M   | Machining process
---|---------------------
M1  | Process parameters
M11 | Cutting modes
M12 | Cutting tool movement trajectory

N   | Diagnostic data registration process

O   | Correction calculation process
---|---------------------
O1  | Correction vectors according to the operational diagnosis force parameters
O2  | Correction vectors according to operative diagnostics of temperature settings
O2  | Correction vectors according to preliminary diagnostic
O3  | Cutting modes corrector

P   | Corrections entering process
---|---------------------

S   | Diagnostic parameters
---|---------------------
\( \Delta^{rc} \) | Lathe technological system deformation
\( \Delta X^l \) | X-axis workpiece deviation
\( \Delta Z^l \) | Z-axis workpiece deviation
\( \Delta X^{A3} \) | X-axis caliper cutting force deviation
\( \Delta Z^{A3} \) | Z-axis caliper cutting force deviation
\( \Delta X^{A31} \) | X-axis instrumental head deviation
\( \Delta Z^{A31} \) | Z-axis instrumental head deviation
\( \Delta R \) | Cutting tool wear
\( V^z \) | Longitudinal feed drive stress
\( V^x \) | Cross feed drive stress
\( \xi \) | Shear layer deformation coefficient

For example, to simulate the process of diagnostics deviations contour cutting tool [8, 9, 10], the operands are used, indicating the location of the operation, the object and the subject of the process, as
well as the conditions and the output function describing the result.

1) Model diagnostic tool wear:

$$A = B \ni \Delta_R \land E2 \in \{f : \varphi \rightarrow \Delta_R\} \Rightarrow G1 \exists G$$

Reading as: For a machine tool in the instrument $B$, where there are deviations from the original contour $\Delta_R$ in the range of $\varphi_1 - \varphi_2$ with steps 1° when measuring device $E2$, described by the function $f$ with range $\varphi$ and domain $\Delta_R$ of the recorded data acquisition system diagnostics $G1$, of the CNC $G$.

![Figure 2. Tool wear diagnostic](image)

Thus, the mathematical model of the process diagnostics of deformations in the technological system has the form:

$$A = B \ni A3 \ni A3_1 \land D3 \exists \Delta X^{A3} \land E1 \in \{f : OZ \rightarrow \Delta X^{A3}; P_X\} \Rightarrow G1$$

Reading as: For a machine tool exists, having the ability to move along the axis OZ, caliper $A3$ and installed on it, which has the ability to move along the axis OX toolholder $A3_1$, measuring arising under the influence of the load device $D3$ positioning error $\Delta X^{A3}$ determined by reacting with measuring device $E1$, described by the function $f$ range of values OZ and domain and $P_X$, recordable data recording system diagnostics $G1$.

For diagnostic results generated depending on the direction of movement and direction of the load elements of the technological system (figure 3) were constructed three-dimensional graphs of variation in the positioning of the load carriage operation range shown in Figure 4.

As a result of the approximation of diagnostic data we obtain the dependence of deviations positioning along the OZ axis of the component $P_X$ of the cutting force over the entire range OZ.
machine coordinate. So to determine the surgical correction is enough to know only the forces acting at a particular time on the elements of the machine.

![Diagram](image)

**Figure 3.** Technological equipment deformations diagnostic

![Graphs](graphs)

**Figure 4.** The dependence of deviations from the positioning of the load caliper in the operating range
After converting the surface by smoothing the quadratic polynomials we obtain the second degree, respectively, with positive and negative loading and forward and backward movement of the caliper.

Mathematical models of deviations with positive and negative loading and forward and backward movement of the caliper

\[ \Delta Z = -0.0027 - 2.9192 - 5 \times X - 0.0039 \times P_z + 1.5938 - 7 \times X^2 + 3.4677 - 5 \times X \times P_z - 0.0005 \times P_z^2 \]

\[ \Delta Z = -0.0048 - 3.1299 - 5 \times X - 0.0008 \times (-P_z) + 2.1588 - 7 \times X^2 + 4.4859 - 5 \times X \times (-P_z) - 0.0013 \times P_z^2 \]

\[ \Delta Z = -0.0134 + 0.0001 \times X + 0.0087 \times P_z - 1.7195 - 7 \times X^2 + 3.8369 - 5 \times X \times P_z - 0.0028 \times P_z^2 \]

\[ \Delta Z = -0.0069 + 1.6564 - 5 \times X + 0.0067 \times (-P_z) + 8.5116 - 8 \times X^2 + 4.2091 - 5 \times X \times (-P_z) - 0.0025 \times P_z^2 \]

Supplied directly to the interpolator move command can take into account the necessary corrective feedback, calculated on the basis of the application submitted by mathematical models. That is counted identified errors of technological system.

In addition to the data obtained as a result of diagnostics, it is assumed the input error correction eliminates determined by operative diagnosis and regulatory regimes in order to optimize the cutting process.

**Summary**

The method of simulation processes using mathematical logic and the proposed method of surgical correction of the input to the control program of the CNC machine directly to the interpolator - tested and have been known for many years. However, to realize the full possibilities offered by these methods appeared only with the invention of new ways to diagnose the cutting process. Applying the proposed methods can also be offset and error caused by other factors

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