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MODEL OF MACHINING PROCESS CONTROL ON MULTI-TOOL SINGLE-CARRIAGE ADJUSTMENTS

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Abstract: Based on the developed models, the article reveals the degree of influence on the machining accuracy of a complex of technological factors, including the structure of a multi-tool single-carriage adjustment, the deformation properties of the subsystems of the technological system, cutting conditions. A number of ways to control multi-tool single-carriage machining based on the developed accuracy models are shown, including improvements in the structure of multi-tool single-carriage adjustment, calculations of limiting cutting conditions. The developed control models make it possible to predict the accuracy of machining for given conditions, including such technological components as the adjustment structure, properties of the technological system, machining conditions, thereby creating a methodological base for CAD for multi-tool single-carriage machining. They can serve as a basis for developing a digital twin model of the process.

Keywords: *control model, multi-tool machining, multi-tool single-carriage adjustment, machining productivity, predetermined dimensional accuracy, scattering fields, matrix model of accuracy.*

Introduction. One of the most important factors in improving the productivity of the technological process is the concentration of transitions. The highest efficiency of concentration of transition is ensured by its implementation in multi-tool adjustments [1-6]. Dimensional accuracy is a paramount requirement in the design, debugging and implementation of the technological process. In the works of Koshin and Yusubov, the principles were formulated and the foundations of the theory of dimensional accuracy design of multi-tool machining were laid [1-6].

The basis of the theory of accuracy of multi-tool machining is mathematical models of the accuracy of dimensions performed by multi-tool adjustment tools. Therefore, of particular interest is the current level of mathematical models for the formation of dimensional errors in single-tool and multi-tool adjustments. [1-11].

As in the case of single-tool machining [7], for multi-tool single-carriage adjustments, the inverse problem is more relevant: assign the maximum allowable cutting conditions (and possibly other setup parameters) to ensure the highest productivity with a given dimensional accuracy [1].

Since the feed has the greatest influence on the values of the components of the cutting forces, here it is also advisable to take the feed as the main control parameter, which is the same control factor for all setting tools. To develop a control model, it is enough from the simulation model (3.117), (3.118), (3.119) [2], to highlight the dependence of the feed on the required accuracy and other machining parameters.

Process control model for multi-tool single-carriage machining. For homogeneous adjustments from equation (3.116) [2] we obtain:

$$\Delta g \geq e^{01}\left\{\omega \cdot \sum_i \overline{p_{ti}} + \sum_i \overline{p_{\Delta ti}}\right\} \quad (1)$$

In formula (1), Δg is the allowable value of the scattering field. It is due to the requirements for the accuracy of the dimension and is calculated by the formula:

$$\Delta g = \sqrt{TD^2 - \Delta_{adj}^2 - \Delta_{wear}^2 - 3(\Sigma\Delta_m)^2 - 3(\Sigma\Delta_T)^2} \qquad (2)$$

where TD is the value of the tolerance field of the dimension being performed; Δ_{adj} - the adjustment error of the machine to the dimension being performed; Δ_{wear} – error due to dimensional wear of the cutting tool; $\Sigma\Delta_m$ - geometric errors of the machine, affecting the performed dimension; $\Sigma\Delta_m$ - error due to thermal deformations of the technological system [12]. e^{01} - combined matrix of compliance of the technological system as a whole: ω - the value of the total scattering of the properties of the technological system. Designation: $\Delta j+v=\omega$ [2], where, v is the variability of mechanical properties (for example, hardness) of workpieces within a batch, Δj - variation in stiffness of different machines of the same model; vector $\sum_i \overline{p_{ti}}$ characterizes the degree of influence of depths of cut t_i, vector $\sum_i \overline{p_{\Delta ti}}$ characterizes the degree of influence of allowance fluctuations Δt_i [1] .

The values of fluctuations in the depth of cut Δt, determined by the initial error of the workpiece for each tool, are calculated by the formula:

$$\Delta t = TZ + \Delta_{adj} + \Delta_{wear} + \Delta_m \qquad (3)$$

where TZ is the value of the workpiece tolerance field for the dimension being performed.

Thus, the group of dependencies (1), (2), (3) is a model of feed control according to the criterion of accuracy of performed dimensions for multi-tool single-carriage machining.

To find the feed with the other machining parameters given, inequality (1) must be resolved relatively *S*. However, the right side of the inequality is a piecewise analytic transcendental expression with respect to a variable, which does not allow an analytic representation of the inverse function. Therefore, for the practical use of the control model (1), the "Maple 7" application package is proposed, where a system of nonlinear and transcendental equations can be solved using the "solve" function. For the algorithmic representation of the control model, a computer program has been developed that allows using a computer to calculate the maximum allowable feeds in terms of accuracy for any set of other technological factors.

Performance of the process control model in multi-tool single-carriage machining. The performance of the control models (1), (2), (3) in terms of taking into account the main factors of the formation of scattering fields, using the example of adjustment from turning cutters, is illustrated by the graphs in Figure 1.

Here, to the right of the graphs, changes are indicated relative to the basic version, and inside the field of graphs - changes relative to the base curve, which in this case corresponds to n=1, i.e., single-tool machining.

It can be seen that the required accuracy of the dimension being performed has the strongest influence on the feed: reducing the accuracy requirements to ITD 13 allows you to increase the feed by 83-90%, and for ITD 14 - by 260-275%. At the same time, the influence of multi-tooling is preserved: in the basic version (Fig. 1 a) and in the versions for ITD 13 (Fig. 1 b) and ITD 14 (Fig. 1 c), working with a block of two cutters, while maintaining the total depth of cut, reduces the feed by 28 %, for three cutters by 45% and for four by 4-55%.

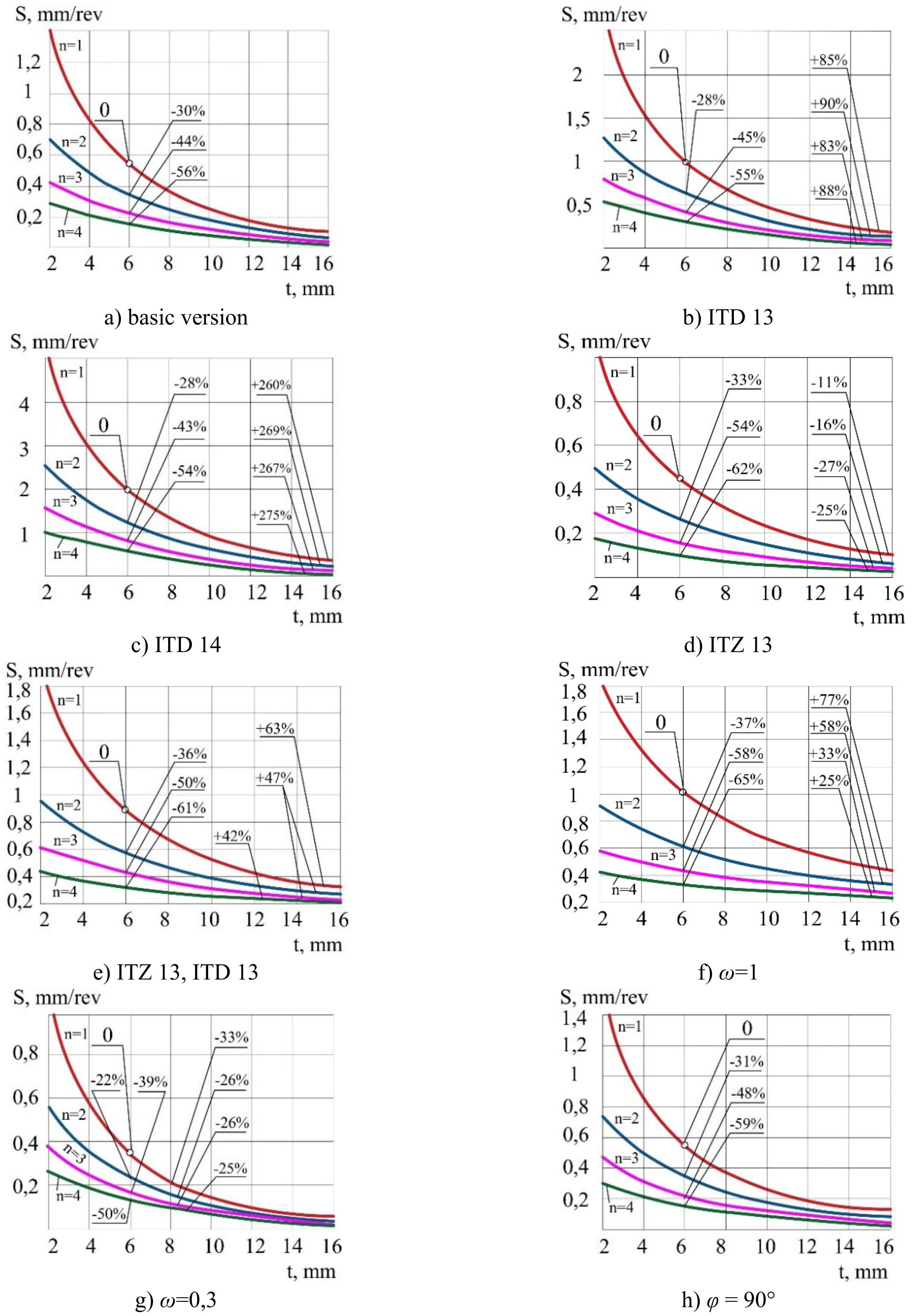


Figure 1. The influence of technological factors on the feed, limit accuracy of diametrical dimensions, in multi-tool single-carriage machining (setup - Fig. 3.7. [2]). Basic version: the workpiece – stamping, precision of every surface ITZ12, Steel 45; tools – turning cutters (n-number) P6M5, φ=60°, γ=15°, r=2mm; instability of the technological system ω=0,2; the total depth of cut is evenly distributed over all the cutters of the setup. Changes are indicated for other versions.

As can be seen from fig. 1 (a), in the basic version, we have real feeds (0.4-0.6 mm / rev) for adjustment not exceeding 2 cutters. For roughing (ITD13-14), setups of 3-4 tools are allowed.

Working with coarser workpieces leads to a decrease in feed (Fig. 1 d). The combined influence of the initial error of the workpiece and the accuracy of the performed dimension is shown in fig. 1 (e). Stabilization of the properties of the technological system (Fig. 1 f, g) has a noticeable effect on the limit feed, allowing it to be increased by 25 -77%. Figure 1 (h) shows the effect of the geometry of the cutters on the limit feed: an increase in the main angle in the lead up to 90 ° allows you to increase the feed by almost 2 times.

Patterns for linear dimensions, when they are formed from a transverse carriage, are shown in fig. 2.

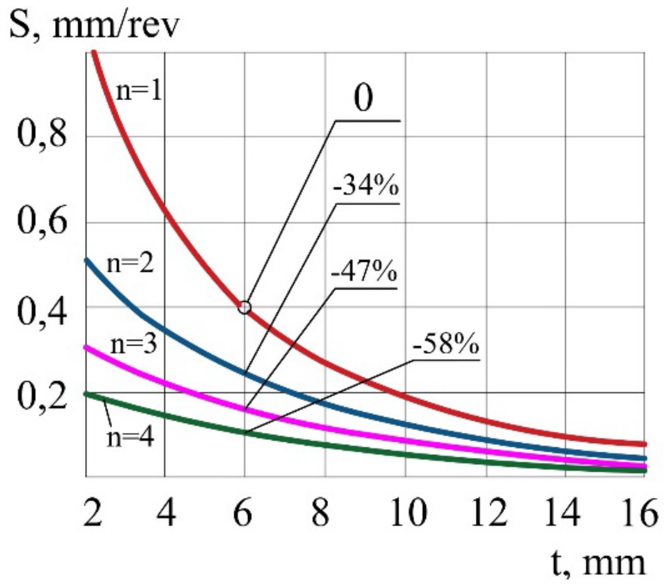


Figure 2. The influence of technological factors on the feed, the limit accuracy of linear dimensions, in multi-tool single-carriage machining with facing cutters (conditions according to Fig. 1)

Figure 3 shows the effect of accuracy requirements on the limit feed for different versions for multi-tool single-carriage adjustments with a total depth of cut t=6 mm. From the basic version (Fig. 3 a) it follows that machining according to the 12th grade is possible only for setting up 1-2 cutters, 11th grade can be provided with only one cutter. Machining according to ITD13 and ITD14 is possible with simultaneous operation of up to 4 cutters, however, depending on the number of cutters, the feed changes by almost 2 times. Figures 3 (b, c, d) show feed changes (with different instability of the technological system): for a rougher workpiece (b), when the setup is transferred to machines with increased accuracy (c), with the simultaneous influence of both previous factors (d). On the right of each version, the effectiveness of the influence of these factors is shown. Such roughening of the workpiece to ITZ13 requires a feed reduction of up to 36%, transfer to machines with increased accuracy allows you to increase the feed by 20 - 91%.

Figures 1 - 3 describe the machining of a piece workpiece, when each tool has its own initial surface in the workpiece with its own ITZ grade (in accordance with the scheme of Fig. 3.7 [2]). Such machining is used on semi-automatic lathes. On lathes, the workpiece is a bar, and therefore, a group of turning cutters often works according to a different scheme - the previous cutter forms the initial surface for the next one.

In this case, fluctuations in the depth of cut will appear only in the first tool of the setting, while the remaining factors of the scattering field - stiffness fluctuations *Δj* and hardness fluctuations *v* - appear on all tools of the setting. The developed models make it possible to calculate this scheme as well.

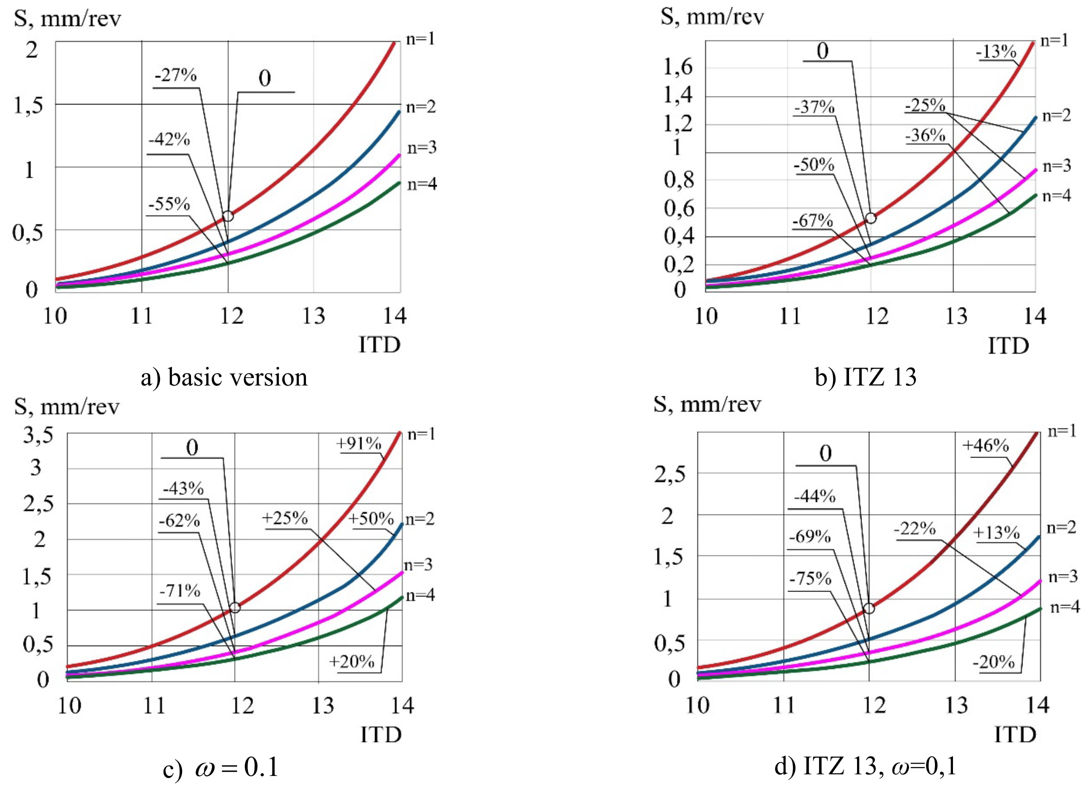
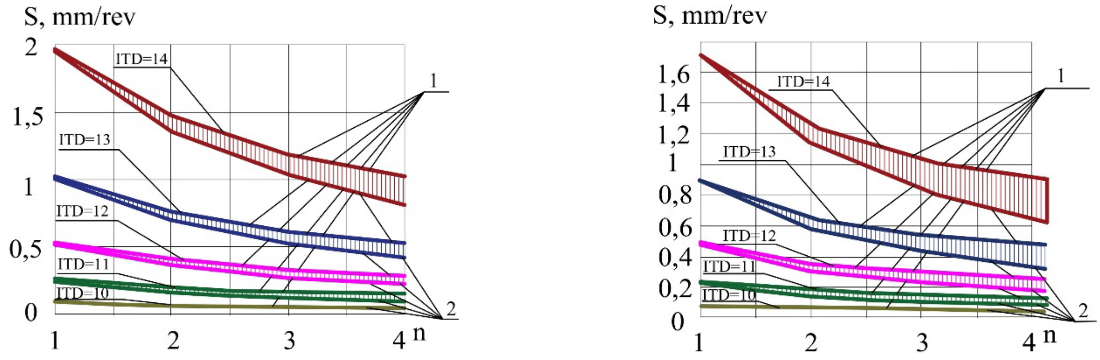


Figure 3. Influence of dimensional accuracy on feed in multi-tool single-carriage machining. Basic version: workpiece – stamping, Steel 45, precision of every surface ITZ12; tools – turning cutters (n-number) P6M5, φ=60°, γ=15°, r=2mm; instability of the technological system ω=0,2; total depth of cut t=6 mm. Changes are indicated for other versions.

Figure 4 shows a comparison of the limit feeds for the case of machining a piece workpiece according to the scheme shown in Figure 3.7 [2] and for a workpiece from a bar according to the scheme described above.



a) workpieces according to IT12 b) workpieces according to IT13

Figure 4. Comparison of feed accuracy limits for multi-tool single-carriage adjustments (4 turning cutters, other conditions according to Fig. 6.13): 1) workpiece - bar, (the first cutter forms the initial surface for the second, and so on.); 2) piece workpiece (adjustment on Fig. 3.7 [2])

As can be seen from fig. 4, machining according to the scheme, when the previous cutter forms the initial surface for the next one, allows us to increase the feed. Moreover, this increase strongly depends on the accuracy of the performed dimension and the error of the workpiece.

Comparison of graphs in fig. 1 - 3 with normative recommendations [13] shows their good convergence (within 15%)).

Conclusion. A matrix generalization of feed control models by the criterion of accuracy of the performed dimension for multi-tool single-carriage machining has been developed. Control models make it possible to calculate the maximum permissible cutting conditions in terms of machining accuracy.

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