LMT Fette Gear Cutting Tools and Knowledge
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The visual appearance of the products may not necessarily correspond to the actual appearance in all cases or in every detail.

Bildquellen: Liebherr-Components Bilbarach GmbH, Bilbarach an der Riss; Liebherr-Verzahntechnik GmbH, Kempen; Siemens AG, Bocholt
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2 前言
Foreword

3 公司介绍
The company

4 新型切削材料——独树一帜
“速切王”
The new cutting material –
in a class of its own

5 加工圆柱齿轮、斜齿轮、
和蜗轮的滚刀
Hobs for producing straight- and
helical-tooth spur gears with involute
flanks

6 圆柱齿轮滚刀及规格说明
Notes to the descriptions and
tables for spur gear hobs

7 多切削槽滚刀（高效率滚刀）
Multiple-gash hobs

15 我们能优化你的滚削工艺
We can also optimize your
hobbing process

16 滚刀图例及规格说明
Pictograms – Description

17 滚刀询价表格
Inquiry form
Sehr geehrte Kunden und Interessenten,

The newly structured catalogue "LMT Fette Gear Cutting – Tools and Knowledge" consistently pursues the new LMT catalogue concept.

We have been producing cutting tools for gear production for decades already. We have brought innovative developments to serial production status to meet the ever increasing requirements. Today, we offer the widest tool range for gear cutting on the market to our customers. The product range includes small-module and large-module tools for roughing and finishing of gears.

This gear cutting catalog is to serve you as a product guide for the selection of the optimum tool for your application. The newly structured selection criteria, clear symbols and application recommendations will support you in this.

We have also placed great emphasis on the Technical Appendix to provide you with comprehensive information about using our tools.

We look forward to a productive cooperation

Your team for gear cutting

Dear customers and potential customers,

we have been producing cutting tools for gear production for decades already. We have brought innovative developments to serial production status to meet the ever increasing requirements. Today, we offer the widest tool range for gear cutting in the market to our customers. The product range includes small-module and large-module tools for roughing and finishing of gears.

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www.lmt-tools.com

Foreword

Sehr geehrte Kunden und Interessenten,

最新的《齿轮切削刀具和技术参数》样本，一贯地坚持了屡获公司新的样本概念。

我们生产齿轮刀具已经有百年的历程，我们持续不断地创新产品来满足始终增长的需求。今天，我们提供最大范围齿轮切削刀具给我们的客户。产品范围包括小模数和大模数的齿轮和精切刀具。

这本样本是一个产品向导为了您加工齿轮应用优化刀具的选择来服务于您。最新概念，清晰标号和应用推荐数据将支持您。

我们一直致力于将我们的技术资料提供给您，便于了解和应用我们的刀具。

我们期待着为您提供生产合作。

您的齿轮切削加工团队
德国舒尔茨金属加工技术集团整合了精密工具技术领域一应齐全的能力，所汇聚的专业知识使舒尔茨镍钢制
定并推向全世界提供刀具解决方案，所涉及的加工材料涵盖从高强度钢至复合材料等范围。

公司拥有1200多名员工和专业的合作伙伴，可向全球范围内的客户提供全面的刀具、切割材料和设备，
满足多样化的需求和非切割用途及刀具修磨和刀具管理领域的各项服务要求。

德国舒尔茨金属加工技术集团总部位于德国奥伯库什，旗下有十多家制造公司，包括舒尔茨贝林、舒尔茨菲特、
舒尔茨基宁格和舒尔茨昂思路，以及生产服务机构和全球经
营销售机构。

LMT Tools combines the competences of leading specialists in
the field of precision tool technology. This pooled expertise
enables LMT Tools to develop and deliver tool solutions
world-wide for processing materials ranging from high–strength
steel to composite materials.

More than 1,200 employees and a network of specialized
partners enable the company to offer its customers worldwide a
comprehensive range of tools, cutting materials and services for
the most diverse cutting and non–cutting applications as well as
various services in the fields of tool reconditioning and tool
management.

LMT Tools is based in Oberschoen, Germany. The company
group encompasses the manufacturing companies LMT Belin,
LMT Fette, LMT Kieninger and LMT Onsrud, production and
service facilities and a globally operating sales organization.

LMT Belin is based in Lavancia, France, and specializes on
precision tools for the machining of plastics, light metals and
composite materials. LMT Belin has been part of the Group
since 2001 and together with LMT Onsrud forms the Group’s
competence center for the machining of composites.

LMT Fette is based in Schwarnauke near Hamburg, Germany,
and is one of the world’s leading manufacturers of precision
milling tools, gear hobs, thread rolling systems and taps. LMT
Fette was a founding member of LMT when it was established in
1993 and is the Group’s a competence center for applications in
the fields of milling and thread cutting and rolling.

LMT Kieninger has established a global reputation as a
specialist manufacturer of specialized tools for challenging
machining applications. As a competence center for die and
mould making and component machining, the automobile and
automotive supplier industries are a key area.

LMT Onsrud specializes in tools for the high–speed machining
of aluminium, plastics and composite materials. LMT Onsrud
and LMT Belin together form the competence center for the
machining of composites within the Group.
新型切削材料——独树一帜“速切王”
The new cutting material – in a class of its own

速切王切削材料是为了磨刀新研发的基体材料，增加热硬度的合金元素化合物，与PM4/14粉末高速钢刀相比至少提高30％切削速度。在不降低刀具寿命情况下减少了制造时间，及遵从客户的意愿简化了装夹和易于回收利用。速切王材料配上涂层使刀具达到顶尖的性能易于实现和高可靠性。

SpeedCore is a newly developed substrate for hobs. The increased hot hardness of the intermetallic cutting material allows for cutting speeds of at least 30% higher compared with HSS-PM4/14 hobs, resulting in shorter production times without sacrificing tool live and complies with the demand of customers for easy handling and easier recycling. Combining the new SpeedCore substrate with a custom coating achieves top performance with easy implementation and high reliability.

优势:
- 提高生产率70%以上。
- 加工工艺可靠（如同粉末高速钢）
- 在旧设备上易于使用
- 重磨和涂层没有问题

Advantages
- Improved productivity of up to 70%
- Process reliability (like HSS-PM)
- Easy to implement also on older or unstable machines
- Regrinding and coating possible without problems

速切王应用见网址：www.lmt-tools.de, watched us on YouTube
SpeedCore application see www.lmt-tools.de, watched us on YouTube

www.lmt-tools.com
Hobs for producing straight- and helical-tooth spur gears with involute flanks

The fundamental geometrical concepts of a spur gear hob for generating gears with involute flanks are laid down and explained in detail in DIN 8000. According to this, the basic body of a hob is always a worm. If this worm is now provided with flutes, cutting teeth result. These become capable of cutting by being backed off or relieved.

This relieving operation is carried out on machine tools specially developed for this process; it is very time consuming and therefore also expensive. For hobs to moderate accuracy specifications, relief turning is sufficient; for stricter quality requirements the hob is relief ground.

Generally, relief turned hobs achieve quality class B approximately to DIN 3968. Relief ground hobs achieve quality classes A, AA and higher. The highest quality class in DIN 3988 is AA. For exceptionally high quality requirements it is usual to restrict the tolerances of quality class AA still further. Quality class correspondence to AAA to DIN 3988, without comment, means the restriction to 75 % of the AA tolerances for all measurable variables.

If special tolerance restrictions of the AA tolerance are required, this is also done with the AAA reference, but the individual measurable variables and the tolerance restriction are now given in % or directly in mm. E.g. quality class AAA to DIN 3988, item nos. 18 and 17 restricted to 60 % of the tolerance of AA.

The purpose of hob tolerances is to assign the tools to a quality class according to their accuracy. On the basis of the hob quality class, the expected gear quality can then be forecast.

Not all requirements aimed at a "good gear quality" in the wider sense, e.g. very quiet running or a specific addendum- and dedendum relief are achieved solely through a high cutter quality. For such needs, hobs with a defined crowning depth have proved successful. Depending on the load and the required gear performance, the suitable crowning depth can be selected from the various tables N102S, N1025/3 or N1025/5. It must be noted that the tool depth crowning is not transmitted completely to the gear. The lower the number of teeth of the gear, the less the effective convexity proportion.
### 特殊等级的滚刀公差 公差单位1/1000（微米）

<table>
<thead>
<tr>
<th>公差带</th>
<th>0.63-1</th>
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<th>1.6-2.5</th>
<th>2.5-4</th>
<th>4-6.5</th>
<th>6.3-10</th>
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</table>

| N 102 S/3   |        |        |         |       |       |        |       |       |       |
| F₉₀₀        | 12     | 14     | 16      | 18    | 20    | 25     | 32    | 40    | 50    |
| F₉₁₂        | 8      | 8      | 10      | 12    | 16    | 20     | 25    | 32    |
| F₉₁₆        | 4      | 4      | 5       | 6     | 8     | 10     | 12    | 16    |
| F₉₂₀        | 0      | 0      | 0       | 0     | 0     | 0      | 0     | 0     |
| F₉₂₅        | 12     | 14     | 16      | 18    | 20    | 25     | 32    |
| F₉₃₀        | 8      | 8      | 10      | 12    | 16    | 20     | 25    |

| N 102 S/5   |        |        |         |       |       |        |       |       |       |
| F₉₀₀        | 8      | 8      | 10      | 12    | 18    | 20     | 25    | 32    |
| F₉₁₂        | 4      | 4      | 5       | 6     | 8     | 10     | 12    | 16    |
| F₉₁₆        | 0      | 0      | 0       | 0     | 0     | 0      | 0     |
| F₉₂₀        | 0      | 0      | 0       | 0     | 0     | 0      |
| F₉₂₅        | 8      | 8      | 10      | 12    | 16    | 20     | 25    | 32    |
| F₉₃₀        | 0      | 0      | 0       | 0     | 0     | 0      |

### 可获得的齿轮质量

**Attainable gear qualities**

<table>
<thead>
<tr>
<th>单头滚刀</th>
<th>可获得的齿轮质量DIN 3962第1-8.78部分(F₉)</th>
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<tr>
<td>质量等级</td>
<td>Attainable gear qualities to DIN 3962 part 1 – 8.78 (F₉)</td>
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<tr>
<td>质量等级</td>
<td>Module ranges</td>
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<td>A</td>
<td>7</td>
</tr>
<tr>
<td>C</td>
<td>12</td>
</tr>
</tbody>
</table>

1) 低于质量等级12
Inferior to quality 12

单头滚刀的其它公差等级符合DIN3968标准。

总共有16种不同的公差类别，它们部分互相依赖，且属累积误差。

啮合区域的接触比率误差Fe作为整体误差，对于评估滚刀质量具有重要参考作用。在限制条件下，该参考值也可用来铰削齿轮面形状进行预测。

为了保证滚刀的形状，必须在每次磨刀后对前刀面的形状和位置，齿距和方向允许偏差进行检查。（序号7到序号11）

The permissible deviations for single-start hobs are laid down in DIN 3968.

There are 16 individual deviations, which are partly interdependent, and one cumulative deviation.

The contact ratio deviation Fe within an engagement area, as a collective deviation, is the most informative value when assessing hob quality. It also allows, within limits, to forecast the flank form of the gear.

To maintain hob quality, it is necessary to check the permissible deviations after each sharpening operation for form and position, pitch and direction of the cutting faces (item nos. 7 to 11).
Notes to the descriptions and size tables for spur gear hobs

Dimensions
The four main dimensions of the hobs are stated in the following sequence: cutter diameter, cutting edge length, total length and bore diameter; e.g. for module 8, cat. no. 2032; dia. 125 x 130/138 x dia. 40. Diverse measurements may become necessary due to the workpiece shape, because of the limitation of the cutter dimensions due to the measurements and performance of the hobbing machine, through the dimensions of the available cutter arbors or to achieve specific cutting parameters or machining times.

Hob materials
The standard material is the high-speed steel EMo5Co5 (1.3243).
For higher cutting speeds and feeds, high-alloy high-speed steels are used which were produced with the powder-metallurgy process. An increase in performance over PM-HSS can be achieved by the SpeedCore material. SpeedCore is made from cobalt, molybdenum and carbon-free iron. This combination enables a marked increase of the red hardness of the cutting material compared to traditional PM-HSS substrates. Carbide materials are used for high-performance milling in wet and dry machining or for skiving hobs.

Coating
A hard coating with a thickness of 2 to 3 μm increases the life of the hobs, or permits higher cutting rates. Further information on the coatings can be found on pages 134 to 136 in the technical section of the catalogue.

Basic tooth profiles
The definition and description of the various reference tooth profiles are found in the technical part of the catalogue on pages 113 to 132.

Pressure angle
The pressure angle, as also the module, is determined by the gear cutting data of the workpiece and must be taken into account when deciding on the basic hob profile.

Tip edge chamfer
To protect the tip edges against damage, they are chamfered. This tip edge chamfer can be produced during manufacture with a suitably dimensioned hob. To determine the hob reference or basic profile correctly, the complete gear cutting data are needed. The size of the tip edge chamfer depends on the number of teeth, i.e. when using the same hob for different numbers of gear teeth, the chamfer will decrease with a smaller number of teeth. For a large tooth number range, several different cutters are needed.

Information about these relationships and recommended chamfer sizes can be made available on request.
Notes to the descriptions and size tables for spur gear hobs

Profile modification
The purpose of the profile modification is to reduce or avoid the interference when the teeth roll into mesh while a gear pair is running under load. To decide on the basic profile of the hob, the complete tooth cutting data or the workpiece drawing are necessary. The size of the profile modification produced depends, similarly as with the tip edge chamfer, on the number of teeth.

Protuberance
The protuberance creates a clearance cut in the root of the tooth, so that during the next operation the grinding wheel or the rotary honing wheel does not machine the tooth root. This prevents stress peaks through grinding- or shaving processes.

The protuberance basic profiles are not standardized and are supplied on request to your requirements. If you do not have relevant experience, we can submit suggestions and if necessary prepare profile plots for your gear cutting data.

Multi-start hobs
Multi-start hobs are used to increase hobbing output. This applies particularly in the case of gears with small modules (modulus 2.5) and relatively large numbers of teeth. In the case of hobs with axially parallel flutes, the number of starts should be selected so that a lead angle of 7.5° is not exceeded. The approaching tooth flanks of the hob can otherwise be expected to produce an inferior surface quality on the gear flanks.

Lead direction
With the usual uni-directional hobbing of helical spur gears, the lead direction of the hob and the helix direction of the gear are the same; with contra-directional hobbing they are opposite. In the case of straight spur gears both right-hand- and left-hand cutters can be used. Right-hand cutters are typically used.

Topping cutters
The outside diameter of the gear is topped by the tooth root of the hob. Changes in the tooth thickness also result in changes of the tip circle and root circle diameters.

Chamfer
When hobbing helical spur gears with large diameters, the hobs cannot always be chosen long enough to cover the entire working area. To prevent excessive wear of the hob teeth in the approach area, the hob is provided with a tapered chamfer. For gears with as well, double-helical teeth, hobs with chamfer may be necessary as well, if the distance between the two tooth rows is relatively small.
Depending on whether hobbing is by the climb or conventional method, the chamfer – generally 5 to 6 x module long and 5° to 10° angle of inclination – is situated on the entering- or leaving end of the cutter.

**Rake**

Unless otherwise agreed, hobs have a rake of 0°. This does not apply to heavy duty roughing hobs, which have a rake of +8°, and indexable insert and skive hobs, which have a rake of -10° to -30°.

**Gashes**

A high number of gashes increases the cutting capacity of the hobs and the density of the envelope network; they do however also reduce the useful tooth length, unless the cutter diameter is increased accordingly. For solid type hobs the gashes are up to a helix angle of 6° made axially parallel, and over 6° with helix.

**DP and CP**

In English-speaking countries, diametral pitch and circular pitch are used instead of the module. It is best to convert the above values into module and to proceed with the calculated module in the usual way.

The equations for the conversion into module are:

\[
m = \frac{25.4}{DP} \quad \text{or} \quad m = \frac{25.4 \cdot CP}{3.1416}
\]
具有较多切削槽的带涂层的整体式滚刀比较适合高效率地加工直齿圆柱齿轮。整体式滚刀在性能上比其他组合式滚刀更加强劲。较多的切削槽可以更快地排除加工碎屑。使用涂层也可以相应地提高滚刀的使用寿命，而且涂层可以反复喷涂。

与传统滚刀相比，高性能滚刀应满足以下要求：

- 更长的刀具使用寿命；
- 更少的加工时间；
- 不低于传统刀具的齿轮加工质量。

这些要求是相互关联的，比如采取措施缩短加工时间可能会对刀具寿命或齿轮加工质量产生有害的影响。

仅通过提高加工环境质量便可以对滚刀进行优化。根据齿轮的形状、材料以及品质特性，刀具设计以及切削参数的设计必须满足相应的技术要求。

切削厚度
切削厚度是滚刀设计和优化过程中的一个重要标准。切削厚度为理论上切削最大允许厚度，它由滚刀刀尖切削。

在计算切削厚度时应考虑以下滚刀特性和切削参数：

- 模数
- 齿数
- 锥度角（弧度单位）
- 齿形系数因数
- 滚刀半径
- 切削深度
- 切削长度
- 径向进给量
- 切削深度

Coated solid-type hobs with a high number of gashes are ideally suited to high-performance hobbing of spur gears. The high number of gashes permits a high rate of chip removal, and the tool life is increased substantially by the coating and, where applicable, re-coating.

Compared to conventional hobs, high-performance hobs are required to have:

- A higher tool life quality and
- shorter machining times
- at least equal if not superior gear quality.

These requirements are interrelated, such that measures which for example reduce the machining time, may have a detrimental effect upon the tool life or the gear quality.

Hobs can be optimized only in consideration of the machining environment. Based upon the geometry and the material and quality characteristics of the gear in question, the hob design and cutting parameters must be matched in such a way that the requirements are broadly fulfilled.

Tip chip thickness
The tip chip thickness is an important criterion for hob design and optimization.

The tip chip thickness is the theoretical maximum chip thickness which can be removed by the tooth tips of the hob.

The following hob characteristics and cutting parameters are taken into account during calculation of the tip chip thickness:

- Module
- Number of teeth
- Helix angle
- Profile displacement
- Cutter diameter
- Number of gashes
- Number of starts
- Axial feed
- Cutting depth

学术论著：Bernd Hoffmeister 1970
Dissertation by Bernd Hoffmeister 1970
提高刀具使用寿命
增加滚刀切削槽数是影响刀具使用寿命具有决定性的积极影响的设计方法。当切削长度范围保持不变时，增加切削量是可行的。而且，可以增加刀具寿命。理想切削槽数的选择取决于切削力分析或成本核算。成本构成和加工能力的有效发挥也是重要因素。

切削厚度越小，所能承受的切削力也会减小，因而导致作用在滚刀刀刃上的切削应力降低，从而减少摩擦。因此切削厚度的减小也有助于提高刀具的使用寿命。

如果能够保持滚刀直径不变，增加切削槽数可以减少磨削加工的次数。

带有20至30个切削槽和有效刀齿长度重磨加工次数的为10次的滚刀被称为多槽刀具。

近几年的研究表明，大多数情况下多切削槽刀是最佳加工工具。

Longer tool life
A decisive constructive measure to extend the tool life is to increase the number of gashes. While the length of the cutting edge stays the same, more cutting edges will be available. This increases tool life. The optimum number of gashes can be determined by a cutting value analysis and/or a cost calculation. The cost structure and the capacity utilization of the user also play an important part.

Assuming that the hob diameter remains unchanged, however, an increase in the number of gashes reduces the number of possible regrinds.

Hobs with 20 to 30 gashes and a useful tooth length for approximately 10 regrinds are described as multi-tooth hobs.

Developments over recent years have shown that in the majority of cases, the multi-tooth hob is the most suitable tool.
A hob with a high number of gashes also generates a denser envelope network, i.e. the profile form of the gear is improved. This is particularly significant for workpieces with a small number of teeth.

In order to achieve a high tool life quality, high-performance hobs must be coated. The high degree of hardness of the coating and the reduction in friction between the chips and the cutting faces and flanks of the cutter teeth permit higher cutting speeds and feeds together with considerably longer tool life.

When the hob is sharpened, the coating is removed from the cutting faces. Pitting increases on the now uncoated cutting faces, and the tool life quality is reduced. In order to exploit the high performance potential of these hobs in full, hobs for high-performance machining must be re-coated.

The tool life quality is obviously also increased if the cutter length is extended, since the shift distance is extended equally to the cutter length.

The shift strategy has a considerable influence upon the tool life quality. The strategy for high-performance hobbing is described as coarse shifting.

The shift increment is calculated in the familiar way by dividing the available shift distance by the number of workpieces or workpiece packs which can be machined between two regrinds. On conventional hobbing machines, the standard procedure was to shift the hob through once by the shift increment calculated in this way, and then to regrind it. Practical experience has shown however that the tool life is raised considerably if the hob is shifted through several times with an increased shift increment. It is important that the starting point for the subsequent shift pass is displaced with each shift by a small distance in the direction of shifting.

Coarse shifting also enables the wear development to be observed closely and the specified wear mark width to be adhered to without difficulty, see fig. page 11.

Shorter machining times
The machining time (production time) for the hobbing process is determined on the one hand by the gear width and number of teeth, and on the other by the cutting speed, hob diameter, number of starts, and axial feed.

The gear width and the number of teeth are fixed geometric values. The cutting speed is largely dependent upon the gear material, its tensile strength and machineability.

The machining time however changes with the hob diameter. With a small hob diameter and with the cutting speed unchanged, the hob spindle and table speeds increase, and the machining time is reduced. At the same time, a reduction in hob diameter results in a reduction in the hobbing distance for axial machining.
When selecting the hob diameter, note that the number of gashes is limited by this dimension, and that a high number of gashes is required for good tool life and lower cutting forces.

The cutter diameter should therefore only be sufficiently small to enable a specified cycle time to be achieved. An unnecessarily small hob diameter impairs the tool life and gear quality.

High axial feeds and multi-start hobs reduce the machining time considerably. However, they also lead to higher tip chip thicknesses, dependent more strongly by the number of starts than by the increased axial feed.

A relatively high feed should be selected, and the number of starts kept as low as possible. This combination produces the lowest tip chip thickness. The two variables are of equal importance for calculation of the machining time, i.e., the machining time is determined by the product of the feed and the number of starts.

The number of starts always needs to be increased when the feed is restricted by the depth of the feed marks, without reaching the maximum tip chip thickness. The depth of the feed marks depends whether it is for roughing or finish-hobbing.

**Hobbing processing time**

Machining time (production time) for hobbing

\[ t_h = \frac{z_2 \cdot d_{ag} \cdot \pi \cdot (E + b + A)}{z_0 \cdot f_a \cdot v_c \cdot 100} \]

- \( t_h \) [min] = hobbing time
- \( z_2 \) = number of teeth of the gear to be machined
- \( d_{ag} \) [mm] = hobbing tip circle diameter
- \( E \) [mm] = approach length of the hob
- \( b \) [mm] = thickness of the gear to be machined
- \( A \) [mm] = distance of the hob
- \( z_0 \) = number of starts of the hob
- \( f_a \) [mm/U] = axial feed
- \( v_c \) [m/min] = cutting speed

**Depth on the feed markings**

\[ \delta_k = \left( \frac{f_a}{\cos \beta_0} \right) \cdot \sin \alpha_n \cdot 4 \cdot d_{ag} \]

- \( \delta_k \) [mm] = depth of the feed marking
- \( \beta_0 \) = helix angle
- \( \alpha_n \) = profile angle
- \( d_{ag} \) [mm] = hobbing tip circle diameter

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齿轮质量
齿轮质量的好坏主要取决于滚齿机的精度、滚刀质量、工件夹具的稳定性、工件和滚刀的原始径向和轴向跳动。

轴向进给和滚刀直径对齿轮切削深度有决定性作用。还要考虑有的滚齿机的削屑过程或磨削加工等后续精加工工艺，因此必须对齿轮切削以及进给量加以限制。

刀具头数和切屑槽数对包络切削误差有很大影响。滚刀外径，切削槽数，刀具头数，轴向进给和切削深度在计算切削厚度时都应加以考虑，它会影响切削力和齿轮的加工质量。对于质量方面，不仅必须确保滚刀质量符合DIN3968标准或针对每种滚削操作制定的类似滚刀标准；也必须检查切削厚度，进给切削和包络切削误差，从而确保以上项目在规定的限制范围之内。

小结
滚齿工艺的优化必须充分考虑整个系统，包括滚齿机、工件、滚刀、及切削参数的确定。

如果系统中的一个变量参数发生改变，那么必须从经济性和质量可靠性方面对该变量所能够影响的内容加以检查。

理想的高性能滚刀总能够满足各种类型的齿轮需求。在第34页给出的尺寸表可以作参考，在选用滚刀直径时如果选取范围过大将会加以限制，从而有助于减少成本。

Gear quality
The gear quality is determined primarily by the accuracy of the hobbing machine, the quality of the hob, stable clamping of the workpiece, and zero radial and axial runout of the workpiece and hob.

The axial feed and the diameter of the hob are decisive for the depth of the feed marks. In consideration of the gear quality produced during finish-hobbing or subsequent processes such as honing and grinding, the depth of the feed marks and therefore the feed must be limited.

The number of starts and the number of gashes influence the enveloping cut deviations. The hob diameter, number of gashes, number of starts, axial feed, and cutting depth are included in the calculation of the tip chip thicknesses, and therefore influence the cutting forces and also the quality of the gear. With regard to the quality aspects, not only the correct hob quality must be specified to DIN 3968 or comparable hob standards for each hobbing arrangement; the chip thickness, feed marks and enveloping cut deviations must also be checked to ensure that they lie within the specified limits.

Summary
Optimization of the hobbing process requires consideration of the entire system, comprising the hobbing machine, workpiece, hob, and cutting parameters.

Should one variable in this system change, the effects upon the various targets must be examined, with regard to both economical and quality aspects.

An ideal high-performance hob is always geared to the individual application. The size table shown on page 34 should therefore only be regarded as a guide by means of which the huge range of possible hob diameters can be limited and a contribution consequently made towards reduction of the costs.
We can also optimize your hobbing process

For this purpose we require a complete description of the workpiece, the hob previously used, the process parameters, and the results. A clear target must be specified for optimization.

Description of the workpiece:
- Module
- Pressure angle
- Helix angle
- Number of teeth
- Tip circle diameter
- Tooth height or root circle diameter
- Profile displacement factor or standards for setting the tooth thickness
- Width of the gear
- Material and tensile strength
- Number of workpieces to be machined; lot size, if applicable

Description of the hob employed:
- Hob diameter
- Cutting edge length
- Number of gashes
- Number of starts
- Cutting material
- Coated/uncoated
- Coating with hob in new condition, reground with or without re-coating

Description of the process parameters:
- Cutting speed
- Feed
- Shift increment
- Number of workpieces clamped in the pack
- Single-cut/multiple-cut process
- Climb or conventional hobbing

Description of the results:
- Tool life quality per regrind
- Length of the wear mark on the hob
- Machining time per workpiece or workpiece pack

In the event of quality problems:
- Quality attained on the workpiece

Formulation of the optimization objectives:
Possible targets may include:
- Shorter machining times
- Superior tool life quality
- Superior gear quality

When defining the gearing targets, it has to be considered that, for example, the objective "improvement of the gear quality", influence the machining time and gear generation costs. The objective must therefore always be supplemented by a qualitative and quantitative specification of the remaining process results.

Limit values imposed by the machine must be specified, such as:
- Max. cutter diameter
- Max. cutter length
- Max. cutter spindle and table speed
- Max. shift distance
Hobs with protuberance for involute gear forms

- Keyway
- Pressure angle 20°
- Single-start right-handed
- Single-start left-handed
- Relief ground
- Cobalt alloyed high speed steel
- SpeedCore
- High speed steel PM
- Coatings
- Standard
- Special BP
Hobs for gears and external splines

Company: LMT Fette-Ident-No.: LMT Fette-Workpiece drawing No.: Tool drawing No.:

Tool data:

- Tool grade: AAA
- Quality grade: AA
- Standard: DIN 3968
- Tolerance: N 132
- Non-standard tolerance: Non-standard tolerance:

- Number of starts: 2
- Right direction:

- Outside diameter (D4):
- Cutting depth (h4):
- Overall length (l4):

- Bore diameter (D2):
- Number of gashes:

- Chip breaker:

- Number of teeth:
- Pressure angle:

- Helix angle:
- Tip circle diameter:
- Root circle diameter:
- Effective tip circle dia.:
- Effective root circle dia.:

- Radial amount of the tip chamfer:

- Stock per flank:

- Number of teeth for checking:

- Tooth width:
- Finished:
- Half finished:
- Milled:

- Ball dia./pin dia.:

- Diameter between balls:

- Diameter between pins:

- Addendum at p/2:

- Depth of tooth (h4):

- Tip radius (r4):

- Root radius (r3):

- Depth of cut (f):

- Protrusion amount:

- Profile angle semi toppling flanck:
WALZ-FRÄSER
FÜR STIRNRÄDER
HSS/SPEEDCORE
HOBS FOR SPUR GEARS
HSS/SPEEDCORE

采用高速钢和速切王材料的齿轮滚刀
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9) 需要时选择 on request
涂层备选 Coatings on request

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### Hobs for involute gear forms

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*需货时选配
on request*
重型粗滚刀

Heavy duty roughing hobs

粗滚刀具有很高的切削能力，它能满足粗加工齿轮m6以上及数数和大的齿轮宽度的需要。

它的高切削能力是通过滚刀切削刃特殊的几形状和相对较短的刀具切削刃分配金属移除量来实现的。

由于均匀切削刃载荷，即使采用高进给和大的切屑厚度，加工也特别平稳。

这个重型粗（双切式）滚刀的设计基础是由下列几方面因素决定的：

- 在加工齿轮时，被切削的金属量可以增加2倍，因为齿高比较高，切削槽的数量对螺旋刀具而言会减少。这将增加每个刀齿的载荷。

- 大约75%金属切削部分是靠滚刀的顶部承担的，这个结果是，特别当粗切时，滚刀齿载荷和磨损能非常不均匀。因此，齿顶部的磨损决定了滚刀的寿命，而刀刃的中部及根部却磨损很少。

- 为有效和经济的滚刀必须要有很多的刀槽数，而加大滚刀的外径，顶部的刀刃数必须大于侧面及根部的刀刃数。

High cutting capacities are achieved with our heavy duty roughing hob when roughing gears from module 6 onwards with high tooth numbers and large gear widths.

These high cutting capacities are made possible by a favourable cutting edge geometry and the distribution of the metal removal capacity over a relatively large number of tool cutting faces.

Because of its even cutting edge load, this tool is particularly quiet in operation, even with maximum feeds and high chip thickness.

The design of the heavy duty roughing hob is based on the following considerations:

- The volume of metal to be removed when cutting gears increases quadratically with the module, whereas the number of gashes, because of the greater profile height, becomes smaller in the usual cutter sizes. This results in a greater load on the individual cutter teeth.

- Approximately 75% of the metal removal work takes place in the tip area of the hob teeth. This results, particularly when roughing, in an extremely uneven load and wear distribution on the hob teeth. The greater tip corner wear determines the duration of the service life, whereas the cutting edges in the tooth centre- and root area show only very little wear.

- An efficient and economical hob must therefore have a large number of gashes, without making the outside diameter of the cutter too large. The number of tip cutting faces should exceed that of the flank and root cutting edges.
菲特重载粗切滚刀很好地满足了这些需求。它有垂直交错齿，它的切削齿在第二个齿排有完整的齿高，中间齿只有1/3齿高。

这个设计原则是在可使用的直径上制造出20个刀槽。

在刀具中分布10个完整齿对于加工所需的齿形来讲足够有余。这个重载粗切滚刀因此同样可以当精切刀用。

依据质量要求，这重载粗滚刀可以是铲齿或铲磨。

粗加工时，齿顶开槽可以分割切屑片，减少滚刀切削刃的压力和磨损。

粗切滚刀可以在任何一台标准滚刀磨床上进行修磨。一旦固定，刀槽能够保持特别的槽深，滚刀前刀面有6度的前角，修磨采用加深磨的方法。

粗磨滚刀设计的原则不仅适用于基本齿轮为模数制及DP制的渐开线齿形，同样也适用于所有其它普通齿形和专用齿形。

These requirements are met perfectly by the LMT Fette heavy duty roughing hob with its vertically staggered teeth. The hob teeth only have the full profile height in every second tooth row. The intermediate teeth are limited to about 1/3 of the profile height.

This design principle makes it possible to accommodate 20 flutes on a still practicable hob diameter.

The 10 complete teeth on the hob circumference are generally sufficient for producing the profile shape within the required tolerances. The heavy duty roughing hob can therefore also be used as a finishing tool.

Depending on the quality required, the heavy duty roughing hob is available either relief turned or relief ground.

For roughing, the hob teeth can be provided with offset chip grooves, which divide the chips and reduce cutting forces and wear.

Roughing hobs can be reground on any standard hob grinder. Once set, the gash lead can be retained, independent of the gash depth. Roughing hobs are manufactured with axially parallel gashes up to lead angle of 6°, which is a condition for sharpening by the deep grinding method.

The design principle of the heavy duty roughing hob is of course not limited to the basic profiles for involute tooth systems to module or diametral pitch, but can also be used for all other common profiles and for special profiles.

切除金属量在滚刀上的分布

| 齿根部分约占 F1 = 75% |
| 全部切削范围 = 100% |
| 齿顶部分约占 F2 = 25% |

Metal removal areas on the cutter tooth:

Tooth tip corresponds to area F1 = 75%  
Tooth root corresponds to area F2 = 25%  
Tooth gash volume = 100%
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- **n** 需要时选择
  - on request
- **b)** 断屑槽要求时需选择
  - optionally
- **b)** 对于滚齿机要求的最大切削外径280mm和最大切削长度330mm
  - for hobbing machines with max. capacity = 280 mm dia. and for max. cutter length = 330 mm
### Hobs with protuberance for involute gear forms

![Diagram of hob with protuberance](image)

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1) 需要时选择  
on request

2) 对于磨削和刮削的精切滚刀  
基本轮廓:  h₉₀ = 1.4 · m， h₃₀ = 0.4 · m  
齿所占有的量: q₉₀ = 0.09 + 0.0125 · m  
凸角值:  
pr₉₀ = 0.129 + 0.200 · m bis Modul 7  
pr₃₀ = 0.181 + 0.235 · m gr88er Modul 7  
for rough hobbing prior to grinding or skive hobbing  
basic profile: h₉₀ = 1.4 · m， h₃₀ = 0.4 · m  
allowance per flank: q₉₀ = 0.09 + 0.0125 · m  
protuberance value:  
pr₉₀ = 0.129 + 0.200 · m up to module 7  
pr₃₀ = 0.181 + 0.235 · m above module 7

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<table>
<thead>
<tr>
<th>Page</th>
<th>Chinese Description</th>
<th>English Description</th>
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<tr>
<td>28</td>
<td>整体硬质合金滚刀</td>
<td>Solid carbide hobs</td>
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<tr>
<td>34</td>
<td>整体硬质合金滚刀结构尺寸表</td>
<td>Size table for solid carbide hobs</td>
</tr>
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<td>35</td>
<td>切削滚刀</td>
<td>Skiving hobs</td>
</tr>
<tr>
<td>43</td>
<td>高速切削硬质合金滚刀</td>
<td>Skiving hobs with brazed-on carbide inserts</td>
</tr>
</tbody>
</table>
Carbide hobs permit cutting speeds into the high-speed cutting (HSC) range, and significantly higher than those possible with high-speed steel hobs.

The development of suitably rated hobbing machines enables the advantages of carbide hobs to be exploited in practical use.

The combination of high-speed cutting (HSC) and dry machining presents substantial potential for rationalization.

Modern carbide hobs provide the following characteristics:

- High cutting speeds
- Short machining times
- Long tool life
- High suitability for dry machining
- Lower gear production costs
  (according to the machining task)
Carbide types

The carbide types generally used are those of the main machining groups K and P. The types present advantages and disadvantages according to their material composition (alloying elements and components) and their grain size.

Whereas K carbides, owing to the tendency of chips to bond to the uncoated substrate, can only be employed fully coated, P carbides can also be employed in uncoated form. There is therefore no need for the cutting face to be re-coated following regrinding. This reduces the maintenance costs for P carbide hobs considerably.

By contrast, fine-grain carbides have as yet only been developed for the K types. Fine-grain carbides permit very high hardness values and consequently a high resistance to wear, combined with excellent toughness.

Consequently, fully coated K substrates generally permit higher tool life qualities when compared with hobs manufactured from P carbides, which lose their cutting face coatings at the first regrind at the latest. P carbide hobs must therefore be changed more frequently.

Machining with and without coolant

The machining of steel materials generates considerable quantities of heat at the point of chip removal. If the temperatures reach excessive levels, the cutting edges of the tool are rapidly destroyed.

In order to cool the tool and at the same time to lubricate the cutting edge, cooling lubricants have in the past been applied to the contact point between the cutting edge and the material to be machined. Cooling lubricants also have the function of flushing away the chips which are produced.

Cooling lubricants, however, have considerable ecological, economic, and in many cases also technological disadvantages.

Cooling lubricants present an ecological hazard since they impact the environment in the form of oil vapour and oil mist, and can present a health hazard to humans.

Cooling lubricants are not economically justifiable, because they increase the production costs owing to the very high costs of their supply and disposal. Up to 16% of the total gear production costs can be saved by dry machining.

Furthermore, cooling lubricants may pose disadvantages for technological reasons. The use of cooling lubricants in many honing operations involving carbide cutting edges, for example, may lead to premature failure of the tool owing to stress cracking (temperature shock). For this reason, cutting speeds are limited to 250 m/min for wet machining (in comparison with 350 to 450 m/min for dry machining). The table shows the advantages and disadvantages of cooling lubricant with regard to carbide honing.
The main problem with dry machining lies in the increase in cutting temperature. Up to 80% of the heat which is generated is dissipated with the chips; provided attention has been paid to correct tool design and suitable cutting parameters are employed.

The configuration of the tool is dependent upon the data of the gear to be manufactured. A significant influencing factor is the tip chip thickness, which is derived from the cutter design (number of starts, number of gashes, diameter), the workpiece geometry (module, number of teeth, cutting depth, helix angle) and the selected feed. An important consideration is that dry machining requires observance not only of an upper limit to the tip chip thickness, but also of a minimum thickness value. The greater the chip volume, the greater the quantity of heat which an individual chip can absorb. This must be taken into account in order to ensure that during dry machining, the greater part of the machining heat is dissipated by the chips.

<table>
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<tr>
<th>齿形加工过程中使用冷却液的优点和缺点</th>
<th>优点 Advantages</th>
<th>缺点 Disadvantages</th>
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<td>机床 Machine</td>
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<td>降低机床的温度</td>
<td>需要占用更大的空间</td>
</tr>
<tr>
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<td>支持除屑装置</td>
<td>附加操作的费用支出（例如，电费等）</td>
</tr>
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<td></td>
<td>降低冷却液的温度</td>
<td>Aggregates (filters, pumps, etc.), therefore:</td>
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<td></td>
<td>支持除屑装置</td>
<td>更大的空间要求</td>
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<td></td>
<td>降低冷却液的温度</td>
<td>Additional operating expenditure (maintenance, power, etc.)</td>
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<td></td>
<td>润滑摩擦区域</td>
<td>由于裂纹的生成与切削边缘相互垂直，因而会降低</td>
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<tr>
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<td>降低摩擦区的摩擦</td>
<td>刀具的使用寿命（温度影响）</td>
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<td>降低摩擦区的摩擦</td>
<td>短的工具寿命由于热冲击</td>
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<td>清理必要的</td>
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<td>减少尺寸误差</td>
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<td>Inventory costs</td>
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<td>Contaminated chips, therefore:</td>
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<td>加热工件时间，</td>
<td>expensive recycling processes and</td>
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<tr>
<td></td>
<td>加热工件时间，</td>
<td>higher disposal costs</td>
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</table>

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高速切削（HSC）

高速切削的优点有：

- 良好的表面质量，加工时间少（取决于加工条件）
- 切削力小，其原因在于刀具的尺寸精度高，刀具使用寿命长

由于铣削与切削刀的接触时间短，所产生的热量不会迅速传递到刀具和工件上。因此刀具和工件的温度相对较低。相反，铣削温度剧烈升高，因而必须迅速移开以防止加工设备温度上升。

在应用实例中，没有采用冷却液的调整切削所导致的工作温度上升到大约50至80℃。然而，在铣削产生的位置，在某些情况下的温度会高达900℃。这一点我们可以通过发红的刀具得出结论。在以上观察的基础上，在高速加工激冷过程中采用干加工时，检验工件的微观切削可以发现其微观结构发生了变化。高速加工形成的表面的参考样品与比较可以发现其微观组织并没有发生任何变化。

我们也提到过，高速切削加工必须采用干切削方法。早在20世纪90年代文艺复兴开始了对高速加工的研究。现在的切削工艺已经能够保证在干切削条件下齿轮加工的切削速度达到350m/min以上。

实用实例和切削数据

实验证明，采用整体硬质合金刀具进行齿轮和小齿轮加工的齿轮的模数范围在m=0.5到m=4之间。刀具通常使用稳固的焊接结构用孔式或柄式安装方式加工而成。柄式往往应用于小型刀具。切削速度范围一般在150到350m/min不等，这取决于模数和加工工艺（干加工或冷却液加工）。

图表显示了具有不同抗拉强度的材料采用干加工和冷却液加工的切削速度的不同。该图表的数值适用于整体硬质合金滚刀，模数m=2。

该图表明采用干加工能够比冷却液加工时获得更高的切削速度。

High-speed cutting (HSC)

The advantages of high-speed cutting are:

- High surface quality and short machining times (depending upon the machining application)
- Low cutting forces, with resulting benefits for the dimensional accuracy of the workpiece and the tool life

Owing to the low contact time between the chip and the cutting edge, the heat which is generated does not have time to flow into the tool or the workpiece. The tool and the workpiece thus remain relatively cold. By contrast, the chips are heated very strongly and must be removed very quickly in order to prevent the machine from heating up.

In an example application, HSC machining without cooling lubricant led to the workpieces being heated to approximately 50–60 °C. At the point of chip generation, however, far higher temperatures occur which under certain circumstances may rise to approximately 900 °C as indicated by incandescent individual chips. Based upon these observations, a transverse microsection from a workpiece subjected to the dry machining process under optimum machining conditions for the HSC hobbing process was examined for possible changes to the microstructure.

The tooth flanks machined by the HSC process and the reference samples of a turned blank analysed for the purpose of comparison revealed no changes to the microstructure attributable to the machining process.

As already described, HSC machining must be considered together with dry machining. At the beginning of the 1980s the first studies were carried out on HSC gear hob. Today, this method enables reliable dry machining of gears at cutting speeds of 350 m/min and more.

Applications and cutting data

The proven applications for solid carbide tools for gear and pinion manufacture lie in a module range from m = 0.8 to m = 4. The tools are generally manufactured as stable monoblocs with bore- or shank-type mounting arrangement. The shank type is recommended for smaller tools. The cutting speeds are in the range from 150 to 350 m/min, according to the module size and process (dry or wet machining).

The diagram shows the difference in cutting speeds for dry and wet hobbing of materials with a range of tensile strengths. The values in the diagram apply to a solid carbide hob, m = 2.

Substantially higher cutting speeds can be achieved with dry hobbing than with wet hobbing.
**Wear behavior**

Flank wear is the chief form of wear occurring on carbide hobs.  

Pitting, which occurs on KHSS-E hobs, is not normally significant on carbide hobs. Chipping at the cutting edge following penetration of the carbide coating may occasionally be observed. The chips may adhere to the uncoated cutting edge of K types following penetration of the coating. The point of first penetration of the coating must therefore be delayed as long as possible.

The increase in wear is progressive from a wear mark width of approx. 0.1 mm upwards, and has a considerable influence upon the economic viability of the process. We therefore recommend that a wear mark width of 0.15 mm not be exceeded, and that the cutter be re-coated following each regrind. Chip adhesion to the worn and therefore uncoated cutting edges is much less common with the P types. Re-coating is not therefore necessary with these types.

**Maintenance**

When regrinding solid carbide hobs, ensure that the thermal stress on the tooth tip is kept to a minimum. A defined edge treatment is also recommended. Depending upon the hob design (e.g. positive or negative rake angle, width of the tooth lands), approximately 10 to 20 regrinds are possible.
The "de-coating" and "re-coating" processes are required in addition for hobs manufactured from K type carbide.

Further information on the maintenance of solid carbide hobs can be found on page 162.

### Structural dimensions

The size table indicates the hob dimensions for which LMT Fette stocks carbide blanks. The blanks do not have drive slots. A drive slot can therefore be provided on either the left-hand or the right-hand indicator hub, as desired by the customer.

LMT Fette recommends drive slots with reduced gash depth for carbide hobs. The gash dimensions can be found in the table below.

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<th>Bore diameter</th>
<th>( b_3 )</th>
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<th>( f_3 ) permissible deviation</th>
<th>( f_2 ) permissible deviation</th>
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<td>3.0</td>
<td>-0.5</td>
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\( t_3 \) = DIN 138 1/2 depth

1/2 depth to DIN 138

### Hardfaced pinion drive slot dimensions

Drive slot dimensions of a carbide hob

![Drive slot dimensions of a carbide hob](image-url)
### 推荐尺寸
**Recommended dimensions**

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<th>d₁</th>
<th>l₂</th>
<th>l₁</th>
<th>d₂</th>
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### 可能的柄部尺寸
**Possible shank dimensions**

![Diagram](attachment:image.png)
工艺及适用范围

刮削滚刀是利用刮削滚刀对粗切齿轮和淬硬齿轮进行再加工的一种加工工艺。

刮削滚刀的主要应用领域是直径和宽度尺寸较大的齿轮。此外，对外花键、螺旋形和大部分具有特殊形状的齿轮也可以使用刮削滚刀。有许多情况需要使用这种加工工艺。

齿轮精修加工

刮削滚刀可以消除齿轮的淬火变形，改善齿轮的加工质量。

刮削滚刀在切削金属能力方面比普通的磨削加工工艺要强很多。因此，在大和中等误差的情况下使用刮削滚刀代替传统的磨削加工是比较经济的。

刮削滚刀的齿轮精度可以达到DIN3962标准质量等级为6级的精度级别。

齿廓和齿面的修正，例如齿高修形，齿面修形或齿廓修形等都可以采用合适的滚刀和相关加工设备实现。

磨削的准备工作

对齿轮质量要求较高的情况下，齿轮是采用磨削加工工艺再加工的。如果在进行磨削加工之前采用刮削滚刀将齿轮的淬火变形去除，就可以大大减少加工所需的费用，同时也可以将毛坯材料刮削到磨削加工所要求的加工精度范围内。这样可以降低磨削次数，减少加工的费用，同时获得额外的磨削能力。

设计

刮削滚刀的设计特征是负前角，在刀具基面前方，沿切削进给的方向在刀刃所在的切削平面上，刀刃前角是负的。基面是平行于刀具和刀具轴线的滚刀刀刃所在的平面。

这个负前角是刀具切削刃沿与有效基面（与切削进给方向垂直的面）相交方向倾斜该方向，用这种方式产生刮削。

刀刃基面区域的负前角比刀齿根部的负前角大。刀刃基面没有有效的后角，因此不能进行常规加工。所以刮削滚刀只能进行侧面加工，而挖槽刀具只适用于齿轮的粗加工工艺。

Process and range of applications

Skiving hobbing is a machining process in which skiving hobs are used for cutting rough-milled and hardened gears.

The main area of application is the hobbing of straight and helical spur gears. In addition, external splines, roll profiles and a large number of special profiles which can be generated by the hobbing method can be machined with the skiving hob. There are various reasons for using this process.

Finish-hobbing of gears

Skive hobbing eliminates hardening distortion and improves the quality of the gear.

The metal removal capacity is considerably higher with skive hobbing than with the usual grinding processes. It is therefore economical to replace grinding by skive hobbing in the range of coarse and medium metal tolerances.

Gear quality grade 6 to DIN 3962 can be quoted as an approximate value for the attainable accuracy.

Profile- and flank modifications, too, such as depth crowning, tooth face setback or width crowning, can be produced by suitable hob profiles and corresponding machine motions.

Preparation for grinding

For high gear quality requirements, the gears are ground. The gear cutting costs can be markedly reduced if the hardening distortion is before grinding removed by skive hobbing, at the same time removing material to the necessary grinding allowance. Grinding times and costs are reduced while gaining additional grinding capacity.

Design

The characteristic design feature of skiving hobs is the negative tip rake angle. The tip rake angle is described as negative when the cutting faces of the teeth lie, in the direction of the cutting motion, in front of the tool reference plane. The tool reference plane is the plane in which lie the tip cutting edges of the axially parallel cutter and cutter axis.

Due to the negative tip rake angle, the flank cutting edges are inclined in relation to the effective reference plane (plane perpendicular to the cutting motion) and in this way produce a peeling cut.

The negative rake angle is greater in the root area of the hob teeth than in the tip area. The tip cutting edges have no effective back rake and cannot therefore generate a curling cut. It therefore follows that the skiving hobs should only produce flank chips and that protuberance cutters are used for roughing the gears.
刀具材料
小的切削厚度和锋利的齿形材料对刀具材料的刃口强度提出很高的要求。对于制作削薄刀的材料，通常选用ISO标准的K05类到K15类材料。

设计
根据模数值和要求的精度不同，削薄刀的设计通常有三种设计方案：

- 整体硬质合金
  模数小于等于4，FETTE产品号2028

- 焊接式硬质合金，模数大于4，FETTE产品号2129

- 可转位式硬质合金刀片，模数大于等于5，FETTE产品号2153

上述设计中的一种特殊刀具是采用配备了可转位硬质合金刀片的削薄刀。这种刀具不需要进行重磨加工。在加工过程中我们只需要将磨损达到最大磨损的可转位合金刀片进行更换或更换。

可以理解，使用刀体、刀座和可转位硬质合金刀片组合而成的组合刀具很难达到整体式刀具相同的加工精度。因此，这种配备可转位合金刀片的刀具特别适用于磨削预备工件的加工。

目前绝大多数的削薄刀采用孔式结构。由于加工方面的原因，整体硬质合金削薄刀刀面的一侧或两侧一般带有驱动键槽。由于质量要求较高的削薄刀，一般选用带有端面驱动槽的孔形刀具，而不选用带有轴向驱动槽的刀具。因为制造带有键槽的高空度孔比较容易，而且在磨齿机上的磨刀操作也会减少。对于精度要求非常高的情况，也可以选用杆式工具体补偿刀槽与刀具之间的跳动。

Tool material
Low chip thickness and hardened gear materials make severe demands on the edge strength of the tool material. As the tool material for skiving hobs, carbides of ISO application groups K 05 to K 15 are used.

Designs
Depending on the module size and the accuracy requirements, 3 skiving hob designs can be basically distinguished:

- Solid carbide
  up to and including module 4
  LMT Fette Cat. no. 2028

- Brazed-on carbide tips
  for modules above 4
  LMT Fette Cat. no. 2129

- Indexable carbide inserts
  for modules from 5 upwards
  LMT Fette Cat. no. 2153

A special position among the above designs is occupied by the skiving hob with indexable carbide inserts. This cutter type does not require regrinding. Only those inserts which have reached the maximum wear mark width are turned or changed.

It is understandable that a hob assembled from cutter body, tooth segments and indexable inserts cannot offer the same accuracy as a cutter in solid carbide. This is why the cutter with indexable inserts is particularly suited for preparing the workplace for grinding.

By far the most common skiving hob is the bore type. Solid carbide skiving hobs have a drive slot on one or both ends, for manufacturing reasons. For hobs with a high quality grade, preference should where possible be given to bores with drive slot over those with keyway. A precise bore can be manufactured more easily without a keyway, and the run-out of the hob on the hobbing machine is also reduced. For extreme accuracy requirements, a shank-type tool also permits compensation of the run-out between cutter arbor and cutter.
质量等级
刮削滚刀通常根据DIN3968标准的AA级质量等级制作而成。如有需要，整体硬质合金以及焊接式硬质合金也可以按照AAA质量等级标准制作（AA级允许公差的75%）。

对于齿轮四形齿面通常可使用刮削滚刀加工，能够获得较小的四形齿面。

刮削加工的准备工作
加工质量取决于齿轮的模数和淬火变形程度。经验显示，模数在2到10之间的齿差在0.15到0.30mm/齿侧而之间。

加工前，齿根必须进行预加工，并保证加工硬度，以防刮削滚刀顶刃参加工作。

我们建议使用挖模滚刀FETTE产品号2026。
刮削的齿轮硬度必须符合HRC62±2以内标准。

切削速度
切削速度取决于模数的大小和齿轮的硬度。一般情况下，模数为30的切削速度为36m/min，模数为2的切削速度为110m/min。

模数更小的情况，切削速度可以达到140m/min到160m/min。
但是切削速度过高会降低滚刀的使用寿命，也会对工件结构产生一定的影响。

整体硬质合金刮削滚刀
Solid carbide skiving hob

Quality grades
Skiving hobs are generally manufactured in quality grade AA to DIN 3968. If required, the solid carbide and brazed-on carbide tip types can also be manufactured in quality grade AAA (75% of the tolerances of AA).

A concave flank shape is usual for the skiving hob, to achieve a slight tip relief on the workpiece.

Preparation for skive hobbing
The machining allowance depends on the module size and the hardening distortion. Experience has shown that for the module range 2 to 10 it lies between 0.15 and 0.30 mm/flank.

The tooth root must be pre-machined deeply enough to prevent the tooth tip of the skiving hobs from cutting into it.

We recommend hobs protuberance, e.g. LMT Fette Cat. no. 2026.

The hardness of the gear must for the skive hobbing process be limited to HRC 62 ±2.

Cutting speed
The cutting speed depends on the module size and on the hardness of the gear. As an approximate value, a cutting speed of 36 m/min can be recommended for module 30 and of 110 m/min for module 2.

For the lower modules, higher values between 140 and 160 m/min are also possible. These high cutting speeds do however reduce the service life of the skiving hob and the workpiece structure is increasingly affected.
当工件的硬度达到或超过HRC62时，切削速度首先应该限制在70m/min左右，然后综合考虑切削效率和刀具使用寿命最终确定。

切削进给
滚刀加工表面的结构会受到进给切削深度的影响。进给切削深度随进给深度的增加而增加。因此应该区分精加工和粗加工的进给量。

进给量平均值如下：

- 精加工：1.5到2mm/工件转数
- 粗加工：4mm以上/工件转数

螺旋加工方法
一般情况下选用螺旋加工方法，因为这种加工方法有助于延长滚刀的使用寿命。

齿面修整
为了维持滚刀的使用寿命，每次精加工时每个螺旋面不应超过0.15–0.20mm。
当质量要求较高时，滚齿加工应通过多次加工完成。在进行最后一次滚齿加工时，每个螺旋的加工厚度应确保在0.1mm左右，以确保对齿轮材料的结构影响至最小。

冷却
加工过程中应使用切削油确保对加工刀具、工件、夹具和设备的充分冷却。这样可以减少因温度造成数值误差，并延长滚刀刀具的使用寿命。

For workpiece hardness values from HRC 62 upwards, the cutting speed should be limited initially to 70 m/min and then optimized in consideration of the cutting result and the service life of the tool.

Feed
The structure of surfaces machined with hobs is affected by the depth of the feed marks. The depth of the feed mark increases quadratically with the value of the feed. It is therefore logical to distinguish between feeds for finishing and for roughing.

Approximate value for the feed:

- For the finishing cut
  1.5 to 2 mm/workpiece rotation
- For the roughing cut
  up to 4 mm/workpiece rotation

Climb hobbing method
Climb hobbing for skive hobbing is preferred since this yields the best service life of the skiving hobs.

Removal per flank
To maintain a reasonable service life of the hobs, not more than 0.15 0.20 mm/flank should be removed in one cut.

For high quality requirements, hobbing must always be done in several cuts. For the last cut, a removal of 0.1 mm/flank should be aimed at, to affect the structure of the gear material as little as possible.

Cooling
Intensive cooling of the tool, workpiece, holding fixture and machine with the cutting oils usual for hobbing, the temperature-dependent error values are reduced and the service life of the skiving hobs is extended.
磨擦磨损宽度
刮削滚刀上的磨擦磨损宽度不得超过0.15mm。

随着磨擦磨损宽度的增加，以及刀刃上产生多余的摩擦，切削力也会逐渐增加。

这些情况会产生以下后果：
加工质量下降，硬质合金刀刃脱落，经过预火和再淬火处理后齿轮产生结构变形。

通过偏移轴向使磨擦保持均匀
磨擦现象仅发生在刮削滚刀的表面。磨擦标记相对疏短，并且沿着啮合线的磨擦线分布。

在完成一个啮合过程后的退火加工后，将滚刀沿轴线方向移动调整，使磨擦均匀分布于滚刀齿面和整个切削刃上。如果滚齿机上安装了同步移位装置，那么这个操作就会变得更加方便。这种移位装置还可以确保沿切线方向移动时设备工作台进行旋转操作。在对中过程中保持已设置磨削运动的相对位置。

重磨的刀具使用寿命
重磨的刀具使用寿命等于在两次重磨之间所有滚刀齿加工长度总和。

进行再磨削、刀具要求、刀具费用、计算等的计算都是依据每个滚齿重磨之间的使用寿命进行的。这取决于刀齿切削的齿数和材料硬度。例如，刮削滚刀每个滚刀齿的重磨使用寿命一般在2m到4m之间。

齿轮切削质量
切削加工时齿轮的切削质量取决于许多因素和参数之间的相互作用关系。例如：
- 刮削滚刀（切削材料，刀具是否正确，精度是否足够高）
- 刮削滚刀的刚性
- 滚刀和工件之间的夹紧和对称性
- 滚刀定位是否能保持精度和误差值
- 是否正确选择切削速度，进给速度和滚刀齿的切削厚度
- 是否符合最大磨削精度宽度要求
- 工件材料、准备和热处理的要求

Wear mark width
The wear mark width on the skiving hobs should not exceed 0.15 mm.

Cutting forces increase with greater wear mark width and with very thin chips deflection of the hob cutting edges will occur.

This may have the following consequences:
quality losses, chipping of carbide cutting edges and excessive structural changes through tempering and re-hardening processes on the gears.

Uniform wear through shifting
Wear only occurs on the tooth flanks of the skiving hobs. The wear marks are relatively short and follow the contour of the engagement lines.

By shifting the hob in the axial direction after hobbing a gear or set of gears, the wear is distributed evenly over the flank cutting edges and over the entire cutting edge length of the hob. This process is further facilitated if the hobbing machine is equipped with a synchronous shifting arrangement. This arrangement ensures that the machine table makes an additional turn when the tangential slide is moved. The relative position of the hob motion then remains as set during centering.

Tool life between regrinds
The life between regrinds of a hob equals the sum of the lengths of all hobbed workpiece teeth between two regrinds of the hob.

The calculation of the life between regrinds, the tool requirement, the proportional tool costs etc. is based on the life between regrinds per cutter tooth. This depends on the module value and on the hardness of the material being cut. Experience has shown the tool life between regrinds to lie between 2 and 4 m per cutter tooth for skive hobbing.

Gear cutting quality
The gear quality when skive hobbing depends on the interaction of a large number of components and parameters, such as:
- Skiving hob (cutting material, correctly sharpened, sufficient accuracy)
- rigid hobbing machine
- accurate and stable clamping of hob and workpiece
- Hob aligned with an absolute minimum of runout
- accurate centering
- correct selection of cutting speed, feed and metal removal per flank
- adherence to the maximum wear mark width
- material, preparation and heat treatment of the workpieces
刮削滚刀
Skiving hobs

齿圈和齿向偏差是由滚刀机造成的。

齿廓的形状基本上依赖于滚刀的质量。加工参数、工件硬度和刀具磨损情况主要影响切削力，而刀具的大小则它会作用到刀具和加工设备，从而影响加工齿轮的质量。

当加工条件良好，操作正常的情况下，齿轮的加工精度可以达到DIN3962的8级标准，齿轮表面粗糙度可达到1到2μm。

滚齿机
原则上，传统的滚齿机也可以用作削齿加工。其关键决定因素是设备的运行状况是否良好。

重要的是要保证滚刀刀杆轴向止推轴承运行良好，并使工作台和进给速度越慢越好。

很显然，现代的滚削设备配备有高刚度传动和预载液压工作台，以及用于轴向进给的滚珠式螺杆机构和预载推力轴承为齿轮加工提供很好的加工条件。用于同步偏移和自动对中的装置也是很有用的。

刮削滚刀的维护和保养
当刮削滚刀的磨损达到0.15mm时，应该对其进行修磨使其保持锋利。横向磨削或深度磨削工艺一般使用金刚石砂轮。

由于存在负前角，砂轮必须采用偏心设置。砂轮的偏移量设置依赖于刀具直径值，并在磨腻图中给出，对于每种刀具都有此值。

切削面必须磨削成非常光滑、深度很浅，以防止刀刃产生缺陷和微小裂纹。根据所使用的齿数大小，必须保证DIN3968规定的公差等级。

Pitch- and tooth trace deviations are caused by the hobbing machine.

The profile shape depends basically on the quality of the hob. The cutting parameters, the hardness of the workpieces and the wear condition of the cutters affect mainly the cutting forces, which react on tool and machine and thus contribute to the tooth quality.

Under good conditions and with careful working the gear quality grade 6 to DIN 3962 can be achieved with a surface roughness of 1 to 2 mm.

Hobbing machine
In principle, conventional hobbing machines are also suitable for skive hobbing. The decisive factor is the condition of the machine.

It is vital to keep the play in the hob spindle thrust bearing and in the table- and feed drive as low as possible.

Obviously, modern hobbing machines with dual-worm table drive or hydraulic table pre-loading, with circulating ball spindle for the axial feed and prestressed thrust bearing of the hob spindle offer better preconditions for good gear quality. Arrangements for automatic centering and for synchronous shifting are also desirable.

Maintenance of the skiving hob
The skiving hob should be sharpened when the wear mark has reached a width of 0.15 mm. Diamond wheels are used for grinding with the traverse grinding or the deep grinding process.

Because of the negative tip rake angle, the grinding wheel must be set off-centre. The measurement for the setting of the grinding wheel depends on the cutter diameter in question and is shown in the regrinding diagram, which is enclosed with every cutter.

Cutting faces must be ground with low roughness depth in order to prevent flaws and micro-chipping on the cutting edges. The tolerances of DIN 3968, insofar as they concern the gashes, must be maintained.
### Sharpening Table for Skiving Hobs with Indexable Carbide Inserts

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**Legend:**
- **L**: Tooth length at tooth tip
- **u**: Tooth offset
- **Da0**: Outside Ø
### Skiving Hobs

#### Catalog Number

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<th>Cat.-No.</th>
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1) 基本齿形 \( h_{pb} = 1.15 \cdot m, \phi_{pb} = 0.1 \cdot m \)

Basic profile \( h_{pb} = 1.15 \cdot m, \phi_{pb} = 0.1 \cdot m \)
**Skiving hobs with brazed-on carbide inserts**

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*Basic profile h₁= 1,15 · m, h₂= 0,1 · m

Basic profile h₁= 1,15 · m, h₂= 0,1 · m
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<th>48</th>
<th>高速高效的倒角</th>
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</thead>
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ChamferCut – fast and cost-efficient deburring
Following the cutting phase in gear-cutting procedures, the problem then arises of deburring the workpieces. At the moment, various different procedures are used in industry to chamfer gears, including deburring by rolling, compressing, cutting and manual reworking. These methods need separate devices and machines, making them time-consuming and expensive.

LMT Fette has developed the ChamferCut to save costs and time in the deburring process. All tools for gear cutting and deburring are mounted on one arbor. After the gear has been cut with a LMT Fette hob, the LMT Fette ChamferCut clamped on the same arbor is employed.
Two ChamferCut tools for optimum deburring.
The first ChamferCut is responsible for deburring the top side and creates a uniform chamfer. The second ChamferCut is then responsible for this same task on the lower side. The result is a chamfered gear that needs no additional machining.

The whole chamfering process with LMT Fette ChamferCut can be controlled as an option with machine software. Please contact your machine dealer. ChamferCut is patented.

<table>
<thead>
<tr>
<th>切削分析</th>
<th>Cutting analysis</th>
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<td>每个工件的切削时间 Cutting time per part</td>
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滚齿倒角的应用见：www.lmt-tools.de, 看我们youtube视频
ChamferCut application see www.lmt-tools.de, watched us on YouTube
新发明的倒角刀
可在几秒钟内高速高效去毛刺
Innovation in gear-cutting tools.
Fast, cost-efficient deburring with ChamferCut in just seconds

使用蓝豹金工FETTE滚齿—倒角刀的优点：
- 滚齿和去毛刺在一台机床上完成
- 所有刀具装在一根芯轴上
- 切削过程由机床的软件控制
- 无需后续加工或人工去毛刺
- 不需要额外的设备或刀具来完成去毛刺
- 高质量
- 高刀具寿命

蓝豹金工菲特的倒角刀优化了齿轮的生产
蓝豹金工菲特的倒角刀将为您的产品进行特殊地制造。请告诉我们你产品的参数，我们将对滚刀和倒角刀进行报价。请将询价表包括你的地址发送给我们。

Economic chamfering of gears with the LMT Fette ChamferCut
- Gear cutting and deburring on one machine
- All tools are clamped on one arbor
- Gear cutting software controls the production process
- No machine or manual reworking
- No additional machinery or tools needed for deburring
- High quality
- High tool life

LMT Fette ChamferCut for optimising the production of gears
LMT Fette ChamferCut will be manufactured according to the special requirements for your production. Please inform us of the required parameters for your product and we will prepare a quotation for the required hob and the LMT Fette ChamferCut. Please enter your details including address and send us the inquiry form.
倒角刀
ChamferCut

倒角刀的应用根据滚齿机的刀架尺寸数据确定。

工艺流程满足以下条件：
- 每一把倒角刀完成齿轮的顶部和底部加工
- 在加工齿轮时倒角刀的外径“d”可以设定与滚刀外径相同
- 倒角刀的距离“h”能被设定为0.3 x d
- 直径轴和倒角刀轴的距离“a”可以接下公式计算

\[ a = \frac{1}{2} \left( \left( \frac{d}{2} \right)^2 - h^2 \right) \]  \[ \quad \text{“d”是齿轮的根径} \]

下面被论述的条件必须被验证，是否碰撞机床的夹紧元件，机床的夹紧元件是否能按需要连结。

我们需要下面的参数来计算倒角刀
We need the following details to calculate the ChamferCut tool:

### 齿轮参数 Gear data

- 模数 Module:
- 压力角 Pressure angle:
- 根径 Root diameter:
- 每齿侧的留量 Machining allowance per flan:

### 夹紧元件 Clamping elements

- 直径 a:
- 直径 c:
- 齿轮圆周刀具编号 Ident-No. of the gear-cutting tool:

![Diagram of ChamferCut tool](image)

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Heldenerm Strasse 84 · 73447 Oberkochen
Telefon +49 7364 9579-0 · Telefax +49 7364 9579-8000
lmt.de@lmt-tools.com · www.lmt-tools.com

**LMT Fette Werkzeugtechnik GmbH & Co. KG**
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Telefon +49 415112-0 · Telefax +49 41513797
info@lmt-fette.com · www.lmt-fette.com
WALZ-FRASER

FÜR KETTENRÄDER
ZAHNRIEMENSCHNEIDEN
STECKVERZAHNUNGEN
HOPS FOR SPROCKETS
TIMING BELT PULLEYS
SPLINES

链轮、同步带轮、花键滚刀
<table>
<thead>
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<tr>
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<td>齿轮滚刀</td>
<td>Hobs for sprockets gears</td>
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<tr>
<td>53</td>
<td>直边齿廓同步带轮滚刀</td>
<td>Hobs for synchroflex timing belt pulleya</td>
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<td>54</td>
<td>渐开线齿廓同步带轮滚刀</td>
<td>Hobs for timing belt pulleys with involute flanks</td>
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<td>渐开线花键滚刀</td>
<td>Hobs for spline shafts with involute flanks</td>
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1) 要求时选择
On request
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*“se” 选取范围在20齿以内，超过20齿时等于正常选取
The "se" tooth gap form is applied up to 20 teeth incl., over 20 teeth = normal profile.

顶切刀具
Topping cutter

www.lmt-tools.com
### Hobs for timing belt pulleys with involute flanks

<table>
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- 要时选择
  - on request
- 顶切
  - Topping cutter
### Hobs for spline shafts with involute flanks

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1) 需要时选择
on request
### Hobs for Spline Shafts with Involute Flanks

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1) on request
### Hobs for Serrated Shafts with Straight Flanks for Involute Flank Form on the Component

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WERKZEUGE
FÜR SONDERPROFILE
TOOLS FOR SPECIAL PROFILES

専用歯形刀具
<table>
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| 60 | 压缩机转子滚刀  
Hobs for compressor rotors |
| 61 | 转子粗滚刀  
Hobs, for roughing, for rotors |
| 62 | 转子精滚刀  
Hobs, for finishing, for rotors |
| 63 | 螺杆泵滚刀  
Hobs for pump spindles |
| 64 | 多头螺杆、螺杆、专用铣刀  
Profile milling cutters for multiple thread worms and conveyor screws with special profiles |
| 65 | 成组齿条铣刀  
Rack tooth gang cutters |
| 66 | 专用定装滚刀  
Special and single-position hobs |
Hobs for compressor rotors

Rotors are the multi-thread feed screws of a screw compressor, which are arranged in pairs inside a housing.

The meshing screw threads have a symmetrical or an asymmetrical profile.

Quiet running and good efficiency of the rotors are determined by the accuracy of the rotor profiles.

The advantages of hobbing produce favourable results in rotor manufacture:
- High pitch accuracy
- Low distortion owing to even, constant chip removal in all gape
- Trouble-free maintenance of the hob, which is reground only on the cutting faces.

The use of this technology for rotor manufacture requires the development of the required analysis programs for rotor and hob profiles and high standards of manufacturing in the area of precision hobs.

High demands are placed on the rigidity, output, thermal stability and feed accuracy of the hobbing machines.

The successful use of hobs also depends on the degree to which the tool manufacturer on the one hand and the rotor producer or designer on the other hand communicate with each other about the production constraints imposed on profile shape, amount of "backlash" instead of "play" distribution. This process then does allow modern and economical production, when quality and output depend primarily on the tool and the machine.
转子粗滚刀

Hobs, for roughing, for rotors

Katalog-Nr. Cat.-No.

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The structural dimensions are approximate values for rotor measurements L/D = 1.65.

When ordering, workpiece drawings of the rotors and data about the profile at the face plane (list of coordinates) must be made available.

Owing to their size, not all rotors can be generated by hobbing. Furthermore, the choice of tools is also influenced by the process already in place and the machines which are available.

LMT Fette played a leading part in the introduction of the hobbing process for the manufacture of rotors. LMT Fette can therefore call upon considerable experience in advising its customers.

The advantages of the hobbing method are undisputed and can be summarized as follows:

- Quick and trouble-free production of rotors with good surfaces and accurate profiles and pitch.
- The sealing strips on the tooth tip and the sealing grooves in the tooth root of the rotors can be generated in one operation with the flanks.
- Hobbed rotors can be exchanged at any time, thanks to their uniform accuracy.
- Simple and economical maintenance of the tools, since the hobs are only sharpened on the cutting face.

www.lmt-tools.com
### Katalog-Nr.  Cat.-No.  2092

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1) 符合型 SVC DIN 3988
   narrowed in accordance with DIN 3988

2) 要求时选择
   on request

### Notes:
- The structural dimensions are approximate values for rotor measurements L/D = 1.65.
- The entire profile, including the sealing strip and slot, is machined in one operation. The outside diameter of the rotors is ground to finish size.
- When ordering, workpiece drawings of the rotors and data about the profile at the face plane (list of coordinates) must be made available.
### Drive and trailing spindles

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1) 常规服务尺寸根据DIN 3968
2) \(D\) = 外径, \(d\) = 内径
3) 需要时选择

### Notes

1. Recommended values and may be adapted to the working space of the hobbing machine both in length and in diameter.
2. When ordering, the following workpiece data must be made available: measurements about the profile at face plane, outside diameter, inside diameter, lead and direction of lead – normally drive spindle right-hand, trailing spindle left-hand.
Profile milling cutters for multiple-thread worms and conveyor screws with special profiles

In addition to the usual worm milling cutters with straight flanks, we manufacture special cutters for producing any desired screw type gears by the single indexing method. Such workpieces are, for example, screw pumps for liquids and gases, extruder worms, multi-start involute worms for drives etc.

![Image](image.png)

Fig. 1:
Workpiece: conveyor screw pair, 2-start, for a screw pump; tool: profile finishing cutter, straight teeth, relief ground.

Fig. 2:
Workpiece: drive- and trailing spindle of a liquid feed pump; tool: profile finishing cutter, staggered teeth, relief ground.

Fig. 3:
Workpiece: female rotor of a screw compressor; tool: profile roughing cutter with inserted blades, staggered teeth.

We have at our disposal universal computer programs to determine the cutter profiles for any desired form of thread.

If the cutter profiles are not yet known, we require data in accordance with fig. 4 about the screws to be cut, i.e.:
- the lead of the screw \( H \)
- the coordinates in the face plane \( r, \varnothing, \alpha_0 \) or axial plane coordinates \( r, a, \alpha_0 \)

Coordinates in the axial plane are found with the equation:
\[
s = \text{arc} \varnothing \cdot \frac{H}{2n}, \\
tan \alpha_A = \frac{\alpha_0}{2} \cdot \frac{H}{2n}
\]
Rack tooth gang cutters are used on the conventional horizontal milling machines as well as on the special automatic rack milling machines. Standardized constructional dimensions therefore do not exist. The above table is intended for guidance and should facilitate the selection of milling cutter overall dimensions. The cutter width depends on the module (m) and the number of tooth rows (n).

\[ b_3 = m \cdot \pi \cdot n \]

For larger cutter widths (over 40 mm) the helical-fluted version is preferable (3-6° RH helix). The tools can also be made in the form of tapping cutters. For gear sizes above module 5, rack gang milling cutter sets are recommended.

Unless otherwise specified, we supply with basic profile I to DIN 3972.

To process your order correctly, we need in addition to the gear data the required number of tooth rows on the cutter.
Special and single-position hobs

The hobbing process with its well-known advantages is, in addition to the standard operating- and slip gears as well as gears for belt and chain pulleys, also suitable for a large number of special profiles, of which a few examples are shown here. Hobs for particularly frequently used special profiles have been dealt with in detail in the earlier sections of this catalogue, such as the special-purpose hobs for rotors.

The term “special profiles” applies to all profile types which are not covered by a standard.

The most common types are special-purpose hobs for: ratchet wheels, feed- and conveyor wheels, conveyor rolls, card-board rolls, multi-edge profiles, slotted plates, orbit gears and cyclo gears.

The special form of certain special profiles often makes it necessary to design the cutter as a single-position hob. The profile helix is in this case not uniformly shaped over the entire length of the hob, but the cutter teeth or tooth portions have varying profile forms. These hobs have to be aligned in their axial direction with the workpiece and/or center line of the machine, to make sure that the specially shaped teeth are meshing in the intended position.

If the standardized profile allows it, single-position hobs can be designed for several positions and with a greater overall length to increase efficiency. A particular economical solution for small profile dimensions and greater cog numbers are multi-start single-position fly-cut hobs. With these cutters, the number of starts and the tooth number are identical to the number of gashes.

The question if the hobbing method is suitable for special profile shapes should be clarified in each individual case – if possible, with the help of drawings. For all gear cutting applications with a large number of workpieces with a profile shape that is repeated on the outer diameter, consult the experienced engineers of the LMT Fette development and design departments.
Examples of special profiles which can be generated by hobbing

Example of profiles which can be hobbed with single-position hobs
蜗轮滚刀的尺寸规格是由蜗轮的参数来确定的。

为了避免传动蜗杆在蜗轮中发生干涉用于加工蜗轮的滚刀在任何情况下其圆柱直径都不能小于蜗轮的模数直径。由于是锥形加工，滚刀的直径在磨削后会减小。因此，蜗轮滚刀的圆柱直径在新的状态下必须大于蜗杆的圆柱直径。这个尺寸是由模数、基圆直径和头数组成的函数决定的。

一把新的蜗轮滚刀的外径可以通过下列方法计算：

蜗杆的圆柱直径

\[ \text{蜗杆的圆柱直径} = \text{节圆直径} + \text{节圆增加量} + 2 \times \text{蜗杆齿高} + 2 \times \text{顶端间隙} \]

齿形形式

蜗轮滚刀的齿形形式是由传动蜗杆的齿形来决定的，这些不同的形式已经按DIN3975中作为标准，根据其产生方式，在ZA、ZN、ZI和ZK形蜗杆之间是有区别的。

- ZA型蜗杆在轴截面是直线齿形，这种齿形形式要求当用梯形车削刀具加工时，应把削刀刃放在轴向平面上。

- ZN型蜗杆，在法截面是直线齿形，这种齿形是当使用梯形车削刀具时，在轴向精度进行设定而完成的。它的切削刃位于与平均轴线成夹角的平面上，蜗杆齿形就是通过这种设定加工产生的。

- ZI型蜗杆在主平面上是渐开线齿形这个齿形制造如下：由铣削或磨削形成的直线，此直线与蜗杆轴线所在法平面形成的转角为压力角 “α0” 来加工产生的。

- ZK形是蜗杆在轴平面有一个凸出的面，这个蜗杆齿形的加工是由一个两边是锥度的蜗杆向下旋转，并与平均轴线方向成压力角 “α0” 蜗杆齿啮的对称线通过轴的交点，在此位置完成蜗杆的齿形。

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The specification factors of worm gear hobs are determined essentially by the worm gear data.

In order to prevent edge bearing of the driving worm in the worm gear, the hobs used for producing the worm gears must under no circumstances have a pitch cylinder diameter that is smaller than the centre circle diameter of the worm. Owing to the relief machining, the diameter of the hob is reduced by sharpening. The pitch cylinder diameters of the worm gear hob in the new condition must therefore be greater than those of the worms. This dimension is determined as a function of the module, the centre circle diameter, and the number of threads.

The outside diameter of a new worm gear hob is thus calculated as follows:

\[ \text{Centre circle diameter of the worm} = \text{Pitch circle increase} + 2 \times \text{addendum of the worm} + 2 \times \text{tip clearance} \]

Flank forms

The flank form of a worm gear hob is determined by the flank form of the driving worm. The various flank forms are standardized in DIN 3975, which distinguishes between ZA, ZN, ZI and ZK worms, according to the generating method.

- The ZA worm has a straight-line flank profile in its axial plane. This flank form is obtained when a trapezoidal turning tool is applied so that its cutting edges are in the axial plane.

- The ZN worm has a straight-line flank profile in its normal plane. This flank form is achieved when a trapezoidal turning tool set at axis height is applied so that its cutting edges lie in the plane inclined by the center lead angle and the worm profile is generated in this setting.

- The ZI worm has involute flanks in its face plane. This flank form is produced, for example, when the worm profile is generated by a straight-lined cutting or grinding element whose axis is inclined to the worm axis by the center lead angle and to the normal plane on the worm axis by the pressure angle “α0”.

- The ZK worm has a convex flank form in the axial plane. This worm form is generated when a double taper wheel trued under the pressure angle “α0” is inclined into the center lead angle, where the line of symmetry of the wheel profile passes through the intersection of the axes and generates the worm profile in this position.
Besides the standardized flank forms, there are special forms, of which the hollow flank form is the most used.

The above worm profile forms can also be used in Duplex worm drives. Duplex worms have different leads on the left- and right-hand flanks. As a result, the tooth thicknesses on the worms change continuously in the course of the lead, and an axial displacement of the worm in relation to the worm gear makes it possible to adjust the backlash.

Processes and designs
Worm gear hobs are available in a range of designs. A distinction is drawn between the following types:
Radial method
Cylindrical hobs are employed for this method. The hob enters the worm radially to full tooth depth, and can be displaced tangentially by a small distance in order to improve the enveloping cut on the flanks. This hobbing method has the shortest machining time and is generally employed for worm gear hobs with helix angles up to approximately 8°. The cutting edge length must be at least as long as the penetration length for the worm gear to be machined. Longer hobs can of course also be shifted.

Tangential method
This method is suitable for single- and multiple-start worm drives; the hobbing machine must however be equipped with a tangential hobbing head. The hobs have a relatively long taper lead section, which must remove the greater part of the metal. The cylindrical region contains one or two finishing teeth per hob start. The hob is set to the centre distance prior to the commencement of machining, and the penetration range between the hob and the worm gear must then be traversed tangentially. By selection of suitable feed values, the enveloping cuts which determine the tooth form can be modified as required. Owing to the long tangential runs, this method results in substantially longer hobbing times than the radial method.

径向滚刀
Hobs for worm gears

径向
滚刀为圆柱形。它加工的锥形时，径向全齿高切削，通过微小角度实现切向切削。这种方法与前向切削相似，可以改善齿形的包络曲线。径向切削方法具有最短的加工时间，而且可以用于加工螺旋角到8°的蜗轮。切削刃长度最少不能小于加工蜗轮所需的长度。当然较长的滚刀可以省时。

切向
切向适用于单头和多头的蜗杆传动。此时滚齿机必须配备切向滚齿刀架。滚齿刀有较长的整数长度，用以减小较多的金属材料。圆柱形部位的每个滚刀头位置保证到一个整数高度的加工滚齿。在开始加工之前，将滚刀安装在中心位置，滚刀和蜗轮的相交部分必须切向穿过。在确定了合适的进给量后，确定各牙的包络切削量可以根据要求进行修改。由于长期使用切向加工，这种加工方法会比径向加工所需要的时间更长。

用作切向滚齿加工的最简单结构的蜗轮滚刀是单头或多头的快速切削滚刀。快速切削滚刀是每个刀头只配备一个完整切削刃的滚刀。因此这种滚刀比较简单造价较低，但它切削金属的能力也相对较小。

径向滚刀
Worm gear hob for radial hobbing

双螺杆滚刀
Duplex worm gear hob

径向加工的蜗轮滚刀
Worm gear hob for tangential hobbing

Shank-type worm gear hob for radial hobbing
Shaving worms

For high-precision worm gears, shaving worms are also employed for finish profiling of rough-hobbed worm gears. Shaving worms have pitch circle enlargements of only a few tenths of a millimetre, minimum relief angles, and a high number of gashes. Of all worm gear hobs, their dimensions most closely resemble those of the driving worm, and they therefore also produce the best bearing contact patterns.

Radial Method
with constant centre distance

The use of modern CNC hobbing machines has enabled LMT Fette to develop a method which permits the use of economical tools. The worm gear hobs used in the past had to be re-adjusted each time they were reground, i.e. the bearing contact pattern had to be relocated. This entails high production costs.

In the new method, cylindrical radial hobs are employed, with flanks that are axially relief-machined. The usual tangential hobbing is thus replaced at higher helix angles (> 6°). The tool setting can be calculated as for the new condition. The setting is optimized when the tool is first used, and the tool is then used with the same centre distance and tool cutting edge angle over the entire lifespan.

By careful selection of the arrangement, a bearing contact pattern is produced which can be attained reliably by each reground according to the requirements of the worm gear.

Since the tools are radial hobs, this hob concept has the advantage of shorter hobbing times in comparison with conventional tangential hobbing.

蠕轮削制

对于高精度的蜗轮加工来说，通常选用蠕轮削制工艺是在粗糙加工后的蠕轮。蠕轮削制刀的切割精度可以达到十分之几毫米，后角也可以达到最小，并具有较多的切削槽数。所有的蠕轮滚刀，它们的尺寸形状与蜗轮滚刀基本相似，因此也能够加工出最佳的接触范围。

径向加工方法
采用固定中心距

现代CNC滚齿设备的使用使FETTE能够研究使用更为经济的刀具进行加工。过去的蜗轮滚刀在每次进行修磨后必须加以调整，例如接触关系必须进行重新定位。这就造成生产成本的增加。

新的加工方法采用了圆柱径向滚刀，这种滚刀的侧面是沿轴向铲背的。这样，当螺旋倾角较大时（大于6度）它用来替換通常使用的切向滚刀。刀具的加工参数可以根据新的加工条件进行设置。

在第一次使用时将刀具的设置进行优化，然后根据刀具的使用寿命采用相同的中心距和加工刀刃角度对刀具进行设置。在认真选择加工条件后，接触关系可以根据螺旋滚刀的要求在每次修磨后得到。

由于这种刀具属于径向滚刀类型，因此与传统的切向滚刀相比，这种滚刀有加工时间短的优点。

Contact lines on the worm gear flank

Engagement area

Engagement area

Leaders end

Leaving end

Leaving end

Axial plan

Contact lines on the worm gear flank

Engagement area

Engagement area

Leaders end

Leaving end

Leaving end

Axial plan

www.imt-tools.com
蜗轮滚刀
Hobs for worm gears

啮合区域和接触关系统方式
确定蜗轮齿形和啮合区域的基本参数包括：模数、齿数、齿形形状以及相关联的螺旋线。

现在，使用强大的个人计算机可以很精确地实现蜗轮啮合情况的复杂计算。

在实际上情况中，接触关系方式的接触面可以达到50%至70%。
FETTE公司的软件能够帮助我们的专业部门完成最佳的刀具设计方案。
因此现在可以精确地设计出具有大量参数的蜗轮滚刀。但是还必须指出，齿轮的啮合区域首先由齿轮制造商设定，刀具制造商只能缩小其尺寸。
在滚齿加工过程中接触关系方式的接触比必须大于1。从理论上讲，此时用户要求对刀具的调整问题可以由FETTE公司通过计算机进行模拟实现，从而完成相应的修正。我们的应用工程师还可以提供现场支持。

图解说明：
蜗轮滚刀在加工时可以制成带有键槽或驱动槽的孔式滚刀，也可以制成杆式滚刀。

如果滚刀的直径过小，齿廓很高，那么在加工时就应选用杆式滚刀，而侧的图示内是如何判断加工时应选用键式滚刀合适还是杆式滚刀合适。如果选用的是杆式滚刀，请按照图中所示方法提供滚齿机的类型以及滚刀加工区域的尺寸。

Engagement area and bearing contact pattern

The essential variables which determine the tooth form of the worm gear and the engagement area are as follows: module, number of teeth, profile displacement, and the associated worm. The complex computation of the engagement conditions in the worm gear can now be performed very precisely by means of powerful computers.

In practice, bearing contact patterns with a pattern contact area of 50-70% are desirable. The LMT Fette software enables our specialist department to produce the optimum tool design. Worm gear hobs with high numbers of starts can thus now be designed very accurately and reliably. It must be pointed out however that the engagement area is determined in advance by the gear manufacturer, and can only be reduced in size by the tool manufacturer. The bearing contact pattern during hobbing must be generated such that an contact ratio of > 1 is produced. Cases in which the user is presented with a tool adjustment problem can be simulated theoretically by LMT Fette on the computer. A corresponding correction can thus be made. Our applications engineers are also available for on-site assistance. Selected calculations are shown in the diagrams.

Instructions for ordering
Worm gear hobs can be manufactured as bore-type hobs with keyway or drive slot, or as shank-type hobs. Generally, preference is given to the less expensive bore-type hobs. However, if the hob diameters are very small and the profiles very high, it may be necessary to select a shank type. The diagram on the right can be used to determine whether a bore-type hob is suitable or a shank-type hob is required. If the shank version is selected, please quote the make and type of the hobbing machine and the dimensions of the working area or of the shank-type hob, as shown in the diagram.

蜗轮滚刀齿面图
Topography of the worm gear flank

导入
Leading end

离开
Leaving end

螺杆和蜗蜗面之的间隙
Distance between worm and gear flank

- ≤ 0.005 mm
- 0.005 mm bis 0.010 mm
- 0.006 mm to 0.010 mm
- 0.010 mm bis 0.015 mm
- 0.010 mm to 0.015 mm

74 www.lmt-tools.com
由于以上原因，零部件的尺寸无法实现标准化。它们的尺寸必须符合驱动螺杆的技术数据以及磨齿工艺要求。

制造滚刀时要求具有以下数据信息：
- 轴向模数
- 压力角
- 螺杆节圆直径
- 齿旋方向及头数
- DIN3975标准的齿廓(A, N, I或K)

上述数据也可以以螺杆或螺轮配纸的形式提交。

如无特别说明，滚刀可按以下标准设计：
- 轴向模数 = 1.2 x m
- 全长 = 2.4 x m
- 无滚切
- 尺形铲磨
- 垂向齿形的倒置滚刀导向角度约为8度
- 带导向槽的切向滚刀导向角大于8度

The component dimensions cannot be standardized for the reasons given above. They must be adapted to the technical data of the drive worms and to the hobbing processes.

The following information is required for manufacture of these hobs:
- Axial module
- Pressure angle
- Pitch circle diameter of the worm
- Number and direction of starts
- Flank form to DIN 3975 (A, N, I or K)

The above data can of course also be supplied in the form of worm and worm gear drawings.

Unless otherwise specified, the hobs are designed as follows:
- Addendum = 1.2 x m
- Tooth height = 2.4 x m
- Non-topping
- Tooth profile relief ground
- Cylindrical hob for radial milling up to a lead angle of approx. 8°
- Hob for tangential hobbing, with lead on the leading end, if lead angle > 8°

孔式滚刀与杆式滚刀
Bore-/shank-type hob

![Diagram of Shank dimensions and bore/shank-type hob](www.imt-tools.com)
WALZ-FRASER

MIT HARTMETALL-WENDEPLATTEN FÜR STIRNRÄDER
HOBBS WITH INDEXABLE CARBIDE INSERTS FOR SPUR GEARS
<table>
<thead>
<tr>
<th>Page</th>
<th>Description</th>
<th>English Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>78</td>
<td>可转位硬质合金滚刀</td>
<td>Hobs with carbide indexable inserts</td>
</tr>
<tr>
<td>81</td>
<td>描述</td>
<td>Versions</td>
</tr>
<tr>
<td>83</td>
<td>询价表</td>
<td>Inquiry form</td>
</tr>
<tr>
<td>84</td>
<td>粗切滚刀 预加工</td>
<td>Roughing hobs, Pre-machining</td>
</tr>
<tr>
<td>85</td>
<td>刨齿滚刀 精加工</td>
<td>Skiving hobs, Finish-machining</td>
</tr>
</tbody>
</table>

可转位硬度合金圆柱齿轮滚刀
Hobs with indexable carbide inserts for spur gears

www.lmt-tools.com
可转位硬质合金齿轮滚刀
Hobs with indexable carbide inserts

40多年以来，我们的工程师已经研发了可转位硬质合金齿轮切削刀具，过去刀片采用焊接方式，但现在通常采用可转位刀片结构设计了。这些能与切削材料很好地相匹配和专用的几何参数，这项技术的优点如下面所列出：

- 快速应用
- 快速转换切削刃
- 100％切削率稳定
- 高切削价值/高性价比
- 经济性好，可转位刀片可采用多刀切削
- 对被切削材料进行优化加工
- 硬质合金的材料，几何参数和涂层最佳组合
- 采用新的可转位硬质合金刀片改进现有的工具

接下来，蓝枫菲特公司为您提供了一个全面范围的可转位刀片刀具：

- M6-100粗切和精切，刀片类型
- M6-45粗切和精切，手动和多头滚刀
- 转子铣刀
- 特殊的解决方案

我们现代可转位硬质合金刀具技术能使得齿轮精加工达到高的精度等级，今天我们制造的可靠性高的切削时间是最重要的要求。在这方面蓝枫菲特公司的专家们将很高兴给您指引。蓝枫菲特可转位刀片系列：创新，高性能，通用和可信赖。

For over 40 years, our engineers have been developing gear cutting tools with indexable carbide insert. Cutting inserts used to be soldered, but nowadays they are usually constructed as indexable insert designs. This enables perfect matching of the cutting material and the geometry to the individual application of the tool. The benefits of this technology are characterized by the following criteria:

- Quick availability
- Quick change of the cutting edges
- 100 % reproducible quality
- Enables high cutting values/labor values
- Economic, due to indexable inserts with multiple cutting edges
- Optimization of the material to be machined
- Matching of carbide substrates, geometries and coatings
- Innovation on existing tools with new indexable carbide inserts

On the following pages, LMT Fette offers you a comprehensive range of tools with indexable inserts for:

- Segmented tooth form cutters, module 6 to 100 for roughing and finishing
- Gear hobs, single and multi-start versions, module 6 to 45 for roughing and finishing
- Rotor milling cutter
- Special solutions

Our modern indexable carbide inserts technology enables us to achieve superior accuracy classes for the finishing of gears. Process reliability and short machining times are the main criteria for the manufacturing of gears today. Find out more about LMT Fette’s know-how on the following pages. Our experts will be happy to advise you. LMT Fette Indexable Insert systems: Innovative, high-performance, universal and reliable.

### 粗加工/精加工
Roughing-/Finishing cutters

<table>
<thead>
<tr>
<th>刀具类型</th>
<th>模数</th>
<th>材质等级</th>
<th>质量等级</th>
</tr>
</thead>
<tbody>
<tr>
<td>可转位齿轮滚刀</td>
<td>6 - 70</td>
<td>Gear milling cutter with Indexable Inserts</td>
<td>Module: 6 to 70</td>
</tr>
<tr>
<td>ICI滚刀</td>
<td>6 - 45</td>
<td>Ein- und Zweigängig</td>
<td>ICI hob</td>
</tr>
<tr>
<td>Module: 6 to 45, One and two-starts</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 其他齿轮刀具的产品范围
Other gear cutting tools LMT Fette product range

- ChamferCut
- Solid hobs

其它模数可单独询价
Other modules on request.
The hobbing of gears form module 8 onwards can be carried out extremely economically with these modern tools.

The design concept is the combination of the known advantages of the hobbing process with the performance of carbide and the economy of indexable inserts. Using indexable carbide inserts, large volumes of metal can be removed within a given time at high cutting speeds.

Regrinding, which is necessary with conventional hobs, is eliminated. This saves the cost of sharpening and of tool changes. The wear marks on the individual cutter teeth vary according to the process. In the large-gear sector, these can be partly equalized by shifting. Hobs therefore always contain teeth with different wear mark widths.

When using inserts, only those inserts need to be indexed or replaced which have reached the maximum wear mark width. To change the indexable inserts or the segments, it is not necessary to remove the cutter from the machine. This results in short hobbing machine downtimes.

Changing the indexable carbide inserts also makes it possible to match the carbide grade optimally to the gear material.

To use these carbide tipped tools successfully, it is necessary to have hobbing machines which offer sufficient rigidity as well as the required speed and drive power.
Hobs with indexable carbide inserts

Construction
LMT Fette carbide indexable insert hobs consist of a cutter body, onto which the tooth segments are screwed and indexable carbide inserts. The latter are held by clamping screws in the insert seats of the segments.

A helical groove has been recessed into the cylindrical cutter body. The flanks of the groove ground according to the cutter lead. The parts of the ground cylindrical shell which remain between the groove windings act as support surfaces for the tooth segments. Cylindrical pins arranged in the tooth segments are guided in the groove and determine the position of the segments. The segments are fixed to the cutter body by inhex screws.

The seats for the indexable carbide inserts are arranged tangentially on the tooth segments. Within a segment, the seats are arranged alternately if possible. The purpose of this arrangement is to keep the axial reaction forces on the cutter and the tangential cutting force components on the gear as low as possible.

The indexable carbide inserts must completely cover the cutting edges of the cutter tooth. The necessary number of indexable inserts and their arrangement depend on the dimensions of the inserts and on the size of the gear. To render the pre-cutting of the gear optimal for skew hobbing or grinding, the carbide hobs with indexable inserts can be made so that they produce both a root clearance cut and a chamfer on the gear (see fig. below).
### Pre-machining

**Roughing with a protuberance**

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<td>Zext</td>
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### Finish-machining

**Finish-milling**

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All tool dimensions in accordance with structural dimension series.

2-thread tools available on request.
**Hobs with indexable carbide inserts**

Double-start hob – the fast solution for quality

Single-start indexable carbide inserts hobs (CI) are easy-to-use, technologically advanced and optimized. We are shifting gears for you with the double-start Indexable Hob. This innovation allows you to reduce your production and set-up times, while achieving a better surface finish and gear profile accuracy on top.

**Benefits**
- Lower machining costs
- Shorter manufacturing times, higher productivity
- Safe production
- Low set-up costs
- Low tool costs
- Long tool life
- Design with different profiles (already realized 6 profiles)
- No resharpening
- High gear cutting quality (small feed markings) – up to Quality 8
- Optimal changing of carbide indexable inserts
- Adjusted carbide types and coatings

**Example: Finish hobbing a gear rim**

**Tools**

**Double-start gear hob with indexable carbide inserts**

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**Heavy duty of roughing hob**

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**Cutting data**

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### Inquiry form

**Wendeplatten-Wälzfräser für Stirnräder und Zahnwellen**

Hobs with indexable inserts for straight gears and external splines

Please send your inquiry to: Gearcutting@lmt-tools.com

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1) 需要时选择
on request
### Skiving Hobs, Finish-Machining

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### Notes:
1. Basic profile \( h_{ref} = 1.10 \cdot m \cdot \nu_{ref} = 0.1 \cdot m \)
可转位硬质合金齿轮铣刀

ZAHN-FORM-FRASER

MIT HARTMETALL-WENDEPLATTEN
GEAR MILLING CUTTERS
WITH INDEXABLE CARBIDE INSERTS
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<td>可转位硬质合金齿轮铣刀</td>
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<td>外铣/内铣</td>
<td>External milling/Internal milling</td>
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<td>减少换刀时间的铣刀段</td>
<td>Segmented gear milling cutter reduces tool changing times</td>
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<td>有8个切削刃的可转位刀片</td>
<td>Indexable Insert with 8 Positive cutting edges</td>
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<tr>
<td>95</td>
<td>询价表</td>
<td>Inquiry form</td>
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<tr>
<td>96</td>
<td>齿轮粗铣刀</td>
<td>Gear roughing cutters</td>
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<tr>
<td>98</td>
<td>转子粗切铁刀</td>
<td>Gear milling cutters for roughing for rotors</td>
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<tr>
<td>99</td>
<td>推荐切削参数</td>
<td>Cutting data recommendations</td>
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Productive and innovative:
Gear cutting experts
They can be found wherever large loads and forces are in motion: large gear units. These units are used in industries such as wind energy, marine industry and machine construction. In these gear units, the gearwheels, with external and internal gears, work with the highest precision. These components are produced with different manufacturing processes. For more than 100 years, LMT Fette has been manufacturing gear cutting tools for the production of large-module gearwheels. During this time, our customers have been relying on our know-how gained in the development and use of state-of-the-art tool technology.
Today, process safety and short machining times are the most important criteria for manufacturing. Modern gear cutting machines use tools with indexable insert technology for this purpose. LMT Fette offers a comprehensive range of hobs and gear milling cutters for roughing and finishing machining operations.

LMT Fette gear milling cutters: Innovative, powerful, universal and reliable.

生和创新
齿轮切削专家

在任何大负载的传动中总是能找到一些大的齿轮箱。这些齿轮箱被用于风电行业、船舶行业以及机床建筑行业。在这些齿轮箱中，内齿轮或外齿轮的工作精度非常高。这些零件的制造有着不同加工工艺。一百多年来，LMT Fette一直致力于大批量齿轮刀具的生产。在这期间，我们的客户也很依赖于我们在刀具开发过程中积累的经验以及不断革新的技术与应用。现在，加工工艺的安全性和加工效率是生产中最重要的因素。现代齿轮加工设备与可转位刀具的技术由此而生产。LMT Fette可以提供范围很广的精密加工及精加工用的滚齿刀具和齿轮铣刀。

LMT Fette齿轮铣刀：高效，创新，适用，是您可信赖的。
齿轮铣刀与ICI滚刀的对比

Comparison
LMT Fette ICI hob / LMT Fette gear milling cutter with indexable inserts

齿轮铣刀和ICI滚刀都可用于齿轮的粗加工。然而选择这两种刀具取决于被加工齿轮的批量和齿数。

齿轮的模数较大，齿数较多时，滚齿的效率更高。当齿轮的批量较小，齿数较少时，用齿轮铣刀更合适。以上图表供您参考选择合适的刀具。

从节省成本的角度看，齿轮铣刀无论是单件加工和小批量加工用刀具。以下目录中所列尺寸的齿轮刀具，LMT Fette都可以在较短的交货期内供货。

齿轮铣刀和ICI滚刀的产品范围

LMT Fette product range for large gears

<table>
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<tr>
<th>齿轮铣刀/滚刀</th>
<th>精度等级</th>
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<tr>
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<td>Quality</td>
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<td>Gear milling cutter with indexable inserts</td>
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齿轮刀具产品范围

Other gear cutting tools LMT Fette product range

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<tr>
<td>整体滚刀</td>
<td>Solid hobs</td>
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其它模数可单独订购
Other modules on request.

For the roughing of gears, both gear milling cutters (single tooth method) and ICI hobs can be used. The selection of the best type of tool depends on the lot size to be manufactured and the corresponding number of teeth. Gear hobbing is the most productive method for cutting large-module gears with a high number of teeth. Gear milling cutters are especially preferred for low numbers of teeth or small lot sizes. The diagram contains the guide values for the selection of the appropriate tool.

From a cost point of view, gear milling cutters are more economical both in terms of the tool procurement costs and the recurring costs of the indexable inserts than hob cutters with indexable inserts. Gear milling cutters are technically characterized by the possibility of being designed as a roughing cutter and a finishing cutter. The roughing cutters listed in this catalog include the dimension series which are offered by LMT Fette with short delivery times.
The machining methods for gears with large modules differ considerably in practice. Number and sizes of the gears, the efficiency of the gear cutting machine as well as machinability and gear quality are only a few of the factors which affect the selection of the cutting tools.

Profile roughing cutter for rotary pistons (Roots blower) 2-section, 312 mm dia. x 260 x 120 dia., 92 indexable carbide inserts

Circular-type gear profile cutter m 50, 20° p.a., 11 teeth, without roof radius, 295 mm dia. x 190 x 80 dia., 136 indexable carbide inserts
LMT Fette has considerable experience in the design of these tools. For pre-machining, in particular, high-performance roughing cutters have been developed for a very wide range of machine tools. The solid-type designs are intended for use on conventional gear cutting machines. For gear cutting machines with powerful motor milling heads, we manufacture milling cutters with carbide-tipped blades (Cat.-Nos. 2675 and 2667).

LMT Fette also designs and manufactures custom-designed profile cutters in a range of designs for the production of special forms. In addition, our experience is at our customers’ disposal regarding the use and maintenance of these tools.
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<tr>
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<th>Insert arrangement</th>
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<th>Insert type - flank</th>
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**Roughing of external gears with adapted contour**

**Roughing of internal gears with adapted contour**

**External milling/Internal milling**

**Increasing wheel quality**

**Coarse roughing of external gears**

**Coarse roughing of internal gears**
<table>
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<th>渐开线齿形的粗铣刀</th>
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<td>Roughing cutter with even allowance</td>
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用于外齿轮半精加工的渐开线齿形粗铣刀
Pre-finishing of external gears with adapted inserts

用于内齿轮半精加工的渐开线齿形精铣刀
Pre-finishing of internal gears with adapted inserts

加工外齿轮的精铣刀
Finishing of external gears

加工内齿轮的精铣刀
Finishing of internal gears

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半标准化
Semi Standard

半标准化
Semi Standard

见第96~97页，LMT Fette优先推荐系列
P. 96~97, LMT Fette preferred series on request

见第96~97页，LMT Fette优先推荐系列
P. 96~97, LMT Fette preferred series on request
Gear manufacture is characterized by many different types of gears with different modules, profiles and small batch sizes. For the manufacture of all these gears tools must be used which have been optimized for the individual requirements. For internal and external gears the disassembly of these tools is very time-consuming. And even indexable inserts are often changed after the tool is disassembled. Depending on the design of the machine, tool changes are very time-consuming, in particular, due to the removal of the drive shaft and the time needed for the subsequent set-up.

With the newly developed, segmented tooth form cutter by LMT Fette, the time required for a tool change can be reduced dramatically. The base plate can remain on the shaft for all gear cutting tasks and the pre-assembled segments can be replaced quickly. The segmented tooth form cutter is designed for the largest profile to be cut and, therefore, enables flexible manufacture.

**Benefits**
- Short tool changes, approx. 15 min.
- Changing the indexable inserts can be done outside of the machine
- Internal cooling
- Suitable for internal and external gear
- With optional adjustable chamfer

**8个正切削刃的可转位刀片**
*Indexable insert with 8 Positive cutting edges*

研发有8个正切削刃的刀片对于内和外齿轮铣刀的容屑槽的范围被改进了，现在可以采用正切削刃的刀具来高速进给。硬质合金材料和涂层是根据齿轮切削工艺需要专门做的。这些刀片在粗切时与精确应用一样好。
**Gear milling cutters for internal and external gear**

Please send your inquiry to: Gearcutting@lmt-tools.com

**Tool parameters**

- **Cutting method:**
  - Wet cutting
  - Dry cutting

**Part parameters**

- **Type:**
  - Internal gear
  - External gear

**Material:**

- **Number of teeth:**
  - **Pressure angle:**
  - **Helix angle:**

**Shaft Diameter:**

- **Effective tip circle dia.:**
  - **Effective root circle dia.:**

**Profile:**

- **Pilot radius:**

**Machine parameters**

- **Type of machine:**
- **Diametral dimension between balls:**
- **Diametral dimension between pines:**

**Note:**

- Workpieces p.a.
## Gear Roughing Cutters

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### Preferred dimensions

**Your advantages**
- faster delivery time
- cost saving

- www.lmt-tools.com

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Note: The table above represents the different types and sizes of parts available from LMT Fette.
### Gear Milling Cutters for Roughing for Rotors

**Katalog-Nr. Cat.-No.** 2685

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<th>Rotor Measurements</th>
<th>Cutter Measurements (var.)</th>
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**HL = Hauptläufer Male rotor (MALE), NL = Nebenläufer Female rotor (FEMALE)**

These tools are, because of their high cutting rates and trouble-free maintenance, particularly economical. The profile is formed polygonally form straight sections and contains a minimum allowance for finish milling or grinding. To achieve finishing allowances which are as parallel as possible, modified forms are used in addition to the standard indexable inserts. These are provided with chamfers or rounded edges.

**Indexable Insert Forms**

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**www.lmt-tools.com**
Cutting data recommendations

Recommended values for the power requirement for involute roughing:

\[ P_{\text{kW}} = \frac{3.19 \cdot \text{Mod}^2 \cdot v_t}{1000 \cdot Q_{\text{apex}}} \]

\[ v_t = f_z \cdot n \cdot z \]

\[ f_z = \frac{h_{\text{m1}}}{D} \]

Formulas applicable for full profile depth:

\[ P_{\text{kW}} = \frac{3.19 \cdot \text{Mod}^2 \cdot v_t}{1000 \cdot Q_{\text{apex}}} \]

\[ v_t = f_z \cdot n \cdot z \]

\[ f_z = \frac{h_{\text{m1}}}{D} \]

Additional formulas:

\[ R_{\text{m}} = \text{Tensile strength (N/mm}^2\text{)} \]

\[ V_{\text{c}} = \text{Cutting speed (m/min)} \]

\[ h_{\text{m1}} = \text{Mean tip chip thickness (mm)} \]

\[ z = \text{Number of gashes / 2} \]

\[ f_z = \text{Tooth feed (mm)} \]

\[ a = \text{Radial feed (mm)} \]

\[ D = \text{Tool diameter} \]

\[ v_t = \text{Feed (mm/min)} \]

\[ Q_{\text{apex}} = \text{Power factor (Value taken from table)} \]
102  比较-模数-直径-周节
Comparison: Pitch – module – diametral pitch –
circular pitch
103  单头滚刀的公差
Tolerances for single-start hobs
104  多头滚刀的公差
Tolerances for multiple-start hobs
108  滚刀检测记录
Hob inspection records
108  刃具偏差和刀具装夹误差
The effect of cutter deviations
and cutter clamping errors on the gear
110  滚刀质量等级对齿轮
Effect of the quality grades
of the hob on gear quality
111  滚刀设备的
Tool holding of hobs in the hobbing machine
113  滚切中的滚刀基本齿形
Basic tool profile and gear profile in hobbing
114  滚开式直齿轮和齿轮
Basic profiles for spur gears with involute teeth
116  带有外花键齿轮
Standardized basic profiles for spur gears
with involute flanks
117  滚刀的基本齿廓
Basic hob profiles
124  适用于滚刀齿廓及对应的滚刀
Profiles of current tooth systems
and corresponding basic hob profiles
133  切削材料
Cutting materials
134  PVD涂层
PVD coating
136  齿轮切削刀具的硬质涂层材料
Hard material coatings for gear cutting tools
137  磨损情况
How wear develops
139  滚削加工的切削条件
Cutting conditions in hobbing
150  长度设置
Setting length
154  滚合长度
Profile generating length
156  移位距离
Shift distance
157  有恒定错位的移位
Coarse shifting with a constant offset
158  轴向距离
Axial distance
160  滚刀的保养
Maintenance of hobs
176  凸角式滚刀
Protuberance hobs
181  齿切中的磨损现象
Wear phenomena on the hob
194  可倾斜刀片齿轮铣刀
Gear milling cutters with indexable inserts
196  DIN标准号索引
DIN-number-Index
196  目录索引
Pictogram overview
### Pitch – module – diametral pitch – circular pitch

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# 单头滚刀公差：
DIN3968标准适用于渐开线直齿轮
Tolerances for single-start hobs
for spur gears with involute teeth to DIN 3968 in μm

<table>
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<tr>
<th>项目号</th>
<th>Item no.</th>
<th>检测项目</th>
<th>Measurement</th>
<th>符号</th>
<th>Symbol</th>
<th>精度等级</th>
<th>Quality grade</th>
<th>给定范围</th>
<th>For module range</th>
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<tr>
<td>7</td>
<td>前刀面形状和位置误差</td>
<td>Form- and position deviation of the cutting face</td>
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<td>轮廓曲线方向的渐开线导程</td>
<td>Hob lead from cutting edge to cutting edge in the direction of spiral</td>
<td>f_r</td>
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<td>一轴内切刃在螺旋线</td>
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<td>10 11 12 14 16 20 25 32 40</td>
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1. 项目号是对应于DIN3968标准中的检测项目
Item no. of the measurement points to DIN 3968
2. 为了标准的一致性，非特生产的B级滚刀将采用H5级
In accordance with the works standard, LMT Fette Hobs of quality grade B are made with bore tolerance H 5.
<table>
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<tr>
<th>项目号</th>
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<td>B 14 16 18 20 25 32 40 50 63</td>
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<td>AA 4 5 6 8 10 12 16 20 25</td>
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<td>A 8 9 10 12 16 20 25 32 40</td>
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<td>B 16 18 20 25 32 40 50 63 80</td>
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<td>B 22 25 28 32 40 50 63 80 100</td>
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<td>A 12 14 16 20 25 32 40 50 63</td>
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<td>B 25 28 32 40 50 63 80 100 125</td>
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<td>Pitch deviation between adjacent threads of a tooth segment</td>
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<td>B 14 16 18 20 25 32 40 50 63</td>
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<td>Pitch deviation between any two spirals of a tooth land within the hob lead</td>
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<td>B 28 31 35 39 45 56 70 88 112</td>
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<td>AA 10 10 10 13 18 19 22 29 35</td>
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<td>B 32 35 40 45 51 64 80 101 128</td>
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滚刀检测记录
Hob inspection records

加工展开切直齿的单头滚刀公差按DIN3968标准计算，用于精密机械的滚刀公差按DIN58413标准计算。
多头滚刀的公差值以及特殊齿形的滚刀可根据制造商与用户之间的协商制定标准进行加工。

滚刀按等级高低可分为A，B，C，D以及特殊AA等级。对于具有特殊要求的滚刀，其公差质量比AA等级有更严格的要求时，其对应的质量等级可参考AAA级标准。

<table>
<thead>
<tr>
<th>级数</th>
<th>内孔径</th>
<th>切削刃宽度</th>
<th>导程角</th>
<th>导程角</th>
<th>基本外形</th>
<th>外形修正</th>
<th>修正冲程</th>
<th>切削深度</th>
<th>材料</th>
<th>硬度</th>
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The tolerances of single-start hobs for spur gears with involute teeth are laid down in DIN 3968 and the tolerances for the hobs used in precision engineering in DIN 58413. The tolerances for multi-start hobs and for hobs with special profiles are defined in works standards or by agreement between manufacturer and customer.

The hobs are classified into grades A, B, C, D and the special grade AA. For extreme requirements it is usual to agree further restrictions of the tolerances of quality grade AA, which is then referred to as quality grade AAA.

<table>
<thead>
<tr>
<th>(4)右侧径向导轨</th>
<th>(5)右侧轴向导轨</th>
<th>(6)左侧轴向导轨</th>
<th>(4)左侧径向导轨</th>
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<td>Right-hand radial runout</td>
<td>Right-hand axial runout</td>
<td>Left-hand axial runout</td>
<td>Left-hand radial runout</td>
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| f_t | 5 | AA | 2 | AAA | f_r | 3 | AA | 2 | AAA | f_a | 2 | AA | 5 | AAA | f_n | 12 | AA | 7 | AAA |
|------|---|----|---|-----|-----|---|----|---|-----|-----|---|----|---|-----|-----|-----|----|---|----|-----|

<table>
<thead>
<tr>
<th>(6)齿顶圆角向导轨</th>
<th>(7)前刀面的形式和位置</th>
<th>(8)牙形的齿距</th>
<th>(11)容屑槽导程</th>
</tr>
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<tbody>
<tr>
<td>Radial runout at the tooth tip</td>
<td>Form and location of the cutting face</td>
<td>Pitch of the gashes</td>
<td>Gash lead</td>
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| F_r | 12 | AA | 5 | AAA | F_n | 25 | AA | 11 | AAA | F_a | 12 | AA | 8 | AAA | F_n | 50 | AA | 5 | AAA |
|-----|----|----|---|-----|-----|----|----|---|-----|-----|----|----|---|-----|-----|-----|----|---|----|-----|

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<tr>
<th>(14, 15)右侧螺旋线误差</th>
<th>(14, 15)左侧螺旋线误差</th>
<th>(16, 17)右侧基本节距</th>
<th>(16, 17)左侧基本节距</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right-hand lead</td>
<td>Left-hand lead</td>
<td>Right-hand base pitch</td>
<td>Left-hand base pitch</td>
</tr>
</tbody>
</table>

| f_r | 6 | AA | 3 | AAA | f_n | 6 | AA | 2 | AAA | f_a | 8 | AA | 4 | AAA | f_n | 8 | AA | 3 | AAA |
|-----|---|----|---|-----|-----|---|----|---|-----|-----|----|----|---|-----|-----|-----|----|---|----|-----|

<table>
<thead>
<tr>
<th>右侧轴向齿距误差</th>
<th>左侧轴向齿距误差</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right-hand axial pitch</td>
<td>Left-hand axial pitch</td>
</tr>
</tbody>
</table>

公差标准：
DIN 3968 AAA
Tolerances to:
DIN 3968 AAA

滚刀测量
HOB MEASUREMENT

日期：
审核：
制图号：E1305 05M
文件：E1305 05M
The deviations of the measured values can be written, marked down by hand, mechanically recorded or stored in a computer.

In the case of quality grades AA or AAA it is usual to record the deviations of the measured values in an inspection report. The inspection report is used for monitoring the hob throughout its entire service life.

The inspection report becomes particularly clear and informative when the base pitch or the form deviation of the cutting edge and the deviation of the hob lead are represented in the form of diagrams.

These diagrams can then be directly compared with the profile traces of the machined gears and interpreted.

The test report is shown in DIN A4.

### (12) Form deviation of the cutting edge

<table>
<thead>
<tr>
<th></th>
<th>Intended</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>LF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RF</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Intended</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fs</td>
<td>6</td>
<td>AAA</td>
</tr>
<tr>
<td>Fm</td>
<td>6</td>
<td>AA</td>
</tr>
</tbody>
</table>

### (13) Tooth thickness

<table>
<thead>
<tr>
<th></th>
<th>Intended</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fs</td>
<td></td>
<td>AAA</td>
</tr>
<tr>
<td>Fm</td>
<td></td>
<td>AA</td>
</tr>
</tbody>
</table>

### Evaluations

**Remarks:**

**HOB MEASUREMENT**

- **日期:**
- **核检:**
- **制图号:** 61574
- **文件:** E1305 05M

**LMT-FETTE**

www.imt-tools.com
The effect of cutter deviations and cutter clamping errors on the gear
(for single-start hobs with 20° pressure angle and relief rake angle of approx. 10°)

The quality of a hobbled gear is the product of the interaction of various components and production conditions. The deviations from the intended geometry of the hob and the clamping errors of the cutter on the hobbing machine play an important part in this. In hobbing, a distinction is made between the deviations on the enveloping helix of the cutter and the deviations on the cutting faces of the cutter. The deviations of single-start hobs affect the quality of the gear mainly in the form of profile deviations. It is here important to know in which order of magnitude the deviation on the hob and clamping errors of the cutter affect gear quality.

<table>
<thead>
<tr>
<th>滚刀 Hobs</th>
<th>成因及描述</th>
<th>偏差设计和符号 (VDI 2606)</th>
<th>编号及偏差符号 (DIN 3966)</th>
<th>代表符号及偏差描述</th>
</tr>
</thead>
<tbody>
<tr>
<td>滚刀包括啮合线的误差</td>
<td>滚刀基本节距总误差 F_p</td>
<td>F_p = Total base pitch deviation within an engagement area</td>
<td>Nr. 17, No. 17, F_p</td>
<td>基本节距路径</td>
</tr>
<tr>
<td></td>
<td>单个齿间内切线方向的啮合线最大误差 F_HF</td>
<td>F_HF = Cutter lead height deviation in the direction of start of cutting edges in one convolution</td>
<td>Nr. 15, No. 15, F_HF</td>
<td>基本柱体区域</td>
</tr>
<tr>
<td></td>
<td>齿顶圆径向跳动值 f_a</td>
<td>f_a = Radial runout of tooth tip</td>
<td>Nr. 6, No. 8, f_a</td>
<td>一次切削回转</td>
</tr>
<tr>
<td></td>
<td>基本参考圆柱上的齿厚误差 f_b</td>
<td>f_b = Tooth thickness deviation on the basic reference cylinder</td>
<td>Nr. 13, No. 13, f_b</td>
<td>一次切削回转</td>
</tr>
<tr>
<td></td>
<td>切削刃的形状误差 F_B</td>
<td>F_B = Form deviation of the cutting edge</td>
<td>Nr. 12, No. 12, F_B</td>
<td>一次滚齿回转</td>
</tr>
<tr>
<td>滚刀前刀面的误差</td>
<td>前刀面形状和位置误差 F_M</td>
<td>F_M = Form- and position-deviation of the cutting faces</td>
<td>Nr. 7, No. 7, F_M</td>
<td>一次滚齿回转</td>
</tr>
<tr>
<td></td>
<td>前刀面累积误差 F_MN</td>
<td>F_MN = Cumulative pitch deviation of the gashes (cutting faces)</td>
<td>Nr. 10, No. 10, F_MN</td>
<td>一次滚齿回转</td>
</tr>
<tr>
<td></td>
<td>切削长度超过100mm时的前刀面轮廓误差 f_MB</td>
<td>f_MB = Gash lead deviation over 100 mm cutter length</td>
<td>Nr. 11, No. 11, f_MB</td>
<td>一次滚齿回转</td>
</tr>
<tr>
<td>滚齿设备的误差</td>
<td>两个轴上的径向圆跳动 f_P</td>
<td>f_P = Radial runout of the two indicator hubs</td>
<td>Nr. 4, No. 4, f_P</td>
<td>一次滚齿回转</td>
</tr>
<tr>
<td></td>
<td>轴面上的轴向圆跳动 f_A</td>
<td>f_A = Axial runout on the clamping faces</td>
<td>Nr. 5, No. 5, f_A</td>
<td>一次滚齿回转</td>
</tr>
</tbody>
</table>

www.lmt-tools.com
它们之间的相关关系如表中所示。必须记住的一点是滚刀的加工精度主要受螺旋磨削的影响，因此在每次重磨后，务必对滚刀的表面质量进行检查。

有关滚刀正确的检测步骤，必需的设备和测量结果评估等详细情况可参考VDI / VDE的2606建议内容。

These relationships are shown in the table. It must be remembered that the working accuracy of the hob can be considerably affected by faulty regrinding. A check of the deviations on the cutting faces of the hob should therefore be made obligatory after each regrind.

The correct inspection procedure for hobs, the necessary equipment and the evaluation of the measurement results are described in detail in VDI/VDE Recommendation 2606.

<table>
<thead>
<tr>
<th>齿形误差</th>
<th>Effect of the deviation</th>
<th>影响大小</th>
<th>Order of magnitude of the effect</th>
<th>误差表现</th>
<th>Representation of the deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Profile deviation</td>
<td>≈ 100 %</td>
<td>齿顶</td>
<td>Tip</td>
<td>齿根</td>
<td>Root</td>
</tr>
<tr>
<td>Profile deviation (only the deviation of the profile formation zone in question is effective)</td>
<td>≈ 100 %</td>
<td>齿顶</td>
<td>Tip</td>
<td>齿根</td>
<td>Root</td>
</tr>
<tr>
<td>Form deviation in the bottom of the tooth space (only the deviation of the tip cutting edges forming the root cylinder is effective)</td>
<td>≈ 20 %</td>
<td>齿顶</td>
<td>Tip</td>
<td>齿根</td>
<td>Root</td>
</tr>
<tr>
<td>(齿厚误差) (Tooth thickness deviation)</td>
<td>(≈ 100 %)</td>
<td>齿顶</td>
<td>Tip</td>
<td>齿根</td>
<td>Root</td>
</tr>
<tr>
<td>直径偏差</td>
<td>Diameter deviations</td>
<td>&gt; 100 %</td>
<td>齿顶</td>
<td>Tip</td>
<td>齿根</td>
</tr>
<tr>
<td>Profile deviation</td>
<td>≈ 100 %</td>
<td>齿顶</td>
<td>Tip</td>
<td>齿根</td>
<td>Root</td>
</tr>
<tr>
<td>Profile deviation</td>
<td>≈ 10 %</td>
<td>齿顶</td>
<td>Tip</td>
<td>齿根</td>
<td>Root</td>
</tr>
<tr>
<td>Profile deviation</td>
<td>≈ 10 %</td>
<td>齿顶</td>
<td>Tip</td>
<td>齿根</td>
<td>Root</td>
</tr>
<tr>
<td>Profile deviation (only the deviation of the profile forming zone is effective)</td>
<td>≈ 10 %</td>
<td>齿顶</td>
<td>Tip</td>
<td>齿根</td>
<td>Root</td>
</tr>
<tr>
<td>Profile deviation</td>
<td>≈ 30 %</td>
<td>齿顶</td>
<td>Tip</td>
<td>齿根</td>
<td>Root</td>
</tr>
<tr>
<td>Profile deviation</td>
<td>≈ 100 %</td>
<td>齿顶</td>
<td>Tip</td>
<td>齿根</td>
<td>Root</td>
</tr>
</tbody>
</table>


对于直齿轮，其规格系数的公差由DIN3962到DIN3967标准给出。渐开线的齿轮分ographical十二个等级，分别用数字1到12标出。标记为1的齿轮精度最高。

单头滚刀的许用公差符合DIN3968标准的要求。根据其精度不同，共分为五个等级，即质量等级A、B、C、D和特级AA。

滚刀的基本齿距与齿轮齿距总误差提供了参考。因此将滚刀啮合区域的基本齿距误差Fa与齿轮总齿形误差Ft相比较是有一定意义的。

然而必须注意到，总轮廓误差不仅可能由滚刀本身的误差造成的，也可能是由于滚刀加工设备、工具夹具和滚刀误差以及切削应力造成的。

“可获得的齿轮质量”表是在假设齿轮总误差的2/3是由滚刀造成的前提下得到的。而其他的影响因素如上述内容所述。

<table>
<thead>
<tr>
<th>单头滚刀质量等级</th>
<th>可获得的齿轮质量 DIN 3962第1-8.76部分</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIN 3968 for single-start hobs</td>
<td>Attainable gear qualities to DIN 3962 part 1–8.76 (Ft)</td>
</tr>
<tr>
<td>模数范围</td>
<td>Über from</td>
</tr>
<tr>
<td>1-1.6</td>
<td>1.8-2</td>
</tr>
<tr>
<td>Fz</td>
<td>AA</td>
</tr>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
</tbody>
</table>

1) 高于质量等级12
Inferior to gear quality 12

单头滚刀的许用公差等级符合DIN3968标准。

总共有18种不同的公差级别，它们部分互相依存，且属于累积误差。

啮合区域的接触比率为误差Fz作为整体误差，对于评估滚刀质量具有重要参考作用。在限制条件下，该参考值也可用来对齿轮齿面形状进行预测。

为了保证滚刀的质量，必须在每次磨刀后对前刀面的形状和位置：齿距和方向允许偏差进行检查。

For spur gears, the tolerances of their specification factors are given in DIN 3962 to DIN 3967. The tooth quality is subdivided into twelve quality stages, which are identified by the numbers 1 to 12. Gear quality 1 is the most accurate.

The permissible deviations for single-start hobs are laid down in DIN 3968. Depending on the accuracy, a distinction is made between five quality grades, namely the quality grades A, B, C, D and the special grade AA.

The base pitch on the hob provides some guidance about the total profile deviation on the gear. It therefore makes sense to compare the base pitch deviation Fb within an engagement area of the hob with the total profile deviation Ft of the gear.

It must be considered, however, that the total profile deviation may be caused not only by deviations on the hob itself, but also by the hobbing machine, errors in hob and workpiece clamping, and the cutting forces.

The table of "Attainable gear qualities" is based upon the assumption that 2/3 of the total profile deviation on the tooth is caused by the hob, and the remainder by the influencing factors stated above.

The permissible deviations for single-start hobs are laid down in DIN 3968.

There are 16 individual deviations, which are partly interdependent, and one cumulative deviation.

The contact ratio deviation Fz within an engagement area, as a collective deviation, is the most informative value when assessing hob quality. It also allows, within limits, to forecast the flank form of the gear.

To maintain hob quality, it is necessary to check the permissible deviations after each sharpening operation for form and position, pitch and direction of the cutting faces (item nos. 7 to 11, page 108).
Tool holding has two essential functions: firstly to transmit the torque, and secondly to locate the tool in the machine. The same applies of course to the interface between the hobbing machine and the hob/cutter arbor. The geometrical arrangement of this connection is largely determined by the hobbing machine manufacturer.

The following two chief arrangements are employed at the interface between the hob and the hobbing machine/cutter arbor: the bore-type and the shank-type hob.

The bore-type hob has the following sub-categories:
- Bore with keyway for positive torque transmission
- Bore with drive slot on one or both ends for positive torque transmission
- Bore with frictional torque transmission on the hob face

The shank-type hob has the following sub-categories:
- Short cylindrical shanks at each end with positive torque transmission
- Tapered shank at each end with positive torque transmission
- Different types, cylindrical and tapered, on the drive and support ends
- Hollow shank taper type
- Steep-angle taper on the drive end and cylindrical or taper type on the support end

One of the variants described above, adapted to the function and the task in question, is generally recommended by the machine manufacturer upon purchase of a hobbing machine. Note that there are differences in cutter head design and therefore in tool holding arrangement from one hobbing machine manufacturer to the next. The use of adapters for holding equivalent tools should be regarded only as a last resort, as in the majority of cases it results in a loss in quality on the machined workpiece. For this reason, the compatibility of the interface must be clarified prior to purchase of a hobbing machine. A large number of hobs is required if hobbing machines are employed with different tool holding arrangements.

The most widely used hob type is the bore-type hob with keyway. Bore-type hobs are a good choice for small production runs and where requirements on the workpiece accuracy are not particularly stringent. Hobs are generally manufactured from high-speed steel, with a keyway to DIN 138. Geometric requirements permit designs with a drive slot on one or both ends to DIN 138 (and also in shortened versions). Carbide hobs are always manufactured with drive slots on one or both ends, and almost always in the shortened design (3x drive slot depth according to DIN 138). Bore-type hobs may also be manufactured without keyway or drive slot.
Hobs with short cylindrical shanks at both ends are increasingly being used, particularly for large production runs. The advantages are fast tool changing and very low runout of the hob in the machine. Prealignment on the cutter arbor is not required. There is no interface element (cutter arbor). When hobbing machines are purchased, attention must be given to the compatibility of hobs on hobbing machines from different manufacturers.

If required, worm gear hobs are manufactured with an interface geometry that has been adapted to the hobbing machine (refer to Worm gear hobs chapter).
Pre-formed helical spur gear face profile with chamfer and root clearance cut, with corresponding basic profile of the pre-forming tool (Protuberance)
The flank profiles of spur gears with involute teeth are in the face section (plane of section perpendicular to the gear axis) circular involutes.

The form of the involute depends among others on the number of teeth on the gears. With an increasing number of teeth the curvature of the involute becomes progressively weaker. At an infinite number of teeth the spur gear becomes a tooth rack with straight flanks. The tooth rack can therefore take the place of a spur gear and ensures an even and trouble-free transmission of motion when meshing with a companion gear.

Since the form of a rack is easier to describe than that of a spur gear, it suggested itself to apply the tooth values of spur gears to the 'reference (basic) tooth rack' and to refer to the latter as the basic profile.

The definition of the basic profile is as follows:

The basic profile of a spur gear is the normal section through the teeth of the basic tooth rack, which is created from the external gear teeth by increasing the number of teeth up to infinity and thus arriving at an infinite diameter.

The flanks of the basic profile of an involute tooth system are straight lines. Values of the reference profile are identified by the additional index p.

The basis for the measurements on the basic profile is the module m. The module is a length measurement in mm. It is obtained as the quotient from the pitch p and the number π. It is usual to define the measurements of the basic profile in proportion to the module.

The profile reference line intersects the basic profile so that the tooth thickness and the tooth space width correspond to half the pitch.

The addendum is generally 1·m.

Since the tooth tips of a companion gear must not touch the bottom of the space between the teeth of the gear, the dedendum hpₖ, of the basic profile is larger than its addendum by the amount of the tip clearance cpₖ.

The profile angle αₚ, on the basic profile is equal to the normal pressure angle of the corresponding gear.

Details of standardized basic profile for spur gears are found in:

DIN 867
DIN 58 400
ISO 53
Basic profile of a spur gear

$p = m \cdot \pi = \text{Pitch}$

$e_p = \text{齿廓参考线上的齿间段宽度}$
$Tooth space width on the profile reference line$

$s_p = \text{齿廓参考线上的齿厚}$
$Tooth thickness on the profile reference line$

$h_p = \text{齿高}$
$Profile height$

$h_{mp} = \text{齿顶高}$
$Addendum$

$h_{dp} = \text{齿根高}$
$Dedendum$

$\alpha_p = \text{齿廓角}$
$Profile angle$

$q_p = \text{齿根圆弧半径}$
$Root fillet radius$

$h_{wp} = \text{基本齿廓和啮合齿廓的啮合高}$
$Common tooth height of basic profile and mating profile$

$C_p = \text{基本齿廓与啮合齿廓之间的顶隙}$
$Tip clearance between basic profile and mating profile$

The basic profiles of spur gears are denoted by the index $p$. 
Standardized basic profiles for spur gears with involute flanks

**DIN 867 - Basic profile for spur gears (cylindrical gears with involute teeth)**

- \( h_p = m \)
- \( h_{pa} = m + c \)
- \( c_p = 0.1 \cdot m \) bis to \( 0.3 \cdot m \)
- \( \alpha_p = 20^\circ \)
- \( \varnothing_{max} = 0.25 \cdot m \) - \( \varnothing_{min} = 0.38 \cdot m \) - \( \varnothing_p = 0.25 \cdot m \) - \( \varnothing_p = 0.45 \cdot m \)

**ISO 53 - Basic profile for spur gears with involute flanks**

- \( p = m \cdot \pi \)
- \( s_p = \frac{p}{2} \)
- \( h_{pa} = m \)
- \( h_a = 1.25 \cdot m \)
- \( h_p = 2.25 \cdot m \)
- \( \alpha_p = 20^\circ \)
- \( \varnothing_p = 0.38 \cdot m \)
- \( C_{ap} = 0.02 \cdot m \)
- \( h_{cap} = 0.6 \cdot m \)
Basic hob profiles

Definition of the basic hob profiles

The definition of the basic hob profile is generally derived from the basic profile of the spur gear teeth. This procedure applies to spur gear teeth only within limits and cannot be used for special tooth systems, since no basic profiles exist for these.

The basic hob profile can generally be defined as follows:

The basic hob profile is the normal sectional profile of an imaginary tooth rack, which meshes with the workpiece teeth under the following conditions:

- The basic profile line of the rack rolls on a defined pitch circle diameter of the workpiece.
- The pitch of the rack is equal to the pitch on the pitch circle diameter.
- Meshing with the workpiece takes place:
  - according to the basic law of the tooth system, the common perpendicular passing through the contact point of pitch circle and reference line (rolling point) in the contact point of gear flank and tooth rack flank, or
  - through relative paths of parts of the tooth rack profile on the workpiece.

The computing and design effort for determining the basic profile depends on the nature of the workpiece teeth. The simplest is the determination of the basic hob profile for spur gears with involute flanks.

Basic hob profile for spur gears with involute flanks

The hob or tool profile is the mating profile of the spur gear teeth. The profile reference lines of the basic hob- and spur gear profile coincide, i.e. the tooth thickness \( s_{p0} \) equals half the pitch. The addendum \( h_{p0} \) corresponds to the dedendum \( h_n \) on the basic spur gear profile and the addendum radius \( r_{p0} \) is equal to the dedendum radius \( r_n \) on the basic spur gear profile.

The same hob can be used for producing spur- and helical gears with any number of teeth, helix angles and profile displacements, if the basic hob profile does not contain any profile modifications such as chamfer, tooth profile corrections, protuberance etc.

Standardized basic hob profiles are shown in:

DIN 3972
DIN 58412

Basic hob profile and hob profile

The basic hob profile must not be confused with the hob profile. Although the basic profile forms the basis for the calculation of the hob profile, the diameter and the number of starts of the hob also affect the hob profile. The details concern the hob manufacture. He has to ensure that hobs with the same basic profile produce identical teeth within the scope of the permissible hob tolerances.
Basic cutter profile

- $p = m \cdot \pi$ = Pitch
- $s_p$ = Tooth thickness
- $h_p$ = Profile height
- $h_{ap0}$ = Addendum
- $h_{dp0}$ = Dedendum
- $\alpha_p$ = Flank angle (pressure angle)
- $q_{ap0}$ = Tip radius
- $q_{rp0}$ = Root fillet radius
- $h_{a0p0}$ = Effective addendum height
- $h_{d0p0}$ = Effective dedendum height

Values of the basic tool profile are identified by the addition of P0 indexes.

Basic hob profiles to DIN 3972

- $h_{ap0}$ = Addendum of the basic profile
- $h_p$ = Profile height of the gear = cutting depth
- $h_{dp0}$ = Profile height of the basic profile
- $s_p$ = Tooth thickness
- $q_{ap0}$ = Tip radius
- $q_{rp0}$ = Root fillet radius

DIN 3972 – Basic profile I
20° Pressure angle

- $h_{ap0} = 1.167 \cdot m$
- $h_p = 2.167 \cdot m$
- $h_{dp0} = 2.367 \cdot m$
- $q_{ap0} = 0.2 \cdot m$
- $q_{rp0} = 0.2 \cdot m$
- $s_p = 0.5 \cdot m$

for finishing
DIN 3972 — Basic profile II
— Pressure angle 20°

DIN 3972 — Basic profile III
— Pressure angle 20°

DIN 3972 — Basic profile IV
— Pressure angle 20°
DIN 58412 basic hob profiles

- \( h_{po} \) = 基本轮廓齿根高
  Dedendum of the basic profile

- \( h_{pw} \) = 轮缘与基本轮廓直齿面之间的距离
  Distance between the tooth root and the end of the straight flank of the basic profile

- \( h_{p} \) = 基本轮廓齿高
  Profile height of the basic profile

- \( h_{r} \) = 齿轮齿廓高度 = 切削深度
  Profile height of the gear = cutting depth

- \( s_{r} \) = \( \frac{d}{2} \cdot m \) = 齿厚
  Tooth thickness

- \( \rho_{ap} \) = 顶圆弧半径
  Tip radius

- \( \rho_{ap} \) = 齿根圆弧半径
  Root fillet radius

For gears with basic cutter profile to DIN 58400

For gears with basic cutter profile to DIN 867

DIN 58412 — 基本轮廓 U1
- 顶切 - 压力角20度
DIN 58412 — Basic profile U1
topping - 20° Pressure angle

- \( h_{po} = 1.1 \cdot m \)
- \( h_{pw} = 2.2 \cdot m \)
- \( h_{p} = 2.2 \cdot m \)
- \( h_{r} = h_{po} = 2.6 \cdot m \) 模数为 0.1-0.8
- \( h_{r} = h_{po} = 2.45 \cdot m \) 模数大于 0.8-1.0
- \( \rho_{ap} = 0.2 \cdot m \)
- \( \rho_{ap} = 0.2 \cdot m \) 最大尺寸 max. size

for finishing

DIN 58412 — 基本轮廓 N1
- 非顶切 - 压力角20度
DIN 58412 — Basic profile N1
non-topping - 20° Pressure angle

- \( h_{po} = 1.3 \cdot m \)
- \( h_{pw} = 2.4 \cdot m \)
- \( h_{p} = 2.6 \cdot m \) 模数为 0.1-0.6
- \( h_{r} = 2.45 \cdot m \) 模数大于 0.6-1.0
- \( h_{r} = 2.6 \cdot m \) 模数大于 0.8-1.0
- \( \rho_{ap} = 0.2 \cdot m \)
- \( \rho_{ap} = 0.2 \cdot m \) 最大尺寸 max. size

for finishing
DIN 58412 — Basic Profile U2
- Non-Topping - Pressure Angle 20°

\[
\begin{align*}
& h_{p0} = 1 \cdot m \\
& h_{pw} = 2 \cdot m \\
& h_p = 2.25 \cdot m \\
& \phi_{wp} = 0.2 \cdot m \\
& \phi_{m} = 0.2 \cdot m \text{ max. size}
\end{align*}
\]

For finishing

DIN 58412 — Basic Profile N2
- Non-Topping - Pressure Angle 20°

\[
\begin{align*}
& h_{p0} = 1.2 \cdot m \\
& h_{pw} = 2.2 \cdot m \\
& h_p = 2.25 \cdot m \\
& h_{p0} = 2.45 \cdot m \\
& \phi_{wp} = 0.2 \cdot m \\
& \phi_{m} = 0.2 \cdot m \text{ max. size}
\end{align*}
\]

For finishing

DIN 58412 — Basic Profile V1
- Non-Topping - Pressure Angle 20°

\[
\begin{align*}
& h_{p0} = 1.3 \cdot m \\
& h_p = 2.6 \cdot m \text{模数为 } 0.3-0.6 \\
& h_{p0} = 2.45 \cdot m \text{模数大于 } 0.6-1.0 \\
& h_{p0} = 2.8 \cdot m \text{模数为 } 0.3-0.6 \\
& h_{p0} = 2.65 \cdot m \text{模数大于 } 0.6-1.0 \\
& \theta_0 = \frac{2}{2} \cdot \cos \alpha \\
& \phi_{wp} = 0.1 \cdot m \\
& \phi_{m} = 0.2 \cdot m \text{ max. size} \\
& q = 0.05 \cdot m + 0.03
\end{align*}
\]

For pre-machining

DIN 58412 — Basic Profile V2
- Non-Topping - Pressure Angle 20°

\[
\begin{align*}
& h_{p0} = 1.2 \cdot m \\
& h_p = 2.25 \cdot m \\
& h_{p0} = 2.45 \cdot m \\
& \theta_0 = \frac{2}{2} \cdot \cos \alpha \\
& \phi_{wp} = 0.1 \cdot m \\
& \phi_{m} = 0.2 \cdot m \text{ max. size} \\
& q = 0.05 \cdot m + 0.03
\end{align*}
\]

For pre-machining
基本滚刀轮廓

径向切削基本轮廓

Basic hob profiles for diametral pitch teeth

$h_{p0}$ = 基本转矩高顶高
Addendum of the basic profile
$h_p$ = 轴段切削高度 = 切削深度
Profile height of the gear = cutting depth
$h_{p0}$ = 基本轮廓高
Profile height of the basic profile
$s_{p0}$ = 槽深
Tooth thickness
$h_{c_p0}$ = 修整高顶高
Height of the correction
$C_{p0}$ = 修整宽度
Width of the correction
$R_{c_p0}$ = 修整半径
Radius of the correction
$q_{w0}$ = 顶圆弧半径
Tip radius
$q_{r0}$ = 根圆弧半径
Root fillet radius

适用于1996年BS2062
第一部分的齿形DP1-DP20
压力角20度
For teeth to BS 2062,
Part 1, 1969, for DP 1 – DP 20
20° Pressure angle

11

适用于1965年AGMA201.02
的齿形DP1-DP19.99
压力角14度30分
For teeth to AGMA 201.02 – 1968
for DP 1 – DP 19.99
14° 30’ Pressure angle

12
适用于1968年AGMA201.02
的齿形DP 1 – DP 19.99
20° Pressure angle

\[ h_{pa} = \frac{1.25}{DP} \]

\[ h_p = \frac{2.25}{DP} \]

\[ h_{pa} = \frac{4.65}{DP} \]

\[ s_{pa} = \frac{1.5708}{DP} \]

\[ \varphi_{pa} = 0.3 \]

\[ \varphi_{p} = 0.2 \]

适用1968年AGMA201.02
的齿形DP 1 – DP 19.99
20° Pressure angle

\[ h_{pa} = \frac{1}{DP} \]

\[ h_p = \frac{1.8}{DP} \]

\[ h_{pa} = \frac{2}{DP} \]

\[ s_{pa} = \frac{1.5708}{DP} \]

\[ \varphi_{pa} = \varphi_p = 0.2 \]
Involute teeth for spur- and helical gears, basic cutter profile e.g. DIN 3972 I–IV.

When ordering please quote:
Module, pressure angle, basic profile of the teeth or basic hob profile.

Involute teeth for spur- and helical gears with addendum tip relief. This profile shape is used to avoid interference when the gears roll into mesh.

When ordering please quote:
Module, pressure angle, number of teeth, helix angle, profile displacement and tip circle dia. of the gear, basic profile of the teeth, height and width of the tip relief or basic hob profile.

Gears of high-speed transmissions are corrected in the tooth tips to reduce noise. In this correction the elastic tooth deflection has been taken into account. The cutter correction is then matched to the number of teeth to be cut on the gear.
Involute teeth for spur- and helical gears with tip chamfer.

When ordering please quote:
Module, pressure angle, number of teeth, helix angle, profile displacement and tip circle diameter of the gear, basic profile of the teeth, radial amount and angle of the chamfer or basic hob profile.

The tip chamfer can be regarded as a protective chamfer, which protects the tooth tip edge against damage and burring. For long production runs it is advisable to chamfer the gear tip edge simultaneously with the hob. The number of teeth range which can be cut with one hob is in that case limited, since the size of the chamfer would be reduced with fewer teeth/gear and greater with more teeth/gear.

Involute tooth system, for spur- and helical gears with root (protrubance) clearance. This profile formation is chosen for gears which are pre-machined for shaving, grinding or skiving.

When ordering please quote:
Module, pressure angle, basic profile of the tooth system, machining allowance and root clearance or basic hob profile.

Gears which are cut with shaving- or grinding allowance are best made with a protrubance cutter. The tooth root clearance obtained with this increases the service life of the shaving tool and improves the quality of the shaved or ground gear.
Involute tooth system for spur- and helical gears with root (projection) clearance and tip chamfer.

This profile is used for gears which are pre-machined for shaving or grinding and which are to exhibit a tip chamfer in the finish condition.

When ordering please quote:
Module, pressure angle, number of teeth, helix angle, profile displacement and tip circle diameter of the gear, basic profile of the tooth system, radial amount and angle of the chamfer or basic hob profile.

Involute teeth for spur- and helical gears for the simultaneous topping of the outside diameter (topping cutter). This profile type can also be used for all the previous profiles under 1 to 5.

When ordering please quote:
“Topping cutter” and the details according to the profiles 1 to 5.

Topping cutters are mainly used for relatively small gears, to achieve good concentricity of the tooth flank in relation to the bore. In particular, topping cutters are used when the bore is only finish machined after the teeth have been cut. When the parts are clamped over the tooth tips, accurate concentricity of the bore in relation to the teeth is guaranteed.
用于链子和传动链的链轮机构符合DIN 8187和8188标准，链轮的齿轮机构符合DIN 8196标准，滚刀的基本齿廓符合DIN 8197标准。

如需订货请提供以下参数：
链节距，链子直径，链轮的DIN标准要求。

工作
Workpiece
-p = 链节距 Chain pitch
-d₁ = 链子直径 Roller diameter
-p₀ = 齿顶圆直径 Pitch circle diameter
-d₀ = 根圆直径 Root circle diameter
-d₁ = 齿顶圆直径 Tip circle diameter

滚动式链轮机构（重载）符合DIN 8150标准。

如需订货请提供以下参数：
链节距，链子直径，链轮的DIN标准要求。重载滚动式链轮的刀具基本齿廓符合DIN 8150标准，但并没有标准化。我们制造时使用的压力角值为20度。

工作
Workpiece
-dₘ = d₁ - d₀

Sprocket tooth system for roller- and sleevetype chains to DIN 8187 and 8188, tooth system of the sprockets to DIN 8196, basic hob profile to DIN 8197.

When ordering please quote:
Chain pitch, roller diameter, DIN standard of the chain.

Sprocket tooth system for Gall’s chains (heavy) to DIN 8150.

When ordering please quote:
Chain pitch, roller diameter, DIN standard of the chain.

The basic cutter profile for heavy Gall’s chains to DIN 8150 is not standardized and is made by us with a pressure angle of 20°.
Profiles of current tooth systems and corresponding basic hob profiles

Sprocket tooth system for barrel chains to DIN 8164.

When ordering please quote:
Chain pitch, roller diameter, DIN standard of the chain.

The basic cutter profile for barrel chains to DIN 8164 is not standardized and is made by us with a pressure angle of 20°.

Spline shaft tooth system; basic cutter profile without clearance lug, without chamfer (flank centred).

When ordering please quote:
Inside diameter \(d_1\), outside diameter \(d_o\), spline width \(b\), number of splines, tolerances for \(d_a, d_i, b\). Possibly also DIN standard of the splines shaft.

Designation: “Without clearance lug, without chamfer”

Flank centred spline shafts which find sufficient clearance for the internal and the external diameter in the splineway, are produced with hobs without lug and without chamfer. It must be noted that for technical reasons inherent in hobbing no sharp-edged transition can occur from the spline flank to the inside diameter of the spline shaft. The size of the rounding curve depends on the spline shaft dimensions. It must be ensured that no overlapping occurs between the rounding curve and the splineway. It may be necessary to fall back on a tool with clearance lug.

Flank cutter profile

Flank centred spline shafts which find sufficient clearance for the internal and the external diameter in the splineway, are produced with hobs without lug and without chamfer. It must be noted that for technical reasons inherent in hobbing no sharp-edged transition can occur from the spline flank to the inside diameter of the spline shaft. The size of the rounding curve depends on the spline shaft dimensions. It must be ensured that no overlapping occurs between the rounding curve and the splineway. It may be necessary to fall back on a tool with clearance lug.

Flank cutter profile

Flank centred spline shafts which find sufficient clearance for the internal and the external diameter in the splineway, are produced with hobs without lug and without chamfer. It must be noted that for technical reasons inherent in hobbing no sharp-edged transition can occur from the spline flank to the inside diameter of the spline shaft. The size of the rounding curve depends on the spline shaft dimensions. It must be ensured that no overlapping occurs between the rounding curve and the splineway. It may be necessary to fall back on a tool with clearance lug.
Spline shaft tooth system; basic cutter profile with clearance lug and chamfer.

When ordering please quote:
Inside diameter \( d_i \), outside diameter \( d_o \), spline width \( b \), number of splines, size of the chamfer \( g \), tolerances for \( d_i, d_o, b \).
Possibly also DIN designation of the spline shaft.
Designation: "With lug and chamfer"

In order to achieve with internally centred spline shafts a correct bearing down on to the spline shaft base, the hob is generally made with lug. The necessary clearance in the slot corners of the splineway is achieved by the chamfer.

Workpiece

1. Inside diameter \( d_i \)
2. Outside diameter \( d_o \)
3. Base diameter \( d_b \)
4. Spline width \( b \)
5. Width of the tip relief \( g \)

**Workpiece**

- Inside diameter \( d_i \)
- Outside diameter \( d_o \)
- Base diameter \( d_b \)
- Spline width \( b \)
- Width of the tip relief \( g \)

Spline shaft tooth system; basic cutter profile with lug without chamfer (bottom fitting).

When ordering please quote:
Inside diameter \( d_i \), outside diameter \( d_o \), spline width \( b \), number of splines, tolerances for \( d_i, d_o, b \). Possibly also DIN standard of the spline shaft.
Designation: "With lug without chamfer"

The details under fig. 11 apply to the lug. A chamfer is not necessary if sufficient clearance exists between the spline shaft outside diameter and the corresponding splineway outside diameter.
通用齿轮系统及对应的滚刀基本轮廓
Profiles of current tooth systems and corresponding basic hob profiles

矩形花键轴：无凸肩带倒角的刀具基本轮廓（底部配合）。

如需订货提供以下参数：
内径d1，外径da，花键宽度b，花键数量，da，d1和b的公差。如有条件还可以提供花键轴的DIN制造标准。设计要求：
“无凸肩，带侧角”：

如果内定心花键轴采用不带凸肩滚刀加工，则必须确保螺旋上齿的倒角与轴圆弧不会发生干涉现象。

Spline shaft tooth system; basic cutter profile without lug with chamfer (bottom fitting).

When ordering please quote:
Inside diameter d1, outside diameter da, spline width b, number of splines, tolerances for da, d1, b. Size of the tip chamfer g. Possibly also DIN standard of the spline shaft.
Designation: “Without lug with chamfer”

If internally centred spline shafts are cut with hobs without lug, chamfering on the teeth of the splineway must ensure that interference with the rounding curve of the shaft are impossible.

花键轴精度较：带一个凸肩和倒角的刀具基本轮廓（锥侧或圆柱定心）。
该轮廓适用于SAE采用花键轴的情况。

如需订货提供以下参数：内径d1，外径da，花键宽度b，花键数量，da，d1和b的公差。如有条件还可以提供花键轴的DIN或SAE制造标准。设计要求：
“带一个凸肩和倒角”。

如果内定心的多键花键轴有一个比较深的齿侧通常由滚刀来加工，滚刀只有一个凸起的齿顶。刀具基本轮廓的齿顶非常狭窄以至于只有有限的空间来容纳一个凸肩（对应于凸起的齿顶）。

Spline shaft tooth system; basic cutter profile with one lug with chamfer (Side or major diameter fitting). This profile occurs e.g. in the case of SAE spline shafts.

When ordering please quote:
Inside diameter d1, outside diameter da, spline width b, number of splines, tolerances for da, d1, b. Size of the tip relief g. Possibly also DIN- or SAE standard of the spline shaft.
Designation: “With one lug and chamfer”

Flank-centred multi-splined shafts have a very deep spline profile and are generally produced with hobs which only have one raised tooth tip. The tooth tips of the basic cutter profile are so narrow that there is only sufficient space for one lug (equivalent to raised tooth tip).
Spline shaft tooth system; basic cutter profile with raised tooth for through-cutting a shoulder.

When ordering please quote:
Collar dia. \( d_9 \) and also the details as under profiles 10 to 14.

If in the case of spline shafts the splineway is to be pushed against a shoulder of the spline shaft, the hob cuts into this shoulder. Since, however, the outside diameter of the shoulder must not be machined off, the teeth on the basic cutter profile must be made correspondingly higher.

---

**Serrations to DIN 5481; nominal diameter 7 x 8 up to 55 x 60.**

Basic cutter profile with convex flanks for straight workpiece flanks. Cutters with straight flanks can also be used for the nominal diameter range stated above, if this has been arranged with the customer in advance.

When ordering please quote:
DIN standard of the serration and tolerances. Unless otherwise arranged, we supply the hobs with straight flanks for convex workpiece flanks, as under fig. 17.

Serrations are used for making form-fit plug-on connections.
Profiles of current tooth systems and corresponding basic hob profiles

Serrations to DIN 5481; nominal diameter 7 x 8 to 55 x 60 and 60 x 65 to 120 x 125. Basic cutter profile with straight flanks for convex workpiece flanks. For the nom. diameter range 7 x 8 to 55 x 60 basic cutter profiles as under fig. 16 can also be used.

When ordering please quote:
DIN standard of the serrations and tolerances.

External spline profiles with involute flanks to DIN 5480 and special standards.

When ordering please quote:
Module, pressure angle, tip circle diameter, root circle diameter, diametral two-roll measurement, DIN standard of the external spline.

When ordering please quote:
Module, pressure angle, tip circle diameter, root circle diameter, diametral two-roll measurement, DIN standard of the external spline.

When ordering please quote:
Module, pressure angle, tip circle diameter, root circle diameter, diametral two-roll measurement, DIN standard of the external spline.

When ordering please quote:
Module, pressure angle, tip circle diameter, root circle diameter, diametral two-roll measurement, DIN standard of the external spline.

When ordering please quote:
Module, pressure angle, tip circle diameter, root circle diameter, diametral two-roll measurement, DIN standard of the external spline.

When ordering please quote:
Module, pressure angle, tip circle diameter, root circle diameter, diametral two-roll measurement, DIN standard of the external spline.

When ordering please quote:
Module, pressure angle, tip circle diameter, root circle diameter, diametral two-roll measurement, DIN standard of the external spline.

When ordering please quote:
Module, pressure angle, tip circle diameter, root circle diameter, diametral two-roll measurement, DIN standard of the external spline.

When ordering please quote:
Module, pressure angle, tip circle diameter, root circle diameter, diametral two-roll measurement, DIN standard of the external spline.

When ordering please quote:
Module, pressure angle, tip circle diameter, root circle diameter, diametral two-roll measurement, DIN standard of the external spline.

When ordering please quote:
Module, pressure angle, tip circle diameter, root circle diameter, diametral two-roll measurement, DIN standard of the external spline.

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When ordering please quote:
Module, pressure angle, tip circle diameter, root circle diameter, diametral two-roll measurement, DIN standard of the external spline.

When ordering please quote:
Module, pressure angle, tip circle diameter, root circle diameter, diametral two-roll measurement, DIN standard of the external spline.

When ordering please quote:
Module, pressure angle, tip circle diameter, root circle diameter, diametral two-roll measurement, DIN standard of the external spline.

When ordering please quote:
Module, pressure angle, tip circle diameter, root circle diameter, diametral two-roll measurement, DIN standard of the external spline.

When ordering please quote:
Module, pressure angle, tip circle diameter, root circle diameter, diametral two-roll measurement, DIN standard of the external spline.

When ordering please quote:
Module, pressure angle, tip circle diameter, root circle diameter, diametral two-roll measurement, DIN standard of the external spline.

When ordering please quote:
Module, pressure angle, tip circle diameter, root circle diameter, diametral two-roll measurement, DIN standard of the external spline.

When ordering please quote:
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When ordering please quote:
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When ordering please quote:
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Module, pressure angle, tip circle diameter, root circle diameter, diametral two-roll measurement, DIN standard of the external spline.

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When ordering please quote:
Module, pressure angle, tip circle diameter, root circle diameter, diametral two-roll measurement, DIN standard of the external spline.

When ordering please quote:
Module, pressure angle, tip circle diameter, root circle diameter, diametral two-roll measurement, DIN standard of the external spline.

When ordering please quote:
Module, pressure angle, tip circle diameter, root circle diameter, diametral two-roll measurement, DIN standard of the external spline.

When ordering please quote:
Module, pressure angle, tip circle diameter, root circle diameter, diametral two-roll measurement, DIN standard of the external spline.

When ordering please quote:
Module, pressure angle, tip circle diameter, root circle diameter, diametral two-roll measurement, DIN standard of the external spline.

When ordering please quote:
Module, pressure angle, tip circle diameter, root circle diameter, diametral two-roll measurement, DIN standard of the external spline.
Modern cutting materials are characterized by the combination of excellent machining and application properties. Specific cutting materials are used depending on the application spectrum and the cutting parameters. Cobalt alloyed high speed steels (KHSS-E) manufactured in the conventional way are not used much now due to their low wear resistance and hot hardness, when compared to the materials of the powder metallurgy product family. With the powder metallurgy method (PM), the percentage of carbides (wear resistance properties) can be increased while improving toughness.

The SpeedCore cutting material represents the continuous development of the PM-HSS cutting materials. Compared to PM-HSS materials, SpeedCore offers an excellent and markedly increased combination of higher hot hardness (= hardness during use) and a higher toughness which results in higher cutting values during use.

The generic term carbide includes materials that were manufactured with the powder-metallurgy method which are mostly made up from tungsten carbide (WC) and the matrix binder material cobalt (Co). A technological comparison between the cutting materials available in the market today is contained in the table below.

The operating temperatures of KHSS-E that has been manufactured in the conventional way are around 480 °C. By using the powder-metallurgy method, a higher cobalt content can be achieved, but also a higher percentage of carbide in the PM-HSS, so that the maximum operating temperatures increase to approx. 620 °C.

The combination of manufacturing with the powder-metallurgy method and the inter-metallic structural composition enables a much higher continuous operating temperature of approx. 620 °C for the SpeedCore cutting material, while maintaining the same toughness as PM-HSS cutting materials. Carbide also enables operating temperatures up to approx. 800–1000 °C. These properties make SpeedCore and carbide the ideal materials for machining at high cutting speeds, both for wet and dry.

<table>
<thead>
<tr>
<th>特性值</th>
<th>Characteristics</th>
<th>单位</th>
<th>Unit</th>
<th>KHSS-E</th>
<th>PM-HSS</th>
<th>SpeedCore</th>
<th>Hartmetall Carbide</th>
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<tbody>
<tr>
<td>23℃硬度</td>
<td>Hardness 23 °C</td>
<td>HV10</td>
<td>860–900</td>
<td>880–960</td>
<td>920–940</td>
<td>1500–1900</td>
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<tr>
<td>600℃硬度</td>
<td>Hardness 600 °C</td>
<td>HV10</td>
<td>400–450</td>
<td>450–540</td>
<td>590–630</td>
<td>1200–1500</td>
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<tr>
<td>密度</td>
<td>Density</td>
<td>g/cm³</td>
<td>8–8.3</td>
<td>8.1–8.3</td>
<td>8.2</td>
<td>11–15</td>
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<td>E-Module</td>
<td>kN/mm²</td>
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<td>225–241</td>
<td>224</td>
<td>500–660</td>
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<td>导热系数</td>
<td>Thermal conductivity (up to 20 °C)</td>
<td>W/(m · °C)</td>
<td>19</td>
<td>17–19</td>
<td>32</td>
<td>30–100</td>
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<tr>
<td>热膨胀系数</td>
<td>Coefficient of thermal expansion</td>
<td>m · 10⁻⁹/(m · K)</td>
<td>10–13</td>
<td>10–11</td>
<td>10–11</td>
<td>5–7</td>
<td></td>
</tr>
</tbody>
</table>

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For the coating of gear hobs, the PVD (Physical Vapor Deposition) method is used. It is a plasma vacuum thin layer method, during which high-purity materials are transferred into a plasma via an arc or cathode sputtering. By reacting with reactive gases such as oxygen, nitrogen or carbon, ceramic hard material layers are deposited on the tools.

The generated hard material PVD layers normally consist of refractory metals such as chrome, titanium or tantalum, alloyed with aluminum, silicon and a non-metal (oxygen, nitrogen, boron and carbon). Layer systems which are used for gear cutting today are titanium-aluminum-nitrogen (TiAlN) or aluminum-chrome-nitrogen (AlCrN). The high-performance coatings used are made up of several layers which enables both a high elasticity and high wear resistance.

By rotating the tools along multiple axes during the coating process, an even and homogenous thickness of the layers is achieved on the tool surfaces.

The coating temperatures are in the range of 450 °C. The high-precision coating process management enables the deposition of very thin coatings, to achieve a very sharp and defined cutting edge.

Today, nearly 100% of gear cutting tools are coated.
AIrN PVD 涂层的示意图
Schematic of the PVD layer system AIrN

涂层 - 提高生产率，详见 www.imt-tools.de, watched us on YouTube
Coatings - increased productivity guaranteed, see www.imt-tools.de, watched us on YouTube
Hard material coatings for gear cutting tools

Apart from the high hardness, it is the friction-physical and chemical properties which lead to the extreme tool life increases of coated tools in comparison to uncoated tools. The low chemical affinity of the coating to the hot steel chip results in less friction and, consequently, less friction heat and, therefore, less wear.

The coatings acts like a barrier that shields the substrate below against wear.

Of particular interest to the user are the greater cutting and feeding speeds that can be achieved with coated tools. However, the focus is not only on longer tool life, but also on the reduction of main manufacturing times. The payback period for the coating costs is, therefore, very low for coated gear hobs.

During the manufacture of a sun wheel the tool life of the HSS gear hob increased 5-fold from 100 to 502 gears by adding a coating. After regrinding, the tool was not re-coated and was, therefore, uncoated on the machining surface and coated on the flank only. In this condition, the tool achieved a tool life of an average of 251 manufactured wheels. During a total of 22 grinding cycles, a total of 2300 wheels were manufactured with the uncoated gear hob against a total of 8024 wheels with the uncoated gear hob, i.e. 2.6 times as many. The comparatively small additional cost of the coating therefore easily paid for itself.

Re-coating after grinding the machine surface of the worn gear hob therefore makes sense with regard to costs.
磨损的演变过程

刀具切削刃在使用过程中会受到各种外部因素的影响，这些影响都将促成刀具的磨损。其中加工温度对磨损的影响最大。加工热流量的主要来源以及对刀具整体温度的影响包括：
- 刀具切削刃位置的塑性变形：60%
- 切屑和工具切削刃表面之间的摩擦现象：20%
- 加工工具和刀具后刀面间的摩擦现象：20%

其中一部分热量（大约占总热量的5-10%）传输到刀具上，并使切削材料发生软化。加工温度越高，切削材料就会变得越软，因而对刃具产生的耐磨性就越小。加工过程中大约75-80%的热量通过切屑散发掉了。

随着温度的不断上升，机械摩擦（氧化）比率和热扩散开始显著上升。随着温度迅速上升到某个指定温度后，刀具的使用寿命会急剧降低，以致最终超出其经济上的使用极限。

因此，每一种切削材料在进行不同的加工任务时都具有一个最佳的切削温度范围。被加工的材料、加工要求的公差值、特定的加工条件（如系统的刚性、冷却效率以及切削材料的热稳定性等）对确定该材料的切削速度范围内有重要的影响。

The cutting edge of the tool that is being used is subject to external influences which, collectively, result in tool wear. The machine temperature plays a major part in this. The main machining process temperature sources and their approximate contribution to the total temperature are as follows:
- Plastic deformation in the workpiece just before the cutting edge ... 60 %
- Friction effects between chip and tool machining surface ... 20 %
- Friction effects between workpiece and tool flank ... 20 %

A part of this heat (approx. 5-10 %) flows into the tool and leads to a softening of the cutting material. The higher the operating temperature, the softer the cutting material becomes and the less resistance it has against abrasive friction wear.

Approx. 70-80 % of the heat is dissipated via the chip. With high cutting values, in particular, which coincide with high machining temperatures there will be overlaps of the wear mechanisms of scaling (or oxidation) and diffusion. Their dramatic increase with rising temperatures defines a critical operating temperature limit above which tool lives decrease dramatically, even to the extent of being uneconomical.

Depending on the application, there is a range of optimum speeds for each cutting material. The material to be machined, the required manufacturing tolerances, the machine conditions such as system rigidities, machining conditions, e. g. wet or dry machining and the high temperature strength of the material play an important part in this.

切削刀具的磨损形式

典型迹象的刀具磨损

图中展示了切削刀具在使用过程中的磨损情况，包括切削刃的切削现象、后刀面磨损和其他形式的磨损。

图中还展示了不同材料的热硬度随温度变化的曲线图，包括硬质合金、碳化物、粉末高速钢和高速钢。

www.1mt-tools.com 137
磨损的演变过程
How wear develops

滚齿还有一个现象，即齿刀应力作用位置的磨损现象。其原因在于切削刀具在加工过程中在几个切削面积上的切削造成的。金属的切削量主要是由滚齿的齿形刃实现的，它在切削过程中生成大量的较厚的金属碎屑和相应的热强度。相比之下，滚刀齿面积部分所产生的金属碎屑较薄得多；特定的条件下使刀具开口相对较小，因而该位置在切削时生成热量的部件的加工磨损力也相对较大。与此同时，其产生的碎屑较薄，较小，而且吸热量也较低。于是会产生更多的热量转移到刀具上。

通过刀具移位来补偿刀具的局部磨损。刀具移位会使刀具的应力分布更加均匀，以致分布到每个刀具和每个增强上。热能产生磨损而产生的热能对会均匀分布到整个刀具上。

在刀具移位过程中，刀具区域暂时没有参与加工过程，因此有足够的空间进行冷却处理。

The resulting locally exaggerated wear is compensated for by shifting. Shifting produces a more even tool stress distribution, with regard both to the hob as a whole, and to the individual cutter tooth. Both the abrasive and the thermally generated wear mechanisms are distributed more evenly over the tool.

During coarse shifting, in particular, cutter regions temporarily uninvolved in the machining process have sufficient opportunity to cool down.

温度导致的磨损（根据Viergge）
Causes of wear against temperature (according to Viergge)

![Diagram showing causes of wear against temperature](image)

- a - 初始刀刃磨损
  Initial edge wear
- b - 机械磨损
  Mechanical abrasion
- c - 刀磨
  Built-up edge
- d - 氧化
  Oxidation
- e - 扩散
  Diffusion

总和 Total

切削速度/温度 Cutting speed/temperature
滚削加工的切削条件主要指切削速度和进给量。

“滚削加工的切削条件”篇章中的切削速度和进给量必须视为推荐值。一般情况下用户应根据这些推荐值指导其齿轮的加工。切削参数的优化目前只能在工作实践中获得。高参数的优化从各个相关方面对切削参数的选择加以考虑。

优化的目标可能有所不同。例如：
- 缩短加工时间；
- 提高刀具使用寿命；
- 降低刀具或齿轮的成本；
- 改善加工齿轮的质量。

只有综合考虑了加工工件、滚刀和滚齿机之间的相互作用关系才能正确选择合理的加工参数。

滚削加工过程中的切削参数受以下因素影响：
- 齿轮的材料：化学分析、热处理，拉伸强度，微观结构，可加工性能；
- 刀具的切削材料：硬质合金，等离子合金、化学分析，工作硬度，硬度性，表面类型；
- 加工设备的状况：稳定性，加工精度；
- 工件夹具：径向拉紧，轴向推紧，对变形和振动的预防能力；
- 滚刀的装夹：径向装夹，轴向装夹，滚刀轴承的最小可能间隙。
- 齿数尺寸：模数，切深
- 刀具使用寿命和刀具质量寿命；
- 规定的齿轮质量

最后，决定切削条件的重要因素还包括对精加工和粗加工的不同要求。

对于粗加工，选择可能的最大进给量是为了获得最大的金属切除率。而对齿面的表面质量要求则是其次要求。

在精加工过程中，选择切削条件时必须保证齿轮的质量和表面加工精度。

当然，在选择不同的切削条件时还必须考虑到经济性方面。为了确定切削参数的最佳组合方式，计算刀具和设备的使用费用以及加工所需的时间是很有必要的。

The cutting conditions applicable to hobbing are principally the cutting speeds and the feeds.

The cutting speeds and feeds quoted in these “cutting conditions in hobbing” must be regarded as recommendations. The user will in normal cases be able to cut his gears properly with these recommended values. An optimization of the cutting values is only possible on site, taking into account all the peripheral aspects.

The objectives of optimization may differ.
Examples:
- Short machining times
- High tool life quality
- Low tool or gear costs
- Improvement of the gear quality

A correct choice of cutting conditions is only possible if the interrelation of the workpiece, the hob and the hobbing machine is taken into account.

The cutting conditions in hobbing are mainly affected by:
- Gear material: chemical analysis, heat treatment, tensile strength, microstructure, machineability
- Cutting material of the cutter: SpeedCore, KHSS-E, carbide, chemical analysis, working hardness, red hardness, coating type
- Condition of the hobbing machine: stability, accuracy
- Workpiece clamping: radial runout, axial runout, avoidance of deformation and vibration
- Clamping of the hob: radial runout, axial runout, smallest possible hob spindle bearing clearance
- Gear size: module, cutting depth
- Tool life and tool life quality
- Requisite gear quality

Important for determining the cutting conditions are not least the varying demands made on the roughing and finishing operations.

For roughing, the highest possible feeds are selected in order for a high rate of metal removal to be attained. The surface quality of the flank which can be attained is of secondary importance.

The cutting conditions during finishing must be chosen so that the required gear quality and surface finish are achieved.

Attention must of course be paid to economic aspects during selection of the cutting conditions. It may be necessary to calculate the tool and machine costs and the machining times in order to ascertain the most favourable combination of cutting parameters.
Cutting conditions in hobbing

Cutting materials for gear hobs
Gear hobs are manufactured from both KHSS-E (cobalt alloyed high-performance high-speed steels) and carbides. The most commonly used cutting material is HSS-PM which is made with the powder metallurgy method. It can be used both with and without cooling. For applications without cooling, the tool must be fully coated.

Gear hobs made from SpeedCore can be hardened more without losing toughness. This cutting material is used if higher cutting speeds need to be achieved when compared to HSS-PM, but carbides are not suitable due to the process.

If carbide gear hobs are used for the machining of gears up to approx. module 3 from the solid, the cutting speed is higher by a factor of 3 compared to gear hobs made from KHSS-E. These gear hobs are always coated.

Machineability
The machineability of a gear material can be referenced to a range of characteristics.

### Machineability of the gear materials

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Pre-Numerical</th>
<th>Numerical</th>
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</thead>
<tbody>
<tr>
<td>Plain carbon steels</td>
<td>1</td>
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<tr>
<td>Nickel steels and chrome/nickel steels (low alloy)</td>
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<tr>
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<tr>
<td>Chromium steels and chrome/vanadium steels</td>
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</tr>
<tr>
<td>Silicon/manganese steels</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Chromium steels</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>
Whether a material can be machined easily or not is determined by whether it can be machined at high or low cutting speeds, and with an acceptable tool life quality and wear mark widths.

The machineability can however also be assessed according to the requisite cutting forces, or the ease or difficulty with which a favourable surface quality can be attained.

For the selection of the cutting speed for hobbing, it must first be assumed that a certain wear mark width must not be exceeded (see also “Maintenance of hobs”, page 160). High wear leads to geometric deviations in the cutting edges of the cutter teeth, and to high cutting forces. The result is a reduction in gear quality.

Since the wear increases disproportionately beyond a certain magnitude, the wear mark width must also be reduced for economic reasons.

At the same time, however, an economic tool life between successive cutter regrinds must be ensured. Excessively short tool life leads to long down times of the hobbing machine for the purpose of cutter changes, and to high regrinding costs. In this case, the machineability of the gear material is therefore assessed in relation to the cutting speed at an appropriate tool life quality and wear mark width. The machineability of the gear material as a function of its chemical composition and the tensile strength $R_m$ in N/mm² or the Brinell Hardness HB can be taken from Diagram 1 (original diagram as [1], with minor modifications). The machineability of B1112 steel to AISI (American Iron and Steel Institute) was specified as 100% at a cutting speed of 55 m/min for this purpose, all other steel grades were categorized relative to these values. The machineability is indicated in percent.

Note however that the machineability is influenced not only by the tensile strength, but also by the different microstructures. The relative machineability probably also varies for other cutting speed ranges, as gears with small modules are machined at cutting speeds which are around twice as high as those for which the curves shown were produced. It can however be safely assumed that the machineability must be assessed differently for coated and uncoated hobs, as the chip formation differs markedly.

Cutting speed $v_c$ [m/min]
Diagram 2 (page 142) shows the cutting speed as a function of the module and the machineability. This cutting speed relates to the cutting material S-6-5-2-6 (1.3243, EmoSc05), and applies to the roughing cut (milling from the solid).

For the finishing (second) cut, the cutting speed can be increased by a factor of 1.25.

The cutting speed can be multiplied by a factor of 1.25 for coated KHSS-E hobs.
我們给出了兩個表推薦數值，採用粉末高速鋼制造的鈷刀根據實踐得到的切削速度。

一般的輪機材料根據其可加工性能的高低分為“好”、“中”、“差”三類。切削速度按照每個輪機加工模數和精加工和粗加工進行了分類。表1則根據刀具是否帶有TIN塗層進行了細分。

使用整體硬質合金鈷刀加工模數在3以內的齒輪可以使用或不使用冷卻液如下：

齒輪材料：表面硬化或冷處理鋼材，抗拉強度可達800N/mm²。

切削速度：
帶潤滑冷卻時：
220到250m/min；
不帶潤滑冷卻時：
280到350m/min。

上述鈷刀都有塗層處理

We gave compiled another two tables with reference values for cutting speeds during milling with gear hobs made from HSS-PM, based on practical experience. Commonly used gear materials are classified in the categories “good”, “medium” and “difficult” with regard to their machining properties. The cutting speeds are indicated in relation to the module for roughening cuts and for finishing cuts. The table is subdivided into milling with cooling and without cooling.

Carbide hobs for machining of gears up to approximately module 3 from the solid can be used with or without cooling lubricant as follows:

Gear material: case hardening and heat-treatable steels, tensile strength up to 800 N/mm².

Cutting speed:
220 to 250 m/min
with cooling lubricant;
280 to 350 m/min
without cooling lubricant.

These hobs are all coated.

2

## 切削時的切削速度

*Cutting speed when hobbing*

![Graph of cutting speed vs. machineability in %](image)

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可加工性能 %

Machineability in %

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**Mechanical Machinability**

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</table>

* www.imt-tools.com
Axial feed \( f_c \) [mm/workpiece rotation]
The axial feed is specified in mm per workpiece rotation.

Owing to the large number of parameters which influence the machining process during hobbing, experience has shown that the axial feed is best specified as a function of the tip chip thickness.

The tip chip thickness is the theoretical maximum chip thickness removed by the tips of the hob teeth.

The tip chip thickness is regarded as a criterion for the hob stress; high tip chip thicknesses mean high cutting forces and short tool life.

The tip chip thicknesses are increased when the module, axial feed, cutting depth and number of starts are increased. The tip chip thicknesses are reduced when the number of gear teeth, hob diameter and number of gashes are increased.

Hoffmeister [1] has devised a formula for the maximum tip chip thickness.

If this formula is transposed, the axial feed can be calculated as a function of the other gear parameters. Experience has shown a tip chip thickness of 0.2 to 0.25 mm to be a realistic value.

For economic reasons, as high an axial feed as possible is aimed for, as the machining time is reduced proportional to the increase in feed.

---

**Example:**

- \( m = 4 \)  
- \( \beta_0 = 16 \)  
- \( r_{hi} = 55 \)  
- \( f_c = 4 \)  

**Notes:**

- \( m \) = Module
- \( Z_2 \) = Number of teeth
- \( \beta_0 \) = Helix angle (degree unit)
- \( \alpha \) = Profile displacement factor
- \( r_{hi} \) = Hob radius
- \( i \) = Number of gashes/number of starts
- \( f_c \) = Axial feed
- \( a \) = Cutting depth

---

**References:**

  
  Dissertation by Bernd Hoffmeister 1970
Note however that the depth of the feed markings increases quadratically with the axial feed, and that different maximum feed marking depths are permissible according to the machining step such as finish-milling, rough-hobbing prior to shaving, or rough-hobbing prior to grinding, depending upon the gear quality or the allowance.

If carbide hobs are employed for machining from the solid, the maximum tip chip thickness must be between 0.12 and 0.20 mm. For carbide hobbing without cooling lubricant, in particular, 80 % of the heat generated by the cutting process must be dissipated by the chips. Adequate chip cross-sections are therefore required. For this reason, the tip chip thickness should not be less than 0.12 mm.

Number of starts of the hob
With the exception of worm gear hobs, multiple start hobs have the function of increasing hobbing performance.

It is known that the axial feed must be reduced for a given tip chip thickness when the number of starts is increased (formula for the maximum tip chip thickness according to Hoffmeister).

It is also known that the depth of the feed markings is dependent upon the axial feed (formula for the depth of the axial feed markings).

Machining time (production time) for hobbing

$$t_h = \frac{Z_2 \cdot d_{20} \cdot \pi \cdot (E + b + A)}{Z_0 \cdot f_a \cdot V_c \cdot 1000} \quad [\text{min}]$$

- $t_h$ [min] = Machining time
- $Z_2$ = Number of teeth of the gear to be machined
- $d_{20}$ [mm] = Tip circle diameter of the hob
- $E$ [mm] = Approach length of the hob
- $b$ [mm] = Tooth width of the gear to be machined
- $A$ [mm] = Idle travel distance of the hob
- $Z_0$ = Number of starts of the hob
- $f_a$ [mm/WU] = Axial feed
- $V_c$ [m/min] = Cutting speed

$$\delta_c [\text{mm}] = \left(\frac{f_a}{\cos \beta_0}\right)^2 \cdot \frac{\sin \alpha_n}{4 \cdot d_{20}}$$

- $\delta_c$ [mm] = Feed marking depth
- $f_a$ [mm/WU] = Axial feed
- $\beta_0$ = Helix angle
- $\alpha_n$ = Profile angle
- $d_{20}$ [mm] = Tip circle diameter of the hob

www.imt-tools.com 145
### 多头滚刀的进给量和进给标记深度

<table>
<thead>
<tr>
<th>列</th>
<th>线/列</th>
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<td>3</td>
<td>4</td>
<td>5</td>
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<td>0.2</td>
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<td>f0 x fA</td>
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<td>相对加工时间</td>
<td>Relative machining time</td>
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<td>1.64</td>
<td>2.2</td>
<td>2.69</td>
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<tr>
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<td>Depth of the feed markings</td>
<td>0.026</td>
<td>0.019</td>
<td>0.005</td>
<td>0.002</td>
<td>0.001</td>
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因此，刀头数量、刀刃切削厚度和轴向进给量之间存在一定的关系。通过公式和实验可以得出台词式加工时间、刀头数目和轴向进给量之间的关系。例如当产品的刀头数量和轴向进给量增加时，加工时间就会减少。

因此，选择产品的目标是在不改变刀刃切削厚度和进给量标记深度过大的情况下选择刀头数量和轴向进给量保持最大。

### 根据刀刃切削厚度和进给标记深度确定刀头数量的详细说明

表中以一个齿轮为例列出了刀头数量和轴向进给量的优化值。

刀头数量为1~5的刀刃切削厚度恒定为0.2mm，分别位于第2到6列。

第11列包含刀刃切削厚度为0.2mm时的允许最小进给量。

第12列显示的是产品的刀头数量和轴向进给量。

第2列的相对加工时间等于1，其余列的加工时间根据第2列进行计算。

第13列清晰列出了给定的刀刃切削厚度，单头滚刀可以获得最短加工时间。第14列显示出进给标记深度过小，为0.206mm。

There is therefore a relationship between the number of starts, the tip chip thickness and the axial feed, and between the axial feed and the depth of the feed markings.

In the formula for the machining time, the number of starts and the axial feed form part of the denominator, i.e. the greater the product of the number of starts and the axial feed, the shorter the machining time.

The objective is to select a product of the number of starts and the axial feed which is as high as possible without the tip chip thickness and the depth of the feed markings becoming too great.

<table>
<thead>
<tr>
<th>Specification of the number of starts on the basis of the tip chip thickness and the depth of the feed markings</th>
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<tbody>
<tr>
<td>The table shows the optimization of the number of starts and the axial feed by way of an example gear.</td>
</tr>
<tr>
<td>The number of starts 1 to 6 and a constant tip chip thickness of 0.2 mm were entered in columns 2 to 6.</td>
</tr>
</tbody>
</table>

Line 11 contains the maximum feeds permissible at a tip chip thickness of 0.2 mm.

Line 12 shows the product of the number of starts and the axial feed.

The relative machining time in column 2 is made equal to 1 and the machining times in the following columns calculated in relation to column 2.

Line 13 shows clearly that for a given tip chip thickness, the shortest machining time can be achieved with the single-start hob. Line 14 also shows how the depth of the feed markings becomes excessive, at 0.206 mm.
对于双头滚刀，其进给量必须减少到单头滚刀的约30%。刀头
数量从某种程度上对进给量进行了补偿，如此中的工作台速度是
相同切削速度下的两倍。虽然进给标记深度只有0.019mm，但
是4.78mm的轴向进给量无论对于初削或磨削加工前的粗磨加工
都还是可以接受的。

因此，如果假定齿轮在粗削或磨削加工之前进行滚磨加工，那么
使用双头滚刀，进给量为9.56mm进行加工是最经济的解决方法。

单头滚刀不是可选方案，因为受到进给标记深度和头数的限
制，它的允许最大进给量只有4.78mm，而其轴向进给量也有
4.78mm。

三头滚刀也不适用于该加工情况，受到最大刀刃切削碎屑厚度的
限制，刀头的轴向进给量只有7.14。

因此，计算有关刀头的数量必须首先计算允许进给标记深度，然
后再计算最大轴向进给量。在选择刀头数量时，应保证该刀头在
不超过进给标记深度要求或最大刀刃切削碎屑厚度的条件下，使
刀头数量能够最多，并产生最大的轴向进给量(第11行)。

包络切削误差
尽管多刀头滚削加工具有很多经济方面的优点，但我们仍然不能
忽略它在加工精度方面的情况。根据上述描述的情况进行选择
时，是否选用多头滚刀还需要根据具体加工情况而定。

形成齿面的滚刀齿数的多少取决于齿轮的齿数和压力角大小和滚
刀的切削槽数、齿距和头数。

如果切削槽数保持不变，形成齿形的滚刀齿数，如双头刀或三刀
头滚刀，会减半或减少至三分之一。此时生成的包络网的密度会
有所降低，而包络切削误差会随着齿形所生成的轮廓偏差而增
加。当齿轮的齿数较少时，对包络切削误差的计算和检查尤其重
要，此时包络切削误差会增加，因为轮廓曲线的弯曲很大，每个
滚刀切削的工件也会有相当大的扭度度。

我们可以通过增加切削槽数来显著地减少包络切削误差。

With the two-start hob, the feed must be reduced to approxi-
mately 30% of that of the single-start hob. This is however com-
penated for to some degree by the number of starts, as the table
speed is doubled for the same cutting speed. Since the depth of
the feed markings is only 0.019 mm, however, the axial feed of
4.78 mm is acceptable, either for rough-hobbing prior to shaving
or grinding.

If it is therefore assumed that the gear is being rough-hobbed
prior to shaving or grinding, the two-start hob, with a product of
feed and number of starts of 9.56, represents the most economic
solution.

The single-start hob is not an option, as it permits a maximum
feed of only 4.78 mm even with the single-start hob owing to the
depth of the feed markings, and the product of the number of
starts and the axial feed would only be 4.78.

The three-start hob is also unsuitable in this case, as the product
of the number of starts and the axial feed is only 7.14, owing to
the maximum tip chip thickness.

Specification of the number of starts should therefore first entail
calculation of the maximum axial feed for the permissible depth
of the feed markings. A hob should then be selected with the
number of starts which produces the greatest product of number
of starts and axial feed without the maximum axial feed being ex-
ceeded owing to the depth of the feed markings or the maximum
tip chip thickness (line 11).

Enveloping cut deviations (page 148)
Despite the economic advantages offered by multiple start hobs,
the accuracy of the gear must not be ignored. Whether multiple
start hobs selected as described above can in fact be used must
therefore be considered on a case-by-case basis.

The number of cutter teeth which profile a tooth flank depends
upon the number of teeth and the pressure angle of the gear, and
the number of gashes, pitch and number of starts of the hob.

Provided the number of gashes remains unchanged, the num-
er of cutter teeth forming the profile for example on two- or
three-start hobs is reduced to half or one-third. The envelope
network which is generated is less dense, and the enveloping
cut deviations arise in the form of deviations in the profile form.
Calculation and examination of the enveloping cut deviations is
particularly important when the number of gear teeth is low,
as particularly large enveloping cut deviations arise in this case
owing to the strong curvature of the profile and the relatively large
 torsional angle of the workpiece per cutter tooth.

The enveloping cut deviations can be reduced considerably by
increasing the number of gashes.
刀具刀头的数量对齿面形状和齿轮齿距的影响
为了避免齿面齿面的包络网，对于典型的滚齿加工而言，必须考虑到每个滚齿齿面只能形成一次包络切削，而且包络切削之间的相对位置取决于刀齿面的精度以及滚齿加工设备的分度精度。

单头滚刀对齿轮的分度精度没有影响，因为工件所有的齿都是由一把相同的单头滚刀加工完成的。单头滚刀的加工误差只会影响加工齿轮的齿面形状。

与单头滚刀相比，多头滚刀的齿数按照预先确定的刀头数量进行划分，若头滚刀对齿轮的分度精度有一定的影响。在这种情况下，齿槽的形状是通过一个滚刀刀头加工完成的。这时，刀具齿面齿距的偏差会导致加工工件的齿距产生周期性偏差。由于这种偏差只能通过再次加工进行部分消除（例如剃削），因此应选择具有一定剃削余量的多头滚刀进行加工，此时齿数和刀头数量之比不能是整数。

表面结构
然而，我们仍然应该确定在加工时切屑的宽度和刀头的数量之比不是整数。否则所加工的包络切削从刀头到刀头之间的高度不会相同，而且加工好的齿面还会形成蜂窝状结构。

Enveloping cut deviations

$$\delta y [\text{mm}] = \frac{x^2 \cdot z_3 \cdot m_n \cdot \sin \alpha_n}{4 \cdot z_2 \cdot i^2}$$

$$\delta y [\text{mm}] = \text{包络切削偏差量}$$

- $d$ = 刀头数量
- $m_n$ = 法向模数
- $\alpha_n$ = 舌形角
- $z_2$ = 齿数
- $i$ = 刀具切削模数

Surface structure
However, it should also be ensured that the quotient of the number of gashes and the number of leads during finishing is not an integer. The enveloping cuts will otherwise be generated at different heights from lead to lead, and the tooth flanks will acquire a honeycombed surface structure.
Limitation of the number of leads on the hobs with axially parallel gashes
On hobs with axially parallel gashes, ensure that the increase in the number of leads does not result in a helix angle of 7.5° being exceeded. The surface quality on the corresponding gear flank will otherwise be impaired owing to the excessive wedge angle on the leaving cutter flank.

References

参考:
A distinction must be drawn in hobbing between the pre-cutting zone and the profile generating zone. The greater part of the volume to be machined is removed in the pre-cutting zone. The pre-cutting zone is at the end of the hob which first enters the body of the gear during axial machining. The hob must be positioned until it completely covers the pre-cutting zone. This cutter length, the minimum required, is termed the tool cutting edge length.

The penetration curve (fig. 1) of the tip cylinder of the gear and the cutter must be known for calculation of the setting length. For the considerations below, it is assumed that the gear is helical and that the cutting axis is inclined to the horizontal by the pivoting angle \( \beta - \gamma_0 \). A further assumption is that where a helix angle is present, it is always greater than the lead angle. The direction of view of the penetration curve is from the main machine column in the direction of the cutter and the gear.

The two tip cylinders penetrate each other at a depth equivalent to the cutting depth. The intersecting line between the two bodies is a 3-dimensional curve which follows both on the gear and the cutter cylinder. Where reference is made below to the penetration curve, the projection of the intersecting line into a plane axially parallel to the cutter axis is understood.
贯穿曲线的尺寸和形状取决于：
- 齿轮齿顶圆的直径；
- 刀具直径；
- 旋转轴旋转的角度（齿轮的螺旋角与刀具的进给角度β）。
- 切削深度。

贯穿曲线的计算公式可以参见第168页图13的“磨损的摩擦现象”章节的内容。

所有在旋转过程中不穿过贯穿曲线的刀具切削齿都不会接触到齿轮。因此就不构成加工废屑。对于水平方向穿过贯穿轴的“S”和刀具轴的部分，点1为贯穿曲线的最高点，而点1’为贯穿曲线的最低点。

斜齿

螺纹加工，与螺旋角方向相同

螺纹加工过程中，当刀具从齿轮的较高的平面位置向较低的平面位置，经过点1位置的刀具首先与齿轮的齿顶圆柱相交处。然后刀具的刀刃固定在刀具螺旋方向角所在的平面上，即点1和点1A所在的位置。该点到“S”点的直线正好与刀具的轴线平行，其距离等于点“S”和1A之间的距离。相当于点1与经过轴线“S”和1A之间的刀具长度：

由于通常刀具会向着切削面进行变化，所以加工时，是根据上述计算的方法来计算出来的刀具长度来确定的。如果选择的刀具切削刃长度较短，那么刀具在加工中可能无法切削齿，接下来的加工刀将承担那些较短的功能切削材料。这会导致第二个进入加工区域的齿产生加工应力过大。如果选择的刀具切削刃过长，那么所使用的刀具就不够经济适用，即刀具前段的刀具部分无法参与加工并使用。

The form and dimension of the penetration curve are dependent upon:
- The tip circle diameter of the gear
- The cutter diameter
- The pivoting angle (helix angle β of the gear, lead angle γ of the cutter)
- The cutting depth

The formulae for calculation of the penetration curve can be found in the Chapter "Wear phenomena in hobbing", page 188, fig. 13.

All cutter teeth which do not pass through the penetration curve (fig. 2) during rotation of the cutter do not make contact with the gear body. They are not therefore involved in chip formation. With respect to the horizontal which passes through the intersection “S” of the gear axis and the cutter axis. Point 1 is the highest and Point 1’ the lowest point of the penetration curve.

Helical teeth

Climb hobbing, same lead direction

When the cutter moves from upwards to the lower face of the gear during climb hobbing, the cutter tooth whose path passes through Point 1 is the first to intersect the tip cylinder of the gear. This cutter tooth is then located in a plane at right-angles to the cutter axis, in which Points 1 and 1A are located. The distance to the point “S”, measured parallel to the cutter axis, is equal to the path of which “S” and 1A are the end points. It is equivalent to the cutter length for the Point 1 in relation to the section through the axis “S”.

Following one rotation of the gear, the cutter has moved upwards by the axial feed. A parallel at a distance “L” to the horizontal through Point 1 intersects the penetration curve at Points 3 and 4. The hatched band between the parallels through Points 1 and 4 corresponds to the band of material which is pushed continuously into the working area of the cutter during the machining process. Point 4 is the point on the penetration curve which is still involved in material removal and is located furthest from the axis intersection “S”. All cutter teeth whose paths run through the penetration curve but which are located further away from the point “S” are not involved in the material removal process. The cutter length corresponding to Point 4 is marked “L” in fig. 2. This is the tool cutting edge length of the cutter during climb hobbing of a helical-tooth gear with a cutter which has the same direction of lead as the gear.

Since the cutter is generally shifted towards the cutter entering side, the entering side is positioned at the start of the machining process according to the tool cutting edge length calculated as described above. If a shorter tool cutting edge length were to be selected for the cutter teeth would be absent in the entering zone, and the following teeth would have to assume part of the missing teeth's function of material removal. This could lead to overloadings of the first teeth in the entering zone. Were an excessively long tool cutting edge length to be selected, the cutter would not be economically viable, as the teeth ahead of the tool cutting edge length would not be used.
顺铣加工，与进刀方向相反
如果使用右旋方向的刀具（与进刀方向相反）替代左旋方向的刀具，那么刀具的切削刃角度（β + γa）会发生改变。齿轮从左向右进入刀具的加工区域（贯穿曲线）。切削材料的最外端点为点1。

然后点1处的刀具切削刃长度等于刀具的切削刃长度。在使用反进刀方向的刀具进行顺铣加工时，刀具切削刃长度略短于相同进刀方向的刀具长度。这并不是由进给量的大小确定的。

逆铣加工，与进刀方向相同
如果刀具向下移动到齿轮上表面，经过点1位置的切削齿首先与齿轮外圆的外圆柱面接触，刀具的切削刃长度等于长度l1。

两个半贯穿曲线自左至右沿着刀具轴线的法线方向经过点“S”是比较合理的，反向经过点S的法线和刀具轴线一周，l1 = l1, l4 = l4 = 14°。

组合顺铣方式和齿轮与滚刀的进刀方向
表1显示了采用不同组合加工方法和齿轮与滚刀进刀方向下的进刀末端，螺旋角角度以及刀具的切削刃长度。“顺铣左转”是指从左至右经过贯穿曲线。”顺铣左转”是指刀具切削刃在贯穿曲线上的长度为l4。该位置位于齿轮的左侧。刀具切削刃长度所在的刀面朝上。

再次假设：
观察方向沿主加工设备到刀具和齿轮的方向。对于斜齿轮，螺旋角大于刀具的进刀角度。

Climb hobbing, opposite lead direction
If a right-hand (opposite lead direction) cutter is employed in place of the left-handed cutter, the tool cutting edge angle (β + γa) changes and the gear runs from left to right into the working area of the cutter (penetration curve). The outermost point involved in material removal is Point 1, page 150.

The cutter length corresponding to Point 1 is then the setting length. The tool cutting edge length is shorter in climb hobbing with a cutter with opposite lead direction than with a cutter with the same lead direction. It is not affected by the magnitude of the feed.

Conventional hobbing, same lead direction
If the cutter moves downwards onto the upper face of the gear, the cutter tooth whose path passes through the point 1 is the first to intersect the tip cylinder of the gear, and the tool cutting edge length is equal to the length l1.

Since the two halves of the penetration curve to the left and right of the normals on the cutter axis through the point “S” are congruent and are inverted around the normal by “S” and around the cutter axis, l1 = l1 and l4 = l4.

Further combinations of hobbing method and direction of lead of gear and hob
The table shows the leading end, pivoting angle and tool cutting edge length for different combinations of hobbing method and direction of lead of gear and hob. “Leading end left” means that the gear runs from left to right into the penetration curve. “Leading end left u up” means that the setting length is equal to the dimension l4 in the penetration curve. It is located on the left-hand side in relation to the gear axis. The cutter side on which the tool cutting edge length is facing upwards.

Again the assumptions are:
Direction of view from the main machine column towards the cutter and the gear. On a helical gear, the helix angle is greater than the lead angle of the cutter.

<table>
<thead>
<tr>
<th>齿轮 Gear</th>
<th>刀具：右旋 Cutter: right-hand start</th>
<th>刀具：左旋 Cutter: left-hand start</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>右侧进刀 right-hand lead</td>
<td>左侧进刀 left-hand lead</td>
</tr>
<tr>
<td>顺铣：Climb hobbing</td>
<td>进刀末端 Leading end</td>
<td>左 left</td>
</tr>
<tr>
<td>螺旋角 Pivoting angle</td>
<td>β - γa</td>
<td>10°</td>
</tr>
<tr>
<td>切削刃长度 Tool cutting edge length</td>
<td>l four, up</td>
<td>l four, up</td>
</tr>
<tr>
<td>逆铣：Conventional hobbing</td>
<td>进刀末端 Leading end</td>
<td>左 left</td>
</tr>
<tr>
<td>螺旋角 Pivoting angle</td>
<td>β - γa</td>
<td>10°</td>
</tr>
<tr>
<td>切削刃长度 Tool cutting edge length</td>
<td>l four, right down</td>
<td>l four, left down</td>
</tr>
</tbody>
</table>

152 www.lmt-tools.com
View of the cutter and the gear from the main machine column
轮廓生成长度
Profile generating length

在设计过程中，在啮合线上形成轮廓（图3）。轮廓形成发生的区域是由齿轮齿顶圆啮合线的交叉和一根直线连接齿顶半径过渡点到滚刀基本轮廓所在的曲面（齿顶高）决定的。

滚刀轮廓生成长度
Profile generating length for hobbing
Profiling of the gear takes place exclusively in the profile generating zone, which is arranged symmetrical to the pitch point. The profile generating zone is calculated in the face plane of the gear and is represented there by \( l_{ph} \) and \( l_{ph} \).

Profile generation takes place during hobbing on the engagement lines (fig. 3). The area in which generation takes place is limited by the intersections of the engagement lines with the tip circle diameter of the gear and by a line connecting the transition points from the tip radius to the flank of the basic hob profile (tip form height).

The greater Interval between the end points of the engagement lines, either in the tip region (\( l_{ph} \)) or the root region (\( l_{ph} \)) of the hob profile, is regarded as the definitive length. Whether the end points of the engagement lines in the tip region or in the root region of the basic hob profile are decisive is dependent upon the profile displacement of the gear. Refer here to figs. 4 and 5: fig. 4 represents a gear with positive and fig. 5 a gear with negative profile displacement.

The greater of the two values – \( l_{ph} \) or \( l_{ph} \) – is then converted from the face plane to the axial plane of the hob and termed the “profile generating length \( l_{ph} \)”:}

\[
\tan \alpha_t = \tan \alpha / \cos \beta \\
l_{ph} = 2 \cdot (h_{ph} - x \cdot m_n - z_{ph} \cdot (1 - \sin \alpha_t)) / \tan \alpha_t \\
d_{ph} = z \cdot m_n \cdot \cos \alpha_t / \cos \beta \\
\cos \alpha_t = d_{ph} / d_n \\
d = z \cdot m_n / \cos \beta \\
l_{ph} = 2 \cdot (d_{ph} / 2 \cdot \cos (\alpha_t - \alpha)) - d_z / \tan \alpha_t \\

\begin{align*}
\text{If} & \ l_{ph} > l_{ph}, \text{ then } l_{ph} = l_{ph} \cdot \cos \gamma / \cos \beta \\
\text{If} & \ l_{ph} > l_{ph}, \text{ then } l_{ph} = l_{ph} \cdot \cos \gamma / \cos \beta
\end{align*}

\[ h_{ph} = \text{Addendum on the hob} \]
\[ x \cdot m_n = \text{Profile displacement} \]
\[ z_{ph} = \text{Tooth tip radius on the hob} \]
\[ \alpha = \text{Pressure angle} \]
\[ \beta = \text{Helix angle} \]
\[ z = \text{Number of teeth} \]
\[ m_n = \text{Normal module} \]
\[ d_n = \text{Tip circle diameter of the gear} \]
\[ \gamma = \text{Lead angle of the hob} \]
移位距离
Shift distance

移位距离是指机床在加工过程中必须移动的距离，以便在同一个位置上进行加工。这种移动称为“移位”。

The chip cross-sections within the working area of a hob are known to be very different. In consequence, the individual cutter teeth are subject to different loads, and therefore exhibit non-uniform wear patterns. It is therefore logical for the hob to be moved tangentially in stages once one or more workpieces have been machined in one position. This tangential movement is termed “shifting”.

Shifting continuously brings new teeth into the working area of the hob. The worn teeth leave the working area and the wear is distributed uniformly over the useful cutter length. The number of workpieces upon which a gear profile can be generated between successive regrinds is determined by the length of the hob and therefore also by the length of the shift distance.

In view of economic considerations – high tool life quality, low proportional tool costs, low machine downtimes for cutter changes – shift distances are selected which are as long as possible. The maximum length of the shift distance is determined by the design of the hobbing machine and therefore represents an absolute limit. The relationship between the useful cutter length, the tool cutting edge length, the length of the profile generating zone and the shift distance is shown in fig. 8.

$$l_9 = l_5 - l_6 - l_7 / 2 - 3 \cdot m_9$$

$$3 \times m_9$$ 确定了磨刀未磨损后加工的齿的切削余量。

6

移位距离分析图
Ascertainment of the shift distance

- $l_3$ = 刀具可用长度 Use length of cutter
- $l_6$ = 刀具切削刃长度 Tool cutting edge length
- $l_9$ = 移位距离 Shift distance
- $l_7$ = 轮廓形成区域的长度 Length of the profile generating zone

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### Coarse shifting with a constant offset

<table>
<thead>
<tr>
<th>Formula</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( L_{2F} = \frac{m}{Z_{ahn}} )</td>
<td>Assumed tool life</td>
</tr>
<tr>
<td>( L_{2R} = \frac{z_2 \cdot l}{\cos \beta \cdot 1000} )</td>
<td>Gear cut length per gear</td>
</tr>
<tr>
<td>( N = \frac{Shl \cdot l \cdot L_{2F}}{m_n \cdot \pi \cdot L_{2R}} )</td>
<td>Number of workpieces per regrind</td>
</tr>
<tr>
<td>( Sh_i = 1 \times p \cdot (m \cdot n) )</td>
<td>Shift increment</td>
</tr>
<tr>
<td>( Sh_n = \frac{Shl}{Sh_i} )</td>
<td>Number of shift increments</td>
</tr>
<tr>
<td>( D_n = \frac{N}{Sh_i} )</td>
<td>Number of operations</td>
</tr>
<tr>
<td>( Stv = \frac{Sh_i}{D_n} )</td>
<td>Starting offset</td>
</tr>
</tbody>
</table>

- \( Shl = \) shift length
- \( i = \) number of gashes
- \( m_n = \) normal module
- \( z_2 = \) number of teeth on the gear
- \( \beta = \) helix angle
- \( p = \) pitch
- \( L_{2F} = \) tool life per tooth
- \( L_{2R} = \) gear cut length per gear
Axial distance in hobbing

The axial distance of a hob during axial machining is generally composed of the approach distance, the width of the gear and the idle travel distance. Fig. 7 represents a schematic diagram of the axial distance of a hob during climb hobbing.

The approach distance is the distance which the hob must travel parallel to the gear axis, from the first point of contact to the point at which the intersection of the cutter and the gear axis has reached the lower face plane of the gear body.

The approach distance is equal to the height of the highest point on the penetration curve above the horizontal plane through the intersection of the cutter and gear axis. The formulae for calculation of the penetration curve can be found in the Chapter “Wear phenomena in hobbing”, page 188, fig. 13.
The approach distance can also be calculated with sufficient accuracy by means of the following formula:

**For straight teeth:**

\[ E = \sqrt{h \cdot (d_{ao} - h)} \]

**For helical teeth:**

\[ E = \frac{\tan \eta \cdot \sqrt{h \cdot \left(\frac{d_{ao}}{\sin^2 \eta + d_a - h}\right)}}{\sin^2 \eta + d_a - h} \]

- **E** = Approach distance
- **h** = Cutting depth
- **d_{ao}** = Cutter diameter
- **\eta** = Pivoting angle
- **d_a** = Tip circle diameter of the gear

No idle distance, except for a safety allowance, is required for straight teeth.

The idle distance for helical teeth is determined by the profile-generating zone in the face plane (fig. 8).

The dimensions for \( l_{pa} \) and \( l_{ph} \) are determined by the formulae in the chapter “Profile generating length for hobbing” and are calculated as follows:

If \( l_{pa} > l_{ph} \), then \( U = l_{pa} \cdot \tan \beta \)

If \( l_{pa} < l_{ph} \), then \( U = l_{ph} \cdot \tan \beta \)

\( U = \) Idle distance

Axial distance = \( E + b + U \)
Introduction

In the field of the machining processes for the manufacture of gears, hobbing occupies a prominent position which, also in the future, can only be maintained through constant improvements in quality and economy.

From this point of view, hobbing must be regarded as a system consisting of machine, tool and cutting parameters, which must always be optimized afresh as regards not only a wide range of gear cutting tasks.

Through developing high-performance hobbing machines and hobs the machining cycle times and the auxiliary process times were considerably shortened. This did, of course, increase the importance in the analysis of the gear cutting costs for a specific workplace the tool costs, the costs of the tool change and the maintenance costs of the hob.

It was therefore essential to advance also the technology of the regrinding of hobs by means of high-performance grinding methods, such as the deep grinding process, and by means of suitable abrasives adapted to the various hob cutting materials. Therefore, grinding wheels made from crystalline cubic boron nitride (CBN) and diamond should be used in addition to the conventional grinding materials such as silicon carbide (SiC) and corundum (Al₂O₃).

Although the initial purpose when regrinding a hob is to remove the wear marks from the cutter teeth, a range or other requirements must be met which are formulated below as a task description.

Task description

As with every metal removing machining process with a defined cutting edge, wear marks occur on the cutting edges of the cutter which affect chip formation, produce higher cutting forces and which could therefore reduce gear quality. This is why the wear has to be removed when it has reached a certain value. The maximum width of a still permissible wear mark will be discussed below.

1. 滚刀刀齿的磨损形式
   Forms of wear on the hob tooth

2. 工件加工数量与刀具磨损的关系图
   Flank wear as a function of the number of workpieces cut
All relief turned or relief ground hobs are sharpened by grinding on the cutting face. This process must be performed by high-quality precision tools by expertly trained personnel, and with necessary care.

Regardless of the design, the dimensions, the cutting edge geometry of the hobs and the material of the hobs, the following requirements must be met when regrinding:
- The cutting face geometry must be produced in accordance with the quality grade of the hob,
- heat stress on the cutter material by the grinding process must be restricted to a minimum,
- the roughness of the cutting faces and therefore the raggedness of the cutting edges must be kept as low as possible.
- grinding methods and aids must be chosen so that maintenance and inspection costs are kept within economical limits.

All preparations, the execution and the supervision of the regrinding process must have as their aim the total observation of the requirements listed above.

In addition, the following points must be observed during maintenance operations on carbide hobs
Carbide hobs assigned to the “ISO K” group:
1. Remove coat
2. Sharpen the cutting face
3. Re-coat

Wear phenomena on the hob
Where reference is made to the wear mark width in the context of hobbing, this generally refers to the length of the flank wear on the tip corners of the cutter teeth. In fig. 1, this is described as flank wear. This particularly marked form of flank wear also determines the end of the service life of the hob. The characteristic course is represented for the formation of the wear mark width. This does not develop proportionately to the number of workpieces cut.

The lower curve in fig. 2 has a marked minimum for the proportionate wear of a tool at the transition to the progressive part of the upper curve.

For the gear under consideration, the maximum wear should not therefore exceed 0.25 mm on coated KHSS-E hobs or 0.15 mm on carbide hobs. If the lowest possible unit tool costs are an objective.

Since the wear curves cannot be determined in all cases in the form mentioned, some guide values are included on page 162 in fig. 3.

At the same time it also becomes clear, however, that there are a range of other criteria, such as cutting material, module size, production sequence or required tooth quality, according to which the wear mark width must be evaluated.
The "Roughing" column in fig. 3 shows relatively large wear mark widths for roughing of gears with a high module. These certainly already fall within the range in which wear increases progressively. This can, however, often not be avoided in these cases, because the volume to be removed increases quadratically with the module, whereas the number of cutter teeth involved in the metal removal process remains the same or even decreases. The results are higher stress on individual cutter teeth and therefore greater wear.

**Width of wear mark**
For finishing, the wear mark widths must be markedly lower, because wear-related cutting edge deviations and higher cutting forces reduce gear cutting accuracy.

Experience with coated hobs shows that with wear mark widths of 0.2 mm no longer the hard coating but the base material determines wear development.

When milling hardened gears with carbide skiving hobs, a critical wear mark width is reached at 0.15 mm. The increased cutting forces and cutting temperatures resulting from the blunting of the cutting edge not only stress the workpiece and reduce its quality, but also lead to sporadic chipping and splintering of the tool.

On solid carbide hobs for dry machining, the wear should not exceed 0.15 mm. A further increase in wear leads to destruction of the tool. It is therefore important to determine the tool life quality per gear. The first sign of increased wear during dry machining is the increase in workpiece temperature and in sparking. Should sparking become severe, the machining process must be stopped immediately.

For economical operation, wear distribution is of decisive importance, in addition to the wear mark width.

**3**

<table>
<thead>
<tr>
<th>cobalt insert</th>
<th>cobalt insert</th>
<th>cobalt insert</th>
<th>cobalt insert</th>
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</thead>
<tbody>
<tr>
<td>cobalt insert</td>
<td>cobalt insert</td>
<td>cobalt insert</td>
<td>cobalt insert</td>
</tr>
</tbody>
</table>

**4**

Wear mark width when hobbing with and without shifting

- 1600 Gears with shifting
  - Shift increment: 0.64 mm per clamping
- 40 Gears without shifting
  - Flute length: 1600 mm
如果对每个刀具刀齿的磨损情况进行检查，就可以发现，如果刀具只使用某一固定部分进行加工，其磨损情况的分布如图4中的阴影部分所示。反之，如果刀具在每次加工周期内沿轴向进行加工（移位），新的刀齿不断进入加工区域。磨损量会分布在更多的切削刃上，因而，在连续磨削后生产率会增加几倍。

刀具磨削部门里有经验丰富的工匠会通过观察刀具的磨损标记宽度和磨损分布，从加工质量和经济性角度了解刀具是否正确地加以使用。如果使用值过高或过低，那么应该将此情况向产品生产部门报告。

一般注意事项：
磨削砂轮的圆/轴向跳动值<0.01 mm。必须挑选刚性尽可能好的磨削砂轮。如有必要，应选择较小的接触面。在磨削硬质合金刀具时，优先选择磨而不削的类型。

工作与刀具之间的作用会影响表面加工质量。工作表面和磨削加工工艺之间的传递力矩的所有夹紧元件和结构。

重要注意事项：
硬质合金刀具对温度非常敏感。在运输和储存过程中应注意刀具边缘的保护。装置必须保持一定的精度以防止出现振动现象。

If the wear of each individual cutter tooth is examined, the distribution is found to be that shown in the hatched curves in Fig. 4. Conversely, if the cutter is displaced axially (shifted) following each machining cycle, new teeth are continuously brought into the working area. The wear is distributed evenly over a greater number of cutter teeth, and the productivity between successive regrinds is increased several times.

The experienced craftsman in the tool grinding shop knows by looking at the wear mark width and the wear distribution whether a hob has been used correctly from the points of view of quality assurance and economy. If the recommended values are substantially over- or under-shot, this should always be reported to the production sector.

Requirements placed upon the cutting face grinder (Fig. 5)
Radius/axial runout of the grinding disk < 0.01 mm. A grinding disk form which is as rigid as possible should be selected. If possible, select small contact surfaces. Emulsions should be preferred to oil for the grinding of carbide.

Vibrations between workpiece and tool impair the surface quality. All structural and clamping elements in the torque transmission system between the workpiece and the grinding disk must be kept as rigid as possible in order to avoid vibrations.

Important
Carbide hobs are very sensitive to impact. Protect the tooth tips during transport and storage.
Hob tolerances
The flank cutting edges of the hob are formed by the intersection of the cutting faces with the relief turned or relief ground helical surfaces of the tooth flanks. Since during the hobbing process the tooth profile is formed by enveloping cuts and each individual enveloping cut is generated by another cutting edge of the tool, both the exact form of the cutting edges and the relative position of the cutting edges to each other must be correct.

Regrinding on the cutting face always creates new cutting edges. The working accuracy of a hob can therefore be considerably impaired by regrinding. The cutting edges produced by regrinding only achieve their correct form and position when the newly created cutting faces correspond to the original ones in form, position, orientation and pitch.

Only if regrinding is faultless, will tool accuracy be kept identical with the new condition. The tolerances of single-start hobs for pur gears with involute teeth are quoted in DIN 3968. Depending on the accuracy, a distinction is made between five quality grades, namely AA, A, B, C and D.

The standard contains the permissible deviations for 17 values to be measured. Five of these alone concern the cutting faces:

- Regrinding must therefore be carried out so that the permissible deviations for the following measurement values are maintained:
  - Form and positional deviation of the cutting faces,
  - Individual and cumulative pitch of the gashes and
  - Lead of the gashes.

For high-precision hobs it therefore also goes without saying that the tolerances are checked on suitable inspection instruments after each regrind.

Radial runouts on the indicator hubs and axial runouts on the clamping surfaces (item nos. 4 & 5 DIN 3968)
A prerequisite for all repair and inspection operations on the hob is that the grinding and measuring arbors are running true and that the indicator hubs of the hob run true to each other and to the arbor (figs. 6 & 7).

The aim is to superimpose the axis of the cutter screw with the instantaneous rotary axis and to check this by measuring the radial runouts.

If the high or low points of the two indicator hubs lie in one axial plane of the cutter, the axis of the cutter screw and the rotary axis are offset – the cutter does not run true.

If the high or low points of the two indicator hubs are rotationally displayed in relation to each other, the rotary axis and the axis of the cutter screw are skew, i.e. the hob wobbles, and axial runout will also be found.

When working with or on the hob, the user must know that he will only achieve a sound tooth system when cutting, faultless geometry when regrinding and an informative and reproducible result when checking the hob if the radial and axial runouts are kept as small as possible.
### DIN 3968 Standard Permissible Radial and Axial Runouts to DIN 3968

<table>
<thead>
<tr>
<th>Value to beMeasured</th>
<th>Symbol of the Deviation</th>
<th>Quality Class</th>
<th>Tolerances in μm (1 μm = 0.001 mm) at Module Over 25-40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial runout at the two indicator hubs based on the axis of the bore</td>
<td>f&lt;sub&gt;r&lt;/sub&gt;</td>
<td>AA</td>
<td>5, 5, 5, 5, 5, 5, 5, 5, 6, 6, 8</td>
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<tr>
<td></td>
<td></td>
<td>A</td>
<td>5, 5, 5, 5, 5, 8, 8, 10, 12, 16, 20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B</td>
<td>6, 6, 6, 6, 8, 10, 12, 16, 20, 25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td>10, 10, 10, 12, 16, 20, 25, 32</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D</td>
<td>not determined</td>
</tr>
</tbody>
</table>

The highest points measured at the two indicator hubs must not be offset by more than 90°.
It is therefore understandable that the permissible deviations for the radial and axial runouts are very restricted and that it is essential to measure them not only during the acceptance test of the hob, but also during the inspection after each regrind.

Form- and positional deviation of the cutting faces
(Item no. 7 DIN 3988)
The cutting faces are generated by the straight lines which normally run through the cutter axis of the gear hob (fig. 8a). In those cases in which these straight lines run in front of or behind the cutter axis, they form negative or positive rake angles with the radius (fig. 8b, c). The grinding wheel must be set by the rake angle distance “u” in front of or behind the cutter axis to match the rake angle. This also applies to the height setting of the gauge stylus when checking the form and positional deviations (fig. 9).

For roughing cutters with a positive rake angle, it is enough to maintain the u-measurement specified in the cutter marking when regrinding. In the case of finishing cutters with positive or negative rake angle, e.g., carbide skiving hobs, the u-measurement must be read off a regrinding diagram as a function of the cutter diameter.
<table>
<thead>
<tr>
<th>L</th>
<th>u</th>
<th>Da0</th>
<th>L</th>
<th>u</th>
<th>Da0</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>-20.521</td>
<td>119,899</td>
<td>2,508</td>
<td>-20.104</td>
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<td>2,648</td>
<td>-20.115</td>
<td>117,619</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

L = 刀具齿顶宽  
Tough length at tooth tip  

u = 刀具切削宽  
Cutting face width  

Da0 = 刀具外径直径  
Center diameter
This regrinding diagram applies to the cutter diameter, the rake angle and the relief grinding operation and is supplied with the cutter (fig. 10, page 167).

Deviations from the specified value of the cutting face distance result in flank form and base pitch deviations on the hobbed workpieces.

A bigger rake angle (fig. 11) elongates the cutter tooth and reduces the profile angle.

A smaller rake angle (fig. 12) results in a shorter cutter tooth and a greater profile angle.

The cutting face form deviations can be divided into three main forms: crowned, concave and undulating.
The crowned cutting face form is found when hobs which have a gash lead are ground with straight dressed grinding wheels. This crowning increases with shorter gash lead, greater tooth height and large grinding wheel diameters.

Hobs with crowned cutting faces (fig. 13) produce workpiece teeth on which too much material remains in the tip and root area. These gears exhibit an uneven running behaviour and reduced load bearing capacity and are therefore not accepted. By choosing a grinding wheel with a smaller diameter the crowned form on the cutting face can be reduced. A correspondingly crowned grinding wheel, manufactured in or dressed to this shape, generates a straight or even concave cutting face (fig. 14, 15).

Hobs with a slightly concave cutting face produce workpiece teeth with tip- and root relief. This form of the deviation from the ideal involute form is permissible and is in many cases even specified.

Undulating form deviations on the cutting face are generally caused by badly dressed grinding wheels or worn or badly guided dressing diamonds (fig. 16, page 170).

Pitch deviation of the gashes
Pitch deviations occur when the distances of the cutting faces from each other are not uniform. In practice, individual cutting faces lie in front of or behind the assumed radial pitches, which predetermine the exact specified pitch.

If the cutting face of a tooth is further back than the specified position, the tooth will generate a flank which projects beyond the specified form. A tooth with a projecting cutting face will cut away too much metal at the tooth flank.
每个切削槽的不允许的相邻误差或累积性误差都会导致工件加工齿的面形形状和基本齿距产生不规则形状或周期性误差。

当刀具移位时，这种误差肯定会在工件的加工齿面上。其原因在于节距误差对滚刀的误差的影响是相当大的，以致关系到存在的问题的面形形成区域以及在移位时相关加工齿的位置变化。

切削槽的单个节距（DIN 3968第6条）
如果单个节距的误差是通过两次测量确定的，则该数值必须按照下述要求进行转换：增加刀具完整回转周期内的测量值，标上+号或-号。其差值即代表单个节距的误差。

两个相邻节距的误差值即是齿和齿的节距的误差。

Impermissible deviations from the individual or cumulative pitch of the gashes may cause irregularly or periodically occurring flank form and base pitch deviations on the workpieces.

To this must be added that the flank form on the workpiece changes when the cutter is shifted. The reason for this is that it is important where the hob tooth afflicted by a pitch deviation, is situated relative to the profile forming zone in question and that the corresponding tooth changes its position when shifting.

Individual pitch of the gashes (item no. 8 DIN 3968)
If the individual pitch deviations are to be determined by means of dual gauge measurement, the values read off must be converted as follows: The measured values for a complete cutter rotation are added, noting the + or - signs. The differences correspond to the individual pitch deviations.

The difference between two adjacent individual pitch deviations is referred to as a tooth to tooth pitch error.

### Table 16
<table>
<thead>
<tr>
<th>DIN3968标准的切削刀面形误差</th>
<th>Form- and positional deviation of the cutting faces to DIN 3968</th>
</tr>
</thead>
<tbody>
<tr>
<td>测量值</td>
<td>Value to be measured</td>
</tr>
<tr>
<td>公差符号</td>
<td>Symbol of the deviation</td>
</tr>
<tr>
<td>质量等级</td>
<td>Quality class</td>
</tr>
<tr>
<td>0.63-1</td>
<td>1-1.6</td>
</tr>
<tr>
<td>AA</td>
<td>10</td>
</tr>
<tr>
<td>A</td>
<td>12</td>
</tr>
<tr>
<td>B</td>
<td>25</td>
</tr>
<tr>
<td>C</td>
<td>50</td>
</tr>
<tr>
<td>D</td>
<td>100</td>
</tr>
<tr>
<td>F</td>
<td>Spec. line</td>
</tr>
</tbody>
</table>

Distance "u" of the specified line from the axial plane (at rake angle 0° = zero)

检查图例

![Check Diagram](https://www.lmt-tools.com)
可以通过比较各类分度盘或测量设备分度装置进行测量。所测量的数值表示相对于第一个切削刀的零点位置的测量切削刀的累积分度值。每个节距的误差值等于两个相邻累积节距误差的差值。（图17）

计算过程的归纳如图18所示。

切削刀的累积分度值（DIN3968第10条）
累积节距误差表示以其中一个切削刀为参考面时，切削刀规定位置与实际所处位置之间的误差。

如果使用带有分度盘或相应的具有精确分度装置的测量设备进行测量，那么累积节距误差值可以直接读出。

当然，如果将每个节距的误差连续相加，那么累积节距误差值也可以通过双刻度测量计算得出。

DIN3968标准的第10条的公差是关于总节距误差的。这里所指的总节距误差值是指最大正累积节距误差与最大负累积节距误差的相加值。（图18）

切削刀导向（DIN3968标准第11条）
切削刀导向误差的公差值是沿轴线方向对100mm长度的切削刀进行测量而得到的。该公差值适用于斜齿加工滚刀和直齿滚刀。
该切削刀误差会直接影响到齿形形状，基面齿距和压力角的误差，对于斜齿的加工也会导致齿阶和齿导向的误差。

The measurement can also be carried out by comparison with an indexing plate or with the indexing arrangement of a measuring machine. The values read off represent in comparison to the zero position of the first gash the cumulative pitch of the measured gashes. The individual pitch deviation equals the difference of two adjacent cumulative pitch deviations (fig. 17).

A summary of the computation processes is shown in fig. 18, page 172.

Cumulative pitch of the gashes (item no. 10 DIN 3968)
The cumulative pitch deviation indicates the difference between actual and required gash positions, one cutting face being used for reference.

The cumulative pitch deviations can be read off directly, if the measurement is carried out with the aid of an indexing plate or with a corresponding accurate indexing arrangement.

The cumulative pitch deviations can also be calculated from the twodimensional measurement, if individual pitch deviations are added continuously.

The tolerances in DIN 3968 item no. 10 relate to the total pitch deviation. The total pitch deviation is here the distance between the biggest positive and the biggest negative cumulative pitch deviation (fig. 18, page 172).

Gash lead (item no. 11 DIN 3968)
The tolerances for the deviations in the gash lead are based on an axially parallel measuring distance of 100 mm and they apply equally to hobs with a helix and to hobs with axially parallel gashes.

Directional deviations of the gashes result in flank form-, base pitch and pressure angle deviations and in the case of diagonal hobs also in tooth thickness and tooth lead deviations.

17

切削刀的节距误差
切削刀2：齿距过短，齿形与刀导向的齿形有关。
切削刀3：齿距过长，齿形崩裂，与刀导向的形状有关。

Pitch deviation of the gashes
Cutting face 1: Theoretically correctly placed
Cutting face 2: Pitch too short, tooth profile projects relative to the profile on the cutting face
Cutting face 3: Pitch too great, tooth profile set back relative to the profile on cutting face 1
Roller of hobs
Maintenance of hobs

Computation diagram for individual pitch deviation, tooth to tooth pitch error and cumulative deviation from the measured value readings of the two-dial measurement

Individual pitch deviation \( f_{in} \), tooth to tooth pitch error \( f_{on} \), cumulative pitch deviation \( F_{in} \)

1. Calculation of the correction value
\[
0 + 8 - 2 - 4 + 10 + 4 + 2 = 16
\]
16/8 = +2 correction value

2. Calculation of the individual pitch deviation
indicated value - correction value = individual pitch deviation
\[
0 - (+2) = -2
+8 - (+2) = +6
-2 - (+2) = -4
-4 - (+2) = -6
+10 - (+2) = +8
+4 - (+2) = +2
+2 - (+2) = 0
-2 - (+2) = -4
\]
Tooth to tooth pitch error \( f_{on} \) is calculated by subtracting the previous individual pitch deviation from the individual pitch deviation.
Cumulative pitch deviation \( F_{in} \) results from the addition of the individual pitch deviations.
<table>
<thead>
<tr>
<th>测量值</th>
<th>公差符号</th>
<th>Symbol of the deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>单个切削槽的同齿在齿一半高度位置进行测量</td>
<td>AA</td>
<td>±10</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>±12</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>±25</td>
</tr>
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<td></td>
<td>C</td>
<td>±50</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>±100</td>
</tr>
<tr>
<td>切削槽的累积节距在齿一半高度位置测量</td>
<td>AA</td>
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</tr>
<tr>
<td></td>
<td>A</td>
<td>25</td>
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<td></td>
<td>B</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>200</td>
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<tr>
<td>切削槽导程超过100mm</td>
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<td>±50</td>
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<td></td>
<td>A</td>
<td>±70</td>
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<td></td>
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<td>±100</td>
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<td></td>
<td>C</td>
<td>±140</td>
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<td></td>
<td>D</td>
<td>±200</td>
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<th>质量等级</th>
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<td>大于25-40</td>
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</table>

不同模数范围的公差 μm (1 μm = 0.001mm) 
Tolerances in μm (1 μm = 0.001 mm) at module
The tolerances for the deviations of the gash lead are relatively wide, since they only fractionally affect the tooth geometry. It should be taken into account, however, that the effect on the directional deviations on tooth accuracy is greater with high than with low modules, since the length of the profile formation zone increases with the module size.

Regrinding of roughing hobs

LMT Fette roughing hobs can be reground on any hob regrinding machine.

The hobs are manufactured with a positive rake angle. The cutting face is therefore off-center. The deviation from the center is indicated by the dimension "u" which is indicated on each hob.

Prior to beginning regrinding work, offset the grinding disk from the centre by the dimension "u".

On LMT Fette roughing hobs with a finite gash lead, ensure that the grinding disk is crowned, in order to ensure straight cutting faces.

All LMT Fette roughing hobs have 10 teeth groups, each of which has 2 gashes, i.e. 20 gashes in total.

The gash pitch, the form and location of the gash, and the tip runout must be checked following each regrind operation, for example on a universal pitch tester. The tolerances should be within quality grade A to DIN 3968.
为了获得最佳切屑槽节距，滚刀首先应对16(20)切屑槽进行刃磨加工。砂轮插入小齿间隙中。

符合DIN3968标准的A质量等级的切削槽节距应通过本次磨削加工实现。

然后滚刀对8(10)切屑槽进行刃磨加工。
在本次操作中，插入大齿间隙深度中。

本次磨削加工必须进行到精磨削后齿部达到16(20)节距一致为止。

In order to obtain a perfect gash pitch, the hob is first ground with the 20 pitch disk. The grinding disk is plunged as far as the small tooth gap.

A gash pitch within quality grade A to DIN 3968 should be attained by this grinding operation.

The hob is then ground with the 10 pitch disk.
In this operation, the grinding disk is plunged to the depth of the large tooth gap.

This grinding operation must be performed until a smooth transition to the reground tooth tip portion of the 20-pitch is achieved.

第二部磨削时金属切削过程
Metal removal in the second grinding operation
凸角滚刀

General principles
Hobs with protrusion (fig. 1) are roughing cutters whose profile differs from the standard type to DIN 3972 in that protrubances are present on the tooth tips which project beyond the straight flanks of the basic profile.

The purpose of the protrusion is to create a clearance cut on the tooth roots of spur gears. This is necessary when the teeth are to be finish machined by shaving, grinding or by hobbing with a carbide skewing hob.

For straight spur gears, a distinction must be drawn between the form circle and the effective circle. Tip and root: form circles are circles up to which the involute profile extends. If, for example, a spur gear has a tip chamfer, the tip form circle diameter is the diameter at which the chamfer begins. The tip form circle diameter is therefore smaller than the tip circle diameter of the gear by twice the radial height of the chamfer. The root form circle diameter is located at the point at which the root rounding or the undercut begins. It does not follow however that the flanks between the tip and root form circle diameter actually engage with the mating gear, i.e. are actually used; this depends upon the tip circle diameters of the gear pair, the centre distance, and...
the pressure angle which result from the effective tip and root circle diameter. The effective circles may have the same dimensions as the corresponding form circles. The effective tip circle diameter cannot however exceed the tip form circle diameter, and the effective root circle diameter cannot be smaller than the root form circle diameter. When specifying the protuberance it must be ensured that the root form circle diameter is less than the effective root circle diameter; only then can it be ensured that the effective root circle diameter calculated for the requisite contact ratio is actually present.

In some cases one dispenses during roughing prior to shaving completely with the clearance cut, but makes sure that the tooth root is cut out sufficiently for the shaving cutter no longer to touch the root radius of the gear. The minimum and maximum sizes of the clearance cut are therefore limited by the finishing method – shaving or grinding, form and position of the relative tooth-crest track of the shaving cutter or the grinding wheel, permissible tooth thickness deviations etc. – and by the amount of hardening distortion on the one hand and by the size of the root form circle diameter on the other hand.

In accordance with the importance of the root form circle diameter, the details given below will only deal with the effects of the various tool and workpiece parameters on the size of the root form circle diameter.

Generally, all the teeth/gear numbers of a module can be cut with one protuberance profile.

The addendum of the tools should be greater than 1.25 x m.
凸角滚刀

Protuberance hobs

凸角滚刀是由加工余量和在已加工好的齿轮上所附加的挖入量构成的。这两个值是由后续加工工艺根据工件的尺寸（小齿轮还是环形毛坯）以及在热处理工艺时工件的变形情况决定的。因此在这里不同刀具的滚刀形状都可能不同，因此制造小型齿轮或大齿轮（小于15个）的齿轮，以及制造具有较大负滚刀位移的齿轮，需要设计一种特殊的刀具滚刀。

被加工工件上齿轮结构圆的直径参数：模数、压力角、齿数、螺旋角和滚刀位移。滚刀参数：齿轮高、齿根圆角半径，凸角和凸角的角度。

为了防止您对下面内容中所使用的术语产生误解，以下术语在给出定义时将给出示例帮助说明。

滚刀基本齿廓的使用术语

图6显示了滚刀的基本齿廓形状。下面是有关基本齿廓所定义的术语的辅助解释。

下例给出的例子显示了滚刀基本齿廓的不同尺寸。凸角滚刀在很多场合中使用得很成功。

8

法向截面位置处滚刀的基本齿廓

Basic hob profile in the normal section

凸角滚刀 Protuberance flank

$Q_{W0} = 0.40 \cdot m$
$Q_{P0} = 0.2 \cdot m$
$Q_{O0} = 20^\circ$
$Q_{PO} = 10^\circ$
$Q_{Ro} = 0.09 + 0.0125 \cdot m$
$P_{Ro} = 0.129 + 0.0290 \cdot m$

滚数 $n \leq$ Module 7

$P_{Ro} = 0.181 + 0.0235 \cdot m$

滚数 $> Module 7$

$u = 0.039 + 0.0165 \cdot m$

$h_{Ro} = 1,4 \cdot m$
$h_{PO} = 2,6 \cdot m$

$s_{RO} = \frac{m \cdot \pi}{2} - \frac{2 \cdot Q_{Ro}}{\cos Q_{PO}}$

$Q_{W0} =$ 变形面半径 Tooth tip radius
$Q_{P0} =$ 变形圆半径 Root fillet radius
$Q_{O0} =$ 滚刀 Profile
$Q_{PO} =$ 凸角角高 Profiutance angle
$Q_{Ro} =$ 加工余量 Machining allowance
$P_{Ro} =$ 凸角数量 Amount of protuberance
$h_{Ro} =$ 凸角高度 Height of protuberance
$h_{PO} =$ 齿根高 Addendum
$h_{PO} =$ 齿高 Profile height
$s_{RO} =$ 安厚 Tooth thickness

$u =$ 加工完成的变圆的齿根侧间隙

Root clearance cut on the finished gear

The amount of protuberance is made up of the machining allowance and the residual undercut remaining on the finished gear. These two values depend on the subsequent machining process, on the size of the workpieces (pinion or ring) and on the distortion during heat treatment. It is therefore entirely possible that different tool profiles are needed here. A special design of the tool profile may also become necessary at smaller teeth/gear numbers (less than 15) and with large negative profile displacements.

The parameters for the root form circle diameter are on the workpiece: module, pressure angle, number of teeth, helix angle and profile displacement on the hob: addendum, tip circle radius, amount of protuberance and protuberance angle.

To ensure that no misunderstandings will occur in the text below about the meaning of the terms used, these terms will be defined with the aid of the illustration.

Terms used on the basic hob profile

Fig. 8 shows the basic hob profile. This is complemented by the definition of the terms used in conjunction with the basic profile.

An example showing the different dimensions of a basic hob profile is given below. This protuberance profile has been particularly successful in many cases.
齿轮结构圆直径的计算
齿轮结构圆直径可以使用FETTE开发的软件进行计算。

理论上，齿轮位置的曲线是由齿顶圆角半径包络的区域和凸面构成的轮廓线组成的。第二个区域是渐开线轮廓区域，渐开线与主渐开线的齿轮曲线在该区域相交。其交点位置是由齿轮结构圆直径的大小决定的。然而在大多数情况下，设计齿轮的渐开线区域并不存在，由齿顶圆角半径产生的齿轮弧弧与主渐开线形成相交。

现在已经得到了根据计算的齿轮结构进行绘制的方法以及对绘图结果的分析的有效方法。齿轮曲线与主渐开线的交点位置对于后续加工过程中的齿轮结构圆直径大小进行判断的精确性的影响非常重要。对于经过淬硬和磨削的齿轮，必须考虑淬火处理以及齿面上切削刀的厚度等加工量对齿轮结构圆直径的影响。

实践证明，当齿轮结构圆直径大时，如果齿轮的齿数较少，并且正向轮缘位置会速小时会发生问题。此时可以使用更少的凹角量，加大齿顶高或减小滚刀基本齿数的齿顶圆半径进行改善。

有效齿轮圆直径的计算
Calculation of the effective root circle diameter
如果工件图上没有给出齿轮结构圆直径或有效齿轮圆直径的大小，那么必须根据下列表式计算齿轮数据的有效齿轮圆直径:

If the root form circle diameter or the effective root circle diameter are not specified in the workpiece drawing, the effective root circle diameter must be calculated from the gear pair data according to the following formulæ:

\[
\begin{align*}
(1) \quad d_{HN1} &= \sqrt{2 \cdot a \cdot \sin \alpha_{ht} - \sqrt{d_{N1}^2 - d_{r1}^2} + d_{b1}} \\
(2) \quad d_{HN2} &= \sqrt{2 \cdot a \cdot \sin \alpha_{ht} - \sqrt{d_{N2}^2 - d_{r2}^2} + d_{b2}} \\
(3) \quad \cos \alpha_{ht} &= \frac{z_1 + z_2}{2a} \\
(4) \quad m_r &= \frac{m_n}{\cos \beta} \\
(5) \quad \tan \alpha_t &= \frac{\tan \alpha_n}{\cos \beta} \\
(6) \quad d_b &= \frac{z \cdot m_r \cdot \cos \alpha_t}{\cos \beta}
\end{align*}
\]

Where:
- \(d_{HN1}, d_{HN2}\) = 有效齿轮圆直径
- \(d_{N1}, d_{N2}\) = 有效齿轮圆直径
- \(d_{r1}, d_{r2}\) = 有效齿轮圆直径
- \(a\) = 齿轮中心距
- \(m_n\) = 实际模数
- \(\alpha_t\) = 实际压力角
- \(\beta\) = 螺旋角
公式(1)和(2)中179页，齿顶圆直径或侧角值是已知的，相配合齿轮的齿顶圆直径也可以作为有效齿顶圆直径进行使用。

In formulae (1) and (2), page 179, either the tip circle diameter, or if a chamfer is present, the tip form circle diameter of the corresponding mating gears, are employed as the effective tip circle diameter.

齿面上的齿间圆形状
Tooth gap profile in the face plane
The cutting forces
The hobbing process has been known for over a century. For almost as long, people in the trade have grappled with the problem of hob wear. Whereas in turning and milling the metal cutting process can be characterized by 3 values, namely the cutting speed *v*, the feed "*f*" and the Infeed "*a*", two special points must be taken into account in hobbing. In contrast to turning and milling, considerably more parameters act on the cutting process. These parameters result from the manufacturing process and beyond that from the geometry of the tool and the workpiece.

The effects arising from the cutting process cannot easily be explained by the interrelationship of these parameters. Thümer (1) found already during his studies of the cutting forces during hobbing that the cutting forces occurring on each tool cutting edge can be calculated from the cross-sectional area of cut involved. Calculating the cross-sectional areas of cut is therefore very important in this connection. In addition to this, knowing the cross-sectional areas of cut occurring in hobbing also makes it possible to forecast the tool wear and to assess the suitability of specific cutting materials. The chip thicknesses on small modules and the chip lengths can be influenced only slightly by the cutting speed and the feed rate, and are determined principally by the geometric dimensions of the hob and the workpiece.

Fig. 1 shows the cutting forces occurring on the individual cutting edges for three different axial feeds, as they arise when conventional hobbing a spur gear. At the entering cutter side one can see that the cutting forces initially rise steeply, after which they gradually decrease up to the end of the engagement length. Apart from the first working cutting edges it is found that almost equal cutting forces are present on virtually all other cutting edges despite different axial feeds.

The reason for this phenomenon is that the chip shapes at these cutting edges are determined almost exclusively by the cutter- and workpiece size.
然而在我们的例子中，当刀具每转轴向进给量为2mm时，只有13个切削刃在进刀侧进行加工，当刀具以每转轴向进给量4mm时，有17个切削刃在进刀侧参与加工。最后当刀具每转轴向进给量为8mm时，有20个切削刃的进刀侧参与加工，比进给量为2mm时大50%。

这些切割力变化图还告诉我们，在滚齿加工过程中每个切削刃所承受的载荷大小是不同的，这就自然导致其磨损程度不同。轴向进给对最大主切割力的影响如图2所示。在该例子中，当刀具每次转轴向进给量从3mm时切割力开始增加。当进给量超过3mm时切割力开始迅速增加，而当进给量达到6mm时切割力早期降低。进给量达到10mm时的切割力大约是4mm进给量的两倍左右。

在滚齿加工过程中，从每个刀具切削刃位置展开的切削厚度如图3所示。从刀片到刀片的轴向位置越来越接近，导致每个切削刃的存在一定的误差。几乎所有轴向进给量下情况是相同的。当刀具每转轴向进给量为10mm时，切削的厚度大约0.8mm。当刀具每转轴向进给量为6mm时，切削的厚度大约0.45mm，而当刀具每转轴向进给量为4mm时，切削的厚度大约0.35mm，进给量为2mm时，切削的厚度大约为0.28mm。

Ziegler (2) 说明切割速度对主切割力无明显影响。图4) 当切割速度维持在50m/min时，对任何切割角度进行加工时，主切割力大小几乎维持不变。而当切割速度降低时切割力则有所增加。滚齿加工时切割力的增加幅度比铣齿加工时要大。当切割速度达到50m/min时，切割力开始呈现下降趋势，并与齿轮的参数数据和切割工艺无关。

当切割速度达到一定值后，切割力不应该继续增加。这一特性在使用模数为1.5的硬质合金斜齿刀进行加工时尤为显著。所有刀具的进给量可以选取该刀具模数数的1/3作为实际进给量。主切割力的大小与工件尺寸加工条件有关，特别是与齿轮的模数和模数有关。然而，主切割力的大小还与使用的刀具角度有关，特别是刀具中实际参与加工并转动的刀具角度。

Ziegler (3) 研究表明，其它方面也对切割力有一定的影响。包括切削刃的进刀方向，工件圆周面的应力，以及切削力和工作台的旋转方向的协调。如果刀具的进刀方向和相关工件的运动方向相同，那么主切割力的分力与工件轴线方向相同。这就表明圆周力对机床工作台产生压力作用，因此分度蜗轮对驱动端件有很强的耐力。这样工作台就不会产生附加运动。另一方面，如果进刀方向相反，主切割力的分力顺着工作台旋转的方向。

It can also be seen that the number of cutting edges taking part in the metal removal increases with faster axial feed. Whereas in our example only 13 cutting edges work on the entry side of the cutter at an axial feed of 2 mm per work rotation, this becomes 17 cutting edges already at 4 mm feed per work rotation and finally 20 cutting edges at 6 mm feed per work rotation, i.e. about 50 % more than at a feed of 2 mm.

These cutting force diagrams also reveal that in hobbing the individual cutting edges carry different loads, which naturally results in a non-uniform wear pattern. The effect of the axial feed on the maximum main cutting force is shown in fig. 2. The cutting force increases in the present example degreasingly up to a feed of 3 mm per work rotation. Over 3 mm feed a slightly progressive increase in cutting force is found, which changes at 6 mm into a slightly decrease course. At 10 mm feed the cutting force is approximately double that at 4 mm feed.

The chip thickness which have to be parted off from the individual cutting edges during hobbing are shown in fig. 3. One can see that the chip thickness increase linearly from the point of contact towards the entering cutter side. They are almost the same for all axial feeds and only exhibit certain deviations at the first working cutting edges. At a feed of 10 mm per work rotation the maximum chip thickness is over 0.5 mm. At a feed of 6 mm per work rotation a maximum chip thickness of about 0.45 mm occurs in the present case, whereas at a feed of 4 mm per work rotation the maximum chip thickness becomes 0.35 mm and at a feed of 2 mm per work rotation it becomes about 0.28 mm.

Ziegler (3) demonstrated that the cutting speed has no appreciable effect on the main cutting forces (fig. 4). With all materials, the main cutting forces remain almost constant at cutting speeds above 50 m/min., whereas they rise when the cutting speeds decrease. The rise is somewhat steeper during conventional hobbing than with climb hobbing. The decreasing trend is found up to about 50 m/min., independently of the milling process and the gear data.

At higher cutting speeds the cutting forces can not be reduced any further. This was confirmed particularly by the use of a module 1.5 carbide hob. For the feed, a value was chosen with all cutters which corresponds numerically to about 1/2 of the module. The main cutting forces depend apart from the machining conditions on the work piece dimensions, in particular the number of teeth and profile displacement. They are also affected, however, by the number of segments of the cutter and particularly by the latter’s true running.

Ziegler (3) studied, among other aspects, also the effect of the lead directions of cutter and workpiece on the circumferential force and the coordination of this circumferential force with the direction of rotation of the table. If the lead directions of cutter and workpiece correspond, the component from the main cutting force opposes the workpiece rotation.
This means that the circumferential force presses the machine table and therefore the indexing worm wheel more strongly against the drive worm. No additional table motions can then take place.

If on the other hand the lead directions are opposite, the compo-

4
切削速度对主切削力的影响
Effect of the cutting speed on the main cutting forces

4
切削速度对主切削力的影响
Effect of the cutting speed on the main cutting forces
滚刀的磨损现象
Wear phenomena on the hob

与铣刀和端面齿轮之间的相互作用情况有关，并会导至加工表面的磨损降低力影响表面的表面。主切削力的分力演变加工的工作步旋转的方向。

如果圆周作用力与工作台转向相反，则事实上该作用力对工作台没有影响。但是，如果两者方向相同，则会使得加工时的力会按照滚刀在工作面的接触力的方向作用。这种作用力使齿轮与滚刀在工作面上产生细小的加工质量及细纹波的表面。

切口横截面区域
在研究滚刀的磨损情况时，需要了解每个切削的切口横截面情况。Ziegler（4）对切削力的研究为切口横截面的研究提供了理论保证。

在滚刀加工过程中，滚刀的每个切削的主切削力和切削横截面面积和刀具的角度等因素影响着加工质量的改变。刀具的切削力和切削横截面面积之间的关系确定后，所要的工作就是确定刀具的磨损形状和产生原因。

磨损标准
您需要了解滚刀刀齿中表面磨损，切削刀钝化，粘屑和点蚀等术语之间的差别（图6）。为了客观地研究滚刀的磨损情况，我们与厂商合作，通过大量产品进行测试。图7中，磨损痕迹宽度“B”指的是表面磨损。图7上方的曲线给出了已知的磨损特性，即初始时略有下降，然后上升，上升阶段几乎是以线性比率进行的。随着加工量增加，磨损宽度也逐步上升。下方的曲线是以切削刀齿刃口处为基准的。我们可以找到刀具的最低点，该点对应的磨损痕迹宽度表示此时刀具较佳的磨削量。如果观察每个刀具的磨损情况，其结果如图8所示。此时有40个齿较钝，刀具处于一个特定的位置。

此时的粗加工往往使用相同的切削刀完成的，此时只有少量的切削刀达到最大的磨损量，而其它切削刀则磨损很少甚至没有磨损。另一方面，当刀具产生轴向位移时（端面位移）。每个加工周期内其它切削刀会移动到最大应力作用区域，所以事实上大多数刀具切削的磨损痕迹宽度是相同的。

If the circumferential force acts against the table rotation, it has virtually no influence on the latter. If it acts in the same direction, however, the table on conventional hobbing machines is subjected to movements at the segment engagement frequency, the magnitude of which corresponds to the play between the worm and the worm gear, and which may lead to a rough, rippling machining pattern along the tooth flank to be machined.

The cross-sectional areas of cut
To study the wear behaviour of hobs it is necessary to know the cross-sectional areas of cut for the individual cutter teeth. Already the study by Ziegler (4) of the cutting forces presupposed a knowledge of the cross-sectional areas of cut.

The main cutting force and the cross-sectional area of cut are in hobbing different for each individual tooth of the cutter. This makes hobbing quite different from other machining processes where an increase in feed immediately produces a change in chip thickness. In fig. 5, page 186, the measured cutting forces below and the calculated maximum cross-sectional areas of cut above are plotted one above the other for a particular gear. The cross-sections are sub-divided according to the cutting edges on the tip and on the two flanks of the cutter teeth. It can be clearly seen that in the roughing zone the cross-sections on the cutter tip far outweigh those of the flanks. To obtain the values for this figure, gears with only one tooth space were cut, so that the cross-sectional area of cut could be coordinated with the corresponding cutting force. After the connection between cutting force and cross-sectional area of cut has been established, the task was to define the wear forms and their causes on the cutter teeth.

Wear criteria
On the hob tooth a distinction is made between flank wear, cutting edge rounding, chipping and pitting (fig. 6). To be able to study the wear behaviour of hobs realistically, the tests were carried out in cooperation with the industry under mass production conditions. In fig. 7 the wear mark width “B” refers to the flank wear. The upper curve of the figure shows the well known characteristic of an initially progressive rise, which is followed by an almost linear section. As the number of units increases, the rise becomes progressive. In the lower curve the wear is based on the number of units out. A minimum is then found and consequently a specific value for the wear mark at which the proportional tool costs become minimal. If one looks at the wear of each individual cutter tooth, a representation as shown in fig. 8, page 186, results. Here, 40 gears were cut in a quite specific cutter position.

The roughing work is in the case always carried out by the same cutting edges, so that maximum wear occurs on a few cutter teeth which have to be reground although other teeth show little or no wear. With axial cutter displacement (hob shift) on the other hand, other cutting edges move into the maximum stress area.
The effect of the cutting conditions on tool wear is of particular interest. The dependence of the wear mark width "B" on the feed is shown in fig. 9. With small feeds the chip thicknesses and the cutting forces are small, whereas the number of starting cuts is high. With greater feed the cross-sectional areas of cut increase, and with them the cutting edge stress and temperature, whereas the number of starting cuts decreases.
的，从该区域的研究可以推断，进给量的增加并不受刀具的限制，而是说服齿轮的实质性能，尤其是进给速度确定的，与进给量相比，切削速度对刀具磨损的影响要大得多。稍后我们将回到这一事实上来。

Hoffmeister (5) 根据他的研究发现，采用刀具，加工和齿轮标准的要求对滚刀磨损的影响进行了分类，磨损是受刀具直径，刀具刀位数量以及刀具所有参数影响的。其它影响因素还有齿顶圆半径，刀具磨耗的垫，刀具的形状，切削刀的形状，最后还有刀具的设计和使用的材料等。

磨损主要受以下加工条件的影响：
进给量 "f"，刀具直径 "D"，刀位 "a"，切削速度 "v"。
其它影响因素还有滚齿加工工艺，滚齿加工设备的状况，工作条件，最后是冷却液。

齿轮对滚刀磨损的影响因素包括：齿轮的直径，模数，螺旋角，刀轮位移x·m以及齿轮的厚度。同时我们也不能忽略齿轮材料对刀具磨损的影响。对磨损影响的因素可以分为两类：
1. 构成齿轮的几何参数的数值得以及确定切削弧长度和切屑厚度的刀具。

If one looks in fig. 10 at the mean wear as a function of the feed, one can see that the increase in wear at greater feeds is so little, that the reduction in cutting time achieved by increasing the feed is much more important than the only slightly worse tool wear. It can be deduced from this that in the area studied an increase in feed is not limited by the wear, but by the attainable gear quality, particularly as regards the feed markings.

In contrast to the feed, the cutting speed affects tool wear far more. We shall come back to this fact later.

Hoffmeister (5) classified the effects on hob wear according to cutter, machining and gear criteria. According to his findings, the wear is influenced by the diameter of the tool, the number of starts of the tool, and the number of segments. Further influencing factors are the tool radius, the relief angle of the cutter profile, the rake angle of the cutting edges, and finally factors such as the tool design and material.

Wear is strongly influenced by the following machining conditions:
By feed "f", by shift "a", cutting depth "a", cutting speed "v". Other factors affecting wear are the machining method, the condition of the hobbing machine, the mounting and clamping of the tool (run-out) and the gear and, finally, the coolant.

The gear affects hob wear through its diameter, the module size, the helix angle of its teeth, the profile displacement x·m and through the gear width. The effect of the gear material on tool wear must not be forgotten either. This large number of factors affecting wear can be divided into two groups.
1. Values which from the geometry of the teeth and the cutter determine the length of the cutting arc and the chip thickness.
2. Technological effects, such as cutting speed, cutting material/tool pairing, cutting edge geometry, use of cutting oil etc.

Engagement conditions
Hoffmeister (6) distinguishes between the cutter entering and leaving sides, which are separated by the central tooth, and between a profile generating zone and a pre-cutting zone. The central tooth is the cutter tooth which is situated in the axial hob/gear crossing point. The central tooth lies in the centre of the profile generating zone. The pre-cutting zone depends on the external shape of the hob. This will be greater with cylindrical tools than with tools which have a tapered or round leading end.

In the tool/workpiece penetration (7), fig. 11, the penetration curve forms a cutting ellipse on the cylindrical generated surface of the gear. The position of this ellipse depends on the crossing angle of the two axes. In addition, the shape of the ellipse is determined by the sizes of the hob and the gear. The essential point for assessing the correct setting of the tool on the hobbing machine is the projection of this cutting ellipse in a plane which is parallel to the hobbing machine. If the designations given in fig. 12 are used, the formulae presented in fig. 13, page 188, can be developed.
通过这些公式的帮助，我们可以用来对刀具的设置进行估算（图14）。通过投影椭圆，我们可以在Y轴上得到一个最大值。

该值在刀具轴线上的投影值表示进给加工时的切削区域。如果该曲线沿Y轴向上延伸到Y = Y_{max}，工作件旋转一圈的进给量，我们可以在曲线上得到该点的位置，从而确定进给加工的切削区域的位置。

当刀具和加工齿轮的移动方向相同时，该曲线在刀具轴线上的位置与加工齿轮切削区域的刀具长度相等。如果考虑锥齿轮形状的刀具，那么曲线图的有关知识对大齿轮尤其重要。

图15解释了图面柱形刀具相比锥齿轮刀具的切削长度是如何迅速增加的。

With the help of these formulae a graphic drawing can be produced which makes it possible to assess the tool setting (fig. 14).

In the penetration ellipse we obtain a maximum value for the Y-axis. The projection of this value onto the cutter axis shows the entering zone for conventional hobbing. If the curve is traced beyond Y_{max} up to a value Y = Y_{max}, feed per workpiece rotation, we obtain a point on the curve from which the entering zone for climb hobbing can be determined.

The projection of this curve onto the cutter axis corresponds to the cutter length for the entering zone on helical gears when the tool and the gear have the same direction of lead. If a tool with a tapered lead is brought into the consideration, knowledge of the penetration line is important particularly with large gears.

### 图13
贯穿曲线的计算
Calculation of the penetration curve

\[
\begin{align*}
R_f &= \text{刀具圆角半径} \\
h &= \text{齿高/切深} \\
R &= \text{工件外径} \\
\beta &= \beta_0 - \gamma_0 \\
\beta_0 &= \text{齿轮螺旋角} \\
\gamma_0 &= \text{滚刀螺旋角} \\
A &= R_f - h + R \\
a &= R \left[ 1 - \left( \frac{X}{R} \right)^2 \right] \\
b &= A - R \left[ 1 - \left( \frac{X}{R} \right)^2 \right] \\
c &= R_f \left[ 1 - \left( \frac{A - R \left[ 1 - \left( \frac{X}{R} \right)^2 \right]}{R_f} \right)^2 \right] \\
d &= R_f \left[ 1 - \left( \frac{A - R \left[ 1 - \left( \frac{X}{R} \right)^2 \right]}{R_f} \right)^2 \right] \cdot \frac{1}{\cos \beta} \\
e &= x \cdot \tan \beta \\
f &= R_f \left[ 1 - \left( \frac{A - R \left[ 1 - \left( \frac{X}{R} \right)^2 \right]}{R_f} \right)^2 \right] \cdot \tan \beta \\
g &= \frac{X}{\cos \beta} \quad y = d + e \quad L = f + g
\end{align*}
\]
Fig. 15 shows how the approach lengths become decidedly shorter in the tool with tapered lead as compared with the cylindrical tool. It should here be pointed out that the angle and shape of the lead should also be carefully matched to the conditions, to prevent overloading the entering teeth, because this would again lead to premature wear. Backed by the knowledge of the hob positioning on the hobbing machine the wear studies could now be systematically carried out (fig. 16, page 190).

In the wear measurements one makes a distinction between the tip wear, here identified by “Bb”, the wear of the outgoing flank called “Bw”, and the wear of the approaching flank called “Bf”. The outgoing cutter flank is the flank whose relative motion is the same as that of the leaving gear flank. The approaching tool flank is the cutter flank towards which the gear flank moves during the generating motion. When comparing the results of the wear measurements on the hob which had been used for climb hobbing with the wear measurements on the hob which had been used for conventional hobbing, the direction of rotation of the gear blank and the direction of rotation of the cutter were kept the same.

This means that when the wear curve is drawn, the central tooth (called 0) lies in the wear diagram for climb hobbing on the right-hand diagram side, whereas the central tooth for con-
滚刀的磨损现象
Wear phenomena on the hob

逆铣加工时，主要的切割应力由磨出切削刃承受的。这时，在齿的生成区域磨损情况往往更为严重。这一点我们可以通过以下事实加以解释，即在逆铣加工时齿生成区域内大部分刀具余量的长度仍然比较长。因此，顺铣加工过程中，加工区域主要位于刀具的切削中，而逆铣加工时加工区域主要位于磨出槽。

我们可以对磨损图作出如下解释：在顺铣加工时，位于外侧切削齿面的有效后角比以内切削齿面的有效后角小，这就是外侧切削齿面的最大磨损量会受到小角度后角的影响的原因，这种解释对逆铣是无效的。尽管外侧切削齿面也存在齿面磨损情况，但其有效后角的角度较大。因此，后侧角度大小是齿面磨损的唯一原因。

为了给齿面磨损做出一个合理的解释，需要对此作出进一步的研究。

16
滚刀的磨损分布情况
Wear distribution on the hob

Bk = 齿顶磨损
Tip wear

Ba = 副切削刃磨损
Wear on the leaving flanks

17
切削屑截面的判断
Determination of the chip forming cross-sections

图显示了正常和逆铣加工中切削刃磨损情况。
Chip geometry in hobbing
Sulzer (8) drew up a computation process which accurately determines the geometry of the individual chip. For this purpose he studied the chip formation in a number of cutting planes during the passage of a cutter tooth. The computer now supplies for each cutting plane numerical values which correspond to the chip thickness formed. These values—shown diagrammatically—produce horizontal lines for the cutting planes with the designations 1 to 6 (fig. 18). To gain an overall impression of the size relationships, the scale of the chip forming cross-sections is given on the left-hand side of the diagram. The designations for the cutting zones are situated underneath the base line. The section AB corresponds to the entering cutter flank. Section BC corresponds to the tooth tip width. Section CD corresponds to the leaving cutter flank. When the values supplied by the computer for the chip forming cross-sections are represented by the plotter, we obtain a picture of the chip cross-sections on the cutting planes. This plotter image provides a representation of the chip cross-sections and the chip outline.

If this calculation of the chip cross-section (fig. 17) is carried out with a representation for all meshing hob teeth, one obtains an overview of the chip forming cross-sections and the chip forms in hobbing (fig. 19, page 192). Furthermore one can recognize the stresses on the individual hob teeth and the varying load within the tooth under observation.

When simulating the individual hobbing process such as conventional hobbing and climb hobbing and hobbing in the same or in the opposite direction, the computer supplies different chip forming cross-sections and forms. Hobbing in the same direction means that the direction of start of the hob and the tooth lead of the gear are unidirectional, i.e. a cutter with right-hand start ma-
in the case of hobbing in the opposite direction a cutter with right-hand start machines a gear with left-handed teeth and a cutter with left-hand start machines a gear with right-handed teeth. This computational consideration of chip forming geometry confirmed what Thömer (1) had already found in his studies. Flank wear takes place precisely at those transitions from tool tooth tip to tool flank which are no longer actively participating in the metal cutting process. He states: “In this case the tool cutting edge which just at this corner no longer removes a chip exhibits particularly large wear mark widths, which in turn makes it clear that no direct connection exists between chip thickness and tool wear.”

The plotter images produced by Sulzer’s method (9 and 10) confirm this assumption. Sulzer’s studies covered mainly the wear behaviour of carbide hobs. Instead of flank wear, he found microchipping in this area. Using the scanning electron microscope,

根据Sulzer, Aachen工艺
acc. to Sulzer, Aachen polytechnic
切屑和工件表面的破损现象可以用切屑形状和切屑的流动现象加以解释。当处于齿面靠近刀具齿顶位置时，切削工艺开始进行。如果在切削过程中在齿顶未完全与工件接触，切屑不能自由卷曲。最后，切屑被切断面推离刀具，并沿着工件表面流至切削刃。随着切屑切削的切削运动，压力焊接点被破坏，然后由后面的切屑重新形成。另外在切削过程中工件产生磨损。这表明工件表面逐渐被切削出刀具齿面。切屑以该相对速度从切削面推至切削刃。它会在切削刃产生拉伸应力，该应力会导致硬质合金刀片产生粘屑。当使用高速钢加工时，该位置产生的拉伸应力会造成更多自由表面产生磨损。当切削以反方向运动时，也会产生该现象，但其破坏程度没有这么高。

因此，我们往往把反方向加工作为防止表面磨损的良方妙药。当按反方向进行滚齿加工时，圆周力沿滚压工作表面方向。此时，圆周力作用在表面和中轴线之间的交界处，它按照刀具端部导向的曲率在表面轴向上生产干涉。这导致表面轴线上出现破损标记和整个齿轮的磨损。由此切屑切削面的不断交替转换来减少表面的磨损是切实可行的。该领域的长期试验工作尚未完成，因此对于该方法的准确性判断尚无加以精确描述。

he studied the leaving flanks for chip traces and found pressure welded deposits on the flanks. He states: “The different direction of the cutting traces and of the streaks indicates that these streaks are caused by the chips being removed. They occur at those points on the tooth flank which do not come into engagement with the cutters tooth concerned, i.e. there is generally a gap between the cutting edge and this flank area.”

The collision between chip and workpiece flank can be explained by the chip form and the chip flow. The cutting process commences at the leaving flank near the cutters tooth tip. At this stage it can still curl freely. After that the tip area of the cutters tooth moves into engagement. Because of the complicated shape and the light space conditions in the tooth gap the chip can no longer curl freely. It is at the end pushed by the entering flank beyond the cutting face to the other workpiece flank, where it is welded on. As a result of the cutting motion of the cutters tooth the pressure welds are separated, but are formed fresh by the flowing chip. In addition, a workpiece rotation takes place during the cutting motion. This means that the workpiece flank moves away from the leaving tool flank. It is this relative speed at which the chip is pushed from the cutting face over the cutting edge. This produces tensile forces on the cutting edge which can in the case of carbide lead to chipping. When machining with high-speed steel, squeezing forces occur at this point which produce the greater free flank abrasion. This phenomenon also occurs with hobbing in the opposite direction, but not to such an extent.

It is therefore easy to regard hobbing in the opposite direction as a cure-all for flank wear. With hobbing in the opposite direction the circumferential force acts in the direction of rotation of the table. Since this circumferential force favours the flank clearance between the worm and the indexing worm wheel, it creates a disturbance in the indexing gear unit with the segment engagement frequency. This results in chatter markings on the gear flanks and vibration throughout the gear train. It is feasible that flank wear could be reduced by alternate cutting of the tip flanks. Long-term tests in this field have not yet been completed, so that no definite statement can as yet be made about the success of this measure.

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Involute gear cutter with carbide indexable inserts

Involute gear cutter
For roughing and finish-milling of internal and external straight spur gears, and for worm thread and rack cutting

Involute roughing hob
With tangentially arranged carbide indexable inserts, pressure angle 20°, basic profile IV to DIN 3972. These tools permit an economical production process for the roughing of large gears. Under certain conditions, they offer considerable advantages for the roughing of high-strength gear materials (R_h > 1000 N/mm²). The tooth gaps are roughed trapezoidally with straight-sided flanks. The basic tool profile corresponds to BP IV according to DIN 3972. Other profiles can be supplied as non-standard versions upon request.

Requirements
The user of carbide cutting materials enables considerable increases in performance to be achieved. A powerful and sufficiently rigid machine is however essential. Milling using the plunge process must also be possible. Preference should be given to climb milling.

Involute finishing hob
This method can be employed where medium quality requirements are placed upon the gear quality; quality grade 9 to DIN 3902/86 can be attained.

This process is often employed for the manufacture of ball bearing slewing rings (control gear for jib cranes), and for the profiling of external and internal gears.

Design features
Continuous indexable cutting inserts edges enable the entire profile height to be finish-milled. Problematic transitions are thus prevented from leading to banding.

The indexable inserts can be indexed twice. The cutting edge form is determined by the tooth gap profile specified by the customer. It is dependent to a large degree upon the number of gear teeth and the profile displacement factor.
### 材料与动力因素

<table>
<thead>
<tr>
<th>材料</th>
<th>$R_p$/UTS (N/mm²)</th>
<th>动力因子 $Q_{spaz}$ cm³/min · kW</th>
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<tbody>
<tr>
<td>非合金结构钢 Unalloyed structural steel</td>
<td>-700</td>
<td>22 – 24</td>
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<tr>
<td>自由切削钢 Free cutting steel</td>
<td>-700</td>
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<tr>
<td>结构钢 Structural steel</td>
<td>500 – 800</td>
<td>18 – 20</td>
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<td>热处理钢，中等强度 Heat-treatable steel, medium strength</td>
<td>500 – 950</td>
<td>18 – 20</td>
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<tr>
<td>铸钢 Cast steel</td>
<td>-950</td>
<td>18 – 20</td>
</tr>
<tr>
<td>淬火钢 Case hardening steel</td>
<td>-950</td>
<td>18 – 20</td>
</tr>
<tr>
<td>不锈钢，铁素体，马氏体 Stainless steel, ferritic, martensitic</td>
<td>500 – 850</td>
<td>16 – 18</td>
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<td>热处理钢，高强钢 Heat-treatable steel, high-strength</td>
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<td>13 – 18</td>
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<td>氮化材料钢，热处理 Nitriding steel, heat-treated</td>
<td>850 – 1400</td>
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<td>工具钢 Tool steel</td>
<td>850 – 1400</td>
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<tr>
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<td>灰口铸铁 Grey cast iron</td>
<td>100 – 400 (120–600 HB)</td>
<td>26 – 35</td>
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<td>合金灰口铸铁 Alloys grey cast iron</td>
<td>150 – 250 (160–230 HB)</td>
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<td>球墨铸铁 Nodular cast iron</td>
<td>400 – 800 (120–300 HB)</td>
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<tr>
<td>铸铁 Malleable cast iron</td>
<td>350 – 700 (150–280 HB)</td>
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### 公式

该公式适用于全廓面深度情况：

$$P_{(kw)} = \frac{3,19 \cdot \text{Mod}^2 \cdot v_f}{1000 \cdot Q_{spaz}}$$

$$v_f = f_z \cdot n \cdot z$$

$$f_z = \frac{h_{tip}}{a}$$
### 求标号与索引
DIN number index

<table>
<thead>
<tr>
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</tr>
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<tbody>
<tr>
<td>138</td>
<td>17, 33, 83, 95, 111</td>
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<td>368</td>
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<td>17, 83, 95</td>
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<td>110</td>
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<td>5, 6, 14, 17, 35, 37, 40, 83, 103, 106, 108, 110, 164, 165, 186, 170, 171, 194</td>
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### 图标概述
Pictogram overview

#### 切削材料
Cutting materials
- 硬质合金 Carbidex
- 含钴高速钢 Cobalt alloyed high speed steel
- 硬质合金 Solid Carbide
- 粉未高速钢 PM

#### 表面涂层
Coating
- AL2

#### 标准
Standards
- DIN 3968
- DIN 3969
- DIN 3972
- DIN 3975

#### 基本齿形
Basic profile
- DIN 3969
- DIN 3972

#### 几何尺寸
Geometry
- 压力角20° Pressure angle 20°
- 压力角30° Pressure angle 30°
- 正副角 Rake positive
- 负副角 Rake negative
- 断屑槽 Chipbreaker

#### Ausführung
Version
- 女转子 Female rotor
- 刀段 Segment
- 刀片 Insert
- 铰接 Keyway
- 钻心 Screw pump
- 铲齿 Relief turned
- 铲肩 Relief ground
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