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TECHNOLOGICAL QUALITY OF TEETH OF A CYLINDRICAL GEARS GRINDED WITH USE OF PROFILE DIVIDING METHOD

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Summary

The study presents investigation results of technological quality of teeth of a cylindrical gears made of 18CrMo4 steel, carburized, quenched and tempered, and grinded with use of profile dividing method on grinding machine of Höfler Rapid 900 type. It have been included investigation results of geometrical accuracy and selected properties of surface layer of the teeth after hobbing operation, thermal-chemical treatment and grinding operation.

Keywords: grinded of a cylindrical gears, profile dividing grinding method, manufacturing accuracy, surface layer

Jakość technologiczna uzębień kół zębatych walcowych szlifowanych metodą kształtowo-podziałową

Streszczenie

W pracy przedstawiono analizę wyników badań jakości technologicznej uzębień kół zębatych walcowych ze stali 18CrMo4 nawęglanych, hartowanych i odpuszczanych oraz szlifowanych metodą kształtowo-podziałową na szlifierce Rapid 900 firmy Höfler. Wykonano badania dokładności geometrycznej i wybranych właściwości warstwy wierzchniej zębów obrobionych frezowaniem obwiedniowym oraz obrobionych cieplno-chemicznie i szlifowanych.

Słowa kluczowe: szlifowanie kół zębatych, metoda kształtowo-podziałowa, dokładność geometryczna, warstwa wierzchnia

1. Introduction

High qualitative demands placed on toothed gears, such as silent-running mainly, are enforcing usage of thermal or thermo-chemical treatments, and finishing operation of the teeth, usually such as grinding, to assure at least the 7th class of accuracy and surface roughness of *Ra* 0,8 μm. There are known the

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following grinding methods of cylindrical gears: profile grinding, generation-dividing grinding (the most often with use of Maag, Niles and Hurth method) and continuous generating grinding (with use of Reishauer method) [1-5]. In the second half of the XX century to production of cylindrical gears, in manufacturing of general-purpose gear transmissions, were used two methods mainly: generation-dividing grinding and continuous generating grinding. Intensive development of NC machines at the end of the XX century and at beginning of the XXI century has resulted in return to, and more frequent implementation of profile dividing method to grinding of toothed gears. In the paper are presented investigation results of technological quality comprising geometrical accuracy and selected properties of surface layer (roughness and hardness) of cylindrical gear wheels with external spur gears, produced on hobbing machines and thermally-chemically treated. The objective of this paper was to point at a possibility of profile grinding of the tooth, complying with requirements imposed on shape and dimensional accuracy and on conditions of surface layer.

2. Profile dividing grinding of external cylindrical gears having spur and helical gears

Investigations of the authors have concerned technological quality of machining operations of cylindrical gear wheels with external teeth produced on Höfler Rapid 900 grinder. This type of the grinder enables also, except grinding of cylindrical spur gears, grinding of gear wheels with internal teeth, as well as gear wheels with herringbone teeth. Grinding of active flanks of the teeth, with use of grinding wheel having profile of single tooth space, occurs in result of reversible feed motions of grinding wheel along axis of the gear wheel and rotation of the grinding wheel. In case of helix angle of $\beta > 0^{\circ}$, additionally occurs synchronization of reciprocating motion of the grinding wheel along axis of the grinded gear with rotary motion of the table, to obtain linear contact along helix line of the grinding wheel with the grinded gear.

Methodology and range of the investigations

Investigations of technological quality of cylindrical toothed wheels with external teeth, after thermochemical treatment and grinding operation were performed on gears having the following characteristics: $m = 3$ mm, $z = 67$, $\alpha = 20^{\circ}$, $\beta = 10^{\circ}$, correction factor $x = 0{,}124$ mm and RH helix angle. The toothed wheels, in quantity of 10 pcs, were made of constructional case-carburizing steel of 18HGT (18CrMo4) grade, with the following chemical analysis (by weight): 0,17% C; 1,30% Cr; 0,80% Mn; 0,05% T. After turning of machining allowance of the gear wheel, the teeth were cut with use of NFMc gear-cutting hob of B_p class having the following characteristics: $m = 3$, $\alpha = 20^{\circ}$,

$\lambda = 2^{\circ}35'$, height of the hob H = 52,34 mm, with nose radius 0,6 mm, on hobber of ZFWZ 250×5 type produced by WMW Modul Co. In course of the hobbing the following cutting parameters were used: $n_f = 90$ rpm and $f = 1{,}0$ mm/rotation, and intensive cooling and lubrication with AVIAKOL- EP-22 fluid.

After hobbing operation and removal of burrs from teeth of the gears, the gears were subjected to thermochemical treatment according to IP-10.03 instruction, mandatory in the Bielska Fabryka Reduktorów i Motoreduktorów BEFARED. The gears were case-hardened to depth of 0,8±0,1mm, and next, quenched to hardness of 56±2HRC (temperature 830°±10°C, duration of soaking 0,5 h, and cooling in oil), and tempered up to core hardness of 31÷41HRC. After thermochemical treatment the gears subjected to sand-blasting and cleaning operations.

Next, from one tool setting, a hole and a flank of the tooth were grinded on internal grinder, while the second flank was grinded on flat-surface grinder. Basing on the grinded hole and the flank, the teeth were grinded with use of expansion sleeve.

Exemplary course of contact line of grinding wheel with surfaces of helical tooth space is shown in the Fig. 1.

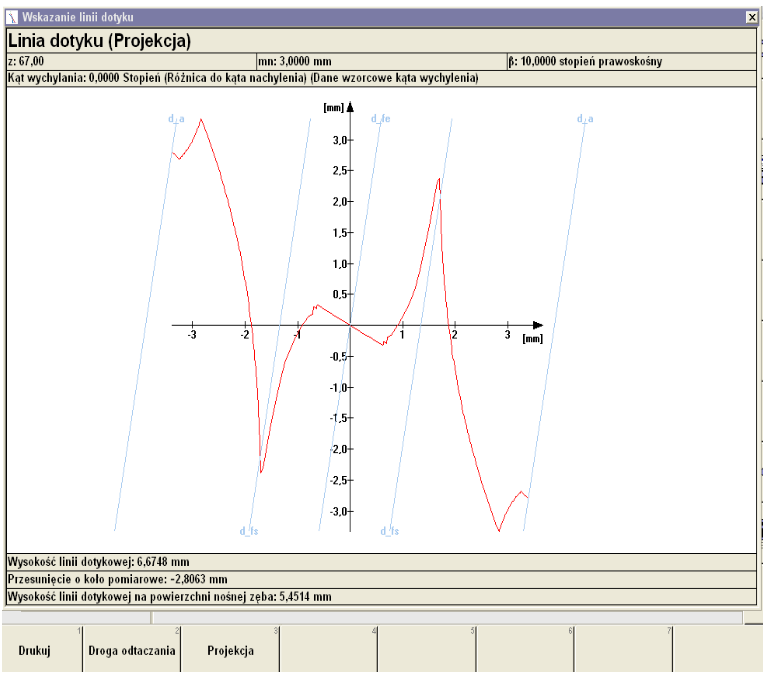


Fig. 1. Contact line (red colour) of the grinding wheel during grinding of helical tooth space of the gear with angle of $\beta = 10^{\circ}$

To grinding operation of the gears a single-profile grinding wheel made of aloxite of SK23w 60/1 G/H 10V 10 type was used, manufactured by *Schleifmittelwerk Burka – Kosmos GmbH Company*, with dimensions: 400/358×45/10×127 mm, profile formed to module $m = 3$ mm, profile E (50 Grad). Parameters of the grinding operation: tangential velocity of grinding $v_c = 35$ m/s for the grinding wheel ø400 mm, speed of reciprocating motion of the grinding wheel $v_f = 5{,}2$ m/min, grinding allowance $a_n = 0{,}2$ mm (grinding depth of roughing passes $a_{pz} = 0{,}02$ mm, number of roughing passes $i_{pz} = 6$; grinding depth of profiling passes $a_{pk} = 0{,}015$ mm, number of profiling passes $i_{pk} = 4$; grinding depth of finishing passes $a_{pw} = 0{,}010$ mm, number of finishing passes $i_{pw} = 2$). The Rotel Spezial 277-4 type oil in quantity of 150 l/min was used as cutting-tool lubricant during the grinding.

3. Results of the investigations and their analysis

Measurements of manufacturing accuracy of teeth of the gears after profile dividing grinding were performed on Rapid 900 grinder with use of MAHR head, implementing GEARPRO software, without necessity of dismounting of the gear from the grinder. Such measurements constitute indispensable part of grinding operation, because the grinder incorporates a measuring module built-in into its control system.

In this study, the following parameters were taken according with [6, 7, 8] to assessment of the manufacturing accuracy of the teeth:

- profile total deviation F_α,
- profile angular deviation $f_{H\alpha}$,
- profile form deviation $f_{f\alpha}$,
- total helix deviation F_β,
- helix slope deviation $f_{H\beta}$,
- helix form deviation $f_{f\beta}$,
- cumulative pitch deviation, total F_p,
- pitch deviation f_{pt},
- single pitch difference f_u,
- radial runout of tooth space F_r,
- tooth thickness s.

On each gear it have been measured LH and RH active flanks of three teeth spaced every 120°. The above mentioned parameters of deviation were measured on the grinder with use of measuring head positioned on measuring arm. In one from the gears after performed hobbing operation, and on the second gear after performed operations of milling, thermochemical treatment and grinding, it have been cut out three teeth from each gear to perform measurements of selected 3D parameters of surface roughness of active flank of the teeth. Using Perthometer

Concept profile measurement gauge produced by MAHR Company and Perthometer Concept 7.0 computer program, measurements of the roughness were performed within area of pitch diameter, in half-width of the toothed ring.

To assess 3D surface roughness of active flanks of the teeth it have been taken the following parameters: S_a, S_q, S_{p}, S_v, S_t, S_k, S_{pk}, S_{vk}, S_{mr1} and S_{mr2}, topography of the surface, distribution of ordinates of surface peaks and areal material ratio curve [9, 10].

Moreover, to perform measurements of the hardness, using a wire erosion machine it have been cut-off sections with length of $l = 8$ mm from each cut-out tooth, and next the sections were embedded in resign; and to measure the hardness, metallographic specimens were cut orthogonally to the flank pitch line. Measurements of the hardness were performed with use of Micro–Vickers HM-210 hardness tester under load of $\mathrm{HV}_{0,02}$ intender, equal to 0,196 N. Photos of the microstructure were made on optical microscope of Carl Zeiss Axiovert 100A type.

Due to the fact that the teeth should be machined in the 6th class of accuracy, while PN-ISO 1328-1:2013 (E) standard recommends parameters: F_p, f_{pt}, s, F_α, $f_{H\alpha}$, $f_{f\alpha}$, F_β, $f_{H\beta}$, $f_{f\beta}$ to assess gears with diameter $d \leq 4\,000$ mm produced in accuracy class from 1 to 6; the analysis was limited to these parameters. To assess tooth thickness, s, it has been used measuring method across k – teeth. There were determined the number of tooth k taken to the measurements ($k = 8$) and theoretical value of parameter $w_k = 69{,}470$ mm; and were performed measurements of this value with use of micrometer with dished type contact tips. Values of parameter w_k obtained from the measurements were situated within interval from 69,460 to 69,467 mm, and were lower than theoretical value [6].

After the hobbing, in case of the LH active flank of the tooth (Fig. 2a), values of the profile total deviation F_α, values of the profile form deviation of the tooth $f_{f\alpha}$ were included within accuracy class 8÷9, while values of the profile angular deviation $f_{H\alpha}$ in the 4th class, values of the total helix deviation F_β, values of the helix slope deviation $f_{H\beta}$ and values of the helix form deviation $f_{f\beta}$ were within the 12th class of accuracy, whereas value of the total cumulative pitch deviation $F_p = 132{,}5\ \mu\mathrm{m}$, what complies with the 10th class of accuracy, value of maximal pitch deviation $f_{pt} = 104{,}0\ \mu\mathrm{m}$, what exceeds allowable value of the deviation for the 12th class with $31\ \mu\mathrm{m}$. In turn, for the RH side of the active flank of the tooth (Fig. 2b), values of the profile total deviation F_α, values of the profile angular deviation $f_{H\alpha}$ and values of the profile form deviation of the tooth $f_{f\alpha}$ were included within classes of accuracy 8÷9, while values of the total helix deviation F_β, values of the helix slope deviation $f_{H\beta}$ and the deviations of the helix form deviation $f_{f\beta}$ – were inside interval of accuracy class of 8÷10, while value of the total cumulative pitch deviation amounted to $F_p = 153{,}0\ \mu\mathrm{m}$, what corresponds to the 11th class of accuracy, value of maximal pitch deviation $f_{pt} = 92{,}0\ \mu\mathrm{m}$, what exceeds with 19 μm allowable value of this deviation for the 12th class of accuracy. Values of the radial runout F_r after the hobbing operation slightly exceeded allowable value of the deviation for the 12th class of accuracy. It is possible, however, to assume with a slight error, that hobbing of the tooth with NFMc type hobbing cutter of the B_p class has assured obtainment of the 12th class of accuracy.

In the Figs 3÷5 are shown frequencies of occurrence of deviation values of the gears within individual classes of accuracy after operations of thermochemical treatment and grinding. Values of the profile total deviation F_α, values of the profile angular deviation $f_{H\alpha}$ and the profile form deviations of the tooth $f_{f\alpha}$ for all investigated gears were included within range of accuracy classes from 1 to 6. Whereas, 90% of the values of profile deviations F_α and $f_{H\alpha}$, in case of the LH active flank of the tooth, were included within interval of accuracy classes from 1 to 3, while value of the profile form deviation of the tooth $f_{f\alpha}$ within range of the classes 3÷5 (Fig. 2a). Whereas, for the RH active flank of the tooth, values of the above mentioned deviations in 97% of the deviations were included within interval of accuracy classes 1÷4 (Fig. 2b). All values of the total helix deviation F_β, values of the helix slope deviation $f_{H\beta}$ and the helix form deviation $f_{f\beta}$, both for the LH and the RH flanks of the tooth were within interval of accuracy classes from 1 to 3. Values of the cumulative pitch deviation F_p, both for the LH and the RH active flanks were within range of accuracy classes from 1 to 6. Whereas in case of the LH flank, values of the deviation Fp in 80% of the cases were included within interval of the classes from 1 to 2, whereas for the RH flank of the tooth all values of the deviation F_p were situated inside the 1st class of accuracy. On the other hand, all values of the pitch deviation f_{pt}, for the RH flank of the tooth were included within range of accuracy classes from 3 to 5, whilst for the LH flank of the tooth in 80% of the cases these deviations were included within interval of the classes from 1 to 5. Unfortunately, in 20% of the cases values of the of maximal pitch deviation f_{pt} were included within range of values from 18 to 26 μm, i.e. in the 9th class of accuracy. Values of the radial runout F_r after grinding were within interval of the accuracy classes from 3 to 5, only in 10% of the cases – in the 7th class of accuracy.

Exemplary diagrams of the profile deviations: F_α, $f_{H\alpha}$ and $f_{f\alpha}$ together with specified values of these deviations, for the LH and the RH flanks of three teeth, after operation of hobbing have been presented in the measuring sheet (Fig. 6), whilst after operations of thermo-chemical treatment and grinding are shown in the measuring sheet (Fig.7). Whereas, exemplary diagrams of the helix deviations F_β, $f_{H\beta}$ and $f_{f\beta}$ after operation of the hobbing have been shown in the Fig. 8, while after operations of thermo-chemical treatment and profile dividing grinding have been presented in the Fig. 9.

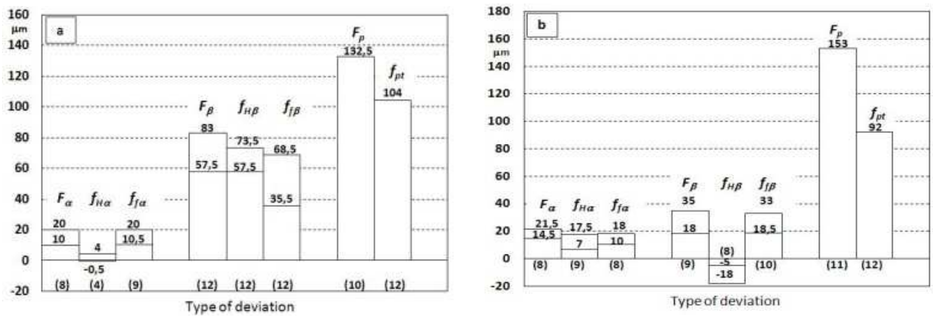


Fig. 2. Maximal and minimal values of the deviations F_α, $f_{H\alpha}$, $f_{f\alpha}$, F_β, $f_{H\beta}$, $f_{f\beta}$, F_p, f_{pt} after hobbing operation: for the LH (a) and RH (b) active flank

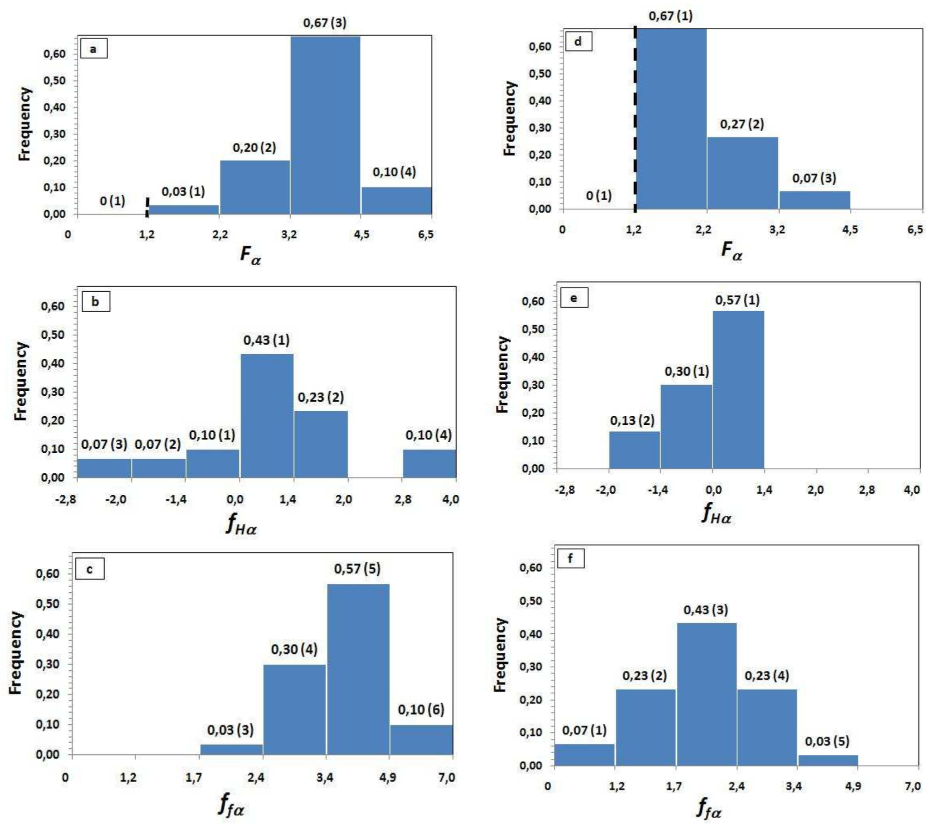


Fig. 3. Frequency of occurrence of the deviations F_α, $f_{H\alpha}$, $f_{f\alpha}$: for the LH active flank of the tooth (a, b, c) and for the RH active flank of the tooth (d, e, f)

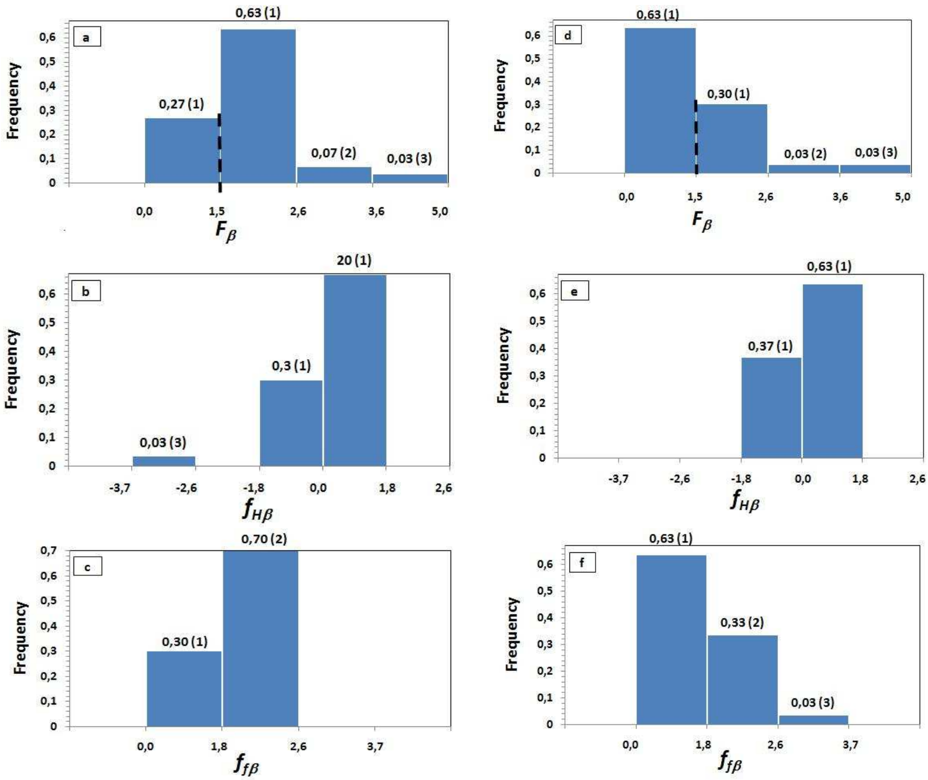


Fig.4. Frequency of occurrence of the deviations F_β, $f_{H\beta}$, $f_{f\beta}$: for the LH active flank of the tooth (a, b, c) and for the RH active flank of the tooth (d, e, f)

Average values of 3D surface roughness parameters of active flanks of the teeth after hobbing operation, for the LH active flank of the teeth, were as follows: $S_a = 0{,}78$ µm, $S_q = 1{,}03$ µm, $S_p = 7{,}93$ µm, $S_v = 6{,}98$ µm, $S_t = 14{,}92$ µm, $S_k = 2{,}07$ µm, $S_{pk} = 0{,}08$ µm, $S_{vk} = 1{,}87$ µm, while for the RH active flank of the tooth: $S_a = 0{,}88$ µm, $S_q = 1{,}23$ µm, $S_p = 13{,}53$ µm, $S_v = 10{,}28$ µm, $S_t = 23{,}82$ µm, $S_k = 2{,}37$ µm, $S_{pk} = 0{,}15$ µm, $S_{vk} = 3{,}15$ µm. On the other hand, after operation of profile dividing grinding there occurred a clear decrease of 3D surface roughness parameters. For the LH active flank of the teeth the above parameters of 3D roughness were included within interval: $S_a = 0{,}35 \div 0{,}38$ µm, $S_q = 0{,}45 \div 0{,}49$ µm, $S_p = 1{,}43 \div 2{,}19$ µm, $S_v = 1{,}89 \div 2{,}05$ µm, $S_t = 3{,}36 \div 4{,}24$ µm, $S_k = 1{,}47 \div 1{,}99$ µm, $S_{pk} = 0{,}03 \div 0{,}05$ µm, $S_{vk} = 0{,}82 \div 0{,}95$ µm, while for the RH active flank of the teeth: $S_a = 0{,}26 \div 0{,}30$ µm, $S_q = 0{,}34 \div 0{,}39$ µm, $S_p = 1{,}49 \div 2{,}34$ µm, $S_v = 1{,}45 \div 2{,}27$ µm, $S_t = 2{,}94 \div 4{,}01$ µm, $S_k = 1{,}13 \div 1{,}25$ µm, $S_{pk} = 0{,}04 \div 0{,}05$ µm, $S_{vk} = 0{,}48 \div 0{,}74$ µm. As seen, after operation of profile dividing grinding, values of 3D roughness for the LH and RH active flanks of the tooth were very similar.

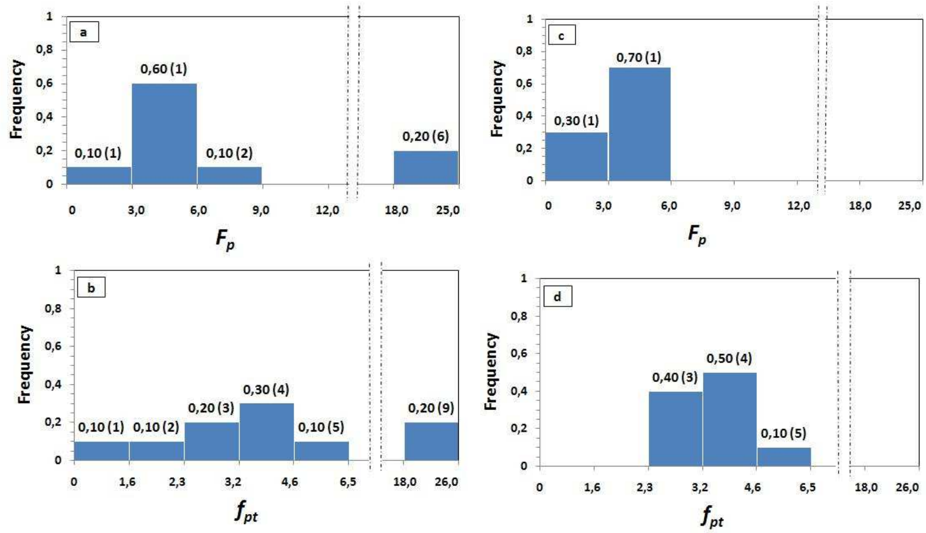


Fig. 5. Frequency of occurrence of the deviations F_p, f_{pt}: for the LH active flank of the tooth (a, b) and for the RH active flank of the tooth (c, d)

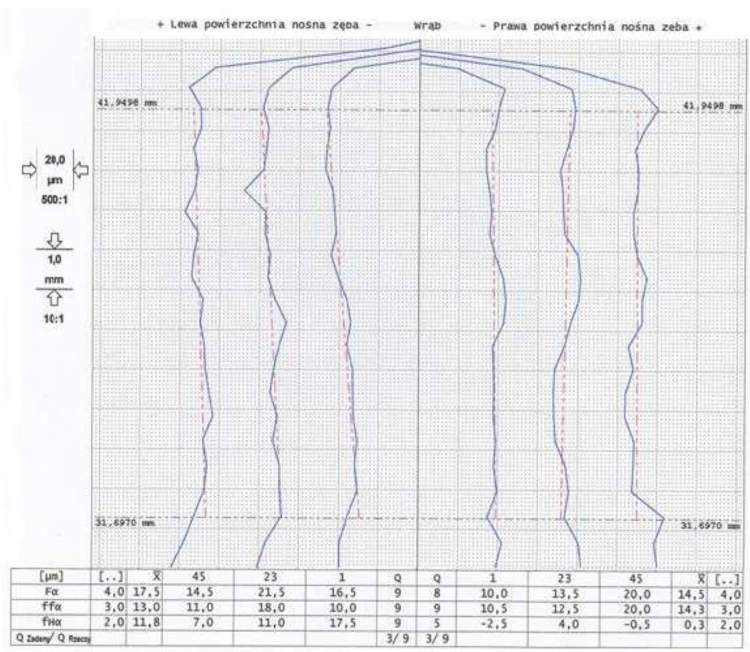
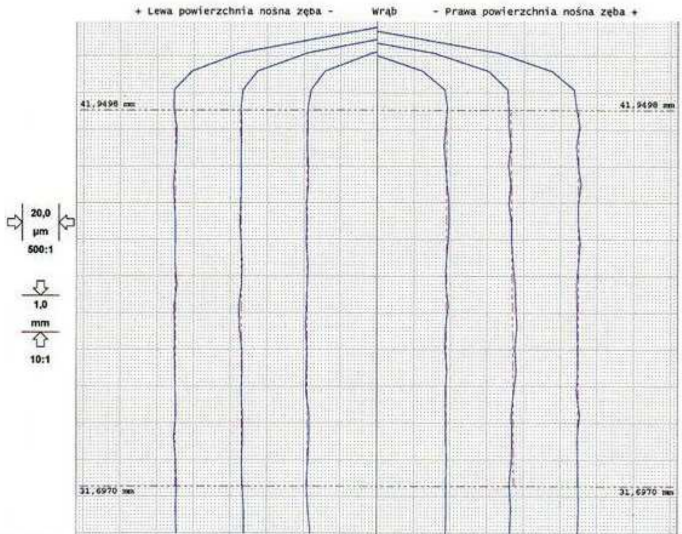
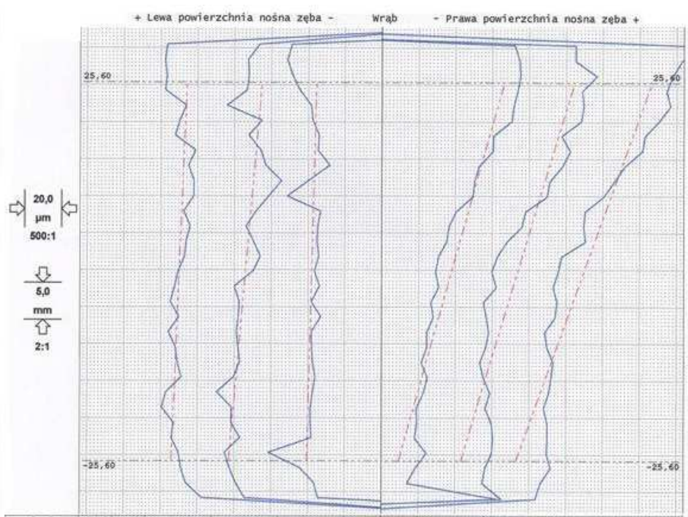


Fig.6. Exemplary sheet with measurement results of the profile deviations: F_α, $f_{H\alpha}$, $f_{f\alpha}$, measured on Rapid 900 grinder, for the LH and RH active flank of three teeth after hobbing operation



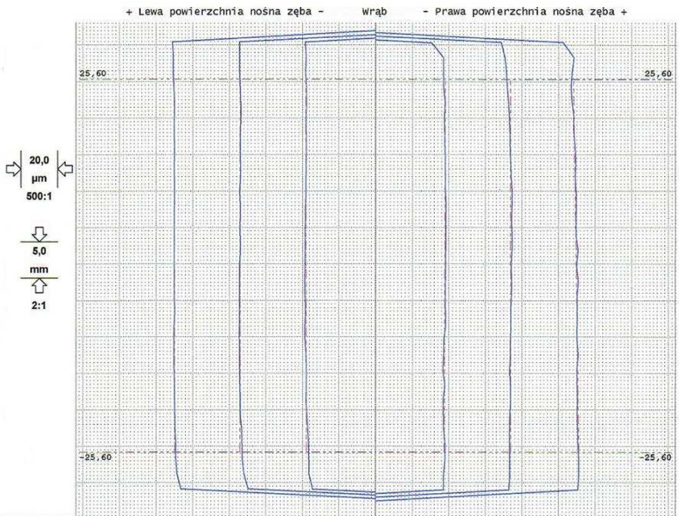
[µm]	[..]	X̄	45	23	1	Q	Q	1	23	45	X̄	[..]
Fα	4,0	2,0	2,0	2,0	2,0	1	4	3,0	4,5	2,5	3,3	4,0
ffα	3,0	2,0	2,0	2,0	2,0	2	5	3,0	5,0	2,5	3,5	3,0
fHα	2,0	0,3	0,0	1,0	0,0	1	2	0,0	-1,5	0,5	-0,3	2,0
Q Zadany/ Q Rzeczy						3/ 2	3/ 5					

Fig.7. Exemplary sheet with measurement results of the profile deviations: F_{α}, $f_{H\alpha}$, $f_{f\alpha}$, measured on Rapid 900 grinder, for the LH and RH side active flank of three teeth after thermo-chemical treatment and grinding operation



[µm]	[..]	X̄	45	23	1	Q	Q	1	23	45	X̄	[..]
Fβ	6,0	28,7	18,0	35,0	33,0	9	11	57,5	63,5	83,0	68,0	6,0
ffβ	5,0	26,8	18,5	33,0	29,0	10	12	68,5	42,5	35,5	48,8	5,0
fHβ	4,0	-10,3	-8,0	-18,0	-5,0	8	12	57,5	61,5	73,5	64,2	4,0
Q Zadany/ Q Rzeczy						3/ 10	3/ 12					

Fig. 8. Exemplary sheet with measurement results of the helix deviations: F_{β}, $f_{H\beta}$, $f_{f\beta}$, measured on Rapid 900 grinder, for the LH and the RH active flank of three teeth after hobbing



[µm]	[..]	X̄	45	23	1	Q	Q	1	23	45	X̄	[..]
Fβ	6,0	2,0	2,0	1,5	2,5	1	2	2,0	2,5	4,5	3,0	6,0
ffβ	5,0	1,7	1,5	1,5	2,0	1	1	1,5	2,5	2,5	2,2	5,0
fHβ	4,0	0,3	0,5	0,0	0,5	1	2	0,5	0,0	-3,0	-0,8	4,0
Q Zadany/ Q Rzeczy						3/ 1	3/ 2					

Fig. 9. Exemplary sheet with measurement results of the helix deviations: F_β, $f_{H\beta}$, $f_{f\beta}$, measured on Rapid 900 grinder, for the LH and the RH active flank of three teeth after thermo-chemical treatment and grinding

For instance, in the Fig. 10 is shown 3D roughness after the hobbing, while in the Fig. 11 after thermo-chemical treatment followed by grinding operation, for the RH active flank of the tooth comprising: topographic map of the surface, distribution of ordinates of surface peaks and areal material ratio curve.

Micro-hardness distribution on depth of the surface layer (WW) for 18CrMo4 steel after hobbing operation and operations of carburization, quenching, tempering and grinding is presented in the Fig. 12. Whereas, WW microstructure of 18CrMo4 steel after hobbing operation is shown in the Fig. 13a and 13b, whilst after carburization quenching, tempering and grinding in the Fig.14a and 14b. Maximal micro-hardness in surface layer (WW) after hobbing operation amounted to $\mathrm{HV}_{0,02} = 263{,}2$ and was located at depth of about 15 μm from real surface WW, and WW thickness didn't exceed 30 μm. Use of thermo-chemical treatment for 18CrMo4 steel, consisting in carburization to depth of about $0{,}8 \pm 0{,}1$ mm, and next quenching to hardness of about 56±2 HRC and tempering to core hardness of 31÷41HRC, have resulted in creation of WW layer having micro-hardness from $\mathrm{HV}_{0,02} = 828{,}7$ to $\mathrm{HV}_{0,02} = 483{,}3$ at depth deeper than 1000 μm. The highest value of the micro-hardness after carburization, tempering and grinding was reported at depth of about 140 μm and amounted to $\mathrm{HV}_{0,02} = 828{,}7$, while the micro-hardness was within range of $\mathrm{HV}_{0,02} = 480 \div 533{,}2$ at depth of the WW layer from 5 to 95 μm.

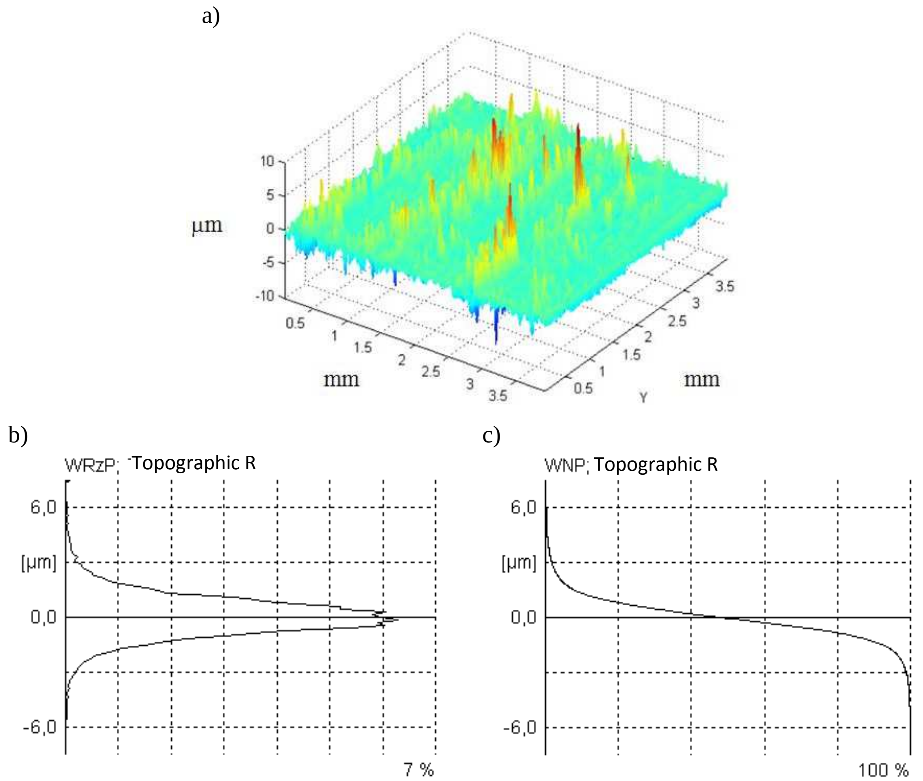


Fig. 10. 3D surface roughness of involute profile, for the RH active flank of the tooth, after the hobbing: $S_a = 0{,}88$ µm, $S_q = 1{,}23$ µm, $S_p = 13{,}53$ µm, $S_v = 10{,}28$ µm, $S_t = 23{,}82$ µm; $S_k = 2{,}37$ µm, $S_{pk} = 0{,}15$ µm, $S_{vk} = 3{,}15$ µm; a) topographic map of the surface, b) distribution of ordinates of surface peaks, c) curve of areal material ratio

Measured values of $HV_{0,02}$ micro-hardness are corresponding very well with the structure observed on cross section of the investigated teeth. The structure observed for the steel after hobbing is typical of 18CrMo4 (1.7243) grade, i.e. irrespective of distance from the surface layer WW it can be seen a ferritic-pearlitic structure, which differs with grain size only (from 5÷95 µm) – what was reflected in measurements of the micro-hardness. In addition, microscopic observations confirm a small deformation of grains near external surface, and a slight defects of the external surface in result of milling operation, what in turn was translated into measured surface roughness.

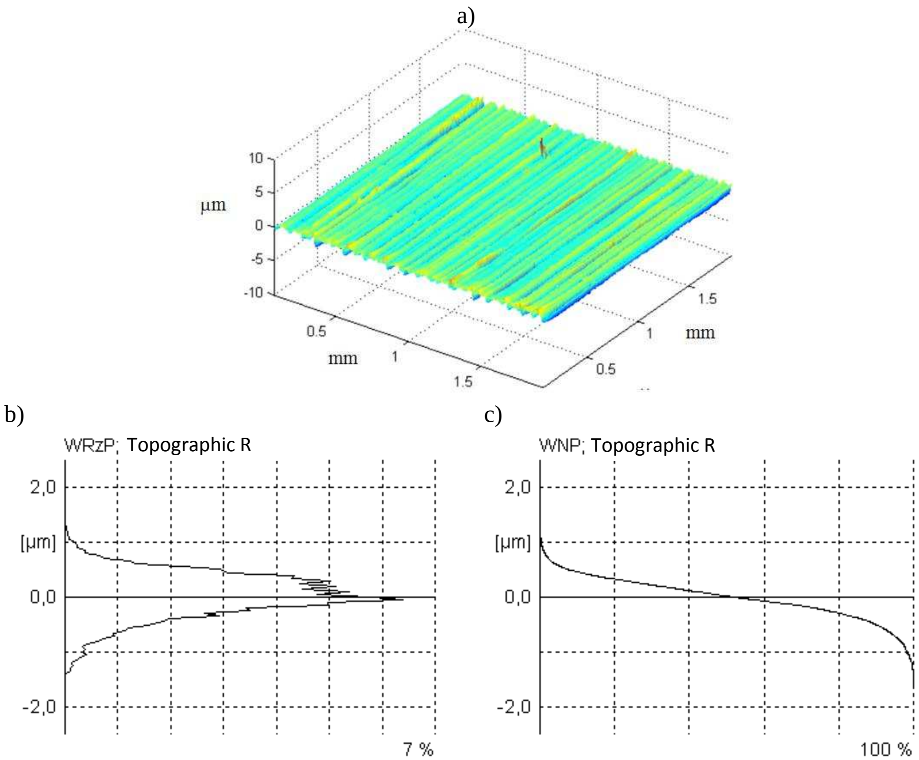


Fig. 11. 3D Surface roughness of involute profile, for the RH active flank of the tooth, after profile dividing grinding: $S_a = 0{,}27$ μm, $S_q = 0{,}35$ μm, $S_p = 1{,}49$ μm, $S_v = 1{,}45$ μm, $S_t = 2{,}94$ μm; $S_k = 1{,}13$ μm, $S_{pk} = 0{,}05$ μm, $S_{vk} = 0{,}74$ μm; a) topographic map of the surface, b) distribution of ordinates of surface peaks, c) curve of areal material ratio

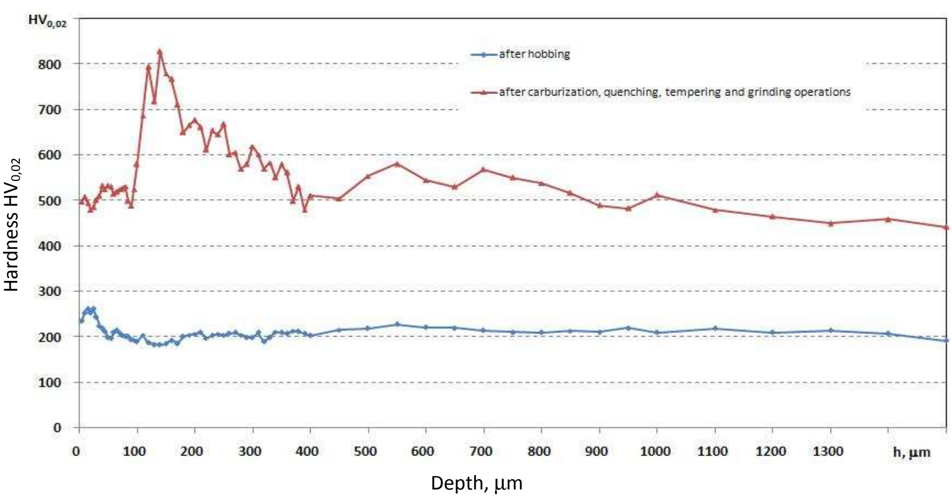


Fig. 12. Distribution of the $HV_{0,02}$ hardness at depth of surface layer „h" of the tooth made of 18CrMo4 steel after hobbing, carburization, quenching, tempering and grinding operations

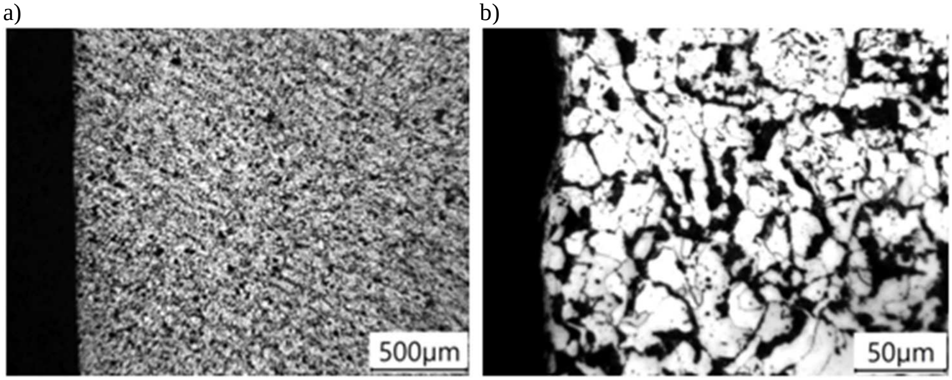


Fig. 13. Microstructure of the tooth seen on cross-section of the tooth after hobbing operation at various magnifications of the microscope, samples etched n 4%HNO_3; a – magn. 500x, b – magn. 50x

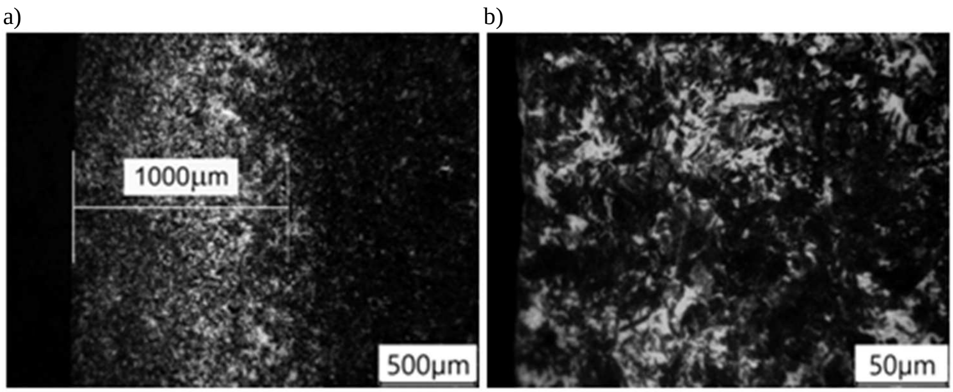


Fig. 14. Microstructure of the tooth seen on cross-section of the tooth after carburization, quenching, tempering and grinding operation at various magnifications of the microscope, samples etched n 4%HNO_3; a – magn. 500x, b – magn. 50x

The microstructure after carburization, quenching, tempering and grinding operations is more diversified. Near the surface layer it can be seen a typical flocky – acicular structure, typical of tempered martensite (with thickness of about 90 µm), which changes into flocky structure as we are drifting away from the surface.

4. Summary

As result of profile dividing grinding operation performed on Rapid 900 grinder of the toothed wheels milled on hobbing machine (machined in the 12th accuracy class), it have been obtained:

- substantial reduction of the value of profile total deviation F_{α}, value of profile angular deviation $f_{H\alpha}$ and value of profile form deviation $f_{f\alpha}$, in result 90% of values of these deviations were included within range of accuracy class from 1 to 5, while only 10% of values of the profile form deviation $f_{f\alpha}$ were within the 6th class of accuracy;
- substantial reduction of the value of total helix deviation F_{β}, value of helix slope deviation $f_{H\beta}$ and value of helix form deviation $f_{f\beta}$, in result all values of the above mentioned deviations were included within interval of accuracy class from 1 to 3;
- decrease, in 80% of the cases, from about 19 to 61 times, of summary deviation of the pitches F_p, in the other 20% of the cases, reduction with about 6 times, in result, values of the deviation F_p in 80% of the cases were included within interval of accuracy class from 1 to 2, whereas others in the 6th accuracy class;
- reduction, from a few to a few dozen times, of deviation of the pitch f_{pt}, as result in 80% of the cases values of this deviation were within interval of accuracy class from 1 to 5, (unfortunately 20% of value of the deviation f_{pt} were included in the class 9);
- reduction of surface roughness depicted by the parameter S_a from about 2,0 to about 3,4 times, by the parameter S_q from 2,1 to 3,6 times, by the parameter S_p from more than 3,6 to about 9,1 times, by parameter S_v from 3,4 to about 7,1 times, by parameter S_t from about 3,5 to 8,1 times, by parameter S_k from 1,04 to 2,10 times, by parameter S_{pk} from 1,60 to 3,75 times, whilst by parameter S_{vk} from 1,97 to 6,56 times.

Use of thermo-chemical treatment, consisting in carburization, quenching and tempering, for the gears made of 18CrMo4 steel has resulted in more than threefold increase of micro-hardness and creation of surface layer WW with micro-hardness from $HV_{0,02} = 828{,}7$ to $HV_{0,02} = 480$ and depth more than 1000 µm.

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