The Development of the Szorenyi Four-Chamber Rotary Engine

Peter King
Partner, Rotary Engine Development Agency

Abstract

A four-chamber Otto cycle rotary engine, the Szorenyi Rotary Engine, has been invented and developed by the Rotary Engine Development Agency (REDA) in Melbourne, Australia. The engine concept has been awarded a U.S. Patent (Number 6,718,938 B2).

The stator of the Szorenyi engine is a similar shape to a Wankel engine. However, the geometric shape of the engine rotor is a rhombus, which deforms as it rotates inside the contour of the mathematically defined stator. This geometry results in a rotor with four combustion chambers. Each revolution of the crankshaft produces one revolution of the rotor and four power strokes. In contrast, the Wankel engine produces one power stroke per crankshaft revolution, although the crankshaft rotates at three times the rotor speed. The Wankel engine is redlined at 9,000 rpm due to its eccentric rotor causing excessive deflection of the crankshaft above those speeds. The deflection can result in the rotor contacting the stator and side-plates of the engine. The Szorenyi engine has a symmetrical rotor and has no such speed limitation. As such, the Szorenyi engine has the compactness of a Wankel, turbine-like power delivery due to its symmetrical rotor, and greater power density than a Wankel engine at engine speeds above the rev limit of the Wankel.

The engine geometry has been translated to a prototype engine design. The prototype engine has been constructed and a successful proof-of-concept engine test conducted.

RMIT University has conducted ideal mathematical modelling of the engine geometry and fuel burn. The model analysed the Szorenyi engine, the Wankel, and a reciprocating engine of the same displacement. This modelling has shown that the Szorenyi engine thermal efficiency is 0.46% greater than the reciprocating engine and 0.38% greater than the Wankel engine.

The prototype engine used in the proof-of-concept test now has redesigned rotor hinges, and that engine is awaiting a program of further testing to assess engine performance. Also, the RMIT University mathematical modelling of the Szorenyi engine, while providing good results, is ideal and so more complex modelling is required to more accurately predict performance.

The Szorenyi engine could be used in any application where the reciprocating and Wankel engines are used. The advantage of the Szorenyi engine is the higher power density, smoother power delivery, and higher thermal efficiency than reciprocating and Wankel engines.

Introduction

A new configuration of a rotary engine has been developed by the Rotary Engine Development Agency (REDA), based in Melbourne. The special features of the engine are that it is a rotary engine with four chambers and the engine stator profile that contains the four chambers is mathematically defined. Named after its inventor, Peter Szorenyi, the Szorenyi Rotary Engine promises to have much higher power than a Wankel engine and match the power of a reciprocating engine. The invention has been awarded a US patent (No 6,718,938 B2). A prototype has passed the proof-of-concept stage of development, and initial mathematical modelling has produced favourable results.

The discovery of the Szorenyi curve was made in 2000. REDA was formed shortly after the discovery and was awarded an ACT Research and Development Grant of $63,000 in 2001. The US patent was awarded in 2004.

Figure 1. Partly Assembled Prototype Engine
The patented engine stator profile can be seen as the large race-track shape, in Figure 1 above, of the partly assembled Szorenyi engine prototype. The CAD depiction in Figure 2 shows the stator profile as well as the other components of the prototype engine.

The stator appears similar to the Wankel rotary engine but the shape of the Szorenyi engine rotor contains a four-segment hinged rotor. The apexes at the hinged joints of the segments remain in physical contact with the stator profile as the rotor rotates. The gap between the engine stator and the rotor segments creates four chambers. As the engine rotates each chamber completes the induction, compression, ignition and exhaust phases of the Otto cycle.

Each of the four chambers in turn draws the air-fuel mixture in through a peripheral port (indicated by the left arrow in Figure 1). As the engine rotates (in a clockwise direction in Figure 1) the trailing apex seal of the chamber passes over the intake port thus trapping the fuel-air mixture in front of it. The mixture is then compressed and ignited. As the rotor rotates, the resulting high-pressure gases generate a force that acts in a line eccentric to the drive-shaft centerline thus spinning the rotor and producing usable power. Further rotation of the engine allows the gases to expand until the leading apex seal passes a peripheral exhaust port and allows the gases to be expelled. (The exhaust port is indicated by the right arrow in Figure 1.) Because the rotor and stator form four chambers, one rotation of the rotor produces a complete engine cycle in each chamber. Therefore there are four power strokes per revolution of the crankshaft.

**The Invention**

The invention is the geometric shape that can contain a four-sided rhombus with the corners of the rhombus in any orientation. The contour of what became the stator profile of the engine has been patented as ‘The Szorenyi Curve’. The profile is shown in Figure 3. The discovery of the curve was made while examining the geometry of the stator profile of a Wankel engine. Using a right isosceles triangle with the hypotenuse (the line AB in Figure 3) representing the flank of one of the four segments of the rotor, the apex of the triangle traced out the shape of a four-leaf clover around the centerline of the stator.

![Figure 3. The Geometry of the Stator Profile](image)

It was then possible to mathematically describe the profile of the stator by utilising the mathematical form of the four-leaf clover ($\sin^2 \theta$). The mathematically described curve represented the profile of the engine stator. The hypotenuse of the triangle represented the face of each of the four hinged segments of the engine rotor. The gap between the stator and the segment creates the chamber of the rotary engine.

The patent describes the geometric derivation of the stator but the mathematical expression for the stator contour can readily be derived. The power of the discovery of the curve and the mathematical expression is that a wide range of stator profiles can be explored to determine the optimum shape of the stator for the particular application of an engine. This feature will also allow the combustion chamber shape to be chosen for optimum performance.

**Design**

After discovering the feasibility of a four chamber rotary engine a workable design was developed by REDA. The prototype engines were produced with stator internal dimensions of 220 x 160 x 70 mm. A compression ratio of 9.5 was used and this resulted in a swept chamber volume of 287cc. So the swept volume of the four-chamber Szorenyi engine prototype was 1150cc.

The internals of the resulting prototype engine design are shown in Figure 4 with the rotor pack sitting outside the engine side plate. The four sides of the deforming rhombus were translated into a four-segment rotor. The

---

1 Although the geometry of the stator appears simple visually, the mathematical expression is somewhat cumbersome. The $x$ and $y$ co-ordinates of the shape contain the angle in the $\sin^2 \theta$ expression for the four-leaf clover. The most usable form of expression for the contour of the stator profile is:

$$x = \sin 20 + \sin (w^2 - \sin^2 20) \sin \theta + \cos \theta) / 2$$

$$y = \sin 20 + \sin (w^2 - \sin^2 20) \sin \theta - \cos \theta) / 2$$

where $\theta$ = the generating angle of the four-leaf clover ($\sin 20$) and $w$ = rotor face width compared to the four-leaf clover radius (unity).
segments needed to be hinged at the apexes and a seal incorporated into the apex. (Thus each chamber of the engine is bounded by the stator, the rotor segment, and the apex seals.) Roller-bearing wheels were mounted on either side of the rotor segment. The wheels roll around a cam whose profile ensures that the apex seals are in constant contact with the engine stator throughout a complete revolution of the engine rotor. The racetrack shaped cam is mounted around the output shaft in Figure 4. The cam-plates are attached to the engine side-plates in order to locate the rotor pack inside the engine stator.

Since the stator profile is mathematically defined, the profile of the cam can also be determined mathematically. If the stator and cam profile are perfectly manufactured, as the rotor rotates, the apex seal will stay in contact with the stator surface without moving in a radial direction.

The biggest design challenge was to create sealed hinges. The first prototype design of the rotor segments suffered from a gas leakage path from the high pressure combustion chamber through the hinge and into the centre void of the engine. The hinge seal design went through a number of iterations and tests before the successful design (as can be seen in Figure 2) was achieved.

The prototype engines did not incorporate any cooling or lubrication systems. Figure 1 shows the first stator design which did include some air-cooling fins. However, the fins added significantly to the cost of producing the stator. This first stator did not have a sufficiently accurate profile and had to be remade. The later stators were made without the cooling gills as that was too expensive.

The output shaft passes through a hole at the center of the cam-plates and is supported by roller bearings mounted in the side-plates. As the engine rotates, each rotor segment bears on a lobe that is attached to the output shaft. The force produced by the high pressure combustion gases bears on the face of the rotor flank and is transferred to the output shaft via the lobe attached to the output shaft. The force is eccentric to the output shaft and creates a torque which rotates the shaft and provides output power.

The two side-plates attached to the stator and rotor assembly have seals running along the length of each rotor segment. Together with the hinge seals and apex seals they create the four airtight chambers.

**Development**

The design of the seals in the hinges of the rotor segments in the first two prototypes was inadequate. Redesign of the seal around the hinge was successful and in a test on 26 February 2008, the engine achieved a sustained idle of 700 rpm. Unfortunately, the engine would not accelerate away from idle revs. After the test, the engine was stripped and it was found that the hinge-pin joining two of the rotor segments had broken. The side plate of the engine was severely scored and so the lack of acceleration from idle revs was attributed to this additional friction of the rotor.

The hinge-pins were redesigned, re-manufactured and the fourth prototype engine assembled. A motoring test indicted that each chamber could achieve 120 psi, more than considered necessary for combustion to occur. However, before any comprehensive test of this fourth prototype could be attempted the inventor, Peter Szorenyi, sadly died. No further testing of the prototype has been undertaken since that time. Instead, mathematical modelling has been undertaken by REDA and RMIT University.

**Modelling**

The Royal Melbourne Institute of Technology (RMIT) University has conducted mathematical modelling to determine the ideal performance of the Szorenyi engine, a reciprocating, and a rotary engine. The model simulated the three engines using a nominal swept volume of 112.5 cc and a compression ratio of 10:1. The modelling was a numerical analysis performed using an Excel Spreadsheet. Firstly, the geometry of the combustion chamber of each engine was established and the volume calculated for small increments in crankshaft angle. The fuel burn characteristics were modelled using a Wiebe function. The same efficiency factor and exponent were used in the Wiebe equations. Throughout the power stroke, the fraction of fuel burned was then calculated and, together with combustion chamber volume, the chamber pressure was determined. An area calculation of the P-V diagram provided the net work value. The ignition point was then varied and iterative calculations perfromed to determine the optimum output.

---

2 L. F. Espinosa MSc and Prof P. Lappas PhD, *Mathematical Modelling Comparison of a Reciprocating, a Szorenyi Rotary and a Wankel Rotary Engine, 2017 (unpublished)*, School of Engineering, RMIT University, Melbourne, Australia.
timing for each engine. Because the model did not include the effects of friction, heat transfer or pumping loss it only predicted the ideal performance of the engine.

The modelling undertaken by RMIT University as described above indicated that, in the Szorenyi engine, the combustion chamber volume remained closer to its fully compressed value for longer than is the case for the reciprocating or Wankel engines. This characteristic improves the fuel burn in the Szorenyi engine and results in higher pressures in the chamber throughout the power stroke. The effect is shown in Figure 5.

![Chamber Volume During the Compression Stroke](image1)

**Figure 5. Chamber Volume during the Compression Stroke**

The modelling also included the predicted fuel burn using a Wiebe function. The fuel fraction burnt is shown in Figure 6. Note that the crank angle and chamber position is different for each engine. The power stroke of the Szorenyi engine occurs in 90° of crankshaft rotation; the Wankel takes 90° rotation of the rotor which is 270° of the crankshaft rotation; and the reciprocating engine takes 180° of crankshaft rotation.

![Wiebe Function vs Crank Angle](image2)

**Figure 6. Wiebe Function vs Crank Angle**

By combining the fuel burn with the chamber volume, the net work done was optimised for each engine by altering the fuel ignition timing. The result of this procedure is shown in Figure 7.

![Ignition Advance](image3)

**Figure 7. Ignition Advance of Crankshaft Angle**

The resultant variation of pressure with volume in the combustion chamber is shown in Figure 8. The higher peak pressure of the Szorenyi engine results in more net work, higher specific fuel consumption and higher thermal efficiency.
The results of the RMIT University modelling is shown in Table 1. This modelling determined that the net work and thermal efficiency of the Szorenyi engine is 0.46% greater than the reciprocating engine and 0.38% greater than the Wankel.

<table>
<thead>
<tr>
<th>Engine</th>
<th>Net Work per Power Stroke (Joules)</th>
<th>Thermal Efficiency (Ƞ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Szorenyi</td>
<td>213.8593</td>
<td>0.474707</td>
</tr>
<tr>
<td>Wankel</td>
<td>213.0435</td>
<td>0.472900</td>
</tr>
<tr>
<td>Reciprocating</td>
<td>212.8758</td>
<td>0.472524</td>
</tr>
</tbody>
</table>

Table 1. Comparative Engine Performance

More sophisticated modelling is required to include better modelling of the combustion process as well as kinematic effects such as friction, heat transfer and pumping losses. However, the modelling done by RMIT University indicates that the Szorenyi engine has the potential to exceed the power of the reciprocating and Wankel rotary engines.

**Rotary Characteristics**

The combustion chamber of the Szorenyi engine is very similar to that of the Wankel engine. Fully compressed it resembles a crescent-moon and fully expanded a half-moon shape. The shape of the combustion chamber is not conducive to good combustion and so the fuel economy of the Szorenyi engine will probably be similar to the Wankel and inferior to the reciprocating engine. The Szorenyi engine is similar to the Wankel engine with respect to the potential compression ratio. The geometry of the stator precludes compression ratios above about 15:1. So use of diesel fuel would require the air to be initially compressed before entering the rotary chamber.

The rotor of the Szorenyi engine has four combustion chambers in contrast to the Wankel engines three. So for one rotation of the rotor, the Szorenyi produces four power strokes and the Wankel produces three. However, this does not translate to an advantage in power density because the space occupied by a Wankel engine rotor during rotation (the cavity of the stator) is smaller than the stator cavity of the Szorenyi engine with the same swept volume. This more compact size of the Wankel is due to the asymmetric motion of the rotor. As the rotor combustion chamber rotates from the TDC to BDC position, the rotor centroid of the rotor moves from one side of the crankshaft to the other. In contrast, the Szorenyi engine rotor at TDC and BDC is at the same distance from the centre of its crankshaft. The motion of the Wankel rotor results in smaller dimensions of the stator than the Szorenyi engine and the overall volume of the engine package is 11% less than an equivalent capacity Szorenyi engine.

However, this compact motion of the Wankel rotor is due to the centroid of the rotor being at a constant radius from the centreline of the crankshaft. This causes bending loads on the crankshaft that have severe consequences. At high crankshaft speeds the bending of the crankshaft mis-aligns the rotor and can cause the rotor to come into contact with the side-plates or the stator. This can result in scoring of the side-plates and stator, or in catastrophic failure of the engine. Bending of the crankshaft cannot be alleviated by increasing its diameter as this also increases the three dimension of the rotor as well as its radius of rotation. Because of this effect, commercially produced Wankel engines are rev limited to, typically, 9,000 rpm of the crankshaft (3,000 rpm of the rotor). The Szorenyi engine does not have this limitation because its rotor is symmetrical and so there are no similar eccentric loads on the crankshaft.

The compact size of the Wankel engine results in higher power density than a reciprocating engine, but it is limited by the constraint on crankshaft speed. The Szorenyi engine power density is slightly less than the Wankel engine. Modelling of the engines reveals that the Szorenyi engine will match the power density of the Wankel at operating speeds of about 3,300 rpm. It is therefore an objective in the development of the Szorenyi engine to establish the revving potential of the engine and prove its power density advantage over the Wankel engine.

**Applications**

The Szorenyi Rotary Engine is suitable to be used for all applications where a reciprocating or Wankel engine are currently used. Small or large versions of the engine could be made. The engine could be run on gasoline, AVGas, LPG, hydrogen or diesel fuel. The Szorenyi (and Wankel) engine is particularly suited to using hydrogen as a fuel. This is because the inlet and exhaust
ports are separated, unlike in the reciprocating engine, and thus pre-heating of the hydrogen can be avoided.

The greater power density of the Szorenyi results in a smaller and lighter powerplant. For light aircraft and UAV applications this translates to larger payloads or greater range and endurance. Also, because the rotor of the Szorenyi engine is symmetrical about the centrally positioned crankshaft, smoother power delivery than a Wankel engine is expected. The Szorenyi engine should be more desirable than the Wankel or reciprocating engine for light aircraft and UAV applications where vibration is undesirable.

Future Development

REDA is confident that the Szorenyi Rotary Engine has the potential to replace the reciprocating and the Wankel engine wherever they are currently used. However, further prototype testing and mathematical modelling is required to support these claims.

The assembled prototype engine is ready for limited testing. However, the prototype engine does not have a cooling or lubrication system so any testing will not provide indicative performance of the Szorenyi engine. Therefore more sophisticated mathematical modelling of the engine is warranted. This modelling needs to include the dynamics of the combustion process, and the effects of friction and heat transfer. The modelling also needs to determine the rev capability of the rotor to ascertain the potential power density of the engine.

Summary and Conclusions

The Rotary Engine Development Agency (REDA) in Melbourne, Australia has developed a new configuration internal combustion rotary engine. Known as the Szorenyi Rotary Engine, it has four combustion chambers and thus offers a significant advantage of the Wankel rotary engine and reciprocating engine in a range of applications. The engine concept has been awarded a U.S. Patent (Number 6,718,938 B2). A prototype engine has been designed and produced by REDA and passed a proof-of-concept test. Mathematical modelling of the engine by RMIT University indicates that the Szorenyi engine is more thermally efficient than the reciprocating and Wankel engine, and will have greater power density when operated above the limited rotor revs of the Wankel engine. Further modelling and testing of the engine is required to establish the engine potential, particularly the revving capability of the engine.

References

1. L. F. Espinosa MSc and Prof P. Lappas PhD, *Mathematical Modelling Comparison of a Reciprocating, a Szorenyi Rotary and a Wankel Rotary Engine*, 2017 (unpublished), School of Engineering, RMIT University, Melbourne, Australia.

Definitions and Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>BDC</td>
<td>Bottom Dead Centre</td>
</tr>
<tr>
<td>CAD</td>
<td>Computer Aided Design</td>
</tr>
<tr>
<td>P-V</td>
<td>The pressure and associated volume in the combustion chamber</td>
</tr>
<tr>
<td>SFC</td>
<td>Specific Fuel Consumption</td>
</tr>
<tr>
<td>REDA</td>
<td>Rotary Engine Development Agency</td>
</tr>
<tr>
<td>RMIT</td>
<td>Royal Melbourne Institute of Technology</td>
</tr>
<tr>
<td>TDC</td>
<td>Top Dead Centre</td>
</tr>
<tr>
<td>UAV</td>
<td>Unmanned Aerial Vehicles</td>
</tr>
</tbody>
</table>