

COMPARISON OF HARD MACHINING PROCEDURES ON MATERIAL REMOVAL RATE

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The economic efficiency of machining plays an important role in the comparison of alternative procedures in the field of precision manufacturing too. It is not easy to perform the comparison because of the dissimilarities of material removal processes and/or procedures. However, there are some indicators that facilitate the analysis. The paper focuses on the economic comparison of the different finish procedures: grinding, hard turning and combined procedures. We analysed the practical material removal rate and the consumption of the used up coolant and lubricant (CL) as the basis of the operation time of the machining. Compared with grinding, hard turning and combined procedures showed lower operation time and higher material removal rate besides lower environmental load.

Keywords: 9 hard machining, operation time, material removal rate

Introduction

The increasing customer needs referring to the quality determine the change of functional properties of the products. To achieve it, the increase of tenacity of the components is important. It can be reached with the hardening of the surfaces too. The hardening is a procedure which is also applied to simplify the production chain in some groups of components. The abovementioned also facilitate the increase of hard surfaces on the components.

Hardening is generally followed by finishing which results the final geometry of the component. For a long time, grinding was the most often used finish procedure but today hard turning and the combination of these procedures play an important role in this field. However, it is not easy to outline the application fields where grinding may be substituted by hard turning [1, 2]. The application of hard cutting and combined procedures requires different machine tools and new production organizing methods. These changes affect the costs of production and other fields of the enterprise. That is why decision makers have to solve an optimization task extending to the whole production chain to compare the possible machining versions.

To compare the procedures, the machined components have to be produced by the same accuracy and quality requirements. Grinding and hard turning are basically different procedures referring to material removal. If the specified accuracy and quality requirements can be assured by two or more procedures, those can be considered as the alternatives of one another.

Besides ignoring or supposing the constancy of the costs of investments, human resources and other

management processes, the practical material removal indicators can be useful to compare the alternative procedures by economic aspect [3, 4, 5, 6].

A special aspect of the investigation is the extent of environmental load. The environment pollution of machining includes several components but we focus only on the consumption of coolant and lubricant.

The applied procedures and environmental load characterising the procedures

The most often analysed hard machining procedures are grinding, hard turning and the combined procedure.

Grinding had a distinguished importance in finishing of hardened surfaces referring to machining of engineering industrial components because the machining of hardened surfaces with high accuracy and low roughness was possible to be provided in most cases by this procedure only. Besides its several advantages, one of its disadvantages is that it particularly loads the environment. Grinding, because of the large amount of CL, pollutes the environment in large measure, damages the workers' health and even the process costs are higher. Grinding requires expensive auxiliary materials, and among the remaining materials the mud and the used up lubricant are considered dangerous waste.

The second hard machining procedure which spreads more and more nowadays is the hard turning. The rapid increase of the procedure can be observed particularly in disc-featured components and by the machining of different bore-holes. Hard turning loads the environment less. Hard turning shows a much more favourable picture than grinding from the point of view of environment

protection, too, as those unfavourable effects do not occur. The machining can be completed without using CL. The chips are the same as the workpiece material, thus they can be recycled. Hard turning provides an entirely environment friendly, clear and hygienic machining of the workpieces while they have the same quality as by grinding [7, 8].

The third procedure is the combined procedure. Roughing is done by hard turning and smoothing is by grinding. To compare that with the traditional procedures, the major difference is, that the machining is carried out on the same machine tool in one clamping in one operation. That is why the smoothing allowance can be smaller. It is important because the environmental load caused by the operation is in proportion with the machining time of the two procedures.

Experiments

On disc-feature components, internal cylindrical surfaces were with different geometry machined. The sizes of the components machined at the plant and the technological data applied there in grinding were considered as basis.

Hard surfaces are often internal cylindrical surfaces, which, in producing parts, are often to be formed. The machining of bore-holes in most cases is a more difficult and more expensive procedure than the machining of external surfaces.

Earlier grinding was the major procedure for machining hardened internal cylindrical surfaces too. Bore-hole grinding is an often used, wide-spread procedure.

Boring can also be done under more difficult conditions compared to external turning. That is why the machining with adequate efficiency of bore-holes and the surfaces being in connection with them is a particularly important task e.g. in the machining of gear-wheels. The aim of the experiments was to establish an order among the procedures.

Conditions of the experiments

The experiments were performed on workpieces (Workpiece: WP) with the same diameter but different lengths and also on workpieces with the same length but different diameters (Table 1).

The data of the workpiece were as follows.

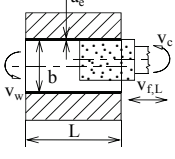
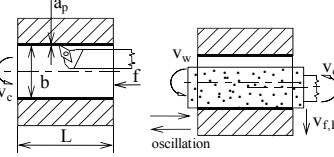
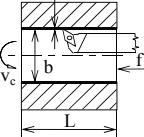
- material: 16MnCr5
- hardness: 61..63 HRC
- accuracy: IT5..6
- ℓ/d relationship: 0.41..1.04
- allowance: 0.15 mm
- sequence size: 200

0.1 mm of allowance was removed by roughing and 0.05 mm by smoothing. The major technological data (machine tool, tool, allowance, feed, cutting speeds etc.) and the drafts of procedures are detailed in Table 2.

Table 1: Geometric data of the workpieces

Sign:	WP1	WP2	WP3	WP4
Diameter, d [mm]	37±1		48	66
Length, L [mm]	29.85	38.45	27.35	

Table 2: Technological conditions of the machining experiments

Procedure	Tool and machine tool	Technological conditions					
		Roughing			Smoothing		
Grinding 	<i>Roughing and smoothing:</i> 40x20x16-9A80-K7V22 <i>Machine tool:</i> SI-4/A	$v_{f,L}=2.2$ m/min $a_e=0.02$ mm $n_w=90$ 1/min			$v_{f,L}=2.0$ m/min $a_e=0.001$ mm $n_w=90$ 1/min		
		Sign	v_c [m/s]		Sign	v_c [m/s]	
		WP1	25		WP1	25	
		WP2	25		WP2	25	
		WP3	29		WP3	29	
		WP4	29		WP4	29	
Combined procedure 	<i>Roughing:</i> CNGA 120408S-Lo CBN <i>Smoothing:</i> 40x40x16-9A80-K7V22 <i>Machine tool:</i> EMAG VSC 400 DS	$v_c=180$ m/min $a_p=0.1$ mm			$v_c=45$ m/s $v_{f,R,S1}=0.0033$ m/min $v_{f,R,S2}=0.0016$ m/min $n_w=90$ 1/min		
		Insert	standard	wiper			
		f [mm/rev.]	0.15	0.24			
		$v_{f,R,LA}=0.108$ m/min $v_{f,R,N}=0.005$ m/min $n_w=90$ 1/min					
		$v_c=180$ m/min $a_p=0.1$ mm					
Hard turning 	<i>Roughing:</i> CNGA 120408S-Lo CBN <i>Smoothing:</i> CNGA 120408 7020 <i>Machine tool:</i> Pittler PVSL-2	$v_c=180$ m/min $a_p=0.1$ mm			$v_c=180$ m/min $a_p=0.05$ mm		
		Insert	standard	wiper	Insert	standard	wiper
		f [mm/rev.]	0.15	0.24	f [mm/rev.]	0.08	0.12

The three different machining procedures (PR) were performed on different machine tools in five different versions.

- PR1: grinding (roughing and smoothing)
- PR2: combined procedure (roughing by standard insert, smoothing by corundum wheel)
- PR3: combined procedure (roughing by wiper insert, smoothing by corundum wheel)
- PR4: hard turning (roughing and smoothing by standard insert)
- PR5: hard turning (roughing by wiper insert and smoothing by standard insert)

The roughing grade of the combined procedure included a grinding process too. The internal traverse grinding (sign A) was performed by two cutting speeds. The workpiece revolution was constant by the grinding procedures. The number of sparking out strokes was $i_k=16$ by all gear-wheels. In case of hard turning an L' length has to be defined, which is the sum of the bore-hole length and the running on and running off lengths of the tool.

Calculation method

Operation time is in close relation with the changing costs of the production. It includes e.g. the preparation, replacement or piece times besides the machining time. Therefore it gives a clear picture about the connection between the economic and technical aspects. Some parameters are calculated by the technological data and others include empirical values resulted by the concrete production. In the industry these empirical values have a major importance. In case of large sequence size the values can be well estimated as a result of a process monitoring. In differing cases the analysis is difficult because there are no acceptable, exact calculation methods. The empirical values were taken from the process documentation of the company where the production was performed.

The machining time is the sum of machining time of roughing and smoothing. The details of the calculation are showed by equations 2, 3 and 4.

$$T_m = T_{m,R} + T_{m,S}, [\text{min}] \quad (1)$$

- Grinding:

$$T_m = \frac{2 \cdot L}{v_{f,L,R}} \cdot \frac{Z_R}{a_{e,R}} + \frac{2 \cdot L}{v_{f,L,S}} \cdot \left(\frac{Z_S}{a_{e,S}} + i_{sp} \right), [\text{min}] \quad (2)$$

- Combined procedure:

$$T_m = \frac{0.27}{v_{f,R,L_A}} + \frac{Z_R}{v_{f,R,N}} + \frac{Z_S}{v_{f,R,S}} + t_{sp} + \frac{L'}{n_w \cdot f_R}, [\text{min}] \quad (3)$$

where:

- i_{sp} – the number of sparking out strokes
- t_{sp} – the time of sparking out

- Hard turning:

$$T_m = \frac{L'}{f_R \cdot n_w} + \frac{L'}{f_S \cdot n_w}, [\text{min}] \quad (4)$$

The replacement time is taken from the technological documentation.

- Grinding: $T_{repl} = 0.4 \text{ min}$
- Hard turning: $T_{repl} = 0.2 \text{ min}$

Base time is the sum of machining and replacement times.

$$T_b = T_m + T_{repl}, [\text{min}] \quad (5)$$

The supplement time is given. When $1.5 < T_m < 8$, value of T_{supp} is the following.

- Grinding: $T_{supp} = 0.15T_m, [\text{min}]$
- Hard turning: $T_{supp} = 0.2T_m, [\text{min}]$

The piece time is the sum of base and preparation times.

$$T_{piece} = T_b + T_{supp}, [\text{min}] \quad (6)$$

- Grinding: $T_{piece} = 1.15T_b, [\text{min}]$
- Hard turning: $T_{piece} = 1.2T_b, [\text{min}]$

The preparation time is given from the data of technological documentation.

- Grinding: $T_{prep} = 180 \text{ min}$
- Hard turning: $T_{prep} = 20 \text{ min}$

The operation time is calculated by the following equation:

$$T_{op} = \frac{T_{prep}}{n} + T_{piece}, [\text{min}] \quad (7)$$

The theoretical value of the material removal rate (MRR) is a widely used indicator, which gives information about the efficiency of machining. It is defined as the amount of the removed material per second (equation 8 in internal traverse grinding, 9 in grinding and equation 10 in turning).

$$Q_w = a_c \cdot f \cdot v_w, [\text{mm}^3/\text{s}] \quad (8)$$

$$Q_w = L \cdot v_{f,R} \cdot d \cdot \pi, [\text{mm}^3/\text{s}] \quad (9)$$

$$Q_w = a_p \cdot f \cdot v_c, [\text{mm}^3/\text{s}] \quad (10)$$

This indicator ignores the factors of the machining included in one procedure and not included in another. To resolve this hiatus a practical value of the MRR was introduced (eq. 11). The essence of the conception is, that the theoretical MRR is corrected by a properly chosen datum of time which is suitable for the actual investigation. Therefore the gained value will fit to the machining times and costs.

$$Q_{wp,op} = \frac{d \cdot \pi \cdot L' \cdot Z}{60 \cdot T_x}, [\text{mm}^3/\text{s}] \quad (11)$$

where:

- d – bore-hole diameter
- L' – sum of bore-hole length and running on and off
- Z – allowance
- T_x – relevant time of investigation
(in present investigation: $T_x = T_{op}$)

To get information about the environmental load, the percentage of the used up of coolant and lubricant was determined depending on the operation time by a simple proportioning.

Results of experiments and evaluation

The machining experiments were separated by the machined bore-hole geometry. In the first step we chose two components with different bore-hole lengths (L) besides the same bore-hole diameters (d). In case of the other two gear-wheels the lengths were the same. We performed a detailed calculation referring to the machining times, material removal rate and environmental load.

By traverse grinding, the machining times ($T_{m,R}$ and $T_{m,S}$) was depended on the bore-hole length (Table 2, PR1). The reason for that was the type of the procedure: the bore-hole is longer than the width of the grind wheel having an alternating motion in axial direction. Therefore, the operation times besides the same bore-hole lengths

were equal. BIn internal traverse grinding the operation time increases with the bore-hole length.

In a combined procedure, the machining time of roughing (hard turning) increases with the bore-hole length (Table 2 PR2 and PR3) by 21–22 percent as well as with the diameter of the bore-hole (Table 3, PR2 and PR3) by 40–43 percent in case of both standard and wiper insert. But the roughing time with wiper insert shows 35–40 percent reduction (Tables 2 and 3, PR2 and PR3). The applied workpiece speeds were different by each part, id. est. WP3 and WP4 were machined at higher speeds. This is the reason for the smoothing machining time reducing with the increase if the bore-hole diameter. Other times were approximately equal by each workpiece. In hard turning, the machining times of smoothing are smaller than in the other procedures, which corresponds with the expectations. By the increase of the length or the diameter, these times increase too. In the first case this value is 16–23 percent, depending on which insert is used (Table 2, PR4 and PR5) and in the second the value is 36–40 percent (Table 3, PR4 and PR5).

Table 3: Contents of operation time and CL quantity (by constant bore-hole diameters)

Procedure		Sign of workpiece				Operation time, T_{op} [min]
		WP1		WP2		
Traverse grinding	PR1					
Combined procedure	PR3					
Hard turning	PR5					
			Machining time (Roughing), $T_{m,R}$		Machining time (Smoothing) $T_{m,S}$	
			Consumption of Coolant and Lubricant		Dry machining	

Table 4: Contents of operation time and CL quantity (by constant bore-hole lengths)

Procedure		Sign of workpiece				Operation time, T_{op} [min]	
		WP3		WP4			
Traverse grinding	PR1						
Combined procedure	PR2						
Combined procedure	PR3						
Hard turning	PR4						
Hard turning	PR5						
			Machining time (Roughing), $T_{m,R}$		Machining time (Smoothing) $T_{m,S}$		Other times ($T_{op}-T_m$)
			Consumption of Coolant and Lubricant			Dry machining	

In the investigation of operation times, it is observable that they increase with the bore-hole length because more material has to be removed. The traverse grinding showed the largest values and the hard turning the smallest. It seems, that this result allows the expectation that hard turning can be the most efficient procedure considering economic aspects but this simple indicator is not enough to enunciate it with absolute certainty. Using wiper inserts results lower operation times in both cases (combined procedure and hard turning).

With the increase of bore-hole diameter, operation times are similar regarding grinding and the combined procedure but the wiper insert results lower values here too. In hard turning these times increase.

We compared the environmental load of the different procedures. The extent of it was calculated by the operation times. Because of the above mentioned reason, hard turning is the most environmental friendly procedure. The lower circle diagrams in the Table 2 and 3 show the results referring to the used CL.

The practical values of material removal rate are summarized in Figs 1 and 2. They include the concrete values of the five investigated procedure versions. Generally it can be stated that the values of the MRR indicator corrected by the operation times are lower besides smaller bore-hole diameter or shorter length. One exception is the internal traverse grinding. With the same diameter, the value of practical MRR is independent of the bore-hole length.

Besides different bore-hole lengths or diameters, the practical MRR values are in proportion with the change of these parameters in hard turning. Furthermore, it is observable that the values are significantly higher by using wiper insert. In combined procedure the effect of the insert type determines these values only to a small extent (7–10 percent). By increasing the bore-hole diameter, the values of combined procedure are sharply different. The reason for that is the higher workpiece speed.

Besides the material removal rate the other widely used indicator is the surface rate. We defined the practical value of that too. But because of the different allowances

and thus the different d.o.c.'s, this parameter gives not such exact information about the economic efficiency as the practical MRR.

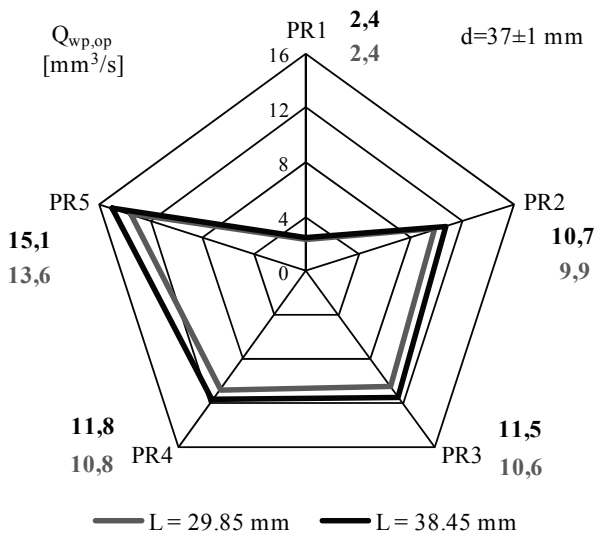


Figure 1: Practical values of material removal rate based on the operation time by the same bore-hole diameter

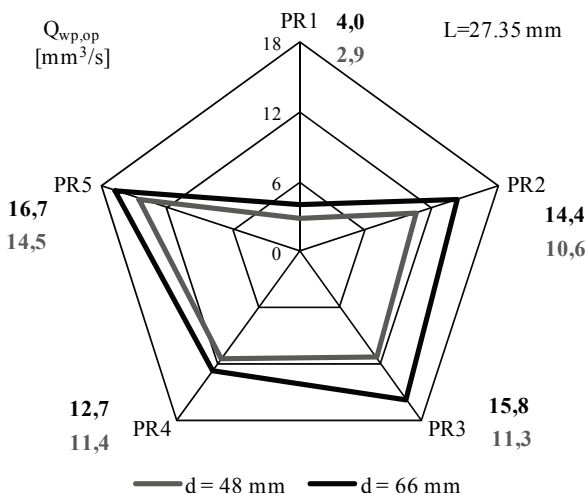


Figure 2: Practical values of material removal rate based on the operation time by the same bore-hole length

Conclusion

Focusing on industrial demands, the applicability of hard machining procedures and the determination of their fields of application have been invariably a key research topic. The required workpiece characteristics (e.g. form- and dimension accuracy and surface roughness), can be provided by the high level reliability of the production processes in these types of machining.

Several decisive advantages and disadvantages of hard cutting and grinding procedures are known, but further research is needed to reduce for example the process time or the environmental load. To reduce the whole process-chain in the hard machining of more and more parts (components) is possible for example by using only one machine tool for the whole process.

Further task: within one process as big part of the allowance should be removed by hard turning as possible.

The experiments proved that the application of hard turning in the finish operation involves both economic and environmental benefits. The comparison of hard turning and grinding in machining bore-holes showed the significant advantage of hard turning referring to economic efficiency. The existing differences were revealed by all investigated parameters, like operating time and the practical values of material removal rate. The combined (hybrid) machining provides economic efficiency similar to hard turning.

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