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DEVELOPMENT IN MACHINING TECHNOLOGY

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This study aims to provide the recent advances in machining for modern manufacturing engineering, especially CNC machining, modern tools and machining of difficult-to-cut materials, optimization of machining processes, application of measurement techniques in manufacturing, modeling and computer simulation of cutting processes and physical phenomena.

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PREFACE

Machining is one of the most popular technique to change shape and dimensions of the objects. Machining operations can be applied to work metallic and non-metallic materials such as ceramics, composites, polymers, wood.

Cutting tools have been used since ancient times to remove excess material from forgings and castings. Nowadays, metal cutting became one of the primary manufacturing processes for finishing operations. In the last few years we have observed a rapid development in automation of manufacturing processes, especially in automatic control systems. Progress in cutting stimulates a significant increase in the metal removal rate and achieving high accuracy in terms of dimensions and shape of machine parts. New materials, which play the key role here, are used to produce cutting tools.

To meet today's high demands concerning accuracy and efficiency of the manufacturing process of machine parts, it is necessary to use computer methods for designing of technological processes.

This study aims to provide the recent advances in machining for modern manufacturing engineering, especially CNC machining, modern tools and machining of difficult-to-cut materials, optimization of machining processes, application of measurement techniques in manufacturing, modeling and computer simulation of cutting processes and physical phenomena.

Wojciech Zębala

PART 1

Machining of Difficult-To-Cut Materials

Chapter 1.3

THE EFFECT OF THE LENGTHS OF BORE HOLES ON THE MACHINING TIMES IN HARD MACHINING

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Abstract: *Several comparative investigations have been done for comparison of difference hard machining procedures. The points of view and criteria of the comparisons are diverse, but their common feature is that their benchmark is always the traditional grinding. We also adjust to the current concepts, but on the basis of the points of view that have not been investigated so far, or only in passing. The matter at issue is the effect of the geometrical sizes of the workpiece in case of bore holes. It has been stated that the length of bore holes considerably influences the selection of the most economical procedure. Herewith five hard machining methods are compared on the basis of time consumption and the gained results are described.*

Keywords: *hard machining, bore hole, geometrical sizes*

1. Introduction

At the beginning, to prove the industrial application of hard turning, roughness and the main machining time were compared to grinding [1, 2]. A significant advantage was stated for the benefit of hard turning. Later the circle was expanded and the whole surface quality (topography, roughness, integrity) was compared to grinding [3, 4, 5]. On the basis of investigations and experience it was found that the regular, so called periodical topography of hard turning is not beneficial in certain cases (e.g.: in seals). Therefore in finish procedure they returned to grinding. This version of hard machining became the combined procedure. Of course the time and cost factors could not remain untouched. The realization of this was achieved by the spread of wiper inserts. These inserts with their modified tip radius can theoretically do twice as long feed as standard inserts besides the same roughness [6]. Thus the time consumption too decreased to its half, or at least significantly.

On the one hand the surface quality requirements, on the other hand the productivity requirements made it necessary to create hard machining versions. The initiator of the development was hard turning done with CBN (cubic boron nitride) inserts, by which hardened bore holes of 57÷63 HRC hardness can be ready machined with 3 to 4 times higher productivity than by grinding. The selection of the proper version needs very thoroughful technical and economic assessment. In hard turning – similarly to other types of machining – the geometrical sizes of components must also be taken into consideration for proper technological decisions.

It is known that in grinding the bore length significantly influences the rigidity of the wheel mounting pin and through this, the moderate rigidity results in a worse roundness, worse accuracy, higher taper and higher deviation from cylindricity.

In boring the problems are similar, therefore efforts should be made to reach the maximum rigidity within the possibilities of the bore hole diameter.

We investigated how the bore length influences the productivity in certain versions of hard machining. It is presented how to select the most productive procedure if not limited by accuracy requirements.

2. An overview of the circumstances of investigation

Bore holes with a given diameter (d_1) have got five different lengths (L_1).Their material is hardened steel, within this there may be bearing steels that can be full hardened (e.g. 100Cr6), or cog-wheel steels (e.g. 20MnCr5). Their hardness is 57÷63 HRC after heat treatment. Besides L_1 bore length, L_2 length also must be defined, which differs from L_1 in the pushing and overrun of single-point tools. The size of pushing and overrun is 1+1=2 mm. The sketch, the sizes and the five investigated procedures as well as their symbols applied later are presented in Fig. 1.

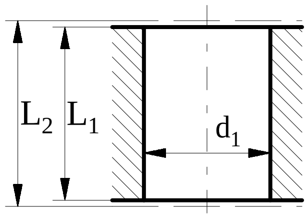
Procedure versions

A: internal grinding with longitudinal feed
B: hard turning with standard insert
C: hard turning with wiper insert
D: combined procedure with standard insert
E: combined procedure with wiper insert

Sizes of bore holes

d_1, mm	L_1, mm				
50	20	25	30	35	40

Sketch



Hardness:
57…63 HRC

Fig. 1. The sizes of workpieces and the investigated versions of procedure

3. Short description of the investigated procedures

Procedure marked **A** is a traditional internal grinding. Its application used to be exclusive before the knowledge of hard turning. The wheel speed is v_c=30 m/s, longitudinal feed, intermittent pass by double strokes, long, moderately rigid grinding pin, the application of a great amount of CL, conditioning by each piece and manual service are characteristic of that.

Procedure marked **B** is the classic hard turning with PCBN insert of ISO system. The tip of the insert is regular, $\mathbf{r_\varepsilon}$ tip radius and facets are typical of that. The cutting speed is v_c=180 m/min. The insert works dry, usually with one roughing and one smoothing pass.

Procedure marked **C** is hard turning with wiper insert. The tip geometry of the wiper insert is modified, various tip radiuses and facets are characteristic of that. The cutting speed is $v_c \approx 180$ m/min, the feed can be double as compared to the standard insert. It ready machines pieces usually with one roughing and one smoothing pass without any cooling.

Procedure marked **D** is a combined one: roughing with a standard insert, smoothing by high speed infeed grinding. The grinding speed is v_c=40÷45 m/s, the manufacturing pass is continuous, the grinding pin is short and rigid, plenty of CL is needed. Wheel conditioning goes on automatically with a diamond disc. The whole work cycle is automatic.

Procedure marked **E** is a combined one: roughing with a wiper insert, smoothing by high speed infeed grinding like in procedure **D**.

The schemes of the procedures and the main technological data outlined in Fig. 2. The symbols applied in Fig. 2 are: v_c – cutting speed; a_p – depth of cut; f – feed; $v_{f,L}$ – longitudinal feed rate; a_e – depth of cut in grinding; $v_{f,R}$ – radial feed rate; v_w – circumferential velocity of workpiece; $v_{f,R,L}$ – infeed speed of air grinding; sp. – spark out; Z – radial allowance; R – roughing; S, S1, S2 – smoothing; St – standard; W – wiper.

4. The efficiency of the procedures on the basis of time consumption

The comparative calculations were done for four normative times. They are as follows: machining time (T_{mach}), basic time (T_{bas}), piece time (T_{piece}) and operation time (T_{op}). The calculation of the consumed times was done with the following formulas:

Turning procedures:

- $$T_{mach} = \frac{L_2}{f \cdot n_w} = \frac{L_1 + 2}{f \cdot n_w} \text{ (min)} \quad (1)$$
- $T_{bas}=T_{mach}+T_{change}+T_{other}$ (T_{change}=0.2 min; T_{other}=0) (2)

- $T_{piece}=T_{bas}+T_{complement}$ $T_{complement}=0.2xT_{bas}$, (3)
  because $T_{mach} \leq 1.5$ min (datum from plant)

- $T_{op} = \frac{T_{prep}}{n} + T_{piece}$ T_{prep}=20 min (4)
  (datum from plant) n=200 (sequence size).

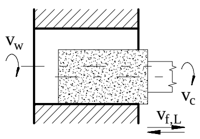
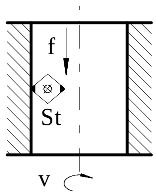
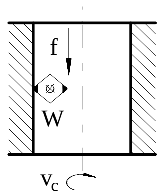
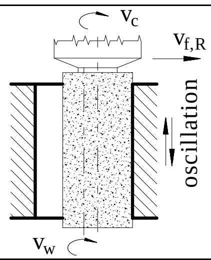
	*Procedure **A***	*Procedure **B***	*Procedure **C***	*Grinding for procedures **D** and **E***
Schemes of procedures				
v_c	*30 m/s*	*180 m/min*	*180 m/min*	*45 m/s*
a_p	—	*R: 0.10 mm* S: 0.05 mm	*R: 0.10 mm* S: 0.05 mm	—
f	—	*R: 0.15 mm/rev* S: 0.08 mm/rev	*R: 0.24 mm/rev* S: 0.12 mm/rev	—
$v_{f,L}$	*R: 2200 mm/min* S: 2000 mm/min	—	—	—
a_e	*R: 0.02 mm/dbl. str.* S: 0.001 mm/dbl. str.	—	—	—
$v_{f,R}$	—	—	—	*R: 0.0050 mm/s* S1: 0.0033 mm/s S2: 0.0016 mm/s
v_w	*18 m/min*	—	—	*55 m/min*
$v_{f,R,L}$	—	—	—	*0.108 mm/s*
sp.	*8 double strokes*	—	—	*6 s*
Z	*R: 0.10 mm* *S: 0.05 mm*	*R: 0.10 mm* *S: 0.05 mm*	*R: 0.10 mm* *S: 0.05 mm*	*R: 0.095 mm* *S1: 0.010 mm* *S2: 0.005 mm*

Fig. 2. Schemes of procedures and their technological data

Longitudinal feed grinding:

- $$T_{mach} = \frac{2L_1}{v_{f,L,R}} \cdot \frac{Z_R}{a_{e,R}} + \frac{2L_1}{v_{f,L,S}} \cdot \left(\frac{Z_S}{a_{e,S}} + sp_d \right) \text{ (min)}. \tag{5}$$

***Infeed internal grinding** (for combined procedures):*

- $$T_{mach} = \frac{0.27}{2 \cdot v_{f,R,L}} + \frac{Z_R}{v_{f,R,R}} + \frac{Z_{S1}}{v_{f,R,S1}} + \frac{Z_{S2}}{v_{f,R,S2}} + t_{sp} \text{ (min)} \tag{6}$$

Symbols in formulas that have not been applied so far: sp_d – sparking out double strokes; 0.27 – radial allowance of air grinding; t_{sp} – time of sparking out.

By the formulas above, the four normative times can be calculated for the sizes in Fig. 1. As an example in Fig. 3 the time consumption of a single case can be seen, when d_1=50 mm and L_1=30 mm. In technical literature such type of comparative diagrams can be seen [7]. Notwithstanding, valuable information can be gained from these diagrams, however, the influencing effect of the bore size hardly appears from them.

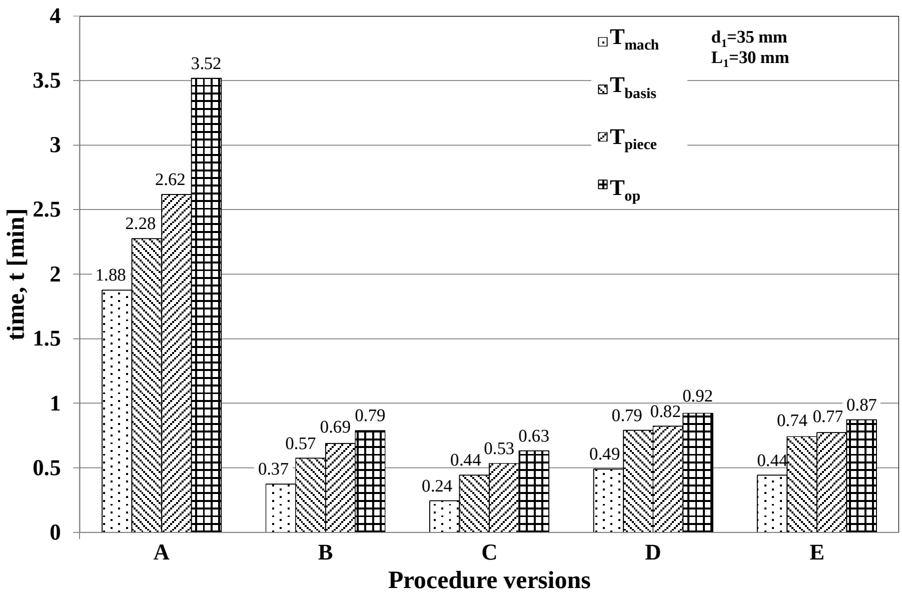


Fig. 3. Time consumption of the five different procedures
d_1=50 mm diameter of bore

However, representing the results of calculation depending on the bore length, their influencing effect can be easily recognized. In Fig. 4-7 the four different normative times were represented depending on L_1 bore length with d_1=50 mm bore diameter. From the figures which critical bore lengths it is clear need the change of the procedure.

On the basis on Fig. 4 (in which the machine time is changed) it is unambiguous that if we want to choose a more productive procedure, with L_1=26 mm we must shift from **B** procedure to **E**, with L_1=31 mm, however, to **D**, with L_1=48 mm from **C** procedure to **E**, with L_1=64 mm from **C** procedure to **D**.

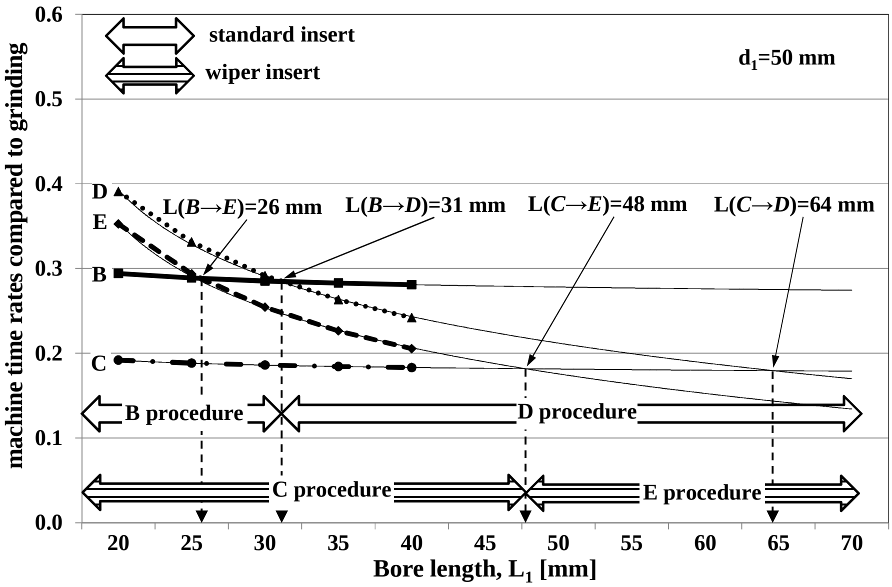


Fig. 4. Critical bore length on the basis of machine time changes

Similar statements can be issued referring to the basic, piece and operation time on the basis of Fig. 5-7.

In Fig. 4-7, in case of L_1>40 mm the critical lengths were defined on the basis of trend lines. Furthermore, already because of the tooling difficulties and efficiency demand etc. their application needs consideration, thus they are regarded as theoretical values.

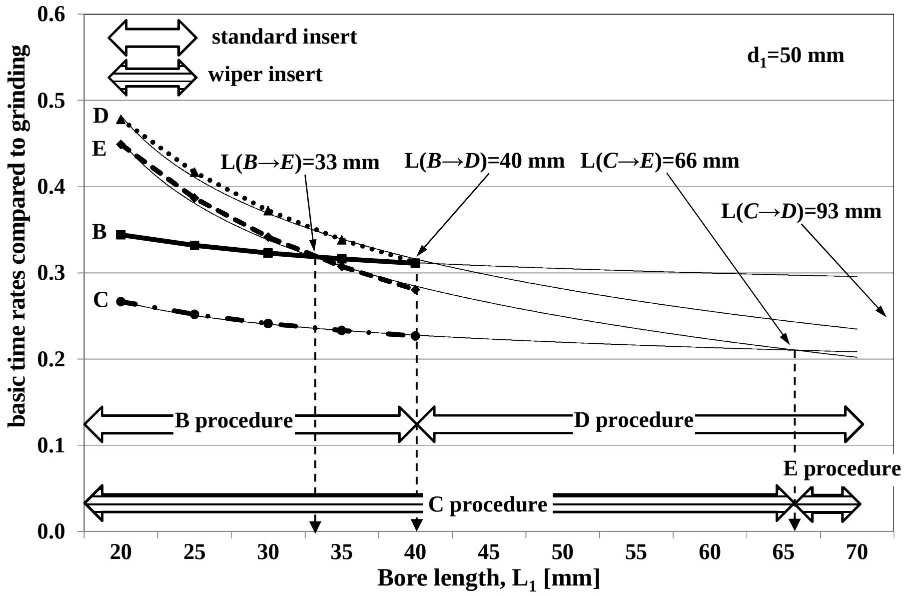


Fig. 5. Critical bore length on the basis of basic time changes

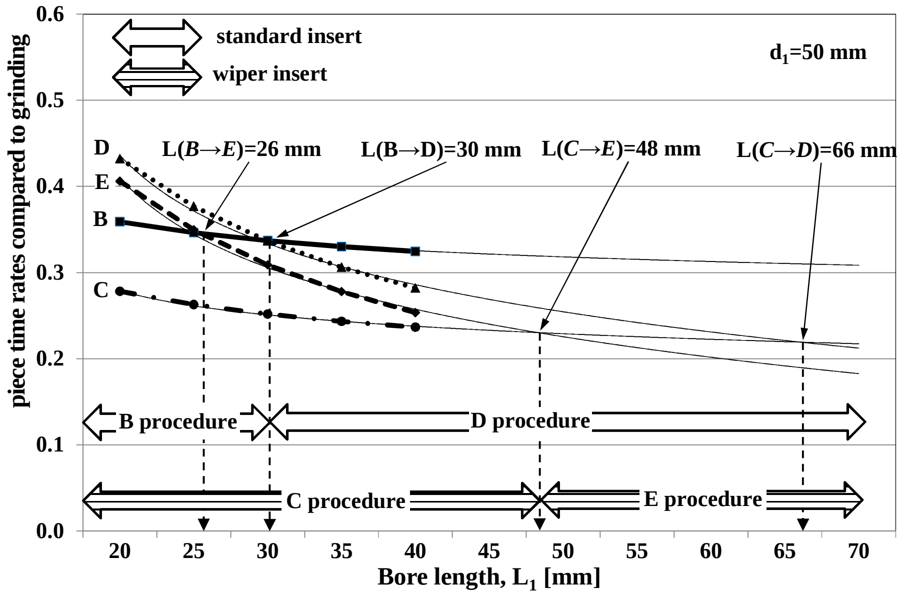


Fig. 6. Critical bore length on the basis of piece time changes

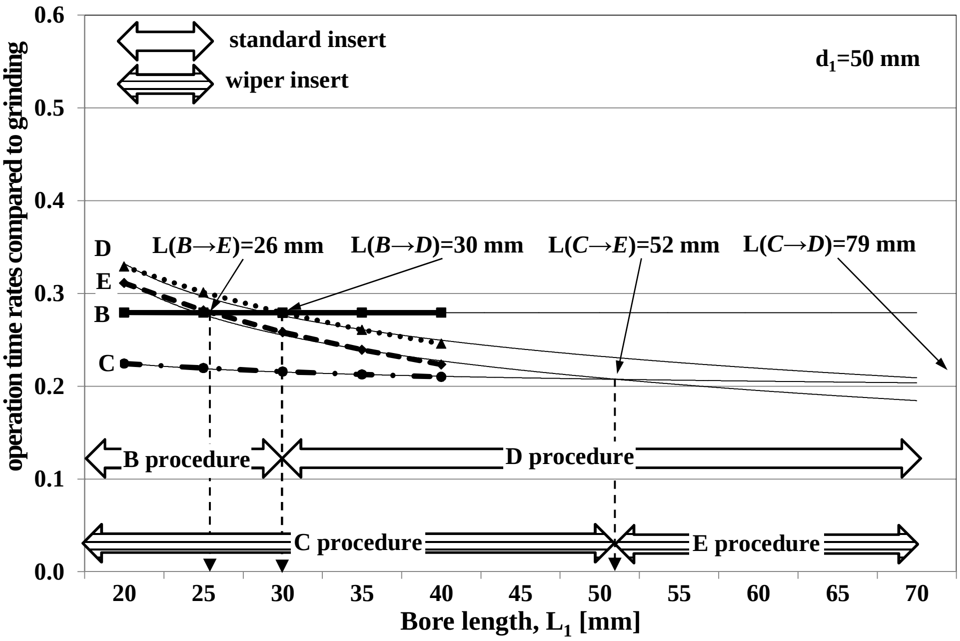


Fig. 7. Critical bore length on the basis of operation time changes

5. Conclusion

The calculations done and the presented figures unambiguously prove that the efficiency of each hard turning procedure is significantly influenced by the bore length. In case of various procedures, the difference in time consumption may reach 20÷25 %, which – having a million per year or even higher number of pieces in car producing industry – may involve either considerable profit or loss.

It is a remarkable result that in case of four different normative times, the critical lengths are at different points. The critical lengths calculated for the machine time differ from the critical lengths calculated for the other three times. Even the latter three are different from each other. Normative times are created according to local prescriptions, therefore, the results referring to them cannot be generalized.

Naturally it also should be noted that sometimes there are only limited possibilities for the selection of the optimal procedure. It happens that because of operational reasons the hard turned topography is not suitable. In cases like that, only two different, combined procedures can be applied, when the finish process is grinding. The comparison becomes simpler, because only two procedures can compete: procedures **D** and **E**. Besides that, other constraints may occur which simplify analyses, at the same time losses should be taken into account when deviating from optimum.

An order of efficiency of the given bore length can be set up between the procedures. At the same time, the time based comparison of different plants can only be realistic if the applied time creation methods are also known.

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