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DESIGN FEATURES AND PARAMETERS OF MOVEMENT OF THE WANKEL ENGINE MAIN ELEMENTS

In this investigation there is analyzed the influence of the ratio of the radii of the movable gear and the fixed gear of the triangular Wankel engine on the configuration of the engine housing, as well as on the kinematic parameters of the rotor points, on the base of the program created in the MatLab system.

Key words: rotary engines, Wankel engine, epitrochoid, synchronized gears.

Rotary engines have been considered as an alternative to classical internal combustion engines since the beginning of the 20th century.

The performed analysis of literary sources of the scientists from different countries allowed to define that at present, the following types of rotary engines are considered by various researchers: automobile [1, 2], aviation [3], used in mining machines [4]; there are designs with 2-stroke [5], 4-stroke [6, 7] and 6-stroke [8] cycles; the number of the main working elements of the engine and the principle of their movement differ either [9] (figure 1).

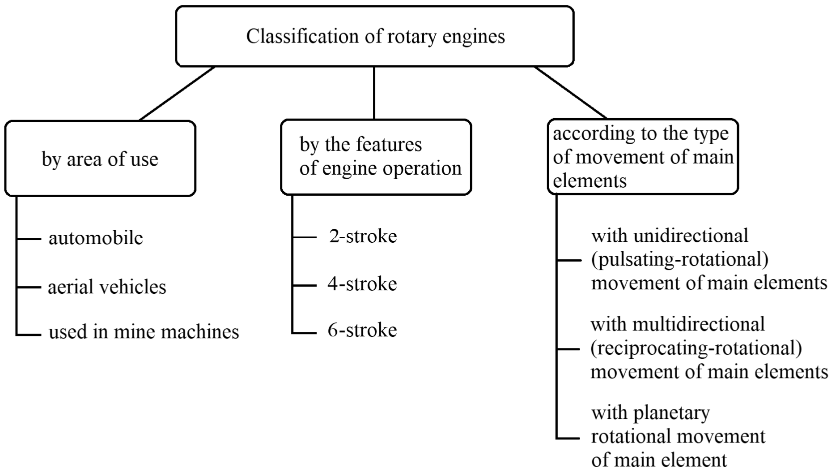


Figure 1 – Classification of modern rotary engines

One of the most widely used designs of rotary engines is the one with planetary rotational movement of the main working element (rotor), named after one of its developers, F. Wankel (figure 2). This variant was developed in 1954 and it was used in the automotive industry in the USSR and abroad, but it had certain disadvantages [10, 11] and it was practically ceased to be used in production by the end of the 20th century.

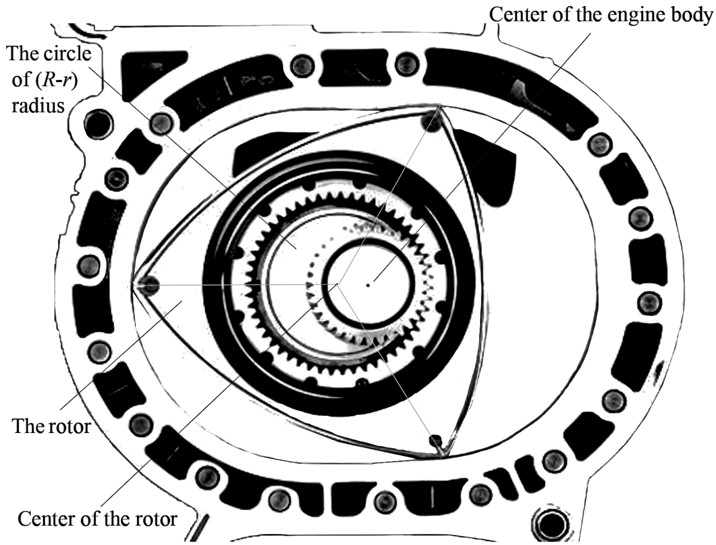


Figure 2 – Scheme of Wankel engine

Currently, the rotary engine of Wankel type is experiencing a renaissance in the internal combustion engine industry, mainly due to the simplicity of its design and high power [12, 13]. Despite the presence of significant disadvantages, the Wankel engine also has a number of advantages; therefore, investigations on its improvement are still relevant at the present time [14–16]. Wankel rotary engines are used as power units in modern machines, such as unmanned aerial vehicles (drones), vehicles with a hybrid engine [17, 18] and etc.

Such an engine consists of a housing and two moving parts: a rotor and an eccentric output shaft (see figure 2). There are two spur gears: the outer one is fixed on the housing side, the inner one is fixed inside the rotor so that the rotor tips are in contact with the housing [17]. The difference $(R-r)$ is called the eccentricity e, its choosing requires to take into account the possibility of the eccentric power take-off shaft displacement through the central hole of the small fixed gear [18]. The fixed gear is rigidly bolted to the motor housing and cannot be rotated. The geometry of the rotor, housing and sides is determined mainly by the parameter R, called the radius of the rotor, and the eccentricity e of the output shaft. The eccentricity $e = R - r$ and the generating radius R are the key dimensions of the Wankel engine. The fundamental difference between such an engine and a classic internal combustion engine is that the rotor plays the role of a piston. That is, it participates in the formation of internal combustion chambers; with its help, gases are admitted and released and it drives the main shaft.

Thus, the purpose of the presented work is to study the influence of the rotor parameters on the trajectory of its points and their kinematical parameters.

The rotor performs two simple movements: displacement of the center of the rotor along the eccentric shaft with radius *e* and rotation around its own center. While the rotor makes one revolution around its center, the output shaft makes three revolutions in the eccentric circle. In this case, the points of the rotor move along a curvilinear trajectory called an epitrochoid.

In technical literature, for example, in [20], the equation for the epitrohoid can be written as follows:

$$\begin{cases} x = (R - r)\cos(n\varphi) + CR\cos\varphi, \\ y = (R - r)\sin(n\varphi) + CR\sin\varphi, \end{cases}$$

where R, r – radii of the movable gear and fixed gear, respectively, m; φ – angle of rotation characterizing planetary motion, rad; n – gear ratio; for this engine type it is

$$n = \frac{R}{R - r};$$

C – dimensionless parameter that determines the dimensions of the engine [20]; it is usually taken equal to 2.1–2.7.

For example, for the engine with parameters R = 108 mm, r = 54 mm; n = 2; C = 2.6; R/r = 3/1 the graphs of changes in the point epitrochoid coordinates along the axes x and y and the type of the epitrochoid, defining the configuration of the engine are shown in figures 3 and 4.

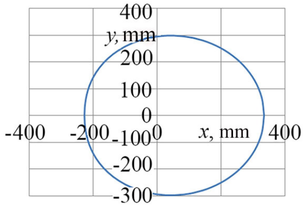
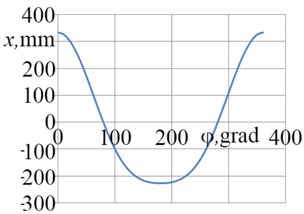


Figure 3 – The configuration of the internal part of the rotary engine at R/r = 3/1

At the development process of a rotary engine configuration it is necessary to select parameters to achieve the required characteristics of the device. Manual selection is very difficult, therefore, there was written the script in the MatLab environment (figure 5) that allows to get the form of an epitrochoid, kinematic parameters (velocity and acceleration values) of the rotor point, which is at distance R from its center for any entered value of R, r, C (figure 6).



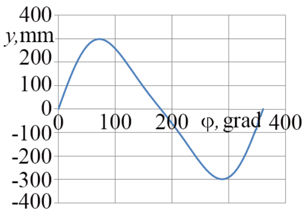


Figure 4 – Coordinates of the rotor extreme point at R/r = 3/1

```
R = input('R (mm) = ');
r = input('r (mm) = ');
C = input ('C = ');
n = R/(R-r);
syms fi;
x = (R-r)*cos(n*fi)+ C*R*cos(fi);
y = (R-r)*sin(n*fi)+ C*R*sin(fi);
Vx = diff(x);
Vy = diff(y);
V = (Vx^2+Vy^2)^0.5;
ax = diff(Vx);
ay = diff(Vy);
a = (ax^2+ay^2)^0.5;
fi = 0:0.01:2*pi;
grid on;
subplot(1,3,1); plot(subs(x),subs(y), 'r');
xlabel('x, mm');
ylabel('y, mm');
subplot(1,3,2); plot(fi,subs(V), 'g');
xlabel('fi, rad');
ylabel('V, mm/sec');
subplot(1,3,3); plot(fi,subs(a), 'b');
xlabel('fi, rad');
ylabel('a, mm/sec^2');
```

Figure 5 – The script for getting the form of an epitrochoid, kinematic parameters (velocity and acceleration values) of the rotor point, which is at distance *R* from its center for the triangle Wankel engine

```
Command Window
R (mm) = 72
r (mm) = 36
C = 2.4
fx >>
```

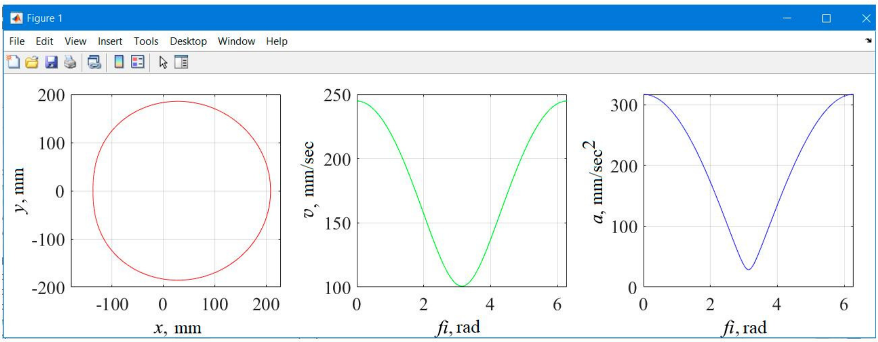
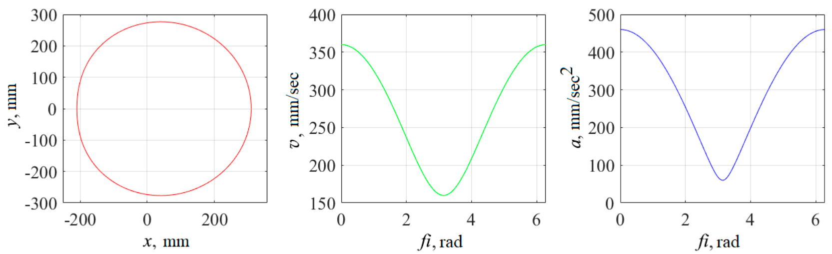
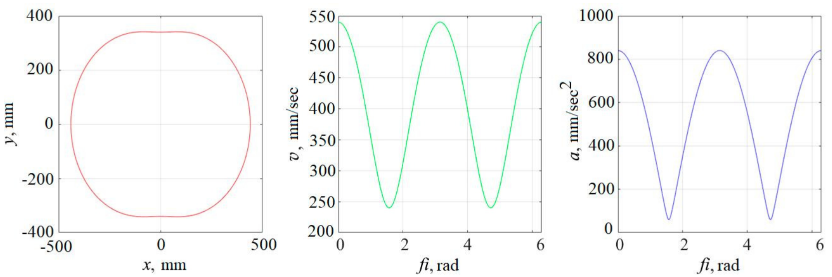
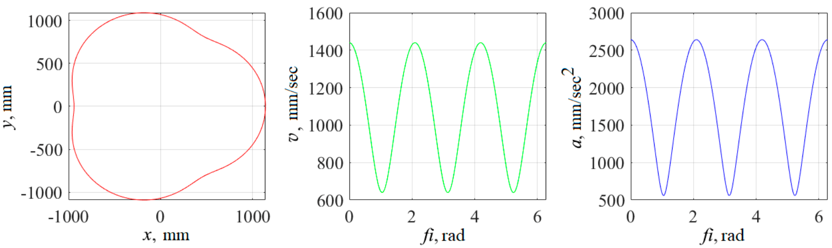
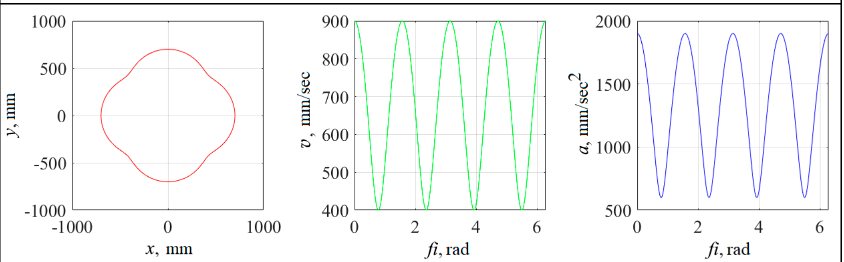


Figure 6 – Example of the MatLab script realization

The analysis of the ratio *R*/*r* influence of on the epitrochoid type was performed, some of the obtained results are shown in the table 1. The calculations were performed for a constant value of the fixed gear radius *r*, taken equal to 50 mm, the parameter $C = 2.6$.

Table 1 – **Some computational results**

R/*r*	The obtained results in the MatLab system
2/1	
3/2	
4/3	
5/4	

The computational results demonstrated that the number of convex sections of the epitrochoid is equal to the denominator of the *R*/*r* ratio, while the dimensions of the engine body, depending on the extreme positions of the points of the epitrochoid, tend to decrease. With an increase in the *R*/*r* ratio, it is necessary to design the engine of large dimensions, and in this case, it may be difficult to produce parts because of the complex geometry and it will be possible only by using laser technologies.

Also, for each value of the radius *r*, there are such ratios *R*/*r*, that lead to the formation of not closed epitrochoid; so, it won't be possible to create an engine configuration for such parameters. For the radius r = 50 mm, such ratios for the numerator range 2–10 are: 3/2, 4/1, 5/1, 5/2, 5/3, 6/1, 7/1, 7/2, 7/ 3, 7/4, 7/5, 8/1, 8/3, 8/5, 9/1, 9/2, 9/4, 9/5, 9/7, 10/1, 10/3, 10/6, 10/7. For ratios 2/1, 3/2, 4/3, 5/4, 6/5, 7/6, 8/7, 10/9, the epitrochoid has a closed contour.

Thus, the ratio of the radii of the movable gear and the fixed gear influence both the dimensions of the Wankel engine housing and the trajectories of the rotor points. There are also possible the variants of the ratio *R*/*r*, when the construction of the engine is not possible for the specific values of *R* and *r*.

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ОСОБЕННОСТИ КОНСТРУКЦИИ И ПАРАМЕТРЫ ДВИЖЕНИЯ ОСНОВНЫХ ЭЛЕМЕНТОВ ДВИГАТЕЛЯ ВАНКЕЛЯ

В работе исследовано влияние соотношения радиусов подвижного зубчатого колеса и неподвижной шестерни треугольного двигателя Ванкеля на конфигурацию корпуса двигателя, а также на кинематические параметры крайних точек ротора с применением разработанной в системе MatLab программы.

Ключевые слова: роторные двигатели, двигатель Ванкеля, эпитрохоида, синхронизирующиеся шестерни.

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