XVII IMEKO World Congress
Metrology in the 3rd Millennium
June 22-27, 2003, Dubrovnik, Croatia

REALIZATION OF ACCURACY AND QUALITY REQUIREMENTS IN HARD CUTTING

Janos Kundrak [1], *P. Herbert Osanna* [2], *Viktoria Bana* [1], *Ali Afjehi-Sadat* [2]
[1] Miskolc University, Miskolc, Hungary
[2] Vienna University of Technology, Vienna, Austria

Abstract - Choosing out of the machining process for the finishing process of machining of the parts requires great attention because by means of that the accuracy and quality requirements prescribed for the parts must be ensured.
This paper analysis two processes, the grinding and the hard turning applied for finishing machining of hardened surfaces and presents what kind of accuracy and surface quality parameters for the gears' hardened surfaces can be ensured with hard cutting.

Keywords: roughness measurement, hard cutting, geometrical accuracy

1. INTRODUCTIONARY REMARKS

The main criterions of the workpiece quality – especially in the finishing process – are the surface quality, mainly accuracy and geometrical characteristics, which remarkably defines the functional characteristics of the workpiece. Adequate information is available about definitions of the accuracy and surface quality parameters applied nowadays and their comparison according to the existing standards [8].

In finishing of hardened steels, hard turning performed with PcBN tools applied under the proper conditions is suitable for replacing the grinding process. The hard turning offers many economical and environmental benefits [1] e. g. in machining of the hardened parts like bearings or gears. Opposite to these the functional requirements are high that are determined together by the geometry and the surface roughness of the workpiece and the state of the surface layer and they strongly depend on the cutting process.

The machine-tool development has made it possible that quality of the hard turned parts will become significantly better. Today it is also possible to produce parts with size and form accuracy in the range of IT4-6 [2]. One of the most advantages of hard turning is the possibility of avoidance of coolant. Thus form errors gain higher importance as a consequence of cutting performed dryly. Form errors of the workpiece generate due to the thermal deformation of the workpiece and the cutting tool that leads to the decrease of the workpiece diameter in the axle direction. On the other hand these thermal effects may also increase non-parallelity of the barrel cams. For compensation of the form errors caused by thermal effects the NC control of lathes with high accuracy produced nowadays gives a suitable possibility. Figure 1 summarises the factors that determine the size, shape and position accuracy of the parts [3].

Precision of the machine tool, controlling system of that and preparation of the cutting tool edge mostly determine the accuracy [4]. It is a basically prescription that clamping forces of the chucking should not cause deformation for the parts. In the most cases it is not possible in the mechanical chucking however it can be realised with application of the magnetic chuck well.

In boring of hardened bearing steels (100Cr6), the form and the shape accuracy showed adequate values [3, 4]. In measurement of the out-of-roundness and the non-parallelity the received values was about third part of the prescriptions. Thus when machining of ∅120 mm bore the out-of-roundness was 2,6 μm, while the non-parallelity was 1 μm [3].

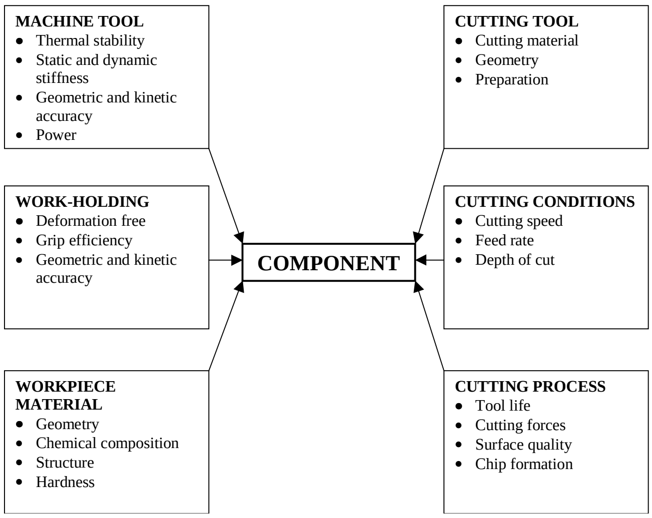


Figure 1. Influencing factors for the size, form and position accuracy of the part

2. COMPARATIVE INVESTIGATIONS

The aim of the investigations was to determinate feasibility of the accuracy and quality requirements prescribed for the parts in hard cutting of gears' bores.
Prescribed accuracy of the diameter is IT5 (G5).

This means the following limits for the accuracy parameters:

Out-of-roundness and cylindrical deviation: 6 μm
Non-parallelity: 8 μm
The required surface roughness is: Rz = 3 μm

2.1. The conditions of the experiments

The investigated workpiece's:

- material: 16MnCr5
- hardness: 61-63HRC
- size of the machined surface
  bore diameters GEAR 1 d80G5 (hard turned)
  GEAR 2 d80G5 (ground)
  GEAR 3 d50G5 (hard turned)
  Length of the bore: l=35 mm

The applied processes

a) Grinding process

- Machine-tool: SI-4/A
- Grinding wheel: Sima korong
  40x40x16-9A80-K7V22
- Technological data:
  n_s =16000 1/min; v_c =33 m/s
  n_w =160 1/min; v_w =24 m/min
  v_f =2,2 m/min

b) Cutting process

- Machine-tool: PITTLER PVSL-2
- Cutting tool: CNGA 120408 7020 (Sandvik Coromant)
- Technological data:
  n=900 1/min , f=0,1 mm/rev
  v_c =180 m/min, f=0,08 mm/rev

2.2. Methods of measuring

We used a measuring instrument type of Rank Taylor Hobson, Form Talysurf Series 120L for defining the roughness parameters and the reference length of the profile. The out-of roundness and the cylindricity were measured with Talyrond 252e measuring machine. The measurement was carried out with a touching head of 4 mm diameter, the applied filter was 1-500 Gauss. In measurement of the shape, the size and the position accuracy we investigated the roundness and the cylindricity of the gear holes and the parallelism of their barrel cams.

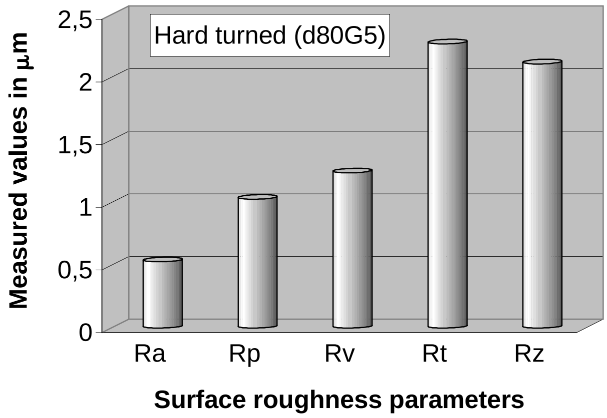
The out-of-roundness is given by the longest distance between points of the super incumbent circle and the real profile while the cylindrical deviation is determined by the longest distance between points of the super incumbent cylinder and the real surface inside borders of the reference length. The typical form of the out-of-roundness is the ovality and the lobbing as the real profile has a mutual shape. We measured the out-of-roundness in three places. The deviation from the cylindricity is given by the roundness profile observed in the three measured planes. The non-parallelity is the difference between the longest and the shortest distance of real barrel cam of the bore and the basis (the bore axle) inside the borders of the reference length.

3. THE RESULTS OF THE MEASURING AND THEIR RESULTS

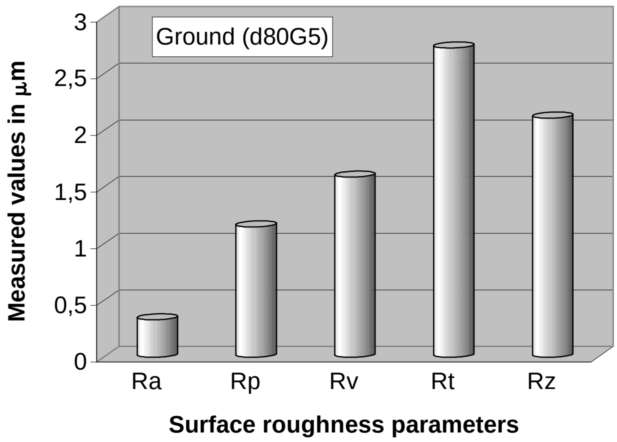
3.1. Roughness of the machined surface

The generation of good microgeometry of the surface cut by polycrystal superhard tool can be explained by the great number of microedges on the worn flank of the tool polish the machined surface during cutting. That is why these surfaces obtain equally good or better microgeometry than the ground surfaces.

Experiments made earlier also showed that the favourable microgeometry is created after the initial wear of the tool and it remains constant in the stable stage of the work [5].



a) GEAR 1



b) GEAR 2

Figure 2. Surface roughness in the case of machining of bores

Figure 2 shows the measured roughness characteristics for grinding and hard turning and Figure 3 presents comparison of the surface measuring numbers applied mainly. It can be seen that closely same values can be achieved in both processes (Figure 2). The comparison also shows that even more advantageous values also happen in hard cutting (Figure 3). On the other hand in boring of gear with little diameter (GEAR 3) the surface roughness according to IT5 can also be ensured (Fig. 4).

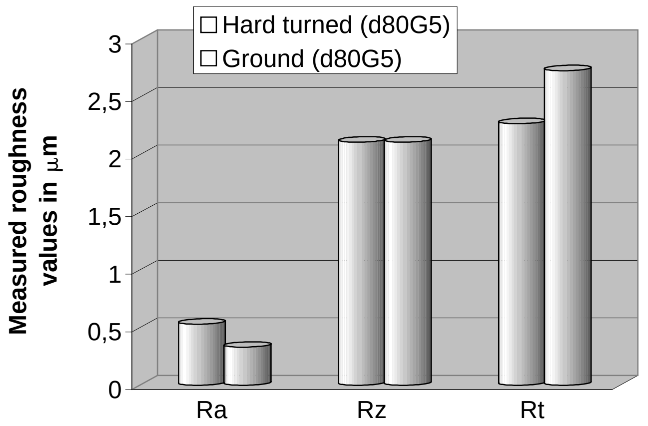


Figure 3. Comparison of surface roughness in the case of grinding and hard turning

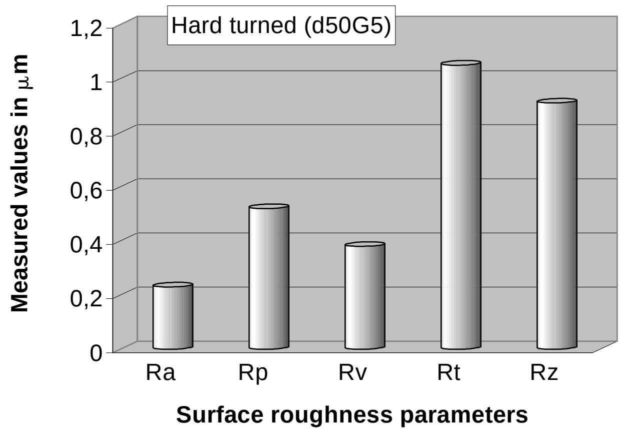
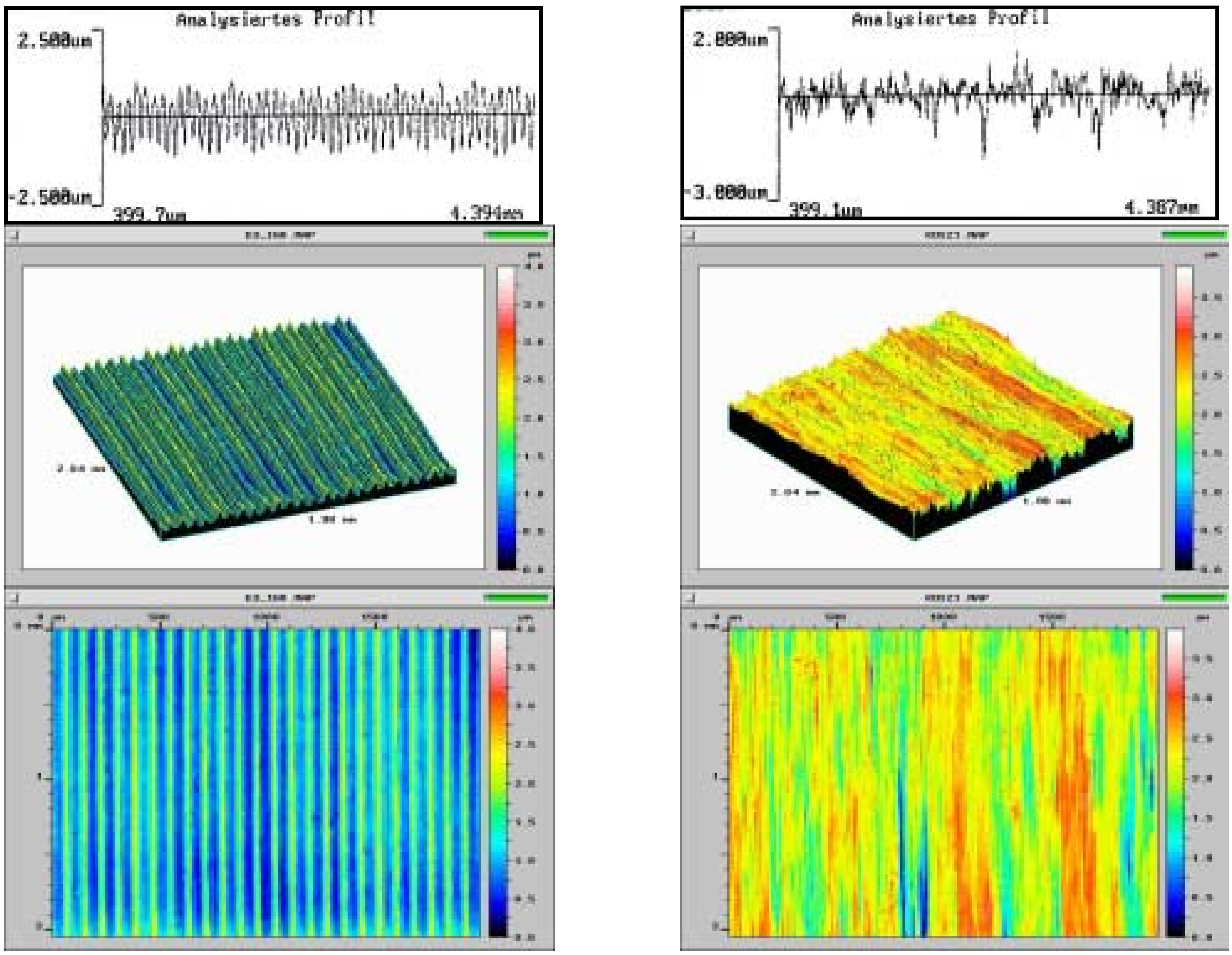


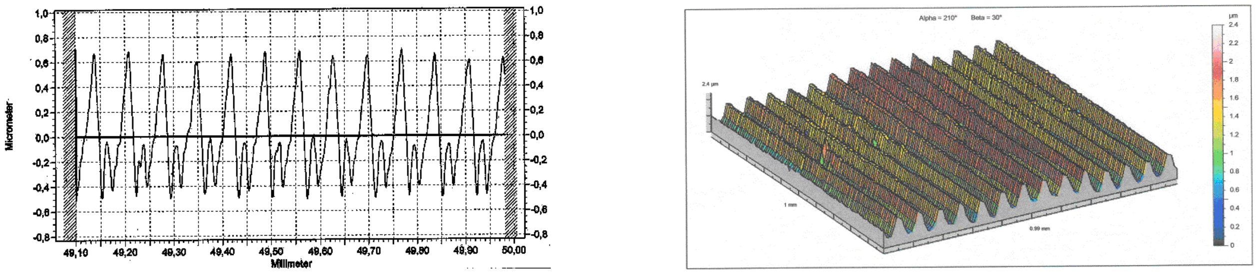
Figure 4. Surface roughness of GEAR 3 (hard turned)



hard turned surface (d80G5)
GEAR 1

ground surface (d80G5)
GEAR 2

Figure 5. Comparison of machined surfaces of GEAR 1 and GEAR 2



a) hard turned surface (d50G5)

Figure 6. 2D profile and 3D topography of GEAR 3

The surface roughness is the most significant geometrical parameter also from the point of view of the friction and wear of the friction surface. Thus, in the practice the determination of its parameters is very important.

Figure 5 and 6 show the true advantages of hard turning well, and the regularly repeated surface elements. It can be seen that both the high points of the surface's microprofile, and their distance from the each other are nearly constant, while in grinding they are very uneven. From the point of view of tribology, the favourable surface roughness depends not only on the characteristics of the materials but also e.g. from the distance of the surface roughness (wavelength). Depending on the roughness height and the distance of the roughness peaks, even the safety range can be given within which the friction surface gets the least damages [6].

It was observed in several cases, that also in the case of frictional metal material pairs, the surface roughness of constructions operated properly adjusts to its optimal value [6].

From the point of view of tribology the profilogram of the rough surface is favourable, if besides the given outstanding sharp roughness peaks and R_a average surface roughness the smoothness index number is smaller, the profile completeness factor is bigger.

The curve of reference surface of the profile shows that on the profilogram, depending on the distance of the cutting plane measured from the highest roughness peak, how the size of the reference surface of the profile changes adding together the sections gained from cutting the roughness peaks.

The favourable numerical values of the reference length of the profile are shown in Table 1 while Figure 7 compares measured profiles of that.

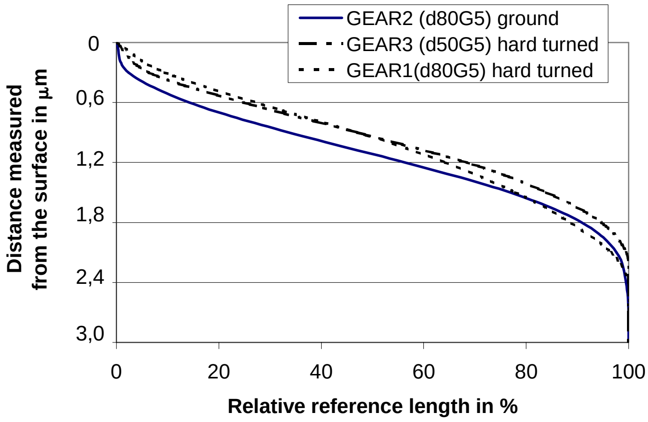


Figure 7. Comparison of values of the relative reference length of the profile

TABLE 1. Values of the relative reference length

	Distance measured from the surface in µm									
GEAR 1 (d80G5)	9,43	32,57	48,75	60,54	71,92	86,04	96,56	100		
GEAR 2 (d80G5)	2,34	12,09	32,11	56,23	76,90	90,89	97,65	99,48	99,96	100
GEAR 3 (d50G5)	6,32	24,77	47,03	69,59	83,94	94,70	99,51	100		

3.2. Size, form and position accuracy

The macrogeometrical deviations and waviness are generated by the defects of the machine and the tool as well as by the oscillation with low cycle number of the machine-tool-workpiece system. The macrogeometrical deviations have significant effect on the spread of the load forming on the friction surface and through that on the friction force, wear, surface damage formation. Therefore their size have to be limited remarkably (together with the situation faults which decisively influence the contact of the parts) e. g. by increasing the accuracy of machining, using stiffer machines and tools [7].

In investigation of the geometrical accuracy the measured values are summarized in Figure 8 and 9. In the case of the turned and the ground gears having same diameter it can be seen well that the values measured after hard turning do not exceed that of grinding. Figure 10-12 give a comparison about profiles of roundness, cylindricity and parallelism gained after the two processes.

The out-of-roundness exceeds 4 µm prescribed in the technical drawing but does not overrun 6 µm according to the standard. In hard turning it can be happened that the sterner roundness prescriptions do not realise beside the proper insurance of the surface roughness. Its firstly reason is that the parts with little wall thickness are very sensible for clamping force of the chucking. For proper setting of this and evaluation of the proper range an increased attention must be paid.

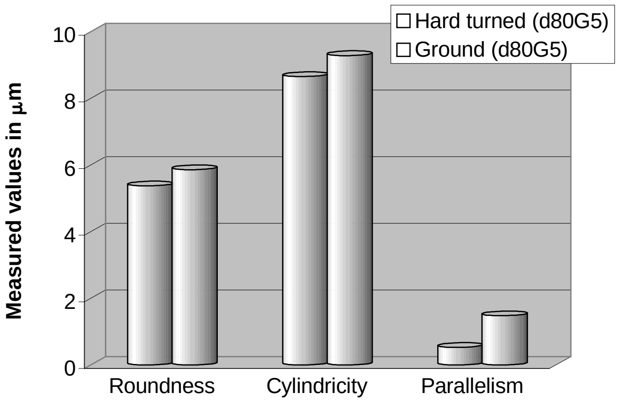


Figure 8. Comparison of geometrical accuracy of hard turned (GEAR 1) and ground (GEAR 2) pieces

In the investigation of cylindricity, the measured values changed between 8,65 ÷ 9,28 µm, which exceed the 6 µm tolerance value (IT5) in the case of both grinding and turning.

Moreover examination of the parallelism shows good values. Here the values changed in the range of 0,53 ÷ 1,48 µm that are lower than the prescribed 8 µm. In the case of both gears we measured lower values after hard turning than grinding which can also be seen from the profile figures well.

Geometrical accuracy of the hard turned gear having lower hole is worse than that of gear having greater diameter (Fig. 9.). Thus here, the machining accuracy must be controlled and/or improved that require further examinations.

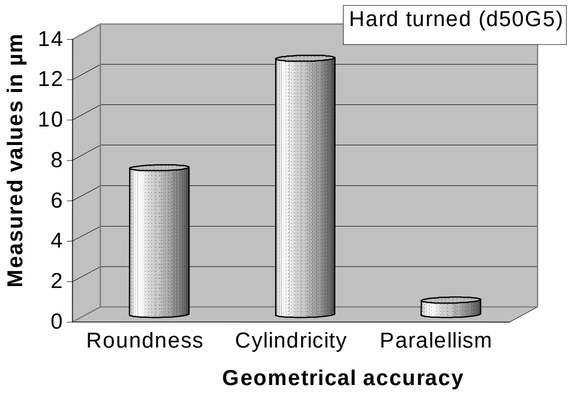
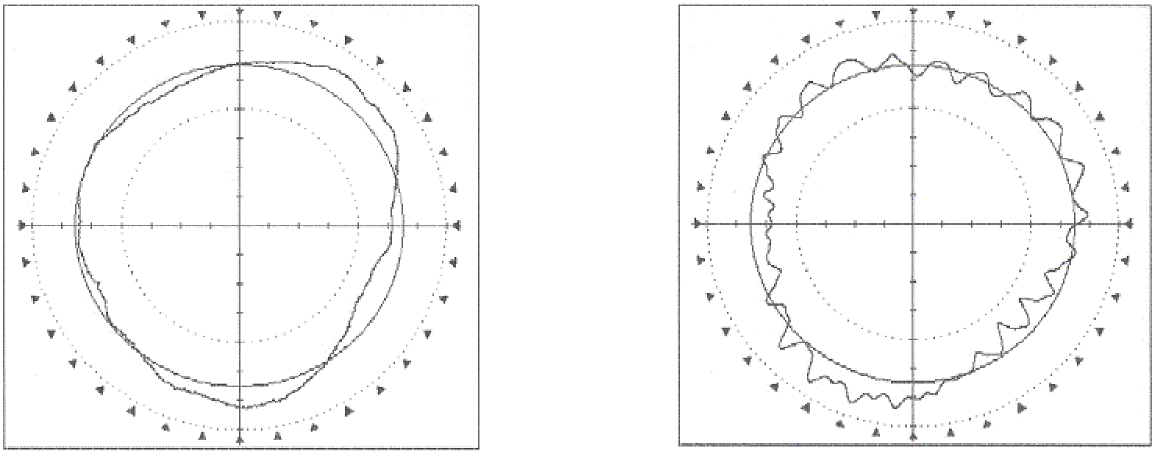
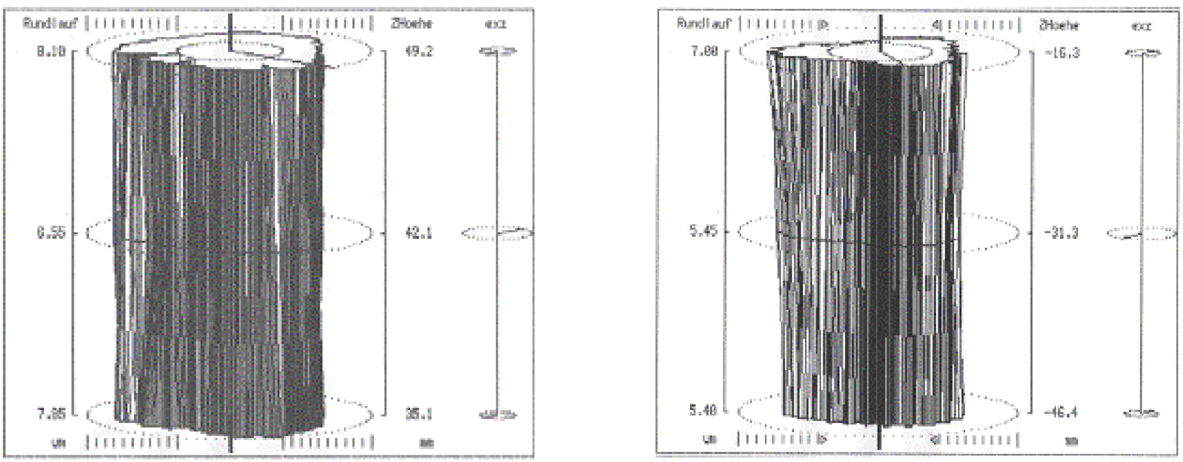


Figure 9. Geometrical accuracy of GEAR 3



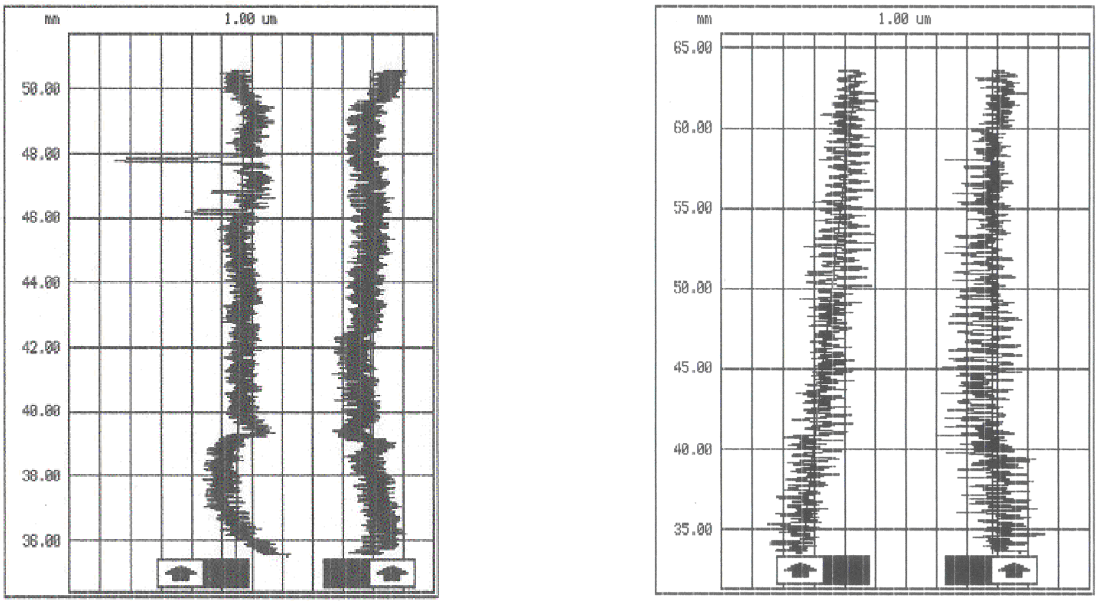
Hard turned Ground

Figure 10. Cylindricity profiles of GEAR 1 and GEAR 2 after grinding and hard turning



Hard turned Ground

Figure 11. Roundness profiles of GEAR 1 and GEAR 2 after grinding and hard turning



Hard turned Ground

Figure 12. Parallelism profiles of GEAR 1 and GEAR 2 after grinding and hard turning

4. ECONOMICAL ASPECTS OF THE QUALITY ASSURANCE

4.1. Material removal rate

The material removal rates calculated on the basis of theoretical investigations were at least as high or better for grinding as for hard turning [2]. The volume related material removal rate is the same or better in turning as in grinding.

This shows that the time of grinding is often shorter than the time of turning. In machining of bore besides the volume related material removal rate the surface rate may become more advantageous. Our investigations showed that in boring the surface rate is already more advantageous, too (Table 2).

TABLE 2. Material removal rate in boring ∅80G5 (l=35 mm)

Machining processes	Q_w [mm^3/s]	A_w [mm^2/s]
Grinding	12,60	44
Boring	37,5	124
Boring / Grinding	2,98	2,81

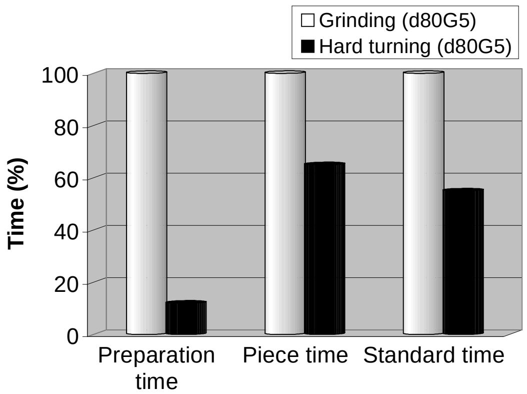


Figure 13. Comparison of costs for grinding and hard turning in machining of gear`s

Thus for cutting of both external and internal surfaces on the basis of the volume related material removal rate furthermore for machining of bore on the basis of the surface rate cutting is recommended.

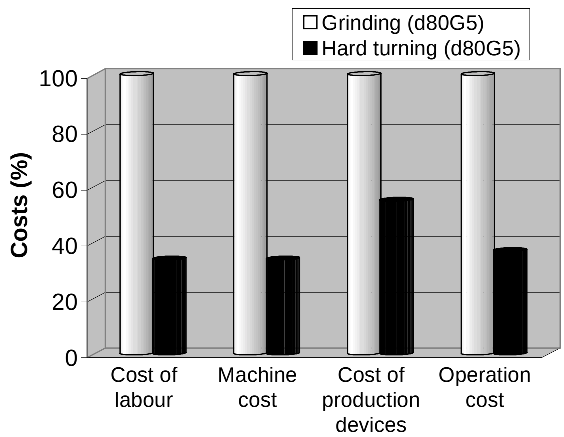


Fig. 14. Comparison of data of time (%) for grinding and hard turning in machining of gear`s bore

4.2. Economical aspects

What mainly influences the economy of machining is how much time a given allowance can be removed.

In machining of bore it can be determined from comparison of the machining time (lot size: 200) that in the experimental range every time value is much less in hard turning. When investigating a series consisting of 225 pieces the preparation time is 13% of grinding, the piece time is 65% while the standard time is 55% of that (Fig. 13). According to this the standard time can also reduce significantly (Fig. 14).

The machining of bore is economical with hard turning because of the factors limiting productivity of grinding (limited wheel diameter, cutting speed, contact length, rigidity, chip cross section). Moreover when applying hard turning the number of the operations can also be reduced remarkably which is a cost reducing factor, too (Fig. 15).

Thus hard turning is recommended for cutting of surfaces of hardened steels, mainly for machining of their bore.

4.3. Ecological aspects

The point of view of election of the operations applied till now (accuracy, surface quality, economy etc.) is completed with the increased respect of the environment protection. In the metal machining industry the coolants help the realisation of prescribed surface quality of the workpieces and the reduction of wear intensity of the cutting tools. From this reason their application was indispensable for a long time.

The substitution with hard cutting reduces the coolant necessity to zero because it is possible to work with PcBN tool dryly. From this point of view the machining performed dryly is notable because with it we replace an operation, which is grinding, requiring a great amount of coolant.

In grinding abrasive and binder material particles peel off during machining and dressing. These particles mix with the coolant, the chip and the other filtered particles the handling and recycling of which generate several problems.

According to the experience gained in the case of the earlier example the daily damage of coolant on a grinding machine may also be 20-50 liters under continuous run and this damage of liquid must be recovered. In a dry process this coolant and its handling cost can be saved.

Thus, from the point of view of the environment protection the application of hard turning as a dry machining is recommended in every case.

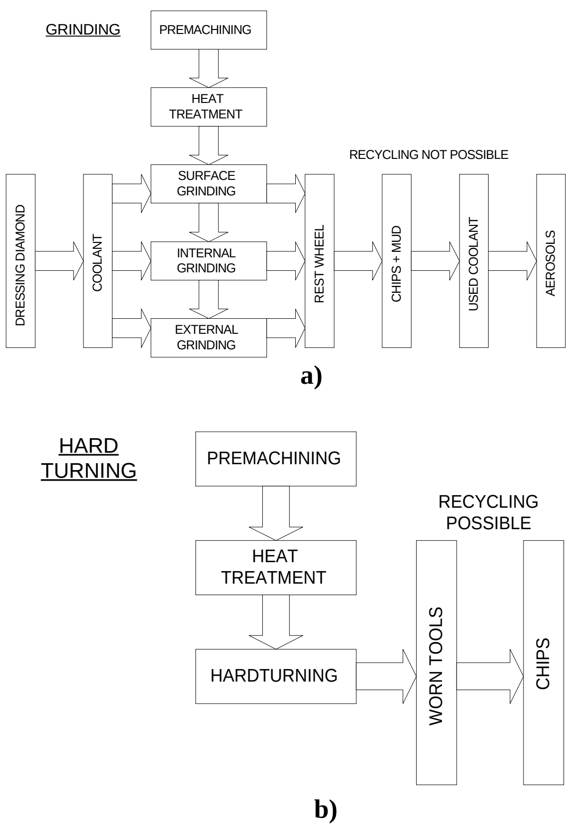


Figure 15. Comparison of procedure of part's machining for grinding (a) and hard turning (b)

5. CONCLUDING REMARKS

Comparative investigations of hard cutting and grinding of holes have proved that under the proper technological design the grinding processes can be replaced by hard cutting, under the presuppositions:

- achievement of higher material removal rate;
- achievement of lower costs and shorter manufacturing time;
- increase of accuracy to IT5 and surface roughness to Rz = 3 µm and better;
- application of environmental-friendly dry machining.

The already carried out investigations proved:

– the accuracy and surface roughness values of holes made of hardened materials, and bored by PcBN tools are the same or even better after turning than grinding,

– the volume and surface material removal rate in boring is better with hard turning than grinding, that boring in itself is economical with the machining of the surfaces and/or shapes connecting to the bore-hole the procedure becomes even more economical because it can be done with one set of tools in the operation.

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Authors: Prof. Dr. habil. Janos **KUNDRAK**, Viktoria **BANA,** MSc; Department of Production Engineering, University of Miskolc, H-3515 Miskolc-Egyetemvaros, Hungary
Phone: +36 46 565 160 & +36 46 565 233; Fax: +36 46 364 941
e-mail: ggytkj@gold.uni-miskolc.hu
ggytbana@gold.uni-miskolc.hu
Prof. Dr. Dr.h.c. P. Herbert **OSANNA**, Dr. Ali **AFJEHI-SADAT**; Department of Interchangeable Manufacturing and Industrial Metrology, Vienna University of Technology, Karlsplatz 13/3113, A-1040 Vienna, Austria; Fax: +431 58801 31196
Phone: +431 58801 31140 & +431 58801 31145
e-mail: osanna@mail.ift.tuwien.ac.at
afjehi@mail.ift.tuwien.ac.at