TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 67, Issue Special II, April, 2024

DESIGN AND OPTIMAL MODELING OF UNCONVENTIONAL WORM GEAR WITH BEARINGS

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Abstract: *The unconventional worm gear, with bearing teeth on worm wheel, is make possible to transform sliding friction to rolling friction. Study and design is important taking into account of the fact that the energy losses at classic worm gear is high. In this study is presented design of unconventional worm gear based on the studies carried out on it. Therefore, the major changes realized, comparing to globoidal worm gear, are: replacing the teeth on worm wheel with bearings, implicit helix of the worm is made in such a way to allow bearings rotation and movement along the helix. Thus by elimination of sliding friction force it change important parameters of transmission: lower working temperature, reduce the backslash, increased operating time.*

Key words: *unconventional worm gear, globoidal gear.*

1. INTRODUCTION

The aim of this paper is to create a 3D model of an unconventional worm gear.

Following the analysis of the geometry and kinematics of cylindrical worm gear [1, 2] and globoidal worm gear [3] results the main of disadvantages. This disadvantages are: sliding friction force, which causes low transmission efficiency and backlash in the gearing, which influences kinematic accuracy.

Since the sliding friction force is high, in unconventional gears [4, 5] it has been replaced by rolling friction, this representing a better constructive version. Basically this is achieved by replacing the teeth of the worm wheel with bearings, which will have a linear contact with the worm spiral. At the same time the backlash in the gearing is considerably reduced due to the way the bearings are positioned, so that we have at least two bearings in the gearing which rotating in different direction. In order to achieve this there will be an area where the bearing will not be in contact with the helix of the worm. This will be in the strangulation portion of the globoidal worm, in its median area.

For the modelling part will be used the principles and characteristics determined in studies on the geometry and kinematics of unconventional worm gear [6, 7]

2. CONSTRUCTIVE ASPECTS

2.1 Worm gear with bearings

The worm gear with bearings is an unconventional worm gear derived from the globoidal worm gear, in which the teeth of the worm wheel are replaced with bearings.

The geometry of the worm is similar to that of the globoidal worm, but with changes in the flank profile.

Practically the flank of the worm is modified to allow to rolling the bearings placed circumferentially on the worm wheel. The transmission ratio between the two machine parts is maintained, specific to the rolling motion of the bearings, which are fixed to the worm wheel on the worm flank helix.

2.2 Advantages of gearing

Due to the replacement of the teeth of the worm wheel with bearings we no longer have sliding friction but we have rolling friction with a much lower coefficient of friction. Due this increases the gear efficiency. If in the case of the classic worm gear the efficiency is approximately $0.7 \div 0.82$ in the case of the worm gear with bearings it has an approximate value of $0.94 \div 0.95$. This results working temperatures will be lover. It will also increase the durability of the transmission.

It is also important to note that, with the modifications that we do, the backlash in the gearbox can be considerably reduced, and resulting the transmission errors will be reduced. This also contributes to increased working time, life of transmission.

2.3 Working principle

In order to bring the backlash in the gears as clot to the value 0 as possible, we need at least two of the bearing in gearing to have different rotation direction from each other, need to have opposite direction of rotation. We can consider that there are two types of bearings on the worm wheel, that is active and passive bearings. Active bearings are those in contact with the flank of the worm, which are in gear, and passive bearings are the rest of the bearings. Basically this means that at least the first and last active bearings must have opposite directions of rotation. In the median strangulation zone of the worm, one bearings must change its direction of rotation that is a passive bearings. To do this, the worm must have at least three bearings in gearing, which successively move from the active state to the passive state, changing the direction of rotation, after which they become active again. For example, seen from the mid-plane of the worm wheel the first bearing is in contact with the right side of the worm flank, and on exiting the gearing, the bearing is in contact with the left side of the worm flank (fig.1). This can reduce the backlash in the gearing down to value of 0.

Bearing size, bearing diameter, axial distance and transmission ratio are the parameters that influence the geometry and kinematics of the worm gear bearings.

In figure 1 is represents the line of contact between the bearings on the worm wheel and the flank of the worm, resulting the working principle of the unconventional worm gear with bearings.

If in the classic worm gear e have contact on a surface, in this case the contact is hertzian, linear over the width of the bearing.

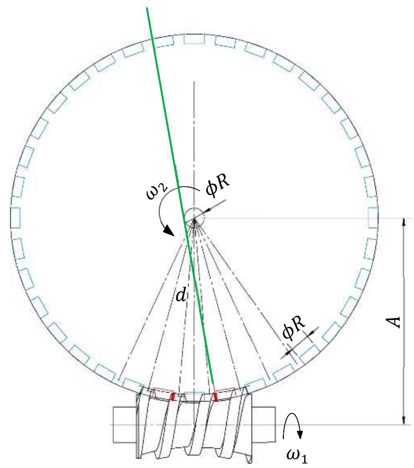

Fig.1. Geometry of the worm gear with bearings

With the red colour marks is the bearing of the worm wheel that are in gearing, in contact with the worm spiral. The thickened part of these bearing is that line of contact through which the transmission of motion is achieved.

Bearings that are in gearing have a specific angular speed given by the rotation of the worm with the angular speed ω_1. The blue colour indicates passive bearings, which are do not in contact with the flank of the worm spiral and not rotate around their own axis respectively do not have angular speed.

2.4 Parameters of the unconventional worm gear with bearings

In order to be able to design the worm gear with bearings so as to maintain the working parameters of a transmission, we need to respect the working principle, geometry and kinematics parameters.

Thus, having the outer diameter of the bearing, implicitly we also have the diameter of circle *C*, which is the circle of the generating profile of the worm flank (reference circle). Therefore, in our case, the generating line *d* is tangent to this circle. With this it will be possible to generate the profile of the flank and the pitch of the worm spiral, practically it will be possible to create the rolling path of the bearings on the worm with the help of the generating line.

In figure 1 is illustrate how the generating line *d* is tangent to the reference circle, which has a diameter equal to the outer diameter of the bearing. At near of the line *d* is also drawn the axis joining the center of the worm wheel and the middle of the distance between two bearings, representing the pitch of the worm spiral. Practically, the characteristics of the worm spiral and the helix generator depend on the dimensions of the bearing which, in this case, are the teeth of the worm wheel.

3. MODELLING OF THE WORM GEAR WITH BEARINGS

This is the first design of the gear according to the studies and principles we have determined in previous studies. This modelling will serve as a basis for determining the characteristics of the contact area between the bearing and the worm teeth. For this it was necessary to choose some data empirically. So after determining the contact area parameters, the next study will be about determining the surfaces, generating them after a mathematical analysis.

In order to facilitate the design of the 3D model, we chose the SolidWorks software.

First of all, we must be chose the bearing we want to use because its dimension are important factors in how the gearing is made.

So for our model the parameters are as follows: bearing code S686ZZ; bearing outside diameter is 13mm; bearing race width 5mm; base diameter of the worm wheel is 220mm; top diameter is 240mm; axial distance is 134.4mm; length of the worm is 75mm.

We'll consider the worm to be single started tooth. The aim is to produce a 3D model in such a way as to result in a continuous transmission with linear contact and a number of advantages. For this we determine: the number of bearings placed circumferentially on the worm wheel, the diameter of the worm wheel and the dimensions of the worm so as to include three bearings at the time of gearing.

The basic parameters that characterize the worm gear with bearings are similar to the basic parameters of a globoidal worm gear, but with the addition of some specific parameters.

The worm is modelled according to its geometric and kinematic determinations, and the worm wheel is designed to be compatible with the worm in order to achieve the transmission of the rotational motion and torque.

3.1 Worm modelling

The design of the worm is similar to the classic globoidal worm, but the flank of the helix is different, resulting an optimal raceway for the bearings which is fixed to the worm wheel.

For the start was made the worm shaft (worm) similar to the globoidal worm shaft, but with the flank of the helix so as to obtain a raceway for the bearings on the worm wheel.

First for modelling the worm was established and made the contact curves.

Due the fact that we want to reduce the backlash in the gearing we have basically made two ways for the bearings, one starting from one end of the shaft and the second from the other end of the shaft. The two way meet in the strangulation zone (the mid-plan of the worm), the moment when the gearing bearing is not in contact with any flank of the worm spiral, where the rotation direction of the bearing can be changed.

Basically the worm flank pitch is made from both sides and in the strangulation zone the pitch is increased, so that the gearing bearing in that zone, moment, is not in contact with any flank of the worm spiral.

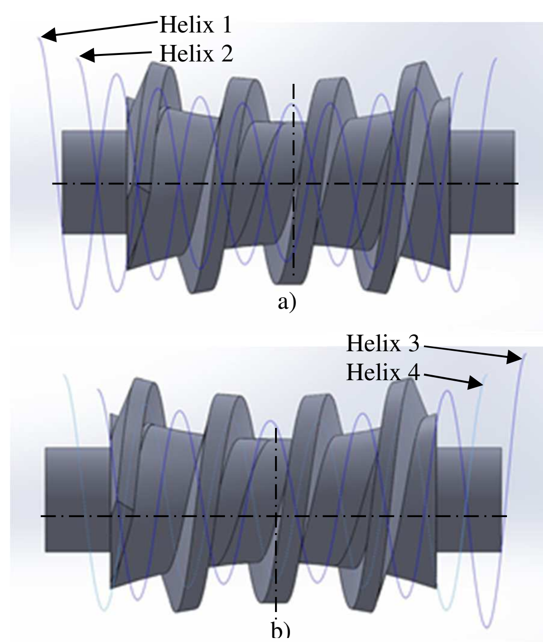

Fig.2. a) Helices of worm flank generators from the left side; b) Helices of worm flank generator from the right side

Thus, in figure 2 a) we have the helix 1 which is the main helix for generating the flank of the worm spiral, and helix 2 is the guide helix for profiling the worm shaft. Seen from the axial plane of the worm, these two helices represent how the worm spiral flank is generated.

This process of forming the flank of the worm spiral is repeated on the right side with the same characteristics of propellers, practically mirroring the helix to the middle of the shaft. The result of this is helix 3, the main helix for generating, and helix 4 is the guide helix for profiling.

Table 1

Main helix parameters.

Nr. Crt	P	Rev	H	D
1	18.37	0	0	67.4264
2	18.37	1	18.37	50.3
3	20.3	2	37.7	39.8
4	22	3	58.85	36.4
5	19.58	4	79.64	41
6	18.37	5	98.62	51

Table 2

Guide helix parameters.

Nr. Crt	P	Rev	H	D
1	19.07	0	0	57.8328
2	19.07	1	19.07	43.6954
3	20.19	2	38.7	36.9344
4	20.19	3	58.89	36.9344
5	19.07	4	78.52	43.6954
6	19.07	5	97.59	57.8328

Where:

P – Pitch
Rev – Revolve
H – Height
D – Diameter

In table 1 is represents the parameters of the main helix (generating helix) number 1 respectively 3. The second table 2 presents the parameters of the guide helix number 2 respectively 4.

Parametrically the main helix and the guide helix are similar. The difference being the way they are realized: helix number1 and 2 have a clockwise winding direction about shaft and the helix number 3 and 4 have trigonometrical winding direction about shaft.

The worm flank was generated by the "removal" of material. A sketch has made which as the cutting path the main helix and the guide helix.

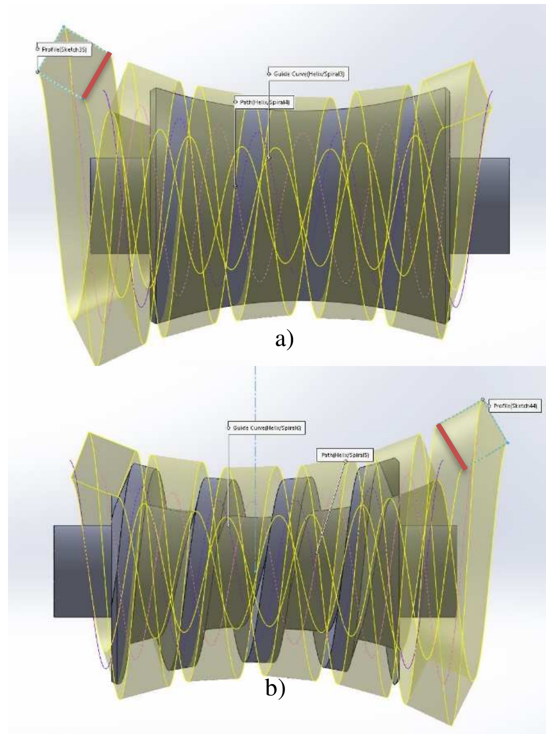

Fig.3. Modelling the flank of the worm shaft

Due to the fact that we want to make a raceway for the bearing, but the bearing must only touch one flank of thee worm spiral, it cannot have two contact areas (lines) because it block the rotational movement of the bearing in gearing.

Thus, the cut-out profile will have the dimensions of the bearing with an addition of 0.2 mm on the side facing the shaft, represented by the red line in figure 3.

It can be seen from figure 3, a) that the first cut-out is made after helix number 1 and respectively 2. After this operation a flank already results, but it is not possible to reduce the backlash in the gearing. Thus it is necessary to make the second cut after helix number 3 respectively 4 (fig.3, b). Practically there are two grooves that interlock so that the resulting raceway allows two bearings to be in contact with the flank of the worm spiral. One of the left side of the worm flank, the other on the right side of the worm flank. Resulting opposite direction of rotation for the two bearings.

In figure 4 is a representation of the worm shaft, in which the helix generating is visible on the worm flank. It can be seen that the position of the bearings on the worm wheel and the helix are passing through the bearing axis are also sketched, but which are offset they pass the strangulation zone exactly in order to be able to create the bearing raceway so as to reduce the backlash in the gearing.

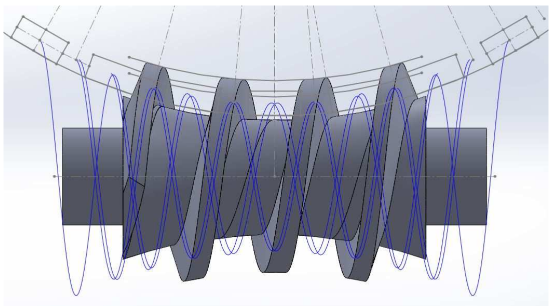

Fig.4. Worm shaft

3.2 Worm wheel modelling

The worm wheel in the worm gear with bearings is the easiest part to make because on this is need only to mount the bearings, to fix on it, it has no teeth (as in the classic worm gear).

In order not to complicate matters, and to facilitate the execution of the every parts, it is provided with bearing bracket fixing and clamping locations for each individual bearing (fig. 5 and 6.).

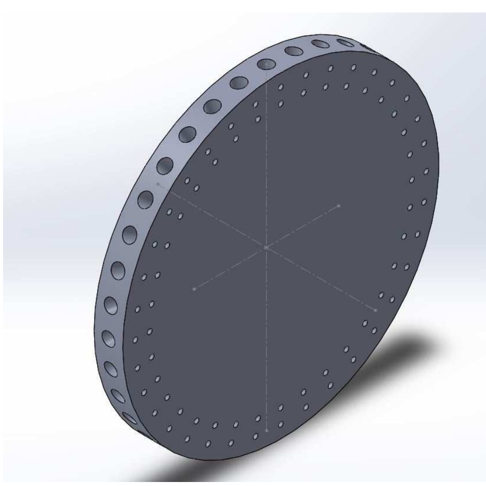

Fig.5. Worm wheel.

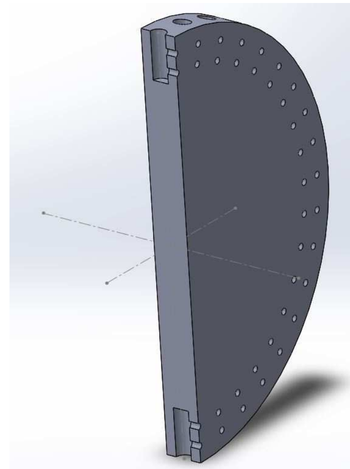

Fig.6. Worm wheel section

From the above figure it can be seen that the bearing bracket is cylindrical, as a result of which holes will be placed around the wheel axis on the worm wheel in which the bearing bracket will be mounted. As can be seen from the front plan of the wheel, on one side there will be two holes for each bracket for fixing them with threaded pins.

Figure 7 represents bearing bracket, supports, that are like a bolt. The end on which is mounted the bearing is like a shaft end portion, the axial fixing of the bearing is simply done with a screw. The bearing fixing is simple and efficient because the axial force are almost nonexistent.

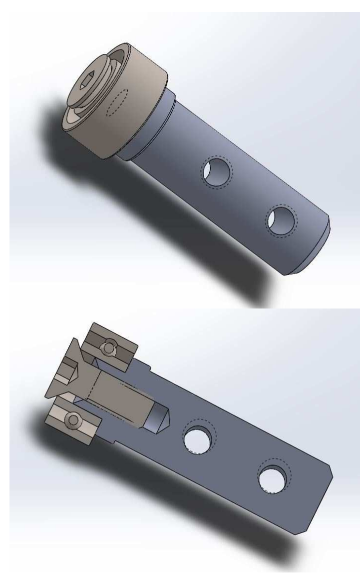

Fig.7. Bearing support

The bracket is fixed to the worm wheel is done with the help of two threaded pins (detail represents in figure 9), therefore the support is provided with two threaded holes.

In order to have a correct and most accurate position, the tolerances for the support and slot on the worm wheel will be in the tolerance class H6/h6.

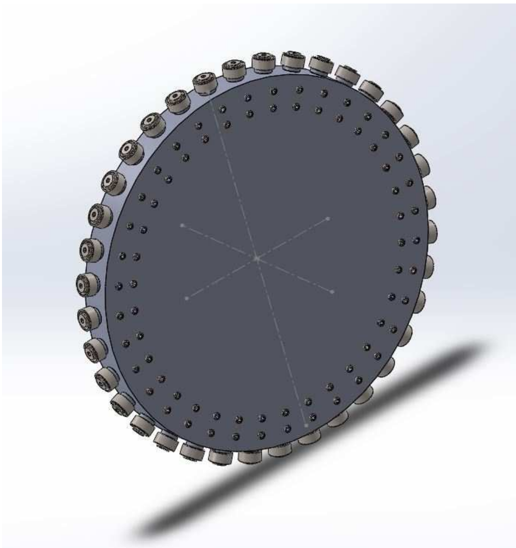

Fig.8. Assembled worm wheel

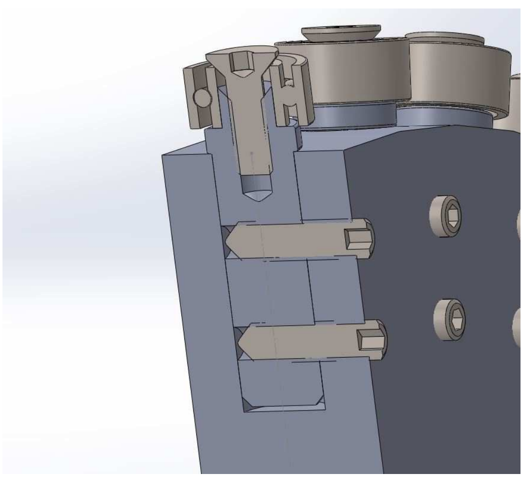

Fig.9. Detail of the bearing support fixing on the worm wheel

3.3 Assembly of the worm gear with bearings

Having modelled all the component parts of the worm gear with bearings, the following assembly can be produced.

Even form the point of view of assembly things are not simplified. There must be logic when assembling the components so that a correct assembly is possible.

Figure 10 represents the model of the worm gear with bearings. With the help of the created model, several important factors and parameters for this type of gear can be observed and determined.

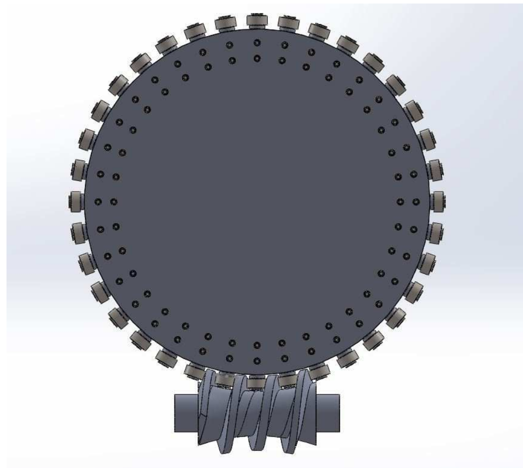

Fig.10. Worm gear with bearings.

From a section of the gear in the contact, gearing, area (fig. 10), it can be seen in detail which bearings is active and on which side of the flank of worm spiral the contact is made.

In order to observe in more detail two more section were made, one in the plane of the passive bearing in the strangulation zone of the worm (fig. 12), and one in the plane of the bearing that is in contact with the left side of the flank of the worm spiral (fig.13).

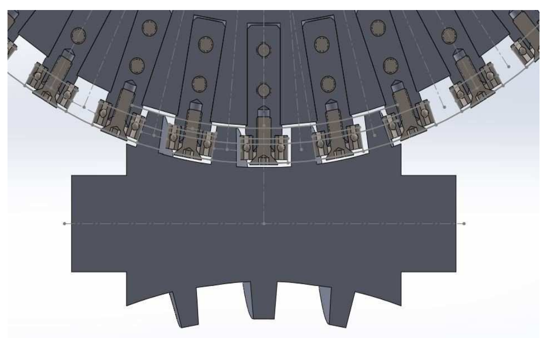

Fig.11. Section of the worm gear with bearings

The bearing with the blue outline marked is the passive bearing, which is at that moment in the strangulation zone of the worm, where it is not in contact with the flank of the worm spiral, and therefore does not rotate around its axis, it is not have rotation movement.

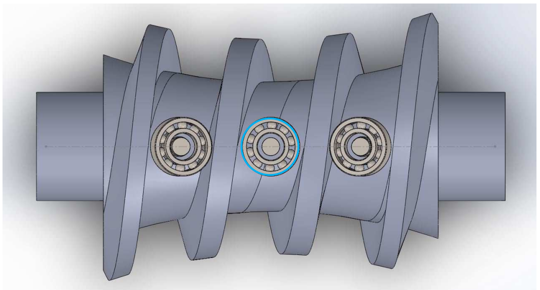

Fig.12. Section in the plane of the passive bearing

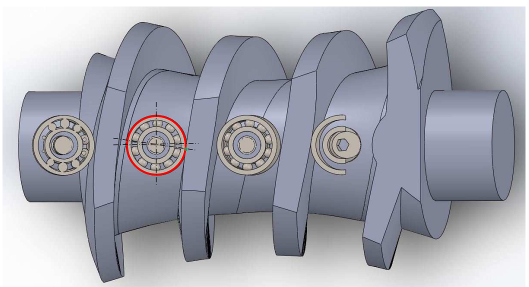

Fig.13. Section in the plane of the active bearing

From view the section in the plane of the active bearing, an important feature is observed, namely that the contact line between the bearing and the flank of the worm spiral is not in the axis of the worm.

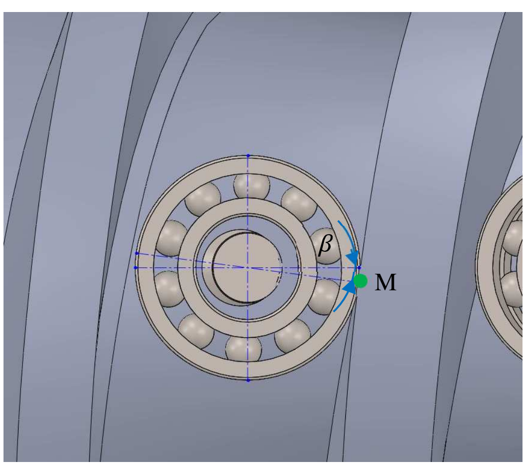

Fig.14. Detail of the bearing in contact with the flank of the worm

Seen in this section (fig. 13), the point M represent a point on the contact line between the bearing and the flank of the worm spiral, placed at an angle β to the axis of the worm shaft.

The distribution of force in gearing will be influenced by this aspect.

4. CONCLUSION

Due to the advantages that unconventional gearing can bring, the study is of great interest for the research area, as at can bring innovation in the field of mechanical transmissions to be used in industry.

An interesting and very complex gearing, but one that comes with a number of advantages is the unconventional worm gear, which uses bearings instead of worm wheel teeth.

The most important features of this type of gearing are: replacement of the sliding friction force by rolling friction force and reduction of backlash in the gearing. These in turn lead to changes in other favorable gearing characteristics.

Following the analysis of the geometry and kinematics of the unconventional worm gear with bearings, it was possible to design its optimal 3D model.

The biggest problem in modelling is making the worm shaft, more precisely the flank of the worm. It must have an optimal, linear raceway of the bearings in gearing. Knowing how the worm is generated, as well as the lines of the contact that must materialize between the active bearings and the flank of the worm spiral, the flank generating helix were made, starting from both ends of the shaft. By “ removing” the material after a profile following these helix the results is the worm shaft where the backlash in then transmission can be reduced, cancelled, due to the fact that the two active bearings are in contact on different sides of the flank of the worm spiral.

By this modelling it can be represented that the distribution of the forces in transmission is not on the axis of the worm shaft, because the contact line between the bearing and the flank of the worm spiral is not on axis of worm.

With this model we have observed new detail about the raceway, the distances required to avoid bearing locking and an important feature is related to the contact area, their position relative to the worm axis. All this data together with previous studies we will create a new paper about surface generation after a mathematical analysis.

Acknowledgment

This paper was financially supported by the Project "Network of excellence in applied research and innovation for doctoral and postdoctoral programs / InoHubDoc", project co-funded by the European Social Fund financing agreement no. POCU/993/6/13/153437

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Proiectarea și modelarea optimală a angrenajului melcat neconvențional cu rulmenți

La angrenajul melcat neconvențional, cu rulmenți în locul dinților roții melcate, este posibilă transformarea frecării de alunecare în frecare de rostogolire. Studiul și modelarea sunt importante ținând cont de faptul că pierderile de energie din angrenajul melcat clasic sunt ridicate. În această lucrare este prezentat modelul angrenajului melcat neconvențional pe baza studiilor efectuate asupra acestuia. Prin urmare, modificările majore aduse acestui angrenaj, în comparație cu angrenajul melcat globoidal, sunt: înlocuirea dinților roții melcate cu rulmenți, implicit spira melcului este realizată astfel încât să permită rotirea și deplasarea rulmenților de-a lungul spiralei. Astfel, prin eliminarea forței de frecare de alunecare, se modifică o serie importantă de parametrii ai transmisiei: temperatură de funcționare mai scăzută, micșorarea jocului, respectiv creșterea duratei de viață.

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