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ASPECTS OF THE INTERNAL GEAR HONING PROCESS

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Abstract: *The paper analyzes the process of internal honing of cylindrical gears, a new and modern method of finishing the gear tooth flanks. At the beginning, the kinematics of the process is being analyzed. By realizing the state of art, we were able to identify the main features of the process, its advantages in terms of surface precision and quality, the residual stresses and the wear of the flanks compared with other finishing processes. An experimental study of the geometric precision, the shape of the flanks and the roughness for honed surfaces compared to the unfinished ones, highlighted the value and the need of this process.*

Key words: cylindrical gear, gear honing, surface quality

1. Introduction

Gears are essential machine parts, which are found in a wide variety of products, indispensable to mankind, such as automotive products, ships, various wind systems, machine tools or automotive gearboxes. The international gears market is constantly expanding due to the continued growth of the demand for cars, as well as wind turbines, ships and heavy machinery. It is estimated that the number of gears produced annually worldwide is 2000 ... 2500 million, of which 1,000-1,400 million are high quality gears (better than IT 5) and the turnover is estimated to be more than 100 billion Euro [8] .

An important area in which high-quality gears are used is that of the gearboxes. The technological process includes plastic deformation operations, such as forging in molds, but also machining operations, as turning, drilling and milling (especially hobbing). These processes, together with the required heat treatment, cause deformations. A major problem is that the nature and occurrence mechanism of these deformations is still unpredictable.

The hard gear processing is the last operation needed to achieve the two most important goals, namely the maximum load capacity and the minimum operating noise. Gao [4] details the characteristics that gear must meet. In order to obtain a high-loading gear, it is necessary to do gear modification (gear tooth correction, root trimming and topological dressing) and to achieve high surface compressive stress and no burns on the tooth surface). In order to achieve a minimum level of noise in operation, it is necessary to reduce tooth errors (circular pitch error, coaxial deviation and rolling error) and improve surface quality (surface roughness and surface texture).

In order to meet these requirements it is necessary to use an appropriate finishing process. Honing of gears has become one of the most used hard-finishing processes, which is subject to continuous improvement.

The paper aims to analyze the current state of gear honing processing and to verify by experimental research the accuracy and roughness of the surfaces obtained during this process.

2. Cylindrical gear honing

Honing of the cylindrical gear (Figure 1) is a hard-finishing process that removes nicks and burrs from the active profiles of the teeth after heat treatment. It improves surface quality and makes minor form corrections. Honed gears causes less noise transmission at high speeds, excellent power transmission, lower wear. The pitting resistance provided by gear honing shows dramatic increases of the honed gears. The honed gears have lower costs, relative to grinded ones.

Since the mid-1970s, gear honing has been used to remove defects that have appeared on the flanks of teeth as a result of interoperation transport. When it was found, due to the surface structure generated on the teeth flanks, that this process decrease the operating noise level and increase the wear resistance of the parts, the process has become increasingly used as a finishing process after hardening. Initially, the maximum depth of cut was 10-15 μm on the flank [9].

Subsequent research, combined with the growth of industrial applications and the development of machine tools and cutting tools, allows a depth of cut of 80 μm. The process has been called "gear honing" [10].

The process is similar to hard shaving. The flanks of an external teeth gear are rolling on an internal teeth honing ring at a low cutting speed. There is a specified radial pressure between them. The work-piece and tool spindles are crossed at a defined angle. The superposition of the in-feed movements gives a resultant gliding movement running diagonally from tip to root of the tooth flank. This produces a micro-cutting process with a short cutting point engagement.

Honing the gear teeth is a hard finishing process with a cutting tool whose cutting edges are geometrically undefined. The tooth honing cutting tools consist of abrasive particles, also used in the grinding operation. Conventional tooth-shaped gears are made of aluminum oxide (Al_2O_3), silicon carbide (SiC), cubic boron nitride (CBN), and diamond bonded by a ceramic binder or synthetic resin.

By a constant and precise variation of speed, in both positive and negative direction, the exact depth of cut on the both sides of the teeth will be determined. The direction of rotation will not change during the processing of both teeth. Work pieces, whose teeth width exceeds that of the honing tool can be machined across the width by a Z-axis oscillation motion.

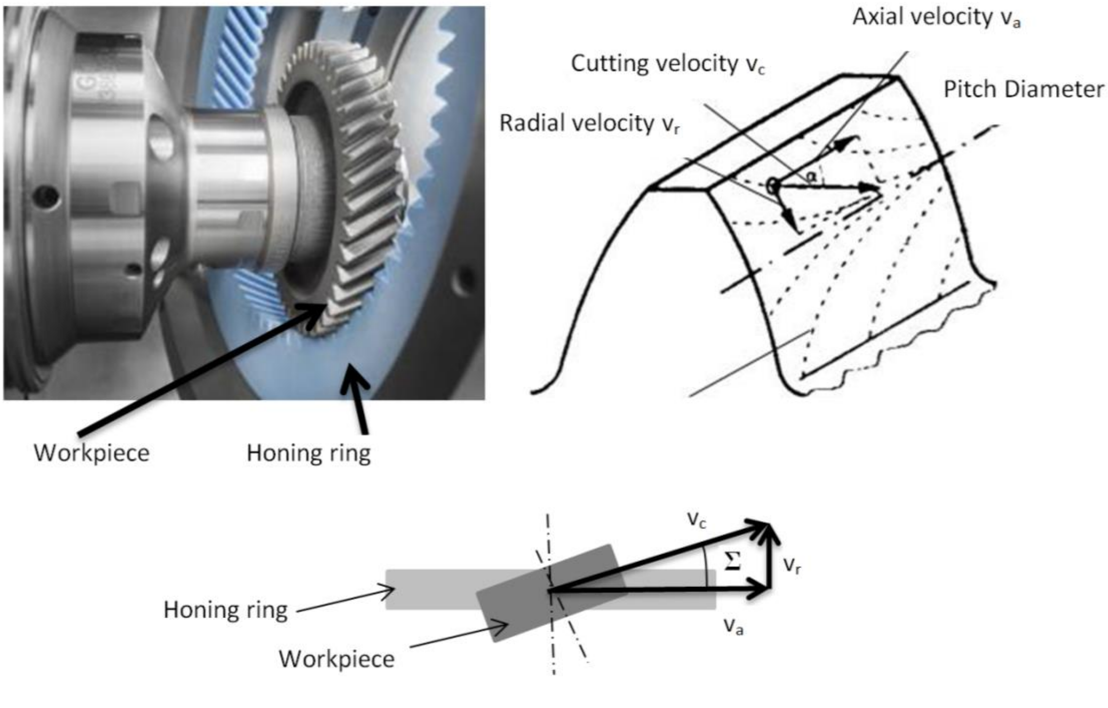

Figure 1: Gear honing

The contact pressure causes the abrasive particles to penetrate into the material of the work piece and to remove fine particles of material from the flanks of the work piece. To obtain the desired profile of the tooth, the honed tool is re-profiled with a diamond tool.

Due to the angle of inclination of the axes Σ (Figure 1), the cutting speed (v_c) has an axial component in the direction of the flank (v_a) and a tangential one, in the direction of the profile (v_r):

$$v_r = 2 \cdot \pi \cdot (\rho_w \cdot n_w - \rho_{HT} \cdot n_{HT}) \quad (1)$$

$$v_a = 2 \cdot \pi \cdot n_w \cdot r_w \cdot \frac{\sin \Sigma}{\cos \beta_{HR}} = 2 \cdot \pi \cdot n_{HT} \cdot r_{HT} \cdot \frac{\sin \Sigma}{\cos \beta_w} \quad (2)$$

$$v_c = \sqrt{v_a^2 + v_r^2} \quad (3)$$

where:

The W and HR parameters define the work piece and the honing tool. The cutting speed in the profile direction (v_r) depends on the radius of curvature ρ of the flanks of the teeth and the speed of the work piece (Equation 1). The cutting speed in the direction of the flange (v_a) is influenced by the angle of inclination of the teeth (b), the cross axis angle (Σ), the part's speed (n_w) and the radius of the work piece (r_w) (Equation 2).

The special kinematic of this process realizes a complex surface structure, by rolling contact on opposite axes of the work piece. The splitting of the speed on the tooth flank results in having a component of the cutting speed in the axial direction so that the abrasive particles come into contact with the entire surface of the flange [7].

The cutting speeds of the gear honing operation are very small compared to the gear grinding process, between 0.3 - 5 m / s. For this reason, the maximum temperatures in the tribological contact area are estimated to be in the 100-300 ° C range [12].

3. State of art

Some of the main studied aspects related to gear honing are the surface topography and structure of the, processed surface, the internal stresses in the sub surface layer, wear behavior.

Bergseth [2] analysed the roughness characteristics of gears manufactured through different final operations. These are presented in table 1

Table 1: Four methods for gear manufacturing

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

Images of the test gear surfaces are presented in figure 2. The 3D surface topography measurements of the same test gears are presented in figure 3. Honing and green shaving gear manufacturing process gives better surface quality than hobbing and grinding.

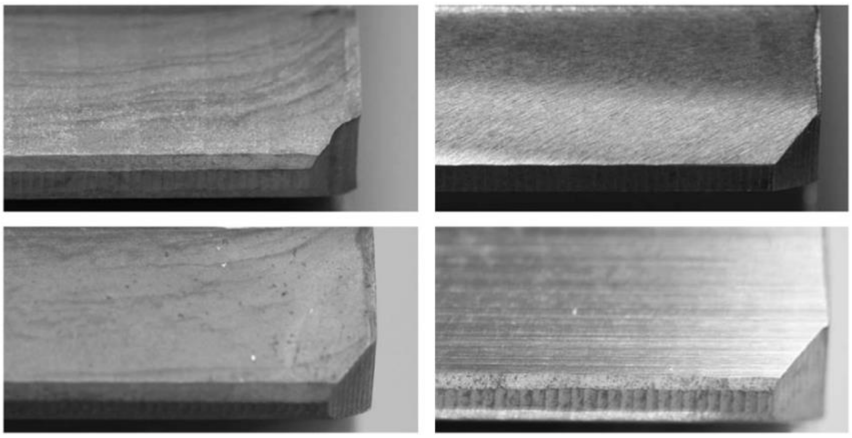

Figure 2: Measurements of test gears surfaces (top left) hobbing; (top right) honing; (bottom left) green shaving; (bottom right) grinding) [12]

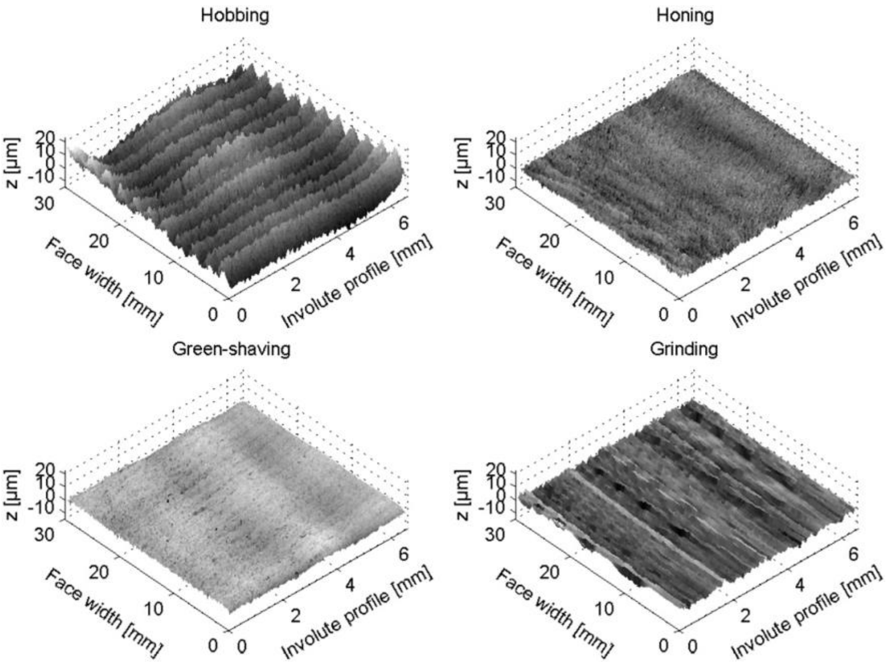

Figure 3: 3D Measurements of test gears surfaces [12]

Of the three gear finishing processes, such as honing, grinding and soft shaving, the most efficient process, that ensures excellent quality of gear surfaces and pinions, compared to the others, is the honing method [1].

The traces of an abrasive particle are formed in the direction of the cutting speed. The surface has a special topography with curved trajectories, which resembles a fish skeleton. This pattern allows a good adhesion of a thin oil layer. This lubrication film which covers the whole flanks surfaces influence positively the noise behaviors of the gearboxes.

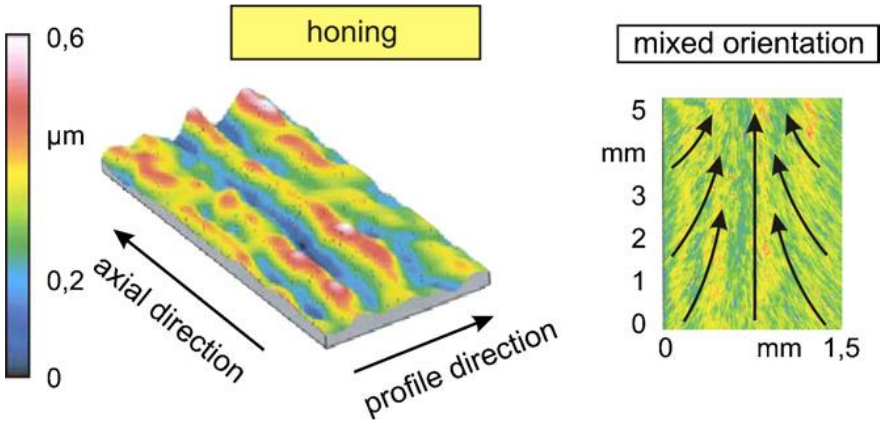

Figure 4: Topography of the flank surface of a honed gear [9]

Dugas [3] concluded that gear honing does not raise tooth surface temperature, does not produce heat cracks, burned spots and does not produce skin hardness. It does not generate internal stresses and in the same time it improves the sound characteristics of the hardened gears, by removing nicks and burrs. It improves the quality of the surfaces through minor corrections in tooth irregularities caused by heat–treatment distortions [11].

This benefit resulted from the comparative measurement of noise in the situation of the honed wheels and those with parallel microstructures obtained by rectification.

During the gear honing operation, the main cutting speed v_c takes low values between 0.5 and 5 m/s. Due to these very low cutting speeds and short contact times, the amount of energy transferred to the flank is small. This means that are no microstructural changes in the gear material and no burns on the tooth flanks during the gear-honing process. [6]

Another major advantage of gear honing is the induction of high residual compressive stresses in the subsurface layer of the gear flanks, especially when using diamond tools. Through X-ray diffraction, residual stresses up to -1400 MPa can be detected directly on the surface. At depths of just 20 µm, the value of the residual stresses drops considerably to values of about -200 MPa, which remain constant up to a depth of 90 µm [10]. These high compressive values of the residual stresses contribute to excellent lifetime performance and to the ability of loading the gear flanks at high values.

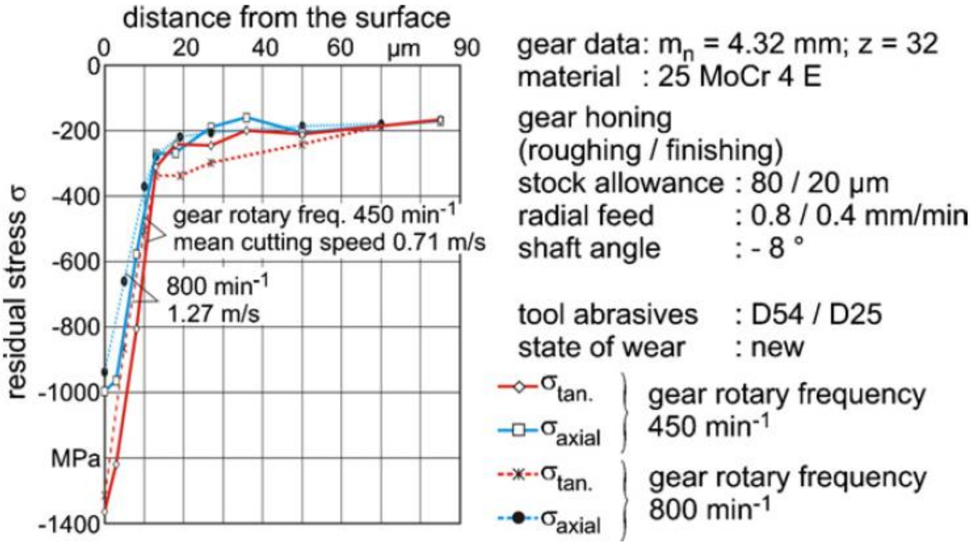

Figure 5: Residual compressive stresses in the flank surfaces after honing operation. [10]

Gear honing technology improves surface finishing and offers the possibility of geometrical tooth flank corrections.

4. Study of geometrical and dimensional precision of honed gears

The aim of the experimental study was to verify the opportunity of gear honing, from the point of view of the geometrical and dimensional precision of the gear flanks.

The samples were honed on a high-performance Gearing Honing Machine Type SynchroFine 205 HSD-A [5], and a cutting speed of 3.5 m / s.

The flanks, the profiles (measures on perpendicular direction of the flanks) and the roughness of the profile direction were measured. A Klingelnberg precision measuring center p40 was used for these measurements.

In figure 6 and figure 8, the tooth profile and the flanks of the gear tooth, after hobbing and case hardening, but before gear honing are presented.

In figure 7 and figure 9, the same parameters measured after the gear honing are presented.

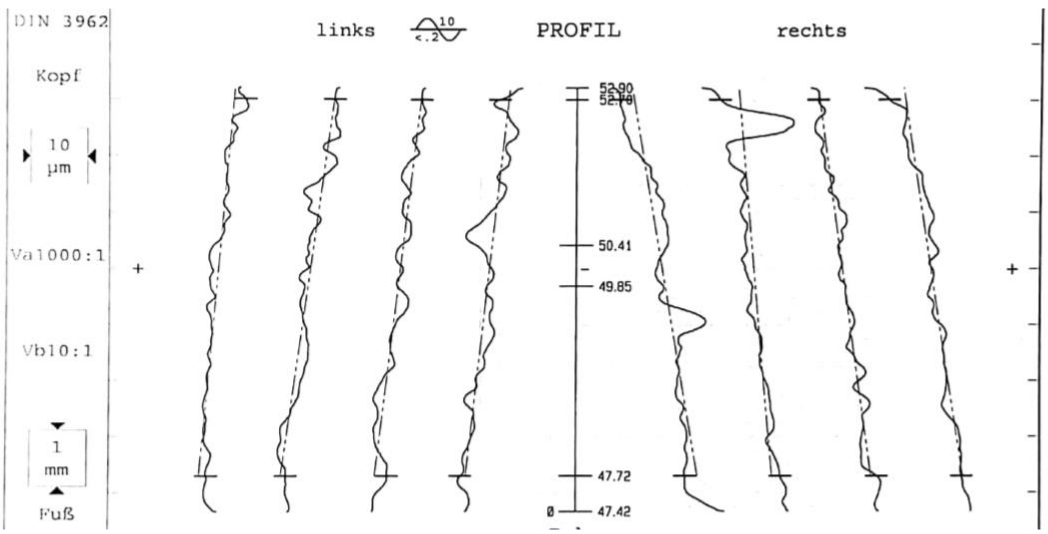

Figure 6: Tooth profile after hobbing and case hardening, before gear honing

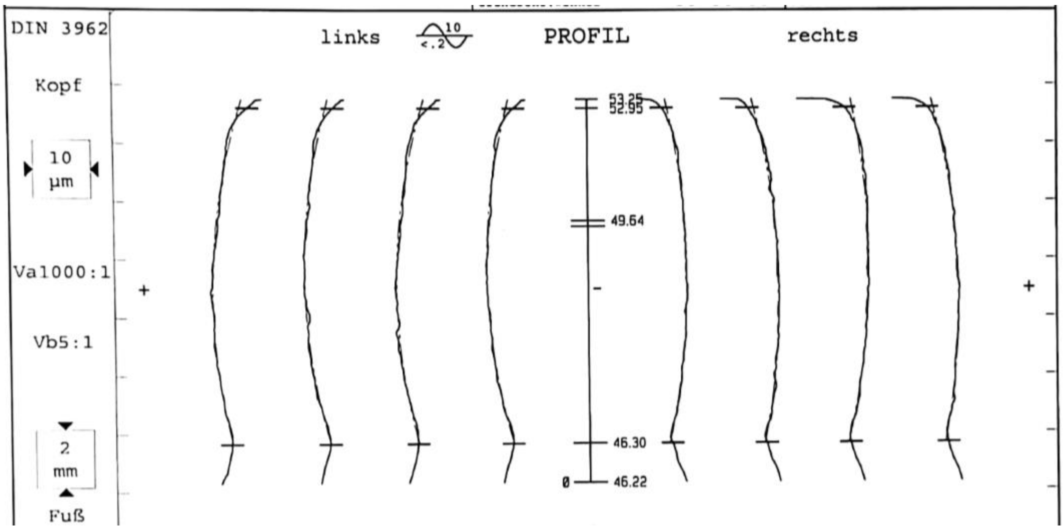

Figure 7: Tooth profile after gear honing

On the left part of the image, the left profiles of the teeth are presented, and, similar to the right. The "+" sign means a plus of material related to the theoretical one. Thus, by referring to the ideal theoretical profile presented with a point line, one can identify areas with missing or plus of profile material.

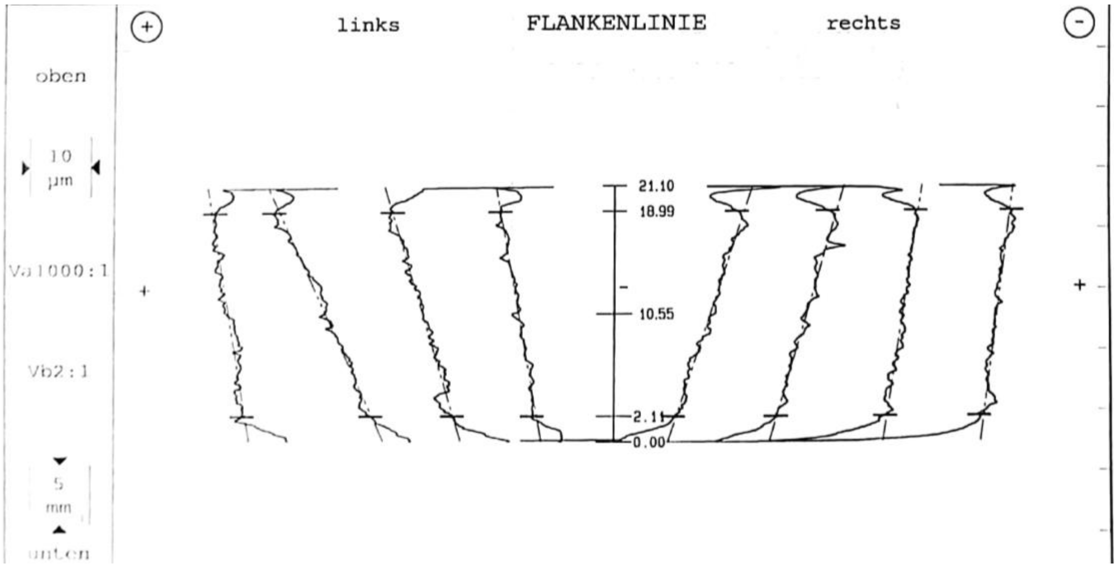

Figure 8: Flank profile after hobbing, before gear honing

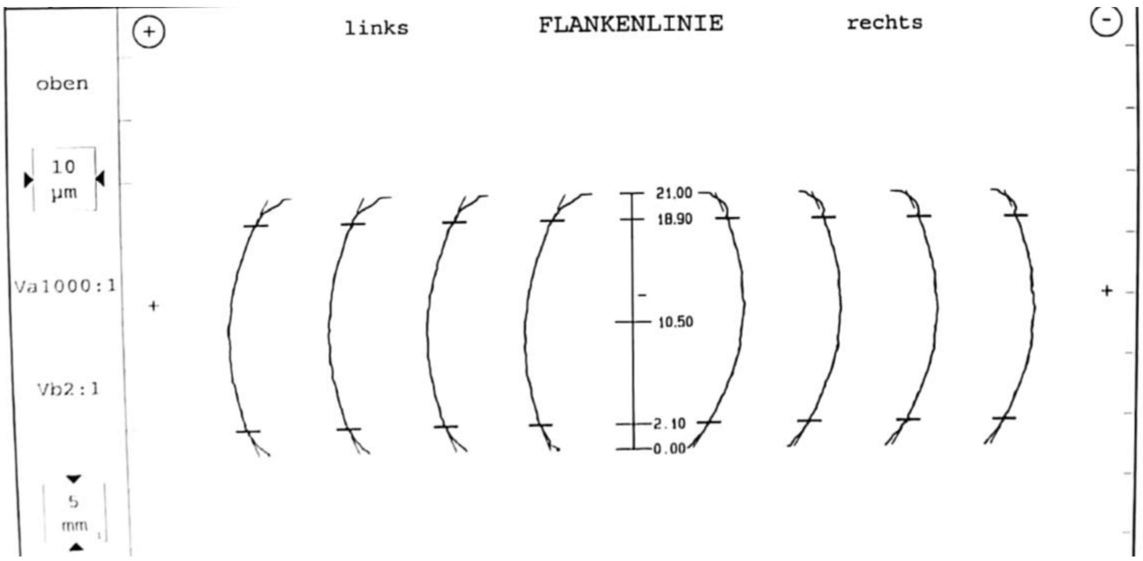

Figure 9: Flank profile after gear honing

After analyzing these diagrams, it can be seen that the profiles of both tooth flanks and tooth profiles are significant improved after honing. The honed profiles are closed to the theoretical ideal profiles. The flanks are curved lines as necessary for a good contact area. At the same time, both the excess material on the flanks and the profiles, as well as the lack of material, are reduced.

In figure 10, the roughness report of a tooth profile after gear honing is presented. The roughness is a very good one. Ra is 0.2315 µm and the maximum height of the profile is less than 1.3838 µm.

Ra	0.2315 µm
Rz	1.2767 µm
Rzmax	1.3838 µm

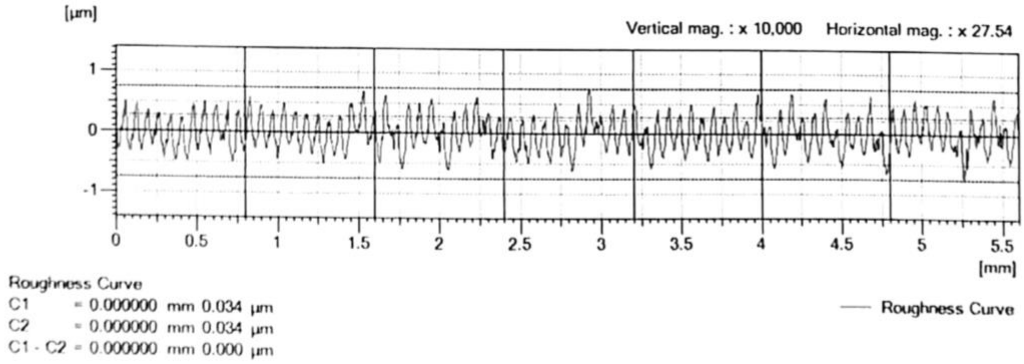

Figure 10: Roughness of the flank after gear honing

5. Conclusions

The study underlines that the gear honing operation is extremely favorable from the point of view of geometrical and dimensional precision.

The literature survey has shown that gear honing can be used to prolong lifetime and increase the ability to load the gears by improving the surface quality. Up to 80% contact surface engagement can be achieved.

Honed gears produce a much lower operating noise and have a longer lifetime compared to those finished by other processes due to the specific structure of its surfaces. The surfaces of the green shaved gears and honed gears have the highest ratio of the actual contact area compared to the surfaces obtained through hobbing or grinding.

The structure of the surface of a honed gear flank resembles a fish skeleton, which facilitates the formation of a lubricant film on the machined surface, which positively influences the behavior related to the operating noise level of a gearbox.

There is no thermal load in the case of gear honing. In fact, there are no microstructural changes in the material of the machined gears, so there is no danger of burns occurrence on the surfaces of the teeth flanks. Even with the increased cutting speed up to a value of 5 m / s, reached by the new generation of honing machines, there is no thermal loading during the process.

Another important advantage of these small cutting speeds is the induction of high residual compressive stresses in the subsurface layer of the flank. These residual compressive stresses are at least 1000 MPa, up to 1600 MPa. The increase in compressive stresses favors the wear behavior of the gear, which results in greater wear resistance and longer life than those that have been processed by grinding or shaving.

In order to increase the productivity of the operation in the industrial environment, further studies of the characteristics of the honed surfaces in the processing situation with more intense regimes are required.

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