Consideration on New Application for Rotary Engine

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Abstract. The paper takes a view on different solutions for rotary engine, such as Mallory and Kaeurtz engine, focusing on Wankel engine. For this one is presented the mathematical background used at inner stator curve, based on peritrochoid or epicycloid curve. The authors makes a cinematic analysis for a triangular rotor, using Autodesk Inventor, in conjunction with a two lobs curve at stator. It is mention another case for a rotary machine, with a rectangular rotor which runs in a curve with three lobs, that can be applied at compressors. The study goes further with a similar analysis for a rotary engine with a pentagonal rotor, which rolls in peritrochoid with four lobs. The simulations allows a comparative study between triangular and pentagonal shape rotor, emphasis the influence of constructive parameters on the expected efficiency of the engine. As a main conclusion the last solution is an interesting application that can be further developed for an experimental engine.

Keywords: Rotary engine · Peritrochoid curve · Reuleaux polygon

1 Rotary Engines

1.1 A Synthetic Presentation of Rotary Solutions

Rotary mechanisms were used since 16th century by different inventors, mainly as a pump device and later in the 19th century as compressors. Yamamoto in [1] presents a brief history of these developments, with illustrations for more than 15 solutions.

Maillard applied in 1938 at a compressor the first modern approach, which uses for the first time a pair of mathematical curves for the inner surface of housing and the outer envelope of the rotor, creating so the basics for the modern rotary engines.

As presented in [1, 2] now days, the rotary engines are at three types:

Single rotating engine: which have a rotor that makes a simple rotation movement around a central axis, which has an eccentricity related to a housing. This engine obtains the compression by the volume variation between the two extreme positions, which corresponds to the largest and smallest volume, as in Fig. 1.

Oscillatory rotating engine: which obtain compression by the volume variation between a set of rotors. At the Kauertz engine the rotors makes two rotation movements around the same central axis: one is for both rotors, and the second one is the

I. Dumitru et al. (Eds.): ICOME 2022, AHE 15, pp. 357–368, 2023.
https://doi.org/10.2991/978-94-6463-152-4_41

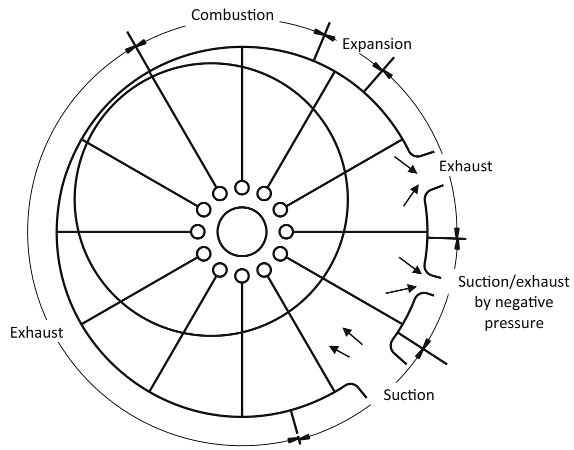

Fig. 1. Rotary Engine - Mallory

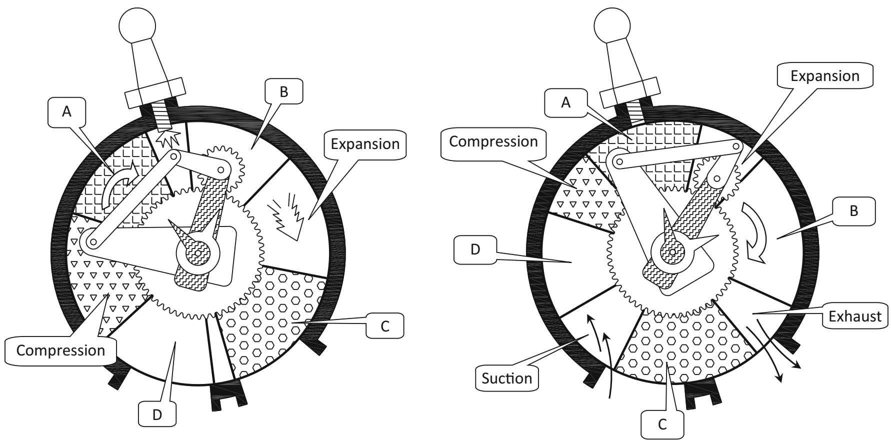

Fig. 2. Kauertz Engine

oscillatory movement, which shrinks and enlarges the working volume, as in Fig. 2. This oscillatory movement is controlled by a mechanism with a set of gears and arms.

Planetary rotating engine: where the rotor combines two rotational movements: one with the engine shaft and another one around an eccentric axis, where the movements works in synchrony due to a set of gears. This last solution is the most used one, as it is at Wankel engine, presented in Fig. 3[1].

[1] In this figure are not represented the seals, front plate and assembly elements.

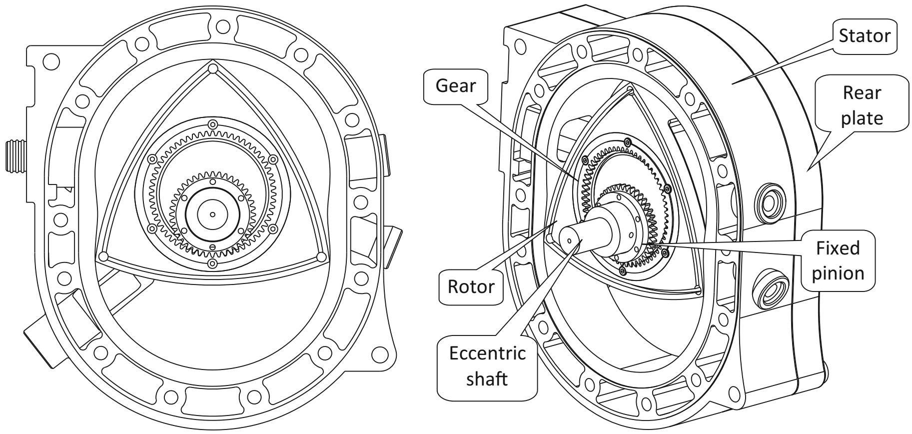

Fig. 3. Wankel Engine

1.2 Inner Profile at Wankel Engine

Now days the Wankel engine could represent a convenient solution as internal combustion engine at hybrid propulsion, as presented in [3], due to its simplicity and compact dimensions. This new application of the Wankel engine has ignited interest of car manufacturers in refining the solutions involved in his construction.

As results from [4, 5] the main characteristics of Wankel engine are: the stator with the special inner curve, and the ratio between the two gears. The inner curve from stator, on which the apex of the rotor slides is a peritrochoid. This one is generated by a fixed point attached to a mobile circle, which rolls around a fixed circle, and also is rotating around his center, as in Fig. 4. The parametric equation of the perithrocoid is as in relation (1):

$$\begin{cases} x = e \cdot cos(\propto) + R \cdot cos(\beta) \\ y = e \cdot sin(\propto) + R \cdot sin(\beta) \end{cases} \quad (1)$$

where:

e: eccentricity – the distance between the centers of the two circles.

R: the length of the arm related to the mobile circle.

α: angle of position for center of the mobile circle.

β: angle of rotation of the mobile circle, around his center.

The ratio between the two angles α and β establishes the number of lobes of the curve, where for Wankel engine, the ratio 2/3 produces the two lobs curve.

A special attention needs at the side profile of the rotor to avoid the interference with the stator curve. As presents [6–8], this curve is a Reuleaux triangle, which ensure the geometrical condition for a proper function of the mechanism. Also [2], derived a parametric relation for the curve as an envelope of the peritrochoid.

More detailed considerations about the side profile of the rotor, are presented in [10], with theoretical developments for the Reuleaux triangle, concluding in a class of rotors the one with a minimum area has a minimum number of circular arcs.

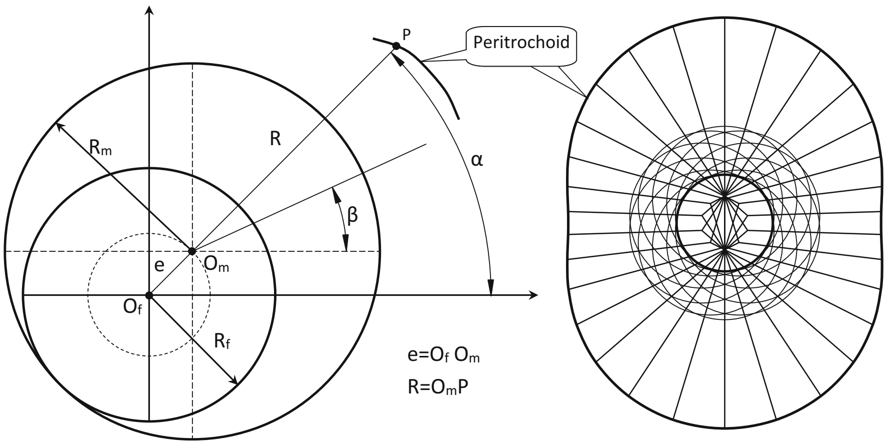

Fig. 4. Peritrochoid parameters

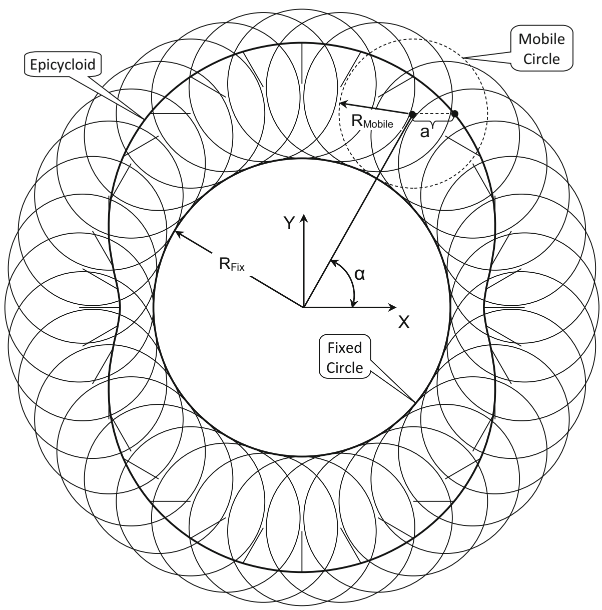

Fig. 5. Epicycloid parameters

According with the consideration from [8, 9], a similar curve with peritrochoid produces the Eq. (2), which is the epicycloid. In this situation, so called double generation, the curve is created by a point attached to a circle, which rolls without sliding on fixed circle, as in Fig. 5.

$$\begin{cases} x = (R_{Fix} + R_{Mobil}) \cdot \cos(\alpha) - a \cdot \cos\left(\frac{R_{Fix}+R_{Mobil}}{R_{Mobil}} \cdot \alpha\right) \\ y = (R_{Fix} + R_{Mobil}) \cdot \sin(\alpha) - a \cdot \sin\left(\frac{R_{Fix}+R_{Mobil}}{R_{Mobil}} \cdot \alpha\right) \end{cases} \quad (2)$$

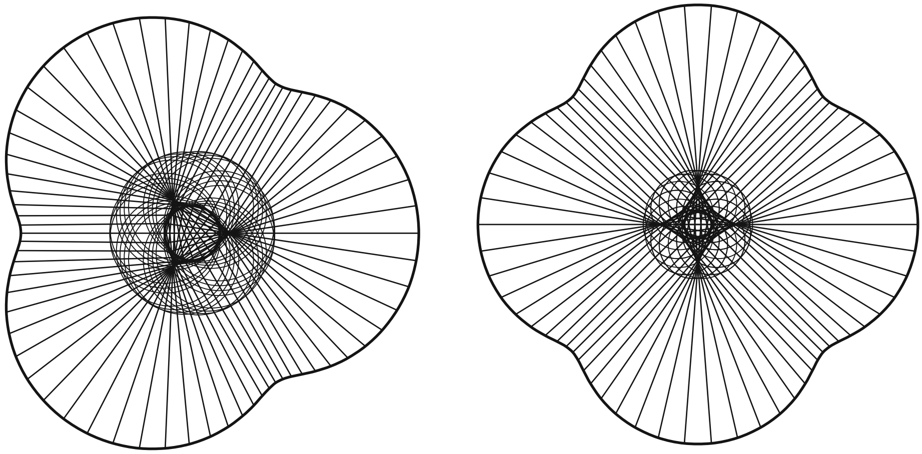

Fig. 6. Peritrochoid with 3 and 4 lobs

where:

R_{Fix}: radius of fixed circle.

R_{Mobil}: radius of mobile circle.

a: distance from the center of mobile circle to the generating point.

α: rotation angle for the center of mobile circle.

Based on any of the previous equations are possible many other particular cases, as in Fig. 6, where are curves with 3 and 4 lobs generated for the ratio with the values 4 and 5.

In [11] is presented an analysis of the geometry at Wankel engine, concluding the solution with triangular rotor a convenient one for a rotary engine, but without making a detailed analysis for other combinations.

In [12, 13] we can find practical solutions for the development of experimental Wankel engines, that can be extended also to other type of rotary engines.

2 Cinematic Consideration on Rotary Engine

2.1 Triangular Rotor Case

In this section we made a cinematic analysis for the case with a triangular rotor, with the geometry from Fig. 7 and 8. The study was done using Autodesk Inventor software, where the movement parameters where defined in the dynamic environment. The characteristics of the single triangular and also pentagonal (analyzed in next section), rotor engine are presented in Table 1, where the geometry of peritrochoid and rotor are especially adjusted to produce the same displacement for both cases.

In Fig. 7 is the triangular rotor engine represented in position corresponding to 0° (fig. a) and 90° (fig. b) for the eccentric shaft, where the apex point P1 is the reference point for the cinematic analysis.

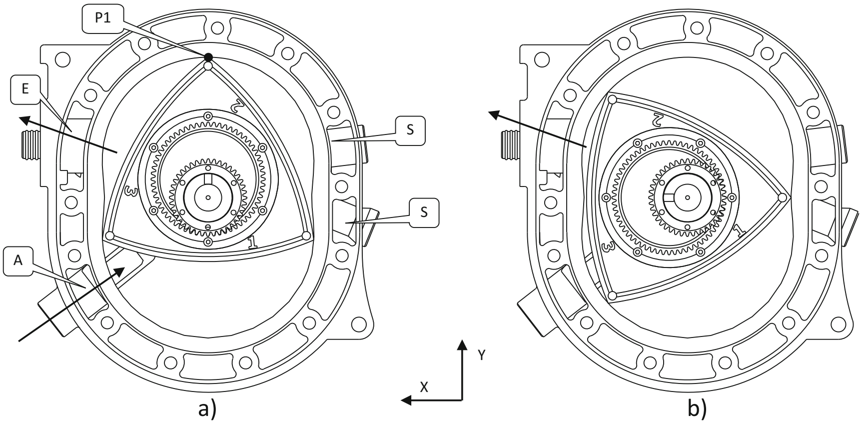

Fig. 7. Triangular rotor engine in different positions

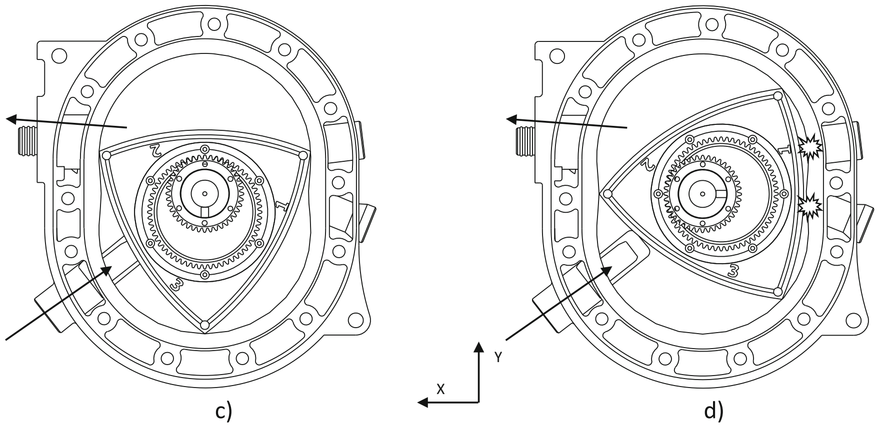

Fig. 8. Triangular rotor engine in different positions

In Fig. 8 is the triangular rotor engine represented in position corresponding to 180° (fig. c) and 270° (fig. d) for the eccentric shaft.

In these figures are marked the admission window (A), the exhaust window (E), and the position of the two spark plugs (S). As we can see for a complete rotation of the eccentric shaft the triangular rotor makes 120° rotation around his center (see position of the rotor side numbered as 1).

Using the simulation environment we derived the coordinates variation for the triangular apex, as presented in Fig. 9, where on horizontal axis is the time corresponding to 3000 rpm for eccentric shaft[2]. The coordinating system is as in Fig. 7, 8, with the origin located in the center of the eccentric shaft. On the graphic are also emphasized the position for the 360° position of eccentric shaft.

2 At 3000 rpm 0.0005 s correspond to a 9° rotation for the eccentric shaft.

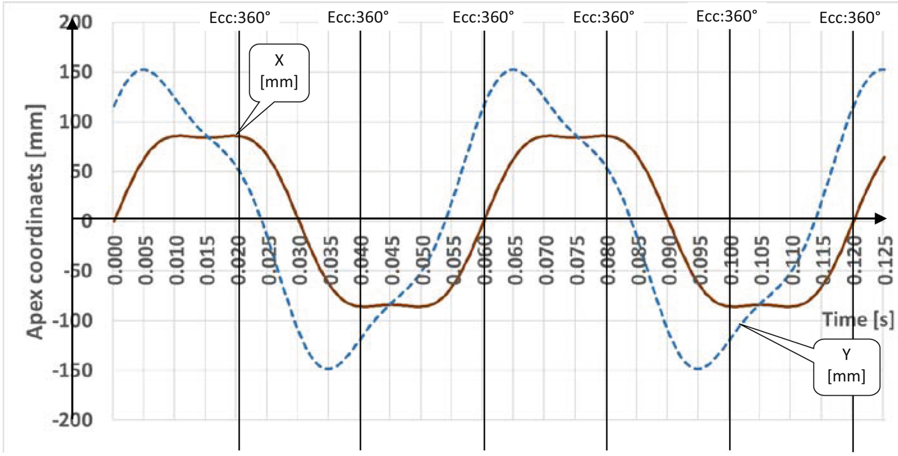

Fig. 9. Apex P1 coordinates at triangular rotor

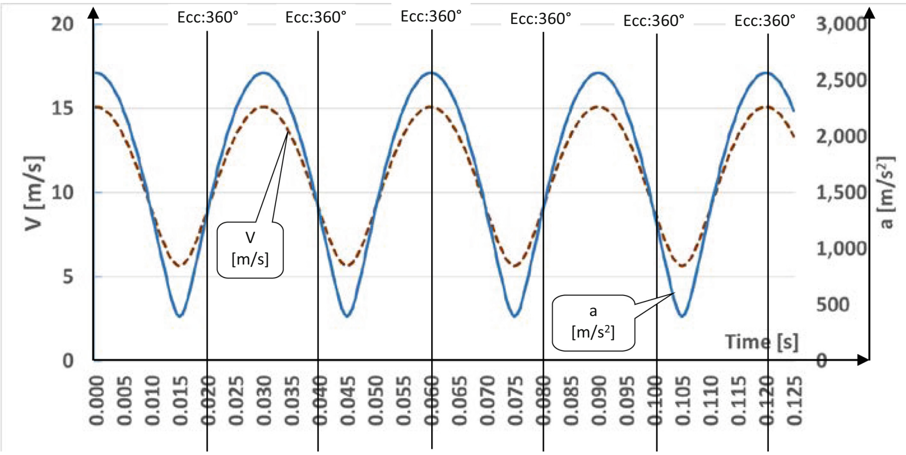

Fig. 10. Speed and acceleration for apex at triangular rotor

At 3000 rpm rotation speed is determined the variation for speed (v), and acceleration (a) of the apex of triangular rotor. We insert the extreme values in Table 1 (Fig. 10).

We can observe that we have a single spark during a rotation of the eccentric, or three sparks for a complete rotation of rotor, which is better than at a reciprocating piston engine. In Table 1 are also mentioned the values necessary to obtain the theoretical compression ratio for the engine, which at our triangular rotor engine is 9.93, where the width of both rotors we use in or virtual model, is 56 mm.

2.2 Pentagonal Rotor Case

In Fig. 11 and 12 are exposed similar considerations for a pentagonal rotor engine with a four lobe peritrochoid. We observe the engine in this case has two different sparks,

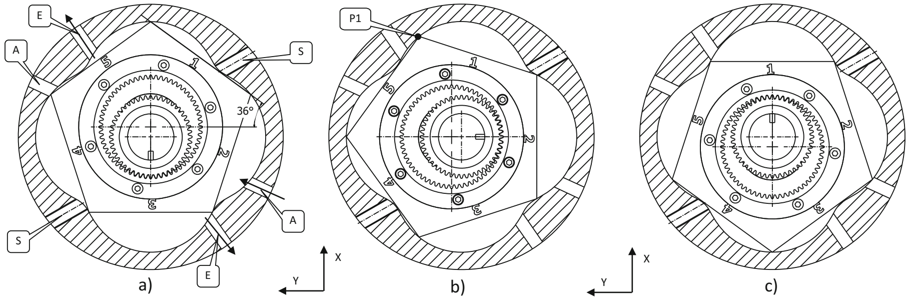

Fig. 11. Pentagonal rotor engine in different positions

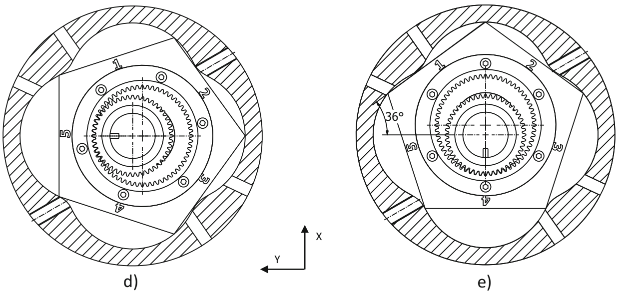

Fig. 12. Pentagonal rotor engine in different positions

positioned into different lobs, as we have two triangular rotor engine into a single working space.

We can observe that for a complete rotation of eccentric shaft (see Fig. 11-a and Fig. 12-e), the pentagonal rotor makes a 72° rotation of around his center (360° divided by number of sides).

In this case we have two sparks during a rotation of the eccentric (see Fig. 13), or ten sparks for a complete rotation of rotor, which is more convenient than at the engine with a triangular rotor.

In Fig. 14 we have the variation for apex coordinates (see point P1 in Fig. 11-b), while the rotor fills a complete rotation around his axis. The coordinating system is as in Fig. 11, 12, with the origin located in the center of the eccentric shaft.

In Fig. 15 we present the variation for speed and acceleration of the apex, during a complete rotation for the pentagonal rotor, where there are emphasized the time value when the eccentric makes a full rotation. We extract the top and bottom values for speed and acceleration in Table 1, to be more easy to compare the parameters with the other solution.

3 Conclusions

If we look in Table 1, and in the above graphics and figures we can conclude the following:

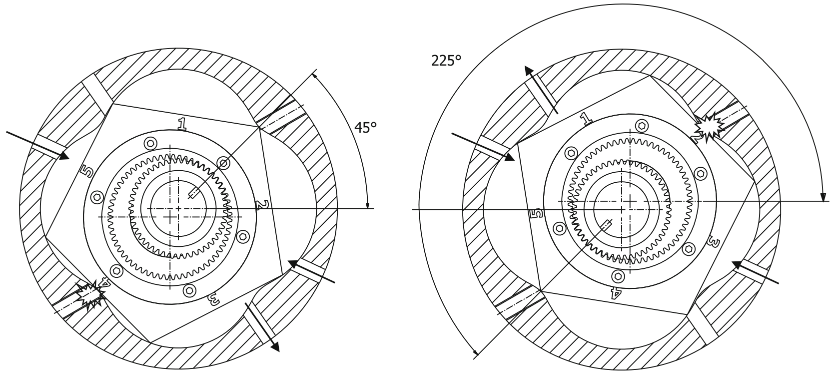

Fig. 13. Rotor position for spark ignition

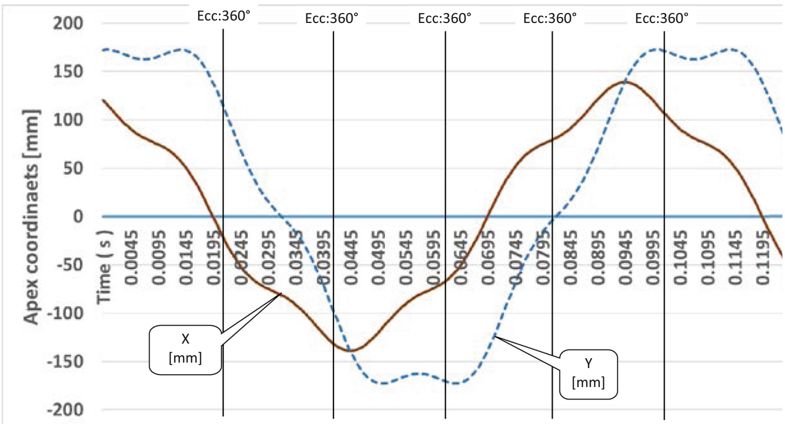

Fig. 14. Apex P1 coordinates at pentagonal rotor

- The theoretical compression ratio, which results from the construction of the engine, is better at the triangular rotor: 9.93 compared to 7.19 at pentagonal rotor (Fig. 16);
- This aspect suggests to use at pentagonal rotor a supercharge system to improve the filling coefficient of working chamber;
- The expected efficiency of the engine is better at the pentagonal rotor, because it gives 2 active strikes at a full rotation of the eccentric, compared to a single active stroke at triangular rotor, aspect that can also enhance the smoothness of the engine run;
- Taking account the maximum values, the speed and acceleration of the rotor apex are smaller at the pentagonal shape, giving a ratio of 0.78 respective 0.65, which can enhance the durability of the engine (Fig. 16);
- A better appreciation on the solutions can be done after a dynamic simulation of the engine, based on current study;

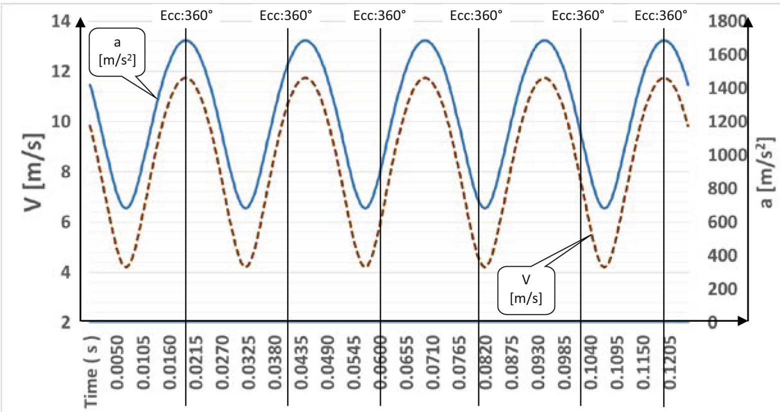

Fig. 15. Speed and acceleration for apex at pentagonal rotor

Table 1. Comparative parameters for triangular and pentagonal rotors at rotary engine

Parameter	Triangular rotor engine	Pentagonal rotor engine
R [mm]	99.00	127.00
e [mm]	15.00	12.00
Peritrochoid volume [cm^3]	1843.03	2147.54
Rotor volume [cm^3]	1049.77	2943.99
Engine cubic capacity [cm^3]	793.26	796.45
Max chamber volume [cm^3]	480.39	291.29
Min chamber volume [cm^3]	48.37	40.50
Compression ratio	9.93	7.19
v_{max} [m/s]	15.08	11.75
v_{min} [m/s]	5.65	4.21
a_{max} [m/s^2]	2566.10	1685.73
a_{min} [m/s^2]	394.78	682.98

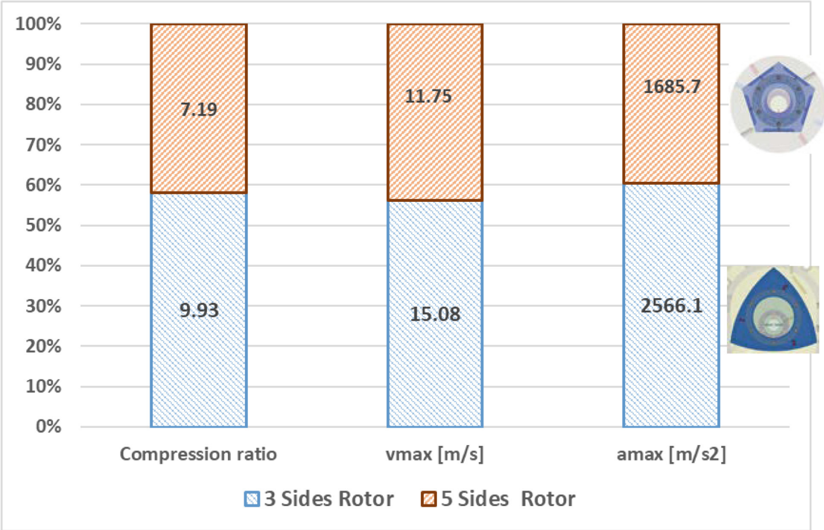

Fig. 16. Comparative parameters

References

1. Yamamoto, K.: Rotary Engine, Sankaydo Co., Tokyo (1981)
2. Yamamoto, K.: Rotary Engine, Tokyo Kogyo Co., Tokyo (1971)
3. Stan, C., Alternative Propulsion for Automobiles, Springer, Zwickau (2016)
4. Ansdale, R.,F., Lockley, D., J.: The Wankel RC Engine Design Performance, Illife Books Ltd., London (1968)
5. Wankel, F.: Rotary Piston Machines, Illife Books Ltd., London (1965)
6. https://www.researchgate.net/publication/266527516_Reuleaux_Triangle_and_its_Derived_Mechanisms: Figliolini, G., Rea, P.: Reuleaux Triangle and its Derived Mechanisms
7. https://doi.org/10.1515/nleng-2017-0082 Espinosa, L., F., Lappas, P.: Mathematical Modelling Comparison of a Reciprocating, a Szorenyi Rotary, and a Wankel Rotary Engine, Nonlinear Engineering
8. https://en.wikipedia.org/wiki/Reuleaux_triangle
9. https://www.mathcurve.com/courbes2d.gb/epicycloid/epicycloid.shtml
10. Bayen, T.: Analytic Parametrization of Rotors and Proof of a Goldberg Conjecture by Optimal Control Theory, In: SIAM Journal on Control and Optimization, Vol. 47, Iss. 610.1137/070705325 (2009)
11. Drogosz, P.: Geometry of the Wankel Rotary Engine, In: Journal of KONES Powertrain and Transport, Vol. 17, No. 3, pp. 69–74 (2010)

12. Norbie, J., P.: The Wankel Engine Design Development Applications, Chilton Book Co., Philadelphia (1971)
13. Yang, L.J., Wang, T.H.: Design of a Small Wankel Engine In: 7th IEEE International Conference on Nano/Micro Engineered and Molecular Systems (2012)