

Properties of Eccentric Elliptical Gearing

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Abstract: Gearing was designed to meet continuous change of gear ratio during one rotation. The gearing consists of two identical gears and the basic shape of the gear wheel is formed by an ellipse. Wheels are designed for only one direction of rotation and the center of rotation is one of the foci of ellipse. Such designed and manufactured elliptical gearing was subjected to the tests and meets all the requirements that were imposed on the gear. This paper deals with properties of gear with variable transmission. Properties of this gearing are different from the properties of standard circular gears.

Keywords: gear, ellipse, continuously variable gear ratio

1. Introduction

We face the ever increasing demands on machine parameters nowadays. This request is expressed by their required loads' growth and dynamics calling for the continuous improvement of various machine parts because of the demanded load capacity, accuracy, durability and safety of the machinery. Therefore, one has to consider the dynamic properties of processes taking place in them.

The internal dynamics of the teeth is one of the most common gearing problems [3]. Detailed knowledge of meshing conditions is a prerequisite for studying kinematic conditions in gearings, as well as the strength calculation of gearing. The article deals with the problems of kinematic properties of non-circular gear. The problem is solved for the elliptical, eccentric gear with a continuously variable gear ratio within the range from 0.5 through 1 to 2.

2. Geometric Properties of Eccentric Elliptical Gearing

Sponsoring of this work by the private sector called for development of the gear model using the CAD system for the variable transmission in the range $u = 0.5$ to 2.0, with the number of teeth $z_1 = z_2 = 24$ and gearing module $m_n = 3.75$ mm, the distance $a = 90$ mm and for one direction of rotation.

Given that each gear must satisfy the conditions of proper meshing, it was necessary to determine the geometric shape of the wheels. The gearing is designed such that the pitch curve is

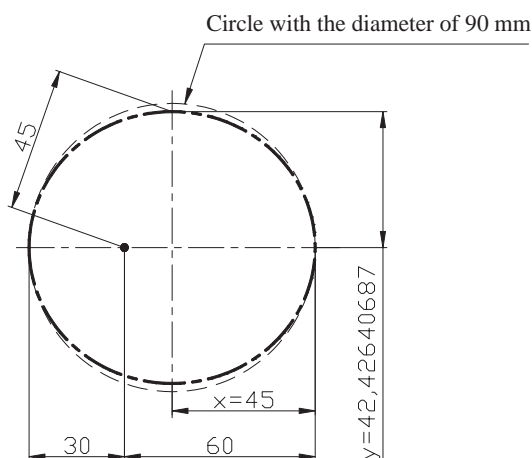


Fig. 1. Dimensions of a pitch ellipse

Rys. 1. Wymiary elipsy tocznej

composed of an ellipse formed with the basic parameters shown in Fig. 1. The geometric centre of the gear is not the centre of wheel's rotation. The center of gear's rotation is in the focus point of the ellipse.

The pitch ellipse has a large half-axis $x = 45$ mm, which is a half of the axial distance. The second half-axis is determined by the distance from the focus point 45 mm (Fig. 1), whose position is determined by considering the desired gear ratio. In this case, one of the conditions of a correct mesh is that the measurements of the pitch on the ellipse pitch must be kept constant. The geometric separation of the pitch ellipse into 24 identical sections is mathematically much more difficult than in the case with the standard gear pitch circles.

The development of this gear is analyzed in detail in the literature [5, 7, 9]. The gears for a given variable transmission have been proposed as elliptical – eccentrically placed (Fig. 2).

The conventional gearing involute starts from the base circle, in which case it is the base of the evolute of the ellipse. The evolutes of the left and right sides of the teeth are not

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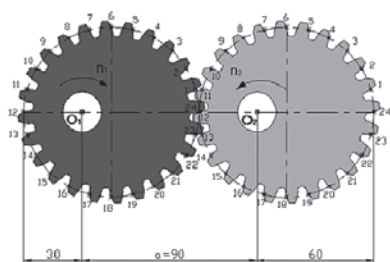


Fig. 2. Designed elliptical gear
Rys. 2. Zaprojektowane eliptyczne koła zębate

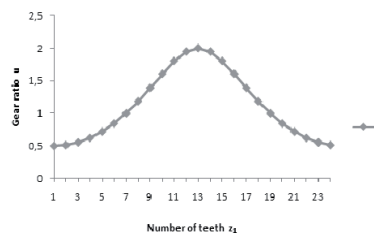


Fig. 4. Continuously variable gear ratio
Rys. 4. Przełożenia przekładni bezstopniowej

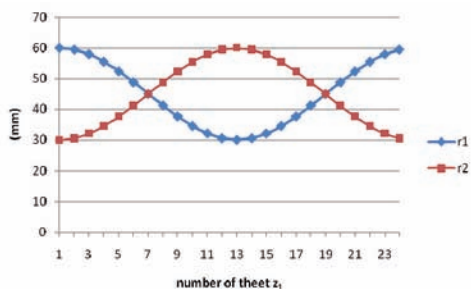


Fig. 3. Radius of mesh points of gear
Rys. 3. Promienie punktów zążeń koła

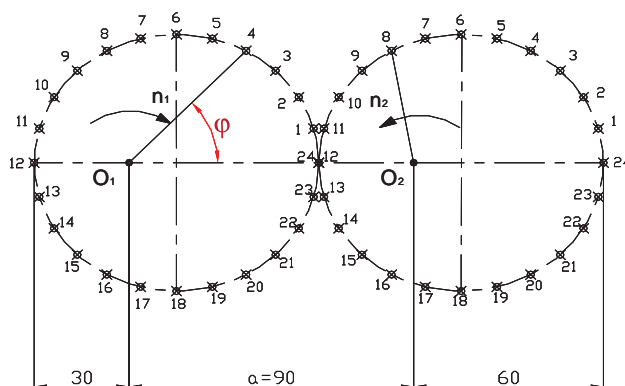


Fig. 5. Designed elliptical gear – definition of angle of rotation
Rys. 5. Eliptyczne koła zębate – określenie kąta obrotu

the same. Each of the twelve teeth is different; the next twelve teeth of the same wheel are the same. The sides curve is the involute, and is different for active and passive side of the tooth; the teeth are asymmetrical. The gearing consists of two identical gears. The geometric model of the proposed gear is shown in Fig. 2.

3. Kinematic Properties of Eccentric Elliptical Gearing

In pursuit of kinematic ratios of the proposed gearings we take into account the right mesh conditions. Kinematic conditions were processed for a gear 1 (the center of rotation at point O_1) and the gear 2 (with the center of rotation at point O_2). The two gears are shown in a kinematic dependence on the graph (on the horizontal axis of the wheel teeth first).

Figure 3 shows the teeth radii of the gear points 1 and 2 for a pair of teeth, depending on the temporary position of teeth in respect to the center of rotation. It is also defined in Table 1.

Fig. 4 shows a course of the continuously changing gear ratio in one mesh generated by the elliptical gear, which continuously varies in the range from $u = 0.5$ through $u = 1.0$ until $u = 2.0$ and back. Thus the gear ratio changes over the time of one revolution. A gear ratio value that is less than 1.0 means that this is an overdrive, and a gear ratio value greater than 1.0 means a speed reduction.

Gear ratio of the designed eccentric elliptical gears depends on the angle of rotation ϕ of the drive wheel (Fig. 5). The gear ratio in the designed eccentric elliptical gears is a function of the angle of rotation (Fig. 6).

The angular velocity of the drive wheel gear and the driven wheel gear is constant for standard spur gears. For the designed

elliptical gearing with the variable transmission, the angular velocity of the driven wheel is not constant but changes according to the continuously changing gear ratio. This is shown in Fig. 7, for the angular velocity is of the drive wheel ($\omega_1 = 100 \text{ s}^{-1}$) and the driven elliptical wheel (ω_{2i}). The variation of angular velocity is also demonstrated in Table 1.

Table 1. Radius of mesh points of gear and gear ratio
Tabela 1. Promienie punktów zążeń koła i wartości przełożenia

Meshing (Fig. 2)	Radius of mesh points		Gear ratio $u_i = r_{2j}/r_{1-i}$	$\omega_{2i} = \omega_1/u_i$ $\omega_1 = 100 \text{ (s}^{-1}\text{)}$
	r_{1-i} (mm)	r_{2j} (mm)		
24 – 12	60.000	30.000	0.500	200.000
1 – 11	59.459	30.541	0.514	194.704
2 – 10	57.892	32.108	0.555	180.310
3 – 9	55.450	34.550	0.623	160.514
4 – 8	52.337	37.663	0.720	138.966
5 – 7	48.779	41.221	0.845	118.343
6 – 6	45.000	45.000	1.000	100.000
7 – 5	41.221	48.779	1.183	84.09
8 – 4	37.663	52.337	1.390	71.63
9 – 3	34.550	55.450	1.605	62.313
10 – 2	32.108	57.892	1.803	55.463
11 – 1	30.541	59.459	1.947	51.366
12 – 24	30.000	60.000	2.000	50.000

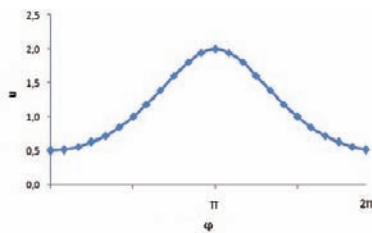


Fig. 6. Changing the gear ratio – function of angle of rotation
Rys. 6. Ciągła zmiana przełożenia w funkcji kąta obrotu

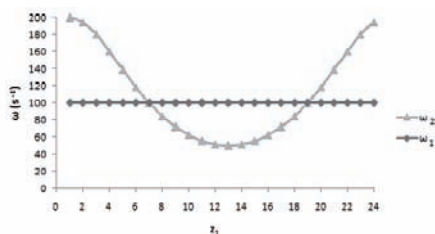


Fig. 7. Angular velocity
Rys. 7. Prędkość kątowna

4. Manufacturing of Eccentric Elliptical Gearing

Selecting the optimum mode of production was limited by conditions, such as the number of units produced (only one pair of gears was produced), production should be ensured by technology commonly available in the area and without any expensive products and the costs of production preparation should be as small as possible.

Technical preparation stage of production was secured by a company, which specializes in the development and distribution of CAM systems and NC programming automation and CNC machines.

Based on the conditions, the NC EDM machine was chosen for cutting (the wire cutter) of the EIR 005 B type with the RS-ER5 control system. This machine allows creation of the designed gears and ensures the estimated necessary accuracy of 0.01 mm and roughness of Ra 1.6 μm . The basic problem was to generate the NC code for the complex shape gear. This code does not allow a general approach when creating NC programs for gears, describing the shape of one tooth, which is repeated by the required number of teeth. Other than that it is based on creating the postprocessor (Compiler) for the machine in the CAM2000 system, which is designed to automate the programming of NC machines. The postprocessor for EDM cutting EIR005B machine with the control system RS-ER5. Its task was to automatically generate the NC code for the designed shape gears. In this way it is possible within a few minutes to develop easily the NC program for any required profile shape.

For the production of the elliptical gear may be used application of method of powder metallurgy. Powder metallurgy products are currently named as the "economically efficient" products because of their price compared to parts produced for

example by material removal operation can be up to 25–50% lower. Powder metallurgy is characteristic of the use of the material up to 95% in the manufacture of the "net-shape" components with no cost to tool machine. Powder metallurgy is one of non-waste technology, and has the character of a closed cycle. Its output is already a finished product ready for installation. It is characterized by up to 50% energy savings and up to 75% saving on product mass. This method is suitable for mass- and large-scale production.

5. Conclusions

The main objective of this paper was to compare the parameters of the designed elliptical gearing with the parameters of the standard spur gear with constant gear transmission.

Gears for specified gearing with time – change of gear ratio was to be designed as elliptical. The elliptical gear was designed using the AutoCAD software. This gear was the basis for making the gear-box designed for the specified parameters.

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Eliptyczne koła zębate i ich właściwości

Streszczenie: Na podstawie specyficznych wymagań została zaprojektowana przekładnia, która podczas jednego obrotu wału napędzającego umożliwi ciągłą zmianę przełożenia. Przekładnię tworzą dwa identyczne koła zębate. Podstawowy kształt koła jest elipsą. Jedno z ognisk jest środkiem obrotu. Koła są zaprojektowane tylko do obracania się w jednym kierunku. Aktywne i pasywne ewolwenty profilów zębów zostały utworzone niezależnie na podstawie odpowiednich fragmentów ewoluty eliptycznego koła. Tak zaprojektowane i opracowane przekładnie zębate z kołami eliptycznymi zostały poddane testom – spełniły wszystkie wymagania, które im postawiono. W przypadku przekładni z kołami zębatymi o kształcie eliptycznym, w przeciwieństwie do przekładni z kołami zębatymi okrągłymi, wartość siły międzyzębnej znacząco zmienia się podczas jednego obrotu koła, co wpływa na różne obciążenie poszczególnych par zębów.

Słowa kluczowe: koło zębate, elipsa, przełożenie w sposób ciągły

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