GEOMETRY OF THE WANKEL ROTARY ENGINE

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Abstract

This article describes the basic principles for determining the geometry of Wankel rotary engines. An attempt is made to clarify if the characteristics of the rotary engine are such that the engine may be brought into more general use as an internal combustion hydrogen engine. An analysis of the data indicates that reorganizing the basic mathematical issues would be useful. Also the clarification of the names used to describe the basic curve characterizing the Wankel engine may be useful too. Now in such names and basic mathematical issues there are many differences generating many difficulties in comparison information coming from different sources. In this article one most convenient name and form of mathematical equation were chosen and described. The chosen name is the best for communication in the English language, but the other described names can be useful when comparing information from other European languages. This is the first time that the chosen form of mathematical equation is proposed to be used in accordance to construction of Wankel engines. Many other applications of the chosen form of mathematical equation ascertain proper and convenient use. The main advantages of this 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.

Keywords: *hydrogen engines, internal combustion engines, Wankel rotary engines, trochoids*

1. Introduction

At the moment there are looking for the use of hydrogen as a power source for vehicles, because various prognoses foresee hydrogen as the fuel of the future. Present predictions are that fuels based on hydrogen as the principle element will, in the longer term, supplant other ecological fuels witch at the present time are the subject of the intensive search. It also appears that the direct combustion of hydrogen in an internal combustion engine will be the most straightforward and cheapest method of accomplishing these aims. The use of hydrogen cells seen from the perspective of the present state of technical progress, will be more expensive and involve grater mass, because the additional elements are required between the fuel reservoir and the electric motor (or motors, whose power per unit of mass is about two times less in comparison to combustion engines), and because of the need to ensure the high purity of hydrogen fuel [1]. One of the first references (2004) to the direct combustion of hydrogen in a serial production of two-fuel combustion engine, earmarked for use in the Mazda RX-8 passenger car, relates to the Wankel 1.3 RE Hydrogen engine [9]. This engine is one of the technical realizations of the engine as envisaged by Felix Wankel. The manufacturer indicates that this type of engine may lend itself exceptionally well to hydrogen fuel. Such a declaration encourages the investigation of the specific characteristics of such engines, and that is way the data below is presented.

2. Principle of rotary engine operation

The energy source of a Wankel engine is the effect of pressure difference on the moveable element tightly enclosing the chamber volume, in which fuel is burned. The energy is supplied in impulses (impulse combustion). The compressibility of the combustion gases and the inertia of the driven mechanisms reduce the unsteadiness of the energy taken from the engine. Wankel type power platforms for present-day mass-produced cars are usually two combined power units with one drive shaft transmitting the mechanical power (via a hydrokinetic clutch) to the vehicle gearbox. Motorcycle engines are constructed with only one power unit. Wankel engines (after the changes developed by Paschke in 1957) are classified as valveless four-stroke combustion engines with fixed casing (theoretically, the internally rotating element working as a piston could be fixed and the rotation could be carried out by the traditionally fixed casing [3], or, as Wankel proposed in 1954, the rotary movement may be carried out by the casing and the piston simultaneously). A characteristic of mass-produced engines of this type is the shape of the combustion chamber and the oval rotary piston which fits tightly within it; these are illustrated in Fig. 1. The flat, oval rotary piston, with curved outline and resembling a triangle with rounded flanks, has a complex flat movement which is simultaneously the execution of a rotation around the geometric centre of the element and the rotary movement of that centre around a second specific point in the same plane. The flat oval surface of the cylinder has a shape somewhat similar to a symmetrical bean. A necessary condition for correct operation of the piston within the cylinder is the continuous and tight separation of each of the changing volumes which occur between the oval piston and the oval surface of the cylinder. For this reason the provision of special seals on the vertices of the piston and the side walls of the flat and oval piston is necessary. The construction and selection of sealing materials is of particular importance, since the moving internal element of the engine functions simultaneously as the piston, valve mechanism and valves, which are separate elements in a traditional combustion engine. The Wankel engine thus consists of fewer parts but its design and production is more difficult. Productions of this type engines requires an accurate working out of the geometry, appropriate production technology and high quality materials. High quality materials are a specific requirement in view of the high operating pressure (up to 12 MPa), gas temperature (up to 2500 °C) and temperature of the working parts (up to 900°C). In Wankel engines the intense friction undergone by the seals on the hot curved surface of the rotary race and the side walls of the cylinder must also be considered [2, 3].

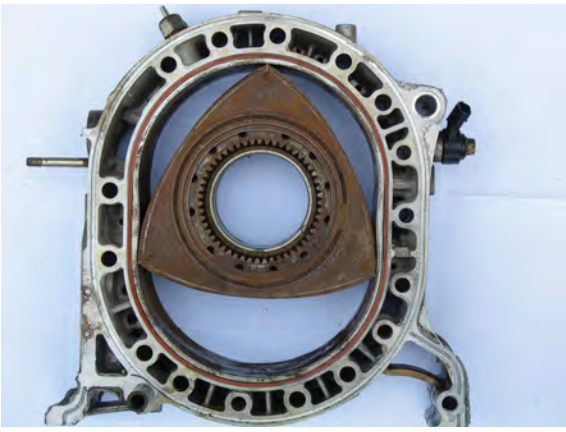

Fig. 1. Photo of flat oval rotary piston and flat oval surface of the cylinder used in combustion engine 1.3 Wankel 13B Renesis 147 kW produced between years 2003-2010 [10] and used in the Mazda RX-8 passenger car

3. Geometry of the Wankel engine

In the design of a mechanism which involves the tight working together of curved lines we find the need for a very close specification of one characteristic of the preliminary curve, to which, on the basis of conditions for ideal work, the remaining constructional drawings are to be found [8]. The same rule governs the specification of the geometry of the most characteristic elements comprising the cylinder of the Wankel engine. In the case of this construction the curve delimiting the theoretical shape of the cylinder surface on the surface at right angles to the axis of rotation of the piston was taken as the preliminary curve. In accordance with the classification of curved planes, this is a cyclically closed pericycloid [3]. Other names are found in the literature relating to this same shape. In the technical literature in Western Europe the most frequent expression is trochoid, in Eastern Europe cycloid. The expression trochoid is considered to be more scientific since it is related to the multi-element articulation theory. The term cycloid is older and is related to mechanical constructions, in which elements are used which are tightly fixed to the wheels rolling over each other without sliding. Both tasks are appropriate to name the curved plane we are interested in.

Work [7] demonstrates that each hypocycloid (hypotrochoid) has a corresponding epicycloid (epitrochoid). The pericycloid is a special case of the hypocyclid (based on [3, 5]). Putting all of this information together, we note that the basic curve characterizing the Wankel engine may be described in the following ways: pericycloid, hypocycloid, epicycloid, pewritrochoid, hipotrocoid, epitrochoid. Each of these curves may be described by equations (or one general equation as combined numbers [6]) with the same mathematical form. The differences between curves, which are attributed to the various labels mentioned above, result from the various relationships between the numerical values of various parameters occurring in the equations. The curve discussed below will be described as a trochoid. Additionally, in view of the constructional character of the applications used in mathematical analyses, the discussion here will be restricted to the simplest mathematical form of first order trochoid as in the following equations [7]:

$$\begin{aligned} x &= a\cdot\cos\varphi + a\cdot p\cdot\cos[\pi-(k-1)\cdot\varphi], \\ y &= a\cdot\sin\varphi + a\cdot p\cdot\sin[\pi-(k-1)\cdot\varphi], \end{aligned} \tag{1}$$

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.

Using equation (1) it is possible to construct several trochoids, both open trochoids and closed cyclic trochoids. For constructional applications closed cyclic trochoids are the most important.

4. Ideal conditions for the mating of Wankel engine moving parts

1. The most useful preliminary curve in the design of a Wankel engine is the curve circumscribing the geometry of the cylinder, that is, the external surface enclosing the working chamber of the engine. Theoretical it is also possible to design such an engine using as a starting point the curved figure circumscribing the internal aspect of the working chamber, i.e. the circumscription of the geometry of the rotational piston. In this case, it turns out that while fulfilling the same basis of conditions for ideal work, the shape of the external surface of the working chamber is less efficient due to the more difficult operating conditions of the circumferential seals fixed to the vertices of the piston, and also due to the slightly larger overall dimensions necessary for the whole construction whilst retaining the same engine power.
2. Among the many possibilities for the shape of the Wankel engine the most useful is that which occurs when the curve circumscribing the chamber surface (circumscribing the volume of the working chambers from the outside) has two symmetrical cycles. An example of this is shown in Fig. 1 and 2.
3. The trajectory of each theoretical apex of the piston must be the same, witch is shown in Fig. 2. For ease of realization of the construction, it is taken that such a trajectory may be described using equations for trochoids of first order as in (1).

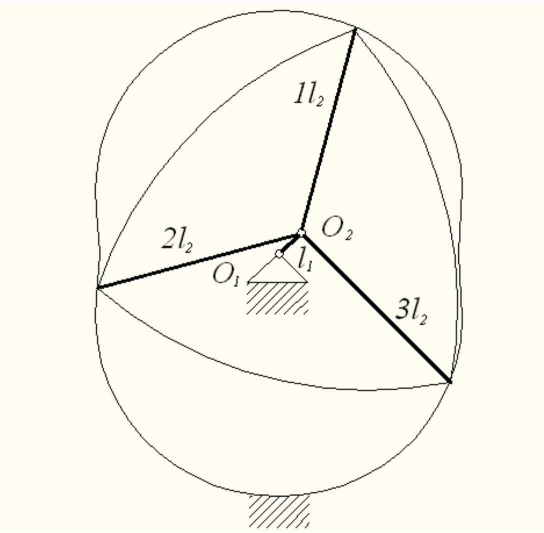

Fig. 2. Geometric scheme of the best construction of Wankel combustion engines with rotary piston. Shape of surface of the cylinder is named as cyclic closed trochoids of first order constructed by two articulation elements. Shape of such surface out to have two lobs. A necessary condition for correct operation of the engines is the special shape of the piston, which out to have three vertices moving one after the other on the same path

4. The outline of the moving internal element functioning as a piston on the surface perpendicular to the axis of its rotation and fixed with it is the internal envelope of the curved internal surface on the housing wall which is rotating around its axis of symmetry and axis of symmetry of crankshafts. This envelope is shown in Fig. 3. For technical reasons usually it is used a slightly smaller outline of the piston approximating the exact internal envelope by the biggest possible radius which we can see in Fig. 4.

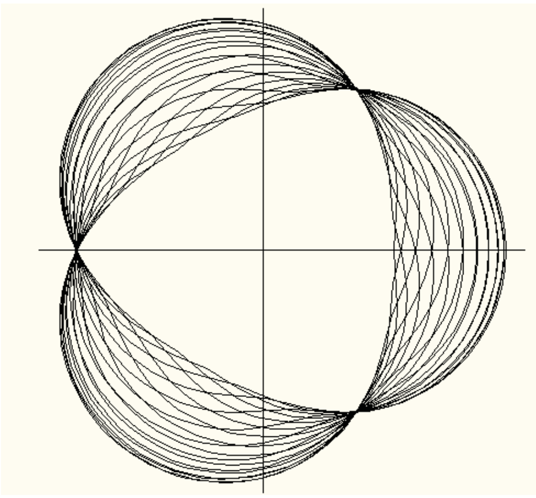

Fig. 3. Internal envelope of shape of surface of the cylinder in coordination system moving together with rotary piston in Wankel combustion engines

5. The number of piston apexes is limited by the permanent proportion of the speed of the external rotational surface and the rotational speed of its geometric centre relative to the housing wall. The number of these apexes may be one less than the number of cycles within the external surface, as is applied in Polish patents 48191 and 48198 [3] and shown in Fig. 5. The number may also be one greater than the number of cycles in the external surface, as is used in engines of the Wankel type and shown in Fig. 1 and 2. The geometry used in Wankel engines is more appropriate for balanced operation of the engine (less vibration) and efficiency of the seals (especially apex seals).

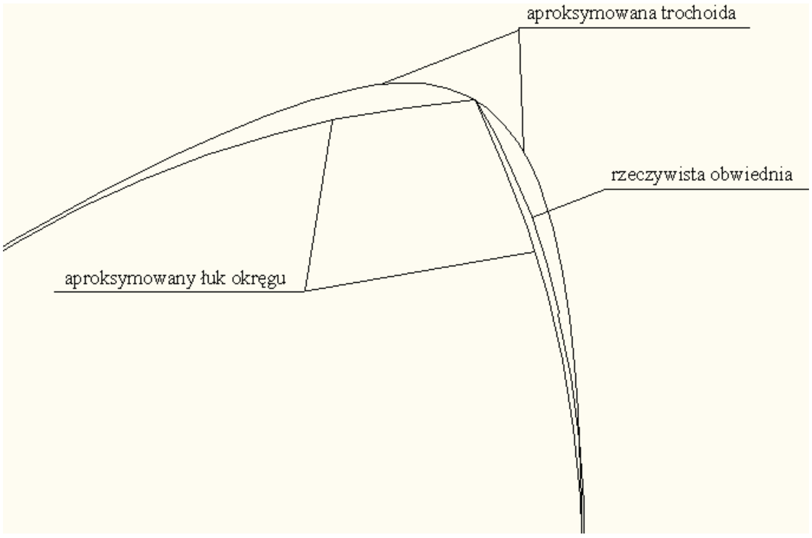

Fig. 4. Comparison of exact internal envelope of shape of surface of the cylinder in coordination system moving together with rotary piston in Wankel combustion engines with approximations of exact internal envelope by combination of arc of circle and trochoid such continuity curve. "Aproksymowana trochoida" means approximations of exact internal envelope by trochoid such continuity curve. "Aproksymowany łuk okręgu" means approximations of exact internal envelope by combination of arc of circle. "Rzeczywista obwiednia" means exact internal envelope of shape of surface of the cylinder in coordination system moving together with rotary piston in Wankel combustion engines

6. When the external surface has two cycles it is best for the inner surface to have three cycles. This is the most useful construction in relation to engine efficiency per unit of volume. In that way the smallest engine for a particular power output is obtained, or the most powerful engine for a particular size.

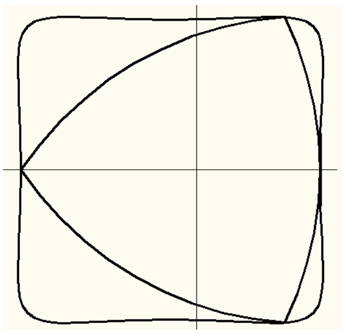

Fig. 5. Geometry of rotary piston with motionless cylinder taken from Polish patents 48191 and 48198 [3]. Early similar geometric dependencies was used in production of oval holes and shafts [7]

5. Results

1) The Wankel engine would appear to lend itself to optimization for a particular fuel.
2) The construction of the Wankel engine is such that intense cooling is possible by enlarging and optimizing the 'water jacket' and the possibility of cooling the piston itself.
3) Gas fuels have a higher combustion temperature in comparison to traditional liquid fuels. Hydrogen burns at a particularly high temperature. In oxygen-hydrogen burners the temperature may reach 3000 °C. In other gas-oxygen burners the temperatures are lowers. In gas conversion systems fitted to passenger cars temperatures in the cylinders are higher to those for liquid fuels. For these reasons an engine burning hydrogen fuel would require a construction allowing particularly intensive cooling. Such a requirement is at the moment best fulfilled by the Wankel rotary engine.

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