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Research Article

Shaping the tooth profile of elliptical gear with the involute ellipse curve

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ABSTRACT

Non-circular gears (NCGs) with the advantage of compactness and simple mechanical structure in creating transmitters with variable gear ratios in the industry, so this is a topic that is being studied by many scientists. However, up to now the research usually focuses on NCGs with tooth profile that is an involute circle called involute tooth profile, while other curves have not been applied in the design of the non-circular gears. In this paper, the author proposes to apply the involute ellipse curve in shaping the tooth profile of the pair of elliptical gears with a rack cutter. A rack cutter with tooth profiles is trapezoidal weight is determined from the involute ellipse curve selected as the NCGs teeth. In order not to undercut and tip sharpening when shaping the gear, two algorithms for correcting the base ellipse according to the even distribution of teeth on the gear and undercutting avoidance condition are performed. A numerical computational software module is written according to the theory and the algorithm is implemented to explore the different cases in the design process. The results of this study show that the teeth are evenly distributed over the entire circumference of the ring elliptical gear, overcoming the phenomenon of uneven teeth in geometry and size when using the involute of a circle as other studies have shown. Also, with the tooth profile that is involute ellipse curve, the pressure angle is increased to improve efficiency the transmission capacity of a pair of gears. Therefore, this is the advantage of the new profile in creating variable automatic transmission for different script applications in industries such as the automotive industry or modern medical equipment.

Key words: elliptical gears, non-circular gears, involute ellipse, rack cutter, pressure angle, algorithms, gear shaping

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INTRODUCTION

The involute of a circle as the tooth profile of NCG has been used in most recent studies. Litvin [1] has proposed the NCG tooth profile generation methods by using the standard rack cutter, which was like that of spur gear generation with a constant transmission ratio. The generation process was done via the pure rolling motion of the pitch line on the rack cutter and centrodes of NCG. Basing on this idea, Bair *et al* . [2,3] have developed the NCG tooth profile equation with the centrode as a centrality ellipse and the rack cutter as a generation tool. Li *et al.* [4] have also proposed a simple and accurate numerical method for generating NCG tooth profiles by making the pitch line of the rack cutter purely rolling on the centrode of NCGs. The NCG tooth profile was generated from the boundary of the cutter profile. This method is very useful for non-circular gears with complex centrodes. However, some negative phenomenon was found during the generation process such as undercutting, pointed teeth, tooth flank intersection, and so on, which have successfully been solved [4–6]. Zheng *et al.* [5] used the equation of meshing and the relative velocity between the rack cutter and NCGs to identify the conditions for avoiding undercutting. Uwe Bäsel [6] proposed a condition for avoiding undercutting when considering the tooth contact between the rack cutter and tooth profile of NCGs, therefore the undercutting occurred when the tooth profile of the rack cutter cut the tooth profile of the gears. However, it is likely that there have not been any foreign research that applies other curves as cycloid [7,8], parabola segment [9], circle segment [2], improved cycloid curve [10–13], Novikov [14] and so on to the design of tooth profile of NCG, even though the spur gears with constant transmission ratio have been used effectively.

In addition, in recent years, Useche *et al.* (2021) [15] have studied shaping elliptical gears whose tooth profile is involute circle curve to create the gear ratio function in the range from 0.5 through 1.0 to 2.0, Prikhodko (2020) [16] applied a planetary ellipse gear system to replace intermittent motion mechanisms in semiautomatic and automatic machinery, Zhou *et al.* [17] have applied the compound elliptical gear train to design the transplanting mechanism for the rice transplanters. Therefore, this research will propose

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solutions for applying the advanced involute of an ellipse to the tooth profile design of the external meshing NCGs with the rack cutter.

DESIGN METHOD THE TOOTH PROFILES WITH CURVES INVOLUTE OF AN ELLIPSE FOR A PAIR OF ELLIPTICAL GEARS

An equation of the involute of an ellipse

Definition: The involute of an ellipse $\{\xi\}$ is the locus of the fixed point K on $\triangle$ line, when the $\triangle$ makes a pure rolling on the ellipse base $\{\Sigma^{CS}\}$ as described in Figure 1. So, the $\triangle$ is called the line of engagement during the generation process of $\{\xi\}$.

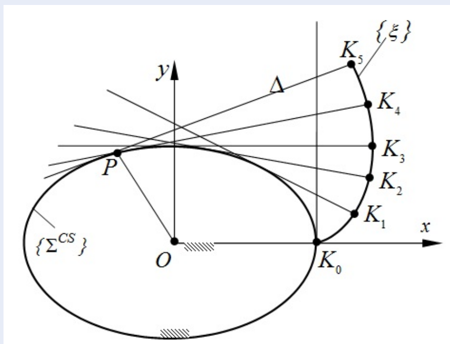

Figure 1: The involute of an ellipse

Therefore, in order to create an analysis equation of $\{\xi\}$ as in Figure 2, we call $\vartheta_1\,\{O_1x_1y_1\}$ the fixed coordinate system in the center of ellipse base $\{\Sigma^{CS}\}$; $\vartheta_2\,\{O_2x_2y_2\}$ the coordinating system on the line $\triangle$ ($O_2x_2 \equiv \vec{n}_P$, $O_2y_2 \equiv \vec{t}_P$ with $\vec{t}_P, \vec{n}_P$ a tangent vector and the normal vector of $\{\Sigma^{CS}\}$ at point P (the contact point between the line $\triangle$ and Σ^{CS}); $r_P(\varphi)$ the polar radius of centrality ellipse with φ parameter; $r_K(\varphi)$ the polar radius of an ellipse involute with φ parameter; K the fixed point on $\triangle$; and θ the rotational angle between ϑ_2 coordinating system and ϑ_1 coordinating system.

$$^1r_K(\varphi) = {}^1r_P(\varphi) + {}^1M_2^2 r_{PK}(\varphi) \tag{1}$$

Note: $^1r_P(\varphi) = [r_P(\varphi)\cos\varphi \;\; r_P(\varphi)\sin\varphi \;\; 0]^T$; $^2r_{PK} = \begin{bmatrix}0 & \overline{PK}(\varphi) & 0\end{bmatrix}^T$; $^1M_2 = \begin{bmatrix}\cos\theta(\varphi) & \sin\theta(\varphi) & 0\\ -\sin\theta(\varphi) & \cos\theta(\varphi) & 0\\ 0 & 0 & 1\end{bmatrix}$; Pole radius $r_P(\varphi)$ of the point $P \in \{\Sigma^{CS}\}$ with φ parameter was created by the formula [18] $r_P(\varphi) = 2ab\left((a+b)-(a-b)\cos 2\varphi\right)^{-1}$ while a, b are the major semi-axis and the minor semi-axis respectively of $\{\Sigma^{CS}\}$;

$\overline{PK}(\varphi) = PK(\varphi) = \int_0^{\varphi}\left((r_P(\varphi))^2 + \left(\frac{dr_P(\varphi)}{d\varphi}\right)^2\right)^{0.5} d\varphi$;

$\theta = arc\cos\left(\vec{n}_P, \vec{i}\right) = arc\cos\left(\frac{\vec{n}_P.\vec{i}}{\left|\vec{n}_P\right|\left|\vec{i}\right|}\right)$ while $i = \begin{bmatrix}1 & 0 & 0\end{bmatrix}^T$ is the unit vector of O_1x_1, $n_P = t_P \times k = \begin{bmatrix}\frac{\partial r_{Py}(\varphi)}{\partial\varphi} & -\frac{\partial r_{Px}(\varphi)}{\partial\varphi} & 0\end{bmatrix}$ while $k = \begin{bmatrix}0 & 0 & 1\end{bmatrix}^T$ is the unit vector of O_2z_2.

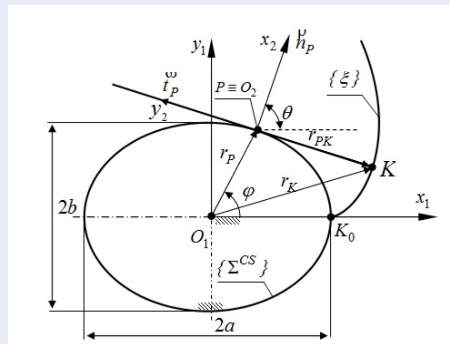

Figure 2: A graph of algorithm mode of an ellipse involute

By abridging Equation (1), the analysis equation for the involute of an ellipse is as follows:

$$\begin{cases} x(\varphi) = a(\cos\varphi + \overline{PK}\sin\varphi(a^2\sin^2\varphi + b^2\cos^2\varphi)^{-0.5}) \\ y(\varphi) = b(\sin\varphi + \overline{PK}\cos\varphi(a^2\sin^2\varphi + b^2\cos^2\varphi)^{-0.5}) \end{cases} \tag{2}$$

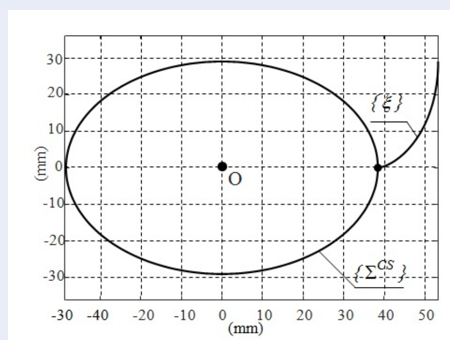

Figure 3: The involute of an ellipse

Figure 3 is an example of the involute of an ellipse curve with the parameters of the base ellipse: $a = 39.37$ mm, $b = 30$ mm and $\varphi \in [0; 0.5\pi]$.

The designing parameters of the rack cutter for NCG generating

Litvin[19] proposed the NCG tooth profile generation methods basing on the enveloping theory described in Figure 4. In this method, the rack cutter was used to generate a tooth profile for the mating NCG 1 and 2 by the pure rolling motion of the pitch line on the rack cutter $\{\Sigma^S\}$ with the two centrodes $\{\Sigma^{L_1}\}$ and $\{\Sigma^{L_2}\}$ of the NCG 1 and 2. So, the rack cutter $\{\Sigma^S\}$ is meshing with NCG 1 and 2 in the process of tooth profile generation. Therefore, when there is a curve for the tooth profile of an NCG 1, the profile of the mating rack cutter can surely be identified.

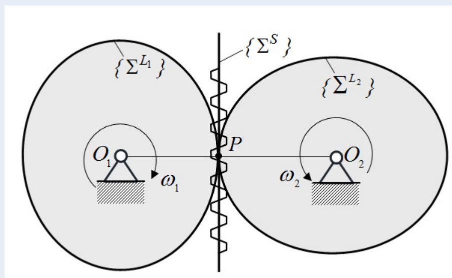

Figure 4: NCGs tooth profile generation methods

In this study, we have based on this theory to identify the parameters of the rack cutter for generating NCG with the profile of the involute of an ellipse. On the other hand, the design parameters of the rack cutter are determined as[20] (1) m_t module - size; (2) α_t pressure angle - profile; (3) w_t pitch of teeth, which are described in Figure 5.

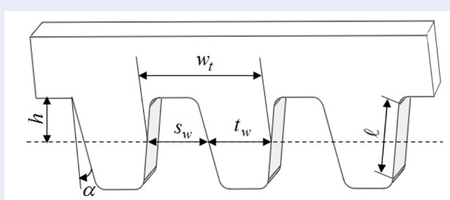

Figure 5: The designing parameters of rack cutter

Module m_t

In order to have the right meshing condition, the two mating NCG 1 and 2 should be of the same module[9]:

$$m_1 = m_2 = m_t \tag{3}$$

The size of the rack cutter inclusive of tooth pitch - w_t, tooth thickness - t_w, space width - s_w(see Figure 5) is calculated as follows:

$$s_w = t_w = 0.5w = 0.5\pi m_t$$

Pressure angle - α_t

As in Figure 6, the pressure angle - α_t of the rack cutter is generally calculated give by:

$$\alpha_t = arc\tan\left(\left(s_1 -{}^t x_K\right)^t \left(y_K^{-1}\right)\right) \tag{4}$$

Therefore, if $\vartheta_f\left\{O_f, x_f, y_f\right\}$ is called the coordinate system attaching to the beam; $\vartheta_t\left\{O_t, x_t, y_t\right\}$ is called the coordinate system attaching to the rack cutter; and $\vartheta_1\left\{O_1, x_1, y_1\right\}$ is called the coordinate system attaching to NCG 1 at O_1 rotation center (in Figure 7), during the tooth profile generation process of NCG (see Figure 7), then *(i)* rack cutter will make a translational motion distance of $s_1(\varphi)$ with the direction of x_f from the beam; *(ii)* NCG will make two motions inclusive of *a)* translational motion with the direction of y_f for a distance of $s_3(\varphi)$ and *b)* a rotation about of O_1 with an angle of φ.

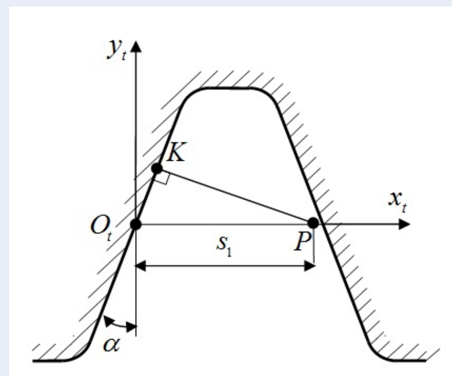

Figure 6: Geometric relation between α and s

This process, $s_1(\varphi) = \overline{O_t P}$ is the translational distance between O_t and P, corresponding to the translational distance between P' and P when NCG 1 rotates around O_1 and moves translationally toward y_f, P is the instantaneous center of rotation with K point; $\left({}^t x_K, {}^t y_K\right)$ is the coordinate of K point of the rack cutter in the coordination system of $\vartheta_t\left\{O_t, x_t, y_t\right\}$.

We need to identify $s_1(\varphi)$ and $\left({}^t x_K, {}^t y_K\right)$ parameters with the already - known $K \in \{\xi\}$ in the $\vartheta_1\left\{O_1, x_1, y_1\right\}$ coordinate system of NCG. If P' is called the joint belonging to $\{\Sigma^{L_1}\}$; φ is called the rotation angle of NCG1 around O_1 to move P' of $\{\Sigma^{L_1}\}$ to coincide with P instantaneous rotation center; $s_1(\varphi)$ is the translational distance toward $O_t x_t$ direction to move O_t of $\left\{\Sigma^S\right\}$ to the instantaneous a rotation center, which is identified as follows:

$$s_1(\varphi) = \widehat{PP'}(\varphi) = \int_0^{\varphi}\left(\left(r_P(\varphi)\right)^2 + \left(\frac{dr_P(\varphi)}{d\varphi}\right)^2\right)^{0.5} d\varphi \tag{5}$$

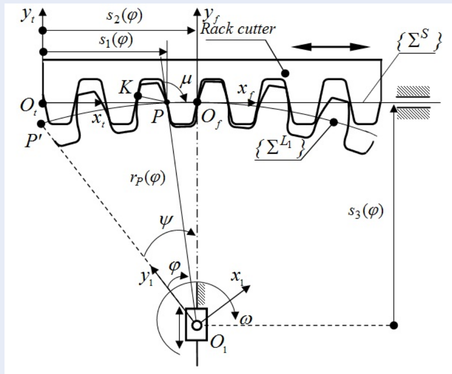

Figure 7: Tooth profile generation process of NCGs by the rack cutter

From Equation (5), φ angle can be identified if we know the values of $s_1(\varphi)$. The mathematical model of the mating rack cutter and NCG profile can be identified as follows:

$$ {}^t r_K = {}^t M_f^f M_1^1 r_K \tag{6} $$

Where: ${}^1 r_K = \begin{bmatrix} {}^1 x_K & {}^1 y_K & 0 \end{bmatrix}^T$ and $({}^1 x_K, {}^1 y_K)$ are the coordinate of K point, belonging to NCG profile in $\vartheta_1\{O_1, x_1, y_1\}$ coordinate system; ${}^f M_1 = \begin{bmatrix} \cos\psi(\varphi) & \sin\psi(\varphi) & 0 \\ -\sin\psi(\varphi) & \cos\psi(\varphi) & s_3(\varphi) \\ 0 & 0 & 1 \end{bmatrix}$; ${}^t M_f = \begin{bmatrix} 1 & 0 & -s_2(\varphi) \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$; $s_2(\varphi)$ is the parameter identifying the location of $\vartheta_t\{O_t, x_t, y_t\}$ coordinating system and $\vartheta_f\{O_f, x_f, y_f\}$ coordinating system; $s_3(\varphi), \psi(\varphi)$ are the parameters identifying coordinating system and $\vartheta_f\{O_f, x_f, y_f\}$ coordinating system. From the Equations (4 - 6), the algorithm identifying α pressure angle of the rack cutter is generated as in Figure 8.

In the above algorithm diagram, $\triangle s_1$ is the increment of s_1, δ_1, δ_y are the accuracy of the generation profile of the rack cutter compared to profile theory. These parameters decide the accuracy of the algorithm to identify *a* pressure angle of the rack cutter with the given *a, b* parameters of $\{\Sigma^{L_1}\}$.

By applying the theoretical basis presented above and algorithm in Figure 8 to design the rack cutter for generating the elliptical gear pair with elliptical centrode and transfer function described in Figure 9. Ellipse centrode $\{\Sigma^{L_1}\}$ *and* $\{\Sigma^{L_2}\}$ have the original design parameters $a = 22$ (mm), $b = 13.5$ (mm).

In order to have the tooth number as an integer, the author has applied the tooth allocation method on NCGs, which was presented in Thai *et al.* (2021)[21]. The calibration parameters of NCGs centrode and designing parameters of rack cutter are shown in Table 1.

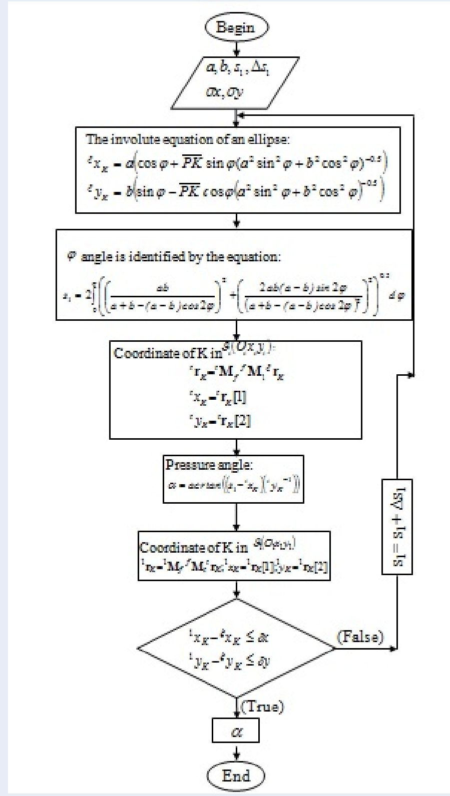

Figure 8: A diagram of algorithm identifying pressure angle α

Designing tooth profile of elliptical gears

On the basis of the centrode and the transfer function of NCGs, applying the designing methods presented in Thai *et al.* (2021)[21], the NCGs designing parameters in Table 2 and the post-programing designing results in Figure 10.

It can be seen from Figure 10b that with the designing parameters of the rack cutter in Table 1 and the contact of the pitch of rack cutter and NCGs centrode, the undercutting phenomenon occurs in NCGs tooth profile. To avoid this phenomenon, favorable conditions have been created hereafter.

Table 1: The designing parameters of the rack cutter

Ellipse base					
Preliminary calculation	Exact parameters				
a_{sb} (mm)	b_{sb} (mm)	z_{sb} (tooth)	a (mm)	b (mm)	z (tooth)
22	13.5	36.47	21.60	13.5	36
Rack cutter					
m_t (mm)	s_w (mm)	t_w (mm)	w_t (mm)	α_t (^{o})	
1	1.57	1.57	3.14	8.59	

Table 2: NCGs designing parameters of the involute of an ellipse

Item	Unit	NCGs	Rack cutter
Number of teeth (z)	tooth	36	-
Module (m)	mm	1	1
Pitch of teeth on elliptical pitch (w)	mm	3.14	3.14
Tooth thickness on elliptical pitch (s)	mm	1.57	1.57
Space width on elliptical pitch (t)	mm	1.57	1.57

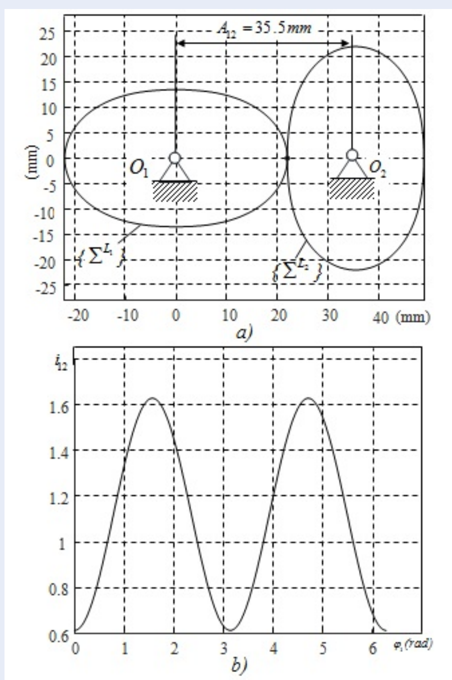

Figure 9: External meshing NCGs with a) Centrode of NCGs and b) transfer function of NCGs

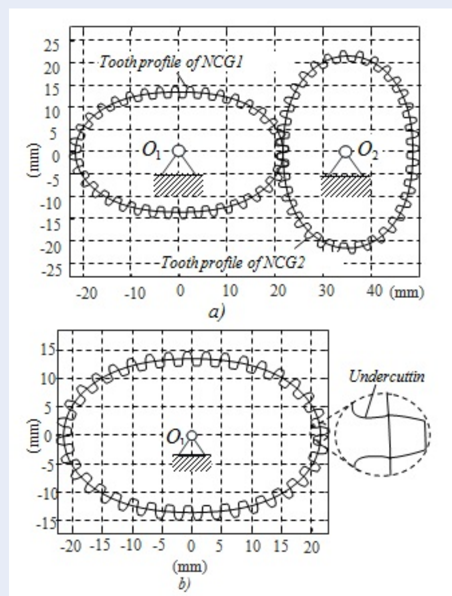

Figure 10: Tooth profile of the undercutting NCGs with a) NCGs after tooth profile generation and b) NCG1 after tooth profile generation

THE CONDITION FOR UNDERCUTTING AVOIDANCE

In order to avoid undercutting, the equation of tooth profile should satisfy[22]:

$$\begin{vmatrix} \frac{dx_t}{d\lambda} & -v_{trx}^{(t1)} \\ \frac{\partial f(\varphi)}{\partial \lambda} & \frac{\partial f(\varphi)}{\partial \varphi}\frac{d\varphi}{dt} \end{vmatrix} = \begin{vmatrix} \frac{dy_t}{d\lambda} & -v_{try}^{(t1)} \\ \frac{\partial f(\varphi)}{\partial \lambda} & \frac{\partial f(\varphi)}{\partial \varphi}\frac{d\varphi}{dt} \end{vmatrix} = 0 \quad (7)$$

$f(\varphi) = \lambda - h\cos^{-1}\alpha - s_1(\varphi)\sin\alpha - 0.5\pi m \sin\alpha$

This can be identified from the meshing equation with λ as the length of the working region on the rack cutter; $h = m$ as an addendum (see Figure 5); $v_{tr}^{(t1)} = \omega\left(y_t i_t + (s_1(\varphi) - x_t)\, j_t\right)$ as the relative velocity at the contact point between the rack cutter and tooth profile of NCGs with $\omega = d\gamma/dt$ as the angular velocity of NCGs in the tooth profile generation process with γ as the rotation angle of the power shaft[23]. The determinant (7) about the condition for undercutting avoidance is dealt with as follows:

$$\frac{\partial s_1(\varphi)}{\partial \gamma}\sin^2\alpha = h - \lambda\cos\alpha \quad (8)$$

Note: $\partial s_1(\varphi)/\partial\gamma = \rho$ [24] is the radius of curvature of $\{\Sigma^{L_1}\}$. With $\lambda = 0$ at the initial point of the working region of the rack cutter, we can identify $h = m(1-\delta)$ with δ as the amount of positive shifting (see Figure 11).

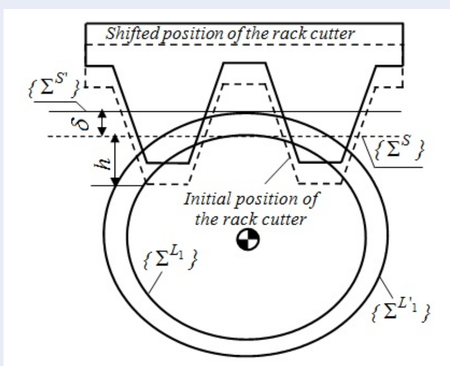

Figure 11: Shifting of the rack cutter

The condition for undercutting avoidance is calculated as follows:

$$m(1-\delta) \le \rho_{min}\sin^2\alpha \quad (9)$$

ρ_{min} is the minimum radius of curvature of $\{\Sigma^{L_1}\}$.

From the Equation (9), with the values of ρ_{min} and the fixed α, we have two solutions for ndercutting avoidance as follows:

i) At negative shifting, we need to select the gear module as follows:

$$m_{max} = \rho_{min}\sin^2\alpha \quad (10)$$

ii) When the module is known, the minimal shift amount of the gear is as follows:

$$\delta_{min} = \left(\rho_{min}\sin^2\alpha - m\right)m^{-1} \quad (11)$$

It can be seen from (10) and (11) that there are two solutions for undercutting avoidance. The solution of positive rack cutter shifting is more favorable for its convenience. The solution of module changing is hardly selected as for its requirement to re-design the rack cutter. Figure 12 shows the results after the positive shifting when re-generate NCG profile with the rack cutter parameters and gears from the example (in above), and using the undercutting avoidance condition in the Equation (11), we have got the minimal shifting of $\delta_{min} = 0.6985$ (mm); choose $\delta = 0.7$ (mm).

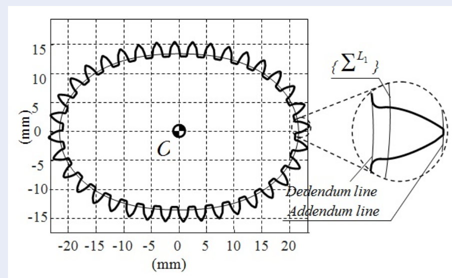

Figure 12: NCG profile after shifting

It can be recognized from Figure 12 that the undercutting has been avoided but the tooth crest and the toe have shifted outside of the center. This has increased the gear size and the deviation of the meshing rule, which leads to tooth intersection. To satisfy the meshing condition without tooth intersection, the center distance should be increased, causing the increase of the gear train size. Therefore, to keep the center distance and centrode size unchanged, we need to adjust the ellipse base.

THE ALGORITHM TO ADJUST ELLIPSE BASE

As analyzed in Section 3, to overcome the above phenomenon, we need to adjust the ellipse base so that the centrode of the NCGs coincides with the pitch line of the gear after generating. The adjusted ellipse base should (1) meet the requirements to avoid undercutting and (2) ensure the allocation of the tooth number on NCG[21]. The algorithm which was used to determine the size of the ellipse base is shown in Figure 13. In the algorithm diagram above $\triangle\delta$ is an increment of the coefficient determining the size of elippse base (δ). To make the NCGs centrode coincide with the pitch line of the gear after generating, we need to shift the rack cutter with a translational distance of δ.

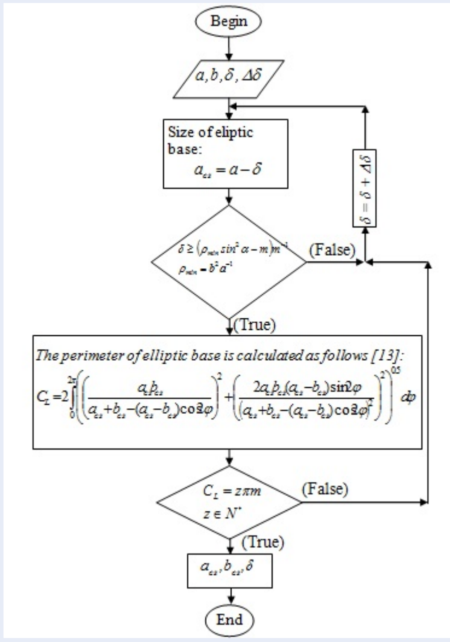

Figure 13: The algorithm to determine the eliptic base[13]

In the algorithm in Figure 13, if both conditions are false cannot find d, then must select parameters a, b of the basic ellipse $\{\Sigma^{CS}\}$ again.

RESULTS AND DISCUSSION

By using the designing parameters in Section 2 and the algorithm in Figure 13, we have got the elliptic base parameters after adjusting in Table 3, and the adjusting results in Figure 14.

The NCGs profile after adjusting the elliptic base has met the meshing requirements and ensure (1) the undercutting avoidance and (2) tooth allocation on NCGs. To compare between the tooth profile generated from the involute of a circle[9,10] and that from the involute of an ellipse, we used the respective circular gear method of Litvin[8] and have obtained the results shown in Figure 15. $\{\xi^C\}$ is the involute of a circle, while $\{\xi\}$ is the involute of an ellipse.

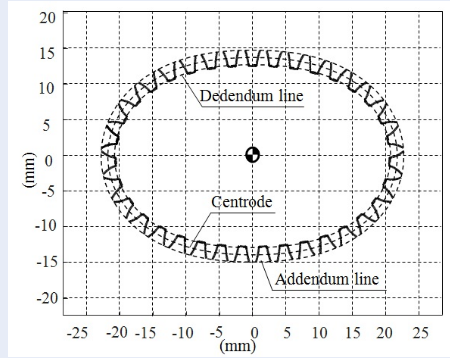

Figure 14: NCGs profile after adjusting ellitic base

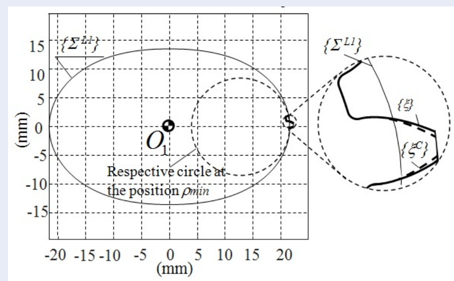

Figure 15: A comparison between the involute of a circle and that of an ellipse

It can be seen from Figure 15 that the curvature radius of the involute of an ellipse is bigger than that of the involute of a circle. So, the contact resistance of this involute (of an ellipse) is higher, which is its advantage. Especially, as the teeth of NCGs are located differently, they have different supporting strengths. The results of this research have overcome the uneven tooth pitch on the centrode of the ellipse gear that the studies[2,3,8,15,17] have not mentioned. In addition, this study also provides the gear manufacturing practice by a different curve with an involute circle curve traditional to make the tooth profile of the ellipse gear.

CONCLUSIONS

The finding of this study is the proposal on the involute of an ellipse as the tooth profile of NCGs, which has the advantage of higher tooth contact resistance. The study also proposed: *(1)* The methodology for designing the rack cutter for generating NCG as the involute of an ellipse, and the conditions for undercutting avoidance; *(2)* The method for adjusting the ellipse base to ensure the unchanged axial distance and

Table 3: Adjusting parameters for the elliptic base

Before		After	
a (mm)	(mm)	a (mm)	(mm)
21.6005	13.5	21.0875	12.9870

not transmission ratio error. The above research results are important for creating new NCG gear trains which have advantages over the previous studies on the degree of tooth contact resistance.

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CONFLICT OF INTERESTS

The author declares that there is no conflict of interests regarding the publication of this paper.

AUTHOR CONTRIBUTION

Nguyen Hong Thai is in charge of all research content presented in the article.

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Bài nghiên cứu

Tạo hình biên dạng răng của bánh răng elíp bằng đường cong thân khai elíp

Nguyễn Hồng Thái*

TÓM TẮT
Bánh răng không tròn với ưu điểm nhỏ gọn, kết cấu cơ khí đơn giản trong việc tạo ra các bộ truyền có tỷ số truyền thay đổi trong công nghiệp, do đó đây là một chủ đề đang được nhiều nhà khoa học quan tâm nghiên cứu. Tuy nhiên, cho đến hiện tại các nghiên cứu thường chỉ tập trung vào các loại bánh răng không tròn có biên dạng răng là đường cong thân khai của đường tròn, còn các loại đường cong khác chưa được ứng dụng trong thiết kế bánh răng không tròn. Trong bài báo này tác giả đề xuất ứng dụng đường cong thân khai của elíp trong tạo hình biên dạng răng của cặp bánh răng elíp bằng dao thanh răng. Một thanh răng có biên dạng răng là các hình thang cân được xác định từ đường đường cong thân khai elíp được chọn làm biên dạng răng của bánh răng không tròn. Để không xảy ra hiện cắt lẹm chân răng và hiện tượng nhọn đỉnh răng khi tạo hình, hai thuật toán hiệu chỉnh đường elíp cơ sở theo sự phân bố đều các răng và điều kiện cắt lẹm chân răng được thực hiện. Một môđun phần mềm tính toán số được viết theo lý thuyết và thuật toán được thực hiện để khảo sát các trường hợp khác nhau trong quá trình thiết kế. Với kết quả của nghiên cứu này cho thấy các răng được phân bố đều trên toàn bộ chu vi của vành răng khắc phục được hiện tượng răng không đều về hình dạng hình học và kích thước khi sử dụng đường thân khai của đường tròn như một số nghiên cứu khác đã chỉ ra. Ngoài ra, với biên dạng thân khai elíp góc áp lực được tăng lên làm tăng khả năng truyền lực của bộ truyền. Do đó, đây là ưu điểm của biên dạng mới trong việc tạo ra các bộ biến đổi vô cấp cho các kịch bản ứng dụng khác nhau trong công nghiệp như các bộ biến đổi vô cấp của ngành công nghiệp ô tô hay các thiết bị y học hiện đại.

Từ khoá: bánh răng elíp, bánh răng không tròn, đường thân khai của elíp, thanh răng sinh, góc áp lực, thuật toán, bánh răng sinh

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