Manufacturing Technology I
Exercise 8

Hard Turning – Hard Roller Burnishing
1 Introduction

Steel parts which are exposed to high level of load, such as gear wheels, roller bearing rings or ball screws (Fig. 1), are frequently hardened in order to improve their wear and strength characteristics. Particularly where geometrically complex parts are concerned, impermissible form changes are likely to occur as a result of distortion due to hardening. When the workpiece is required to meet exacting quality requirements (surface quality, dimensional and form accuracy), end machining operations must therefore be conducted when the parts are in a highly tempered or hardened state.

Hard machining using a geometrically defined cutting edge has now assumed considerable importance as a result of improvements in the efficiency of modern cutting materials (Fig. 2). The high process temperatures and high levels of specific forces occurring in hard machining operations, have given rise to demands for high levels of elevated temperature hardness. This requirement is fulfilled particularly efficiently by the cutting materials compound ceramic and cubic-crystalline boron nitride (Fig. 3). The deployment of these materials permits grinding to be replaced in many cases, by hard and precision turning operations. This has advantages in terms of the increased flexibility of the machining technology. Whereas a separate profiled grinding wheel is often required for each part in grinding operations, an extensive range of contours can be produced using only one cutting edge geometry in hard turning operations. In addition to this, hard turning is considerably more environmentally friendly than grinding, since the energy requirement in turning operations is lower, chips produced in turning operations can be recycled and particularly, because there is no need to use cooling lubricant in turning operations. This saves the users of this turning technology substantial recycling costs. Savings are also made as a result of the relatively high rate of material removal (Fig. 4).

The primary objective in hard turning operations must be the production of high-quality parts. Particular consideration must be given to the levels of surface quality, dimensional and form accuracy and subsurface structure. When hard turning is unable to produce the quality required, this technology cannot stand as a real alternative to grinding. The range of different factors which influence the machining outcome
are problematic in this context. The machining parameters, material, cutting material, tool, clamping equipment and lathe are of particular importance here (Fig. 5).

The results presented in the following provide an indication as to the levels of quality which can be achieved by parts which have been hard-turned.

## 2 Levels of surface quality which can be achieved

### 2.1 Influence exerted by pre-machining operation

Before the influence exerted by cutting conditions and by tool wear on surface quality in hard turning operations is discussed, it is important to determine what influence is exerted on the machining outcome of a hard turning operation by the initial level of roughness. The influence exerted by initial roughness on the final level of roughness is noticeable (Fig. 6). There is a tendency towards increased levels of roughness after hard turning operation, which was performed on the workpiece in its original state of roughness. However, this dependence is less pronounced than the fluctuations in the outcome of the machining operation, given identical initial conditions. This is attributable to the differences in the quality of cutting edge preparation conducted on the cutting edges used /1/.

### 2.2 Influence exerted by cutting conditions

The cutting conditions in the hard turning operation affect the level of surface quality which can be achieved in two ways. The cutting edge corner radius and the feed rate in particular, have a direct effect on the surface structure. In hard turning operations, as in turning in general, the relative movement between the tool and workpiece results in a feed coil. In geometric terms, the theoretical profile of this coil is a function of feed and the cutting edge corner radius. The kinematic or theoretical peak-to-valley height is calculated using the following formula:

\[
R_{t,th} = r_c \left(1 - \sqrt{1 - \left(\frac{f}{2r_c}\right)^2}\right) = f^2 \frac{r_c^2}{8r_c}.
\]

Any increase in feed, has an adverse influence on surface quality, corresponding to the theoretical surface peak-to-valley height. The radius of the cutting edge corner, also exerts considerable influence on surface quality. The comparison between the various characteristic values for surface roughness when various cutting conditions
prevail, shows a very uniform pattern for the values $R_z$ and $R_a$ (Fig. 7). The lowest values, however, are not achieved using the largest cutting edge corner radius of $r_\epsilon = 2$ mm investigated here, but with $r_\epsilon = 1.6$ mm. This is attributable to the increasing cutting and passive forces due to the widening corner radius /2,5/. When there is a large corner radius, the positive effect of the lower kinematic peak-to-valley height is reversed as a result of the more intense oscillations caused by the increased machining forces.

In addition to this, tool wear has a very pronounced effect on the level of surface quality which can be achieved. The surface quality is adversely influenced by the development of forms of wear on the tool, which causes increasing cutting edge serration as wear progresses /2,3,4,u.a./. Whereas a surface quality, $R_z$ of below 1 mm was achieved in the example presented here, at a feed of $f = 0.05$ mm with a new cutting edge, the level of surface quality which could be achieved once the width of wear land reached $VB = 0.1$ mm, was only $R_z = 1.7$ µm (Fig. 8).

3 Chip formation and subsurface damage

The main difference between hard machining and machining operations conducted on steel materials which have not been hardened, lies in the low forming capacity of martensite. This results in other chip forming mechanisms, which are not based on the development of a shearing plane or shearing zone. This is reflected in the appearance of chips with a “saw tooth” shape. The cutting action commences with the development of a crack on the surface ahead of the cutting edge, which is propagated in the direction of the highest level of shearing strain into the workpiece. The chip segment released, is pushed out and a new crack develops. The individual chip segments fuse under the high pressure and the temperature, thus forming a continuous chip /4,7/. The “absorption” of the crack ahead of the cutting edge and the plastic deformation of the martensitic structure, is attributable to the hydrostatic state of compressive strain in the area of the cutting edge rounding /6/.

The chip forming operation described, influences the subsurface of the workpieces which are machined. Note particularly the changes in the state of residual stress and in the structural composition (Fig. 9). These changes depend mainly on the level of wear sustained by the cutting edge and are accompanied by a considerable increase in passive forces /3,8/. This is attributable to the fact that Hertzian stress comparable
to the mechanical load to which the workpiece is exposed, occurs when there is contact between the tool flank and the surface of the workpiece. This causes residual compressive strain in the workpiece subsurface. As tool wear increases, the residual compressive strain is combined with residual tensile stresses. These develop due to the thermal load which arises as a result of the friction at the flank and of forming processes in the material. The micro-hardness is also influenced. Initially, it diminishes deeper in the material and then increases again as from a material depth of approx. 5 µm. The maximum value and the depth position depend on the state of wear of the cutting edge. The maximum hardness is always higher than the hardness of the primary structure.

The high temperatures which develop when hard machining operations are performed using a worn cutting edge, are also responsible for structural transformations and for the occurrence of the so-called “white layers”.

Hard-turned surfaces are coated with an amorphous layer which is a few nanometres thick. However, this is not the so-called “white subsurface layer”, which is too small in an etched structural section, to be detected at the magnification generally produced by the light-optical microscope: It is an oxide layer consisting of $\alpha$-Fe$_2$O$_3$ /9/. During the machining operation, the iron apparently reacts with the atmospheric oxygen as a result of the high temperatures. As a result, the development of a crystalline structure is prevented by the high reaction rates.

The nano-crystalline area lies below the amorphous layer. At this depth, there is a random distribution of crystallites with a grain size is below 0.1 µm. This is the area whose resolution cannot be further increased in the etched structural section under the light-optical microscope and which therefore appears as a white layer.

Analytical investigations conducted on this white layer in TEM mode, indicate that the structure consists of approximately equal proportions of martensite and austenite /10/. Martensitic and austenitic structural constituents are also detected in the “white subsurface layer” of case-hardened 17CrNiMo6 /11/.

Although the “white layer” is clearly distinguishable from the primary structure in the slightly etched structural section, no clear phase boundary between the two areas is detected by the TEM analysis. Instead, the “white layer” blends continuously through a tempering zone into the primary structure.
Contrary to previous fears, the structure of the “white layer” with its extremely fine grains and high proportion of austenite suggests that the structure has good forming characteristics. There are no indications from the crystallographic analysis, that the rolling strength of the hard-turned surfaces is adversely affected by the structural change. This assumption is verified by systematic service life investigations conducted in analogue testing facilities.

4 Form Integrity

4.1 Influence exerted by fluctuations in cutting force

Deviations from the geometrically ideal shape of a part after soft turning and hardening, result in fluctuations in the machining force. These fluctuations in force, have an adverse effect on the level of form integrity achieved.

The influence exerted by changes in the cutting depth, caused when a workpiece is clamped eccentrically on a magnetic chuck, was investigated on a special measuring set-up. As soon as the tool gets in contact with the workpiece, the increase in passive force results in a displacement of approx. 12 µm of the workpiece in relation to the support table (Fig. 10). The tool is pushed approx. 5 µm from its original position. This results in an overall rigidity level for the entire machine-clamping chuck-workpiece-tool system of $k_{xx} = 15 \text{ N/µm}$. In these measurements, this value includes the rigidity of the force measuring platform below the tool holder, which is of only minor importance since it is specified by the manufacturer as $k_{xx} > 1 \text{ kN/µm}$. The slight increase apparent in the measurement graphs showing the distance and the force signals, is attributable to temperature-related expansion of the workpiece.

This measurement set-up was also used to investigate the influence exerted by changing cutting depth, caused by the eccentric clamping of the workpiece on a magnetic chuck. A mean value from the two measurement signals form the laser-optical distance sensors, is shown on the right of Fig. 10 in the bottom diagram. The eccentric clamping position results in a sinusoidal signal symmetrical to the zero line prior to machining. After the entry of the cutting edge, the entire graph moves in a positive direction. However, due to the fluctuation in passive force of approx. 60 N, this shift is not constant. There is a variation in the difference between the curves at the maximum point ($\delta_1$) and in the difference at the minimum point ($\delta_2$). In the case
shown here, the difference is 3 µm. Thus the displacement behaviour under this low-frequency dynamic alternating load of approx. 7 Hz, is the same as under static load.

In terms of part quality, this displacement means that the circular form fault on the machined part, is always greater than 3 µm, since in addition to the spindle displacement, account must also be taken of other influences such as the radial deviation of the work spindle bearings.

However, deviations from the geometrically ideal shape of the finished part are caused not only by fluctuations in the radial over-dimensions. Fluctuations in over-dimensions which run along the feed path due to the differences in cutting depth, also result in displacements between the workpiece and the tool. These axial fluctuations in overdimension, are reflected in insufficient straightness of the surface line.

4.2 Influence exerted by temperature

After cutting force, the second major factor to influence the dimensional and form accuracy of the hard-turned parts, is temperature during the machining operations. As previously explained, one of the decisive advantages of hard turning over its rival technique grinding, is the option of machining without cooling lubricant. Investigations conducted into surface quality and the influence exerted on the subsurface in hard turning operations, show that the use of cooling lubricant has no effect at all – neither positive nor negative - on the outcome of the machining operation /2,11/.

However, macro-geometrically, the effect of machining entirely without cooling lubricant, is very noticeable. The thermal energy of the machining process heats both the part and the tool, resulting in form deviations.

4.2.1 Increased tool temperature

Due to the high level of thermal conductivity, the shaft of the indexable tip holder is heated only lightly when sturdy clamping is used. Additionally, when the tool is positioned parallel to the rotational axis of the workpiece, a change in the effective radial infeed caused by a change in the length of the shaft, can be prevented. In contrast, temperature measurements recorded on an indexable tip insert, show that there is a sharp increase in temperature when the cutting edge enters the workpiece. After the cutting edge is heated at the beginning of the cut, a stationary temperature field sets in, in the course of the machining operation conducted on the surface area con-
cerned. The thermo-elastic expansion of the indexable tip insert associated with the increase in temperature, causes the cutting edge to penetrate further into the workpiece as the machining operation progresses, resulting in the characteristic run-in contour on the first millimetres of the workpiece flank.

The identification of the increase in the temperature of the cutting edge as a cause of these typical form errors which occur when the cutting edge first gets in contact with the workpiece, makes it possible to specify an optimised cutting strategy for machining operations of this nature: The cutting edge is heated at an uncritical area of the workpiece, thus avoiding these surface line faults, when the chamfer is machined before the flank of the workpiece (Fig. 11). However, care must be taken to ensure that the cutting edge is actually cutting throughout the entire transition from the chamfer to the flank of the workpiece. Otherwise, even a short cooling-period is sufficient to cause form errors when the cutting edge re-enters the workpiece. A sharp reduction in feed in the first tenths of a millimetre of the feed path on the flank of the workpiece produces a similar effect to the one achieved by machining the chamfer.

The straightness of the surface lines can thus be improved considerably. Deviations in the parallelity if the surface lines caused by the increased temperature of the part, represent a further quality criterion after the machining operation.

4.2.2 Increased workpiece temperature

Without cooling, the temperature of the workpiece rises continuously throughout the machining operation, resulting in radial expansion. Consequently, the effective infeed of the tool cutting edge likewise increases over the feed path by the amount of thermal workpiece expansion. As a result, the machining operation produces a conical workpiece, whose diameter diminishes in the direction of feed (Fig. 12).

The form errors caused by increased workpiece temperature, depend largely on variation of the variables cutting depth, feed and cutting speed. When the cutting speed is increased, there is only a slight increase in form deviations. The increase in feed speed which accompanies higher levels of heat, compensates almost completely for the change in temperature. As regards feed variation, there are clear advantages to working with larger feed. Due to the increase in thermal output at the same feed speed, the influence exerted by the cutting depth on the level of form error, is even more pronounced than that of feed. The most significant correlation is the
one between form deviation and tool wear. As tool wear progresses, the amount of heat generated in the workpiece increases considerably, along with the level of form deviation /2/.

The resultant form deviations must be avoided, by ensuring that the machine travel is adapted to compensate accordingly. It is vital to take account of wear-related changes in form deviation. The example of a hard-turned roller bearing ring demonstrates the potential of the hard turning technology (Fig. 13).

5 Hard roller burnishing

The technique of hard roller burnishing can be used in order to prolong the service life of tools and thus to increase economic efficiency. The advantages of this technique over grinding or honing, for example, make it an interesting alternative as a finish machining operation for hard-turned parts. Hard roller burnishing can be integrated easily in a lathe, when surface qualities are required which would be uneconomical to produce, using only hard turning technology.

The mode of operation of hard roller burnishing and the surface improvements which can be achieved, are described in the following.

The operation of the hard roller burnishing tool, is based on the hydrostatic principle. A ceramic ball is pressed against the surface of the workpiece by a pressure medium (e.g. emulsion with 3-5% oil content). This allows the ball to swim on a pressure pad and can more virtually without friction in all directions (Fig. 14). As a result, the yield point is exceeded and the roughness tips are levelled off (Fig. 15). In addition to levelling the roughness tips, the surface topography is rounded off, which improves the percentage contact area considerably (Fig. 16, Fig. 17). The possible improvement in surface quality, depends on the initial roughness. The higher this is, the greater the percentage improvement in surface quality.

When the roughness required of the finished part is $R_a = 0.17 \, \mu m$, for example, the arithmetic average peak-to-valley height required after the hard turning operation, is only $R_a = 0.3 \, \mu m$. This level of surface quality can be achieved using even a worn cutting edge. Consequently, the tool service life is virtually trebled (Fig. 18). In addition to initial roughness, a number of other factors also influence the machining outcome. The main factor in this context, is the correlation between material and its
structural condition. The harder the part is, the lower the maximum possible levelling of roughness peaks is. The pre-machining operation and the resultant surface structure as well as any changes to the subsurface, also exert influence which must not be disregarded. Ultimately, the outcome of the finish roller burnishing operation are determined in part by the roller parameters such as roller pressure and roller feed (Fig. 19).

It is not only the improvement in surface roughness and the increase in tool life this permits, which make hard roller burnishing an attractive option. Compressive strain is also induced in the part (Fig. 20). The residual tensile stresses in the layers close to the surface, which are caused by the hard turning operation, are more than compensated for. The resultant residual compressive stresses increase the service life of functional surfaces which are exposed to rolling pressure.

To summarise, it can be stated that the adverse influences exerted by tool wear in hard turning operations, such as the deterioration in surface quality and the generation of a state of residual tensile stress, can be more than balanced out by a hard roller burnishing operation. The surface quality is improved and the associated range of variance is limited. Residual compressive strain is also induced in the part subsurface and surface hardness increases by approx. 3 HRC (Fig. 21).

6 Examples of industrial hard turning applications

It is certainly true to say that hard turning cannot replace grinding in all areas and for all parts. However, where this is possible, considerable advantages in terms of cost and time are frequently achieved as a result of this move. In an operation to machine a gear wheel made of 20MoCr4 (60 HRC), for example, it was possible to reduce the machining time to 35 % of the original grinding time. The machining cost was thus reduced to only 45 % (Fig. 22). Even more significant savings were made when precision X210CrW12 (63 HRC) section rollers were machined. In this case, the machining time was reduced by 90 % and the machining cost was reduced by 70 % in comparison with the cost when a grinding operation was conducted (Fig. 23).
Fig. 1: Parts spectrum for hard turning operations

Fig. 2: Developments in cutting materials illustrated by the example of “milling” technology
**Fig. 3:** Qualitative classification of various groups of cutting materials

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Hardness</th>
<th>Fracture Toughness</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBN-grit</td>
<td>MCD</td>
<td>PCD</td>
</tr>
<tr>
<td>PCBN</td>
<td>Composite ceramic</td>
<td>Fused corundum</td>
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<tr>
<td>Sintered corundum</td>
<td>Oxide ceramic</td>
<td>Nitride ceramic</td>
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<tr>
<td>Cermet</td>
<td>Cermet</td>
<td>Cemented carbide group K</td>
</tr>
<tr>
<td>Cemented carbide group P</td>
<td>High speed steel (HSS)</td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 4:** Hard machining: Turning or konv. grinding

<table>
<thead>
<tr>
<th>Property</th>
<th>Grinding</th>
<th>Hard Turning</th>
</tr>
</thead>
<tbody>
<tr>
<td>costs</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>removal rate</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>environmental impact</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>energy demands</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>cooling lubricant</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>chip recycling</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>flexibility</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>multilateral machining</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>contour machining</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>quality</td>
<td>+</td>
<td>?</td>
</tr>
<tr>
<td>microstructure</td>
<td>+</td>
<td>?</td>
</tr>
<tr>
<td>surface quality</td>
<td>+</td>
<td>?</td>
</tr>
<tr>
<td>accuracy to shape and size</td>
<td>+</td>
<td>?</td>
</tr>
</tbody>
</table>

Source: Koch, Helletsberger, Noichel
Fig. 5: Parameters which influence the machining outcome in hard machining operations

**Work piece holder**
- Mech. rigidity
- Therm. rigidity
- Clamp. Principle
- Clamping

**Lathe**
- Mech. rigidity
- Therm. rigidity
- Resolution
- Traverse precision

**Tool**
- Mech. rigidity
- Therm. rigidity
- Cutting edge preparation

**Part**
- Dimension and form accuracy
- Surface quality
- Funct. characteristics

**Technology**
- Machining Parameters
- Material
- Cutting strategy

**Cut. material**
- CBN-content
- Bond phase
- Grit size
- Manufacture

**Part**
- Dimension and form accuracy
- Surface quality
- Funct. characteristics

**Tool**
- Mech. rigidity
- Therm. rigidity
- Cutting edge preparation

**Lathe**
- Mech. rigidity
- Therm. rigidity
- Resolution
- Traverse precision

**Work piece holder**
- Mech. rigidity
- Therm. rigidity
- Clamp. Principle
- Clamping

**Part**
- Dimension and form accuracy
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- Funct. characteristics

**Tool**
- Mech. rigidity
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- Mech. rigidity
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**Part**
- Dimension and form accuracy
- Surface quality
- Funct. characteristics

**Tool**
- Mech. rigidity
- Therm. rigidity
- Cutting edge preparation

**Lathe**
- Mech. rigidity
- Therm. rigidity
- Resolution
- Traverse precision

- Mean roughness depth $R_z$ before hard turning

**Fig. 6:** Influence exerted on surface quality after hard turning

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**workpiece material:** 100Cr6 (62 HRC)
**cutting material:** PCBN + TiC-Binder
**insert-type:** CNMA 120412
**insert-holder:** Ø40 mm
**cutting speed $v_c$:** 125 m/min
**depth of cut $a_p$:** 0,15 mm
**feed $f$:** 0,08 mm
**lathe:** Weisser Frontor
**dry cut**
**Exercise Hard Turning – Hard Roller Burnishing**

**Table:**

<table>
<thead>
<tr>
<th>cutting speed $v_c$</th>
<th>125 m/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>depth of cut $a_p$</td>
<td>0.15 mm</td>
</tr>
<tr>
<td>workpiece material</td>
<td>100Cr6 (62 HRC)</td>
</tr>
<tr>
<td>cutting material</td>
<td>PCBN + TiC-Binder</td>
</tr>
<tr>
<td>insert-type</td>
<td>DNMA 1506</td>
</tr>
<tr>
<td>dry cut</td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 7:** Surface quality as a function of cutting conditions

**Fig. 8:** Surface quality as a function of the width of wear land
Material:
16MnCr5 E (61 HRC)
Structure: Martensite

Tool:
Cutting tip: PCBN
TiC-Bond
SP-Typ: CNMA 120412

Cutting parameters:
Cutting speed \( v_c \): 125 m/min
feed \( f \): 0,08 mm
Cutting \( a_p \): 0,25 mm
dry machining

Fig. 9: Subsurface characteristics as a function of the width of wear land

constant depth of cut
\( a_p = 0,2 \) mm

varying depth of cut
by excentric clamping of the workpiece
\( a_p = 0,17 - 0,23 \) mm

Fig. 10: Tool/Workpiece displacement as a result of fluctuations in cutting force
**Exercise Hard Turning – Hard Roller Burnishing**

**Machining outcome**

![Graph showing deviation vs. side line](image)

**Fig. 11:** Adapted machining strategy in order to avoid form errors

**Cutting parameters:**
- Cutting speed $v_c$: 180 m/min
- Feed $f$: 0.08 mm
- Cutting $a_z$: 0.15 mm
- Cutting tip: PCBN + TiC-Bond
- Tool wear VB: 0.09 mm

**Workpiece:**
- 100Cr6 (62 HRC)
- 110x80x40 (Dx Dx L)

![Graph showing deviation vs. feed path](image)

**Fig. 12:** Influence exerted by part heating on the form accuracy of the workpiece
Exercise Hard Turning – Hard Roller Burnishing

**Machining operation: Roller bearing ring**

![Hard turned inner bearing](image)

**Machining quality achieved**

<table>
<thead>
<tr>
<th></th>
<th>bore</th>
<th>face</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>circular deviation</strong></td>
<td>2,5</td>
<td>1,0</td>
</tr>
<tr>
<td><strong>straightness of surface line</strong></td>
<td>1,0</td>
<td>0,2</td>
</tr>
<tr>
<td><strong>Arithmetic Mean roughness</strong></td>
<td>0,6</td>
<td>0,2</td>
</tr>
</tbody>
</table>

Fig. 13: Machining outcomes in hard turning operations conducted on roller bearing rings

![Diagram](image)

source: ECOROLL

**Fig. 14:** Hard roller burnishing tool

![Diagram](image)
**Exercise Hard Turning – Hard Roller Burnishing**

**Workpiece material:**

- 100Cr6 (60 HRC)
- Re = 1700 N/mm²

**Cutting conditions:**

- Cutting speed \( v_c \): 120 m/min
- Feed \( f \): 0.08 mm
- Depth of cut \( a_p \): 0.20 mm

**Rolling conditions:**

- Rolling speed \( v_{gw} \): 120 m/min
- Rolling feed \( f_{gw} \): 0.06 mm
- Rolling pressure \( p_{gw} \): 400 bar

**Feed**

- \( R_a = 0.27 \mu m \)
- \( R_z = 1.50 \mu m \)

**Residual stress**

\[
\sigma_T \begin{array}{c}
\text{[N/mm²]} \\
0 \\
-800 \\
-1200 \\
-1600 \\
0 \\
200 \\
600 \\
\text{distance from surface}
\end{array}
\]

**Hardness**

- 60 HRC

**Workpiece material:**

- 100Cr6 (60 HRC)

**Residual stress**

\[
\sigma_T \begin{array}{c}
\text{[N/mm²]} \\
0 \\
-800 \\
-1200 \\
-1600 \\
0 \\
200 \\
600 \\
\text{distance from surface}
\end{array}
\]

**Residual stress**

\[
\sigma_T \begin{array}{c}
\text{[N/mm²]} \\
0 \\
-800 \\
-1200 \\
-1600 \\
0 \\
200 \\
600 \\
\text{distance from surface}
\end{array}
\]

**Hardness**

- 63 HRC

---

**Fig. 15:** Beeinflussung der Werkstückqualität durch Hartglattwalzen

**Turned:**

- \( R_{max} = 1.592 \mu m \)
- \( R_z = 1.417 \mu m \)
- \( R_a = 0.244 \mu m \)
- \( R_t = 1.592 \mu m \)

**Working conditions:**

- Cutting speed \( v_c \): 120 m/min
- Feed \( f \): 0.08 mm
- Depth of cut \( a_p \): 0.20 mm

**Rolled:**

- \( R_{max} = 0.771 \mu m \)
- \( R_z = 0.721 \mu m \)
- \( R_a = 0.125 \mu m \)
- \( R_t = 0.806 \mu m \)

**Workpiece material:**

- 100Cr6 (62 HRC)

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**Fig. 16:** Oberflächenmessschriebe hartgedrehter und hartglattgewalzter Bauteile
Fig. 17: Traganteile unterschiedlich gefertigter Oberflächen

Fig. 18: Verbesserung der Oberflächengüte durch Hartglattwalzen
Exercise Hard Turning – Hard Roller Burnishing

- **Material & heat treatment state**
  - Hardness
  - Microstructure
  - Percentage and distribution of carbides

- **Hard turning premachining**
  - Surface quality
  - Surface structure
  - Subsurface structure

- **Machining parameters in Hard roller burnishing**
  - Rolling pressure
  - Rolling feed
  - Rolling speed
  - Rolling ball diameter
  - Rolling strategy

**Fig. 19:** Factors influencing the machining outcome in hard roller burnishing operations

<table>
<thead>
<tr>
<th>Cutting conditions:</th>
<th>Rolling conditions:</th>
<th>X-ray parameters:</th>
</tr>
</thead>
<tbody>
<tr>
<td>(v_c = 140) m/min</td>
<td>(v_{gl} = 120) m/min</td>
<td>Cr-k(\alpha) ray</td>
</tr>
<tr>
<td>(f = 0,06) mm</td>
<td>(f_{gl} = 0,08) mm</td>
<td>24 mA / 35 kV</td>
</tr>
<tr>
<td>(a_p = 0,2) mm</td>
<td>(p_{gl} = 400) bar</td>
<td>211 - plain 2 (\theta = 156^\circ)</td>
</tr>
</tbody>
</table>

Fig. 20: Residual stresses in hard-turned and hard roller burnished parts
**Exercise Hard Turning – Hard Roller Burnishing**

**Hard Turning**

- Flexibility
- Dry Machining
- High Rate of Metal Removal
- Recyclable Chips

**Advantage**

**Disadvantage**

- Tool Wear with effects on
  - Surface Quality
  - Residual Stresses
  - Microstructure

**Hard Roller Burnishing**

**Hard Roller Burnishing causes**

- Improvement of Surface Quality
- Induces Residual compressive stresses
- Increase of Subsurface Hardness
- Reduces Peak-to-valley fluctuations and wear-related increase in hardness

**Manufacture of parts with constant, high quality in one clamping position**

**Fig. 21:** Combined hard turning / hard roller burnishing process

**Part:** Gear Wheel

**Material:** 20MoCr4 hardened (60 HRC)

**Machining:** Facing OD-Turning ID-Turning

**Fig. 22:** A gear wheel as an example of this application
Fig. 23: Precision profile roller as an example of this application

7 References

1. Liermann J. Hartdrehen wälzbelasteter Bauteile Dissertation RWTH Aachen 1998
3. Winands N. Hartdrehen aus der Umformwärme gehärteter Wälzlagerringe Dissertation RWTH Aachen 1996
5. Stanske C. Werkzeuge für die moderne Fertigung Reihe Kontakt und Studium, Fertigung, Bd. 370, 1993
8. Goldstein M. Optimierung der Fertigungsfolge Kaltfließpressen-Spanen durch Hartdrehen als Feinbearbeitungsverfahren für einsatzgehärtete Preßteile
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<th>No.</th>
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<th>Title</th>
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</thead>
</table>
| 9   | Klaar H.-J.| Persönliche Mitteilungen
Gemeinschaftslabor für Elektronenmikroskopie der RWTH Aachen 1997 |
| 10  | Klaar H.-J.| Transmissionselektronenmikroskopie
Informationsschrift des Gemeinschaftslabors für Elektronenmikroskopie der RWTH Aachen |
| 11  | Brandt D.  | Randzonenbeeinflussung beim Hartdrehen
Dissertation Universität Hannover, 1995                                                   |
Questions:

1. To which technology combination is hard turning followed by hard roller burnishing an alternative? List 4 advantages of hard turning with subsequent roller burnishing over the technology combination it can replace.

2. What requirements must be met by the hard turning technology in terms of the characteristics listed? Please give reasons for your answers.

   low high insignificant

   a) Surface quality
   b) Material removal
   c) Subsurface damage
   d) Dimensional and form accuracy

3. Please calculate the theoretical peak-to-valley height in hard turning exactly and as a rough estimate for a cutting speed of $v_c = 140 \text{ m/min}$, a feed of $f = 0.06 \text{ mm}$, a cutting depth of $a_p = 0.15 \text{ mm}$ and a corner radius of $r_e = 12 \text{ mm}$ (State all formulae used).

4. How do any deviations between the peak-to-valley height calculated and the peak-to-valley height measured after the hard turning operation occur?

5. What characteristic chip shape is produced in hard machining operations? Explain why this is the case.

6. When is the “white subsurface layer” most likely to occur in hard machining operations conducted using a geometrically defined cutting edge. What are its structural constituents?

7. How can form deviations caused by increased cutting edge temperature be avoided on form elements which are relevant to the function of the part?

8. How does the state of residual stress in the subsurface of hard turned parts change in dependence on tool wear?

9. How can form deviations caused by an increase in the temperature of the workpiece be avoided?
10. List 3 advantages in terms of workpiece quality, which can be achieved by conducting a hard roller burnishing operation after hard turning.

11. Describe how the hard roller burnishing tool works.

12. Why are the roughness peaks levelled off in hard roller burnishing operations even when the machining forces are low?