Geometric optimization of the shape of a non-circular gear

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Abstrakt: Non-circular gears have specific uses in mind. Due to the high costs associated with their manufacture, they were not previously employed extensively. Modern technologies, the use of computer-controlled machine machines, and the development of new mathematical models for non-circular form calculations have made it possible for non-circular gear to actively replace mechanisms with cams in the twenty-first century. The increased interest in non-circular gears can be attributed to their improved possibilities in both design and manufacture. The problem of creating non-circular gears for a certain set of gear ratios is discussed in this paper. For the gears, an elliptical design was used. The choice of an ellipse as the evolute to create the involute curve of the gear tooth is what distinguishes the suggested approach from others.

Keywords: non-circular gear, creation, varying gear ratio

1. INTRODUCTION

The fundamental component for moving objects from one location to another and transforming mechanical energy is a gear. Humanity knew about them and employed them before our time. The discoveries made by Aristotle (384–322 BC), who used gear wheels to learn about gears, further support this. Gears were utilized for pumping water by the mathematician and scientist Archimedes (287–212 BC). Many modern gears may be found in Leonardo da Vinci's (1452–1519) systems [1]. One may argue that gears are now considered an engineering icon.

A gear pair, which consists of a driving and a driven gear, is the fundamental component of a gear transmission. In practical applications, standard gears—which have a fixed gear ratio—are the most often utilized. This indicates that the driven gear spins consistently with the driving gear, keeping the gear ratio constant over the course of a revolution. These standard gears' teeth are of the same size and have symmetrical profiles—or, in rare instances, asymmetrical profiles. These common gears are made to transfer torque as efficiently and noisily as possible. [2].

More and more often in practice we can also encounter non-standard gears, i.e. those that do not have a constant gear ratio. Non-circular gears have specific uses in mind. A non-circular gear's main objective might be to achieve a variable gear ratio, axle displacement oscillations, and other significant qualities and characteristics.

Due to the high costs associated with their manufacture, they were not previously employed extensively. In the twenty-first century, the non-circular gear has been aggressively replacing mechanisms with cams because of advances in technology, the use of computer-controlled machine tools, and the development of new mathematical models for non-circular shape computations [3, 4]. Utilizing specialized machinery, quick prototyping, and electron discharge machining, non-circular gear production was established through rolling or duplicating. The increased interest in non-circular gears can be attributed to their improved possibilities in both design and production.

A novel hybrid six-bar mechanism with non-circular gear constraints and its optimal synthesis method for complex multi-pose rigid body guidance tasks was proposed in work "Optimization Synthesis of Hybrid Six-Bar Mechanism With Non-Circular Gear Constraints" [5].

Non-circular gears have the characteristics of gear ratio accuracy and good dynamic performance but are difficult to manufacture. Wire electrical discharge machining can process almost all kinds of non-circular gears. The study [6] identifies the optimum machining parameters of non-circular gears by this manufacturing method.

Liu [7] developed a conjugate gear model using the envelope approach and suggested a novel variable involute and incomplete variable cycloidal composite tooth profile.

Zhou [8] concentrated on creating the tooth profile for a transplanting mechanism's non-circular gears with a changeable gear ratio. A theoretical model was developed for predicting the tooth profile of non-circular gears with further changes, based on the gear shaping concept employing gear-cutting tools.

The geometric design of a gear mostly determines its quality [9, 10]. If the geometric design is faulty, then dependability cannot be guaranteed by even the best materials [11]. On the other hand, well-designed geometry can occasionally result in cost savings on pricey materials. The process of modeling a non-circular gear transmission with eccentrically positioned gears and a smoothly varying gear ratio for certain parameters is explained in this paper.

2. INPUT PARAMETERS FOR GEARING DESIGN

It was required to suggest an unusual toothed gear with a smooth gear ratio shift that repeats continuously in the range of u = 0.5 to 2 in order to meet practical requirements. Two equal toothed gears with teeth $z_1 = z_2 = 24$ and a module gear $m_n = 3.75$ mm, with a center distance a = 90 mm in one direction of rotation, were another need for the gearing.

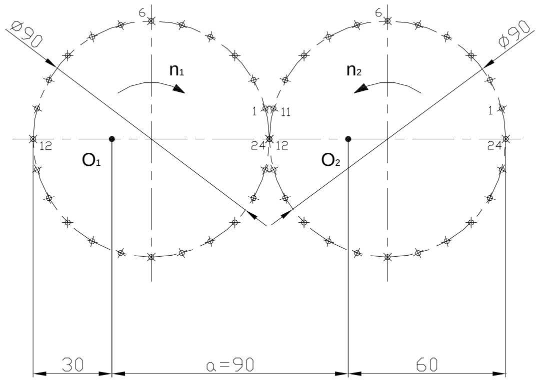

Fig. 1. Gear wheel pitch circles according to the initial model

The contractor also supplied a gear wheel made so to speak "roughly". The basis of the delivered model were two circular gears with an eccentrically located center of rotation (Fig. 1) and with a pitched circle with a diameter of d = 90 mm ($d = z \,.\, m_n$).

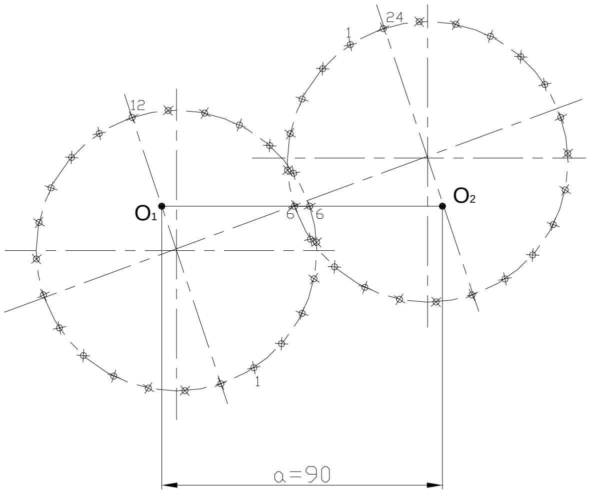

Fig. 2. Incorrect engagement when choosing a circular gear with eccentric centers of rotation

The centers of rotation of gears O_1 and O_2 were determined from the requirement to create a transmission with a time-varying gear ratio in the range of 0.5 to 2. The solution through circular gears placed eccentrically does not meet the basic condition of rolling pitch circles. There was "intrusion" of one circle into another and the greatest penetration occurred at the engagement of the teeth marked with the number 6, as shown in Fig. 2, which led to the idea of using an elliptical shape of the gears.

3. DESIGN OF NON-CIRCULAR GEARING FOR THE GIVEN PARAMETERS

Based on the results of the choice of circular gearing with eccentrically placed centers of rotation, the elliptical shape of the gears was chosen. The size of the main semi-axis of the spacing ellipse was 45 mm (Fig. 3) based on the specified axial distance a = 90 mm. The centers of rotation of gears O_1 and O_2 were determined from the requirement to create a transmission with a time-varying gear ratio in the range of 0.5 to 1.0 to 2.

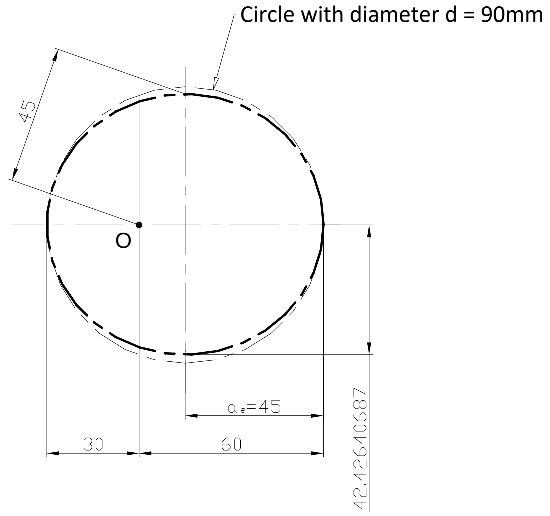

Fig. 3. Dimensions of the designed pitch ellipse of the non-circular gear wheel

The size of the secondary semi-axis equal to 42.42640687 mm (Fig.3) was determined. Points O_1 and O_2 (Fig.4) are also the foci of the pitch ellipse. It is based on the property of the ellipse that for each point of the ellipse, the sum of the distances for the point O_1 and the tracked point plus the tracked point and the point O_2 is always equal to twice the semi-major axis, in this case the axial distance.

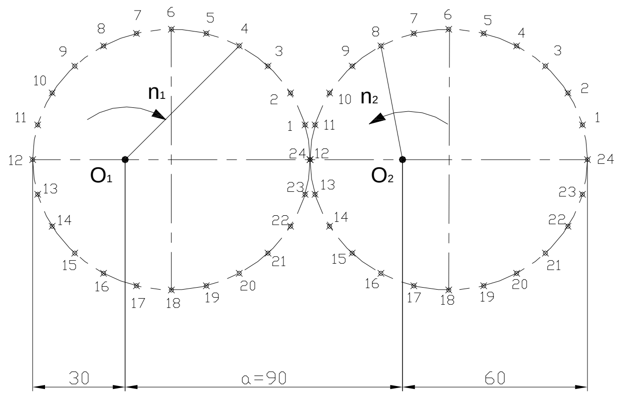

Fig. 4. Designed pitch ellipses of a non-circular gear pair

In standard involute gears, an involute, whose involute is a circle, is used to profile the teeth. Accordingly, the forming straight line is the normal of the involute and at the same time a tangent to the base circle (evolute) with a point of contact in the center of curvature of the involute. The involute in this case is clearly determined by one parameter, namely the radius of the base circle. In this case, a different method was used. An ellipse was chosen as the evolution of the involute (Fig. 5).

A trochoid method of construction was used for the construction of the involute, in which involute points were painstakingly constructed for each side of the tooth. The more involute points constructed by the trochoid described above are constructed, the more accurate the shape of the involute part of the tooth flank will be.

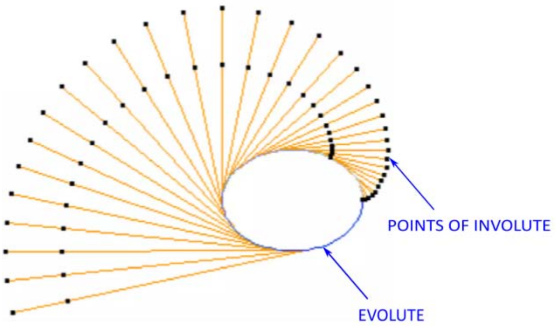

Fig. 5. Points of involute, shape of evolute

Figure 6 shows the resulting shape of the designed non-circular pair of gears. The transmission consists of two identical gears of an elliptical shape with an eccentrically located center of rotation.

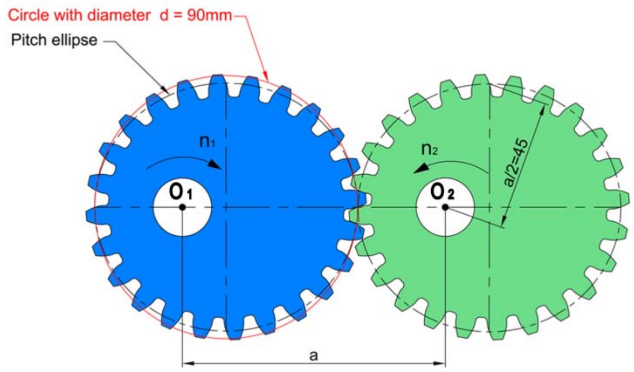

Fig. 6. Shape of the designed non-circular pair of gears

This designed transmission was subjected to an analysis of engagement, speed and power ratios, as well as the issue of deformation and stiffness of the designed gearing, as it differs from a standard circular gear.

4. PROPERTIES OF THE DESIGNED NON-CIRCULAR GEAR

Involute gearing is characterized by a straight engagement line. This also applies in the case of a designed non-circular gear, if the involute involute is an ellipse. Fig. 7 shows the result of the examination of the shot points.

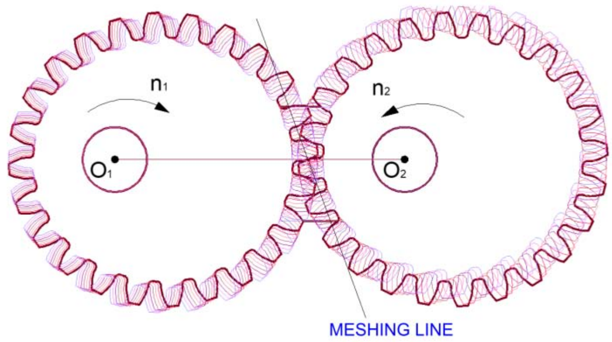

Fig. 7. The shape of meshing line

In the case of a standard involute ring gear, the length of the mesh segment is the same for the entire toothing, i.e. for each pair in mesh. In this case, when the toothing is composed of teeth with different profiles, the length of the engagement segment for individual pairs in the engagement changes. In Figure 8 shows the engagement segment for a given pair of teeth in meshing.

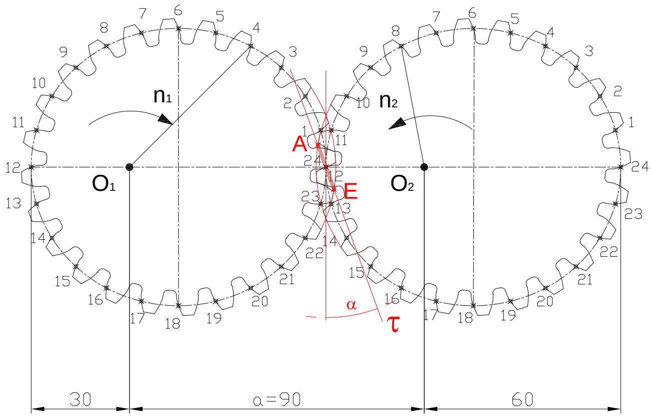

Fig. 8. Meshing segment for teeth 24 – 12

For the designed elliptical eccentric gear, it is not possible to use the formula valid for the circular involute gear to calculate the length of the engagement segment.

Table 1 shows the values of the length of the meshing segment and the coefficient of contact ε_α for selected pairs of involute gear teeth in engagement.

Tab. 1 The length of the meshing segment and the coefficient of contact

Meshing teeth driving - driven	$\overline{AE}$ (mm)	ε_α
24 - 12	14.406	1.222
1 - 11	14.412	1.223
2 - 10	14.436	1.225
3 - 9	14.503	1.231
4 - 8	14.52	1.232
5 - 7	14.548	1.235
6 - 6	14.594	1.239

The coefficient of contact ε_α (equation 1) is used to express the engagement ratios of the gear wheel.

$$\varepsilon_\alpha = \frac{\overline{AE}}{p_{tb}} \quad (1)$$

where $\overline{AE}$ is length of the meshing segment (mm)
ε_α is coefficient of contact (-)
p_{tb} is spacing in the frontal plane measured on the base circle (mm),

The designed elliptical gear takes the largest value of the length of the meshing line for a pair of teeth that reach a gear ratio of 1.0 during engagement. The designed involute gear is characterized by the fact that the toothing consists of teeth with different profiles, and therefore the length of the meshing segment as well as the engagement duration coefficient for individual pairs of teeth in engagement are not constant, as in the case of a standard circular spur gear.

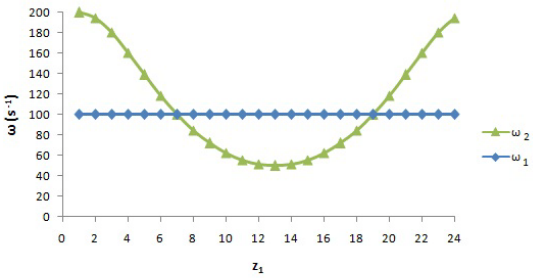

Fig. 9. Course of angular velocities in the designed non-circulargear

In Fig. 9 shows the course of angular velocities on the driving (ω_1=100 s^{-1}) and driven (ω_{2i}) elliptical gear. Unlike standard ring gears, where the angular velocity on both the driving and driven gears is constant, in this case the angular velocity on the driven elliptical eccentrically mounted gear is not constant, but varies depending on the continuously varying gear ratio

5. CONCLUSIONS

The capacity to create variators with any law varying the gear ratio, however, is the primary benefit of non-circular gear. Typically, when designing, they rely on pre-existing variators that use cam mechanisms, gear wheels with evolving profiles, and other mechanisms. However, by using non-circular gear, you can create a car that follows any given law of motion for the input and output links. Additionally, non-circular gears often allow you to work at high speeds and make the car more compact. Numerous studies have also demonstrated that non-circular gears have a longer fatigue life than their counterparts because of their larger contact area. For instance, non-circular gear enables the transmission of large loads, in contrast to cam-type devices.

However, the flexibility to create variators with any law of altering the gear ratio is the most significant benefit of non-circular gearing. In most cases, when designing, they rely on pre-existing variators that use mechanisms such as cams, evolvent profile gear wheels, and other mechanisms. However, by using non-circular gear, you can create a car that follows any given law of motion for the input and output links. Additionally, non-circular gears often allow you to work at high speeds and make the car more compact. Numerous studies have also demonstrated that non-circular gears have a longer fatigue life than their counterparts because of their larger contact area. For example, in contrast to cam-type mechanisms, non-circular gear allow high loads to be transmitted and are highly reliable. They also do not require special fixtures or springs to maintain contact continuity in the upper pair, resulting in a simplified design and increased manufacturability.

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