Proceedings in Manufacturing Systems

Proceedings in Manufacturing Systems, Vol. 5 (2010), No. 1 ISSN 2067-9238

GENERATION OF THE WORM HELICAL SURFACE

Tadeusz NIESZPOREK[1], **Kazimierz ŁYCZKO**[2]

Abstract: *The helical surface of a worm is most often formed using a rotary tool with the rectilinear axial profile of the tool action surface. It is very rarely machined with a tool of a circular or other profile. The worm surface is machined with a finger-type, disc-type, cup-type, or ring-type tool over the whole profile height. The form of machined surface is determined not only by the geometrical parameters and profile of the tool, but also by the tool type. The increasingly wide use of modern CNC machine tools and CAD/CAM type software applications enable also the development of technologies for machining helical surfaces. By the Lace Cut method using a finger-type spherical cutter, helical surfaces of any profile can be formed.*

Key words: *worm, helical surface, modelling, hobbing machining.*

1. INTRODUCTION

The helical surfaces of worms are generally formed by the hobbing method using rotary tools (shape machining by turning is increasingly rarely used) [2, 3, 4, 8, 9, 11, and 13]. The finger-type, disc-type or cup-type tool (a cutter or grinding wheel) forms the helical surface of a worm over the whole profile height. Generation of a worm helical surface for any type of grinding wheel is generally treated as a separate design task. Aside from the geometrical parameters and profile of the tool, also the tool type determines the profile of a surface being machined [9]. The structure of a universal program allows the selection of a tool, its geometrical parameters, and its settings for machining a set helical surface.

Modern CNC machine tools enable the development of worm gear technologies and the formation of worm surfaces with a spherical finger-type cutter in many passes by the Lace Cut method. This allows the formation of a helical surface of any profile using a tool, whose profile is not coupled (mutually enveloped), with the profile of the surface being machined [17]. This method of forming cylindrical worms of any profile should also enable the development of technology for variable-pitch cone worms machined with a conical or cylindrical finger-type cutter [15, 16].

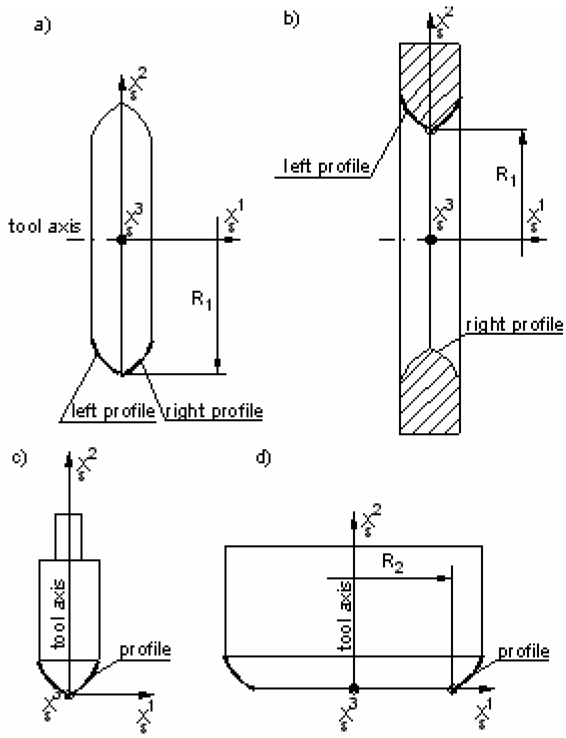

Fig. 1. Tool type: *a* – disc; *b* – ring; *c* – finger; *d* – cup.

2. GENERATION OF A HELICAL SURFACE

The equation of the tool action surface axial profile has been set by the coordinates of points and the slopes of the tangents at these points [13]. Most often, this profile is rectilinear and circular or other profiles are much more rarely used [1]. Thus, the general equation of the tool action surface (Fig. 1), as obtained by rotating of the profile around its axis of rotation, is as follows:

$$\bar{x}_s = \bar{x}_s(u, \quad \varphi) \tag{1}$$

where: u – tool action surface axial profile parameter, φ – tool action surface parameter..

After considering the tool positioning in the worm system (Fig. 2) and the relative helical motion of the tool and the machined surface, the equation of the family of tool action surfaces in the worm system is a function of three parameters [4, 9, 13]:

$$\bar{x} = \bar{x}(u, \quad \varphi, \quad \nu) \tag{2}$$

where: ν – tool action surface family parameter.

[1] Prof., PhD, Eng, *E-mail: tadek@itm.pcz.czest.pl*l

[2] Dr, PhD, Eng., *E-mail: kazimierzlyczko@op.pl*

Częstochowa University of Technology,
Al. Armii Krajowej 21, 42-200 Częstochowa, Poland
Tel. +48 34 3250 509

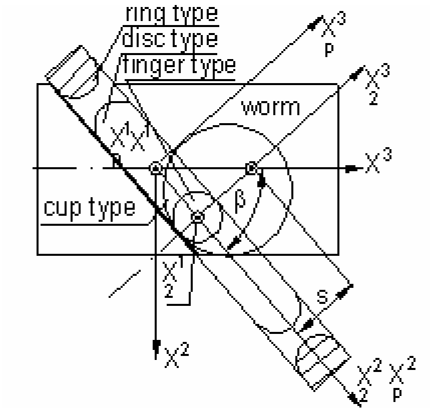

Fig. 2. Tool positioning relative to the worm.

In order to obtain the equation of the worm helical surface, the envelope condition must to be added to equation (2), which can be written in the form of the triple product of three vectors

$$f = \overline{\mathbf{x}}_u \, \overline{\mathbf{x}}_\varphi \, \overline{\mathbf{x}}_v = \overline{\mathbf{x}}(u, \quad \varphi) = 0 \tag{3}$$

and which in this case is a function of two parameters [4, 11, and 13].

Tools with a rectilinear action surface axial surface are used for forming cone-derivative helical surfaces, while torus-derivative helical surfaces are formed using tools with a circular profile. The shape of worm and wormwheel teeth influences the course and length of the contact line [11] and also determines its position relative to the slip velocity, which has an effect on the conditions of lubrication in the tooth contact region. In some cases the contact between worm and wormwheel teeth can be punctual [9, 10, and 13]. So, this means that the tooth shape has an influence on the efficiency of the gear, and also determines the effective radius of curvature and the magnitude of contact stress [12]. Torus-derivative worm gears (Convex-Concave; C-C; CAVEX; HOLROYD) with a concave worm convolution profile are able to transfer larger loads and have higher efficiency.

The wormwheel is machined by either the tangential or radial hobbing method. The tool action surface and the wormwheel form a technological worm gear in the machining process (Fig. 3) [7 and 8]. The hob for machining of a wormwheel should therefore have an action surface the same as the surface of the design worm which is to operate with that wormwheel in the worm gear. Hobs used for machining wormwheels are thus geometrically complex and technologically difficult to execute, especially in the case of curvilinear profiles.

Fig. 3. A wormwheel-hob technological gear.

Therefore, wormwheel are also cut with cutters by the tangential method, which is less efficient machining. Due to technological difficulties [5, 6, and 12], only few companies manufacture CAVEX type worm gears.

In the classical method of forming worm or wormwheel toothing, the wheel tooth surfaces and the tool action surface are mutually enveloping surfaces.

3. HELICAL SURFACE MACHINING WITH A SPHERICAL FINGER-TYPE CUTTER

The development of modern multi-axial multitask CNC machine tools creates new opportunities also for developing worm and wormwheel designs and technologies. For instance, variable-pitch conical worms can be machined not only on a special CNC milling machine, but also on a universal multitask CNC machine or on a turning lathe with rotary tools [15, 16]. The Lace Cut machining method, often used for machining by milling of geometrically complex forms with a spherical finger-type cutter, can also be used for the machining of the helical surfaces of worms and wormwheels [17]. In this technology, the tool is a small-diameter spherical finger-type cutter which is positioned in the worm axial plane perpendicularly to the axis of the worm in a defined position (Fig. 4).

In this technology, the tool action surface and the worm toothing surface are mutually enveloping, so they are not coupled, that is they are independent. Therefore, a universal tool is used in this case, which can be used for forming a helical surface of any profile. Solid full-carbide cutters are most often used which allow high machining parameters to be used and are high-performance tools. Finger-type spherical-end cutters are manufactured as cylindrical and conical with diameters generally up to 20 mm, and there are companies that specialize in the production of these particular milling cutters. Assuming a given number of cutter positions over the worm axial profile, the parameters r_o and f_o (Fig. 4) of the initial tool tip position are determined in the machined helical surface system from the hobbing condition (Fig. 5).

The ultimate number of cutter positions, or the number of tool passes necessary for the formation of the convolution surface can be selected from the condition of the specified profile angularity, or the condition of specified machining accuracy (Fig. 6), and generally is a trade-off between the machining time and the profile accuracy to be obtained.

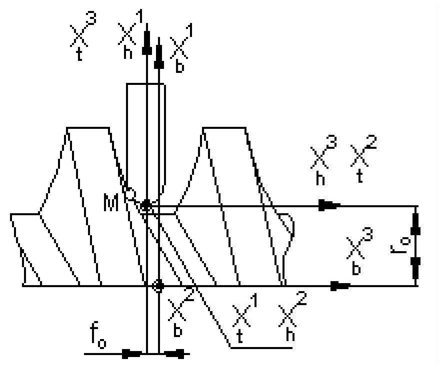

Fig. 4. Cutter positioning relative to the worm.

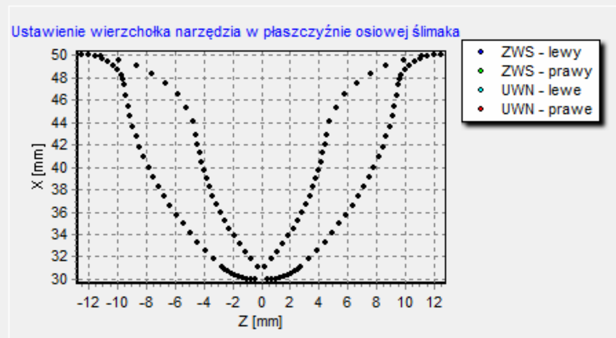

Fig. 5. Tool tip positioning and the worm axial profile.

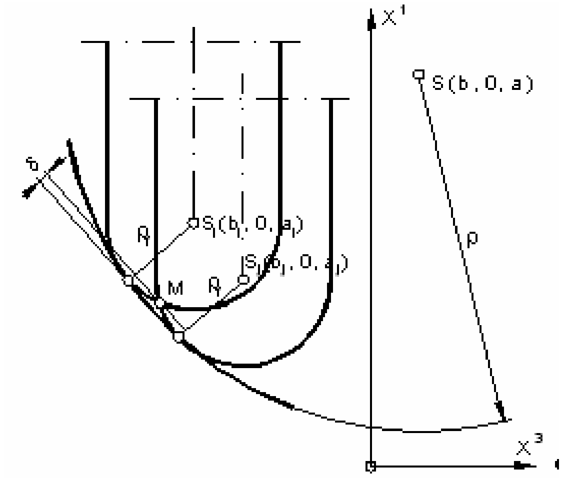

Fig. 6. Schematic diagram for the determination of worm circular profile angularity.

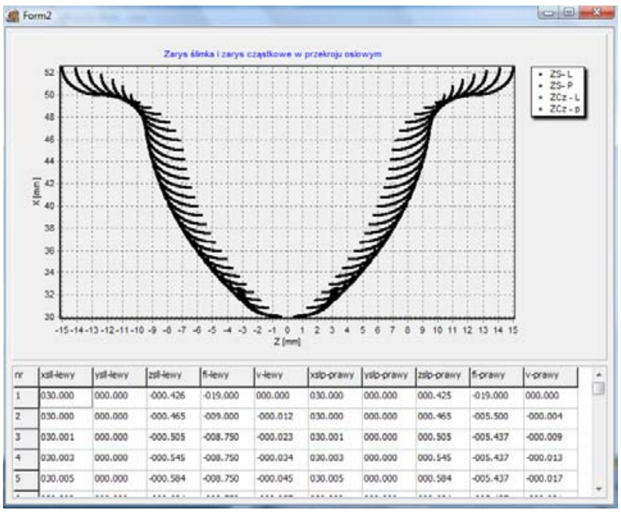

Fig. 7. Axial profile of partial helical surfaces.

The helical surface of a worm is the envelope of partial helical surfaces obtained after each tool pass (Fig. 7). For pre-cutting of the worm cut, larger-diameter cutters can be used, taking into account the cut depth, provided that the other cut flank between the convolutions is not undercut. A different (as a rule smaller) number of passes should be adopted for forming transition profiles than for the worm profile proper. For the formation of the upper transition profile, a cutter with a larger sphere radius (e.g. $1.0m_0$ – Fig. 8) can be used, which enables the pre-

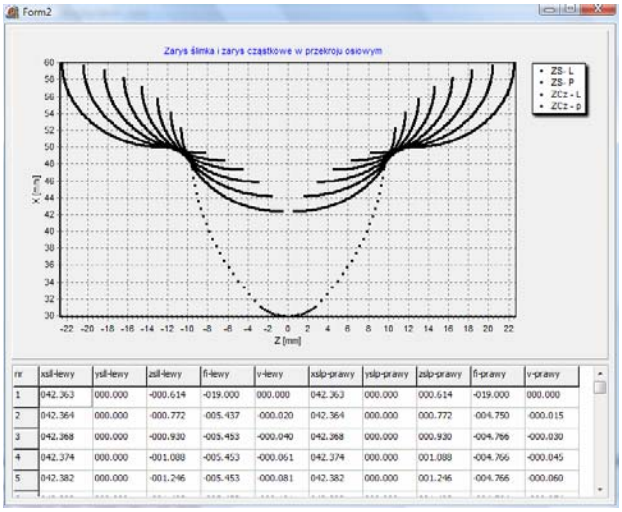

Fig. 8. Axial profiles of partial helical surfaces after machining with a cutter of a sphere radius of $\rho_f = m_o$.

cutting of the cut and reduction of machining allowance remaining for further machining. In turn, for the machining of the lower transition curve, a cutter with a sphere radius smaller than the transition profile radius (e.g. $0.25m_0$) should be adopted. Such a division of machining and cutter selection causes the whole cut to be cut out during machining of the left-hand and right-hand worm cut profile sides alternately at the same level (Fig. 8 illustrates only “halves” of the machining traces on the machined surface side).

It is practically not possible to machine a worm over the whole height of its profile with a cutter of a radius larger that the transition radius at the convolution bottom and it is for this reason that the definition of the tool setting limits is essential (this particularly being true for machining on CNC machine tools). The use should therefore be made of the possibility of placing several cutters in the CNC machine-tool toolbox, whose replacement takes only a few seconds.

Machining can be programmed in the EIA/ISC code using standard G functions for screw cutting. Cutter setting parameters can be entered to the machine tool’s control system in the form of a data file. A cutter positioning perpendicular to the machined worm axis is assumed. Therefore, the finishing machining allowance should be small. Any cutter positioning approximately perpendicular to the surface being machined is rather not possible due to the limited cutter length and the possibility of a collision occurring between the spindle and the machined worm; and, besides, this angle should change for successive cutter positions. Of course, this is theoretically possible and consists in the turning of the tool spindle around the centre of the cutter spherical end in the worm axial plane, and the machining simulation allows the collision to be eliminated at the stage of worm machining designing and programming. Machine setup can be conveniently checked by the CNC panel. Additionally, the unique Mazatrol function makes it possible to simulate the machining of a new program during the machining of the current workpieces [16].

4. CONCLUSIONS

For the case of the traditional technology it was assumed that the left-hand and right-hand sides of the worm cut could be machined separately with two tools (having different profiles and being differently positioned), and that any tool (disc, finger, ring, or cup) type could be used. The mathematical model and the computation program developed on this basis are generic and universal in character. Worm convolution and worm-wheel tooth surfaces are generated within one program for different technologies and arbitrary tool profiles. This enables different worm gear machining technologies to be compared and the selection of the best solution for given conditions to be made.

The development of the technology of worm helical surface forming with a spherical finger-type cutter enables a helical surface of an arbitrary profile to be machined on a CNC machine tool (e.g. on a turning lathe with rotary tools) and the further development of the design and technology of worm gear drives. The accuracy of machining is determined by the cutter diameter and the number of passes adopted for the formation of a worm convolution over the whole profile height. It was assumed that the transition profile of the convolution on its top would be machined with a cutter of a larger diameter and with a smaller number of passes. The lower transition profile of the convolution into the cut bottom is machined with a cutter of a diameter correspondingly smaller than the radius of the profile cut bottom rounding and with a small number of passes. The cutter diameter and the number of passes for convolution profile machining are selected based on the assumed profile angularity condition and the condition of machining the profile over its whole height. Thus, the convolution profile and transition curves on the top and at the bottom of the convolution are formed in this case by the hobbing method. The helical surface of the convolution is formed as the envelope of partial helical surfaces being cut in successive passes of the spherical finger-type hob. A spherical finger-type hob should also be used for machining worm-wheel teeth, as in the case of curvilinear profiles special hobs are technologically difficult to execute and are very expensive.

Helical surfaces of an arbitrary profile, that is not only cone-derivative and torus-derivative, but also ruled and other surfaces, can be machined by this technology.

The machining of worms according to this technology should be conducted on CNC machine tools with rotary tools, or on multitask CNC machine tools which enable many tool settings to be programmed with high accuracy.

REFERENCES

[1] M.W. Balul, *Obrabiarki do skrawania metali* (Machine tools for metal cutting), WNT, Warszawa, 1974.

[2] V. Boca, Cs. Gyenge, O.M. Gurzau, L. Olah, *Research regarding analitycal and numerical determination of worm gear with parabaolical profile*, C. Gyenge (Ed.), pp. 13–16, Cluj-Napoca, October 2009, MTeM 2009, Cluj-Napoca.

[3] M. Borzan, L. Hancu, H. Iancau, *Study of the ZK4 worm grinding process,* C. Gyenge (Ed.), pp. 71–72, Cluj-Napoca, October 2007, MTeM 2007, Cluj-Napoca.

[4] I. Dudas, *The theory and practice of worm gear drives*, Penton Press, London, 2000.

[5] L. Dudas, I. Dudas, *Analysing surface undercuts of ZTA type worm gearings*, pp. 29–35, Academic Journal of Manufacturing Engineering, Vol. 6, ISSSUE 4/2008.

[6] I. Dudas, *Complex analysis of the features of production geometry and developing of hobs of up-to-date worm gearing*, C. Gyenge (Ed.), pp. 81–86, Cluj-Napoca, October 2009, MTeM 2009, Cluj-Napoca.

[7] Cs. Gyenge, B. Barisic, V. Boca, *Mathematical model for virtual technological system used at high quality worm driver manufacturing*, C. Gyenge (Ed.), pp. 179–182, Cluj-Napoca, October 2007, MTeM 2007, Cluj-Napoca.

[8] C. Gyenge, V. Boca, A. Mureşan, *Some technological aspects of high precision worm-gear manufacturing*, pp. 154–159, Academic Journal of Manufacturing Engineering Supplement, ISSSUE 1/2008.

[9] R. Gołębski, *Analiza geometryczna przekładni ślimakowej walcowej* (Orthogonal worm-gear drive geometrical analysis), Politechnika Częstochowska, Częstochowa, 2006.

[10] F.L. Litvin, *development of gear technology and theory of gearing*, NASA Reference Publication 1406.

[11] T. Marciniak, *Przekładnie ślimakowe walcowe* (Orthogonal worm-gear drives), PWN, Warszawa, 2001.

[12] T. Marciniak, *Obciążalność zazębienia przekładni ślimakowych* (Load capacity of meshing in worm gear transmission), Politechnika Łódzka, ZN Nr. 934, Łódź 2004.

[13] T. Nieszporek, *Podstawy konstrukcji narzędzi skrawających do obróbki walcowych uzębień zewnętrznych* (Principles of the design of cutting tools for orthogonal external toothing machining), Politechnika Częstochowska, Częstochowa, 2004.

[14] T. Nieszporek, P. Boral, *The analysis of the meshing of worm and worm gear surfaces*, MTeM 2007, C. Gyenge (Ed.), pp. 315–318, October 2007, Cluj-Napoca, Romania.

[15] T. Nieszporek, *Manufacturing of variable-pitch cone worms*, Academic Journal of Manufacturing Engineering, Vol. 7, Isssue 1/2009, pp. 68–73.

[16] T. Nieszporek, T. Szczepanik, W. Szymański, *Manufacturing of variable-pitch cone worms on an universal cnc machine tool*, Academic Journal of Manufacturing Engineering Supplement, Isssue 2/2008, pp. 95–101.

[17] J. Wojciechowski, *Metody programowania obróbki powierzchni śrubowych o zmiennym skoku* (Programming methods of variable pitch helical surfaces machining on multi-axis machine tools), Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa, 2001.