ANALYSIS OF THE ANGULARITY OF THE SURFACE IN THE AXIAL SECTION OF THE WORM WHEEL OBTAINED BY COMPUTER SIMULATION OF MACHINING

Analiza graniastości powierzchni w przekroju osiowym ślimacznicy uzyskanej metodą komputerowej symulacji obróbki

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A b s t r a c t: Obtaining an accurate worm wheel requires a wheel model with the appropriate accuracy. This model can be obtained by computation, however, this is a complex and labor-intensive issue. In the CAD environment, there is a possibility of simple and quick modeling of the dentition, which is an alternative to mathematical calculations. It consists in creating micro surfaces and their approximation. The paper presents a comparative analysis of two methods of approximation of a discrete surface and the influence of modeling accuracy on the deviation of the profile of a wormwheel tooth was determined. It has been shown that the use of 30 surfaces allows to obtain the required accuracy of the outline.
K e y w o r d s: worm wheel, machining, CAD/CAM

S t r e s z c z e n i e: Uzyskanie dokładnej ślimacznicy wymaga modelu koła o odpowiedniej dokładności. Model ten można uzyskać na drodze obliczeń. Jest to jednak zagadnienie złożone i pracochłonne. W środowisku CAD istnieje jednakże możliwość prostego i szybkiego zamodelowania uzębienia stanowiąca alternatywę do przeprowadzania obliczeń matematycznych. Polega ona na utworzeniu mikropowierzchni oraz ich aproksymacji. W pracy dokonano analizy porównawczej dwóch metod aproksymacji powierzchni dyskretnej oraz określano wpływu dokładności modelowania na odchyłkę zarysu zęba ślimacznicy. Wykazano, że zastosowanie 30 powierzchni umożlia uzyskanie wymaganej dokładności zarysu.
S ł o w a k l u c z o w e: koło ślimakowe, obróbka, CAD/CAM

Introduction

Obtaining the correct geometry of the worm gear wheels and the correct trace of their contact is a difficult process. The methods of obtaining the correct geometry of the screw have been described, inter alia, in articles [2, 7, 8, 12]. In the case of a worm wheel, usually in industrial practice only a simplified outline is obtained. Unfortunately, this has negative consequences for the proper cooperation and durability of the gear. In order to obtain the correct contact pattern of the gears, give the gears to the wheel lapping process. However, it should be remembered that this process has its limitations and disadvantages. These limitations are especially important when we want to use a worm wheel that would be able to withstand a greater load with less susceptibility to wear. In such cases, it would be advisable to obtain a more accurate worm wheel.

For a more accurate worm wheel, a sufficiently accurate wheel model is required. This model can be obtained by calculations resulting from the kinematics of the gear operation. For such calculations, we try to determine the correct geometry based on the required contact trace. The principle of operation of this type of methods and their possible application to the analysis of the operation and strength of the transmission are presented in articles [4, 5, 6].

An alternative to mathematical calculations may be the appropriate adaptation of the machining simulation method to create a worm wheel model [11]. On its basis, the created micro-surfaces are approximated. The smoothing process is necessary to obtain a better surface quality. However, the literature on the subject does not state the accuracy of this method. Therefore, the aim of the article is to determine the influence of modeling accuracy on the deviation of the contour of a worm wheel tooth.

Materials and methods

The machining simulation method is based on simulating the contact of the tool with the workpiece. When cutting the worm wheel, the worm becomes a tool. The model of the worm wheel shell was adopted as the workpiece. The method requires the determination of the kinematics of cooperation. For the considered

Table 1. Systems defining kinematics on the work of the worm gear and worm wheel

Case No.	Type of worm movement	Type of worm wheel movement
1	Rotation	Rotation
2	Translation	Translation
3	Rotation	Translation
4	Translation	Rotation
5	Translation and rotation	No movement
6	No movement	Translation and rotation

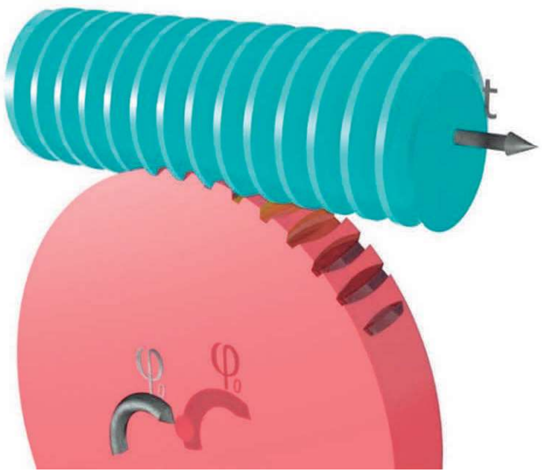

Fig. 1. Scheme of the system adopted for simulation (variant 4 from Tab. 1)

transmission, 6 systems defining the kinematics are available (Tab. 1).

System No. 1 is usually the first choice as direct transmission adaptation. Unfortunately, due the way CAD software works, does not always give the best results [9, 10]. The principle of operation of this method according to the layout No. 4 is shown in Fig. 1.

The practical application of the method is based on the execution of a task loop which consists of:

- snail translation,
- rotation of the worm wheel,
- performing the "pain" algebra operation (difference: we subtract the snail from the envelope; the snail remains available).

These operations are repeated until the entire interdental notch is obtained. In order to automate this process, Visual Basic Language [1, 3] was used in the CAD software.

It is important for the process that the result is a set of micro surfaces, not a single surface. This means that in the axial plane and other planes perpendicular to the axis of the worm wheel, we will not obtain the curve forming the outline directly. We only get a certain number of episodes. The necessity to approximate these elements causes the contour mapping error. Therefore, in the further part of the work, the focus was on determining the inaccuracy of the method for the adopted simulation parameters.

The choice of the approximation method

There are few studies in the literature on the influence of the approximation method on the accuracy of the worm wheel modeling [9, 10, 11]. For this reason, it was decided to test two simple-to-implement methods of discrete surface approximation for the selected simulation step. Fig. 2 shows a comparison of both methods. One of the methods (Fig. 2) is based on drawing the curve (red line) through the points of intersection of the surface edge with the axial plane. The second method is to draw a curve (green line) through the centers of the segments built at the edges of the intersection of the surfaces. Other methods can also be used, however, this involves a significant complexity of the process. As shown later in the article, the accuracy of the results obtained with the chosen method seems to be sufficient for the considered element.

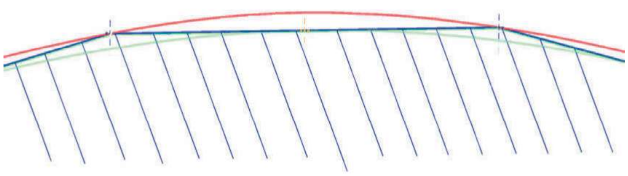

Fig. 2. Comparison of discrete surface approximation methods

Table 2. Parameters adopted for the simulatio

No. simulation	Rotation angle (°)	Offset value (mm)	Number of simulation steps	Number of surfaces obtained
1	6	6.283185307	6	6
2	4	4.188790205	8	8
3	3	3.141592654	11	11
4	2.4	2.513274123	14	14
5	2.142857143	2.243994753	15	15
6	2	2.094395102	16	16
7	1.875	1.963495408	17	17
8	1.5	1.570796327	20	20
9	1.25	1.308996939	25	26
10	1	1.047197551	30	32
11	0.5	0.523598776	59	64

The values of the deviations determined for individual methods were shown in Tab. 3. The comparison of these methods shows that the absolute value of the deviation is very similar. Unfortunately, the first method is not suitable for further analyzes because, due to the direction of the deviation, it may lead to incorrect contact of the gears and the effect of the system jamming. Tab. 2 presents the parameters adopted for the simulation.

The simulation No. 5 was deliberately carried out with an irrational angle of rotation and displacement in order to check how important the error resulting from the lower accuracy of the program regarding the angular dimensions would be for the size of the tooth deviation.

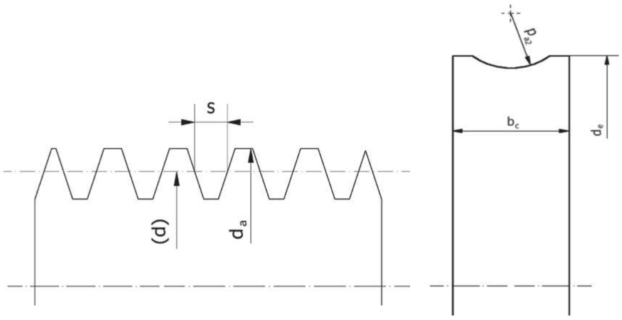

Fig. 3. Modified dimensions of the worm wheel

Purification before brazing process

The produced and checked resonator, being positively admitted to further assembling, obtains its individual number with the assigned table of mechanical size measurements. A positive reaching of all expected parameters allows chemical preparing of the structure's elements to the process of their mechanical and permanent joining by brazing. Purity of the materials before soldering of the cavities is very important [2, 3]. Dirt and the oxides, generated during the treatment have a negative effect on electric conductivity and decrease the wettability of the solder. The cavities are washed in ultrasonic scrubber in the mixture of petrol and acetone and then, they are rinsed with distilled water. After the mentioned treatment, they are subjected to the electro-polishing. The completion of purification process puts extremely difficult requirements concerning hygiene regime before the operators, implementing the successive stage of the structure production.

Modification of the worm and worm wheel

When creating a worm wheel, the problems resulting from the modeling techniques used, and problems with a different treatment method than usual should also be taken into account. Fig. 3 shows the dimensions of the model that have been intentionally modified to prevent certain phenomena.

Fig. 3. Modified dimensions of the worm wheel.

Two modifications were made on the cochlea. Both were related to the necessity to take into account the lateral clearance values. In the case of, for example, all-round technology, the lateral play is an automatically generated element. This is due to the behavior of the tool and shell during machining. However, when using the machining simulation method, a discrete surface is obtained that does not take into account the clearance value. It follows from this that it is necessary to introduce the value of the slack on the component (worm) which is the tool cutting the worm wheel in order to obtain the discrete surface transformed by the value of the slack in the appropriate direction. That is why the outer diameter of the worm d_a was increased and the thickness of the tooth s in the axial section was reduced by the value of the lateral play.

Three elements were modified in the worm wheel. The outer diameter d_e is increased, the concavity radius p_{a2} is decreased, and the worm wheel width b_c is increased. These modifications were necessary due to the use of a "spline" curve as an element approximating a discrete surface. The introduction of these modifications made it possible to generate additional points that allow to determine the tangency of the curve for the end points. This allowed for a smaller deviation of the profile of the worm wheel tooth.

Results and discussion

Conducted simulations and analyzes allowed to assess the impact of modeling accuracy on the deviation of the worm wheel tooth profile (rys. 4, 5). Table 3 presents the most important input data for individual simulations and information on the number of surfaces under consideration. All simulations were performed for the same kinematic system. The variable element was the number of simulation steps. Note that the number of surfaces forming the contour of a worm wheel tooth is not always the same as the number of simulation steps. The inaccuracy regarding the ratio of the number of points measured to the number of surfaces forming the side of the tooth of the generated worm wheel results from the type of envelope adopted and the measurements limited to the axial plane. Not all of the generated surfaces are necessary for axial measurements. However, their number is important if we would like to conduct further research.

Table 3 shows examples of the deviation values along the tooth height obtained by simulating the surfaces 6, 8 and 11. The deviation values given in the table are absolute values. Relationship (1) allows you to relate the value of the deviation in relation to the axis of the screw.

$$d_{zi} = \frac{a - r_{ki}}{2} \qquad (1)$$

Fig. 3. Deviation values

6 surfaces			8 surfaces			11 surfaces		
No.	Deviation value (µm)	Worm diameter (mm)	No.	Deviation value (µm)	Worm diameter (mm)	No.	Deviation value (µm)	Worm diameter (mm)
1	8.292887	115.0733617	1	3.948354	114.6690336	1	1.739283	114.4846455
2	26.062451	117.9739879	2	9.18649	116.3489535	2	4.82334	115.6477044
3	30.599552	121.9579928	3	10.836457	118.5296151	3	5.055735	117.0974698
4	22.075501	126.9223807	4	12.94157	121.1839893	4	6.611305	118.823448
			5	17.690217	124.2817277	5	7.262665	120.8138014
			6	5.478508	127.7905919	6	8.57126	123.0557023
						7	9.089895	125.5356745

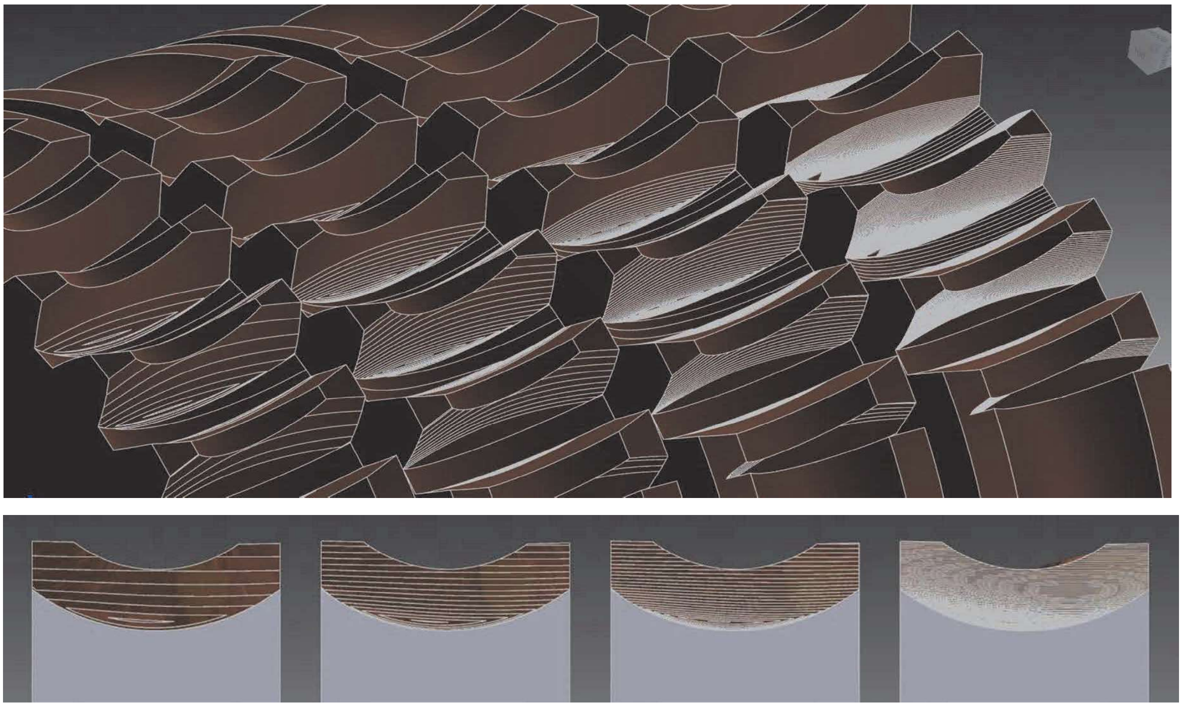

Fig. 4. Surfaces obtained as a result of the simulation

where:

d_{zi} – the conversion value of the diameter in relation to the worm axis (mm),

a – gear axis distance (mm),

r_{ki} – value of the radius of the worm wheel on which the measurement was made (mm).

Based on the simulation, the influence of the number of surfaces on the outline deviation was determined (Fig. 6). The analysis of Fig. 4 shows that the use of 30 surfaces makes it possible to obtain the required accuracy of the outline. Further increasing the amount of space seems to be pointless, as it does not contribute to a significant improvement in the accuracy of the simulation with a significant increase in its labor consumption.

Fig. 6. The influence of the number of surfaces on the deviation of the outline (in the axial section).

The maximum value of the deviation depending on the number of surfaces, disregarding the results of simulation No. 5 conducted with an irrational angle of rotation and shift, can be determined on the basis of the relationship (2):

$$y = 1205.3x^{-2.025} \qquad (2)$$

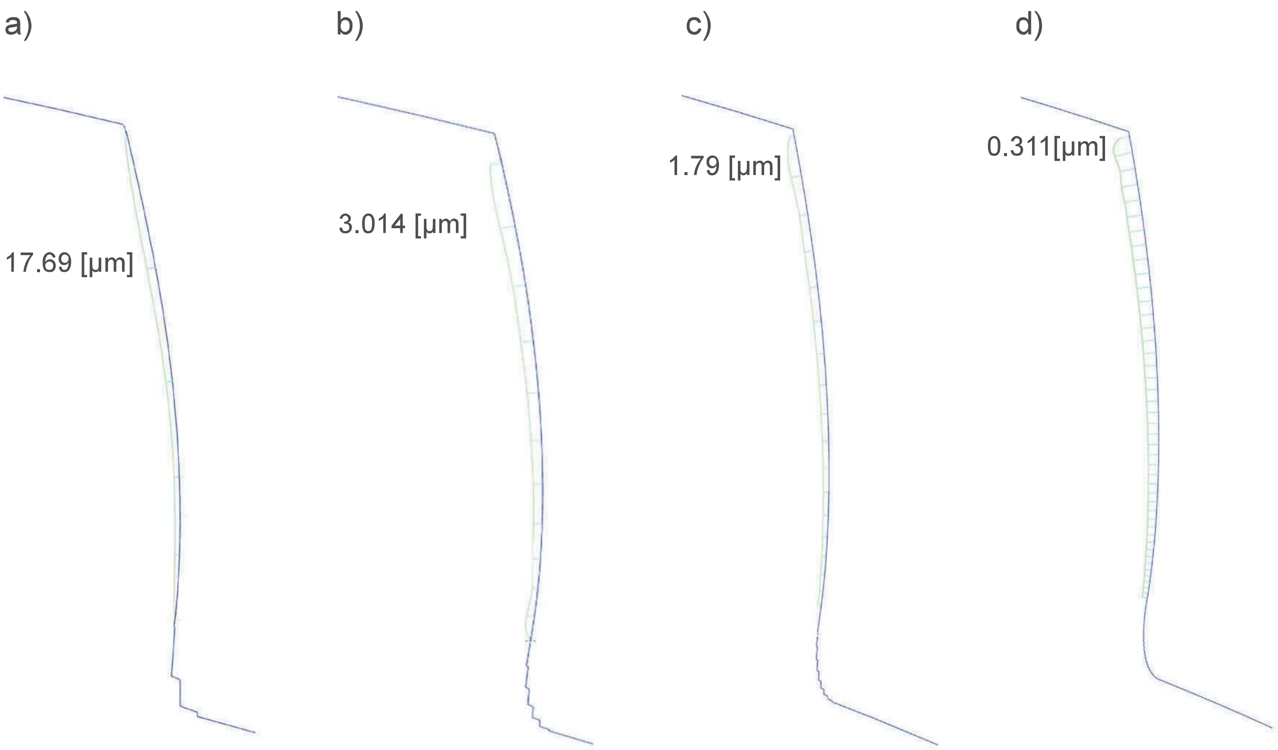

Fig. 5. Distribution of deviations for selected simulations and the maximum values for: a) 8 surfaces. b) 17 surfaces. c) 26 surfaces. d) 59 surfaces

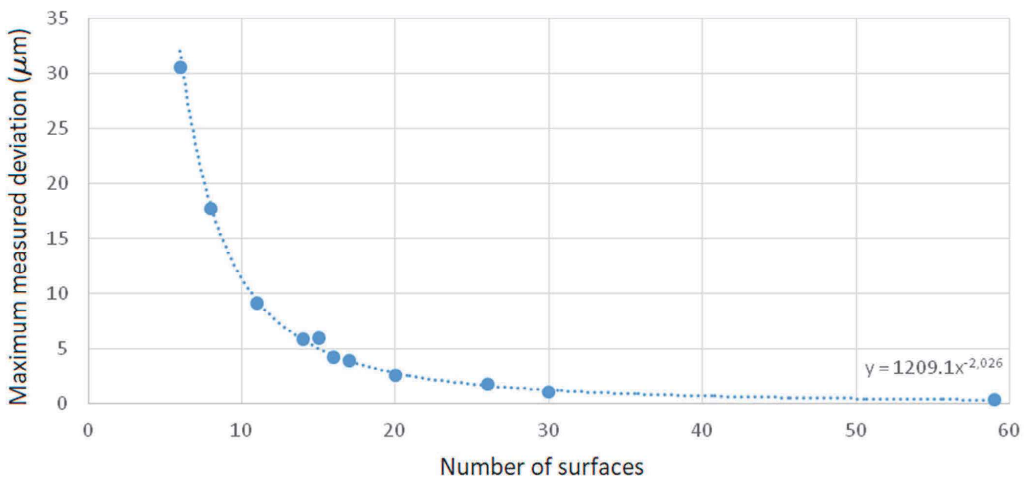

Fig. 6. The influence of the number of surfaces on the deviation of the outline (in the axial section)

while taking into account the results of simulation No. 5 based on the dependence (3):

$$y = 1209.1x^{-2.026} \quad (3)$$

This allows for the exact selection of the number of surfaces depending on the required accuracy of the outline.

Conclusions

Modern CAD/CAM software provides new possibilities both at the stage of design and technology of gear teeth machining. Development of the worm gear teeth model directly in the CAD environment is not an easy task. This is due to the fact that the tooth contour is different in each cross-section.

Creating a worm wheel by simulating machining allows to obtain a virtual model of the worm wheel. This can be useful for e.g. examining the gear contact pattern, or it can be used as a template for CAM programs using manufacturing techniques other than envelope machining. In addition, the method allows you to generate a worm wheel model for any contour without the need to produce a cutter with a special contour. Thanks to the machining simulation method, it is possible to obtain a virtual model of the worm wheel with an accuracy sufficient for simulation errors to have a negligible impact on the part being made.

The simulations carried out in the work allowed to assess the influence of the modeling accuracy on the deviation of the worm wheel tooth profile. On their basis, it has been shown that to obtain the required accuracy of the outline, it is necessary to generate about 30 surfaces forming the outline of a worm wheel tooth. The use of a larger surface area does not significantly affect the accuracy of the contour of the worm wheel.

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