Comparative Analysis of Quasiturbine and Wankel Rotary Engine: Two Concepts 100 Years Apart

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Abstract: ***The Wankel rotary engine, introduced nearly a century ago, has undergone extensive development but has never posed a serious challenge to piston engines. While it demonstrated the feasibility of rotary designs, it also raised concerns about their practicality. This paper compares the Wankel (WK) engine with the more recent Quasiturbine (QT) concept, introduced in 1990, which offers improved efficiency, a more favorable surface-to-volume ratio, and superior environmental performance. By analyzing the conceptual strengths and limitations of both engines, this study aims to highlight the potential of rotary engines in modern applications, including hydrogen fuel and detonation techniques. The Wankel (WK) concept (based on an eccentric piston-like shaft) requires extensive explanation, as its triangular Rotor does not fit easy into the orthogonal Stator geometry, as it has a hybrid nature producing 70 % of his power radially and 30 % tangentially, as it has a 25 % torque dead time per rotation, and exhausts in a common chamber with fresh fuel mixture (somewhat like does the 2-stroke piston?). This explains why several conceptual difficulties of the Wankel engine remain unresolved. The Quasiturbine (QT) engine concept has received considerable attention for properties different from the Piston and the Wankel, and by explaining how the Wankel could have totally avoided difficulties in the first place. The Quasiturbine cycle is unique as the strokes do not experience acceleration reversal, firing at TDC with blades at their maximum tangential velocity and accompanying the fluid flow until the BDC at minimum (not null) velocity. Also unique, 100 % of the torque comes from the tangential chamber pressure (not radially) without torque dead time. All Quasiturbine components are external parts, including the Rotor accessible from the engine center. This step-by-step analysis of two complex engine devices with numerous differences, is a necessary piece of knowledge toward solutions not only equivalent, but superior to Piston engine in term of power density and environmental cleanness.***

Simplicity is the ultimate sophistication - Da Vinci

Note: This scientific disclosure does not constitute permission for commercial manufacturing.

Keywords: Quasiturbine; Wankel Engine, Rotary Engine, Engine Design; Engine Detonation, Combustion Efficiency

1. Introduction

This paper is not about engine history, nor about the technology, but about visiting abstract concepts and their impacts. People tend to forget the importance of concepts supporting technology and project; often a major and costly mistake. Concept are essential and important at all time, also because they invite everyone to keep thinking. Good concepts are of eternal value, and sound concept may save a technology, but technology can rarely save a deficient concept. Sometime, concept execution may be delay by some missing complementary accessory, technology or material, but can keep its full potential value for the future. Engine concepts are of prime interest, rarely easy to understood, often qualified ridiculous, always subject to improvement and, finally submitted to scientific validation and popular acceptability. All this is necessary to bring a concept to maturity. This century hundreds of new rotary engine concepts have been patented, almost all exclusively based on a Rotor made of a rigid one-piece (or with complementary pieces), innovative designs not generally offering a global engine solution, particularly in regard to modern fuel, hydrogen and detonation mode. In the world of rotary, most effort seem to focus on the Rotor innovation, while the Stator structure and shape append to be of prime importance in driving the overall characteristics.

The present dual-concepts analysis is not about any specific design version, but covers common standard engine layout exposed in literature, referring to typical sizes, proportion and tendency. Both QT and WK engines have complexes and non-intuitive characteristics, the Quasiturbine [1] is straight forward to introduce but theoretically most difficile to understand, while the Wankel [2] is the hardest to present due to simultaneous component movements associated to the eccentric shaft not well understood by many. Both engines share some visual similarity (rarely disclosing the underlayer realty), and some basic common characteristics like higher power density, some continuity in circular movement in contrast with alternance devices, but they do not share much in term of deep concept approach and advanced mechanical energy conversion, especially in term of displacement volume per rotation, specific weight, combustion chamber kinetic, thermal management, efficiency, noise and vibration…

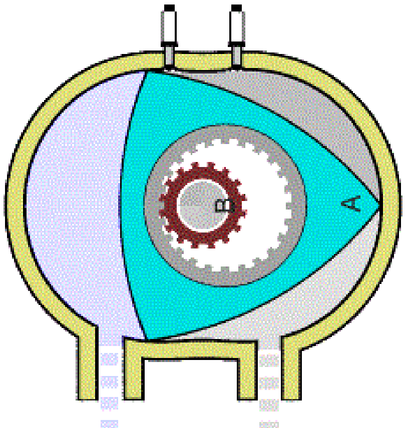

Figure 1: The Wankel (WK) Engine Concept.
A three faces pistons Rotor in a common orthogonal cylinder Stator, with the synchro gears set and the intake and exhaust ports.

Felix Wankel designed a rotary compressor in the 1920s, and received his first patent for a rotary type of engine in 1934. This concept [3] was making sense considering the objectives at the time, which are now much more demanding. Most rotary engine concepts attempt primary to suppress the alternance in engine components (acceleration; stop; deceleration… flow inversions, synchro valves and dead times) to make more homo-kinetic, continuous and vibration free devices. Wankel concept is a paradox, since eccentric shaft alternance, vibration, torque dead time, and synchro gears-set are all present in the WK [5] concept. The development of an engine concept is never easy, and despite some complexity, the WK concept has been the Rotary of hope for over half a century, without seriously challenging the Piston engine. For that, some new approaches were needed. In fact, the Wankel has conceptual difficulties [4] that have never been widely exposed (mainly due to its own complexity) which are responsible for the present reluctance. To unlock the skepticism, this paper enters into the complex intimate of the Wankel CONCEPT details (not the technical development) to explain a century of multiple challenges which add-up to an incomplete solution in the world of modern efficiency and environment cleanness.

Behind superficial relative appearances, both WK and QT concepts have their own complexity and subtilities, and comparison approach must avoid temptation to attribute the vertu or default of one concept to the other, without deep understanding of their similarities and differences, and their own potential for the future. Du to novelty, only sparce comments have been written before the present paper on the differences between the QT and the WK, urging for a need of mutual concepts comparison on their similitudes, characteristics, objectives, differences, advantages and performances.

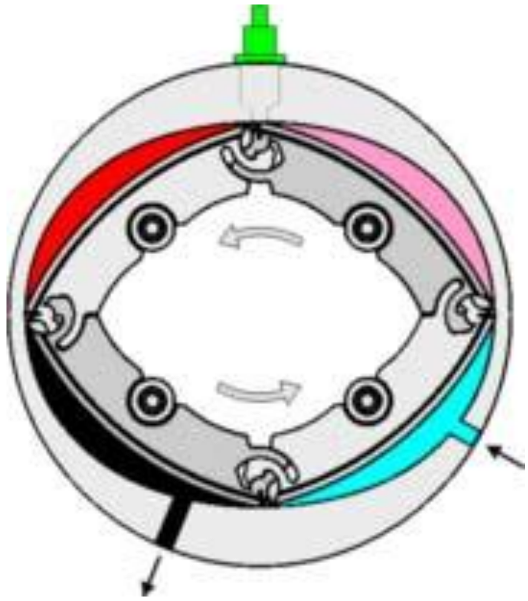

Figure 2: The Quasiturbine (QT) Engine Concept.
A deformable 4 pivoting blades chain Rotor auto-synchronized in an orthogonal Stator, with the intake and exhaust ports.

Since 1990, the Quasiturbine QT pump and engine concept base on a “Deformable QT Rotor” (version QT-SC and QT-AC) [6] has emerged, not only to simplified some of the WK concept difficulties, but also to offer practical and performant solutions to modern engine concerns, including additional Stator design degrees of freedom for specific application [7] and future combustion techniques, like detonation and stratified hydrogen development. While far from being a WK sistership concept, the Quasiturbines have attracted a lot of attention and curiosity [8] in the WK historical context, and has been the object of multiple interrogations and superficial comparisons of limited interest, with discussions or opinions generally non adequately substantiated and often based on unclear similarities, and consequently rarely conclusive. A comparison framework appeared to be necessary.

In most concept the Rotor imposes a unique Stator and designers have no control on the chamber, while the Quasiturbine Rotor can fit in a multitude of contour profiles, allowing tuning of the chamber characteristics for the fuel type or the application, by proper Stator shape selection. The Quasiturbine is much simple that the Wankel to expose, but somewhat more theoretical difficult to master. The Quasiturbine fires sequentially 4 times per rotation without torque dead time, has a perfectly balanced Rotor with no synchronization needs, and run efficient with low RPM high torque in expanders and/or combustion engine mode. The result shows that within a rotary Stator, different Rotor concepts produce different amount of power and efficiency, and if the Wankel concept double the crank shaft power actions over the single piston engine, the Quasiturbine Rotor concept reaches 1.6 time the power density of the Wankel (six times the single piston shaft actions). The Wankel environmental failure is due to both, the chamber surface-to-volume ratio and the impossibility to make optimum ports positioning with triangular symmetry in an orthogonal Stator concept, and minorly to some oil burning to maintain seal adherence through Stator TDC bump.

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This paper aims to highlight the similarities and differences between the WK and QT concepts (including relevant comments about Piston engine), and to expose some new flexibility and potential unique to the QT concepts [9] not only to match, but to exceed the Piston engine interest [10]. While the WK is mainly the subject of technical improvement articles [11], often discarding the aspect of conceptual approach [12] developed more than half a century ago, the theory behind the QT and its virtues have been extensively detailed [13] in the perspective of engine objectives not considered in the past, like optimum efficiency, modern fuel including hydrogen and detonation combustion mode.

This study aims to compare the conceptual design and efficiency of the Wankel and Quasiturbine rotary engines to evaluate their suitability for modern engineering applications. This comparative study provides insights into the strengths and limitations of rotary engine concepts, informing future advancements in sustainable engine technologies.

2. Suggested Guideline Prior Further Reading

The study primarily follows a conceptual comparison methodology, which is appropriate for the subject matter, and most respectful of both concepts.

About alternance and rotary concepts. Concepts are not just mechanical, they must include considerations on security, efficiency, energy, thermal management and more. The piston cylinder alternance offer one TDC and one BDC per rotation, while rotary Stators in WK and QT offer two TDC (top and bottom on diagrams) and two BDC (right and left). In 4-stroke combustion engine mode, for every "two shaft rotations ", the Piston fire once, the Wankel fire 2 times, and the QT fires 8 times. Piston and rotary are different world of concepts, as Rotaries offer several (specialized) chambers along a perimeter, each one for a specific stoke type, while the alternance concepts handle all the strokes types in the same (unspecialized) cylinder chambers; hot chambers for cold intake, and cold chamber for hot relaxation. Much is involved between alternance and circular concepts, as it is much more than making an equivalent device. The QT is one of the most recent (1990) advanced analysis targeting 100 % direct conversion of tangential pressure in vibration free high-torque power, while maintaining a narrow speed kinetic variation of components. In addition of being sound, all concepts must also be feasible with contemporary low-cost technologies.

The Piston engine is at the top of alternance concept, with the eccentric shaft crank-pin inducing alternance in connecting rod, piston, valve tringles and a multi-role single pressure chamber: Notice for example that the piston reverses its acceleration ad mid-course (internal stress) to start and end at rest, while the QT blade never stops, and accelerates smoothly and continuously during all the course of compression and subsequently all the exhaust (no variation reversal) and decelerate continuously during all the course of intake and all the relaxation, to further help the flow of gas. Piston components experience wide speed variations from zero at BDC and TDC, to maximum speed in-between, for poor overall homo-kinetic characteristics. Nevertheless, the Piston is a King worry about its upgrade, thermal efficiency, and modern detonation and hydrogen fuel capability?

About the Wankel (WK):
It is useful to know upfront that the concept is complex. The WK is a sort of hybrid concept stacking three pistons as the three triangle faces around an eccentric shaft crank-pin, keeping the Piston radial motion for 70 % of the power in a rotary piston packaging concept (30 % being pure tangential pressure power). The WK concept, by sharing momentarily in common its exhaust and intake chambers, is doing somewhat like the 2-stroke piston engine does, which is flushing its exhaust in presence of fresh gas mixture. In this respect the WK can also be seen (while more manageable?) as a 2-stroke engine, and bear similar environmental critics. Not surprising it takes pages to layout the WK concept and to properly justify detailed comparisons:

First, the single-triangular Rotor is not and is never centered within the engine, but it is turning on the eccentric shaft crank-pin (rod bearing journals) off a central main eccentric shaft. Consequently, the Rotor is simultaneously translating and rotating within the WK engine according to the position of the eccentric shaft crank-pin.

Second, to precisely fit within the Stator contour shape, both the translation and the rotation of the triangular Rotor must be gear-teeth synchronized with the Stator, not the central eccentric shaft.

Third, the equilateral triangle Rotor create three elongated 120 degrees chambers separated by 3 apex seals, each one progressing simultaneously to the position of the previous one at every central shaft rotation, meaning the Rotor turns at 1/3 of the shaft RPM.

Forth, each Rotor chamber has a 120 degrees periodicity, while only 90 degrees Rotor rotation is needed on the Stator for the power stroke from TDC to BDC, the Rotor requiring a complementary 30 degrees repositioning dead time, which disjoint each stroke from the preceding and the following, and make continuous sequential strokes impossible.

Fifth, in the WK 70 % of the pressure energy is deliver radially to the eccentric shaft-pin just like the piston does, and up to 30 % is from the tangential peripheral pressure force resulting from the rocking pressure chamber effect.

About the QUASITURBINE (QT):
It is useful to know upfront that the QT concept is simple to introduce, but involve a wide number of processes occurring concurrently which are difficult to visualized together, with benefits far from being intuitive. QT never share in common its intake and exhaust chamber (as the 2-stroke Piston does, and also the WK) and is a true 4-stroke engine. While the QT concept can be explained in a few paragraphs, some tangential pressure management needs more theoretical attention:

First, the Rotor is a chain of 4 pivoting blades which center of mass is moving continuously on a cercle (no radial back and forth alternance), in a perfectly balanced movement.

Second, the Rotor create 4 chambers with 90 degrees TDC to BDC periodicity compatible with the orthogonal Stator and the 4-strokes requirement, chambers which are jointed for continuous sequential power stroke, without any gap or torque dead time.

Third, the QT Rotor is self-synchronized with the Stator, each 3 blades synchronizing the fourth.

Forth, the chamber pressure energy is extracted 100 % in tangential torque from the blades sole rocking effect, avoiding eccentric shaft concepts.

Fifth, the central straight-shaft (not eccentric) with its differential is not needed for the QT engine to run (the Rotor being an external engine part).

Sixth, the complex multi-degrees of freedom Stator shape is calculated independently form the Rotor and offers tuning options which impacts the future of efficiency, detonation and hydrogen as fuel.

About Common Coordinates:
The Quasiturbine simple polar coordinate gives straight forward exact location of the chambers (the blade pivot-to-pivot being the unit reference size). In the WK (the radius of the circle passing by the 3 seals is the unit reference size), the center of the triangular Rotor being on the crank-pin with a variable position, and the Rotor orientation angle changes with its lateral translation. For discussion in the present work, angles in all engine type are expressed from the engine Stator central point (central shaft). The WK face mid-point center A, B, C identified each triangular face, and allows to track the state of each chamber, in relation to the eccentric shaft crank-pin orientation (over three shaft rotations or 1080 degrees). It is convenient for the WK to devise the 1080 degrees into 60 incremental steps of 18 degrees each (20 x 54 degrees increment on the main eccentric shaft rotation). For torque comparison, a constant uniform unit pressure is assumed in all closed chamber, and null pressure in all open chamber.

About Definitions and Conventions:
The present discussion referred to arbitrary anti-clockwise direction of movement (unless said otherwise) from the X axis. In the QT, the centers of each blade rotate on a circle at constant radius. For the WK, the Rotor has three 120 degrees apart axes that swept over its center (Rotor center moving with the eccentric shaft crank-pin), each axis (shorter to the face side, longer to the opposed apex seal) is being referred in time by the name of the chamber they are crossing and their actual letter A, B, C. For most volume modulator devices (like Piston, WK and QT), reversing the direction of rotation (statically) preserved the volumetric and kinetic description such as explanations do not need to be duplicated, as the compression-strokes is equivalent to the relaxation-stroke in reverse rotation, and as the intake-strokes is equivalent to the exhaust-strokes in reverse rotation (providing appropriate ports and peripherals are adequately considered). Because the WK Rotor simultaneously rotate and translate (radially and transversally), the Wankel could have been explicitly named (suggestion?) the WANKEL ROTOR-TRANSLATOR ENGINE, which torque and power result mainly from Piston-like crankshaft-pin movement.

3. The Quasiturbine (QT) Description

Remember not so longue ago, when questions were: Can a steel boat float? Can an airplane fly? Can a bike stand-up? Will an artificial satellite be useful? All audacious concept raises spontaneous doubt, like too simple to be true? If true, it would have been done before? Improvement has to be complex? As for today: Can the positive displacement engines have the continuity characteristics of the turbine? The Quasiturbine QT [14] has the inconvenience to look incredibly simplistic, and such simple option does not seem to merit a looked at, until the hidden complexity is revealed Fig. 3 and 4. How can a Rotor fit in several different families of confinement shapes, simply because it is deformable? Why and how this concept can unlock unobvious qualities, and makes the QT attractive and useful?

Figure 3: A look at the Quasiturbine (QT) technology? The Model QT-SC expander with internal Rotor and external Stator, while opened for manual inspection. The two intake ports are interconnected (red hose), and interlaced with two opposed large diameter exhaust ports.

The present authors have written extensively about the Quasiturbine (in AC or SC version) pump and engine concepts and technologies in a Book [15], and in term of Stator shape [16], in displacement and power density [17], and about the QT internal components role and behavior [18]; all complemented by the present comparison [19] with the Wankel Engine. The QT is an assembly in chain of 4 blades pivoting at their extremities Fig. 4, forming a deformable lozenge which is enclosed close fit in a perimeter confinement profile of appropriate thickness. In the internal center of each blade is a supporting roller bearing and accessory for optional power takeoff. For a given Rotor design, there are an infinite numbers of exact confinement profiles quite complexed to calculate [16],

but straight forward to use. A set of 4 contour seals are located at each of the apex, and when needed, each blade carries lateral seals as well.

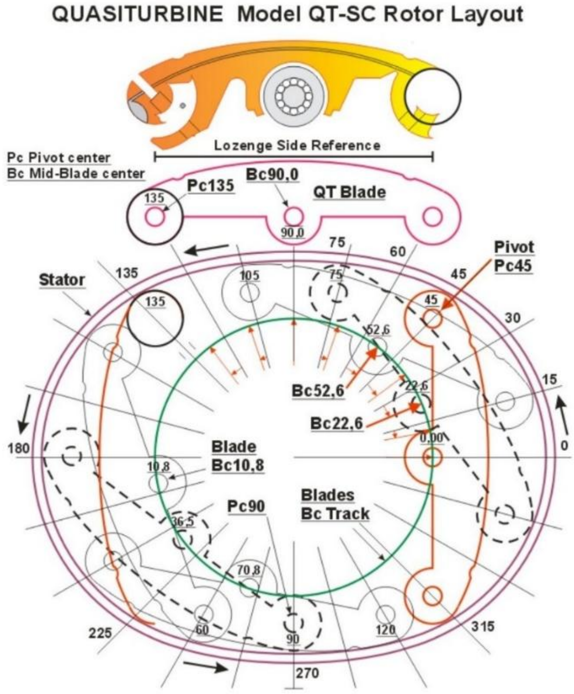

Figure 4: The Quasiturbine concept schematic of Rotor blade component. The chamber volume between blade and wall vary as the blades moves on peripheral. This figure is reproduced from [18].

As pump or fluid expander mode, the Stator holds 4 radially interlaced intake and exhaust ports. Expanders can be made self-starting by brief pressure step, if the top blade can divide the chamber in two parts when near TDC. As a 2-stroke combustion engine (not much cleaner than the 2-stroke piston engine), 2 sets of axially facing intake and exhaust ports are located on the lateral engine sides. As a 4-stroke internal combustion engine Fig. 4, the perimeter supports radially one exhaust port at the end of one BDC, and one intake port at the beginning of one TDC. Every shaft rotation, the QT handle the 4 strokes of each of its 4 chambers. In the QT, blades-end pivots have constant angular rotation speed [18] (forming an orthogonal system at all time.

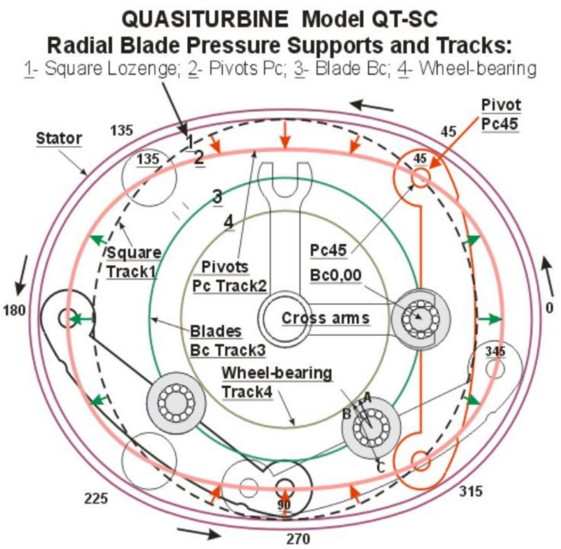

Figure 5: The Quasiturbine concept of the optional shaft and differential. Central device is not necessary for the engine to run. Since the central area can be accessible, all the QT components including the rotor are external part, and can be used for thermal transfer. Two cross harms are linked to opposite blades, and the angular difference drives the central shaft. This figure is reproduced from [18].

As for the QT central area Fig. 5, it holds a simple differential making the straight shaft rotating at constant RPM. Shaft of which the circular wheel-bearing track may be part (and turning with the blades set). There are 2 crossing harms linked to the opposite blade roller axes which crosses at different angle during the rotation, and driving the differential. The shaft and differential are not necessary for the engine to run, and can be omitted when not needed (magnetic induction, central turbine pump…). Contrary to most engines (including WK and Piston) where the Rotor concept imposes a unique complementary Stator or cylinder geometry allowing no design control on the chamber shape and evolution, the QT concept offer this fundamental independence in the multi-degrees of freedom Stator shape calculation (symmetrical or not) [16], allowing the chamber design tuning for the fuel type or hydrogen, the application and the combustion technics including HCCI and detonation.

Generally, rotary engine concepts involve rigid components articulated in a well-defined repetitive way, but the QT concept is a rare exception based on a truly deformable assembly of blades, which accepts a multitudes of confinement contours, which are complex to calculated [16], while allows new fundamental ways to optimized engine to fuel, environment cleanness and application. The QT concept is easy to introduce briefly, the difficulties are in understand the non-intuitive outstanding characteristics that common engine do not consider. In internal combustion mode, the QT presents 4 consecutive zones each specialized for only one function: Intake, compression, expansion and exhaust. All with smooth continuous homo-kinetic operation.

4. The Wankel (WK) Description

In the 1920s, the Wankel team most audacious idea was to insert a triangular Rotor into an orthogonal symmetry Stator. The WK [20] uses a conventional eccentric shaft Fig. 6 and a triangular tri-faces Rotor centered on the eccentric shaft crank-pin, with contour seals at the apex's seals. Each Rotor's face experience rotation and translation and is properly guided by a synchro gear (not shown), and can make its way within a confinement contour shape, because the radius to each face is shorter than the radius to its opposite apex seal. The contour shape is unique and easily determined by tracking the guided seal positions (which repeats for the three faces over 3 shaft rotations).

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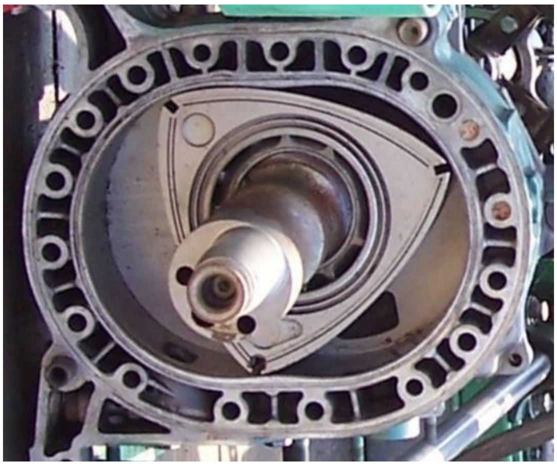

Figure 6: A look at the Wankel (WK) technology? A view at the robust Wankel external Stator with cooling conducts. The triangular central Rotor with apex seals is visible, with the eccentric shaft and its exceeding large diameter crank-pin. The Rotor-to-Stator synchronization gears are not shown.

For the WK in 4-stroke internal combustion mode [21], the perimeter supports one exhaust and one intake located relatively close one another near the TDC (below). Some designs locate intake port on the lateral side cover [25]. Every shaft rotation, the WK executes a total of 4 strokes across its 3 different chambers, and fires once. To guide the Rotor translation and rotation within the Stator confinement shape, a synchronization gears-set is needed to maintain the relation between the Stator (holding a fix pivot-gear attached to one of the lateral side covers) and the triangular Rotor internal crown-gear (maintaining the same direction of rotation for the shaft and the Rotor). Notice that the main central eccentric shaft holds no gear. For lubricating these essential eccentric shaft and synchro gears, the WK central area act as an engine pan.

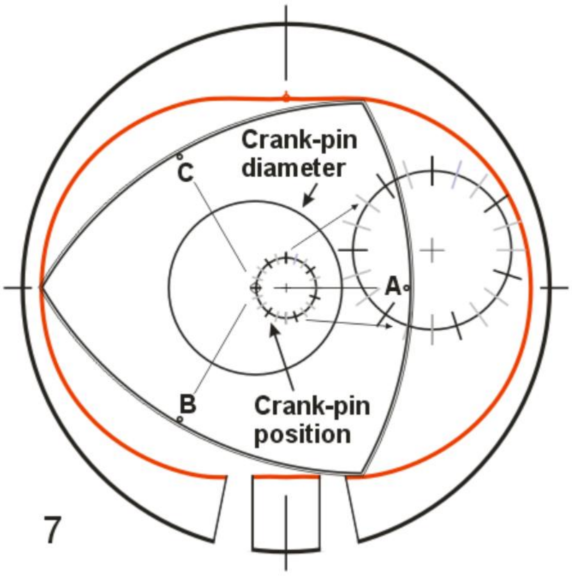

Figure 7: The Wankel concept typical eccentric schematic. Since the Wankel central area cannot be accessible, the rotor is an internal component, and cannot be used for thermal transfer. Notice the two TDC (over and below) and the two BDC (left and right), the eccentric shaft turning at 3 times the Rotor RPM. The Rotor face A is conveniently positioned at BDC 0 degrees (right) to explore fire ignition (up) and ports management (below). The large diameter circle in the center of the triangular Rotor sits on the eccentric shaft crank-pin, which center moves on the small engine concentric perimeter graduated in 18 degrees Rotor steps (54 for the shaft). A situation that repeats for each face of the Rotor. To minimize the Stator bumps at both TDC, the shaft eccentricity must be small, a design limitation of the torque. The ports below are for intake and exhaust according to the direction of rotation.

The WK Rotor has a large hole in center, to hold the eccentric shaft with its shaft crank-pin on which its sit, and around which is a crown gear for synchronization. The triangular Rotor is never positioned in the center of the engine, but translates and rotates on a small circle around that engine center, shown on Fig. 7. The triangle Rotor axes going through each face are sweeping left or right of the engine center (producing Rotor face rocking effect) and aligned by the engine center only at TDC and BDC. The WK eccentric crankshaft imposes also its orthogonal periodicity to the symmetrical Stator 4-stroke contour shape, while dealing with a triangular Rotor shape mounted on its eccentric shaft crank-pin, and holding only three elongated chambers along the Stator perimeter, with relatively high surface-to-volume ratio. Because the WK concept needs to match both 90- and 120-degrees symmetries, each 120 degrees triangular Rotor step is composed of a 90 degrees power stroke from TDC to BDC, plus an additional 30-degree torque dead time. To achieve 4 strokes with a three sides triangular Rotor, the WK concept must momentarily share in common the exhaust and intake chambers, somewhat like the 2-stroke piston engine does, which is flushing its exhaust with mixture gas. In this respect the WK engine is sort of a 2-stroke engine, and bear similar environmental critics. Even if the WK concept relays on Piston-like radial pressure on its eccentric shaft, the Rotor translation produces a rocking effect of the Rotor face in the course of its power stroke, which carry up to 30 % of its WK energy through Rotor tangential torque. This pressure energy reaches tangentially the eccentric shaft with the help of the synchronized gear-set.

A noticeable difference between the current 4-strokes engines is the numbers of power stroke (fires) per shaft rotation, which is 0,5 for the single Piston (with half 75 % torque dead time), 1 for WK (with 25 % torque dead time) and 4 for the QT (continuous with 0 % torque dead time). The object of this paper is to focus on engine concepts rather than engine technologies or mechanical development. Even if the WK did not meet all the conceptual expectations, it was the most interesting and ingenious concept available at the time, and has later been recognized as a major technological achievement [22], and is still today [23] the most credible bases and references in helping validation of the future Rotary engine concepts.

(QT avoid alternance principle and vibration; has no eccentric shaft and uses orthogonal periodicity for Rotor and Stator; offers fundamental Stator design independence from the Rotor by multiple degrees of freedom; uses four relatively short reasonable ratio chambers, with continuous output 100 % from tangential torque).

5. Wankel Unbalanced Eccentric Shaft (QT Balanced)

The WK shaft crank-pin positions circle has a small diameter Fig. 7, which reduces the torque but minimize the bumps at both TDC. In the piston, the eccentric shaft has counter-balanced weights to cancel vibration from crank-pin mass and some connecting rod weight, and fortunately, the linear vibration induce by the piston acceleration and deceleration is unidirectional and one of the easiest to deal with. The eccentric shaft can transfer power efficiently, but the WK concept does not offer any space for internal counter-weight balancing. Not only the eccentric shaft itself is not totally counter-balanced, but its crank-pin gets on it the total mass of the triangular Rotor. In engine dynamic balancing is of importance also in term of internals stress as the centrifugal forces can be destructive. Furthermore, this unbalanced system adds to the angular Rotor power load fluctuation, which smooth-out is also demanding on flywheel. Unbalanced mass being a stress factor affecting the engine lifetime, coupling two out of phase side by side engine stages can partially smooth-out the net engine bloc vibration, while doing little to relief internal WK engine components stress.

(QT does not make used of eccentric shaft, using a strait shaft and differential to directly capture the tangential pressure torque; central shaft is not mandatory for QT to run; the blades set is moving vibration-free and homo-kinetically on a circle, and acting as flywheel).

6. Wankel Doubled Rotations: Rotor and Shaft (Single Rotation in QT)

The WK triangular Rotor hold three axes 120 degrees apart, with distance from the center to the apex tip being superior to the distance at the opposite face A, B, C. In the WK, the center of the triangular Rotor sits on the eccentric shaft crank-pin, and is moving on a circle round the engine center while rotating simultaneously on the supporting crank-pin, involving algebraic sum of rotation angles. The total amplitude of the triangle translation is twice the eccentricity of the shaft. The triangular Rotor center translate and rotate in reference to the central engine shaft, which is also the engine center. There is no simple way to describe such a relatively complex rotation. A practical approximation would be to assume that the Rotor center is never far from the engine center, rather than turning around it, but this would lead to substantial distortions of the Rotor axes orientations, when measured from the engine center.

Tracking the position of the faces point A, B, and C of the Rotor is a practical way to describe the angular (and spatial) position of each Rotor face as shown on Fig. 10, from BDC (right) to TDC (up). The Rotor repeats its movement for different strokes types, in such a way that for a given engine position, if A is in combustion, after one shaft rotation the next B will be in combustion and the same after another rotation for C, over 1080 degrees shaft rotation cycle. Each of A, B, C point execute a 2-dimensional spatial (radially and angularly) movement. Consequently, the WK Rotor turns at 1/3 the central shaft RPM.

(QT blades central point Bc equivalent to A, B, C are turning on a circular constant radius path and are simply described by their angles, as all the blades execute all the 16 strokes in 1 shaft rotation, compared to 12 strokes in 3 rotations for the WK).

7. Wankel Piston-like Radial Volume (None in the QT)

In the piston, the eccentric shaft drives an upper cylinder translation to TDC, from which pressure is applied until the downward translation to BDC (right). In the WK Fig. 8, this movement from TDC (top) is radial and simultaneously accompanied by a -90 degrees rotation of the Rotor axis in the course of the power stroke, to end in BDC (right) position, as shown by the tracking curve of the face point C on Fig. 10. The cylinder head is fixed in the Piston, while in the WK the Stator wall equivalent moving during rotation. The eccentric shaft crank-pin position is at TDC on the Stator shortness vertical diameter, and at BDC on the Stator longest horizontal diameter.

(QT piston cylinder head equivalent is also the Stator wall; as the blade rotate on a circle at constant radius, it has no radial swept volume, all swept is tangential).

8. Wankel Tangential Volume by Apex Rocking (As in the QT)

Regardless of the shape of a pressure chamber, if the two apex seals of a chamber have at a given time a different radius, then a net pressure will act tangentially on the excess extension of the longest radius. This is the case in any non-circular Stator shape. Viewed from the engine center, a chamber with un-equal apex seal radius means the Rotor face is rocking back and forth (in relation to its radius) while moving along the Stator internal wall. The rocking movement is requested by the Stator, but must be offered by the Rotor face to fit within the WK at all time, as the Rotor face progresses-in its axial and angular rotation. This rocking action in is produced when the eccentric shaft crank-pin is either left or right of the face axis, and null at TDC and BDC, as the crank-pin is then on the Rotor face axis (Similarly to the base of the piston connecting rod which is rocking transversally while its top is moving up and down). This lateral Rotor motion makes the Rotor face to rock from zero to a maximum (or minimum) and down to zero in the course of a single stroke, and create an additional tangential sweep chamber volume Fig. 8 (red curve) which generate tangential torque and power in WK, in addition to the radial face translation acting similarly as piston. This tangential volume variation is independent from the axial face movement and both effects co-existed independently, while in rotation. This tangential translation is also useful for the Rotor to make is way within the Stator.

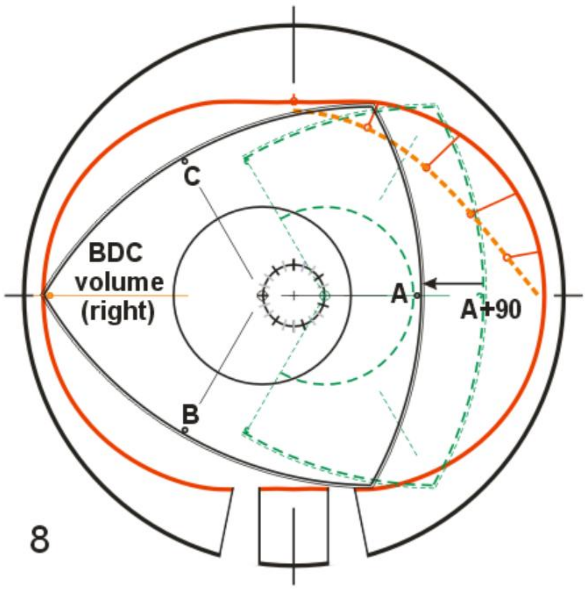

Figure 8: The Wankel displacement volumes: 70 % radial and 30 % tangential. The clockwise Rotor chamber volume is initially minimum at TDC and increases to maximum when the Rotor face get vertical BDC, at the right. To keep reference of the initial position at BDC, let rotate the initial top Rotor face position by -90 degrees to the right as A+90 over-printed (in green), which reveal a radial swept volume, which appear inferior to the total BDC volume. During that rotation, the 2 apex seals radius vary, the differences being drawn from the Stator surface (in red at top right) at 6 intermediary face positions, which reveal the tangential swept volume completing exactly the missing BDC radial volume. A situation that repeats for each face of the Rotor. In the Wankel the displacement volume swept is 70 % radial and 30 % tangential, while it is all radial in the Piston and all tangential in the Quasiturbine.

Since the triangular faces have a maximum radius at TDC (up and below on Fig. 8) and minimum radius at (left and right) BDC, be attentive about an optical illusion for the contrary. Trace of the TDC face position A+90 is rotated -90 degrees and overprinted on the exterior of the BDC face A, to show the initial and final radial face position over a power stroke. Notice that the volume in between the two vertical face position (the BDC interior, and the TDC exterior) is less than the actual BDC chamber volume, but complemented by the tangential sweep volume shown in red. Said otherwise: At 0 degree, the Rotor face A is at minimum BDC radius, and perpendicular to its radius (no rocking), while at 90 degrees, the Rotor face C is about to get at maximum TDC radius (adding the shaft eccentricity), and perpendicular to its radius (no rocking). During counter-clockwise rotation the face A radius increases radially (adding the shaft eccentricity) till reaching face position A+90 at maximum radius. It is during this radial face movement that the rocking occurs simultaneously: at first the front seals radius shortens (till face reaching mid-course) while the tailing seals radius increases, then the reverse as the front seals increases and the tailing shortens both becoming equal when face A+90 reach the 90 degrees position. It is the differential of the apex seals radius which is sweeping the tangential torque volume.

The difference in radius is shown in Fig. 8 (in red) for discrete intermediary position of the A face, to confirm that the final BDC total volume is in fact the sum of the axial face 70 % swept, plus the tangential 30 % swept. These two processes are statically reversible in compression and relaxation, and not dissipative as fluid expansion energy by these processes would be transformed in mechanical energy. As known by the Archimede principle, the static pressure energy within chambers is independent of the shape of the chamber surface, as PV is independent of geometry. Understanding the physic of both the radial and the tangential process permit to distinguish the relative power of each, however a proper surface integral of the rocking face would produce the same global result (without partitioning the physical origine). Basically, it is the lateral translation of the Rotor axe which drive the precious tangential volume variation in a WK, since without his tangential volume, the Wankel would not qualify as a rotary, but rather as a 100 % radial piston engine.

(QT blades are rocking by concept in relation to engine radius; it is the difference of radius at the ends of each blade which create a tangential movement; all the swept volume are tangential; since the blade centers rotate on a circle of constant radius making no radial swept).

9. Wankel Chambers Not at a Fix Location

The concept analysis imposes additional curiosity to check observations. Understanding pressure, push, torque, and power is easy when the combustion chamber has one surfaces at a fix position in relation the engine center, since all force effects can then be attributed to the moving surface. Again, WK does not make it simple. For the three types of engines considered (Piston, Wankel and QT), the pressure chamber involves two opposed surfaces: The piston surface against the cylinder head (fix), the QT Rotor blade surface (radially fix, as blades are moving on a concentric circle), and Wankel Stator wall (not fix) against the Rotor triangular face (not fix). In the Wankel engine type, none of the two opposed surfaces are fixed, per say each triangular Rotor surface and their internal Stator confinement wall move radially and angularly during the strokes (including compression and combustion), making the overall chambers position to move in the course of the stroke.

Archibald principle state that the pressure varies only with volume, and providing the volume is conserved, the pressure is not altered by the chamber shape or location. This is a most useful argument to guarantee that compression or expansion energy will not be lost in the chamber moving process, and consequently the power will have to flow in (or come from) the most favorable direction, which is to make the WK shaft turning, For this, the synchronization of the triangular Rotor with the Stator through a gear-set (not linked to the central shaft) plays an energy transfer role in preventing the Rotor to exceed or lag its due position in the Stator.

(QT has the Rotor blade chamber surfaces at a fix distance from the engine center moving on a concentric circle, the internal wall of the Stator not being fix; different blade's end radius produce tangential force with no blade radial displacement).

10. Wankel Angular and Radial Synchro (QT self-synchro)

Why are there gears inside the Wankel? The WK triangular Rotor needs to be continually guided in the Stator, simultaneously in orientation and in translation. For any position of WK eccentric shaft, the triangular Rotor cannot be left free to rotate on the shaft crank-pin, since it has to be at the correct translation and unique orientation angle to make is way within the Stator. For this, the WK concept offers no self-synchro. For the orientation, the WK Rotor needs to be geared with the Stator only (not the eccentric shaft) in a repetitive way for each of its 3 faces; while transversally, the triangular Rotor is properly guided by the eccentric shaft crank-pin, providing the assembly is done accordingly with the orientation synchro gears. Notice that the diameters of the synchro gears are not imposed by the shaft, but the ratio must be kept.

The synchronization of the triangular Rotor with the Stator is needed to prevents the Rotor from exceeding or lagging in reference to the Stator shape, but is also essential for the Rotor to transfer the tangential pressure torque up to 30 % toward the eccentric shaft. The eccentric WK eccentric shaft will turn under the near axial 70 % pressure Rotor force applied on the eccentric shaft crank-pin (piston-like), and the synchro gear set will guide the Rotor angular position with regard to the Stator (not the eccentric shaft). Conversely, forcing the central eccentric shaft to turn will make the Rotor to progress accordingly. Without the synchro gears-set, tangential force on the Rotor surface would accelerate its rotation out of phase with the Stator contour wall shape, but thanks to the synchro-device (between the Stator and the Rotor, not directly to the eccentric shaft), the tangential force experiences a constraint which impose the central shaft to turn (even without direct gears links) and accept the supplement of the tangential Rotor energy.

To provide the angular and spatial reference, one of the Stator's side cover Fig. 6 hold at its center a fix immobile pivot-gear through which the eccentric shaft passes freely out of the engine, and on which the Rotor internal crown-gear gets the correct angle and radius synchronization. As the eccentric shaft crank-pin makes the Rotor to turn around (with teeth ratio of 2/3: example: Stator 16 / Rotor 24), the eccentric shaft and the Rotor keep the same direction of rotation (due to the crown-gear). Since the synchro play an active role in delivering tangential pressure energy, it has to be strongly built, as well as the WK engine side covers.

(The QT needs no synchro gears, or said otherwise, any three of the blades do auto-synchronized the fourth; the side covers don't have to stand gear-torque stresses).

11. Wankel Strokes Cycle (QT 4 times 4-Strokes)

In the WK concept, the length of the pressure chambers has 120 degrees aperture, and exceeds the length of the physical stroke which is 90 degrees. If the longue chambers are physically jointed through their apex seals, the shorter physical strokes are not, and prevents continuous combustion. The triangular WK Rotor creates three jointed pressure chambers insulated one from the others by their tips contour seal, and each being crossed by their face-to-apex axis. In engine mode, the mixture compression stroke must end at TDC where it converts itself into the combustion-relaxation stroke. From Fig. 8, with superposition of the initial TDC face, it is apparent that the combustion-relaxation stroke starts from TDC (compressed minimum volume) and end at BDC (expansion maximum volume), corresponding to the Rotor 90 degrees rotation (270 on the eccentric shaft). The track of mid-position face central point either A, B, or C, are shown on Fig. 10 during the course of the stroke, and revels the radial face sinusoidal-like displacement (and axial and tangential velocity). The total radial face movement is the limit radius difference from the minimum and maximum.

At the end of the 90 degrees Rotor stroke, the next upcoming mixture fuel stroke is not yet in position to fire at TDC. During the compression stroke in Fig. 10, the Wankel contour wall gets radially inward while the triangular Rotor face moves radially outward, such as the average position of the compression chamber moves radially during the compression. Conversably, during the relaxation power stroke, the WK contour wall gets radially outward while the face of the triangular Rotor moves inward. Reverse action appends at exhaust and intake. However, it is important to notice that these translations of the chambers average position do not involve energy lost (PV rule) and don't affect the total WK engine power.

It is also important not to confuse the "WK engine 4-strokes cycle" with the individual stroke rank in the 1080 degrees 3-turns shaft cycle. Ignoring the triangular geometry for a moment, and focusing the single Rotor face A, that face does not execute endlessly 4 consecutive strokes every 120 degrees Rotor rotation, but only over a full Rotor rotation (while some strokes are simultaneously executed by the other faces); as this face A will get its firing rank in the engine cycle only once every 3 eccentric shaft rotations. In three consecutive rotations of the eccentric shaft, the firing sequence is A, B and C, and A, B… and this is repeated continuously in that order. This is why it is necessary to name each face A, B, C to keep track of their ranks.

(QT chambers and the physical strokes have the same length without torque dead time; the blades and the chambers are at constant radius, and each of the 4 blades execute their 4-strokes every shaft rotation).

12. Wankel Stator "No Port Zone" (None in QT)

Like in most engine (including the Piston and WK), the Rotor concept imposes a unique complementary cylinder or Stator geometry living no designer choice on the chamber shape and evolution, as this would require a Stator design independent from the Rotor, to allow such chamber tuning for the fuel type or application. For one, the WK Stator imposes a small diameter shaft crank-pin positions circle

Fig. 7, which reduces the torque but minimize the bumps at both TDC, but there is more, as the Stator imposes also restriction on ports location.

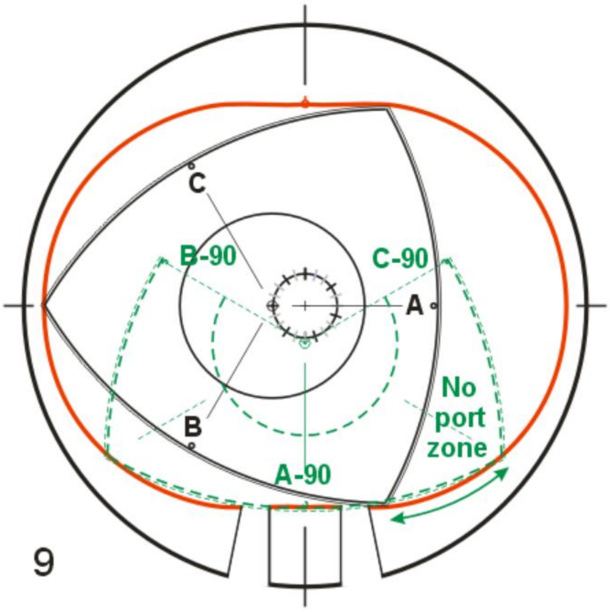

Figure 9: The Wankel "No Port Zone". The ports must be located on the Stator, each to service one and only one chamber type (exhaust, intake…). In clockwise, the BDC exhaust chamber A (right) evolve to become at TDC and later an intake chamber A-90 (below), while any port in the 30 degrees gap would initially access (by the forward seal) in the BDC exhaust chamber A, this same port would later access (by the tailing seal) in the TDC intake chamber A-90; What is the value of a single exhaust port ending as an intake port? The WK difficulty is that when a stroke end, the next one is not ready to begin, and will not start at this is same point where the first one ended. If a port favors a chamber, it spoils the other or both. Consequently, these 30 degrees gap in each quadrant are 'No Port Zone', which helps understand why WK exhaust and intake port are so closed one another, away from optimized thermal efficiency location.

As shown in Fig. 9, by superposing the BDC over the TDC (at different time, see bottom-right), the elongated chamber length fits easy along the TDC (below) long horizontal rectilinear Stator, while this same chamber length was (90 degrees before) closer to the engine center to fit in the more pronounced curvature of the vertical Stator at BDC (right). Consequently, even if the chambers are physically joined by their apex seal, the BDC and TDC strokes ends are disjointed 30 degrees apart on the Stator wall, creating four "No Port Zone" on the Stator (covering a total of 120 degrees or 33 % of the perimeter). Notice that the gap is not a physical overlap, but a zone swept while the chamber is two distinct types. Fuel combustion is one way to get pressure into an engine, another way is to feed the engine from an external pressurized source (gas expander, or reversable pump), with similar WK problematic, as it is not possible to position an engine port at the frontier of two consecutive strokes. In WK concept, the chambers pertain to the 120 degrees apex seals triangle faces, and the problem occurs because TDC can never be simultaneously at right angle with BDC, as they are always 90 + 30 degrees Rotor rotation apart. This makes continuous operation or combustion of the WK impossible, neither in pneumatic or steam expander mode. It is an unfortunate paradox since for efficiency, the optimum port position would be somewhere in that zone. As a consequence, it is not only the surface-to-volume ratio that is responsible of engine efficiency reduction, but as well the compromise on optimum Stator port location.

(QT has joined 90 degrees strokes operating continuously without needs of synchro, with blades of relatively shorter length, moving around at constant radius without restriction on optimum efficiency port positioning at the frontier of consecutive strokes in all operation mode).

13. Wankel Face Path and Repositioning Dead Time (None in QT)

All Rotor faces A, B, C points follow a path curve in the orthogonal Stator, giving angular and radial position with velocity (intervals density). This curve has a maximum and minimum radius corresponding to the radial piston like movement, and show the radial rest point at TDC and BDC and the speed in-between. This allows to follow Rotor face movements in the WK. The Rotor simultaneously turns and translates, and because the WK concept has to deal with both 90- and 120-degrees symmetries, it is important understand that each 120 degrees triangular Rotor step is composed of a 90 degrees stroke from TDC to BDC, plus an additional 30-degree Rotor of REPOSITIONNING torque dead time.

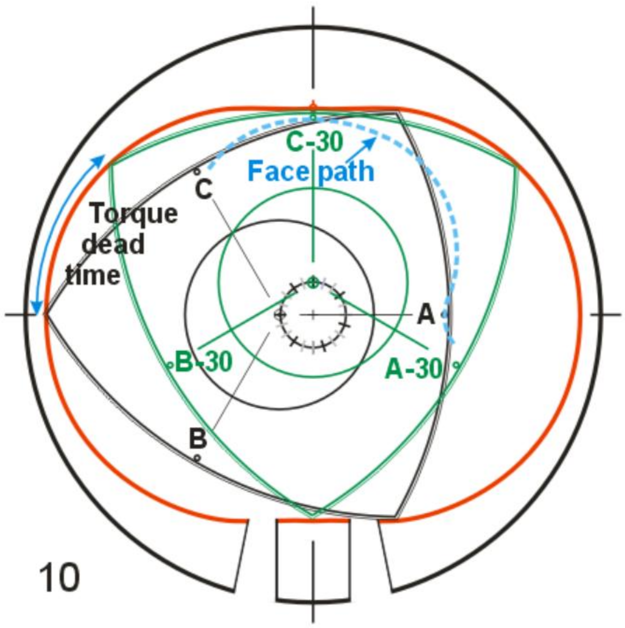

Figure 10: The Wankel face path and Repositioning torque dead time. All Rotor faces A, B, C points follow a path curve in the orthogonal Stator, giving angular and radial position with velocity (in relative intervals). The clockwise Rotor ends its relaxation stroke with a vertical face at BDC as shown in the right. At that time a fresh mixture is partially compressed by the following Rotor face C in the second quadrant (top left), but before firing the Rotor needs to rotate an extra 30 degrees to reach the TDC position (shown in green). Since no stroke is at that time active in relaxation power production, the Rotor needs to

relay on inertia and flywheel to cover the 30 degrees gap over the 120 degrees Rotor face, which is a 25 % of the Rotor rotation (or 90 / 360 degrees for the shaft). A situation that repeats for each face of the Rotor.

Not all engines can deliver continuous positive torque on output shaft (Piston being one). Why does the WK Rotor needs repositioning? Every time the eccentric shaft makes a full rotation; the Rotor move 120 degrees from one face to the next (it needs 3 eccentric shaft rotations to visit and fires the 3 different faces). The lengths of the WK chambers are dictated by the triangular Rotor to be 120 degrees and are physically joined by their apex seals, while the strokes are driven by the orthogonal 90 degrees Rotor rotations as shown on Fig. 10, and are consequently disjointed. Since moving from one face to the next require the Rotor to rotate 120 degrees (100 %), and the power stroke needs only 90 degrees (90 / 120 = 75 %), the additional 30 degrees (30 / 120 = 25% %) Rotor rotation is power torque dead time. For this, each WK Rotor face needs a 30 degrees power dead time repositioning at the end of each power stroke. The same can be described from the eccentric shaft point of view, since moving from one face to the next require 360 degrees shaft rotation (100 %), and the power stroke lasting only 270 degrees (270 / 360 = 75 %), the additional 90 degrees (90 / 360 = 25 %) shaft rotation is power torque dead time. In fact, due to “no port zone”, the power output is reduced somewhat before and after the dead time zone, such as the 25% is a theoretical minimum.

About the Rotor repositioning, one may thing that the 30 degrees power dead time gap between WK power strokes will make the strokes and the volume chambers quite independent one another. Again, the WK makes things more complex, as this is not the case, since from Fig. 9, the BDC bottom-end chamber volume and the lower TDC right-end chamber volume are visiting (at a different time) the same 30 degrees Stator zone where chambers are meeting. When a power stroke ends, the following power stroke starts on the following triangle face only after a 30 degrees (25 % of the time) Rotor rotation (repositioning), when the next upcoming triangular Rotor face reach its TDC. This is (possibly dissipative?) a total time lost (not necessarily efficiency lost) of torque (25 % of the time) in-between each WK power strokes, which count on inertia or flywheel to pass over. This power torque gap prevents WK to achieve continuous cycle for combustion, pneumatic or steam, in addition to the No Port Zone supplemental optimization impeachment. Power torque dead time is a source of eccentric shaft harmonic (deceleration) and tangential vibration. Like for circular vibration, stacking 2 engines stages out of phase side by side can smooth out shaft torque harmonics. (QT chambers and physical strokes are of the same length and jointed, which permit power stroke to be consecutive in continuous combustion and other mode, without any torque and power dead time).

14. Wankel dissipative Repositioning (None in QT)

During WK engine torque dead times, essential stroke actions continue like useful exhaust, intake or compression strokes which can borrow energy from inertia or fly wheel, to restitute it later, which are not net energy lost, but time lost. The “No Port Zone” explains why intake and exhaust ports are so closed in WK, and while the exhaust port is somewhat quite late after the BDC (not optimized), and intake port too early in TDC (not optimized). In addition to poor flow characteristics, there is also some recompression and expansion of gas capture in chambers in coincidence with the power torque dead time which is dissipative and counter-productive energy lost.

Look what append in the 30 degrees WK Rotor torque power gap. As seen on Fig. 10, to execute one power stroke of 90 degrees Rotor rotation, the WK eccentric shaft needs to turn 270 degrees, while accomplishing complementary strokes to the other Rotor faces and continuing the upcoming Rotor face additional 30 degrees toward the next TDC. Then, there is no more positive torque on the eccentric shaft and thanks to inertia and flying wheel for swing across these 30 degrees dead torque Rotor gap (which is 25 % of the time or 90 degrees on the main shaft). Because the port location cannot be optimized right at the end of the exhaust stroke, nor exactly at the beginning of the compression stroke, closed chambers capture fluid on which dissipative work is done, such as a volume of exhaust gas is useless recompressed and a missing gas mixture volume is useless expanded, both being undesirable counter-productive dissipation (not mentioning the incomplete mixture intake). These are not important dissipative engine losses, but enough to be taken into account. However, the 30 degrees gap Rotor rotation must be done, and is necessary to complete the mixture compression until next TDC, and to expel the exhaust through the BDC chamber port.

(QT has physically jointed chambers and strokes being of the same length it suppresses the “ No Port Zone ” since the Ports location are optimized. Not only there is no dead time torque gap in QT, but neither counter-productive dissipative flow captured due to optimized port position).

15. Wankel with no Stator flexibility (QT with degrees of freedom)

In order to turn closed-fit within a Stator contour wall, each Rotor position needs a « proper axial and lateral translation » within the engine (provided by the eccentric shaft) and a « synchronized orientation » in reference to the Stator assumed by a gear-set between the Rotor and the Stator (not geared to the eccentric central shaft). The designer has little liberty (apart maybe some mechanical angle synchro timing?), but to let the Rotor circled around the center of the Wankel engine, with the amplitude of the eccentric shaft crank-pin to create the engine displacement, and imposed the needed Stator confinement profile eccentricity. The close-fit Stator shape is easy to determined (or calculated) once the sizes of the WK internal components (including synchro) are selected, suffice to rotate the eccentric shaft to trace the uniquely defined seals positions as the unique close-fit Stator profile, and its eccentricity. Surprisingly, in the WK concept, the triangular Rotor turn and translate (and rock) to produce an orthogonally symmetrical Stator shape, essentially driven by the orthogonal nature of the eccentric shaft, not the triangular Rotor geometry. The Rotor

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movement defined its Stator shape, then the Stator impose its absolute rule to the WK engine.

The WK concept imposed strong requirements on Stator robustness, as the peripheral shape need to handle the asymmetrical Rotor sweep, but the side covers also require robustness, first to withhold and carry the eccentric shaft circular vibration, but also to stand extra stress from a robust synchronization device between the Stator side cover and the Rotor, by which the tangential force on the Rotor is transferred to the power eccentric shaft. Let's recall that the WK fire once per shaft rotation, with a 25 % dead time, and need three shaft rotation to make the three faces Rotor to fire one after the other. Furthermore, resulting from the eccentric shaft crank-pin small radius compromise, as does the total displacement, the bumps on the middle of the two TDC are singularity requiring rigidity from all the WK components, including the Stator. Some contour simplification may attenuate the bumps (for toys?) by reshaping Stator [24] from the intersection of two perfect circles.

(QT offers contour shape freedom of choice. Stator eccentricity, chambers displacement and pressure profiles are not dependent uniquely from internal component parameters, but can be later tuned by the large degrees of freedom in calculating its contour profile shape, symmetrically or not, to accommodate specific optimization. Homo-kinetic operation without synchro and absence of TDC bumps reduce substantially the requirement for QT Stator robustness and weight, while it fires 4 times per shaft rotation).

16. Wankel 2-Stroke Exhaust-Intake (QT being Full 4-stroke)

In external expander mode, the port handles pressure energy from TDC to BDC. In WK internal combustion, the ports do not deal with high pressure energy, but use TDC (as the Piston uses the BDC) to exchange exhaust gas volume, by fresh mixture gas volume. In 2-stroke piston engine, combustion and compression chambers are made in common, before the end of the power stroke till after the beginning of the compression stroke; a similar step occurs in the WK where the lower TDC play the role of the Piston BDC in an active exhaust expulsion by intake. The WK concept, by sharing momentarily in common its exhaust and intake chambers, is doing somewhat like the 2-stroke piston engine, which is flushing its exhaust with a flow of mixture gas. In this respect the WK is a 2-stroke engine, and bear similar cleanness environmental critics. To achieve this volume replacement, no port is required in the chambers stroke junction area, but rather in the middle of the TDC (below) on Fig. 9. Since the WK execute exhaust and intake in the same stroke, one can say that WK Rotor executes a total of 4 strokes in 120 degrees rotation, including its 30 degrees dead time. Instead of having two perimeter ports, some WK designs have one perimeter exhaust port and one intake port [25] in the engine lateral side cover.

The compression stroke from BDC to TDC Fig. 10 and the relaxation power stroke from TDC to BDC are essential and most critical in any engine, and they can hardly be compromised. Consequently, in a small angular space, the exhaust strokes need to coexist with the mixture intake stroke. A little before the completion of the relaxation power stroke at the BDC, both ports Fig. 9 are in a TDC chamber just ending a previous exhaust evacuation, and starting to increase volume, vacuum-in fuel mixture (and hopefully little exhaust back flow). As the mixture chamber tailing seal tip passes first over the exhaust port, the relaxation exhaust starts flowing out, while intake process is now insulated and continues. Then the intake tailing seal tip passes over the intake port interrupting it somewhat before its BDC, so that the exhaust continues flowing out (in company of the open intake port, as a compromise) till TDC. Then the cycle repeats for the following Rotor face. Notice that the exhaust cycle is retain till the exhaust port appears but is not interrupted before its total completion, while intake mixture cycle is interrupted (compromise) before ending its optimum volume. Notice also that this is a simplified static flow description, that sophisticated kinetic flow and ports positioning can mitigate somewhat in practice. The WK moves three chambers simultaneously while rotating.

(QT concept execute 4 strokes in 4 separated chambers per rotation, and never make in common exhaust and intake chamber, for true clean 4-stroke cycle).

17. Wankel Chambers Pressure Profile (QT matching Piston)

In the WK, the triangular Rotor and the engine shaft turn in the same direction (thanks to the crown gear), and the main shaft needs to make a full rotation (including a 25% or 90 degrees shaft torque dead time) for each of the 3 faces of the Rotor. The WK produces its volume displacement in two ways, radially and tangentially. In addition to the radial 70 % displacement, the WK tangential 30 % volume swept are due to rocking effect of the Rotor faces, which make the 2 end-seals of each chamber to move with different engine radius during the Rotor rotation. Radial and tangential volumes append to have similar evolution and make their own fair pressure contributions. A synchronization of the triangular Rotor position with the Stator gear set (not linked to the central shaft) prevent the Rotor to exceed or lagging its due position in the Stator shape. Consequently, the RPM stabilization and the chambers angular speed are largely controlled by the shaft flywheel.

The compression air pressure (theoretically, without fuel mixture) versus the device shaft angle (at constant RPM) is an important geometric characteristic for comparison with other engine type, regardless of the chamber surface-to-volume ratio. For the reference Piston engine, this geometric pressure is generally described by the 3 R +/- 1 R theoretical piston [18], and goes near the sinusoidal. Apart from the piston surface, the piston uniform cylinder wall is not swept any surface nor dragging any gas flow, and being progressively masked during the compression or becoming visible during combustion, does not produced any tangential surface or volume. Pressure profile in rotary is achieved under some tangential wall speed, and in this respect, it was the WK which has practically demonstrated the feasibility of the chambers having tangential volume and speed wall. Base on the eccentric shaft used, it is not surprising that the WK pressure profile generally reported also fits the sinusoidal model (excluding the stroke 25 % torque dead time), and confirm sharing of the piston credibility in this regard. Since it is not the purpose of this analysis to build a WK, the readers can make their own WK pressure curves from data of Fig. 11.

(QT-SC pressure profile 100 % tangential matches the piston, needs no synchro gears and produces little stress on side cover; has maximum blade speed at TDC unlike the piston which is resting; QT-AC [18] offers a different unique detonation profile.

18. Wankel Static Basic Data Summary

By definition all engine aims to make a stable RPM (with less possible harmonic, and minimum extra flywheel), an objective difficult to reach with alternance concepts, but believed to be naturally reachable with the rotational continuity expected in rotary tangential concepts. Rather, the WK bring the alternance concept in the world of rotary, with torque dead time, and radial speed face movement like in piston engine, which evolve tangentially of course. A need to develop upside down look (triangular face being at maximum radius at TDC and minimum at BDC), and hard to notice reversal of the radial face acceleration in the course of the strokes (reversal as with the piston is resting at beginning and the end), while there is no acceleration reversal of the tangential speed, as usual with rotary concepts. This is a lot to considered at once.

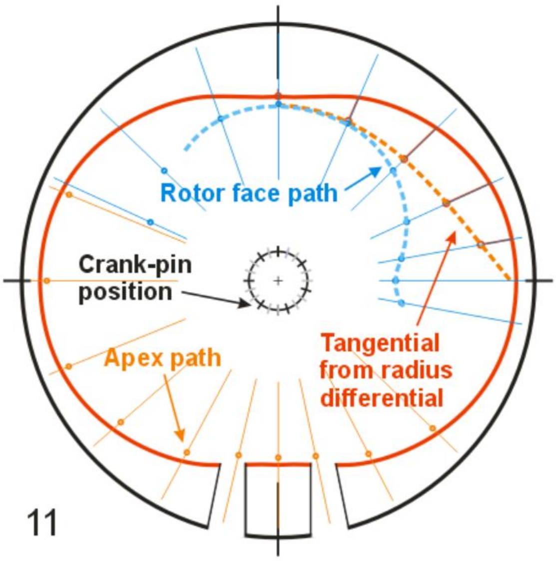

Figure 11: The Wankel components positions and paths within the Stator. This is a global picture of the Wankel components dynamic: the crank-pin angle (graduated at the center); the path of the central face A, B, or C point (blue, can be extended in a symmetric close curve); the path spacing variation of the apex at the Stator wall (brown); the tangential swept surface within strokes (red); and the Rotor orientation synchro increasing as the crank-pin angle. Using crank-pin graduated angle step reference (center cercle) to ensure the tracking points and their spacing variation (velocity) are at constant RPM. Each face and apex follow their same path in the Rotor orthogonal symmetry, and knowing for one quadrant provides the others. A situation that repeats for each face of the Rotor.

In an effort to summarized the WK concept characteristics, and before being more specific on the kinetic of the components, it is essential to gather visually most of the WK static details on a single diagram like Fig. 11. Knowing the path (blue) followed by the Rotor face central point is the key in understanding the WK, the synchronization, and the face firing order. Tracking center face points (angle and radius) provides step positions, while spacing variation gives angular and radial velocity. Each apex is at a fix distance of the opposite face central point, but tracking along the Stator wall provide correct positions (angle and radius), while spacing variation gives angular (much different from face mid-point) and radial (slightly different) relative velocity. Tracking chamber ends apex radius differential provides tangential swept surface (Fig, 11 in red), in addition to face rocking angles. The data are there, up to the readers to exploit them outside the present conceptual discussion.

19. Wankel Rotor Face and Apex Seal Kinetic

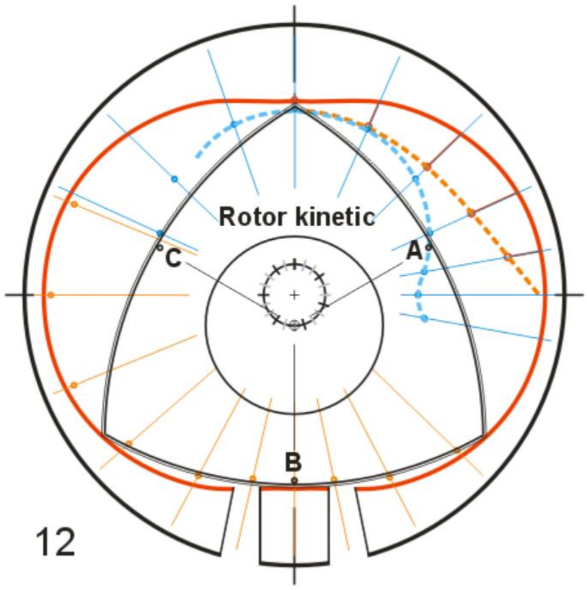

Figure 12: The kinetic of Rotor Face and their opposed Rotor Apex. Consider the Rotor face A on the blue curve toward 2 x 18 = 36 degrees direction, its apex is opposed in the triangular Rotor, but not in the Stator due to lateral translation of the eccentric shaft crank-pin. The blue curve can be extended in a symmetric close curve and match all three Rotor faces A, B, C simultaneously. The distance between each point has a radial and a tangential angular component, which spacing is inversely proportional to the component velocity. In the interval 0 to 90 degrees, face A is at minimum radius and slowest angular speed at 0-degree BDC, while at maximum radius and highest angular speed at 90 degrees TDC. The blue curve also gives radial speed information from rest at 0-degree minimum radius, followed by rapid acceleration till inversion (like in Piston) at mid-course for a slower deceleration and rest at 90 degrees maximum radius. Equivalent data are given on apex (brown curve), with reassuring minimum angular speed at the bumps, attenuating acceleration-deceleration over them. The information is also available on the Rotor rocking face (red curve) which begin from null, increase and reverse to decrease to null in the course of all strokes. A situation that repeats for each face of the Rotor.

Both the eccentric shaft and the Stator shape have orthogonal geometry, such as the absolute angular and radial velocities in one quadrant is the same in the others three. The central mid-points of the Rotor mobile faces (piston center, Blade center Bc, and Wankel face mid-point A, B and C) are good reference to describe and compare different engine types in term of position, chamber volume and component angular and radial velocity.

When focusing on a single power stroke (one quadrant Rotor rotation in the Stator) on the Fig. 12, there are much to notices. The angular velocity (never rest) of the Rotor face point A (the rocking angle pivot) from minimum at BDC 0 degree to maximum at TDB 90 degrees, for consecutive 270 degrees shaft angle interval. The angular velocity (never rest) of the Rotor apex seals from maximum at 180 to minimum at 270 degrees (on the bumps with some risk of seal flying over). The Radial velocity of the Rotor face point A (the rocking angle pivot) resting at both BDC and TDB, increasing outward from BDC to a maximal at mid-interval (acceleration inversion) and decreasing outward to rest at TDC. The Radial velocity of the Rotor apex seals resting at both 180 and 270 degrees, increasing inward from 180 to a maximal at mid-interval (acceleration inversion) and decreasing inward to rest at 270 degrees (on the bumps with some risk of seal flying over). Consequently, there are smooth acceleration-decelerate in WK tangential swept movement, but twice more acceleration-deceleration inversions for all axial movements driven by the eccentric shaft Piston-like action.

About the kinetic in the piston engine, the cylinder wall is not dragging any gas flow, and even if it is progressively masked during the compression or becoming visible in combustion, it cannot be considered as being a tangential sweeping wall as it is in the rotary. Kinetic effects in the rotary are achieved under radial wall radius differential, and in this respect, it was the WK which has practically demonstrated the feasibility of the chambers having tangential volume sweeping wall. There is a kinetic concern in the WK about the seals speed over the bumps, and some tendance to flyover, reduced by de presence of lubricant ending up burning with the mixture. Finally, as the moving Rotor face get close to the stationary Stator wall near TDC, the tangential speed difference over two such a long surface can generate turbulence and some mixture gas roll can develop in the WK concept due to this elongated combustion chamber, which has been subject of critic also because its high surface-to-volume ratio. Finally, the kinetic of the WK engine is slowdown 25 % of the time by the Rotor repositioning torque dead time, which should not be expected from a rotary concept. Consequently, the stabilization of RPM and the chambers speed are largely controlled by inertia and the flywheel. Since it is not the purpose of this analysis to build a WK, the readers can make their own WK speed curves from data of Fig. 11.

(QT has no radial displacement; only non-stop tangential torque; no reversal of axial or tangential acceleration within stroke; fewer mixture roll with shorter blade faces of favorable ratio and optimum port position; no torque dead time).

20. Wankel Efficiency and the Environment (Optimum for QT)

About three illusions in WK engine? First, not all the engine produces the same amount of mechanical energy from a liter of fuel and that is efficiency, while the engine waste of time is not about inefficiency, nor is the positive torque dead time. The waste of precious engine time is related to performance, affecting the specific engine characteristics, but not necessarily consuming energy. It must not be confused with thermodynamic inefficiency, even if both are somewhat currently associated. Second, because neither the Rotor or the Stator surfaces are at fix radius, the whole WK chamber positions move, simultaneously with its volume variation; fortunately, this does not require correction for energy expansion as Archimedes principle state that for equal volume, the position and shape of the chamber is irrelevant. Third and most important, while the Piston engine has axial and no tangential sweep, and the QT has only tangential and no radial sweep, the WK has both radial and tangential volume swept. Never forget the hidden tangential volume swept in WK analysis to avoid constancy problem as the BDC volume will falsely appear larger than the radial Rotor swept as visible on Fig. 8, and falsely reduce the chamber pressure and the energy conversion efficiency. The total WK volume displacement is always the sum of the Radial plus the Tangential chamber volume swept, which have the same efficiency, and confirm the theoretically competitiveness of the WK internal pressure energy conversion.

About torque dead time. Even if the pressure chambers in the WK triangular Rotor concept are successive and jointed, they have unfortunately 120 degrees aperture on the Rotor, while the power stroke in the orthogonal WK Stator requires the Rotor to move forward only 90 degrees from TDC to BDC, involving an extra 30 degrees torque dead time (25 % also on the shaft). The WK concept of successive 120 degrees chamber aperture can never make successive chambers orthogonal one to another, preventing the Rotor to make continuously torque. All being relative, the 4-stroke single Piston has a 75 % torque dead time, and still imposes itself with efficiency. In the WK concept, the 30 degrees Rotor power gap cannot be removed, as it is useful and necessary to complete the mixture compression until next TDC, and to complete expelling off the exhaust through the lower TDC chamber port. This maybe regrettable in term if power density or specific weight, or shaft harmonic… but engine concept can NOT be rejected on this aspect alone, as proven by the Piston.

About flywheel. Since the power strokes are only 90 degrees Rotor rotation, while the Rotor chambers have 120 degrees aperture, repositioning of the WK Rotor during the torque dead time is necessary. From the shaft 1080 degrees perspective, the power stroke last 3 times 270 degrees (75 % of the time) and the torque dead time 3 times 90 degrees (25 % of the time), but the three Rotor repositioning require energy to complete the compression of mixture near TDC, to recompress some exhaust gas before expulsing, and to create the vacuum needed to intake new fuel mixture. As for the Piston, the WK needs inertia and flywheel to store kinetic energy during the power strokes and to restitute it during torque dead time to maintain essential engine functionality, and smooth the instantaneous RPM. It is a heavy accessory with some inconveniences, but with negligible energy consumption, and not considered as serious conceptual concern.

About the elongated combustion chambers, the WK concept presents three difficulties. First, the chamber with 120 degrees Rotor angular aperture exceeds the physical 90 degrees Stator stroke angle, which stroke gap creating "No Port Zone" preventing to displace the Port of the intake chamber to load its maximum mixture volume, and to displace the Port of the combustion chamber to make full relaxation to its BDC maximum volume, like the piston does. Said otherwise, because the Port location cannot be right at the end of the exhaust stroke, nor the other Port exactly at the beginning of the compression stroke, the closed chambers must capture residual stroke fluid (or be short of) and on which dissipative work is done, such as a volume of exhaust gas is needless recompressed and a missing gas mixture volume is needless expanded, both being counter-productive (not to mention the incomplete mixture intake). Second, the high combustion chamber surface to volume ratio, as lengthily chambers can make some obstacle to flow, produces strong rolling drafts, requiring a second or third sparkplugs, imposed some fuel quality, extra exhaust combustion control, etc. Third, the large hole needed in the center of the triangular Rotor leaves little thickness at the center of the Rotor faces, which limit the design options for deep cup combustion chamber, and better combustion achievement. These three concerns produce conceptual minor loss of thermodynamically efficiency, in addition to normal conventional losses as they append at the end of Piston strokes, but adding significant pollutants to the engine exhaust, compromising the environmental interest of the concept.

About burning lubrication oil. Among the unwelcome bugs in the WK concept are the 2 little Stator bumps at TDCs, that the apex seals must pass over. In the lower ports area, the apex seal has a minimum tangential angular speed, and separates two consecutive chambers of relatively low pressure when moving over the bump at the ports area, where one chamber is expelling combustion gas, while the other is almost filled with fresh fuel mixture. It is more critical in the upper TDC spark-fire area on Fig. 10, where the two apexes seal angular tangential travel at higher speed, while insulating two active chambers under considerable pressure, and while maintaining leakproof is essential. The Stator wall pressure on the apex seal reverses over the bump, where the seal tends to fly off the Stator wall at high RPM, compromising the leakproof condition. A solution is to keep a fine film of oil on the inner Stator wall to maintain the apex seal adherence, and accept that some of this oil burn together with the fuel mixture. Under proper control, this conceptual inconvenience could be manageable (?).

About common exhaust-intake chamber. In the 2-stroke Piston engine, the intake and exhaust ports are simultaneously open near the BDC, such as the mixture blowing-in flushes the exhaust gas out from the common exhaust-intake chambers, getting ready for the next stroke. This is a compromise where some residual exhaust gas may not be expelled and reduces fresh mixture-in volume, and where some fresh mixture may get expelled in the exhaust port and not contribute to thermomechanical power. There are 2-way loss of efficiency, while throwing some unburned fuel in the environment. No matter how near perfect is the process, billions of cycles mean no modern environmental acceptability for the 2-strokes piston engine. This example is an appropriate introduction to similar concerns in the WK by exhaust and fuel mixture handling. In the piston it appends at BDC maximum chamber volume during transition from exhaust to intake, with an external blow of fresh mixture; while in the WK a similar process appends but at TDC minimum chamber volume also during transition from exhaust to intake, in presence of an internal fuel mixture vacuum. Both techniques make a chamber in common where some residual exhaust gas may not be expelled entirely, and where some fresh mixture may get expelled directly in the exhaust port. Here also, there is a possible reduction of efficiency and some unburn mixture thrown in the environment. Will billions of WK cycles mean no environmental acceptability like it is for the 2-stroke piston engine? Worst, is the WK be classified as a 2-stroke engine? The flow regime is very different in the WK, and advanced flow analysis may offer better solutions, in addition to post treatment. Meanwhile cleanness environmental critics persist and hope for technology to answer…

About the Wankel environment future? This explains why several conceptual difficulties of the Wankel engine remain unresolved, and why the Wankel environmental failure is due to both, the chamber surface-to-volume ratio and the impossibility to make optimum ports positioning on an orthogonal Stator, due to the 120 degrees triangular face concept, and minorly to some oil burning to maintain seal adherence through Stator TDC bumps. Ether the concept is revised or abandoned, or more research is done to make WK engine concept environmentally clean enough to revive and compete the Piston, as it could need more than an intelligent valve system… Electric vehicle range extension seem to be the focus application [26], based on the WK higher power density. Concepts are not just mechanical design, they must include considerations on security, efficiency, performance, energy, thermal management and more, as some alternances device fail to specialize the chamber, and waist thermal efficiency by doing cold strokes in hot chambers, or hot strokes in cold chambers; heat is a precious energy which can be a crucial argument in favor rotary engines specialized chambers. Today, energy efficiency and environment cleanness impose new rules to engine concepts, and making an interesting engine concept is not enough, as the 2-stroke Piston engine has learned in the past years. Modern engine must take credit of gains in a lot of application by reducing weight and suppressing gearbox. Efficiency is always a complex route between the initial and final states. Concepts are essential, as roadmaps to follow.

(QT is a truly 4-stroke with no chamber volume sharing; has chamber of favorable ratio with optimum port positioning; thick blade allows for deep pot combustion design; has no combustion time lost or dead time; blades get orthogonal for torque continuity on a perfect circle; no Stator bump seal lifting requiring lubrication; no flywheel needed; concept targets the optimum efficiency and cleanness).

21. Wankel Displacement and Power Density (Versus Piston and QT)

The government fiscal definition of engine displacement for automobile is useless here. Assuming similar efficiency, an engine which accepts little fuel produces little power, but size and characteristics may be different. The Wankel having a hybrid chamber volume, the eccentric shaft piston-like radial displacement accounts for 70 % of the chamber volume intake (energy or power), while the ends radius tangential volume intakes the additional 30 %. The engine displacement is the "geometric volume" (radial + tangential) of fuel mixture (atmospheric or not, in comparable condition) an engine can intake per 2 shaft rotations (An arbitrary double rotations, for ease of later comparison with the standard 4-stroke Piston engine, where displacement is equal to the sum of all the cylinder's volumes). In a cylinder, not all piston concepts operate with the same power and efficiency, and it is the same within the rotary Stator, where different inside Rotor concepts produces different amount of power and efficiency. To quantified these rotary Stator power density, it is useful to defined the geometric dimensionless " 4-stroke Intake to Stator volume Ratio" as 4-sISR = (4-stroke, 2 Revolutions intake volume) / (internal Stator volume). This is a dimension-less Ratio of two values within the same engine. These are different for WK and QT, and can somewhat include Piston engine for comparison (the cylinder estimated as 10 % of the single piston engine volume). The 4-stroke Intake to Stator volume Ratio 4-sISR (not a standard scale) is approximatively proportional to engine power density in volume and weight, and can be simply estimate for each engine type:

Type Single chamber Intakes 2 rev. = 4-sISR
Piston 10 % engine vol. x 1 = 10 % Engine vol.
WK 21 % du Stator x 2 = 42 % Stator vol.
QT-SC 8.3 % du Stator x 8 = 67 % Stator vol.
QTL 20 % du Stator x 8 = 160 % Stator vol.

There is no need to assume engine of equal size or RPM, since the ratio are specific to each engine configuration (just equivalent efficiency):

For the single Piston, the cylinder displacement is arbitrary estimated at 10 % of the external Piston engine volumes, and it does intake only once in the 4-stroke 2 revolutions mode (need flywheel).

4-sISR Piston single = 10 % engine volume (a base reference).

For the WK (considered as a 4-stroke), the chamber volume is about 21 % of its Stator volume, and intakes and fires 2 chambers in 2 shaft revolutions (need flywheel).

4-sISR WK = 42 % (a power density of 4 times the single 4-stroke Piston).

For the QT, the chamber volume is about 8.3 % of its Stator volume, with 8 chambers intaking and firing in 2 shaft revolutions (no need of flywheel).

4-sISR QT-SC = 67 % (a power density of 1.6 times the Wankel, or 6 times the piston).

For the QTL Limit (Theoretical), the chamber volume is 20 % of its Stator volume, with 8 chambers intaking and firing in 2 shaft revolutions (no need of flywheel).

4-sISR QTL = 160 % (a power density of 3.8 times the Wankel, or 16 times the piston).

This is for each specific type of engine concepts, making use of different engine shaft and Rotor geometry. Assuming nearly equivalent efficiency, the 4-sISR is a geometric engine characteristic leading to different absolute power output, since the Ratio of engine displacement over its own Stator volume, canceled the Stator size. The next step in engine comparison [28] could involve similar set of engines with, for example the same RPM, which involves the making of these engines, each with appropriate displacements (power), to find out about the resulting relative engine components and global sizes. This would require proper selection of Piston diameter and course, proper individual WK and QT Stator diameters and active thicknesses, and their Stator external envelope dimensions. This would provide global relative engine volume and weight comparison under similar output conditions. This kind of estimation could be straight forward if needed.

(QT-SC intakes 4 chambers volumes and fires 4 times per shaft rotation, which is from 0.6 time the Stator internal volume, and up to 1.6 for QTL the theoretical skating rink Stator shape; It is reasonable to expect the external QT size with no need of flywheel, to fit within 3 internal QT Stator volumes, but more would be need for the WK).

22. Engine Type User's Choice?

There are a multitude of ways to classified pumps, compressors, expanders, engines… either by concepts (alternance or rotary) or by specific characteristic. Despite hundreds of engine concepts, users don't have much choices of concepts, and consequently are more concern about characteristics like displacement, specific weight (flywheel), torque, RPM, load factor (shaft harmonic), maximum power, specific consumption, vibration, noise, environment cleanness, life time … and technical maintenance and services. Power continuity with minimum flywheel, is one criterion that users should be sensitive to when comparing different types of engines, because it does impact the power density. Let's recall shaft continuity for single unit device in the 4-stroke combustion cycle, where the gas relaxation (combustion) strokes are the only one producing instantaneous RPM increase:

- In the single Piston: The shaft gets 1 power stroke every 2 revolutions, it does need much flywheel;
  Piston = 25 % of the time in power stroke / 75 % in torque dead time.
- In a single stage Wankel, the shaft power stroke last 270 degrees, followed by 90 degree of repositioning torque dead time, this being repeated for each Rotor face (over 1080 degrees of engine shaft rotation), it does need some flywheel;

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Wankel = 75 % of the time in power stroke / 25 % in torque dead time.

- In a Quasiturbine, each of the 4 Rotor blades fires once per 1 revolution, producing 4 shaft accelerations per rotation, it does not need flywheel (blades play this role in-situ);
  Quasiturbine = 100 % of the time in power stroke / 0 % in torque dead time.

Engine concepts are becoming user's value as efficiency and environment become majors cost concerns with long run intensive engine application. High specific displacement and power density in volume and weight are also indirectly involve in saving space and weight in transportation cost. Finally, high specific torque is much in demand, especially where it reduces the needs of costly and sensitive gearboxes. Some compatibility regarding diversity of future fuels, combustion technics, maintenance and live time expectations are also much in engine user's interest.

(QT is an efficient, light weight and compact, vibration free, high specific displacement and high torque type of engine, open to new fuel techno).

23. Rapping-up List of Engine Concepts

The present Wankel and Quasiturbine concepts analysis is not a matter of competition but complement in continuity. The objective of is paper is not engine story, but to provide a factual aggregated source of information focusing on both concepts. As a short rapping-up, here a list the numerous Wankel conceptual elements in the following format:

Wankel concept element
[interest and concerns]
(QT comment)

1) The Wankel WK is definitely a major engine concept [20] by introducing a Rotor, and densifying the movements. [Reduces the single Piston 75% torque dead time to 25 %. The concept misses the initial purpose of rotary to eliminate alternance of mass acceleration and deceleration.] *(QT use no alternance as the blades rotate around on a circle at constant radius with no torque dead time, and densified even more the movements without flywheel).*
2) The WK concept use a triangular 120 degrees 3 faces Rotor. [The 120 degrees is a wide-angle aperture defining elongated chamber between 2 apex seals] *(QT Quasiturbine: uses short blades for shorter chamber length, no radial or transversal movement, smooth homo-kinetic in monotone-no-bump shape Stator).*
3) The WK Rotor concept imposes a unique Stator geometry, and reciprocally the WK Stator imposes a small diameter shaft crank-pin circle to minimized the bumps at both TDC, which reduces the torque. [No designer control on the chamber volume. The tuning of the chamber volume for the fuel type or application, would require a Stator shape design to be calculated independently from the Rotor (symmetrical or not)] *(QT concept offers this Stator fundamental design independence from the Rotor by the multi-degrees of freedom calculation).*
4) Inspired by the Piston, the WK concept fixes its triangular shape (3 x 120 degrees) Rotor on the crank-pin of an eccentric shaft. [The shaft imposing 4 x 90 degrees symmetry to the Stator contour shape which has to be orthogonal. The unbalanced Rotor does complex axial and transversal movements to make its way within the Stator] *(QT has no eccentric shaft while using also a 90 degrees periodicity orthogonal Stator, and the Rotor is self-balanced).*
5) The WK Stacking unit side-by-side smooths the overall engine apparent vibrations, while adding internal stress). [The WK concept does not provide internal space and way to counter balanced the Rotor masse] *(QT has a balanced Rotor acting also as flywheel, and needs no counter weight).*
6) The WK concept inserts a triangular symmetry Rotor into an orthogonal symmetry Stator. The 90 degrees TDC to BDC stroke pertain to the orthogonal Stator, while the 120 degrees chambers pertain to the triangle Rotor faces. [Consecutive chambers can never be at right angle for continuous operation. Executes 4 strokes for each shaft rotations, with a 90 degrees shaft torque dead time] *(QT concept uses orthogonal symmetry both for the Rotor and the Stator, making 4-stroke per rotation with no torque dead time).*
7) The WK central area cannot be accessible, making the rotor an internal component. [The rotor cannot be used for direct thermal heat transfer] *(QT central device is not necessary for the engine to run or can be made somewhat accessible. Conceptually, all the QT components including the rotor are external part, and can be used for thermal transfer).*
8) The WK concept needs a large center hole in the triangular Rotor reducing the thickness at the Rotor face. [Not suitable for deep combustion chamber cup. The central aria being a potentially leaking (?) oil pan] *(QT offers thick blade wall for deep combustion cup, while the central area needs nothing to keep the engine running).*
9) The WK concept does not fired its Rotor 3 faces in one rotation, but over 3 successive rotations. [This introduces in the engine five confusing periodicity of 90, 120, 180, 360, and 1080 degrees.] *(QT 4-stroke fires its 4 blades in a single rotation with only two periodicity 90 and 360 degrees).*
10) The WK concept needs 3 shaft rotations to fire all its three Rotor faces. [The WK produces relatively low torque and needs to run at higher shaft RPM to match other engines power] *(QT fires 4 times per shaft rotation for high torque, low RPM engine type).*
11) The WK concept needs a ROTOR REPOSITIONNING after each power stroke for the following Rotor face to reach fire position. [This is due to the elongated 120 degrees chamber. It appends within the 30 degrees Rotor torque dead time.] *(QT chamber and stroke have the same 90 degrees aperture, and are consecutive without repositioning or torque dead time).*
12) The WK concept creates 4 "STATOR NO PORT ZONE" on the Stator perimeter, while sweeping the excess chamber length. [Due to the elongated 120 degrees chamber. I t coincides with the 30 degrees Rotor torque dead time.] *(QT chamber and stroke have*

the same 90 degrees aperture, and there is no Stator restriction on ports positioning nor torque dead time).

13) The WK concept of "STATOR NO PORT ZONE " affects the Stator perimeter, but as well the engine internal operation. [It prevents Port positioning optimization. In a 4-stroke combustion engine mode, when the front chamber apex seal opens the intake port, one would expect the tailing seal to closes the exhaust port, but such optimization is not possible due to port position restriction] *(QT chambers are sequential without port positioning restriction)*.
14) The WK concept makes the chambers of the triangular Rotor physically jointed by their apex seals [Due to the orthogonal Stator, the chamber are not however "time jointed" for consecutive combustion. The gap during the torque dead time prevents continuous processes] *(QT chamber and stroke have the same 90 degrees aperture, and are sequential for continuous combustion)*.
15) The WK concept need to conciliate the triangular and the orthogonal symmetry. To save time at BDC, the 2-stroke Piston engine expel its exhaust with a flow of fresh mixture gas. [The WK does similarly by sharing momentarily in common its exhaust and intake chambers at TDC. In this respect the WK look like a 2-stroke engine, and bear similar environmental critics] *(QT never make its chamber in common, and is a true 4-stroke engine)*.
16) The WK concept requires a complex crown gears set for synchro, and for tangential pressure conversion. [WK concept fail to provide self-synchronization of its Rotor orientation with the Stator] *(QT needs no Rotor to Stator synchronization, each 3 blades synchronized the fourth)*.
17) The WK does not have a direct mechanism to convert the tangential forces into shaft torque. [The tangential pressure is making use with extra stresses, of the synchro-gears set to reach the eccentric shaft] *(QT optional shaft and differential does it when require, while not being necessary to make the QT running)*.
18) The WK concept is difficult to compare. Like different pistons produce different characteristics in a cylinder, different Rotor concepts produce different amount of power and efficiency within their rotary Stators. [The 4-stroke Intake to Stator volume Ratio, 4-sISR shows that the WK concept has 4 times the power density of the single 4-stroke Piston engine] *(QT-SC Rotor concept shows a specific power density 1.6 times the WK, or six times the single piston, and more for QTL)*.
19) The WK concept is a rare hybrid radial-tangential swept volume engine. On Fig. 8 the BDC volume is 30 % larger than the volume swept by the Rotor face during a full stroke. [Fortunately, this difference corresponds to the tangential swept of the rocking seals radius differential, and confirm P x V energy conservation in WK] *(QT has no radial, only 100 % tangential swept volume)*.
20) The WK as all other engines are actually constantly under review for efficiency and environmental cleanness [A concept with a list of compromises is no more sufficient. Times have change and just replacing the Piston is no more a valid objective] *(QT is an option toward new fuel, new combustion principles and new thermal efficiency and recovery. It is another starting point…)*.
21) The 2-stroke Piston unacceptably is a first engine acceptability failure and a strong signal toward perfection. If the WK concept also fails for environmental reason, it will be due to both: [The chamber surface-to-volume ratio (elongated chamber), and the impossibility to make Stator optimum ports positioning in WK Stator, and minorly to some lubrication oil burning to maintain seal adherence through Stator bumps]. *(Unless the three deficiencies are concurrently solved, the rotary future may have to wait)*.

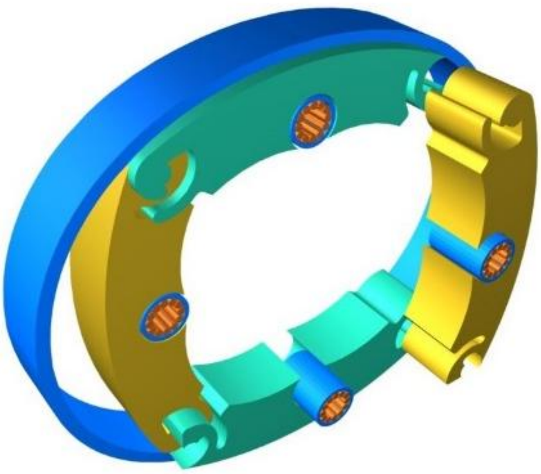

Figure 13: The QUASITURBINE 3-D concept. No central device is necessary for the engine to run. *Simplicity is the ultimate sophistication - Da Vinci*

FINALY the Wankel concept is far from being dead. It has been extremely useful for engine progress, and is still today the standard for considerable research on improvement and development, but also on new combustion fuel and technics in rotary concepts, including hydrogen [23] and photo-detonation. *Thanks to Mr. Wankel and teams…*

24. Conclusion

Engine comparison will never be global, and must involve specific applications and user's criteria, which is beyond the scope of this work, which is limited to rotary engine CONCEPTS. Despite the appearances, the Wankel (WK) and Quasiturbine (QT) concepts have little in common, the Wankel being an oblique radial 3-pistons-like engine, while the Quasiturbine is a tangential pressure torque convertor. The Wankel concept has been in the center of engine world for years, and the hope of many mechanics fascinated by Rotary engines. The present analysis introduces parallelly detailed concept of the Wankel and Quasiturbine, and by clarifying the limited scope of similarities, this paper provides the basic knowledge for sound discussion and comparison between these two complex engines, while recognizing the Wankel technological achievement, and its contribution in validating present [20] and future rotary. Among the Wankel and Quasiturbine similarities are a Rotor turning in an oval-like orthogonal Stator. Intentionally or not, it did make sense to look at the Wankel concept as an attempt to package three (triangular) pistons faces around an eccentric shaft, which turn out to be a complex challenge. The QT concept avoid eccentric shaft, in converting 100 % of the tangential pressure directly into engine torque and power, and is much simple that the Wankel to expose, but somewhat more theoretically difficult to master.

In the Wankel, every turn of the central eccentric shaft brings one face of the triangular Rotor piston to combustion, such as the shaft turns at 3 times the Rotor RPM. The Wankel Rotor is never at the center of the engine, as it turns around on the eccentric shaft crank-pin, and simultaneously rotate and translate, and the Rotor orientation angle is provided by synchro gears between Rotor and Stator (not the shaft). The lateral translations amplitude sweeps sideways across the eccentric shaft producing rotor face rocking movements, generating 30 % of tangential swept volume similar to in the Quasiturbine, the other 70 % being due to radial eccentric shaft piston-like movements, In the Wankel, even if the successive elongated 120 degrees chambers are physically joined by an apex seal, the shorter 90 degrees strokes are not functionally jointed like they are in Piston and Quasiturbine, and prevent contiguous combustion. At the end of each power stroke, the rotor needs an extra inertial 30 degrees rotations to be REPOSITIONED for the next fire ready, a 25 % Wankel torque dead time. During that torque dead time, the chambers apex end seals swept a 30 degrees Stator " NO PORT ZONE " which prevent efficient optimization of Port localization in the Wankel. This is in addition to the concerns of chamber high surface to volume ratio, vibration (live time), and high-RPM low-torque characteristic, and environmentally burning lubrication oil. However, the most critical concern is about sharing momentarily in common the exhaust and intake chambers, where flushing exhaust in presence of mixture gas is a sophisticated fluid flow operation. In this respect the Wankel look like a 2-stroke engine (but more manageable), and bears environmental critics.

In the literature, the conceptual and theoretical detail as why the Wankel has failed to imposed itself is often resumed to efficiency and cleanness, while this work suggests some concept weaknesses. This explains why several conceptual difficulties of the Wankel engine remain unresolved, and why the Wankel environmental failure is due to both, the chamber surface-to-volume ratio (elongated chamber) and the impossibility to make optimum ports positioning on an orthogonal Stator, due to the 120 degrees triangular face concept, and minorly to some oil burning to maintain seal adherence through Stator TDC bump. Within a rotary Stator, different Rotor concepts produce different amount of power and efficiency, and the specific power density goes as "Intake to Stator volume Ratio ", where Wankel concept power density reach 4 times the single 4-stroke Piston, while the Quasiturbine Rotor concept power density get to 1.6 times the Wankel (or six times the single 4-stroke piston). Worth to notice with the new environmental rules, the future of the Wankel in combustion constantly over review, however researches and projects on Wankel engines are still very active and useful, with hope especially in regards new heat sensitive fuel [23] like hydrogen.

This work also explains why the Quasiturbine concept [15] bypass many of the Wankel difficulties by dealing only with tangential pressure force, and direct tangential conversion to shaft torque (when needed, as the Quasiturbine does not need central device to run). The Quasiturbine has received considerable attention for properties different [8] from the Piston and the Wankel, as all its components are external (including the rotor), it uses no eccentric shaft, and its Rotor rotation modulate tangentially 100 % of the chamber volume, while staying at all time centered and perfectly balanced, each blade is turning at constant radius without torque dead time. The Quasiturbine cycle is also unique in smooth kinetic as the strokes do not experience acceleration reversal, firing at TDC with blades at their maximum tangential velocity and accompanying the fluid flow until the BDC at minimum (not null) velocity. Finally in most concept the Rotor imposes a unique Stator and designers have no control on the chamber, while a Quasiturbine fundamental unique characteristic come from the multi-degrees of freedom available in a later confinement contour shape calculation and selection, allowing for the same Rotor, the tuning of the chamber characteristics for the fuel type or the application, by proper Stator contour shape selection (symmetrical or not). Fixing the internal components sizes of the Quasiturbine does not impose a unique Stator confinement wall, as for the Wankel and other rotaries. The Quasiturbine fires sequentially 4 times per rotation without torque dead time, has a perfectly balanced Rotor with no synchronization needs, and run efficient with low RPM high torque in expanders and/or combustion engine mode.

There are so much to say about rotary engine concepts, and this paper has no pretention to be complete. The Quasiturbine brings a set of interesting new solutions for conversion of pressure within engines, despite production in limited series coincide with a period of vast transition toward electrification of engine application. Even if Quasiturbine has not yet achieved maturity, the present analysis confirms a definitive potential for efficient and cleaner engines, an offers precious additional options to pumps and pressure expanders vastly used in energy recovery processes and thermal management. The Quasiturbine evolution is toward previously inaccessible engine efficiency, with fine Stator combustion chamber shape tuning for HCCI detonation or hydrogen fuel. Even if the alternance concepts have dominated so far with the Piston, it will be no surprise if the Rotary concepts become more attractive in the future…

This study provides a comparative analysis of the Wankel and Quasiturbine rotary engines, highlighting their respective advantages and challenges. While the Wankel engine has historical significance, its conceptual limitations, including torque dead time and environmental inefficiencies, hinder its competitiveness against piston engines. The Quasiturbine, on the other hand, offers a more efficient and environmentally friendly alternative, with continuous torque output and adaptability to modern fuels. Further research should focus on practical implementation and optimization for real-world applications.

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Definition / Abbreviation
4-sISR - 4 stroke Intake to Stator volume Ratio
A, B, C – Wankel Rotor faces center
Bc - Blade center (QT Blade)
QT - Quasiturbine
QT-L - Quasiturbine Limit Rotor extension
QT-SC - QT without carriage
QT-AC - QT with carriage (for detonation)
TDC - Top Dead Center
BDC - Bottom Dead Center
WK - Wankel engine

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