Manufacturing Technology I

Exercise 10

Preparing grinding wheels for use
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1 Introduction

The range of requirements to be met by different grinding techniques and processes used in industry, is enormous. It extends from micro-finishing operations which must meet extremely exacting requirements in terms of surface roughness, forma and dimensional precision, to high-performance and abrasive cutting processes, in which the focus is on minimum manufacturing time. In addition to the machine characteristics and the choice of suitable machine variables and cooling lubricant condition, the use of the most appropriate tool is particularly important. Thorough knowledge of the characteristics of the components and of the resultant overall characteristics are essential, when it is important to select the most appropriate grinding wheel for each machining task which arises. The high number of influencing factors and their interaction with one another, make the design of a grinding process, a very complex operation. Yet the ability to select the “right” tool, i.e. the grinding wheel, is vital. It is impossible to predict the suitability or the process characteristics of a newly specified grinding wheel for a certain grinding task with certainty. However, some points of relevance in relation to the type of grit, grit size, hardness and structure are explained in the following and can be used to specify the grinding wheel characteristics.

The condition of grinding tools on delivery or after a longer period of use, is generally either not yet or no longer “fit for use”. Grinding wheels have macro-geometric faults (e.g. circularity faults, waviness, loss of profile) which result in malfunctions in the machining process or to a lack of dimensional accuracy in the parts which are machined. Micro-wear, i.e. when the grit cutting edges become blunt, manifests itself in an increase in grinding forces and in the level of grinding power required. Additionally, there is a danger of structural damage in the workpiece subsurface. The aim in preparing wheels for use (c.f. Fig. 1), is to ensure that the grinding wheel is capable of meeting the requirements of the grinding process for which it is to be used. This preparation work is essential prior to the initial use of the grinding tool and secondly, it must be carried out repeatedly in order to ensure uniform workpiece quality throughout the duration of the process. Application-oriented grinding wheel preparation has a significant influence on the efficiency of the grinding operation.
Introduction

<table>
<thead>
<tr>
<th>Macro wear</th>
<th>Micro wear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial wear</td>
<td>Edge wear</td>
</tr>
</tbody>
</table>

Fig. 1: Reasons for preparing grinding wheels for use (König/Klocke Vol. 2, P. 199, Fig. 5-1)

2 Tools and techniques of preparing the wheel for use

The term *conditioning* is used to describe the operations performed in order to prepare grinding tools. Basically, distinctions are drawn between profiling, sharpening and cleaning grinding wheels. The *profiling operation* eliminates geometrical faults and gives the tool the required shape. The *sharpening operation* produces the required cutting properties. Finally, the *cleaning* operation removes clogging in the pore and chip spaces resulting from residual chip, grit and bond material.

When conventional grinding tools containing grit made of corundum or silicon carbide are concerned, the profiling operation produces not only the tool geometry required, but sharp cutting edges and a sufficiently large chip space at the same time. When this is the case, the terms profiling and sharpening are not used: The operation is referred to instead, as *dressing*. The tools and techniques used for profiling and dressing operations, are basically the same. Consequently, the more
common terms “dressing tool” and “dressing operation” are frequently used in the following (c.f. Fig. 2).

<table>
<thead>
<tr>
<th>non-rotating dressing tools</th>
<th>rotating dressing tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>single grain profiler</td>
<td>profile roller</td>
</tr>
<tr>
<td>dressing plate</td>
<td>form roller</td>
</tr>
<tr>
<td>multi grain profiler</td>
<td>cup wheel</td>
</tr>
</tbody>
</table>

Fig. 2: Kinematics and tools used in the most common dressing operations (König/Klocke Vol. 2, P. 201, Fig. 5-2)

The tools used to dress grinding wheels can be categorised depending on their kinematics, as

- Rotating dressing tools and
- Non-rotating dressing tools.

### 2.1 Dressing conventional grinding wheels

The dressing tools should be harder than the grinding grit material in order to guarantee a defined level of material removal from the wheel. Consequently, tools with a diamond surface are the generally used to dress conventional grinding wheels. The use of other equally hard or less hard materials is rare, since this usually results in a high level of dressing tool wear, which makes it impossible to perform a defined dressing operation on profiled grinding wheels.

Automatic dressing operations conducted on conventional grinding wheels, virtually always involve the use of diamond tools. Non-rotating tools such as:

- Single grain diamonds,
- Dressing plates and
• Multi-grain dressing tools

Have only a comparatively small diamond content. The rotating diamond tools used to dress grinding wheels are:

• Diamond profile roller,

• Diamond form roller and

• Diamond cup wheel.

Diamond cut wheels are used predominantly to dress grinding wheels used in serial manufacture. However, their area of application is limited to linear profiles. Diamond profile rollers and diamond form rollers are more suitable for dressing grinding surfaces with several profile elements.

2.2 Profiling and sharpening diamond and CBN grinding wheels

The use of diamond tools to machine diamond grinding wheels is economically efficient only in special cases. In the majority of cases, diamond grinding tools are dressed using wheels with silicon carbide grinding wheels. The principle shaping mechanism is based on the abrasive effect of the silicon carbide.

Diamond is approx. 50 % harder than CBN. This makes it possible to profile CBN grinding wheels using diamond tools.

• *Diamond grinding tools are profiled using silicon carbide.*

• *CBN-grinding wheels are profiled using diamond.*

In operations to profile CBN and diamond grinding wheels, a distinction is drawn between the profiling tools which containing diamond and those with no diamond content. Profiling operations conducted without the use of diamond grit, affect primarily the grinding wheel bond. The most well-known profiling techniques which work without diamond grit, are listed in the following:

• Profiling using SiC-grinding wheels;

• Crushing and

• Electro-chemical or removal of bond material in an electrical discharge machining operation (when metallic bonds are concerned).
Profiling operations conducted on CBN grinding wheels using diamond tools, are very important. Like the operations to dress conventional grinding wheels, a distinction is drawn between those involving stationary tools and those involving rotating tools.

The major drawback of using stationary dressing tools to prepare CBN grinding tools for use, is that only a few diamonds engage with the grinding wheel. As a result, these tools are exposed to heavy wear, which causes profiling faults in the grinding wheel surface. Stationary dressing tools are therefore very rarely used to dress CBN grinding wheels.

The tool life spans of rotating diamond tools such as the profile roller, the form roller or the cup wheel, are considerably longer. These can be used in reciprocating or plunge grinding operations, although diamond rollers used in plunge grinding are profile-bound and are used exclusively in industrial scale and mass manufacture due to their prohibitive price.

When CBN grinding wheels are profiled using tools containing diamonds, the resulting grinding surface is frequently very level. The diamonds cut CBN grit and the bond, creating a smooth wheel topography which leaves insufficient chip space for the transport of chips and cooling lubricant during the grinding process. In addition to this, the fact that the grain and the bond are cut at the same time results in high levels of compressive and thermal load due to the unfavourable contact conditions. Consequently, the diamond tool sustains high levels of wear. This wear can be reduced if the grinding wheel bond is pushed back during the profiling operation.

The action of pushing back the bond, is known as sharpening. The grinding wheel bond is worn, producing the chip space required. Since the basic principle of the majority of sharpening operations is based on the abrasive removal of the bond material, corundum and silicon carbide are generally used in sharpening operations. Block sharpening operations, in which a sharpening block is fed radially to the grinding wheel, is the most widely used sharpening technique.

The most important process variables in block sharpening are as follows:

- Peripheral grinding wheel speed;
- Worn sharpening block volume and
• Plunge cutting speed of the sharpening stone.

Ceramic bonds have a porous structure. Due to the pore volume available, it is possible to dispense with the sharpening process for certain machining tasks (c.f. self sharpening effect).

### 3 Influence exerted on the grinding process by tool preparation

The topography of the grinding wheel after tool preparation, has a very significant effect on its cutting characteristics and therefore on its behaviour during the process and machining outcome. The grinding wheel surface can be adapted to suit the requirements of the operation in hand, by careful management of the preparatory operation. It is useful, for example, to generate a rough topography when high cutting forces or thermal influence is likely to affect the workpiece subsurface, when the cutting edge area is required to have a large chip chamber volume and when the requirements relating to the workpiece surface, are not excessively high.

As one of the most important quantities used to quantify the actual form of the dressing tool, the effective width $b_d$ can be determined using an image of the active profile of the dressing tool. The dressing feed is adapted to the current tool geometry via the level of dressing contact $U_d$, defined as the ratio between the active width and the dressing feed. It must remain constant to guarantee a uniform dressing outcome.

*The dressing contact ratio $U_{d_i}$ specifies how often a certain point on the grinding wheel is crossed by the dressing tool.*

The cutting edge area has a larger number of cutting edges, after a fine dressing operation with high levels of dressing contact. Since each cutting edge in engaged in frictional work which is independent of the cross-sectional area of cut, as well as cutting when chips are formed, the cutting force relative to the cross-sectional area of cut of the individual cutting edge, increases. Due to the constant total cross-sectional area of cut under identical grinding conditions, the grinding forces must therefore rise as dressing contact ratio increases.

In terms of the wear sustained by the wheel, it is not the level of the total cutting force which is decisive, but the load imposed on, and the stability of, each individual cutting edge. The radial wear sustained by a wheel which has been rough-
Influence exerted on the grinding process by tool preparation

dressed, is therefore higher despite the lower overall cutting force. The few cutting edges are exposed to greater load and become less stable with diminishing levels of dressing contact due to the deep action of the dressing tool. The progression of radial wear shown in the right hand side of Fig. 3, therefore develops as a function of the level of dressing contact.

The large number of cutting edges produced by a high level of dressing contact, has a positive effect on the average peak-to-valley height. The reason for this is that the thickness of the undeformed, comma-shaped chip is reduced by the larger number of active cutting edges under otherwise constant conditions.

The typical progression of the functional correlations shown in Fig. 3, indicates that there is a maximum practical dressing contact ratio. Any increase beyond this value, makes no difference to the surface quality of the workpiece, but increases the dressing time and therefore the dressing cost unnecessarily. This maximum useful level of dressing contact depends on the grinding wheel specification concerned.

When the dressing operation is conducted using a rotating diamond form roller which is not so bound to a certain grinding wheel profile, there are three factors which are largely responsible for determining the outcome of the dressing operation:

- Dressing depth of cut per dressing stroke \( a_{ed} \);
- Speed ratio \( q_d \) and
- Dressing contact ratio \( U_d \).

The grinding surface produced, becomes rougher with diminishing levels of dressing contact and increasing depth of cut in the dressing operation. This is reflected in the increased levels of roughness recorded by the workpiece after grinding.
Influence exerted on the grinding process by tool preparation

Fig. 3: Influence exerted by the dressing contact ratio on process characteristics and on the machining outcome (König/Klocke Vol. 2, P. 211, Fig. 5-8)

The grinding wheel surface can best be adapted to the requirements of the grinding process, via appropriate selection of the individual dressing parameters. This permits the grinding wheel to be prepared specifically for either the rough grinding or the finish grinding process.

Two conflicting objectives can be achieved by specifying the dressing conditions and the intervals between dressing operations:

1. Selective modification of the grinding wheel topography, in order to increase the flexibility of the individual machining operation involved (rough machining and finish machining).

2. The dressing conditions can be matched to the topography, in order to ensure that the machining outcome is identical for each workpiece in a mass production environment.
4 Examples of use and exercises

4.1 Exercise 1

The surface quality of the roller raceway must not exceed $R_z = 2 \, \mu m$. What is the minimum integral level of dressing contact required in order to meet this requirement?

Calculate the feed speed $v_{ad}$, required, when the depth of cut specified for the dressing operation, is $a_{ed} = 5 \, \mu m$. Use the following diagrams in Fig.s 4 & 5. Note the following specifications:

- Relative volume of material removal per unit of time $Q'_w = 3 \, mm^3/(mm*sec)$,
- Grinding wheel diameter $d_s = 28 \, mm$,
- Peripheral grinding wheel speed $v_S = 30 \, m/s$.

![Fig. 4: Mean peak-to-valley height as a function of $U_d$ and $Q'_w$](image)

![Fig. 5: Active dressing tool profile](image)
4.2 Exercise 2

Your task is to design a time-optimised bearing seat manufacturing operation using the circumferential plunge grinding technique for a small series of 60 parts. The peak-to-valley height of the part surface after grinding must not exceed $R_z \leq 4 \mu m$. The parameters relating to the grinding process are listed in the table below.

<table>
<thead>
<tr>
<th>Process management</th>
<th>single-stage (only rough machining)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grinding wheel</td>
<td>EK 80 Jot 7 Ke</td>
</tr>
<tr>
<td>Wheel dimensions</td>
<td>$b \times d = 70 \times 400 \text{mm}^2$</td>
</tr>
<tr>
<td>Grinding wheel speed</td>
<td>$v_s = 45 \text{m/s}$</td>
</tr>
<tr>
<td>Material</td>
<td>100 Cr 6; 63 HRC</td>
</tr>
<tr>
<td>Cooling</td>
<td>3 % Emulsion</td>
</tr>
<tr>
<td>Spec. Machining volume</td>
<td>$Q_w' = 8 \text{mm}^3/(\text{mm}\cdot\text{s})$</td>
</tr>
<tr>
<td>Diameter of the finished bearing seat $d_E$</td>
<td>79.70 mm</td>
</tr>
<tr>
<td>Diameter-related over-dimension</td>
<td>$z = 300 \mu m$</td>
</tr>
<tr>
<td>Dressing tool</td>
<td>Dressing plate</td>
</tr>
</tbody>
</table>

Since you must react very swiftly and since only 60 units are to be machined, any measures requiring time-consuming retooling or preliminary testing are out of the question. You must therefore improvise in order to achieve the required quality of $R_z \leq 4 \mu m$ by varying the dressing contact ratio with a view to optimising the time factor. You are aware from investigations recently carried out, that your dressing plate-Abrichtplatte has an effective width of $b_d = 525 \mu m$ at a dressing infeed of $a_{ed} = 20 \mu m$. It can also be assumed that this will not change within the next hundred dressing strokes.

**Task:** Use the information above and the information contained in Diagram 6, to determine the optimum dressing contact ratio when the objective is to design a time-optimised process.

**Note:**
- The dressing contact ratio can only assume the values stated in the diagram. Do not attempt to interpolate values.
Examples of use and exercises

- In addition to the purely dressing and grinding times, only the following non-productive times should be taken into account:

  1. Non-productive time for the travel path from grinding to dressing and back, 15 seconds each way.

  2. Approach and run-out dressing paths, 10 mm each.

  3. The wheel must be completely re-dressed before work commences.

  4. The grinding wheel is dressed in each case by one run of the dressing plate.

Fig. 6: Influence exerted by the relative rate of material removal on surface roughness for various levels of coverage