RESEARCH ON INFLUENCE OF GEAR HONING PROCESS ON INVOLUTE HELICAL GEARS QUALITY

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ABSTRACT: Gear finishing processes, such as shaving – soft and hard, skiving – soft and hard, and gear grinding are used depending on different applications, as to achieve the required quality. Gear honing process is a gear hard finishing process, similar to hard shaving, recently developed, as to get fine finished surfaces. Gear honing is getting a universal technology, but is mostly used in automotive, aerospace and heavy equipment industry. It is used wherever a quiet, robust and reliable gearing process is required. The process provides smooth, noiseless, high wear resistance to micro-pitting, as well as increased bearing capacity surfaces. Thanks to its kinematics, gear honing process will induce no “burns” into flank surface; the process introduces no “bias” or “twist”, while running; however, if this is required, the process allows this option. Gear honing process is used more and more as an efficient alternative to other gear finishing processes, such as gear grinding, thanks to its technical and economic advantages.

KEYWORDS: gear honing, micro-pitting, burnt flank surface, gear bearing capacity, twist-free process.

1 INTRODUCTION

This paper highlights a case study about applying gear honing as hard finishing process for some involute helical gears, in order to reach the required quality. The main goal is to highlight how this process influences the quality of workpieces.

Over the past few years, gear honing has prevailed as an economic and high-performance hard finishing process for manufacturing gear wheels or gear shafts. Honed gearing surfaces make a decisive contribution to lower noise levels and reduced component wear in modern vehicle gearboxes (Präwema, 2018),(Yu-Ren Wu, 2016). Wherever the gears are used, the main demands are: low level noise transmission at high speeds, power optimization and high wear resistance (Fässler, 2018). The process of gear honing is ideally suited for getting these features. The flanks of an external teeth gear and an internal teeth honing ring are in rolling contact with a specified radial pressure at a low cutting speed. (Fässler, 2018, figure 1).

The driven work-piece and tool spindles are crossed at a defined angle. The superposition of the in-feed movements gives a resulting gliding movement running diagonally from tip to root of the tooth flank. This produces a micro-cutting process with short cutting point engagement. (Fässler, 2018)

The usual gear honing cutting velocity (figure 2) is about 1…10 m/s, much lower, as compared to gear grinding. By improving the surface finish and the quality of the geometry of the gear tooth, we can achieve interference free gear performance with full contact between the two rolling surfaces. This gives extremely smooth rolling of the gear and thereby noiseless operation, excellent power transmission and low wear. (Fässler, 2018)

Economically, gear honing, has become an essential part in the production of high-speed transmissions. Gears that have been honed, compared to ground, offer excellent wear
characteristics and are extremely quiet. But the benefits of this finishing technology don't end with high-speed transmissions. In addition, the finishing operation offers other significant advantages that many people in the industry do not consider. One, the gear honing process will not produce burning on the gear flanks as gear grinding can. (figure 3) As we know a burnt gear flank will result in pre-mature failure. Two, the gear honing process does not introduce bias (twist) into the part as gear grinding naturally does. However, if bias is wanted then the hone stone can be dressed to produce the desired bias. Three, gear honing is perfect for finishing gears with very little clearance due to shoulders or because of multiple gears on a shaft, areas where grinders cannot operate. We have processed gears with as little as 1.8 mm clearance in the past. (Matthew, 2014)

The stock allowance is about 10…120 microns per flank, the roughness of the surface achieved is < 3 microns, gear quality Q2…6, according to DIN 3962, residual compressive stress on flanks 1.000…1.600 N/mm². (Fässler, 2018)

The reason of the noiseless behavior of honed gears is the surface structure. The ground surface in the transverse plane of the gear looks like a saw. This causes vibrations and the gear is loud. A honed surface in the transversal cut of the gear looks smoother than the ground gear, the vibrations are less. (Fässler, 2018)

2 RESEARCH METHODOLOGY

As stated at the beginning, within chapter 1, the main purpose of this paper is to highlight the influence of gear honing process on gear quality, being applied as hard finishing process on some involute helical gears.

The working principle supposes applying the gear finishing process on our workpieces after hardening, in order to observe the quality achieved afterwards. Therefore, there will be two steps, such as follows:

- workpiece data: part geometry, incoming and outgoing quality;
- gear honing process: equipment, process run-off parameters, input and output data.

Further on, there will be approached these topics, as to perform the experimental analysis.

2.1 Workpiece data

Our workpieces are planetary gears (figure 4), involute helical type, used in last generation, high performance automatic transmissions, in order to takeover by up to 1.000 Nm of torque.

Table 1. Workpiece geometry data

<table>
<thead>
<tr>
<th>Feature</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal module</td>
<td>( m_n )</td>
<td>1.24</td>
</tr>
<tr>
<td>Teeth number</td>
<td>( z )</td>
<td>27</td>
</tr>
<tr>
<td>Pressure angle</td>
<td>( \alpha )</td>
<td>17°30’</td>
</tr>
<tr>
<td>Helix angle</td>
<td>( \beta )</td>
<td>18°</td>
</tr>
<tr>
<td>Width</td>
<td>( b )</td>
<td>20 mm</td>
</tr>
<tr>
<td>Tip diameter</td>
<td>( d_a )</td>
<td>38.4 mm</td>
</tr>
<tr>
<td>Inner diameter</td>
<td>( d_i )</td>
<td>24.5 mm</td>
</tr>
</tbody>
</table>

The nominal stock allowance in this case is practically 0, incoming from soft machining, as these parts are already finished in a soft state. But, while hardening process, the workpiece is affected by normal distortions, specific to this process. Incoming gear quality is thus, Q7 or Q8, according to DIN 3962, as the gear hobbing process allows achieving Q6, for some key feature is even better – Q5, according to DIN 3962. After hardening process, the stock allowance is about 10…20 microns per flank, so it is only need to smoothly clean the surface, as to get lower noise values.
2.2 Gear honing process

The process supposes using a high performance machining equipment – in our case it is about a twin-spindle gear honing machine, called Präwema Syncrofine (Figure 5), made by Präwema GmbH, member of DVS group.

As we speak about high accuracy and the stock allowance is relatively reduced, the equipment has an innovative technical solution, called “smart honing” - in order to shorten the cycle time, the allowance is measured by checking the axis-centre distance on the raw part before machining. Depending on the allowance, the rapid feed is adapted in order to avoid inefficient machining paths. (Präwema)

Further on, there will be highlighted the main process parameters, used in order to machine these workpieces, that have been noisy, detected while inspecting the noise produced, while gearing to a master gear, on a noise test bench. These process parameters, referring to both entities – workpiece and honing tool, are listed within table 2.

Table 2. Process parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workpiece spindle speed</td>
<td>5,400 min⁻¹</td>
</tr>
<tr>
<td>Honing tool spindle speed</td>
<td>1,000 min⁻¹</td>
</tr>
<tr>
<td>Workpiece radial infeed</td>
<td>1,00 mm/min⁻¹</td>
</tr>
<tr>
<td>Dressing cycle</td>
<td>200</td>
</tr>
<tr>
<td>Tip dressing infeed</td>
<td>0,3 mm/min⁻¹</td>
</tr>
<tr>
<td>Profile dressing infeed</td>
<td>0,05 mm/min⁻¹</td>
</tr>
</tbody>
</table>

The tools used for this process are usually, ceramic profiled, ring type, designed according to workpiece gear data. In this case, the honing ring has number of teeth, z=113, normal module mn=1,24; for dressing, diamond tools are used, for both profile and tip diameter. (Figure 7)

In order to reach the quality demands, the process runs on cooling oil, fed directly from equipment’s oil tank. Using these set of main parameters, the workpieces have been finished, as to get the quality requirements.

As specified before, the incoming quality is Q7 and Q8, according to DIN 3962, stock allowance about 10...20 microns, only those distortions from hardening. Outgoing quality will be presented further, within next chapter, when the results will be highlighted.

3 RESULTS

Within this chapter, the results will be presented, highlighting the most important aspects for gear quality, achieved using gear honing, as finishing process. There have been selected three workpieces from a lot of 1,000, measured before and after gear honing process.

These workpieces, were detected as being noisy while testing them to a master gear. These three parts are relevant enough for this purpose, as they show very well how gear quality changes when applying gear honing process.

Figure 8 shows clearly how quality changes: incoming for teeth profile is mostly Q7, DIN 3962, but one parameter, profile angle deviation , is Q8; for teeth direction situation is even worse – only tooth trace profile form is on Q7, the other parameters are either Q8 or even Q9 (tooth trace angle).

Roughness, Rz, is also higher than 6.3 µm, maximum allowed. After honing, the quality for profile is Q4...Q5 and Q5...Q6 for direction, roughness – Rz 4...6 µm.

Figure 9 shows similar facts, when profile gear profile parameters are on Q7 and Q8, gear teeth
direction Q7…Q9. After gear honing, we have Q5 for gear profile and Q6 for gear direction. Roughness – Rz before is about 8…10µm, afterwards about 3…5 µm.

Figure 8. Sample 1 – a) before honing; b) after honing

Figure 9. Sample 2 – a) before honing; b) after honing
The last sample, highlighted by figure 10, shows even better results, as quality achieved after gear honing is Q4 for gear profile and Q5 for gear direction. Roughness – Rz is about 3…4 µm.

As presented above, gear quality is positively influenced by gear honing, the result is a smooth and refined flank surface, with superior values when comes about low noise level & vibrations. These results have been achieved using a high performance gear measuring equipment, Klingelnberg P26.

These workpieces had no nominal stock allowance from soft machining process, only those distortions from hardening process, so it has been needed only a smooth adjustment of the flanks, that it means 10…20 microns per flank. Further on, there will be highlighted the main ideas of this paper, within next chapter.

4 CONCLUDING REMARKS

This case study highlights some important guidelines when comes about gear quality, basically the advantages of using this process for gear finishing, after hardening process. Based on the facts and results presented before, it can be noticed that:

- the process is highly performant and reliable, especially when comes about smooth corrections on the flanks;
- process productivity is much higher, as the dressing cycle it means 200 pieces;
- due to “smart honing” solution, there can be fine adjusted workpieces with no nominal stock allowance;
- gear quality has been significantly improved, without compromising the surface on the flanks; after gear honing we have Q4…Q6, according to DIN 3962;
- the values for roughness achieved were between Rz 3…5 µm;
- the process is the best option for these kind of workpieces, concerning the geometrical and dimensional features;
- due to fine and smooth finishing, the values for noise and vibrations are much lower while gearing process to matting gears.

These facts stated above are the main concluding remarks of this paper, based on results achieved. However, it worths to underline the main general advantages of this hard gear finishing process, such as follows:

- excellent surface finish and extreme small roughness values;
- noiseless surface structure;
- very good wear behavior due to the induction of high compressive residual stresses (1000 ... 1600 N/mm2);
- no thermal stresses; no changes of the material microstructure; no grinding burn;
- no bias from the process or twist-free process;
- excellent profile and lead qualities (DIN 6 ... 2);
- quite good correction of pitch errors and run out (DIN 6 ... 2);
- high process capability because of direct drive technology;
- low tooling costs because long tool life of ceramic bonded honing stones;
- high stock removal possible, by up to 120 µm on the flank;
- economic finishing process - especially in mass production.

5 REFERENCES
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►Yu-Ren Wu, Van-The Tran, Transmission and load analysis for a crowned helical gear pair with twist-free tooth flanks generated by an external gear honing machine, Mechanism and Machine Theory 98 (2016) 36–47

6 NOTATION
The following symbols are used in this paper:
\( A_{\text{cc}} \) = area of core concrete;
\( A_t \) = total area;
\( fH_\alpha \) - profile angle deviation;
\( fH_{\alpha m} \) – average profile angle deviation
\( F_\alpha \) – total profile form deviation
\( F_f_\alpha \) – profile form deviation
\( C_\alpha \) – tooth profile crowning
\( F/K_\alpha \) – \( F \_ \text{root diameter}, K_\text{tip diameter} \)
\( fH_{\beta m} \) – average tooth trace angle deviation
\( fH_\beta \) - tooth trace angle deviation;
\( F_\beta \) – total tooth trace angle deviation
\( f_f_\beta \) – tooth trace form deviation
\( C_\beta \) – tooth trace crowning
\( Fu_\beta \) – unit size on measurement protocol