TRAJECTORY OF THE APEX SEALS OF THE WANKEL ROTARY ENGINE

Piotr Drogosz

University of Warmia and Mazury
Technical Sciences Faculty, Department of Mechatronics
Słoneczna Street 16A, 10-710 Olsztyn, Poland
phone: +48 89 5245101, fax: +48 89 5245150
e-mail: piotr.drogosz@uwm.edu.pl

Abstract

This article describes the basic principles for determining the trajectory of the apex seals of Wankel rotary engines. An attempt is made as the Wankel engine seems to be the convenient as the burning hydrogen fuel engine. The main advantage is particularly intensive cooling. The main disadvantage is high pollution of combustion gases. Analyzing the working constructions it is possible to find the main sources of pollution. After all it seems that specific work of rotating piston seals are the main reason of usage big volume of lubrication oil. But part of lubrication oil is burnt together with the fuel increasing the pollution. Even using hydrogen as fuel it remains difficult to meet EURO V regulations of combustion gases pollution made by transport vehicles. Every possibility of volume reduction of lubrication oil is important. In the article the trajectories of apex seals are discussed. As the mathematical model of trajectory a special formula of trochoid was chosen. The main advantages of the chosen form of mathematical equation are applications of two main parameters: curve size parameter and dimensionless curve parameter. These two parameters decided about convenience in changing volume of internal combustion engines and comparisons of performance characteristic of different Wankel engines. In other publications connected with Wankel motors more complicated mathematic formulas are still used.

Keywords: *Internal combustion engines, Wankel rotary engines, trochoid, seals, equidistant*

1. Introduction

Various kinds of pumps, compressors, pneumatic motors, hydraulic motors and combustion engines in which rotary pistons are used are known [2]. Ramelli's sliding vane rotary pump of 1588 is considered to be the first example of this type of construction. Several steam engines using rotary pistons of various types were produced in the 19th century. Similar internal combustion engines were produced in the 20th century, with both spark-ignition and auto-ignition (in Diesel engines). The most famous engine of this type is the internal combustion engine (with a rotary piston and spark ignition) based on Wankel's patent. Experimental engines of this type and engines for special use have been used for powering boats and even aircraft. Other power platforms using rotary pistons are used most often in compressors, pneumatic engines, pumps and hydraulic motors. In all of these power transforming machines the continuous and tight separation of working volumes is necessary. To achieve this necessary condition the correct and effective work of seals is needed. But this aim is difficult to achieve. In general, this creates the main serious construction difficulties in production and exploitation of all volumetric power platforms with rotary pistons. Especially it applies to Wankel engine. This general rule requires tight fitting of the flat, oval rotary piston in the housing of the engine. Independently of the tight fitting of the piston, it is necessary to use special seals on the apex of the piston and the side walls of the oval piston. In Wankel engine the seals are fitting and moving together with the rotating piston.

The side walls seals function simultaneously as the chamber seals and valves seals. Geometrically, they tighten two flat surfaces which are rotating against each over. The seals are usually made of materials typically used to produce ring piston seals applied in conventional internal combustion engines. To achieve the effective work of side walls the seals must be pushed to the opposite side walls. The forces of pushing are produced by pressure of the working gas or special springs elements (actuators). The pressure over the head of seals ought to exceed the working pressure of working gas. During the rotation of the moving piston the working pressure in each chamber of the engine is changing. The floating pressure changes the pushing force of seals. It is convenient but serving spring elements are always necessary. The pushing force on the head of each plate seals makes the serious problems with friction. For that reason the correct and effective lubrication is needed. The large lubricated surface needs relatively big volumes of lubrication oil. Parts of lubrication oil burn together with the fuel. The big volumes of burning oil make it difficult to meet EURO V regulations of combustion gases pollution made by transport vehicles.

Similar issues refer to apex seals though the work of apex seals is more complicated. The main disadvantage of the work of apex seals is the complex movement they realize. This complex movement is a consequence of simultaneous rotation made by the geometric centre of the piston and the rotation made by the piston around its geometric centre. For that reason the apex of the piston moves on the cyclic flat path similar to the curve named trochoid [3]. The trajectory of apex seals needs further explanations about its construction and the construction of engine housing.

2. Construction of the apex seals

In Figure 1. we can see the commonly used construction of the apex seals:

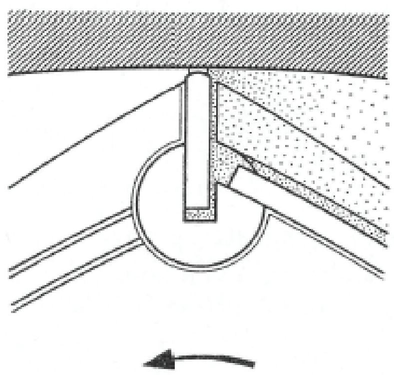

Fig. 1. Typical plate of apex seals [1]

The apex seals are made of flat plate. The material of that plate is similar to the ring piston sealing of other internal combustion engines. The length of the plate depends on the depth of the flat working chamber. The usually used height is three times longer than the thickness of the plate. The thickness depends on size and proportions of trajectory of the apex seals plate which is described in the next section. In general the mass of the seal plate will be minimal.

In Figure 2. we can see the geometric parameters of the apex seal. The most important characteristics of the apex seal are: its thickness, the trajectory of movement, and curve of the head. The trajectory will be described in next section. Thickness of the plate will be minimal because plate mass minimization is important. Less mass limits the inertial force. During rotation centripetal force depends on the mass, conversion of the radius of rotation and square of linear speed number. During the rotation radius and linear speed are changing. Radius depends on geometric trajectory of apex seals. Trajectory is constant in the chosen construction. Linear speed depends on trajectory and temporary speed of rotation. When the speed of engine is changing, the temporary speed of rotation is changing too. For that reason there are two real possibilities to influence the value of centripetal inertial force. One possibility is changing the trajectory and the other is minimization of mass of the apex seal plate. The best way is to use both these possibilities.

The thickness of the plate cannot be too small. It depends on the position of the contact point between apex seal plate and oval surface of the cylinder. This contact point moves on the head of the plate. The range of movement of the contact point on the head of the plate increases when the following increase: the whole size of the engine, the radius of apex seal head, and dimensionless curve parameter (*p*, see first equation). If a = 105 millimeters and p = 1/7 (used in the combustion engine 1.3 Wankel 13B Renesis 147 kW produced between the years 2003-2010), then $b_{\min}$ (see Fig. 2.) should be bigger than 1.74 millimeters [2] (in the combustion engine 1.3 Wankel 13B Renesis 147 kW produced between the years 2003 - 2010 the thickness of the apex seal plate is two millimetres). From this analysis we can see that the minimization of the mass of apex seals has limitations. It leads us to consider the possibilities of changing the trajectory.

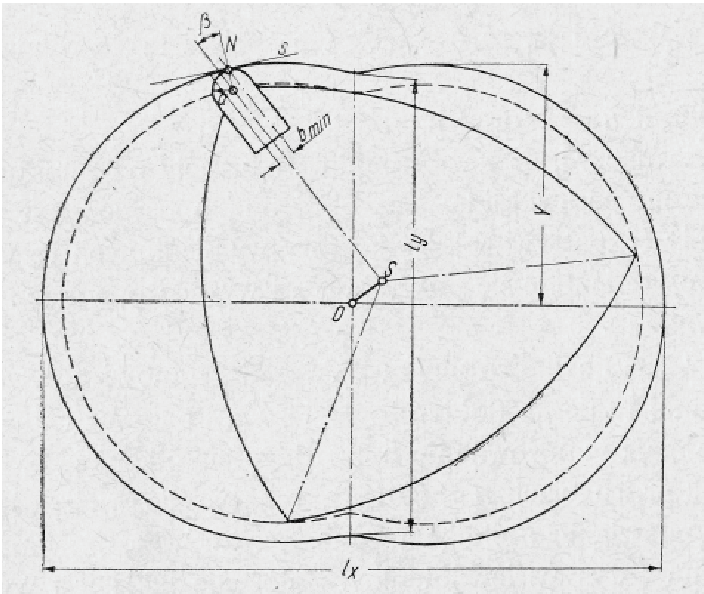

Fig. 2. Geometric parameters of the plate apex seals [2]

3. The mathematical model of the trajectory of the apex seals

In the most common construction of the Wankel engine the mass centre of apex seal plate was moving along equidistant of the trochoid. The action of first order trochoid can described the following equations [4]:

$$x = a \cdot \cos\varphi + a \cdot p \cdot \cos[\pi - (k-1)\cdot\varphi],$$
$$y = a \cdot \sin\varphi + a \cdot p \cdot \sin[\pi - (k-1)\cdot\varphi] \quad (1)$$

or

$$x = a \cdot \cos\varphi - a \cdot p \cdot \cos[(k-1)\cdot\varphi],$$
$$y = a \cdot \sin\varphi + a \cdot p \cdot \sin[(k-1)\cdot\varphi], \quad (2)$$

where:

a - curve size parameter in mm,
k - number of curve cycles in a full angle,
p - dimensionless curve parameter,
φ - independent variable (rad),
$e = a \cdot p$ - distance of the centre of rotation of the ‘triangular piston’ from the centre of rotation of the engine shaft.

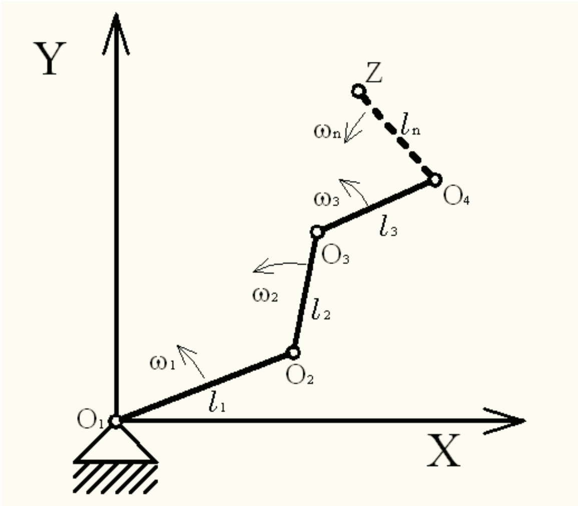

Fig. 3. Main rules of building trochoids of different orders

The main rules of building trochoids are represented in Fig. 3. We can build the trochoids by using two or more rotating elements (similar to parts of compound pendulum with many members). The first order trochoid needs two rotating elements. The second order trochoid needs three rotating elements etc. Equations (1) and (2) describe first order trochoid only. Using one of these equations it is possible to construct several trochoids, both open trochoids and closed cyclic trochoids. For constructional applications closed cyclic trochoids are the most important. In the Wankel engine we should use special closed first order trochoid with two lobs only. Examples of such curves, with various numbers of cycles resulting from the combined values of the parameter *k* and the small value of the parameter *p* are shown in Fig. 4. Fig. 5. shows the result of increasing the size of *p* parameter whilst retaining the value of parameter *k* with fixing the number of trochoid cycles. Parameter *a*, which is a coefficient of scale, defining the size of the trochoid, was changed in such a way that certain curves of each trochoid shown in Fig. 4-5 would be of the similar size.

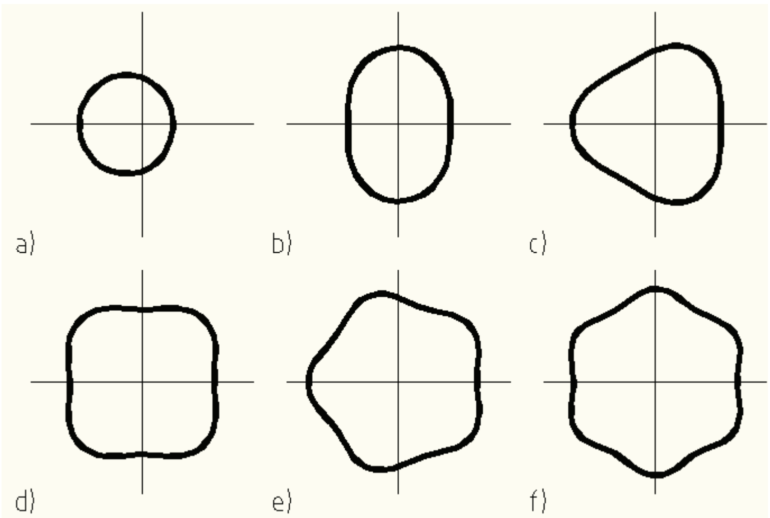

Fig. 4. Examples of trochoids with various numbers of lobes with the same certain curves (its mean different value of parameter a), the same small value of parameter p and different value of parameter k as follows: a) k =1; b) k = 2; c) k = 3; d) k = 4; e) k = 5; f) k = 6

To describe the trajectory of an apex seal we should choose some characteristic point connected with it. The best way is to choose the mass centre of apex seal plate. In Fig. 2. some other point was chosen. Fig. 2. shows the most common construction of the Wankel engine. In that

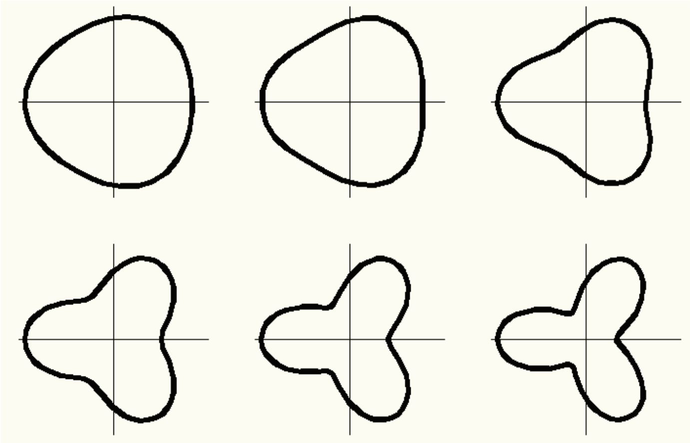

Fig. 5. Examples of trochoids with the same numbers of lobes (k=3) with the same certain curves (its mean different value of parameter a) and different value of parameter p

construction the mass centre of apex seal moved along the equidistant of the trochoid, because the oval surface of the cylinder was the trochoid. Constructions like that are convenient in production, checking and calculating. But difficulties in the work of apex seals suggest that it would be better to move the mass centre of the apex seal plate along a continuity curve of trajectory. Such a curve does not have singular points, and does not have sudden changes of acceleration. As the continuity curve we can use one of trochoids or other curves. As a result, the mathematical model of the equidistant of the trochoid or other curve will describe the shape of oval cylinder. The possibility of sliding seal plate on the apex of the rotating piston makes it possible to neglect even small errors in fitting moving parts. However, the plate sliding way in body of piston should be minimized.

Calculating, production, checking and regenerating of the Wankel engine need mathematical model of constructional shape of the projection of the cylinder surface into the surface perpendicular to the engine crankshaft. When the mass centre of the apex seal plate moves along the trochoid, the shape of oval cylinder should be taken as the equidistant to the theoretical trochoid. The name equidistant means curve equidistant to any other curve. The equidistant may be internal or external. In the case of trajectory of the apex seal plate this will be the external equidistant of the trochoid, given below as systems of four equations [4]:

$$
\begin{aligned}
x &= a\cdot\cos\varphi - a\cdot p\cdot\cos[(k-1)\cdot\varphi],\\
y &= a\cdot\sin\varphi + a\cdot p\cdot\sin[(k-1)\cdot\varphi],\\
X &= x + r\frac{\dfrac{dy}{d\varphi}}{\sqrt{\left(\dfrac{dx}{d\varphi}\right)^2+\left(\dfrac{dy}{d\varphi}\right)^2}},\\
Y &= y + r\frac{\dfrac{dx}{d\varphi}}{\sqrt{\left(\dfrac{dx}{d\varphi}\right)^2+\left(\dfrac{dy}{d\varphi}\right)^2}}.
\end{aligned}
\tag{3}
$$

where r indicate the distance between the equidistant and given curve.

The geometric notion of equidistants is closely defined. Nonetheless, in the literature, symbolic notification of equations of equidistants has very different mathematical forms. This suggests that there may be no general form for equidistant equations, and they are usually used in specific formulations. This is connected with the use of equidistants defined in relation to various curves with various equations. In equations directly connected with the geometry of Wankel engines, differences frequently occur resulting from the interchangeability of the signs '+' and '–'. This phenomenon is connected with the relation between numeric values given for parametric positions in individual equations. It relates particularly to first order trochoid equations given here as equation (1) or (2). When concrete numeric values are given for certain parameters all ambiguities disappear. However, when comparing similarly named equations which are used in the description of various constructions (or even in analogous constructions, whose preliminary curves are different) it should be noted that formal discrepancies occur which are connected with the use of the '+' and '–' signs in relation to concrete consideration of construction figures and concrete numerical values for all parameters.

5. Results

1) The correct and effective work of seals is necessary in exploitation of all volumetric power platforms with rotary pistons. In relation to Wankel engines it demands the usage of special seals on the apex of the piston and the side walls of the oval piston.
2) The main problems in work of special side walls seals in the Wankel engine are friction and lubrication. The large lubricated surface needs relatively big volumes of lubrication oil which burn with the fuel and increase exhaust gas pollution.
3) The main difficulties in the correct work of apex seals in the Wankel engine are friction, lubrication and trajectory of mass centre of apex seal plate.
4) The best trajectory of mass centre of apex seal plate in the Wankel engine is any continuity curve. As the continuity curve we can use one of trochoids or other similar curves .
5) Special equidistant of the trochoid or of other continuity curve seem to be best as the shape of oval cylinder used in Wankel engines.

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