Honing of Gears

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Introduction

The honing of gears — by definition — facilitates ease of operation, low noise and smoother performance in a transmission. Honing also contributes to reduced friction in the powertrain. Both the intense cutting (roughing process) as well as the functionally fine- finishing of transmission gears can be performed in one setup, on one machine. Honing in mass production is a well-established process, owing to the intelligent machine layout and other combinations with defined cutting geometries. As such, it should be technologically and economically considered as a serious production method. Furthermore, the combined process of flat surfacing and honing on one machine is an even more recent innovation for the finish machining of planetary gears in mass production. The design of components for modern vehicle transmissions such as manual, automatic or dual clutch styles seeks to reduce friction, thereby increasing gear efficiency and function. Therefore, for the gear bores of various active transmission components and planetary gears, low-friction and wear-resistant contact topographies are required. There is also the desire for economical finish machining of the bore in one process, whenever possible.

The finish machining of transmission components in mass production is currently being done using rough honing and finish honing. In one process — consisting of two steps on one machine — the functionally accurate shape and position tolerances, as well as the desired surface structure, can be achieved. Therefore secondary hard turning and grinding processes are seldom required as finish processes in mass production — neither individually nor as combined processes in a work cell.

The diverse quality characteristics require an adjustment to individual process components of honing. The manufacturing quality of the conventional hone process is defined by the terms "dimensional tolerance" and "surface finish." Furthermore, for the function of gear wheels, the quality terms "axial run-out" and, respectively, "perpendicularity" and "radial run-out" (out of round) are relevant. If one also wants to use honing for the finishing of gear wheels, the process of these broadened quality terms is modified accordingly.

Function and Quality

With the bore in a control wheel, i.e. — any free gear in a transmission vs. spline-mounted, thus requiring bore finishing — the transmission component functions as a rotary and translational slide-way. The tolerances are selected accordingly. The honed surface topography with high load bearing area benefits the frictional behavior and uniformly distributes the application of force. The honed surface profile with a large topographical contact surface enables a stabilization of the lubricating film, when mixed lubrication condition occurs. Honing produces a tribologically friendly surface that prevents a breakdown of the lubricating film on the contact surfaces. This acts to reduce friction and minimize wear under high loads on the contact surfaces, as well as under the light loads on a rotating idler. Also, the oblique angles of the honing marks contribute to the even distribution of the lubricating oil in the lengthwise and circumferential direction of the bore.

In order to avoid local high surface pressures, there are also tight shape and position tolerances of the required macro-geometrical conditions for equal lubrication gap widths. The tight geometrical tolerances (axial run-out) and radial run-out have a positive effect on the smooth operation of the gear wheel sets. This is the purpose of the statistical tolerance limits. At a machine capacity of cmk ≥ 1.33, for example, the straightness is reduced from 3 µm to about 2.1 µm, despite very different wall thicknesses.

Table 1 Quality characteristics for honing gears

Dimensional tolerance	⌀	Diameter
Shape tolerance	⌭	Cylindricity
	○	Roundness
	—	Straightness
Directional tolerance	//	Parallelism
	⊥	Perpendicularity
Run out tolerance	↗	Axial run-out, Radial run-out
Surface tolerance	√Rz, Ra	arithm. mean deviation R_a averaged surface Roughness R_z

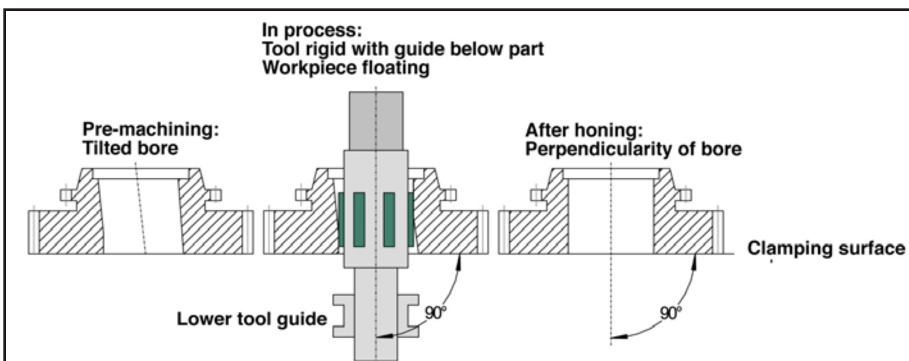


Figure 1 Machining principle for position correction of gear wheel bores in gear wheels.

Honing involves the boring of gear wheels (Ref. 1) (such as planetary gears, transmission gears, switching sleeves, lay-shaft gears, bevel gears) of various shape, dimension, material and hardness. Honing of transmission gears goes beyond the previous quality terms. The following tolerances can be defined as (Table. 1):

In addition to the geometric tolerances, highly stressed components are increasingly evaluated according to the near surface zone of the functional surface. The mechanical and thermal stress of the material due to the machining forces during the final machining steps contributes to the residual stresses in the area near the surface. For example, abusive grinding imparts detrimental residual tensile stresses, whereas honing imparts beneficial compressive stresses because the honing process has comparatively low machining forces and temperatures.

Honing Control Wheels: Machining Principle

An important feature of honing is the alignment of both tool axis and bore axis. In the conventional layout of tool and part, the expansion of the tool results in an equiaxial alignment. The tool-part system has designated degrees-of-motion freedom that enables the centering and tilting to identical axis positioning. An improvement in dimension, shape and surface quality is achievable with this mechanical system.

If the position of the bore needs correcting, that is — the perpendicularity of the bore axis to the front face — or the axial runout of the front face to the bore axis — then the angular degree-of-freedom (tilting) must be replaced by a rigid, perpendicular repositioning of the tool axis and clamping surface (Ref. 2). The reference surface for honing is the machined front face, which is supported on the clamping level (Fig. 1); centering on an inaccurate gear tip circle diameter is not necessary.

Now, the center of the gear wheel bore can align itself to the tool via the floating part holder. In this condition the radial run-out (bore-to-gear teeth) remains unchanged; the deviation of the angle position of the bore axis to the tool axis is corrected in the subse-

Table 2 Layout of honing machines for machining components

	Control Wheel Machining
Machine type	Rotary indexing machine
Spindle configuration	vertical
Fixture	Floating single part holder
Qty. of hone operations	2
Tools	In-process adjustable multiple stone tools with CBN-abrasives of various grit
Machine layout	• Load and unload • Mechanical pre-gaging • Rough honing • Pneumatic post-gaging[1)] • Finish honing • Pneumatic post-gaging • Spin-dry

1) Instead of pneumatic post-gaging, a pneumatic in-process gage can also be used.

quent material removal. Next, the tool machines the raised areas of the lateral surface. With the additional clamping, the entire bore is machined and a new bore axis is established.

Honing Transmission Components: Machining Concept

The common principle among the various possibilities for gear wheel machining is the moveable part holder and the rigid tool holder. Also, the conventional honing process with adjustable honing stones has been carried through. For honing such components, vertical rotary indexing machines with the single part holder in floating fixtures are used (Table 2).

The preparation consists, as a rule, of boring and hardening, so that they must be machined in two honing operations. The tools are exclusively loaded with CBN-abrasives. Furthermore, fully automated production honing machines are equipped with various standard components such as gage stations, handling systems, force-controlled electromechanical feed devices (EMZ-F) and electromechanical ball-screw stroke drives.

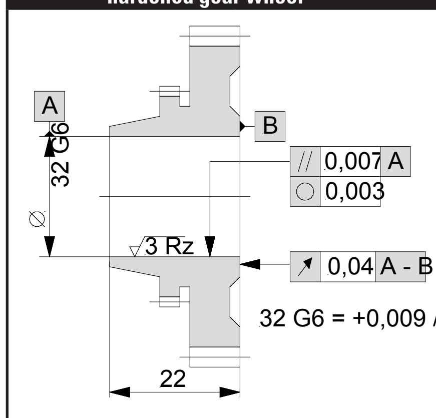
Honing Transmission Components: Requirements and Process Considerations

Because honing of hardened gear wheels has undergone major development in the past few years, this illustration is presented simply as an example. The hardened gear wheels are mainly machined on fully automatic, multiple-spindle, rotary indexing honing machines. The machining concept for individual machining consists of conventional multiple stone tools. The attachments are designed to be interchangeable for various gear wheels. Honing a gear wheel bore is defined by the following quality terms and tolerances (Table 3):

The high stock removal during rough honing with a honing allowance of up to 0.350 mm is the prerequisite for the successful implementation of the honing process in the mass production of gear wheels. This is how honing maintains its competitiveness compared to hard turning. The smoothing of the surface end quality takes place in the second machining station only by changing the cutting material and adjusting the process parameter; the radial run-out achieved in pre-machining should remain unchanged.

The layout of a machine for machining gear wheels shows the stations named in Table 2. After the load and unload station, the mechanical pre-gaging is performed. Here, the minimum dimension of the bore is checked in order to prevent a collision with the tool. Rough honing

Table 3 Required machining quality on a hardened gear wheel



Control wheel 4th gear	
Total hone allowance	≤ 0.350 mm
Cycle time	20 s
Hone time	18 s
Machine utilization	120 parts/h at 80%
Material	Forged steel
Preparation	Turned and hardened on 680 HV30

Table 4 Machining parameters for honing gear wheel bores

	Rough honing	Finish honing
Qty. of honing stones	4 to 6 (depending on diameter)	
Cutting material	CBN	
Grit size	B213	B 46
Bond	Sinter metal	Sinter metal
Dimension	4 × 4 × 25 mm	4 × 4 × 25 mm
Cutting speed	145 m/min	95 m/min
Feed	electromechanical (EMZ-F)	
Allowance	0.200-0.300 mm	0.015-0.025 mm
Hone time	approx. 18 s	approx. 18 s
Gage-control	Pneumatic in-process gaging	Pneumatic post-gage with feedback function

Figure 2 **Machining stations for honing gear wheels.**

works with robust parameters — especially at a high cutting speed of about 150 m/min and large removal rates of about 20-30 μm/s in diameter. The subsequent finish honing operation completely removes the rough profile of the rough honing operation and leaves behind the functional component quality (Fig. 2). Pneumatic post-gaging is the final quality assurance; spinning the gear minimizes the spreading of the honing oil.

The machining parameters are summarized in the following (Table 4):

The high removal rate is primarily determined by the high delivery rate and high cutting speed. With increasing rpm, a rise in material removal is clearly noticeable (Fig. 3). The mathematical removal characteristic is determined by the feed rate; i.e., by the diametric preset diametrical honing stone feed-per-unit-of-time. The difference between calculated and measured stock removal results from feed losses caused by deflecting the components in the complete feeding system. The increasing deviation from about 1,500 rpm is explained by an increase in coolant flow at increased rpm. The influence of the stroke speed in the area examined is not significant. Because of the material properties and the high cutting capacity, the rough honing operation produces less fine-grained hone sludge. Instead, fine, long continuous chips in the form of a steel wool ball result.

The function of CBN abrasives of a middle concentration (stock removal ≤ 0.300 mm in 18 s) is decisive for the entire process. The use of low-viscosity honing oil ($\eta = 4.6\ mm^2/s$) has a positive effect on the cutting behavior and, thereby, on the consistent manufacturing quality and tool life. In addition to the constructive design of the hone tools, the condition of the abrasives is of vital importance. They are composed of a metallic binder, fused with the proper concentration of CBN abrasive crystals (Fig. 4). Apart from the selection of binder and grain material, the sinter parameters in the manufacturing process of honing abrasives determine the quality. The hone tools are rigidly connected to the spindle. Below the part, the tool body is formed as a carbide-reinforced guide shaft. The tools, depending on design feasibility, have as many abrasives as possible; this improves the machining accuracy with regard to dimensional stability and increases cutting performance and tool life.

The individual processing with conventional abrasive tools is the most economical variation of gear honing. The stationary fixtures are arranged under the two hone spindles. With the rotary index movement, the gears are loaded into the fixture. The fixture consists of the floating part holder and the zero-clearance, hold-down device (Fig. 5). The part is situated on one of the flat sides of a moveable pallet. The hydrostatic friction bearing of these pallets enables effortless, but not un-damped, movement on the flat. A torque recorder in the gear teeth has been proven effective. This occurs by means of the insertion of the gear into an integrated switch sliding sleeve or by applying a safety catch. The zero-clearance hold-down to accept the upper facing axial force helps with the deformation-free fixation of the gear. The lower guide stabilizes the tool axis to the clamping level at a right angle.

The described process design can reliably achieve the required tolerances. (Note: The roughness and the axial run-out are not statistically evaluated here. (With the finish hone stones [B46], the Rz value amounts to about 1.5 – 2.5 μm, and the axial run-out precision of 15 – 25 μm only meets about 40% to 50% of the tolerance. The cycle time achieved is 20 s, with an allowance of ≤ 0.300 mm

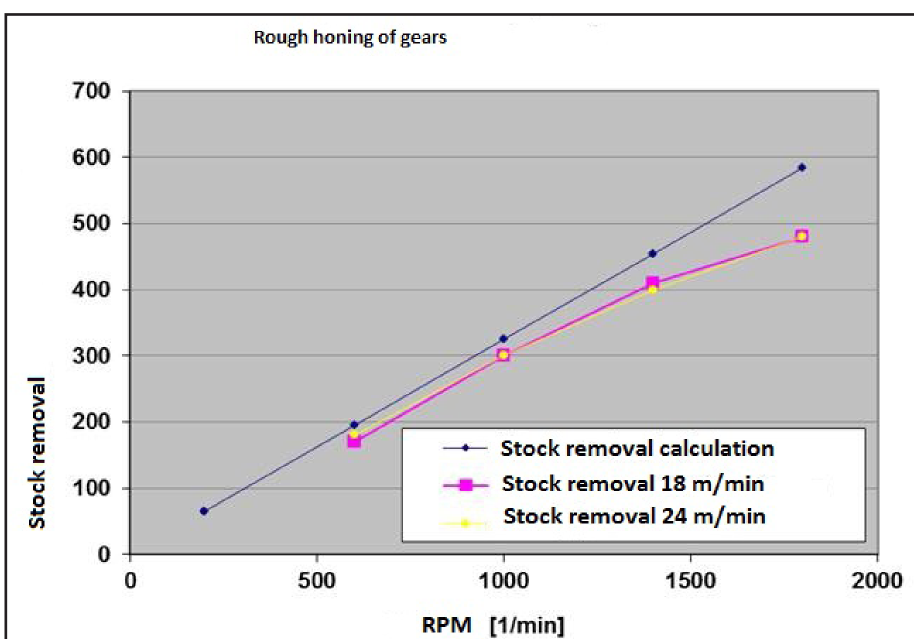


Figure 3 **Correlation of rpm and stock removal: control wheel diameter 35 × 26 mm; forged steel; 680 HV30; hone time 18 s; L600 honing machine.**

Figure 4 Hone tools with lower guides and CBN abrasive crystals (B213/B46).

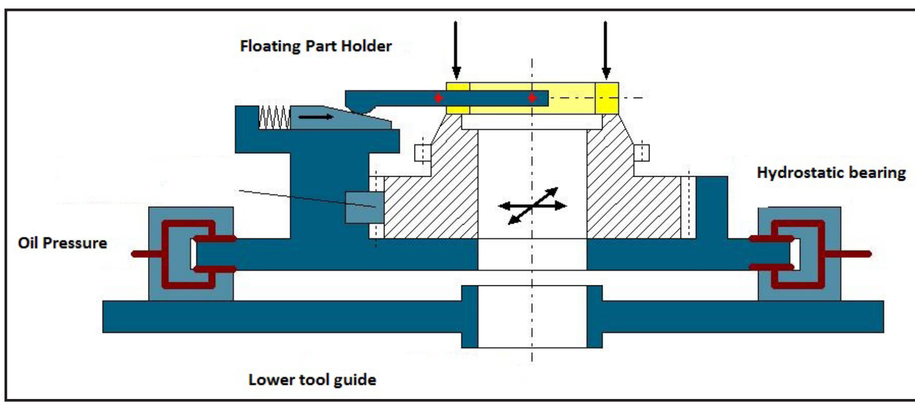


Figure 5 Floating uptake with zero clearance hold-down.

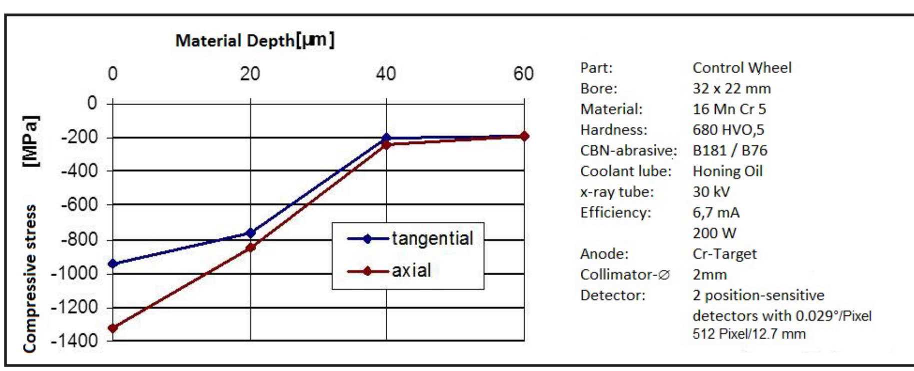


Figure 6 Progression of compressive stress with increasing material depth.

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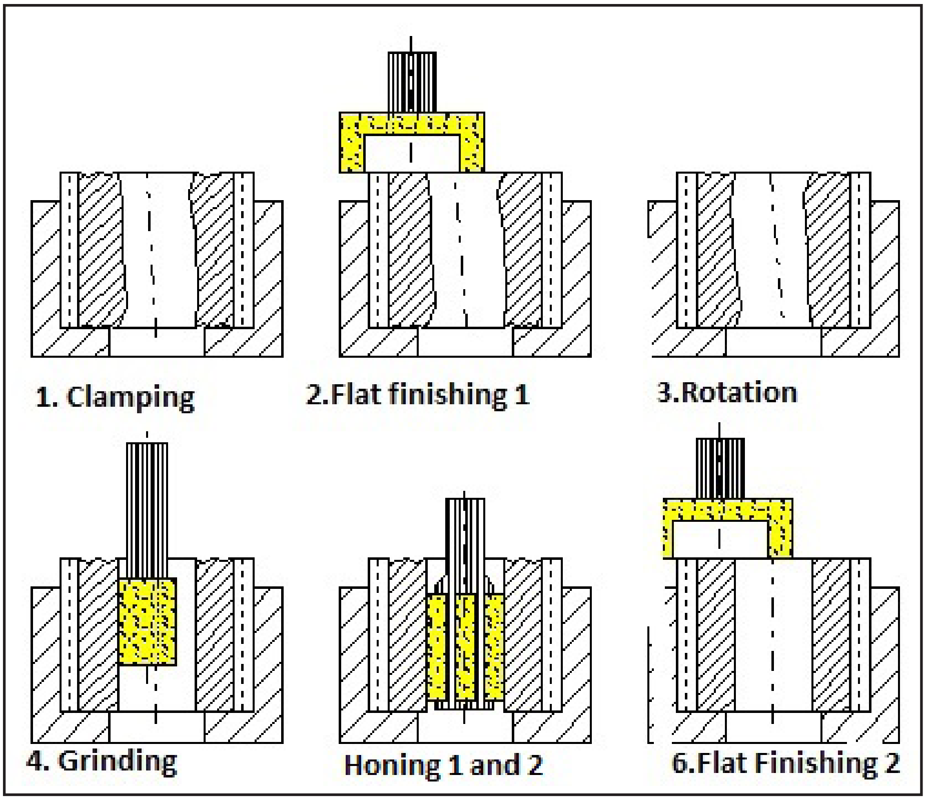


Figure 7 Process steps for combination machining.

in the first operation (determined by cycle time). The quality parameters of diameter, roundness and parallelism are also calculated to meet tolerances and satisfy the statistical tolerance limits.

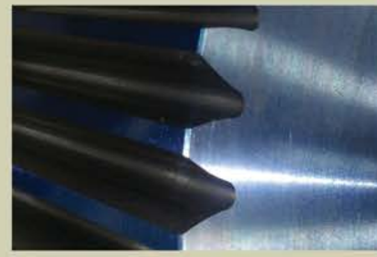
Measuring the residual stresses with x-ray diffraction shows the condition of the material structure in the area of the near surface zone of the honed bore surface. The stress in the area of the functional surface is substantially influenced by the hardening process and the stress of the finishing operation.

The available measurements (Fig. 6) were taken with a Stresstech XSTRESS 3000 instrument; the values were measured axially and tangentially. The hone angle of about 20° causes an uneven distribution of the compressive stresses in both directions on the honed surface. With increasing material depths, that is, where the surface is traditionally less impacted by the machining forces, the uniformity of the clamping method is measurable. This is a good indication of how the consistency of the impact force in honing differs radically from that of turning and grinding the same surfaces with, for example, extended tooling. The high residual compressive stresses clearly exceed the values of such competitive processes (Ref. 2).

Honing Planetary Gears in Combination Machining

As demonstrated, the combination machine with the processes of flat finishing, grinding and honing offers a new possibility for machining planetary gears. This rotary indexing machine completes the processes on the part, one after another, in one clamping. This versatility allows various machining geometries, such as one bore and one face surface to be machined — each with tight tolerances relative to the other. The compact machine workspace essentially consists of a circular rotary table on which the rotary-driven units are constructed, and the central column, where the machining units are assembled to the upright surfaces. The result is a self-sufficient machine with a small footprint and short transport route in the indexing of the part. The circular rotary tables make the machining units easily accessible for maintenance work and tool changes.

Figure 7 depicts the process steps for such combination machining. The part is only pre-machined on the front and in the bore. The gear wheel is located in the fixture with an unfinished side up, and is clamped radially on the gear teeth. The



tip diameter or the involute teeth are the geometric-identifying elements for the position of the part. The upper front is machined by flat finishing 1 (Example 1). Then the part is turned so that the previously finish-machined end surface fits in the fixture as the locating surface. In the subsequent grinding operation the bore is ID ground centric to the gear teeth. With this, the desired radial run-out tolerance is achieved.

The above enables the subsequent station to work with a tightly clamped hone tool, because the alignment is made to the unchanged clamping fixture and guarantees the centric ground bore; therefore, a new bore axis will not be partially processed. The hone process consists of a rough hone and finish hone operation. Between the two hone operations is a gage station in which a plug gage records the rough hone diameter using the principle of pneumatic length measurement. After finish honing, the flat finishing (Example 2) takes place. Here, the second end face is machined parallel to the first end face. (See Figure 8's depiction of the individual machining stations.)

Figure 8 Machining stations for machining planetary gears.

The machine concept is designed such that other process sequences are configurable. There is also the opportunity to integrate modified modular units such as deburring, wheel dressers, belt finishing or reaming. The concept of combined machining is especially useful in the manufacturing of planetary gears. Previously, the manufacturing processes for flat finishing, ID grinding and honing required different machines.

The consolidation of the processes into one machine allows high capital investment savings, increased productivity and reduced operational footprint (Fig. 9). For planetary gears, cycle times of 7 s with material removal in the bore of ≤ 0.15 mm are achieved.

Figure 9 Machine for combination machining of gears.

Summary

The possibility of position correction with high-precision and material removal of up to 0.350 mm in 18 s placed the single-machine honing of control wheels firmly into current automotive manufacturing technology. Despite very high cutting performance, the low machining forces and temperatures enable the lowest near surface zone variances and high residual compressive strength. The surface roughness with a high load bearing area in low cutting depth, and the hone angle structure have a positive tribological effect on the sliding function of the gear wheel.

An additional innovative manufacturing strategy is the use of machines for combination machining; it is especially advantageous in the machining of planetary gears. Here, the process of flat finishing, ID grinding, and honing are systematically combined in a single machine.

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