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A Review On Internal Gear Honing

Dilip T. Mehta
ME Scholar, Mechanical Engineering
Department, Government College of
Engineering, Aurangabad (MS)

Prof. M. G. Rathi
Asst. Professor, Mechanical Engineering
Department, Government College of
Engineering, Aurangabad (MS)

Abstract

In recent years a new method for hard gear finishing that produces a favorable surface texture and possibly allows gear correction was introduced. Among the techniques used in surface finish machining of gears, the internal gear honing process has been highlighted due to high efficiency in the finishing of hardened gears and ease of adjusting the involutes profile and incident angle in the counter-part. Material removal by the shave-grinding or gear honing process is the result of a rolling and sliding movement between the geared workpiece surface and the abrasive grits bonded in a resin, vitrified or metal tool matrix, shaped similar to an internal gear wheel. The internal gear honing process is used to eliminate errors that appear after the heat treatment on the tooth surface. Although the material and cutting speed of the tool are similar to the grinding process, honing the process simulates true cinematic movement of the mesh gear, which provides a better surface roughness compared to the hobbing, green-shaving and grinding. The present study is aimed at a deeper understanding of internal gear honing process, mechanism and advantages over other gear finishing processes. Results of the investigation shows that among all gear finishing processes internal gear honing is most efficient process of gear finishing provides an excellent surface finish of the sprockets compared to the other processes like green-shaving and grinding.

Keywords: Grinding; Green-shaving; Internal gear honing;

1. Introduction

Gear finishing operations are used to improve the accuracy and/or uniformity of the various gear tooth elements. The functional requirements of gears determine the degree of accuracy required. Greater accuracy is necessary if the gears are required to operate quietly and at high speeds and/or to transmit heavy loads.

Finishing processes in gear manufacturing are mainly classified into three categories i.e. shaving, grinding and gear honing. Often, gears have to be treated by a combination of these operations, i.e grinding and gear honing. This is because gear honing operations do not remove enough, stock although they do create a surface lay favourable for quiet operation. Gear grinding processes, on the other hand, do remove stock efficiently but create a noisy surface lay [1].The main difference between processes mentioned is the tool used during the operation. Among that Internal gear honing process having several operational advantages over grinding and shaving which are discuss in detail afterwards.

Internal gear honing is a hard gear finishing process that was developed to improve the sound characteristics of hardened gears by:

1. Removing nicks and burrs.
2. Improving surface finish.
3. Making minor corrections in tooth irregularities caused by heat-treat distortion.

The process was originally developed to remove nicks and burrs that are often encountered in production gears because of careless handling. Further development work with the process has shown that minor corrections in tooth irregularities and surface finish quality improvement can be achieved. These latter improvements can add significantly to the wear life and sound qualities of both shaved and ground hardened gears [2].

In this paper we have studied the internal gear honing process in details like process mechanism, advantages over other gear finishing processes like grinding and shaving.

2. Literature Review

Ellen Bergseth and Soren Sjoberg are studied the contact between real gear surfaces produced by different manufacturing methods by using of surface measurements and contact simulations. For this investigation they was taken gear surfaces produced by four different manufacturing methods like hobbing, honing, green-shaving and grinding. The results show that the surface topography generated by the manufacturing method has a significant influence on the contact area ratio. For the gear surfaces used in this study, the result shows that honing and green-shaving are preferable over grinding [3].

Sandro Pereira dos Santos was compared two processes, namely internal gear honing and hard hobbing in order to assess the adequate strength in the direction of clockwise rotation and counter clockwise, which represents the actual effort exerted by the driver of the vehicle. In his investigation he was compare the surface finishing of gear obtain by honing and hobbing on the basis of surface quality error like total profile error, profile form error, profile angular error. Thus, it can be concluded that this internal gear honing process provides an excellent surface finish of the sprockets having a direct impact on the returned vehicle steering system [4].

H. K. Tonshoff was studied the Properties of tooth flanks such as roughness, surface topography, residual stresses, material structure and hardness influence the lifetime of a gear running under load. These properties have been generated by the gear's finishing process, but they do not remain constant when the gear comes into mesh. The results have shown that the properties of tooth flanks which were finished by gear honing change rapidly under load. Grinding grooves which were left by gear honing are levelled after short running time due to plastic deformation of the surface topography. Consequently, the surface roughness decreases, with increasing load duration, fatigue effects occur at the surfaces which become visible in SEM examinations as small pitting and cracks. Local plastic deformations caused by load stresses lead to a decrease of compressive residual stresses and an increase of material hardness. Nevertheless, the lifetime of the examined test gear was not limited by surface fatigue but by macro pitting which have their origin in deeper material regions. For performance of gears, the state after running in is more important than the state after machining. Because of that, the alterations of the tooth flanks' properties should be taken into consideration when designing the process parameters of a finishing process for gears. The results enlarge the knowledge of fatigue mechanisms that lead to failures of gears when high loads persist over a long running time [5].

Johan P. Dugas was briefly studied the internal gear honing process and he was conclude that Gear honing does not raise tooth surface temperature, nor does it produce heat cracks, burned spots or reduce skin hardness. It does not cold work or alter the microstructure of the gear material, nor does it generate internal stresses at the same time improve sound characteristics of hardened gear by removing nicks and burrs, improving surface finish, making minor corrections in tooth irregularities caused by heat-treat distortion [2].

N. Amini and H. Westberg were studied on the effect of wheel speed in internal gear honing on gear surface topography. During investigation they are selected two parameters like honing wheel speed varying from 140, 280, 420, 560 rpm and grain size 180, 120 by keeping other parameters constant and studied the effect on surface topography. Two 3D measuring machines were utilized during the study. one stylus machine and one white-light interferometric measurement machine. The stylus machine was used to evaluate surface roughness parameters. Surface amplitude parameters consistently decrease by increasing tool rotary speed. A reduction of the undulation amplitude (fwa) and a shortening of wavelength (λa) was observed. The main reason for the reduction of (fwa) was the increasing tool speed. While tool grain size is of minor significance due to gear surface topography, it does have an indirect influence. The grain size can shorten the wavelength of the surface undulations and in turn can offer a better condition for accomplishing lower amplitude levels. In other words, the problem is that in order to produce lower fwa, shorter λa are required [1].

3. Internal Gear Honing Process Details

3.1 Basic

Internal gear honing is a crossed-axis, fine, hard finishing process that uses pressure and abrasive honing wheel with geometrically undefined cutting edges to remove material along the tooth flanks in order to improve the surface finish and improves run out, lead and profile characteristics by Making minor corrections in tooth irregularities caused by heat-treat distortion [6]. Profile and Lead measurement before and after honing are shown in Figure 1 below,

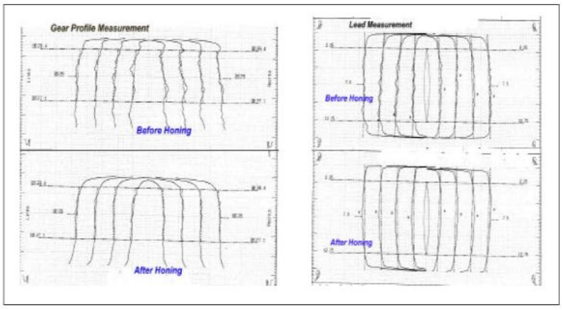


Figure 1 Profile and Lead measurement before and after honing

Internal gear honing is a finishing process, in which a tool called hone carries out a combined rotary and reciprocating motion while the workpiece does not perform any working motion. During the internal gear honing process abrasive honing wheel is performing three overlapping movement component. These are rotational movement, an oscillating stroke movement in axial direction and the radial feed movement of the honing wheel towards workpiece [7]. The primary benefits are the higher contact surfaces offered by rolling a given gear with an internal gear. These higher contact surfaces provide better equilibrium of the internal contact forces. The honing ground gear, besides noise improvement, is its ability to reduce break-in time and increase load carrying capacities by as much as 30% and wear life by as much as 1000% [6]. The honing wheel is held against the workpiece with controlled light pressure. In honing rotary and oscillatory motions are combined to produce a cross hatched lay pattern as illustrated in Figure 2,

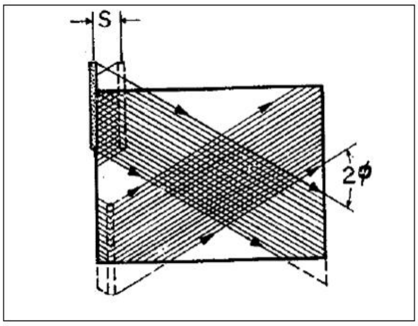


Figure 2 Lay pattern produced by combination of rotary and oscillatory motion

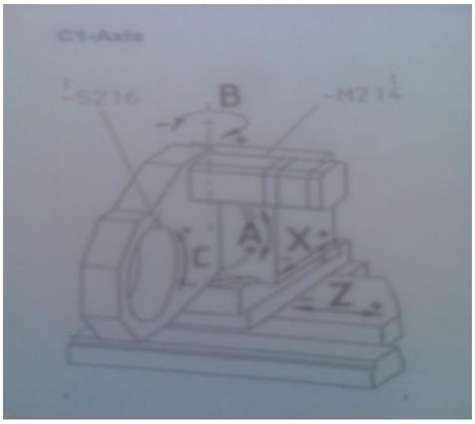


Figure 3 Fassler Gear Honing CNC Machine Axis

Generally Fassler Gear Teeth Honing CNC Machine (Siemens Auto.) use has two linear, two swivels, and one rotational axis.

Table 1 CNC Machine axis and Description

Axis	Description
Linear axis	
x	Cross slide for the radial movement (infeed) of the honing wheel towards workpiece or dressing tool.
z	Longitudinal slide for the axial movement of the honing wheel (oscillation movement).
Swivel axis	
A	Swivels the honing wheel to the axis-crossing angle.
B	Swivels the honing-wheel head (the pedestal on the Cross slide) for longitudinal crowning and tapering (Conical honing).
Rotational axis	
C	Honing-wheel drive: positions and rotates the honing wheel. Positions and rotates internal gears.

CNC gear honing offers extensive benefits in addition to fast setup times. These benefits include automatic calculation of new machine axes positions to maintain size after diamond dressing and calculation of a new, increased crossed-axis angle setting to maintain constant pressure and force distributions between the teeth of the workpiece and the tool during the entire life of the tool. Some CNC honing machine operates in both rotational directions to balance the tool wear, Stock removal and profile errors. During internal gear honing, honing oil ‘HON7‘was used as a cutting fluid having low viscosity and lubricity. Because internal gear honing process is fine finishing process, during operation material removes in the form of fine particles due to rolling action between internal geared honing wheel and workpiece. So in order to remove the particles from contact surfaces high honing oil pressure use this is in between (1-2 bar). Otherwise the particles are welded to teeth flank due to the higher temperature at the contact zone which affects surface quality.

The nomenclature of this process is not yet standardized and therefore not uniform in literature. Shave-grinding is also called "gear honing" or "power honing". The tool type determines that shave-grinding is an abrasive process that has nothing to do with lapping. The question is whether it should be called honing or grinding. Honing in general is characterized by two components of cutting movement where at least one component has an oscillating character [8]. Result of the total cutting movement is the typical "honing pattern" of crossing traces of active grains on the workpiece surface. Such a pattern cannot be detected on shave-ground workpieces because the amount of oscillative speed is by much lower than any of the other cutting speed components. The other reason why the mentioned way of gear finishing should be regarded as a grinding process is that the material removal is the result of a periodic contact between active grains and workpiece which is characteristic for grinding [8], [9], [10]. As the process kinematics has many similarities with gear shaving [11] the authors and several companies encourage the use of the word "shave grinding". Generally a conventional gear honing is done after gear profile grinding process for fine finishing of gear flank. The stock remove in conventional honing process is 5 -10 µm per tooth flank. But now a day a high performance internal gear honing is done directly after case hardening with increased stock removal as a substitute for gear grinding and conventional gear honing. This process also known as “Direct honing” or “Power honing”. About 20 -40 µm per flank material remove in power honing. [1]

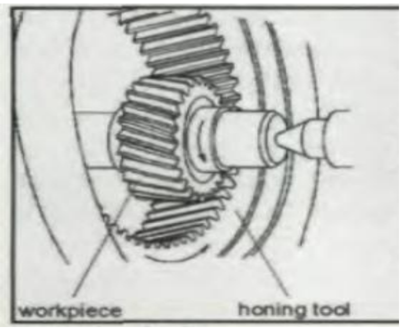


Figure 4 Internal gear honing

Compared to profile or generating grinding traditionally used in gear manufacturing, the technology is applied with approximately 10–60 times lower cutting speeds and 20–30 times lower specific material removal rate [12]. According to Silva [13], the internal gear honing process simulates the true cinematic movement of the gear mesh, which generates a surface roughness better than the grinding process.

The combination of external geared helical gear workpiece and internal geared honing ring has a couple of essential advantages compared to the combination of external geared helical workpiece and external geared honing ring. As a result of the small axes distance, it is possible to build the machine tool in a compact design. Due to the higher overlapping ratio and the resulting better force distribution the achievable honing quality is more constant [14]. The cutting speed of the honing process is the vectorial sum of the longitudinal sliding (axial direction) and altitudinal sliding (radial direction) speed. The longitudinal sliding speed is determined by the angle between the workpiece axis and the tool axis.

Cutting speed ranges in the area of vc = 0.3 ... 5 mls being comparable to the typical range of gear honing process. Low cutting speeds vc result in very high specific normal forces Fn up to 40 N/mm for a material rate of Q', =0.055 mm3/(mm **s).** Process forces of shave-grinding can significantly be lowered by employing higher cutting speeds. Wear resistance of the tool will also increase with this method [15].

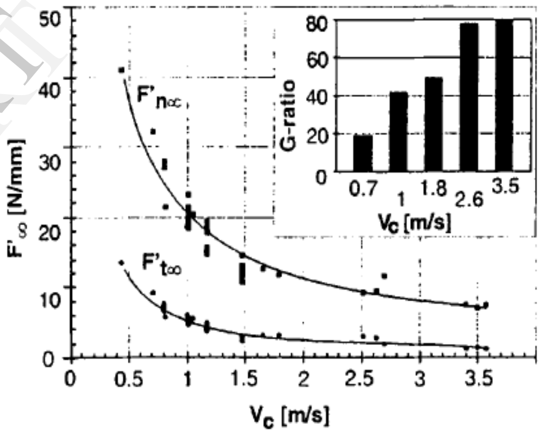


Figure 5 Process forces and G-ratio dependent on cutting speed

A normal shaving cannot be used for machining hardened tooth flanks because of its geometrically defined cutting edges. All cutting edges would have to penetrate the hardened workpiece elastoplastically along the line of contact, resulting in very high contact pressures. For this reason, tools with geometrically undefined cutting edges must be used for gear honing in order to reduce the surface contact between therefore machining hardened tooth flanks because of its geometrically defined cutting edges. All cutting edges would have to penetrate the hardened workpiece elastoplastically along the line of contact, resulting in very high contact pressures. For this reason, tools with geometrically undefined cutting edges must be used for gear honing in order to reduce the surface contact between the tool and workpiece flank, thus also reducing the contact pressure [1]. Internal gear honing operation is called differential pressure operation. A pre-selected low pressure is present between the hone and 'the low point of an eccentric gear, and a pre-selected increased amount of pressure is present between the hone and the high point of eccentricity. This method has an of the desirable features of the constant pressure method plus the ability to slightly correct eccentricity, The amount of eccentricity in the gears with differential pressure honing may cause the hone to wear faster than the constant pressure method.

However, because a gear has to be heat treated, a process that usually roughens the tooth surface to a degree, the honing process tends to restore the hardened tooth surface finish to its original shaved condition and actually improves it. In all cases, the honed surface finish is better than the surface finish before honing.

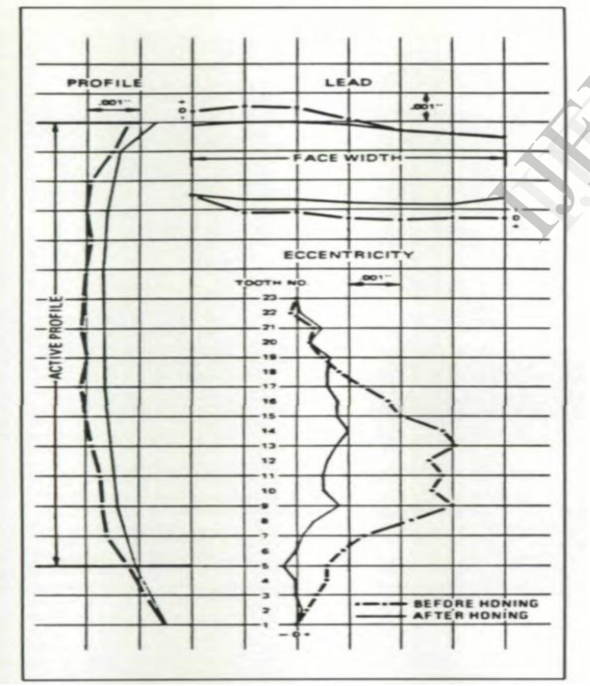


Figure 6 Improvement in tooth accuracy achieved by gear honing

3.2 Mechanism

The process uses an abrasive-impregnated, helical gear shaped tool. This tool is generally run in tight mesh with the hardened work gear in 'crossed-axes relationship under low, controlled center distance pressure. The work gear is normally driven by the honing tool at speeds of approximately 600 surface ft. per minute. During the work cycle, the work gear is traversed back and forth in a path parallel to the work gear axis. The work gear is rotated in both directions during the honing cycle. The process is carried out with conventional honing oil as a coolant. The z-axis moves in the axial direction of the machine, exactly the size of the length of the pinion to be machined. The pinion is fixed by means of account-points and the X axis moves in the axial direction of the product removing of material in the evolving profile and helix angle.

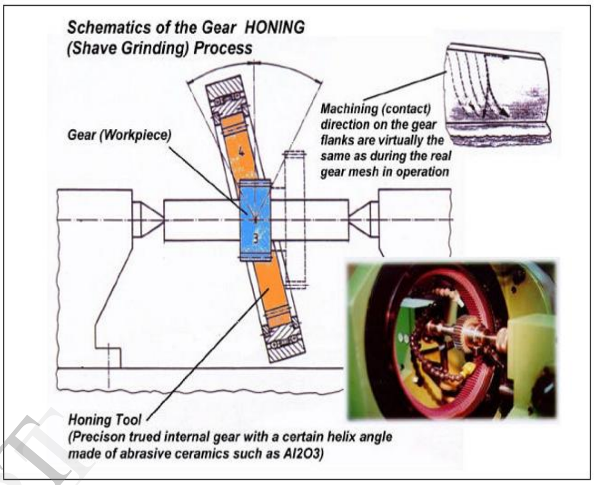


Figure 7 Schematics of Internal Gear Honing

The material removal is a result of the kinematically imposed relative movement (sliding) between abrasive grits of the tool and workpiece. The total sliding speed Vg results of the relative motion in direction of the involute Vgev through the rolling action between the gears and the relative motion in direction of the helix Vgs due to different helix angles of tool and workpiece. The cutting angle ***a*** describes the geometrical deviation of the total sliding speed vg from the direction of the helix (speed component vgs). The relative movement is responsible for the typical pattern of scratches on ground workpiece as shown in Figure 8 [15].

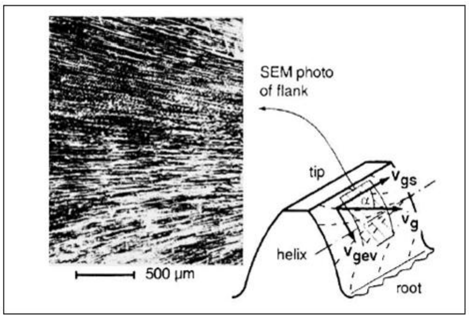


Figure 8 Surface structure of honed gear

3.3 Advantages

- Internal gear honing can also be used to prolong the wear life and increase the load carrying capacity of hardened ground gears by improving surface finish to a point where upto 80% surface contact can be achieved.
- Honed gears produce less noise and have a longer use life than other gears due to their typical surface structure. The structure of the surface of a honed gear, which resembles a fish skeleton, facilitates the formation of a lubrication film surface from the tip of the flanks to the pitch diameter and thereby positively influences the noise behavior in the gearbox. The special process kinematics cause this surface structure by which the honing tooling makes rolling contact on opposed axes of the work piece. The resulting speed division on the gear flanks results in having a cutting speed component in the axial direction so that the cutting grain comes into contact with the entire flank.
- The cutting velocities at gear honing are very low in comparison to gear grinding and lie between 0.3 – 5 m/s. Because of these low cutting velocities, maximum temperatures in the tribological contact area are estimated to be in the range of 100–300 ◦C [16]. There is no thermal load at the gear honing process. In fact, there are no micro structural changes in the gear material. The much feared “grinding burn” does not appear! Even when increasing the cutting speeds up to 5 m/s, which are reached with the new machine generation, there is still no thermal loading during the gear honing.
- A further important advantage as a result of these low cutting velocities is the induction of high residual compressive stresses on the flank surface. These residual compressive stresses are minimum 1,000 N/mm2 up to 1,600 N/mm2. Increasing the residual compressive stresses benefits the wear behavior of the gears, which results in greater wear resistance and a longer gear lifetime than gears, which have been hard finished by using other processes.
- Internal gear honing does not raise tooth surface temperature, nor does it produce heat cracks, burned spots or reduce skin hardness. It does not cold work or alters the microstructure of the gear material, nor does it generate internal stresses [2].

3.4 Honing tool (wheel)

General-purpose honing tools are made in variety of resin and abrasive mixes for gears that have been shaved and heat-treated. They are available in eight grit sizes ranging from 50 to 600 grit. Honing tools are made in diameters from 85 to 320mm with 25, 40, 50 mm face widths. Most gear hones are made with approximately 225 mm diameter. Honing tools are mounted on special machines in a crossed axes, controlled mesh relationship with the gear to be honed. During the honing cycle, the work gear is run with the honing tool at about 600 rpm. The honing tool is traversed back and forth across the gear face and the direction of rotation of the honing tool is reversed at the end of each stroke. Particles removed by the honing process are flushed away with conventional honing oil.

Internal geared honing wheel consist of a grit material is a mixture of refined aluminium oxide (70%) and Sol-Gel- Corundum (30%) with a grain size 180.The grains were bonded in synthetic resin. The modulus of elasticity of the alloy wheel is 21 N/m2 and it has a density of 2.45 g/cm3 [17].

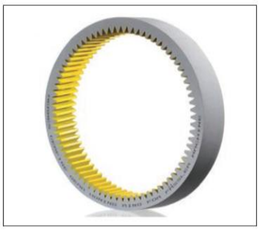


Figure 9 Honing wheel

4. Previous Research work in the area of Gear Honing

Gears are manufactured in a sequence of operations including hardening, which results in different surface topographies. Ellen Bergseth was taken four different sequences of gears manufactured were measured and analyzed in his study as follows,

Table 2 Four manufacturing methods

Process sequence	Gear 1 (hobbing)	Gear 2 (green-shaving)	Gear 3 (honing)	Gear 4 (grinding)
Rough machining	Hobbing	Hobbing	Hobbing	Hobbing
Soft machining		Green-shaving		
Heat treatment	Case-hardening	Case-hardening	Case-hardening	Case-hardening
Hard machining			Honing	Grinding

The surface which is produced by hobbing, green-shaving, gear honing and grinding was measured using 3-D surface topography measurement. Honing and green-shaving gear manufacturing process gives best surface quality than hobbing and grinding.

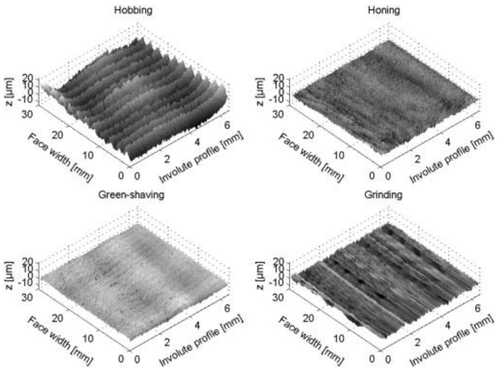


Figure 10 3-D Measurements of test gear surfaces

Photo images of the tooth flanks, as supplement to the 3-D measurement are shown in Fig. 11

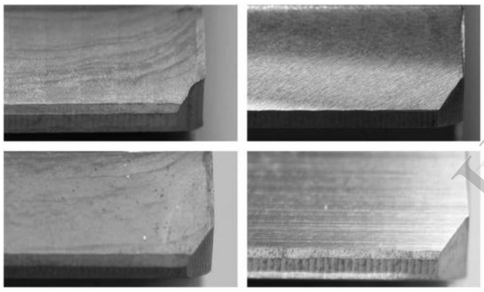
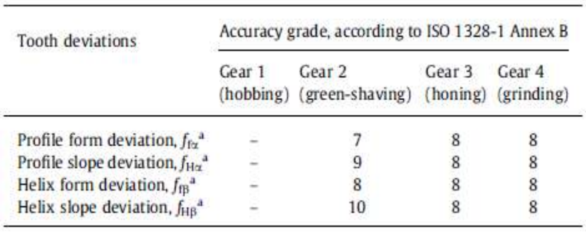


Figure 11 Photo images of the test gear surfaces referred to as: (top left) hobbing; (top right) honing; (bottom left) green-shaving and (bottom right) grinding.

Also in his investigation he was compare the accuracy grade of gear obtain by gear honing, hobbing , green-shaving and grinding on the basis of surface quality deviation like profile form deviation , profile slope deviation, helix form deviation, helix slope deviation Thus, it can be concluded that honing and grinding provides an excellent surface finish of the sprockets having direct impact on gear noise.

Table 3 Tooth deviations for the test gears



Tooth deviations	Accuracy grade, according to ISO 1328-1 Annex B			
	Gear 1 (hobbing)	Gear 2 (green-shaving)	Gear 3 (honing)	Gear 4 (grinding)
Profile form deviation, $f_{f\alpha}{}^{a}$	–	7	8	8
Profile slope deviation, $f_{H\alpha}{}^{a}$	–	9	8	8
Helix form deviation, $f_{f\beta}{}^{a}$	–	8	8	8
Helix slope deviation, $f_{H\beta}{}^{a}$	–	10	8	8

According to John P. Dugas investigation Ground tooth surfaces usually have a surface finish in the 16 to 32 µ range. Honing with type "AA" honing tools can bring this surface finish down to the 8 to 10 µ range as shown in figure 12,

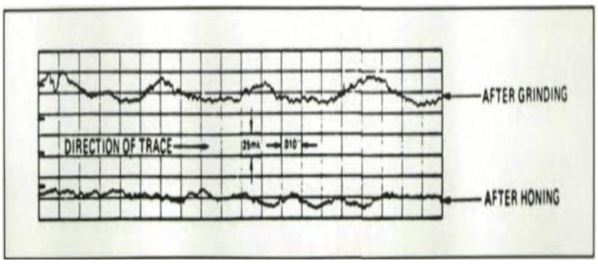


Figure 12 Tooth error

Ellen Bergseth concludes that surface topography caused by the manufacturing methods has a large influence on the real contact area in the early life of the gear. The green-shaved gear surfaces and the honed gear surfaces have the highest contact area ratio after manufacturing (as manufactured), which could be advantageous for future gear life with respect to e.g. the running-in process. In this study the real 3-D surface topography is measured on new spur gear tooth flanks produced with four different manufacturing methods. The measured topographies are used as input to software for contact analysis, and the pressure distribution for two different loads is calculated at different gear mesh positions. It is suggested that the real contact area ratio (the ratio between the real contact, area of asperities in contact carrying the load, and Hertzian contact area). Two load cases with normal loads of 2500 N and 11,500 N were studied, chosen from the mean and the maximum load for the gear in its original application. At normal load 2500N real contact area of the gear which is manufactured by hobbing, gear honing, green-shaving, grinding as shown in fig.13,

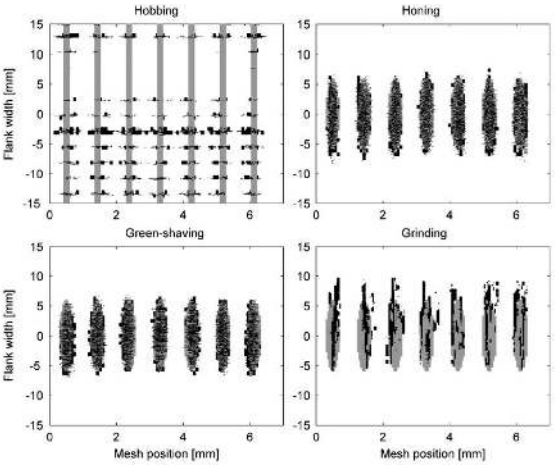


Figure 13 Calculated real contact areas at high load (2500 N)

At normal load 11500N real contact area of the gear which is manufactured by hobbing, gear honing, green-shaving, grinding as shown in fig.14,

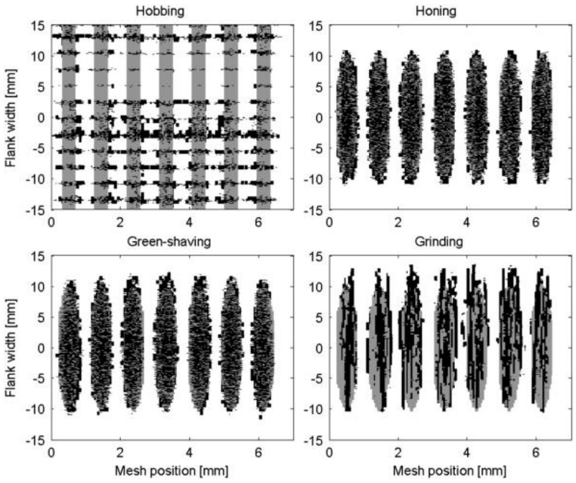
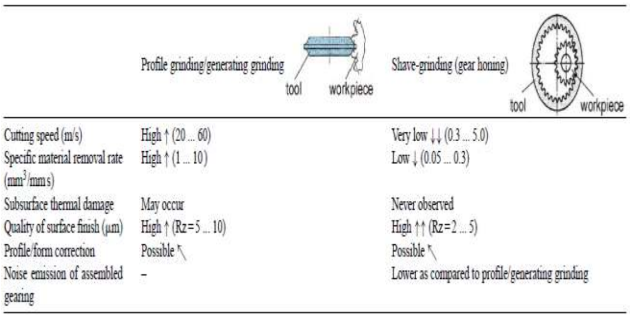


Figure 14 Calculated real contact areas at high load (11,500 N)

According to E. Brinksmeier gear honing is a process carried out at very low cutting speed i.e 0.3-5 m/s results in provide high quality of surface finish R_Z = 2-5 µm than profile grinding. Compared to profile or generating grinding traditionally used in gear manufacturing, the technology is applied with approximately 10–60 times lower cutting speeds and 20–30 times lower specific material removal rates, see Table 1. Due to low cutting speeds, maximum temperatures in the tribological contact area are estimated to be in the range of 100–300 °C. Such low temperatures in combination with contact duration in the magnitude of some micro-seconds explain the fact, that workpiece thermal damage in these processes has never been observed in the past. Subsurface layers of the low speed ground gear flanks show high compressive residual stresses, which remain detectable at somewhat lower amplitude over the entire gear lifetime. The technology improves surface finish and offers the possibility of geometrical tooth flank corrections. Furthermore, a characteristic surface texture of the finished gears reduces the noise emission of gearboxes.

Table 4 Comparison of profile grinding and gear honing



	Profile grinding/generating grinding	Shave-grinding (gear honing)
Cutting speed (m/s)	High ↑ (20 ... 60)	Very low ↓↓ (0.3 ... 5.0)
Specific material removal rate (mm^3/mm s)	High ↑ (1 ... 10)	Low ↓ (0.05 ... 0.3)
Subsurface thermal damage	May occur	Never observed
Quality of surface finish (µm)	High ↑ (Rz=5 ... 10)	High ↑↑ (Rz=2 ... 5)
Profile/form correction	Possible ↖	Possible ↖
Noise emission of assembled gearing	–	Lower as compared to profile/generating grinding

According to Silva [13], the internal gear honing process simulates the true cinematic movement of the gear mesh, which generates a surface roughness better than the grinding process.

Finishing processes reviewed in this paper show common characteristics due to the ability of producing gear teeth surfaces' topography. These similarities are implied in the kinematics of the processes. Different operating conditions (i.e. setup parameters), irrespective of processes, contribute to the velocity components VL (in lead direction), Vi (in involute direction) and Vn (normal to the surface). These velocity components in turn contribute differently either to the cutting action, to the frictional work or to the stock removal rate during the operation. In the following, the effect of these velocity components on different classes of surface properties is discussed separately. Results are based on observing 3D topographical measurements, two-level fractional factorial investigations and their subsequent extended experiments or velocity pattern simulations.

Result concerning surface structure

Surface structure is an interesting property. It is reasonable to believe that interaction of contact surfaces' main direction can play a significant role. Lubricant retention volume, surface wavelength measured relative sliding speed direction, penetration depth and all other tribological properties will be affected. The relative speed direction and the contact line direction are conditioned by the macroform and the assembly of the gears, but the surface lay direction can be affected by the manufacturing procedures through the design of the tool, parameter set-up and also assembly condition i.e. mainly the axis cross angle. The ratio Vi/VL determines the surface structure in all processes under all operating conditions. The instantaneous angle of scratches measured from the centerline of the surface in lead direction is equal to atan(V i /V). This ratio is also important in the case of applying one of these processes after the other, e.g. honing after grinding. Because, the efficiency of the process is correlated with the cutting direction relative to the existing surface main direction. According to figure 14, the area around the pitch diameter where the velocity component Vi is zero or close to zero, the path of abrasives coincide with the already existing scratches and consequently the cutting action is minimized. The effects of this ratio in different processes are simulated Since the path of each abrasive grain over the work surface is guided by its gradient, the surface structure can easily be obtained utilizing simple calculation of velocity pattern over the surfaces, These figures are, as expected, in good correlation with the measured surfaces except for the green-shaving. In that operation, the surface main direction tends to be as diagonal straight lines instead of scratches with curvature which should follow the ratio Vi / VL [18]. Among three process gear honing is the most significant process provides the structure of the surface, which resembles a fish skeleton, facilitates the formation of a lubrication film surface from the tip of the flanks to the pitch diameter and thereby positively influences the noise behavior in the gearbox.

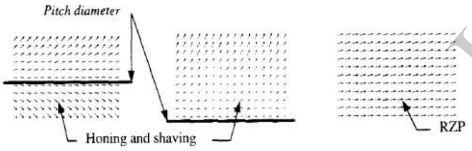


Figure 15 velocity patterns for different conditions

5. Conclusion

- Among three gear finishing processes like internal gear honing, grinding and green shaving, internal gear honing is most efficient process provides an excellent surface finish of the sprockets compared to the other processes.
- Honed gears produce less noise and have a longer use life than other gears due to their typical surface structure.
- The green-shaved gear surfaces and the honed gear surfaces have the highest contact area ratio compared to hobbing and grinding.

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