International Journal of Modern Manufacturing Technologies
ISSN 2067–3604, Vol. VII, No. 2 / 2015

ASPECTS OF LOCALIZATION OF CONTACT AT THE MANUFACTURING OF WORM GEARS

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Abstract: Paper includes description of graphic method used in worm gear designing. Simulation of manufacturing process to determine and modify worm and worm gear profiles to assurenecessary contact pattern. Method is used to anticipate contact pattern and necessary adjustments during manufacturing process.Other authors propose mathematic methods to determine worm and worm gear profiles Lashnev, Litvin, Hiltcher, propose numerical method, used to determine and localize contact pattern. All methods give same results.
Key words: worm, worm gears, manufacturing, simulation, CAD, contact pattern, fly cutter.

1. INTRODUCTION

Manufacturing worm gears is complex process which require adequate design of tools, their installation parameters and adjustments of manufacturing process. Worm gear coupling quality can be checked by contact pattern test. Adequate contact pattern guarantee adequate load resistance and reduce influence of transmissions errors.First step to complete this task is proper choose of worm and worm gear mate profiles. Modifying profiles we can localize contact pattern along the height of tooth. Making adjustments in tool's installation parameters we can adjust pattern position along the length of tooth and pattern size. Hiltcher, [1], in his article describe how mate profiles and tool installation parameters modify pattern contact and propose a numerical simulation method to pass contact pattern test.In this article we solve task describe above using graphical approach, which represent simulation of mathematics using CAD software.

2. PRESENTATION OF GRAPHICAL METHOD

Method presented in this article is graphical approach of worm gear manufacturing tasks. Graphical method represents a computer simulation of manufacturing and gearing process. Obtain result can be compared to result of mathematic method proposed by Lashnev [1], Litvin [2], Hiltcher [3]. Method algorithm is shown in Fig. 1.The main advantages are as follows: graphical method is more intuitive than mathematical; graphical method represent simulation of manufacturing process, which can be compared with real process at every step; its result are graphical, CAD data, which can be used in other graphical manipulations. The disadvantage could be the require laborious work, but process can be automatized using macros.

3. GRAPHICAL METHOD APPLICATION IN WORM GEAR DESIGN AND MANUFACTURING

Worm gear design and manufacturing process can be validate by contact pattern test, which determine the quality of resulting worm gear. So, every phase of designing and manufacturing process shall be developed to perform that test. Hiltcher [1] propose a generic algorithm for contact pattern simulation (see Fig. 2).

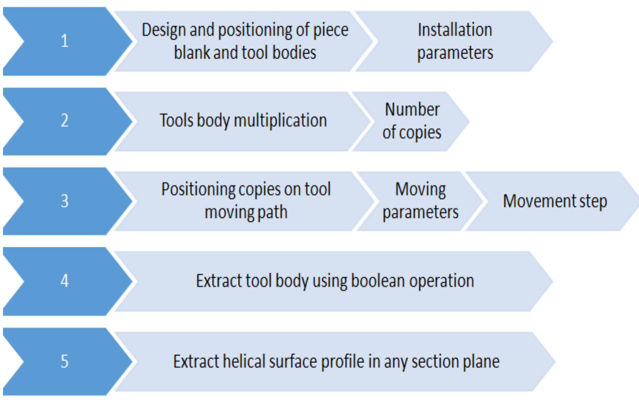

Fig. 1. Graphical method algorithm

3.1 Worm geometry and tool geometry phase

Worm surface can be formed moving tooth profile along its reference helix. Every point of profile perform helical motion given by equations in coordinate system attached to worm:

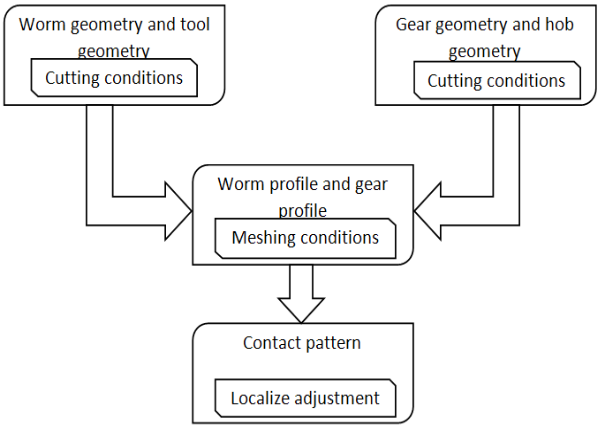

Fig. 2. Algorithm for contact pattern simulation, [3]

$$x = r \cdot \cos(\delta + \varphi)$$
$$y = r \cdot \sin(\delta + \varphi) \quad (1)$$
$$z = p \cdot \varphi$$

In this equation r is radius of current point, δ is angle between axe x and line which connect current point and origin O, φ represent rotation angle (of point in screw motion).

The tool and worm blank are represented in their coordinate system in figure 3:

Coordinate system Oxyz is attached to worm blank and $O_ix_iy_iz_i$ coordinate system is rigidly attached to tool body (figure 3).

Transformation equation from S to S_i:

$$x_i = y \cdot \sin\psi + x \cdot \cos\psi - a$$
$$y_i = -(y \cdot \cos\psi - x \cdot \sin\psi)\cos\varepsilon - z \cdot \sin\varepsilon \quad (2)$$
$$z_i = (y \cdot \cos\psi - x \cdot \sin\psi)\sin\varepsilon - z \cdot \cos\varepsilon$$

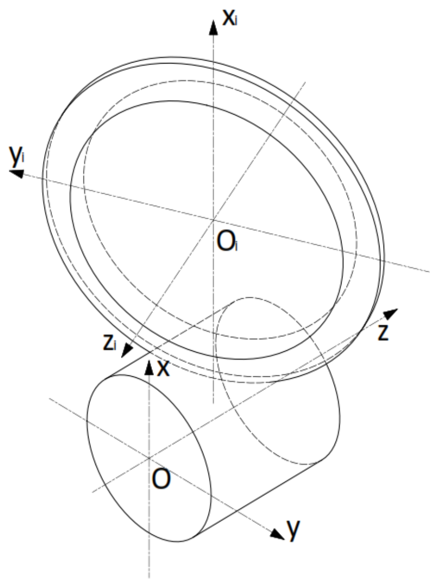

Fig. 3. Tool and worm blank and their coordinate systems

In this equation ψ is angle between *x* and x_i axes; ε is crossing angle and *a* is shortest distance between axes *z* and z_i (figure 4).

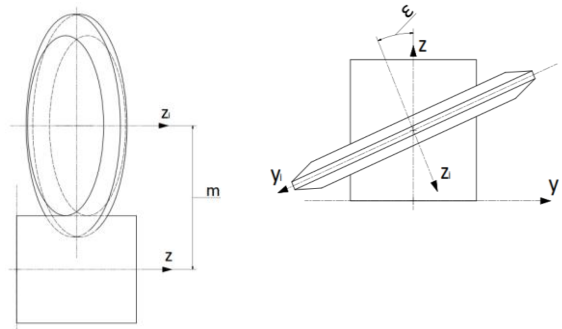

Fig. 4. Positioning parameters between tool and worm blank

To determine worm flank profile Litvin, [2] and Lashnev, [1] propose mathematical methodology based and meshing equation. Unlike their method we apply graphical method of simulation manufacturing process to succeed this task. Steps and results of methodology are shown below.

We applied this method on ZK type worm with 6 threads. Method simulates grinding process using uniconic grinding wheel (figure 4). We strictly respect algorithm presented in section 2.

Process start withpositioning tool and worm blank strictly respect positioning parameters: distances between axes (*a*), crossing angle (ε), symmetry of tool displacement (ψ). Schematic representation of process is shown in figure 5.

Then multiplied tool body and positioned then on its moving path. Grinding wheel perform helical motion around worm blank *z* axe. Having enough step proceed to obtain complete section we extract worm's axial profile, later used it to design worm (figure 6).

3.2 Gear geometry and hob geometry phase

Worm gears are manufacturing using worm hob or fly cutter (figure 7). To obtain theoretic linear contact gear must be manufacture using hob identical to mate worm. Many authors show that is preferably to cut worm gear using an oversize hob due to reduced sensitivity of worm gear to alignment errors Simon, [6].

Gear geometry can be obtain using mathematical models proposed by Litvin [2], resulting surface resulting from worm tool cutting proposed by Lahnev [1], mathematic models for worm gear surface given by Fang and Tsay, [7].

We determine worm gear surface using graphic method, which simulate worm gear cutting process with tangential feed using oversize fly cutter (figure 8).

Positions parameter between worm gear blank and fly cutter are: axes distance (shortest distance between axe *z* from coordinate system attached to worm gear and axe z_s from coordinate system attached to fly cutter), hob (fly cutter) inclination angle (angle formed

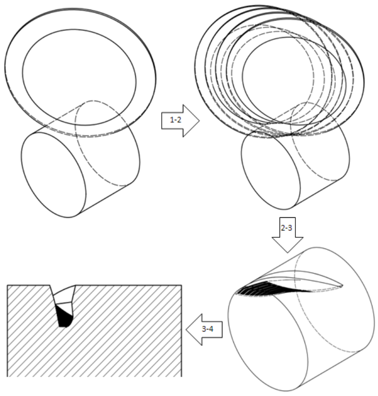

Fig. 5. Steps of grinding process simulation using CAD software

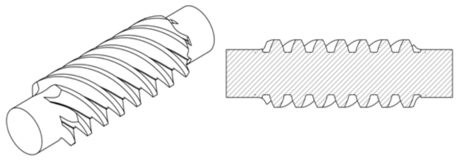

Fig. 6. ZK worm generated with profile resulted from presented methodology

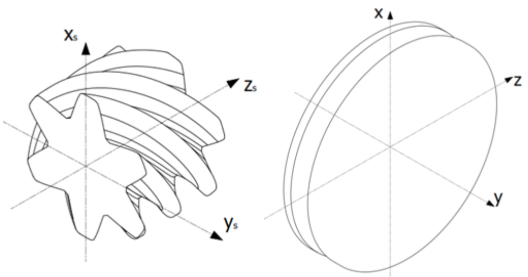

Fig. 7. Fly cutter and worm gear blank bodies

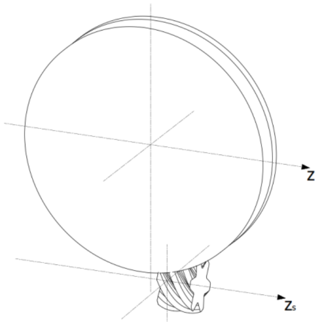

Fig. 8. Worm gear and fly cutter positioning

by z_s axe and central axe of fly cutter cylinder) and symmetrical displacement of fly cutter with respect to worm gear mid plane (plane formed by *x* and *y* axes).During cutting worm gear with tangential feed fly cutter perform rotation about axe z_s and translation about same axis. Tangential feed is perform symmetrically. Worm gear blank perform rotation around axe *y* according to transmission ratio plus additional rotation dependent from tangential feed. The results can be seen in figure 9.

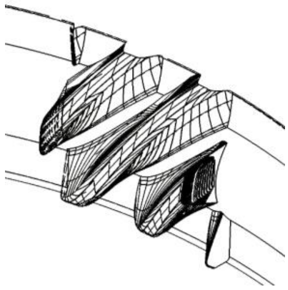

Fig. 9. Resulting worm gear tooth

3.3 Worm and gear profile phase

In previous two sections we describe process how to obtain worm and gear profiles using graphic method. Profiles have influence on height of contact pattern and it's localization on tooth height. Hiltcher [3] in his article describe this influence and offer examples of coupling different worm and gear profiles. Best solution resulting from his examples is using ZI or ZK worm and gear manufacturing by ZN fly cutter. In example shown above we manufacture ZK worm and gear manufacturing by fly cutter with slightly convex profile. Also a comparison of different solution will be presented bellow in figure 10.

Using oversize fly cutter to manufacture worm gear transform ideal linear line contact into pattern of contact. Oversize hob has different helix in compare to worm so manufacturing process must be adjusted to get corresponding contact pattern. Hiltcher [6] in his article describe how to optimize manufacturing process and get localized pattern with required size. Hiltcher present a numerical method for this task. We use gearing and manufacturing simulation to mark and modify contact pattern.

3.4 Localization of contact pattern phase

Modifying worm and worm gear profile we can adjust contact pattern on tooth height. In figure 10 is shown how fly cutter or hob profile influence contact pattern. Due to difference between worm and fly cutter, in particular their helix angle the resulting contact pattern is necessary to be localized along tooth width. Fly cutter is inclined with angle equal to difference between helixes during cutting worm gear.

Hiltcher [6] describe how a contact pattern can be moved along tooth width modifying fly cutter inclination angle. This modification is applying over helix correction described in previous paragraph. Its value can be positive or negative.

Using graphic method we obtain contact pattern by coupling resulted worm gear and worm. Rotating worm around *x* axe of worm gear we note contact pattern modification (mark in red color) (figure 11).

With contact pattern in right position, note worm inclination angle and apply it to fly cutter in new worm gear cutting simulation. Resulted worm gear is coupling with worm in functional position, then compare resulted contact pattern (figure 12).

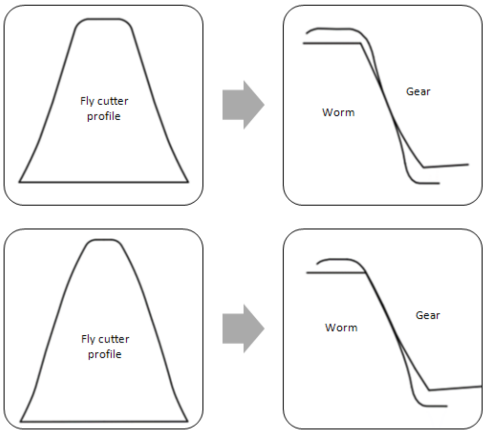

Fig. 10. Fly cutter profile influence on contact pattern

We manufacture worm gear with fly cutter inclination angle equal to 1.91 degrees. Figure 12 shows contact pattern resulting by coupling gear with inclined worm (left image) and resulting contact pattern after apply same angle to fly cutter during simulation (right image). As we can see in figure above contact pattern a similar as position. So presented method can be used for localization contact pattern along tooth width.

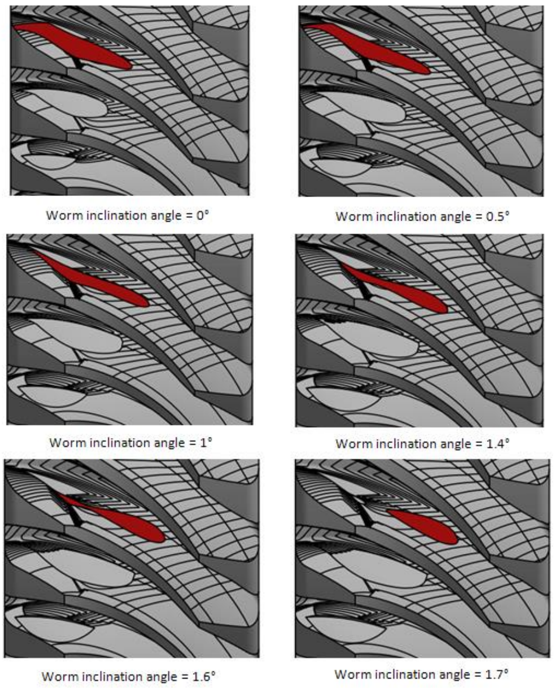

Fig. 11. Contact pattern modification due to worm inclination angle

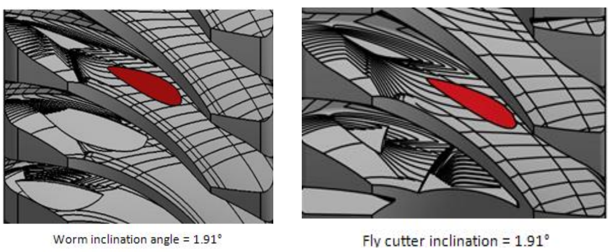

Fig. 12. Contact pattern modification due to worm inclination angle

4. CONCLUSIONS

This article present a graphical approach to contact pattern problem. It permits to fix tools geometry, cutting parameters and to see the result of modifications made during design process.

Contact pattern determine worm and worm gear quality and reliability. Every phase of worm gears design must be adjusted to gain corresponding contact pattern.

Manufacturing tools geometry has effect on worm and worm gear profile, permits to localize contact pattern along tooth height. CAD simulation permits to fix modifications and see the result.

Adjust worm and gear cutting parameters permit to localize contact pattern along tooth width. Also using CAD simulation we can see contact pattern position and make necessary modification of installment parameters.

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Received: June 30, 2015 / Accepted: December 10, 2015 / Paper available online: December 20, 2015 © International Journal of Modern Manufacturing Technologies.