General model for boring tool optimization

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Abstract. Optimizing a tool (and therefore those for boring) consist in improving its performance through maximizing the objective functions chosen by the designer and/or by user. In order to define and to implement the proposed objective functions, contribute numerous features and performance required by tool users. Incorporation of new features makes the cutting tool to be competitive in the market and to meet user requirements.

1. Introduction
In order to optimize a tool or a manufacturing process carry out for a cutting tool, it must be taken into consideration that both the tool and the process can be approached as an engineering systems (figure 1). An engineering system is specially designed to fulfil a specific function, [1]. In the design process of a boring tool, the specific function of the system is monitored to obtain a working tool capable to execute certain bores. In the widen process, the specific function is to obtain certain dimensional values, accuracy and surface quality achieved after manufacturing

![Diagram](image_url)

**Figure 1.** The boring tool and the boring process as engineering system.
2. Optimization model
Optimization consists in choosing and implementing the best solution of all possible solutions. The systemic approach facilitates the optimization of both the boring tool and the widen process.

Figure 2 shows a general scheme to optimize the cutting tools, also, valid for boring tool. We note with $X_1, X_2, \ldots, X_m$ the entries in the engineering system for designing and manufacturing tool, with $C_1, C_2, \ldots, C_s$ the control factors and with $P_1, P_2, \ldots, P_q$ the environmental disturbance factors. It is noted that the outputs of the system are divided into two categories: Wanted – $Y_1, Y_2, \ldots, Y_n$ – and waste – unwanted errors, denoted by $e$. The flows from engineering system are marked with continue arrows, and the interrupted arrows are shown the optimization actions. By optimizing the tool (the boring tool) is intended to achieve certain values for one or some of the output. Figure 2 show the outputs $Y_A, Y_B, \ldots, Y_K$ which aims is to optimize the value through the objective function $F_{ob}$. In this respect the aim is to obtain certain values: $Y_{A\text{ optim}}, Y_{B\text{ optim}}, \ldots, Y_{K\text{ optim}}$.

![Figure 2. The general scheme proposed for optimization of cutting tools [2].](image-url)
On Figure 2 were marked the 5 level solutions [2] obtained from the design and processing of cutting tool, according to TRIZ theory (Russian language acronym) / TIPS – Theory of Inventive Problem Solving – of Russian inventor Dr. Genrikh S. Altshuller – a theory applied usually to other products:

a. Standard cutting tool - which is obtained from the application of standardized design procedures based on classical calculations.

b. Changed cutting tool - which required engineering studies beyond typical procedures.

c. Innovation - which, in this case, is opening a new field for the concept of that groups of cutting tools.

d. The invention - which is a new application of scientific principles, of physical, chemical, etc. rarely used in cutting tools.

e. The discovery - which is based on newly discovered phenomena and not yet used in design tools.

By optimizing tool these steps will be challenged in their ascending order. Not every optimization cycle will lead to a jump to a higher level, but how these cycles will be more frequent, increasing the chances that leap. Of course, there are cases in which a single optimization cycle can lead to a jump of two or more steps. The last step - discovery - is usually a jump to a new family of tools, unknown to date. It can use Taguchi methods in order to optimize a standard (existing) tool without any intention of getting innovations or inventions, but only to enhance the quality of the tool through an efficient handling of production costs and, obviously, to increase the company profits.

Taguchi methods are based on the interaction between the components shown in Figure 1 - input, output, control and noise factors - optimization of engineering system and strategies for making measurements. In order to achieve the goal (certain performance of existing tool), those two major steps are reducing the output variation Y and adjusting the outputs. In this regard, a parameter of "robustness of quality" is the S/N (Signal/Noise). The desired signal is generated at the exit of the system are noted with Y and the signal generated by the noise with e. [1] For the scheme from figure 2, we can write many such reports, assuming that the output could be measured separately:

\[
(S/N)_A = \frac{Y_{A,\text{opti}m}}{e_A} = \frac{Y_{A,\text{opti}m}}{Y_A - Y_{A,\text{opti}m}}
\]  

\[
(S/N)_B = \frac{Y_{B,\text{opti}m}}{e_B} = \frac{Y_{B,\text{opti}m}}{Y_B - Y_{B,\text{opti}m}}
\]

\[
(S/N)_K = \frac{Y_{K,\text{opti}m}}{e_K} = \frac{Y_{K,\text{opti}m}}{Y_K - Y_{K,\text{opti}m}}
\]

where the output signals results as dependent functions by input, by control factors and by distractions:

\[
\begin{align*}
Y_A &= f_A \left( X_1, X_2, ..., X_m, C_1, C_2, ..., C_s, Z_1, Z_2, ..., Z_q \right) \\
Y_B &= f_B \left( X_1, X_2, ..., X_m, C_1, C_2, ..., C_s, Z_1, Z_2, ..., Z_q \right) \\
&\quad \vdots \\
Y_K &= f_K \left( X_1, X_2, ..., X_m, C_1, C_2, ..., C_s, Z_1, Z_2, ..., Z_q \right)
\end{align*}
\]
Based on these parameters of "robustness", Taguchi method suggests choosing those values to control factors that provide the highest value for the reports S/N, because the engineering system provides in this case the answer less sensitive to control and disruptive factors. The output will consist of a tool with high index of "robustness of quality"; while after a few cycles of optimization - which in this case are only adjustments to control factors - can get ideal values for the parameters YA, YB, ..., YK of existing tool. Taguchi methods are highly efficient for improving existing boring tools or widening existing processes, without brings substantial changes able to cause a jump to another level of the solution obtained (Figure 2) according to the theory TRIZ. So Taguchi methods will be used when:

- The constructive form of the tool not undergone major changes – in the case of boring tool.
- A manufacturing process will be conducted in the same manner, on the same type of equipment, only adjusting the control parameters (cutting speed, advance, etc.) - for enlargement.

Optimizing a boring tool - or any cutting tools in general – (when the objective is to increase competitiveness ), will pursue a better quality, respectively increase the scores awarded according to the relations (1) or (2). In this case, the aim is to maximize the overall function of the boring tool no. 1, $F_{g1}$. Where $F_{g1}$ is the most complex example of multiobjective function, encompassing both related targets into it and indifferent and antagonistic objectives.

If $F_{g1}$ – directly connected with the competitiveness tool in a specific market - is a optimized function, we can say that we are facing the most difficult optimization problem. But through optimization the intention could be, for example, to maximize/minimize (from case to case a) of other objective functions (one or more of the standard functions elementary or grouped, as it were summarized in Figure 2).

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**Figure 3.** Boring tool whose accuracy needs to be improved.

An example of an optimization objective function for the boring tools with interchangeable inserts could be increased machining accuracy. For example, the boring tools with two or more series of inserts cuts at different bore sizes (figure 3). After several optimization cycle, were obtained widened bars with individual micrometric adjustment. But it continued to optimize (according to Fig. 2.) and several researchers from the University of Michigan [3] proposed a new construction, "smart boring tool" (figure 4) provided with a piezoelectric reader (sensor) and with a laser position detector, which records every wrong move of the tool and any variations of cutting force. The laser source incorporated into the widened bar (these are not shown in figure 4.) emits two laser rays in order to appreciate the position of the tool: one for laser detector - placed in the cutting tool axis (figure 4) and another to a detector attached to the other part of the widened bar.

The tool has therefore incorporated in its system for measuring the forces, a data and power transmitter, and at the opposite side of the cutting part, there are (attached to the tool axis, too) the whole package of instruments for evaluation and process control. A microcomputer assess the situation of forces every 150 µs, then transmitting individual the necessary corrections for translational mechanism of each inserts. The shifting of the inserts will be made exclusively on the cutting depth direction. The computer control system can be (optional) connected to the control system of the machine tool. The inserts are attached to a mechanism for bending, making it possible its movement to the tool body.
The optimization cycle presented in figure 2 can be resumed. Theoretically this cycle will go so many times until the errors \( e_A, e_B, \ldots, e_K \) cancelled. Even the boring tool presented in the figure 4 can be improved.

Figure 5 proposed a variant of boring tool with tangential inserts, with individual monitoring of forces and of position for each inserts. The transmission of signals to the computerized block for data processing and control corrections is make wireless.

Blocks no.1 monitors the state of each forces developed for each inserts (for example, with piezoelectric system) and measured its coordinates (position) to the reference block no. 6 (detector). The transmission of data’s to the computerized block no.3 - located in the retaining tool - is wireless. It will process the information and adopt the necessary corrections, which, as the case may be:
- Translation engage of the intermediate bodies no 4 or 5 in the direction of depth of cut;
- Commands to modify the advance or speed machine tools;
- Commands to stop the manufacturing and to withdraw the boring tool from the reaming (to overcome some breakpoints force, in case of excessive wear of inserts or crash).

Figure 5. Widened head with individual monitoring and correction of inserts using wireless data transmission [2].
In the figure 5 the numbers are as follows:
1 – Force measuring unit and of the position of an insert;
2 – position adjustment block;
3 – computerized block;
4 – Adjustable intermediate body provided with roughing insert;
5 – Intermediate body adjustable with finishing inserts;
6 – The position of the reference block (detector).

The correction commands will be transmitted wirelessly to the blocks no. 2 - block for position adjustment of intermediate bodies on which are fixed the inserts (red interrupted arrows), or of the machine tools (purple arrow). Thus it can be taken individually the wear of inserts or the deviations due to variations of cutting forces, but are reported also the urgent circumstances requiring replacement of a insert or reconditioning the tool. This coud represent an advantage especially in the processing of long bores.

The proposed original boring tool (figure 5) can re-enter into the optimization cycle (figure 2), thereby achieving more efficient variant.

3. Conclusions
The boring tools continuous growth performance (and of cutting tools in general) is possible by adopting an optimization cycle similar to that presented in figure 2.

In this cycle, the step of comparing the characteristics of real boring tool with ideal characteristics requires a continuin theoretical and experimental research work. In order to plan and coordinated properly this work, this paper drew a connection between the general functions of a cutting tool and its quality characteristics. A structurally-functional classification of tools made by a manufacturer, combined with modern methods of determining the values of quality characteristics of the tools in question, will help the researchers to give a score correctly to its own products, properly to the actual market position. (These include the marketing research and benchmarking).

Once with establishing the score of a boring tool compared with the best boring tool in the market, will permit to choose the essential elements of the optimization process from figure 2, as follows:
- the best methods, techniques and procedures for comparing the characteristics of real quality with the ideal ones;
- the most effective measures to optimize the quality of the boring tool and most appropriate corrective actions to reduce the disturbances factors, to adjust the control factors and to assure the input elements needed for the design and processing boring tool;
- the objective functions will become more efficient, encompassing new features requested by the client or required by economic and technical progress.

References
[1] Yih-fong T 2006 “Parameter design optimisation of computerised numerical control turning tool steels for high dimensional precision and accuracy”, Materials and Design 27 (Elsevier Ltd).
[2] Moraru G M 2007 “Contribuţii privind proiectarea unor scule de lărgit cu plăcuţe schimbabile așezate tangenţial (Contributions to the design of boring tools equipped with tangential interchangeable inserts)”, PhD Thesis, “Lucian Blaga” University of Sibiu, Romania.
[3] Min B K, O’Neal G, Koren Y, Pasek Z 2002 “A smart boring tool for process control”, Mechatronics 12 (Elsevier Science Ltd).