CZASOPISMO TECHNICZNE M
WYDAWNICTWO POLITECHNIKI KRAKOWSKIEJ

z. 3-M/2008
ISSN 0011-4561
ISSN 1897-6328

ANNA ULATOWSKA*

PARAMETRIC 3D MODEL OF A PLANETARY GEAR MOTOR

PARAMETRYCZNE MODELOWANIE 3D HYDRAULICZNYCH SILNIKÓW OBIEGOWO-KRZYWKOWYCH

A b s t r a c t

The paper describes solid modelling application in design and understanding the construction and working principles of gear motor. Most computer programs create engineering models via 2-D drawing, 3-D wire-frames or 3-D surface models. Complete product description, down to the proper dimensioning scheme and tolerances were impossible. This changed with the introduction of parametric modelling allows the designer to let the characteristic parameters of a product drive its design. In the case of gear designers the key dimensions that would describe the gear include diametric pitch, pressure angle, root radius, and tooth thickness. The parameters also cover key process information such as hardening specifications, quality grades, and metallurgical properties together with load classification for the given gear. In the present study a 3D model of a motor has been generated in Pro/Engineer. It can be concluded that the feature-based parametric modelling systems allow CAD/CAM/CAE software to become a more integral part of product design process.

Keywords: *CAD system, parametric modeling*

S t r e s z c z e n i e

W artykule przedstawiono zastosowanie aplikacji modelowania bryłowego w systemach CAD i zaproponowano sposób zaprojektowania i zrozumienia budowy oraz zasady działania silnika przekładniowego.
W artykule podjęto zadanie modelowania parametrycznego hydraulicznych silników obiegowo-krzywkowych. Silniki obiegowo-krzywkowe są złożonymi urządzeniami, w których wykorzystuje się przekładnie z kołami zębatymi o kształtach nieokrągłych. Zbudowanie zwykłego modelu 3D takiego silnika jest bardzo złożone, dlatego też postawiono sobie zadanie parametryzacji w celu umożliwienia szybszego wykonania rodziny tego typu silników. Do budowy modelu parametrycznego zastosowano program Pro/Engineer. Stworzono algorytm, za pomocą którego wykonano model silnika w sposób programistyczny. Dzięki zastosowaniu parametryzacji zdefiniowano podstawowe parametry projektowe, takie jak: średnica podziałowa, kąt przyporu, promień zaokrąglenia dna rowka i grubość zęba. Mogą być one użyte jako parametry definiujące koło zębate.

Słowa kluczowe: *silnik obiegowo-krzywkowy*, *parametryzacja*, *modelowanie*

*Anna Ulatowska, MSc, supervisor: Edward Lisowski, PhD, DSc, prof. of CUT, Institute of Applied Informatics, Cracow University of Technology.

Denotations

n – number of satellites
L_z – number of teeth
m – module pitch of a gear [mm]
α – pressure angle [deg]
x – addendum modification coefficient
y – tooth altitude coefficient
r_1, r_2 – pitch curve radius [mm]
g – gear thickness [mm]
d – pitch diameter [mm]
d_b – involutes diameter [mm]
c – tip clearance [mm]
h_a, h_f – tooth point addendum and tooth root dedendum
d_a, d_f – tooth point and tooth root diameter
p_r – root radius
d_s – planet gear diameter [mm]
a, b – local co-ordinate systems to primary co-ordinate systems distances

1. Introduction

In spite of intensive development of CAD systems modelling of entities with difficult geometry may pose considerable problems. To accelerate the modelling, libraries and parametric modelling is frequently utilised. Many CAD systems offer a wide variety of facilities in respect to parametric modelling. It provides a simple way of model modification. However, if programming-like approach to create the model is required, a lot of difficulties may occur during this process.

A method of defining a geometrically complex structure of a cam planet gear motor has been suggested in the present paper. Additionally, an algorithm generating the parametric model of this engine has been determined. Such a modelled object using Rapid Prototyping has been manufactured at the Bergen University College (Norway).

2. Geometrical dependence

Curves describing the external and internal gear wheel profile are trochoids with a different number of cycles. Depending on trochoids' number of cycles the number of satellite wheels varies. The number of satellite wheels equals to the sum of cycles of external gear wheel trochoid and internal gear wheel trochoid

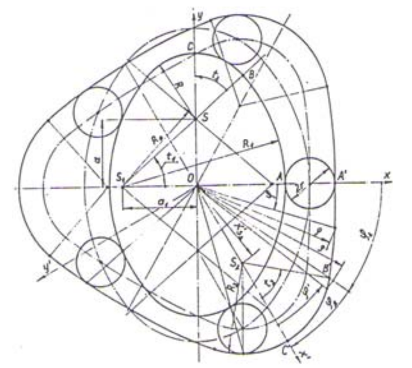
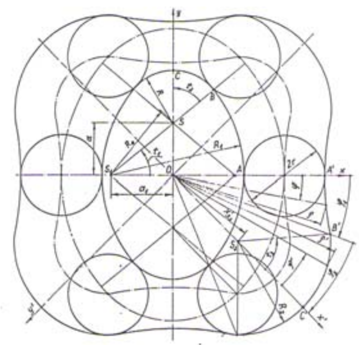
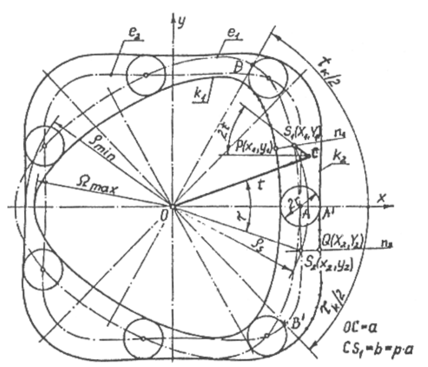
$$n = k + l \tag{1}$$

where:

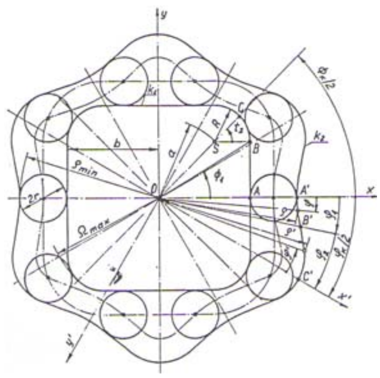
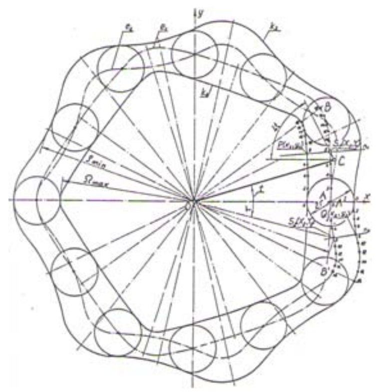
n – number of satellites,
k – number of cycles of internal gear wheel trochoid,
l – number of cycles of external gear wheel trochoid.

Table 1

Curves describing the gear wheel profiles

Number of satellites	Number of cycles of internal gear wheel trochoid	Number of cycles of external gear wheel trochoid	Curves describing the gear wheel profiles
1	2	3	4
5	2	3	
6	2	4	
7	3	4	

cd. tab. 1

1	2	3	4
10	4	6	
12	5	7	

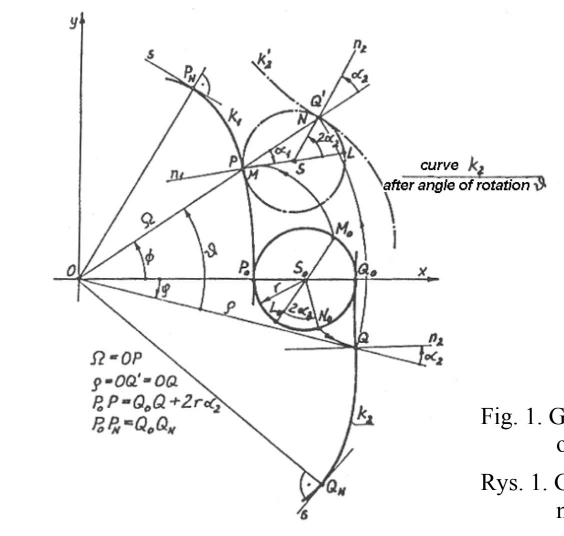


Fig. 1. Geometrical coordination conditions of non-circular gear

Rys. 1. Geometryczne warunki współpracy nieokrągłych kół zębatych

For a motor with seven satellites the curve describing the internal gear wheel profile is trochoid of three cycles and the curve describing the external gear wheel profile is trochoid of four cycles.

To make a reciprocal motion possible the curves describing the external and internal gear wheel profile must not overlap and the distance between them in the locus where the satellite wheel is located must meet involute gear conditions.

3. Parametric notation of geometry

Modelling of toothed elements of motor using 1st, 2nd and 3rd order curves defined in several co-ordinate systems, located in space, is proposed.

For the discussed case (the planet wheel of cam planet gear motor, whose outline contour is a trochoid with three cycles) six local co-ordinate systems have been defined. These co-ordinate systems have been translated from the global co-ordinate system and described in polar coordinates. Using the command Relations, in Pro/Engineer system, the location parameters have been introduced. The corresponding parameters defining the position of coordinate systems in space have been set as the system variables.

Figure 2 shows the spatial arrangement of local co-ordinate systems.

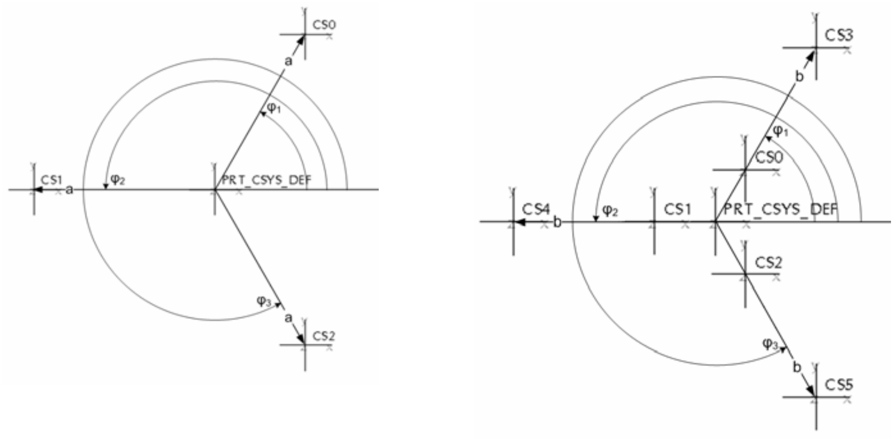


Fig. 2. Spatial a local co-ordinate systems, on the left CS0, CS1, CS2, on the right CS3, CS4, CS5

Rys. 2. Rozmieszczenie lokalnych układów współrzędnych, z lewej CS0, CS1, CS2, z prawej CS3, CS4, CS5

The next stage was to make curves describing the gear wheel profile and generating solid on the basis of this profile. The Profile was created on the grounds of six tangent arc– a fragment of circles (Fig. 3) of two different radii.

Similarly, a pitch curve and a tooth root curve were defined. The tooth tip curve (gear wheel profile) and the tooth root curve along with involute curves determine the involute tooth form.

The involute was written using the equation of involute to a fundamental circle (gear wheel profile). Tooth form parametrical for every fragment of planet (for every fragment

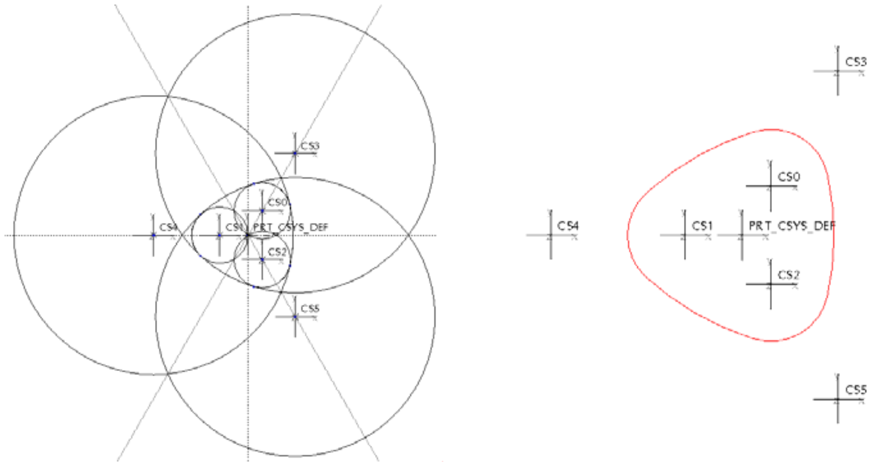
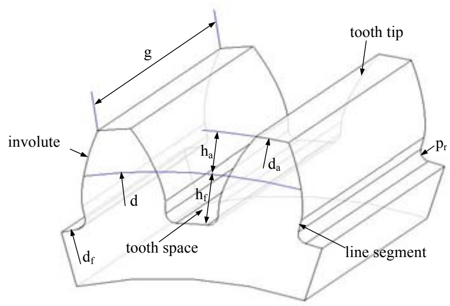


Fig. 3. The circles creating internal gear wheel profile – trochoids with three cycles
Rys. 3. Okręgi tworzące linię toczną wewnętrznego koła zębatego o liczbie cykli trochoidy równej 3, z prawej zarys planety silnika obiegowo-krzywkowego

of circle) was written in a separate local co-ordinate system. The tooth form and parameters describing it are shown in Fig. 4.



d – pitch diameter,
d_f – tooth root diameter,
d_a – tooth tip diameter,
h_f – tooth root dedendum,
h_a – tooth point addendum,
p_r – root radius,
g – gear thickness

Fig. 4. Parameters describing tooth involutes
Rys. 4. Parametry opisujące kształt zęba

Parametric notation of tooth form was made using command Relations. In the window of this command equations and relations defining involute gear teeth were introduced [3].

$$d = L_z \cdot m \tag{2}$$

$$c = 0{,}2 \cdot m \tag{3}$$

$$h_a = (y + x) \cdot m \tag{4}$$

$$h_f = (y - x) \cdot m + c \tag{5}$$

$$d_b = d \cdot \cos(\alpha) \tag{6}$$

$$d_a = d + 2 \cdot h_a \tag{7}$$

$$d_f = d - 2 \cdot h_f \tag{8}$$

$$\alpha_d = \arccos\left(\frac{d_b}{d}\right) \tag{9}$$

$$\phi = \frac{\tan(\alpha_d) \cdot 180}{\pi} - \alpha_d \tag{10}$$

$$\theta_b = \frac{90}{L_z} - \frac{360 \cdot x \cdot \tan(\alpha)}{d \cdot \pi} - \phi \tag{11}$$

$$p_r = \frac{(d_b - d_f)}{6} \tag{12}$$

where:

- d – pitch diameter,
- c – tip clearance,
- h_a – tooth point addendum,
- h_f – tooth root dedendum,
- d_b – involutes diameter,
- d_a – tooth point diameter,
- d_f – tooth root diameter,
- α_d – thread angle,
- ϕ – angle-coordinare of curve k1,
- θ_b – beginning involute unrolling of base circle,
- p_r – root radius.

The equations of involutes for corresponding co-ordinate systems were written using command Insert > Datum > Curve/From Equation.

Table 2

Involutes equations describing tooth form

Curves denotation	Mathematical notation	Notation in Pro/Engineer
Curve id 70	$r = -\left(\frac{d_b}{2} + \frac{t \cdot (d_a - d_b)}{2}\right)$ $a = \arccos\left(\frac{d_b}{2 \cdot r}\right)$ $\theta = \left(\mathrm{tg}(a) \cdot \frac{180}{\pi} - a - \theta_b\right)$ $z = 0$	/*------------------------------ r=-(db/2+t*(da-db)/2) a=acos(db/(2*r)) theta=tan(a)*180/pi-a-teta_b z=0
Curve id 72	$r = -\left(\frac{d_b}{2} + \frac{t \cdot (d_a - d_b)}{2}\right)$ $a = \arccos\left(\frac{d_b}{2 \cdot r}\right)$ $\theta = -\left(\mathrm{tg}(a) \cdot \frac{180}{\pi} - a - \theta_b\right)$ $z = 0$	/*------------------------------ r=-(db/2+t*(da-db)/2) a=acos(db/(2*r)) theta=-(tan(a)*180/pi-a-teta_b) z=0

On the basis of the generated involute curves, tooth root curve and tooth point curve of a single tooth space have been determined. It has been subsequently duplicated on each of six model fragments in relation to the axes of subsequent six local coordinate systems, respectively. In the next step the arrangement of toothing, using the parametric method, on the circumference of the planet wheel has been performed. Parametric notation of this and the previous operation is shown in Fig. 5.

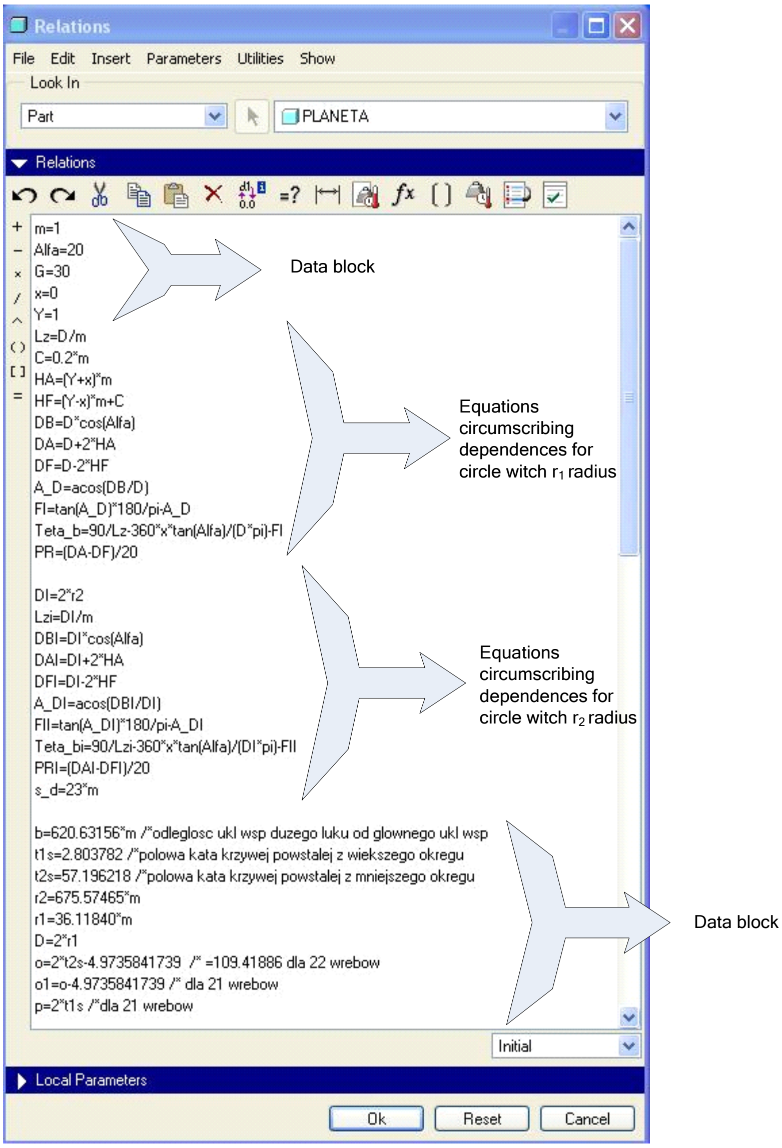


Fig. 5. Code in Relation window
Rys. 5. Kod programu w oknie polecenia Relation

Fig. 6. Model of cam planet gear motor manufactured
by Rapid Prototyping method
Rys. 6. Model silnika obiegowo-krzywkowego wykonany
metodą Rapid Prototyping

Similarly redisual toothed elements of cam planet gear motor were created and manufactured using Rapid Prototyping method. Figure 6 illustrates this model.

References

[1] Balawender A., *Analiza Energetyczna i Metodyka Badań silników Hydraulicznych Wolnoobrotowych*, Zeszyty Naukowe Politechniki Gdańskiej, Nr 422, Gdańsk 1988.

[2] Kujawski M., *Mechanizmy obiegowe z nieokrągłymi kołami zębatymi*, Podstawy projektowania i wykonania, Wydawnictwa PP, Poznań 1992.

[3] Lisowski E., *Modelowanie geometrii elementów, złożeń oraz kinematyki maszyn w programie Pro/Engineer Wildfire*, Wydawnictwo PK, Kraków 2005.

[4] Katalog Hydroster, http://www.hydroster.com.pl/index.php.