



Gear Honing Technology

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1 Introduction

Chip-forming machining in gear manufacture makes particularly stringent demands on process and tools, due to the high technological requirements for the product. The trade-off between cost-effective manufacturing and gear quality requirements is particularly important in hard finishing of tooth flanks (Fig. 1). High profile accuracy requirements for the tooth flanks and their surface qualities and the maintenance of geometric gear tolerances are achieved by various grinding processes which are already in general use in high-volume production. In addition, many passenger car gearboxes require low-noise operation of the gears. The specific surface texture on the tooth flanks after gear grinding, running transverse to the flank engagement direction, promotes an undesirably high level of noise generation.

A considerable reduction in gear noise can be achieved by gear honing. Grinding of the tooth flanks is followed by a further machining operation on gear honing machines, with tools specially developed for this process. The specially designed process kinematics remove the roughness peaks of the tooth flanks. Previously known honing techniques permitted only a slight correction in the flank profile, due to the very small infeed increments achieved with them. In some cases, conventional honing may even result in a deterioration of the ground gear quality.

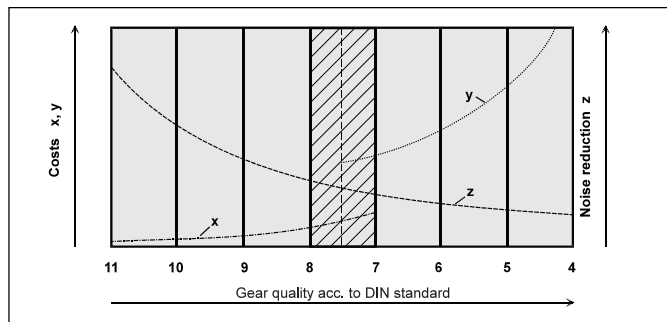


Fig. 1: Noise reduction as a function of gear quality, and associated costs [1]

Expensive “reworking” of tooth flanks has already led to considerations of replacing gear grinding completely by gear honing. This can only be successful if there are high-performance machines and tools available, that are capable of generating the tooth flank profile and the specified surface texture after hobbing and hardening. Machine manufacturers and tool suppliers have recently started their first development work on this.

2 Classification of chip-removing gear manufacturing methods

Chip-removing gear manufacturing methods may be systematically classified by various principles [2]. A practical proposal is shown in Fig. 2. Gear honing is classified in the category of precision machining with geometrically non-defined cutting edges. It may be sub-divided into the variants “chip-removing processes with internal-tooth honing rings” and “chip-removing processes with external-tooth honing rings” (Fig. 3). The use of external-tooth tools is known in the industry as hard shaving.

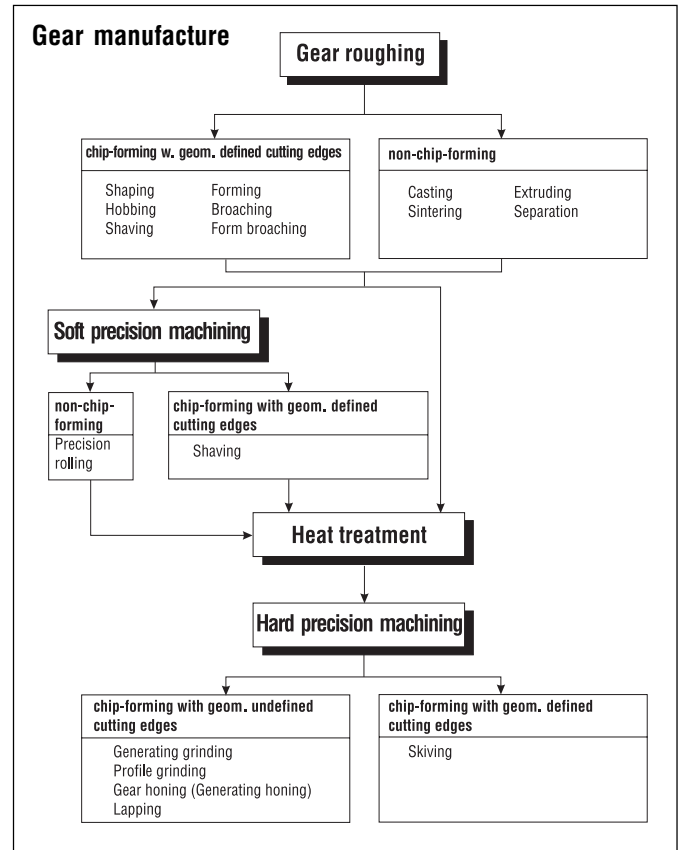


Fig. 2: Classification of gear manufacturing processes

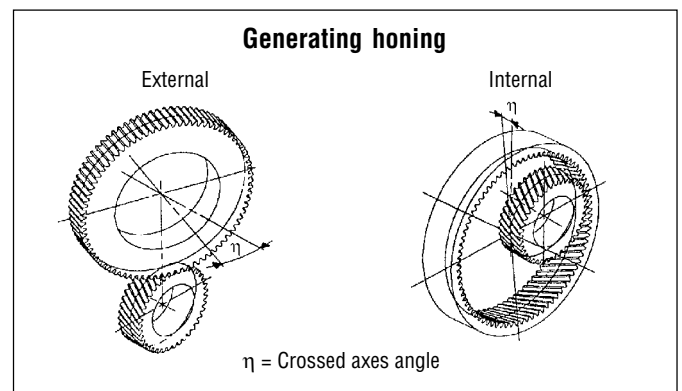


Fig. 3: Variants of tooth flank honing [3]

In order to achieve the most cost-economic production possible, while still meeting the accuracy requirements high cutting speeds and feeds are used for soft machining.

The chip-removing process is carried out by tools with geometrically defined cutting edges. Examples of methods used are hobbing, shaping and gear shaving.

Roughing is followed by heat treatment. The hardening distortion and the required profile accuracy of the hardened workpieces can then only be achieved and maintained by conventional gear grinding processes (hard machining). The dominant methods here are generating grinding and form grinding (Fig. 4).

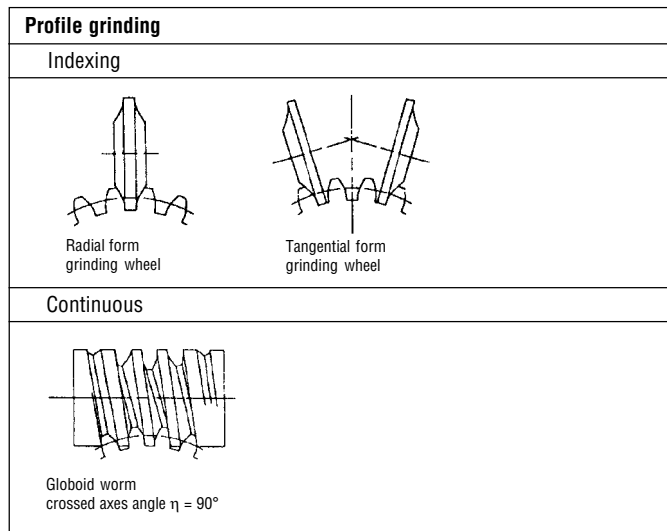
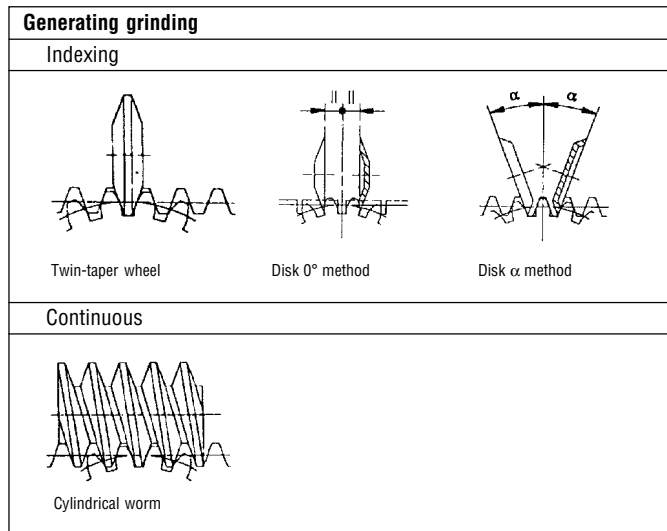


Fig. 4: Gear grinding processes [3]

The following chapters deal mainly with gear honing with internal-tooth honing rings in view of the technological significance of this process.

3 Kinematics of gear honing

Gear honing is one of the continuous chip-removing precision machining processes, and its kinematics are basically analogous to gear shaving. The driven honing tool and the generally non-driven workpiece are in rolling contact with a specified radial pressure (Fig. 5).

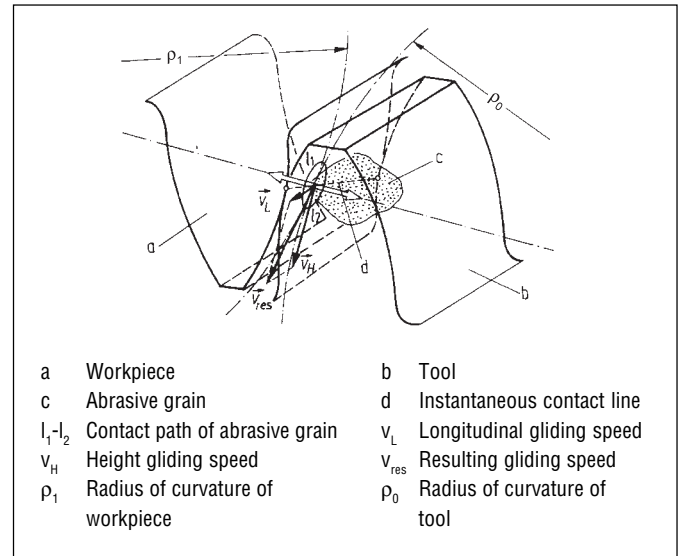


Fig. 5: Cutting kinematics in generating [1]

The fact that the axes are crossed at a defined angle (crossed axes angle) means that the superposition of the feed movements gives a resulting gliding movement in the material removal region, running diagonally from tip to root, thus producing a micro-cutting process with short cutting point engagement. The large number of grains engaging in the tooth flank at the same time means there is a steady removal of chips, which in turn generates a surface texture on the tooth flank which is favourable for the gear operation (Fig. 6).

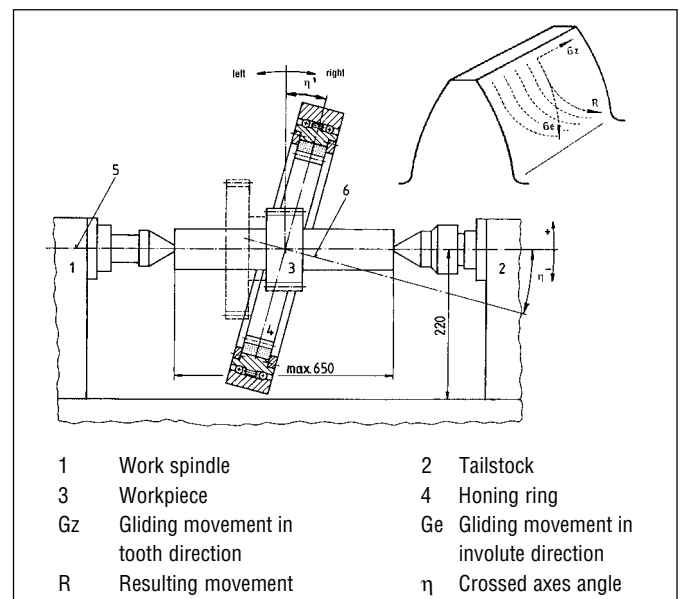


Fig. 6: Working kinematics [4]

4 Geometrical design of internal-tooth honing tools

The geometrical design of honing rings (internal-tooth honing tool) is based on DIN 3993 [6, 7]. The main parameters are as follows:

- ⇒ Internal diameter d_i
- ⇒ Width U
- ⇒ Addendum modification $x \cdot m$
- ⇒ Helix angle β .

The tooth data of the workpiece play a very important part. The internal diameter of the honing ring, also known as the tip circle, should be between 245 and 375mm if possible, in order to avoid possible engagement disturbances. If the tip circle is specified as large as possible, which is equivalent to a larger number of teeth, this increases the tool life of the honing ring. If the addendum circle is specified small, this improves the overlap factor, and thus increases the correction capability for individual and cumulative indexing faults.

The number of teeth of the honing tool must be chosen such that the same point on the workpiece and honing tool only meets after a number of revolutions i.e. the number of teeth of the tool and the workpiece must not be a multiple of one another.



Fig. 7: Internal-tooth honing ring

A large honing tool width makes it possible to increase tool life and overlap of module gaps. On the other hand, a smaller width results in increased workpiece removal volume, because the specific honing forces rise, giving greater penetration depth of the grains.

The addendum modification of an involute gear according to DIN 3960 [5], which is an important parameter for the honing process, is the distance of the profile reference line from the pitch cylinder. The amount of addendum modification is indicated as a multiple of the standard module with the addendum modification coefficient x :

$$\text{Addendum modification} = x \cdot m_n$$

If the profile reference line is shifted from the pitch circle towards the tip circle, this gives a positive addendum modification and hence a greater tooth thickness in the pitch circle than for addendum modification equal zero. If there is a negative addendum modification, the profile reference line is shifted from the pitch circle towards the root circle, and thus gives a smaller tooth thickness in the pitch circle than at addendum modification equal zero (Fig. 8).

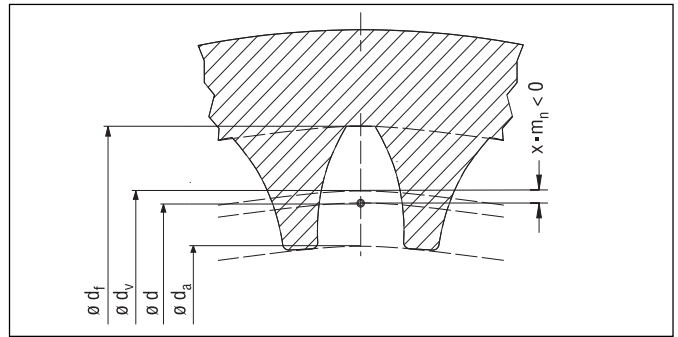


Fig. 8: Negative addendum modification on a honing ring

The addendum modification on the honing tool should be 0.5 greater than on the workpiece. If, for example, there is an addendum modification of zero on the workpiece, the addendum modification on the honing tool can be specified up to +0.5 in unused condition. The aim should be to maximize addendum modification, in order to give better utilisation of the tool. As specified in DIN 3960, helix angle β is the acute angle between a tangent on a pitch cylinder flank line and the pitch cylinder envelope line through the tangent contact point. Helix angle β depends firstly on the selected crossed axes angle and is a function of workpiece diameter. The usual crossed axes angle for straight and helical gears as follows:

- ⇒ 1° bis 6° for cluster gears
- ⇒ 6° bis 8° for gears with $D_o > 200\text{mm}$
- ⇒ 8° bis 10° for gears with $D_o = 100 - 200\text{mm}$
- ⇒ 10° bis 12° for gears with $D_o < 100\text{mm}$.

The direction of inclination of the honing tool on the honing machine (crossed axes angle) depends on whether automatic loading or manual loading is used. For automatic loading, the honing tool must be designed so that it is always inclined to the right, in order to leave space on the left for automatic loading and unloading (Fig. 8). For straight gears, the honing tool inclination angle is the same as the crossed axes angle.

As a general principle, an internal-tooth honing ring must be designed such that its tooth geometry corresponds to the tooth geometry of a high-precision gear pair (internal worm gear), in order for the gear engagement to run smoothly.



Fig. 9: Fässler D-250-C with automatic loading and unloading [4]

5 Machining with honing rings

Gear honing is the final machining process, and therefore has to meet the very highest requirements for precision and reproducibility. The essential parameters here are profile retention of the gear and the dressability of the tool as a whole.

The tool life of the honing ring is dependent on a number of factors, of which the most important are removed volume, workpiece material, number of teeth, hardness, surface damage of the teeth and run-out errors, pitch errors and honing ring composition.

Internal-tooth honing rings comprise a resinoid matrix, with aluminium oxide or silicon carbide abrasive grains embedded in it, and pores which are dependent on the compression factor during pressing.

Important quality criteria are the homogeneity of grain distribution in the bond and the hardness, rigidity and wear resistance of the tool, particularly with respect to profile retention of the tooth shape during machining. If the bond percentage is reduced in the honing ring, it has a softer and more free-cutting action. But the tool has to be re-profiled more often.

The three-component diagram (Fig. 10a), which includes the volumetric percentages of grain, bond and pores, can be used to show a wide range of formulation variations (Fig. 10b).

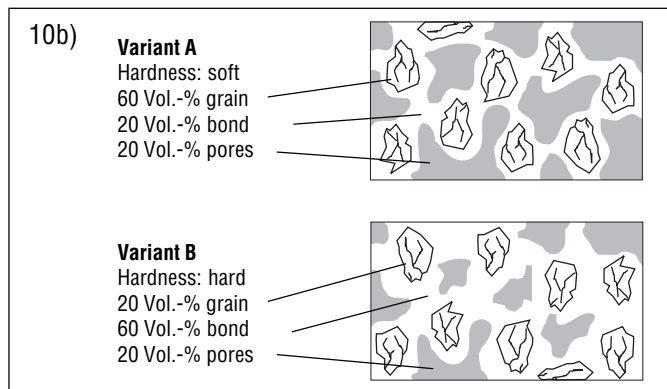
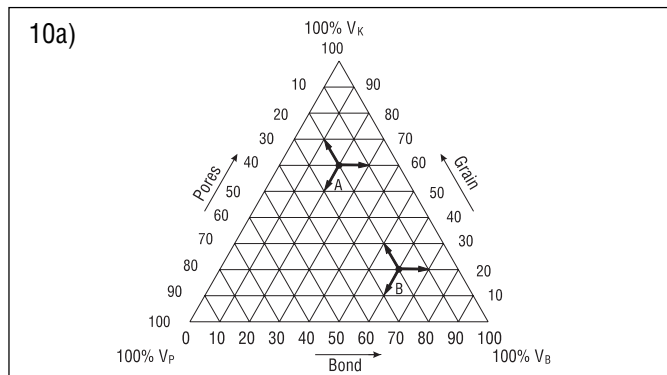


Fig. 10: Three-component diagram 10a) and formular variants 10b)

An increased percentage of bond is appropriate for smaller material removal rates, e.g. for machining ground gears where only slight geometrical corrections are necessary. The module range to be honed is between 0.5 and 8mm, and the helix angle between 0 and 45°. Grain size is mostly between F100 and F220: F100 for high material removal rates in larger module ranges, and F220 for very fine surfaces with small material removal rates in small module ranges. Gear hardness is mostly below HRC 64.

The guideline for honing ring hardness is dependent on the module range of the gears to be machined. The honing ring is designed softer with increasing module size. If hard machining has already been done, e.g. hard milling, hard shaving or continuous profile grinding, then hardness may be specified one level higher.

Different tool lives are achieved, depending on preparation and variations in allowance. The longer the dressing cycles, and the more often re-profiling is possible, the greater is the total tool life. With pre-ground gears it is possible to achieve very good tooth geometry and to achieve a surface finish of $R_z = 1.5$ to $2.5\mu\text{m}$ an allowance of only 5 to $10\mu\text{m}$ per flank has to be removed. For milled/hardened or shaved/hardened gears, a layer thickness of up to $20\mu\text{m}$ per flank has to be removed in order to eliminate hardening distortions. The honing ring speed is between 20 and 500rpm and has an influence on involute shape, material removal volume and surface quality.

6 Dressing internal-tooth honing rings

Honing rings profiled by the manufacturer have to be prepared prior to the machining operation through dressing on the machine. The generation of the desired topography and geometry has a decisive influence on the total life of the honing ring. Dressing is done by diamond dressing gears ("master gears"), which have the profile of the workpiece to be machined (Fig. 11). The diamond dressing tool profile is projected onto the honing ring, which in turn reproduces its profile on the workpiece. The honing ring is thus the link between the initial profile (master gear) and the required workpiece profile (gear).

Before the diamond dressing gear is used, the tip diameter of the honing ring is first dressed by means of a cylindrical diamond dressing ring, at a honing ring speed of about 400rpm. The total dressing amount is usually 0.2mm/radius. This step removes any existing radial run-out in the honing ring. Radial run-out in the honing ring addendum circle causes high pressure during profile dressing in the root area of the dressing gear, which has a negative effect on the projection of the toothing onto the honing ring.

The outer diameter and the width of the diamond dressing ring correspond to those of the diamond dressing gear.

Once the tip diameter has been successfully dressed, the next step is initial dressing of the gear profile. On initial dressing, the total dressing amount is mostly between 0.3 and 0.6mm,

measured in radial direction, until the target topography and geometry has been completely projected. The initial dressing amount is very much dependent on the toothing precision and design of the honing ring.

The re-profiling operation occurs dependent on

- ⇒ Pre machining of the workpiece
- ⇒ Workpiece quality
- ⇒ Module
- ⇒ Workpiece tooth number
- ⇒ Workpiece diameter
- ⇒ Honing ring specification
- ⇒ State of diamond layer

after 10, 25, 50, 70 or even after 100 workpieces. The dressing increment per cycle is between 0.05 and 0.08mm / radius. All acting forces and movements are analogous to those of honing. Reprofileing exposes new abrasive grains and creates new pores for the disposal of chips. The honing ring speed for profile dressing is usually 50rpm.

The greater the dressing cycle, and the more often re-profiling is possible, the greater the total life of the honing ring.

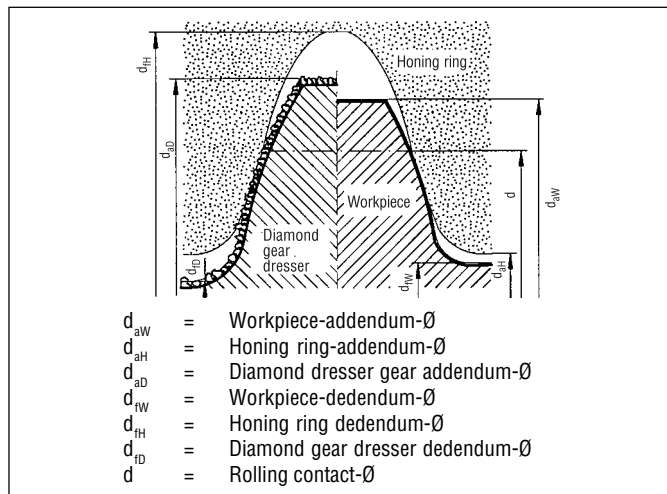


Fig. 11: Honing ring - diamond gear dresser - workpiece

When manufacturing diamond gear dressers, a distinction is made between positive electroplated single-layer dresser and negative electroplated single-layer dresser. The geometry of the diamond gear dresser corresponds precisely to the specified geometry of the workpiece, apart from the addendum and dedendum circle diameter. The addendum circle diameter is a little greater and the dedendum circle diameter a little smaller than that of the workpiece. This gives the minimum clearance required between the honing ring and the workpiece.

a) Positive electroplated single-layer dresser

The electrolytic process causes the synthetic diamond grits to be embedded up to about 80% in a layer of nickel (Fig. 12).

Only about 60% of the diamond grits is in contact with the workpiece during the dressing process. Tool life is between 1000 and 1500 dressing operations, depending on workpiece diameter, honing ring specification and dressing amount. Provided there is no damage to the core after the diamond layer has been used up, the core can then be re-plated.

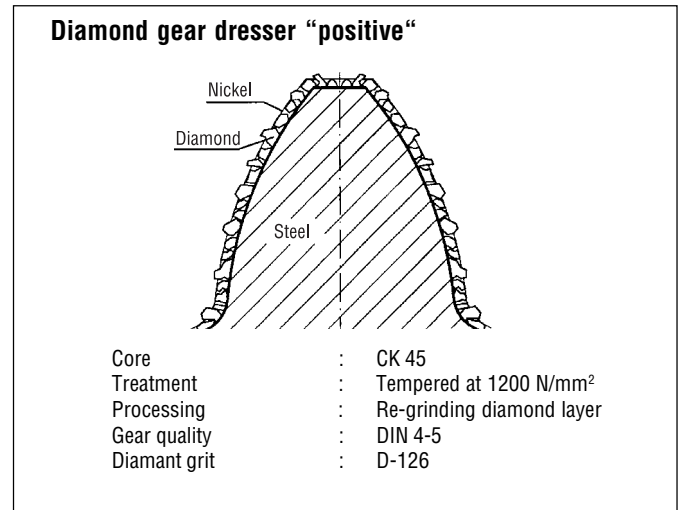


Fig. 12: Positive plating

b) Negative electroplated single-layer dresser

For manufacturing a negative single-layer dresser, first a negative mould is made from the high-precision ground master gear. Before the negative mould is covered with a diamond layer in the electroplating process, the master gear is eroded out. After the core is cast, the negative envelope is destroyed in the electroplating process. In contrast to the positive-plated gear dresser, 100% of the diamond grits can be used in this process. A diamond gear dresser with a negative layer achieves a tool life which is 3 to 5 times longer, but the purchase cost is also three fold (Fig. 13).

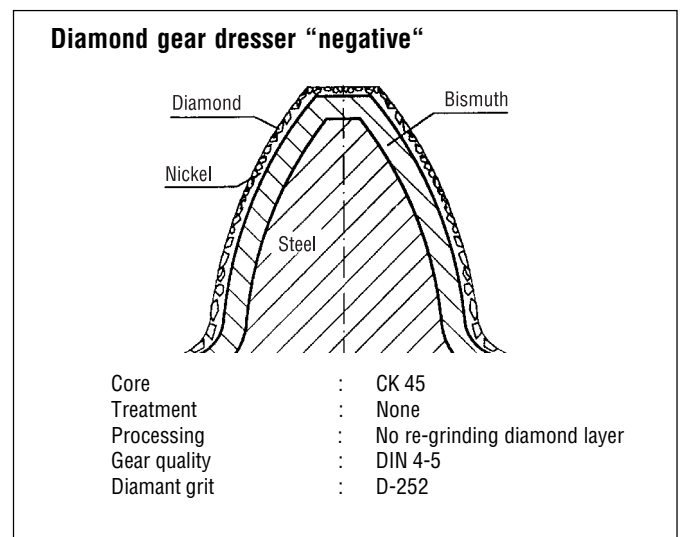


Fig. 13: Negative plating

7 Gear honing machines

Measured by the number of new machine manufacturers since the last EMO in Hanover in 1993, the importance of gear honing must be increasing. Machine developments are important particularly when it comes to the idea of replacing gear grinding by gear honing.

At present, there are about 7 manufacturers of gear honing machines for the use of internal-tooth honing rings. The original machine concept for rework of previously ground tooth flanks is shown in Fig. 14. The honing tool is driven at a defined speed, and the workpiece is carried along by it in a positive lock by the comb-like engagement of the tooth, like a planetary gear. In general, there is provision for a reversal of rotation direction. The workpiece is driven by the tool.



Fig. 14: Gear honing machine D-250-C (Source: Fässler)

This operating principle only permits very small infeed increments and thus extremely small material removal rates, if the machine construction is relatively light. The requirements for surface texture improvements of the tooth flanks can be met reliably and consistently if the honing rings are correctly specified.



Fig. 15: CNC honing machine RZR (Source: Reishauer)

Investigations have been started with the building of statically and dynamically more rigid machine tools, and with the capability of controlling tool and workpiece by separate drives (in some cases CNC axes), so as to increase the infeed amount and thus achieve greater material removal volumes. The drive powers likewise have to be adapted to the increased cutting forces. This generation of gear honing machines is shown in Figs. 15 to 17.



Fig. 16: CNC honing machine PH 280 (Source: Pfauter)

Test results for “high-performance honing” with these machines and adapted honing rings are only available in limited numbers and have got to be confirmed so that no breakthrough of this technology is currently known. The honing ring geometry is a basic problem here. The gear profile is subject to bending stress under the influence of the cutting forces, causing unacceptable deformations due to increased notch effect. The deformation of the tooth is an obstacle to chip formation, and at the same time the increased load causes increased tooth breakout.



Fig. 17: CNC honing machine ZH 250 (Source: Hurth)

The improvement in overall rigidity, i.e. reduction of elasticity of the internal-tooth honing ring, is currently up against its physical composition, in particular of the bond systems and the grains (e.g. Hermes Sapphire Blue, conglomerates) which looks promising.

8 Application example

The following example shows the design and application technology and the honing result.

Example	Automobile transmission, 4th gear
Machining sequence	Milling - soft shaving - hardening - honing
Honing machine	Fässler D-250-C, automatic loading
Total tool life	3850 parts

Gear parameters	Workpiece	Honing ring	Dresser gear	Dressing ring
Normal module	1,80	1,80	1,80	--
Number of teeth	35	-108	35	--
Pressure angle	15°	15°	15°	--
Helix angle	30,33° right-hand	38,33° right-hand	30,33° right-hand	--
Tooth width	22,50	24,00	24,20	24,20
Tip diameter	79,13	240,94	79,50	79,50
Root diameter	67,40	251,2	67,22	--
Addendum modification coefficient	-0,222	0,611	-0,222	--
Material	20 MoCr S4	HSK-HRQ 26111091	CK45	CK45
Diamond layer	--	--	D126	D181

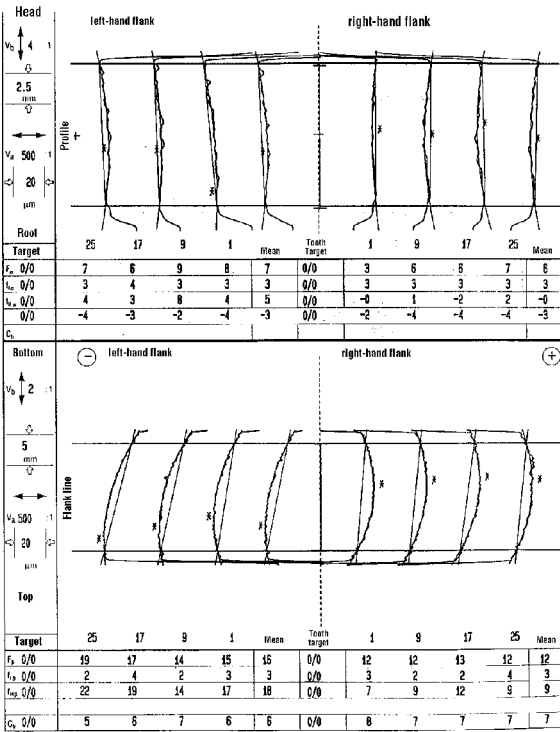
Setting parameters (related to honing ring)	Tip dressing	Profile dressing	Honing
Speed [rpm]	400	40	380
Table speed [mm/min]	250	220	230
Infeed per table stroke [mm]	0,005	0,002	0,001
Feed in X-axis [mm/min]	10	10	10
First dressing amount [mm]	0,2	0,4	--
Dressing increment per cycle [mm]	0,05	0,05	--
Machining time [min]	5	15	0,66
Material removal [mm]	--	--	0,010 / flank
Dressing cycle	50	50	--
Crossed axes angle η [°]	--	--	-8
Current consumption [A]	4-5	4-5	7-8

Total tool life can be calculated by the following approximate formula:

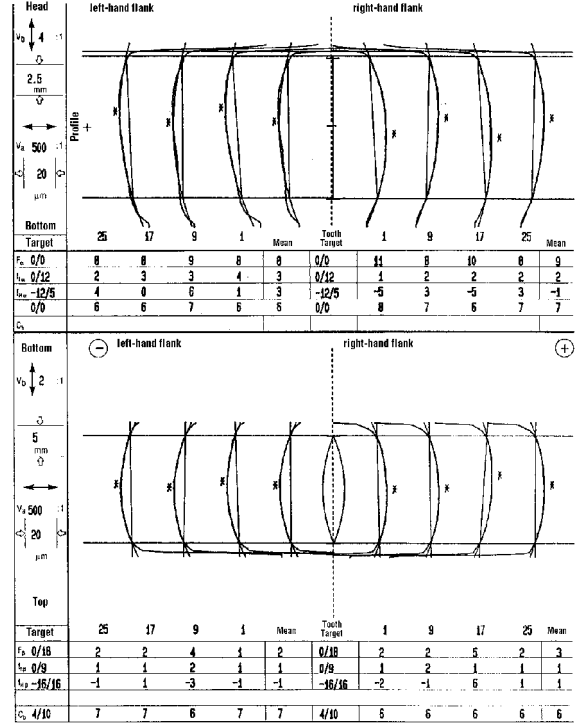
$$\text{Total tool life} = \frac{(\text{Axis distance "End" - Axis distance "New"})}{\text{Dressing amount in cycle}} \times \text{dressing cycle}$$

The following profile and flank diagrams show gear quality before and after honing

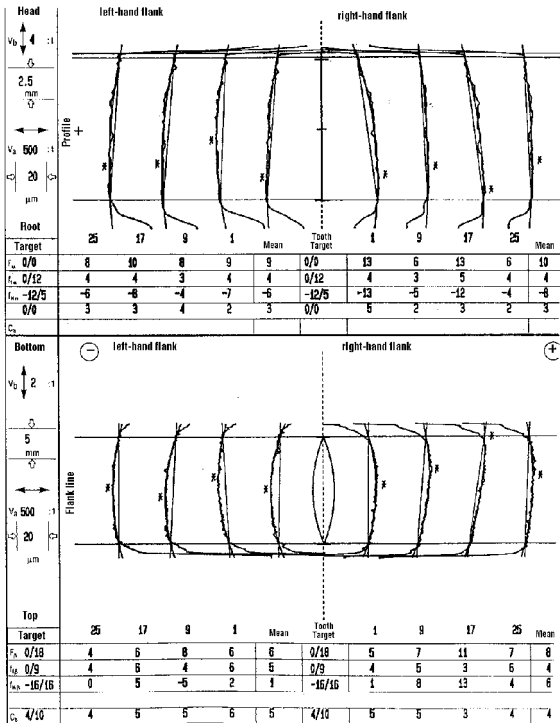
Machining: Soft shaving



Machining: Soft shaving, hardened and honing



Machining: Soft shaving and hardened



9 References

1. Schiefer, H: Hartfeinbearbeitungsverfahren mit zahnradförmigen Werkzeugen.
In : Moderne Zahnradfertigung, Band 175.
Hrsg. : Prof. Dr.-Ing. Wilfried J. Bartz,
Esslingen. Expert Verlag, Renningen 1994.
 2. Weck, M: Spanende Verzahnungsherstellung.
In : Handbuch der Fertigungstechnik,
Band 3/2. Spanen.
Hrsg. : Prof. Dr.-Ing. Günter Spur.
Carl Hanser Verlag, München Wien 1980.
 3. Autoren-Team: Verzahnungsschleifen
In: Reishauer-Fibel
Hrsg: Reishauer AG, CH-Wallisellen
 4. N.N.: Zahnradhonmaschine D-250-C
Firma : Fässler AG, CH-Dübendorf
(Firmenprospekt)
 5. DIN 3960 (3.87) Begriffe und Bestimmungsgroßen für Stirnräder (Zylinderräder) und Stirnradpaare (Zylinderradpaare) mit Evolventenverzahnung
 6. DIN 3993 T 1 (8.81) Geometrische Auslegung von zylindrischen Innenradpaaren mit Evolventenverzahnung; Grundregeln
 7. DIN 3993 T 2 (8.81) Geometrische Auslegung von zylindrischen Innenradpaaren mit Evolventenverzahnung; Diagramme über geometrische Grenzen für die Paarung Hohlrad-Ritzel
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