Strategy of profile dividing gear grinding on Höfler grinding machines

Strategia szlifowania kształtowo-podziałowegokół zębatych na szlifierkach Höfler

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The strategy of implementation of grinding operation of toothed gears with use of profile dividing method on Höfler grinding machines is presented. Results of this operation will depend on adopted strategy and machining conditions and the type of tool.

KEYWORDS: a tooth gears, profile dividing grinding, results of the grinding operation

In gearboxes, the most common are carburized and inductively hardened wheels requiring at least 56 HRC hardness. Heat treatment and thermo-chemical treatments, even barrage of carefully machined wheels, cause them to exhibit tooth line defects and angles due to deformations associated with heat treatment. In this case, in order to obtain a specific accuracy class, any errors are removed by grinding. There are two groups of teeth grinding methods: shape and circumference [1-3, 9]. The undoubted advantage of the method of shaping is that they allow the contours of the teeth to be shaped and allow the grinding of the teeth in the internal gear teeth [7, 9].

Characteristics of the stand equipped with Rapid Höfler 2000 grinder

The research was carried out on the Rapid Hofler 2000 grinding machine for profile grinding of gears installed at Befared SA, a leading manufacturer of general purpose reducers and geared motors. Realization of grinding operations with this type of machine tool is relatively quick. Figure 1 shows a view of the machine tool along with a description of the axes and main axes movements. The individual axes are assigned to the main sub-assemblies that perform the following functions [7, 8]:

- grinding head (*A* axis) - inclination of the grinding wheel to the angle of incline,
- workpiece table (*B* axis) - graduation,
- grinding spindle (*C* axis) - rotation of the grinding spindle during grinding,
- dressing spindle (*C2* axis) - rotation of the dressing roller during dressing,
- workpiece slides (*X* axis) - diameter adjustment,
- tool slide (*Y* axis) - jump stroke,
- dressing (*Z2* axis) - creating a tool profile.

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Technical specifications of the workpiece are as follows: maximum wheel diameter d_a = 2000 mm, module (depending on toothed data) m = 3.5÷30 mm and maximum inclination angle left/right 45°.

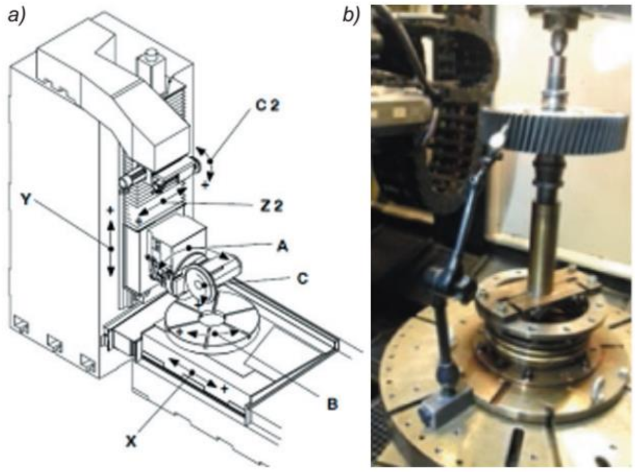

Fig. 1. Rapid Höfler 2000 grinder: *a)* axis description, *b)* centering and alignment [7, 9]

Development of strategy of profile shaping-division for selected gears

The shaping-division strategy shall be understood to mean all the operations necessary to develop the machining task. Each task has its own pre-set and workpiece data and process data. Achieving a high quality and accuracy of ground gearing requires machine operators with a lot of experience and practical knowledge so that in each area of the job definition window they are able to determine the proper parameters. The present paper discusses how to develop a grinding wheel strategy with external gearing in industrial conditions.

Grinding operations were made on the Rapid Höfler 2000 grinding wheels of C55 steel after induction hardening, with the following characteristics: module m = 5 mm, teeth number z = 68, division diameter d_p = 345,131 mm, angle of engagement α = 20°, angle of tooth alignment inclination β = 9°53'30", correction factor x = 0. The wheel grinding was performed after grinding 7, 9, 11, 13, 15 and 17 of the gear teeth. For grinding wheels with different wheel dressing variants, measurements were made on the coordinate measuring machine discussed below, with the following deviations: F_α, $f_{f\alpha}$, $f_{H\alpha}$, F_β, $f_{f\beta}$, $f_{H\beta}$, F_p, F_r [4-6].

Six quality grade non-alloyed toothed wheels were investigated for the C55 thermal improvement, containing the following elements: 0.52-0.6% C, 0.6-0.9% Mn, maximum 0.4% Si, maximum 0.045% S, maximum 0.4% Cr, maximum 0.4% Ni, and maximum 0.1% Mo.

After rolling, overhauling, thermal improvement, turning, drilling and threading, the gear teeth were cut using NM5 PA20 PRE-GR PROTUB, high speed steel with ALCROM Al2 + (FUTURA NANO), diameter D = 119.8 mm, width B = 140 mm and the following characteristics: module m = 5, clamping angle α = 20°, cutter helical angle λ = 2°41'. The cutting was performed on a SAMPUTENSILI S800 envelope milling machine with SINUMERIK control. Envelope milling was performed with cutting parameters: n_f = 186.09 rpm, f = 2.50 mm/rev, v_c = 70 m/min. Intensive cooling and lubrication with MOBILMET 443 base oil, containing additives, was applied.

After milling and de-burring the teeth, they are subjected to induction hardening by tooth-to-tooth method, to a hardness of 58-60 HRC. The hardening of the individual teeth was carried out by the feed method - one tooth was divided in the process. Use a 35 kW HF generator and an IV-630 feeder (UNITERMA 35/50) at a frequency of 300-400 kHz. For gear wheels with module 5, IP-10.03.04/03 recommends the following operating parameters: current intensity 670 A, feedrate 2, layer thickness approximately 1 mm. After induction, the wheels were tempered in accordance with IP-10.03.02.

At the first stage of the shape-division grinding strategy, the grinding table with the workpiece was integrated, which was attached to the spindle diaphragm. After mounting, the alignment of the sprocket with the table axis was determined and the radial run was checked using the Miraco RRY 483 sensor. The radial run rate of 5 m was obtained. The alignment and alignment of the gearwheel relative to the axis of the machine finishes the grinding preparation step. Once the mount height has been determined and the grinding program is set, the machining strategy can be defined. In one of the window fields to define the task, an involuntary profile was established. For the workpiece, the values of the parameters characterizing its geometry and the settings of the foot and apex and the tooth bearing surface line were introduced. Additional geometry is the height of the lower edge of the workpiece that is 1209 mm. This is an operation required by the machine tool control system needed for intra-programmatic collision control. The diameter of the grinding wheel was 276.0962 mm.

The correct course of grinding also depends on the determination of the additional up/down of the grille. The runway length was assumed to be 15 mm. In one of the fields are set parameters to optimize the angle of tilting the grinding wheel. During grinding, the grinding wheel is inclined by an angle deviating from the angle of inclination – e.g. to minimize runoff or force equalization during the ascent and descaling of the grinding wheel [7]; in the developed task, the difference in the angle of inclination was determined to be 0.0885°. Gears were appropriately labeled so that the grinding operation is carried out in each case from the notch numbered 1.

Grinding of selected gears required the adoption in the treatment program: radial dressing, k_d coverage index [10], dressing index η (ratio of circumferential speed of the dressing roller to the peripheral speed of the grinding wheel). The mentioned wheel dressing parameters were as follows:

- in passage 1: radial delivery of dressing 0.05 mm, k_d = 1, η = 0.6;
- in passage 2: radial delivery of dressing 0.05 mm, coverage ratio k_d = 1, η = 0.6;
- in passage 3: radial delivery of dressing 0.05 mm, coverage ratio k_d = 1.5, η = -0.3;
- in passage 4: radial delivery of dressing 0.05 mm, coverage ratio k_d = 6, η = -0.6.

In the analyzed machining task, it was decided to manually find the carcass, while the center of the carcass was performed automatically. In this centering method, the centers of the bevels are determined by the automatic touching of the support surfaces of the tooth by gripping the grinding wheel. The number of beams specified for automatic centering was 6, while the number of planes - 2 (upper and lower planes evenly distributed in the entered area). Beginning of the treatment required defining the number of passes and setting the jump table for both 2- and 1-surface grinding. In the developed task of the implemented grinding strategy were adopted 2-sided grinding of gears in 4 passages:

- for passage 1, the sum of deliveries 0.120 mm (6 jumps of 0.02 mm), total delivery 0.310 mm, radial delivery 0.055 mm, feedrate 7000 mm/min, and cutting volume V'_w = 26.44267 mm^3/mm;
- for passage 2, the sum of deliveries 0.120 mm (6 jumps at 0.02 mm), total delivery 0.310 mm, radial delivery 0.055 mm, feedrate 7000 mm/min, and cutting volume V'_w = 26.44267 mm^3/mm;
- for passage 3, the sum of deliveries 0.05 mm, total delivery 0.310 mm, radial delivery 0.041 mm for 2 jumps of 0.015 mm - feedrate 4500 mm/min, radial delivery 0.028 mm for 2 jumps of 0.01 mm - feedrate 4000 mm/min, cutting volume V'_w = 11.011 mm^3/mm;
- for passage 4, the sum of deliveries 0.020 mm (2 jumps at 0.01 mm), total delivery 0.310 mm, radial delivery 0.028 mm, feedrate 2200 and 1800 mm/min, cutting volume V'_w = 4.4044 mm^3/mm.

Once the first wheel has finished grinding, a calibration has been carried out to prepare and carry out grinding measurements. After calibration, the exact position of the sensor is obtained.

According to the developed strategy, grinding 6 gears with different grinding patterns was performed. After milling, inductive hardening and grinding operations, the accuracy of gear teeth was measured on the CARL ZEISS PRISMO NAVIGATOR coordinate machine using Vast Gold scanning head and ZEISS GEAR PRO Involute 2014 software. PN-ISO 1328-1): total deviation of profile F_α, deviation of profile $f_{H\alpha}$, deviation of shape $f_{f\alpha}$, total deviation of tooth line F_β, deviation of tooth position $f_{H\beta}$, deviation of tooth shape $f_{f\beta}$, deviation of circle deviation F_p, deviation scale f_p and radial run F_r. Exemplary graphical representations of the obtained gear wheel wears with the adopted wheelbase grinding wheel every 17th point are shown in fig. 2 and fig. 3.

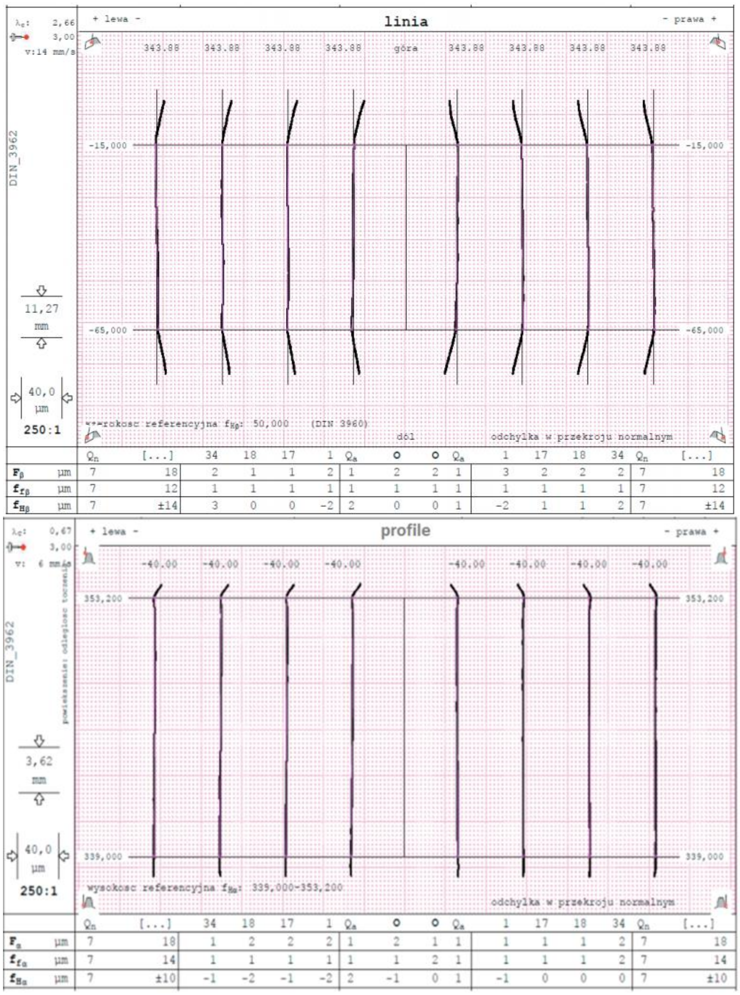

Fig. 2. Sheet of measurement results of pitch deviations and radial runout of a gear

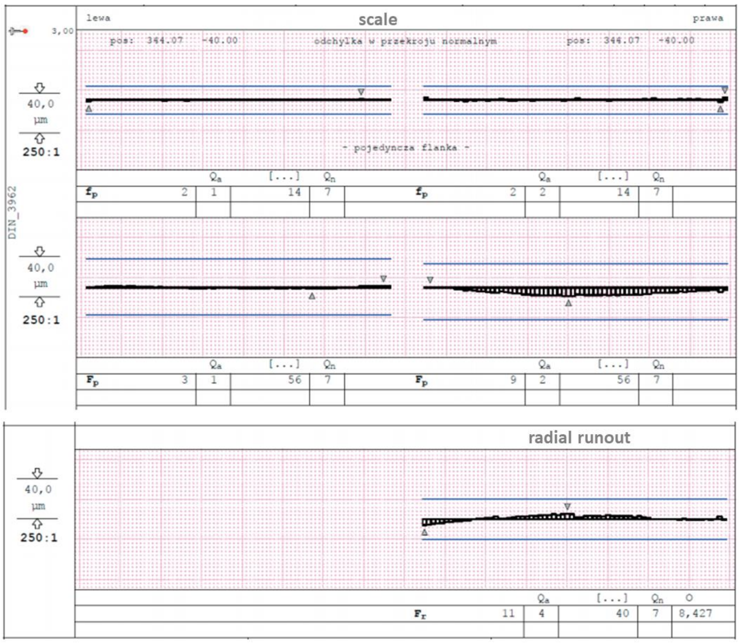

Fig. 3. Sheet of results of deviation measurements of the profile and gear line

Conclusions

The presented strategy for the development and implementation of shape-division grinding with different grinding wheel variants made it possible to obtain a high degree of grinding dentistry, which confirmed the results of the measurement of selected deviations. F_{α}, $f_{H\alpha}$ and $f_{f\alpha}$ deviation mean values corresponded most often to 2nd accuracy class, whereas deviations F_{β}, $f_{H\beta}$ and $f_{f\beta}$ were in 1st grade. It can be assumed that the development of a suitable grinding strategy - including the specific task, gear geometry, pre-grinding treatment, grinding and fixing method - and grinding tactics will translate into the suitability of the ground grinding. Grinding on Rapid Hofler grinders is a very complex process, taking into account many input factors.

Based on the analysis of the knowledge upon grinding of gears, it can be stated that the shaping-division grinding will continuously be the leading treatment finishing of gear teeth.

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