Automation of Tooling Backup and Cutter Selection for Engineering Production

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Abstract. This paper reports the analysis of a tool support procedure for mechanical engineering and basic trends in the automation of this field are revealed. The system of technical-organizational measures directed at the formation, management and development of the tool stock and a high degree of technological readiness of manufacturing are described. The problems of an automated optimum cutter selection are considered. A mathematical support for a choice of cutters with through-away tips is described. A simulator for the description of combined cutters is presented. Basic criteria defining cutter choice are established. The problem of a multi-criterion fuzzy estimation of alternatives at different significance of choice criteria is solved. The criterion significance ranking at the parameter choice of cutter plates and tool supports is carried out. A set of estimations of cutter plate forms and other cutter parameters taking into account a relative significance of criteria is defined. The application of a decisive rule in the choice of an alternative required is described, which consists in the definition of the intersection of sets of alternative estimations.

1. Introduction
The machinery-tool equipment is typically the first thing to be concerned in production optimization, while tooling stock is usually forgotten. The system of organizational and technical measures directed at creating, controlling and developing tooling stock and maintaining a high efficiency level of the production readiness is called Tool Management. Speaking about mechanical treatment in general, it should be mentioned, that nowadays its technology is mostly predetermined by tooling solutions. Certainly, technical equipment of the enterprise and overall production organization are also important. However, the use of appropriate tooling solutions even on the outmoded equipment ensures quite acceptable results [1]. So, the task of tooling backup is becoming very acute and demands an advanced approach.

For the most efficient mechanical treatment, technological processes should be developed in accordance with the features and capabilities of modern cutting tools.

The choice of an optimal cutting tool and rational cutting parameters is one of the directions to improve the efficiency of metal working. Nowadays researches dedicated to determination of optimal tooling and cutting mode parameters are of particular importance. These researches should also take
into account maximal equipment productivity and compliance with the requirements to a qualitatively treated surface.

2. Materials and Methods

Modern tools are normally considered as a system, which operation is influenced by tool geometry, working part material and coating. All elements complement each other and wrong selection of one of them can significantly deteriorate total results.

When selecting an optimal cutting tool the following parameter criteria should be considered: toughness of cutting edge, absence of vibrations, quality of heat removal from cutting zone, chip formation quality and equipment capacity required for the treatment, as well as cutting tool versatility, which is determined by the number of operations this tool can be used for [2].

The task of selecting an optimal cutting tool for lathe machining on PNC (programmed numerical control) machines, where some target function should be maximized by a number of criteria, should be regarded as a multi-criteria optimization problem and its solution is rather complicated. Some criteria can be contradicting and have opposite meaning.

When solving the problem of selecting an optimal cutting tool, the situation is significantly more complicated, if optimization criteria have different degree of importance. In such cases, there is a need to coordinate the criteria considering their particular degree of importance. Here, on the basis of finding function extremum of several variables, different methods of criteria convolution are used - additive, multiplicative, distance to ideal, minimax, maximin and etc. [3].

Even a more complicated case is multi-criteria tasks, solved in conditions of uncertainty and regarded as fuzzy ones. Task fuzziness can be predetermined by the objective fuzziness and corresponding fuzzy description of the objective function. Sets of alternatives which rational choice presents task solution as well as constraint sets can also be fuzzy. Fuzziness of decision making can be caused by the fuzziness of the applied optimality criteria. Such tasks include the selection of the optimal lathe machining tool due to the fuzziness of evaluation of alternatives by optimality criteria. We can consider the parameter superiority of one tool over the other by some criteria; however there are no accurate evaluation values [3].

3. Results

To research selection of an optimal cutting tool for lathe machining on PNC machines, it is necessary to determine a set of tools, available for the use at cutting tool enterprises. To carry out the research and practise the methods, we chose a set of tools, corresponding international standards ISO 1832:2004 – “Indexable inserts for cutting tools. Designation” and ISO 5610-1:2010 – “Tool holders with rectangular shank for indexable inserts. Part 1. General survey, correlation and determination of dimensions” [7,8]. Besides, a set of the selected tools is manufactured by the most cutting tool manufacturers. Thus, conducted research covers the most part of lathe tools applied in machine building.

According to the standards, identification of cutting insert P includes 11 basic components:

\[ P = <Pf, Ab, Tc, Ls, Pd, Pt, Re, Cs, Cd, Cw, Ca>, \]

where \( Pf \) is a range of inserts forms; \( Ab \) is a range of the insert outside angle; \( Tc \) is a range of insert tolerance; \( Ls \) is a range of insert types (fixation); \( Pd \) is a range of insert dimensions (cutting edge length); \( Pt \) is a range of insert thickness; \( Re \) is a range of point radius; \( Cs \) is a range of cutting edge type (condition); \( Cd \) is a range of insert configuration (cutting direction); \( Cw \) is a range of land width of the face or chip breaker; \( Ca \) is a range of the face angle.

\( Pf \) insert form definition is the following:

\[ Pf = \{Pf1, Pf2, \ldots Pf17\}, \]
which is determined by the angle value of the insert point. A multitude of insert forms, manufactured at enterprises is described in the standard. All components of inserts identification and inserts holders are described analogically.

Let us consider the problem of selecting optimal insert \( Pf \) form among the multitude of manufactured inserts.

This selection is based on the degree of conformity of alternatives to the number of requirements determined by system 5 of different criteria \( Ci \):

\[
Ci = \{C1, C2, C3, C4, C5\}. \tag{3}
\]

C1 – heat removal efficiency.
C2 – minimum power consumption.
C3 – insert strength.
C4 – vibration minimum.
C5 – insert versatility.

In this case, each \( Ci \) criterion can correspond to a fuzzy set.

\[
ACi = \{\mu Ci (Pf1), \mu Ci (Pf2), \ldots, \mu Ci (Pf17)\}. \tag{4}
\]

Here, value \( \mu Ci (xj) \in [0,1] \) presents evaluation of alternative \( Pfj \) by the \( Ci \) criterion. In other words, it characterizes its compliance with the requirement determined by criterion \( Ci \). A set of evaluations by criteria is determined by experts. Figure 1 graphically presents a set of evaluations.

In our case, a multi-criteria optimization task should be solved under the conditions of different criteria importance for reaching objective function maximum. Then, each \( Ci \) criterion corresponds to some weight factor \( \lambda i \geq 0 \).

Naturally, the more important is the criterion, the larger value its weight factor has. The weight factor values are determined on the basis of the standard pairwise comparison of criteria. First of all, Matrix \( B \) of pairwise comparisons is formed (as presented in Table 1) in order to find elements \( b_{ij} \).

![Figure 1. A set of insert form evaluations.](image)

| Criteria       | Heat removal | Capacity | Strength | Vibration | Versatility |
|----------------|--------------|----------|----------|-----------|-------------|
| Heat removal   | 1            | 1/3.     | 1/7.     | 1/5.      | 1/3.        |
| Capacity       | 3            | 1        | 1/7.     | 1/7.      | 1/5.        |
| Strength       | 7            | 7        | 1        | 5         | 7           |
| Vibration      | 5            | 7        | 1/5.     | 1         | 7           |
| Versatility    | 3            | 5        | 1/7.     | 1/7.      | 1           |
As comparison of any criterion with itself is only of equal importance, then, when $i=j$, all $b_{ij}=1$. In addition, due to the symmetry of the criteria importance ratio, let us assume $b_{ij}=1/b_{ji}$.

After this, with the help of Gauss method, we find vector $w$ of matrix $B$, which corresponds to its preliminary calculated maximum number $v_{\text{max}}$:

$$Bw = v_{\text{max}}w.$$  

Desired values of weight factors $\lambda_i$ are found by multiplying an appropriate elements of vector $w$ by criteria number $m$:

$$\lambda_i = m\cdot w_i$$

Calculating the matrix eigenvector, the following values of its components will be obtained: $w_1=0.06$, $w_2=0.082$, $w_3=0.878$, $w_4=0.44$, $w_5=0.158$. Multiplying them by a criteria number equal to five, we will obtain weight factor values, which characterize importance of each criterion: $\lambda_1=0.3$, $\lambda_2=0.408$, $\lambda_3=4.39$, $\lambda_4=2.201$, $\lambda_5=0.792$.

The $\lambda^i_{Ci}$ sets are built on the basis of weight factors:

$$A^{\lambda^i_{Ci}} = \{\mu^{\lambda^i_{Ci}}(Pf \ 1), \mu^{\lambda^i_{Ci}}(Pf \ 2), ..., \mu^{\lambda^i_{Ci}}(Pf \ 17)\},$$

which will be presented as shown in fig. 2.

Initial problem solution will be such alternative $Pf$, which mostly satisfies the requirements of the entire criteria set. Decision rule $D$ of the best alternative selection under the conditions of multi-criteria task with non-equal criteria $Ci$, with weight factors $\lambda_i$, applies the procedure of finding fuzzy sets crossing:

$$D = A^{\lambda_1}_{Ci} \cap A^{\lambda_2}_{Ci} \cap A^{\lambda_3}_{Ci} \cap A^{\lambda_4}_{Ci} \cap A^{\lambda_5}_{Ci}.$$  

In accordance with finding fuzzy sets crossing, membership function of the desired solution is defined as

$$\mu_\mu(Pf_j) = \min_{i \in \mathbb{R}}(\mu_{A_i}(Pf_j)), j=1,n.$$  

Applying the rule of the target alternative selection (an optimal form of the cutting insert), the set crossing is determined, which will be presented as follows (figure 3):

![Figure 2. A set of insert form evaluations with regard to relative criteria importance.](image)

$$D=\{x_1; 0.00004\}, \{x_2; 0.0013\}, \{x_3; 0.0027\}, \{x_4; 0.0027\}, \{x_5; 0.00506\}, \{x_6; 0.01713\}, \{x_7; 0.02219\}, \{x_8; 0.03308\}, \{x_9; 0.03308\}, \{x_{10}; 0.03843\}, \{x_{11}; 0.0477\}, \{x_{12}; 0.05114\}, \{x_{13}; 0.06687\}, \{x_{14}; 0.06687\}, \{x_{15}; 0.02585\}, \{x_{16}; 0.00287\}, \{x_{17}; 0.00205\}.$$
4. Discussion and Conclusions

On the basis of the proposed mathematical apparatus, there has been developed an automated system of selecting an optimal cutting tool for PNC machines which is applied in the educational process of BSTU and in a number of small innovation enterprises of Bryansk Region. The results of the automated system operation are recommendations containing necessary data on the tool strategy of machining engineering and design elements, advisable tools, advisable cutting modes and preliminary calculation of machining time and cost.

The proposed automated complex allows one to arrange and automate the process engineering for modern high tech equipment applying the latest achievements in science and technology into the production process. The proposed solutions are based on the developed technology of process engineering automated systems with the use of the specialized software and development of new models, algorithms and software packages for complex automation of process engineering. This method consists in selecting a modern highly productive cutting tool and machining strategies as the objects of automation in order to reduce manufacturing costs and to increase the competitiveness of manufactured products.

References

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Figure 3. Minimum evaluation values.

Thus, such best insert form should be selected that inserts form $P_{j}^{*}$, which membership function value $\mu D(P_{j})$ will be maximum, that is:

$$\mu_{P}(P_{j}^{*}) = \max_{i \in \mathbb{N}} (\mu_{P}(P_{j}))$$  \hspace{1cm} (10)$$

Only this alternative is the solution of the initial task as it mostly satisfies the requirements of the entire set of the criteria concerned.

Optimal values of all cutting tool components are determined in the similar way, which ensures unambiguous determination of the optimal cutting tool for the specified treatment conditions.
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