Quasiturbine High Power Density Pump-Expander-Engine with Displacement Exceeding External Device Volume for Light and Compact High Torque Applications

Gilles Saint-Hilaire Ph.D.[1], Roxan Saint-Hilaire MBA[2],
Ylian Saint-Hilaire M. Sc.[3], Françoise Saint-Hilaire M. Let.[4]

[1], [2], [3], [4], Quasiturbine Académie, Montréal, Québec, Canada

Authors Email: gilles[at]saint-hilaire.com

Abstract: ***There are numerous « positive Displacement » engine designs, among them the Piston engine, all looking for improvement in term of power density. The «total Displacement ratio over external engine volume» is generally much less than 1, and needs to be increased to make lighter and more compact powerful engine. The Quasiturbine (QT) is a fairly recent rotary engine design with unique characteristics as pump, expander and internal combustion engine, where the timing for a framework contribution is appropriate. Each of the QT rotor 4 pivoting-blades executes 4 strokes, for a total of 16 strokes per rotation (as does the Piston8 (8-cylinders) in 1 rotation). Strong similitudes in engine management are shown with the Piston (8-cylinders) in term of strokes number; shaft RPM, torque, power, intake-strokes and total Displacement. In the context of positive Displacement devices, the QT dual circuits (2-strokes cycle) for pumps and expanders, the QT 2-strokes IC engine, as well as the QT (4-strokes, 2 rotations), all match (interchangeable) with the corresponding mode Piston (8-cylinders) device of equal stroke volume and total Displacement. The Quasiturbine can typically be 3 to 5 times more compact and lighter than the Piston of equivalent power at moderate RPM, while suppressing the need for step down gearbox in some applications. Current QT expander QTL (60 psi and 500 RPM) has a volume Displacement ratio « over its external device volume» (excluding ports and thin covers) of 0,62 to 0,85 while future optimized QT design would reach a theoretical volume Displacement ratio well over unity of 1,2 to 1,6 while doubling the relative power output as well, with no stator external volume increase. Criteria for optimum QT Displacement design are given in term of stator eccentricity and confinement profile. A stator optimum configuration is presented among solutions that can involve different pivoting-blade and differential designs. Such a high-power density device still allows for high compression capability, efficiency, low RPM, and high torque (reduced gearbox?) for light and compact applications, including airplane engine. In the engine world, power density, high torque, low-cost manufacturing, and durability through perfectly balanced design are characteristics in demand, especially if sustainable locally and not high-tech dependent. The Quasiturbine is a step in that direction, at a time where hydrogen and synthetic fuels offer new perspectives. Not only a Piston8 (8-cylinders) in different modes can be substituted (interchangeable) with a single Quasiturbine of equal volume Displacement, but the QT total volume Displacement ratio could exceed unity.***

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

Keywords: Quasiturbine; Rotary engine; Steam engine; Air engine; Rotary pump; Rotary expander; High engine power density; Engine displacement; Light and compact engine;

1. The Challenge-Race for Higher Power Ratio

Power, RPM, torque… describes engines regardless of their physical sizes. The most common engine characteristics that link engine parameters to its external size volume or weight is the « POSITIVE DISPLACEMENT », which is a static value of the total gas mixture volume TDV an engine can handle in each of its complete repetitive cycle (in usually 1 or 2, or fractional shaft rotations, regardless of atmospheric or turbo compressed mixture). The strokes-cycle total Displacements TDV (expressed in cubic inch, cubic liter, stroke or chamber volume…) is proportional to power output (only within similar type of devices), regardless of the shaft RPM (not an absolute value like is the torque XRPM).

It does make sense to compare different types of engines only if they have the « same mixture intake flow rate » under the same RPM. The 4-strokes piston, 2-strokes piston, 6 strokes cycle, 2-strokes Quasiturbine, 4-strokes QT . . . all may have different shaft and RPM relations with total Displacement and intake mixture flow rate. For this reason, positive Displacement volume is generally used for comparison within similar type of devices. The simple total Displacement definition (based on the total intake volume per comparable stroke-cycle) restricts inter-types devices comparison to well selected compatible device models (of equal stroke number, stroke volume, and full strokes-cycle with same number of rotations, or fractional). For different types of engines with the same Displacement, comparison must take into account the shaft rotation angle necessary to intake, compress, expand, and exhaust the total Displacement volume TDV, which can make it tricky and quite complex. Because Displacement comparisons are so much in use in matter of Piston (pomp, compressor, engine), it is one of the purposes of the present work to establish such a relation between the Quasiturbine and the Piston.

Remember also that reducing the sizes of an engine by a factor of 2, cut the volume (weight and cost…) by a factor of 2^3. The race for performance is also about the highest engine power density, express in total Displacement ratio DispR normalized to « external engine volume » and/or total weight. In this regard, it is useless to have a large Displacement device, if the device itself is enormous. The objective is to have the highest possible Displacement per full cycle TDV, within the smallest possible engine external envelop. That defined the geometrical Displacement Ratio:

DispR = (Total Displacement TDV) / (external device volume) …or total weight

For piston designs, typical fractional DispR ratio values are well under unity. The Displacement ratio DispR is a fundamental power densities parameter and a most valuable characteristic of design in a multitude of applications [1] as airplane engine, including light and compact portable generator and onboard hybrid vehicle, but also as compressor, high flow fluid pump and thermal energy recovery heat-pump, refrigeration and heat blower process.

The fundamental question in the race for Piston and QT large Displacement ratio DispR could be: Is there a limit? Can the total Displacement volume exceed the outside volume of a device? Or otherwise, can the DispR « (Displacement TDV) / (external engine volume) »exceed unity? Based on Piston design, it is unlikely to conceive a pump, expander or engine with a « Displacement volume » larger than the device itself. DispR greater than 1 is nevertheless one of the remarkable characteristics of the Quasiturbine [2] rotary device.

2. Quasiturbine rotor and Stator designs

The Quasiturbine is made of two major components, the rotor and stator which are of equal strategic importance in this technology, as they defined groups of devices with specific characteristics and suitable applications. The Quasiturbine (QT) has been introduced in two different families of perfectly balanced devices:

- The QT-AC not shown (Avec Chariots-rotor with carriages), (for any size, with complex looking rotor) intended primarily for photo-detonation engine, described in 2000 patent [3], a type of QT also sensitive to Displacement consideration, but discarded from the scope of the present work (due to the combustion mode currently in development) and;
- The QT-SC typically Fig.1 (Sans Chariot-rotor without carriage), (for any size, with simplified looking rotor) intended for pump, compressor, expander, and IC (internal combustion) engine, described in 2005 patent [4] (relevant to the present paper).

As of 2022, only 2 Quasiturbine designs (both of QT-SC type, without carriage) have been published, the QTL (medium eccentricity) and QTD (optimum eccentricity Displacement) with their distinct stator confinement profile and corresponding rotor design (the ones considered in the present paper). The QTD is calculated at the limit of the confinement profile inflexion, where the 2 stator lobes joint in straight line. The Models QTL (moderate eccentricity) can carry a stator with 2 ports (for 4-strokes IC internal combustion) Fig.4, or a stator with 4 ports (for dual circuits pump-expander or for dual 2-strokes IC internal combustion) Fig.3. Similarly, the model with large eccentricity for optimum Displacement QTD can carry 2 and 4 ports as well Fig.6.

Generally, the QTL rotor of Fig.1 is a deformable chain of 4 interconnected blades by pivoting hinge at their ends [4]. As such, there is no self-rotor constraint or limitation of deformation to its square and lozenge shape. This rotor is placed within an appropriate closed fit confinement enclosure [5] to rotate freely, the 4 pivoting-blades revolving around the central area, with or without power shaft. Spaces in-between the rotor pivoting-blades and the confinement contour wall define variable chambers volumes as the square-rotor configuration transforms itself into a lozenge, and vice-versa. The Quasiturbine QT moves the gas around in 4 steps per rotation (4-strokes), but when only 2 steps are required (like pump in-and out -), the QT 4 steps are spited in QT dual circuits to double the flow. As the rotor shape moves from square to lozenge configuration, the central cross-bar of Fig.3 does not stay perfectly perpendicular, this requires some kind of differential mechanism to properly link the pivoting-blades to a central shaft. Different differential designs are presented in patents [3, 4], and others in [2].

In regard to device Displacement TDV, this paper refers to the following QT nomenclature, with total Volume Displacement TDV expressed in reference (normalized) to the associate single stroke volume:

TVD = 8 QTL-PE (2-strokes, dual circuits, 1 rotation) pump and/or expander (air, steam, gas…). interchangeable with the Piston8-PE (8 cylinders, 2-strokes).

TVD = 8 QTL-IC (2-strokes, dual circuits, 2 side feed-through ports, 1 rotation) IC internal combustion engine. Interchangeable with the Piston8-IC (8 cylinders, 2-strokes).

TVD = 8 QTL-IC2R (4-strokes + 4-strokes, 2rotations) IC engine, interchangeable with the Piston8-IC (8 cylinders, 4-strokes, 2 rotations).

TVD = 4 QTL-IC (stand-alone) (4-strokes, 1 rotation) IC internal combustion engine. Not interchangeable with any Piston IC (RPM mis-match).

All QTL designs have their version in optimum eccentricity QTD

TVD = 8 QTD-PE (2-strokes, dual circuits, 1 rotation) … and so on / QTD-IC / QTD-IC2R / QTD-IC

In regard to strokes, the Piston nomenclatures BDC for maximum volume and TDC for minimum volume are used. Pistons devices are referred to as following:

TVD = 8   Piston8-PE (8-cylinders, 2-strokes, 1 rotation)
TVD = 4   Piston4-PE (4-cylinders, 2-strokes, 1 rotation)
TVD = 8   Piston8-IC (8-cylinders, 2-strokes, 1 rotation)
TVD = 8   Piston8-IC (8-cylinders, 4-strokes, 2 rotations)
TVD = 4   Piston4-IC (4-cylinders, 4-strokes, 2 rotations)

Note about the QTL-IC2R rotations with Piston8 (8-cylinders) : TVD = 8 QTL-IC2R (4-strokes + 4-strokes, 2R rotations) IC engine: About the Quasiturbine stroke chamber being faster than the piston chamber, comparison of a (4-pivoting-blades) against a (8-cylinder piston engine) may require the Quasiturbine (stand-alone) TVD = 4 QTL-IC (4-strokes, 1 rotation) IC engine to make an additional rotation. In such a situation, a double Rotation 2R device must be considered as a distinct QT engine defined as TVD = 8 QTL-IC2R (4-strokes + 4-strokes, 2R rotations) instead of 1 rotation, with its own characteristics.

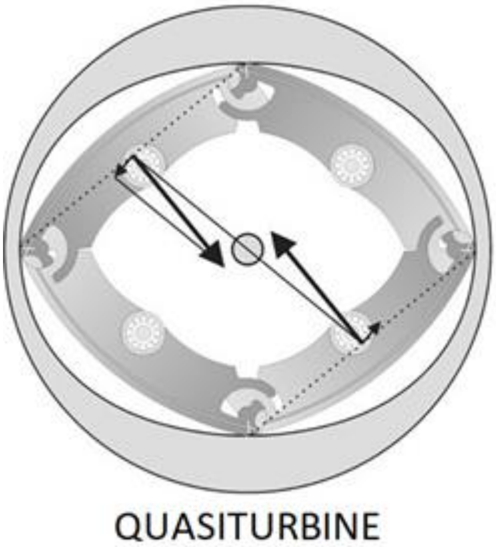

Figure 1: Origin of the forces shown in the QT diagram of Quasiturbine QTL and QTD rotary engine (stator ports not shown). Contrary to vane motor, the QTmid-stroke rotational forces do not result from tangential pressure on contour seals, but from pressure on the entire surface of the pivoting-blades. The rotor is perfectly balanced at all angle during rotation. The QT does not need a central shaft to run. This applies either to QTL-PE (2-strokes, dual circuits, 1 rotation) pump-expander, to QTL-IC (2-strokes, dual circuits, 4 ports) configuration engine, or to IC internal combustion QTL-IC (4-strokes, 2 ports) configuration.

About absolute sizes? The currently manufacture QT-5LSC-Expander block would make (following development) a QTL-IC2R of 8 strokes volume of 600 cc each, for a Total Displacement in 2R rotations of TDV = 4, 8 liters (293 cu. in.) in QT 4-strokes IC engine, with moderate QTL or optimum QTD eccentricity internal stator sizes of:

QTL-IC2R X = 34, 6 cm (13, 6 in.) Y = 27, 0 cm (10, 6 in.) Z (thick) = 10, 6 cm (4, 0 in.),

QTD-IC2R X = 37, 2 cm (14, 6 in.) Y = 23, 2 cm (9, 20 in.) Z (tick) = 10, 6 cm (4, 0 in.),
of near equal QTL and QTD internal stator volume of 8 liters (490 cu. in.).

QTL-IC2R with 8 x 600 cc strokes = TDV = 4, 8 liters, DispR ratio = 4.8 / 8 = 0.6

QTL-IC2R with 8 x 1100 cc strokes = TDV = 8.8 liters, DispR ratio = 8, 8 / 8 = 1, 1 approx.

and with the central area discarded DispR ratio = 8.8 / 6.4 = 1, 4 or more. Of course, the real word could reduce this impressive ratio, but thin wall enclosure may not increase the external engine volume much over 10 % ?. Nevertheless, this is a good starting point for a QT engine interchangeable with Piston8-IC (8-cylinders, 4-strokes, 2 rotations), Piston8 which is at least 4 to 5 times more encumbering (?). Will see what good engineering can do in the future…

The rotary Vane motor cannot use high eccentricity without inter-chambers overlap or back-leak flow, which compromises their efficiency. Contrary to vane motor, the Quasiturbine rotational forces do not result from tangential pressure on contour seals, and there is no stroke cycle overlap and no efficiency lost, even at high eccentricity. The QT does not need a central shaft to run. The QTrotor is perfectly balanced at all angle, and the empty central area volume could be a very useful space for shaft differential, as well as for propeller or application not needing power-shaft, but central area could also play a very active role in volume modulation to pump or to condition a combustion mixture…

Figure 2: The Quasiturbine pump-expander QTL-PE (2-strokes, dual circuits, 1 rotation), intake 8 strokes per clockwise rotation (4 per sequential circuits): 4 intake volumes (below left) and 4 intake volumes (top right). Notice the basic geometry of the peripheral intake and exhaust ports, which could be designed tangentially and be more compact. The QTL « pivoting-blades acts like a piston» in modulating the volume of the pressure chambers in-between the inner-stator wall. The QTL-PE (2-strokes, dual circuits, 1 rotation) and the pump Piston8-IC (8-cylinders, 2-strokes, 1 rotation) devices produce the same number of strokes per rotation, but grouped differently, which explains their operational match and similitudes.

The Quasiturbine is a low RPM, high torque device for pump, compressor, gas expander, thermal cycle, flow-meter (dosimeter) and IC internal combustion engine… QTLand QTD series comprise sets of several design parameters interacting one another, generating families of designs with their own look and specifics' characteristics. In addition to fix components (blades, pivots, supporting track…) design parameters, prior selection of the confinement profile eccentricity greatly affects the device look and characteristics. Furthermore, it has been demonstrated [5] that the designs and sizes of the rotor components and the imposed eccentricity, do not uniquely define the rotor confinement profile, which emerges from each individual designer own selection of branches of stator confinement seed curves (Symmetrical, as well as asymmetrical), for an infinity of stator contour confinement options producing specific device characteristics [5].

With sufficient eccentricity, the Quasiturbine total Displacement volume TDV can exceed the inside of the stator confinement volume, for a high DispR Displacement« over engine external volume » ratio in excess of 1. This is one of the remarkable characteristics of the QT rotary device [2].

3. Understanding the Quasiturbine Multi-Strokes

How can the Quasiturbine achieve such a high Displacement ratio compare to Piston engine? There are basically 5 reasons:

- First, without claiming to be the best, the Piston engine imposes itself as the historical reference to which new technologies must compare (for the best or the worst) in terms of Displacement, strokes, RPM, efficiency…. The Piston being the reference, many are under the impression it is the best in all respect, which it is not, and a new technology claim often emphasis the surprising potential of improvement for Piston engine even today.
- Second, while the physical « pistons » are independent pieces of equipment, the QT 4 pivoting-blades are stacked together on a single rotor for substantial geometrical and space gain. Furthermore, all pivoting-blades share a common compact stator (sort of a cylinder).
- Third, the QT has faster engine cycles than the Piston. This can be illustrated by the QTL-IC (4-pivoting-blades, 4 strokes, 1 rotation) which has 4 pivoting-blades just like the Piston4-IC (4-cylinders, 4-strokes, 2 rotations), but the QT accomplishes all its strokes-cycle in 1 rotation, while the piston needs 2. Consequently, considering 4-pivoting-blades against 4 pistons at the same RPM, the QT is twice as fast as the piston and for this reason the QTL-IC (4 pivoting-blades, 4-strokes, 1 rotation) does not match the Piston4-IC (4-cylinders, 4-strokes, 2 rotations) in term of RPM and indirectly in term of power (assuming same stroke volumes). However, a QTL-IC2R (4-pivoting-blades, 2R) against the Piston8-IC (8-cylinders, 4-strokes, 2 rotations) matches just fine in RPM and power.
- Forth, The Quasiturbine moves the gas around in 4 steps per rotation (4-strokes, one per quarter of turn), but when only 2 steps are required (like pump in-and out -), the QT full 4 steps are spited in quasi-independent dual circuits to double the flow, which increases further the QT total Displacement TVD of the application.
- Fifth, the QT physical space is used and reused to outreach and exceed the reference Piston engine. This can be illustrated when making a Piston8-IC (8-cylinders, 4-strokes, 2 rotations) by stacking colinearly two Piston4-IC (4-cylinders, 4-strokes, 2 rotations) engines, while there is no need to stack 2 QTL-IC (4 pivoting-blades, 4-strokes, 1 rotation), letting this faster QT make a second additional rotation with QTL-IC2R (4 pivoting-blades, 4-strokes + 4-strokes, 2R rotations) does it (re-using the same QT equipment twice), and match nicely the Piston8-IC (8-cylinders, 4-strokes, 2 rotations) in term of RPM and power.

For all these reasons, the Quasiturbine total volume Displacement TVD can exceed the total external QT device volume. For simplification, let's ignore for now the intake and exhaust ports, and focus on the QT chamber volume between the pivoting-blades and the stator interior wall as of Fig.1, showing a simple monotone confinement profile and moderate eccentricity. All positive Displacement devices, including Piston and QT, deal with the notion of chamber volumes variation. Within the QT, the intake, combustion, expansion, and exhaust chambers are volume spaces in-between each rotor pivoting-blades and the contour stator confinement profile, occurring when moving from minimum to maximum volume (a stroke), and moving to minimum volume again (another stroke), regardless of the direction of rotation. By analogy, let's use the Piston nomenclature of TDC Top Dead Center for Quasiturbine minimum chamber volume (upper and lower rotor blade position on the pictures), and BDC Bottom Dead Center for QT maximum chamber volume (left and right rotor blade position on pictures). As a high compression-able device, the QT pivoting-blade (piston equivalent) at maximum volume at BDC Bottom Dead Center defines the compression ratio «over the residual TDC volume », a compression ratio not to be confuse with the Displacement ratio DispR « over the external QT volume » (excluding intake and exhaust ports). To get the complete picture, one has to carefully find out the number of strokes occurring in a QT complete rotation.

Pump-expander QTL (2-strokes, dual circuits, 1 rotation) understanding maybe more explicit on the stator pump configuration in Fig.3, also with 2 intake ports, interlaced with 2 exit ports, revealing the dual quasi-independent sequential pumping circuits (of same flow capacity), each circuit being activated by the same 4 revolving pivoting-blades (for a total of 8 intake strokes per rotation). Contrary to pump-expander, to make a stand-alone QTL-IC (4-strokes, 1 rotation) internal combustion IC engine firing 4 times per rotation, one must have the stator configuration of Fig.4 with only one intake and one exhaust port (adding a spark plug at the center top of the minimum volume chamber).

Before looking at the side-by-side operation of the QT and the Piston engine (section 6.), it is important to understand the Quasiturbine multi-stroke repetitive mechanism and strokes-cycle (with ports location) for each mode, which is not as easy to visualize as like the Piston engine. QT Displacement, multi-strokes and additional rotation to match the reference Piston8-IC (8-cylinders, 4-strokes, 2 rotations) are linked together. Within the QT, the intake, combustion, expansion, and exhaust chambers are volume spaces in-between each rotor pivoting-blades and the contour stator confinement profile, and moving in location along the internal stator wall (while at a same physical location for the Piston device).

Device Displacement is a common basis of comparison, which works well within similar pump-expander-engine, but not so well when considering different types of devices, partly because it is defined regardless to the device number of shaft rotation, which impacts torque, flow and power. The Displacement is the ability to process volumes across a device, but not all the strokes are accomplishing the same, in internal combustion IC engine for example, out of the intake, compression, combustion and exhaust (… cooling? Refreshing?) strokes, only intake strokes are considered and summed up over a complete strokes-cycle to determine the engine Displacement (The mixture intake strokes driving the Piston and the QT power output). Device Displacement need to take into account the stroke volume, the total device strokes-cycle and the shaft rotation angle necessary to accomplish the strokes-cycle.

Now that QT strokes have been defined and similarity with Piston device understood, multiple positive displacement devices can be introduced:

- Pumps, compressor and expanders (including QTL-PE (2-strokes, dual circuits, 1 rotation) 2 strokes having intake and exit strokes;
- Internal combustion (IC) engines 2-strokes including QTL-IC (2-strokes) have overlapping combustion and exhaust strokes, while intake and compression strokes only overlap as well, for less efficiency;
- Internal combustion (IC) engines 4-strokes Piston engine including QTL-IC (4-strokes) have complete distinct intake, compression, combustion and exhaust strokes. Wankel rotary engine overlaps 4-strokes in 3 (A conceptual weakness the QT does not have);
- Internal combustion (IC) engines 6-strokes or more (QT compatible) incorporate cooling or air refreshing strokes; modern idle control may skip loading some strokes… and other fuel management strategies interfere with past years conventional stroke unique role.

Of all the possible strokes, the most significative in term of flow rate and power output is the initial intake strokes volume common to all devices; if a device does not intake, it does not accomplish anything. The Quasiturbine presents similitudes and some differences with piston volume stroke modulation:

- The volume area between each of the rotor pivoting-blade and the stator wall increases during intakes and expansion strokes, and reduces during compression and exhaust.
- Each of the QT rotor pivoting-blade must be considered as an independent piston from « volume variation » point of view (but with faster move than piston), for a total of 4-blades pistons-equivalent acting simultaneously within their own individual strokes-cycles;
- While piston volume increases and decreases once per rotation, each volume pivoting-blade of the QT does alike in only half a rotation (Fig.1), reaching BDC at left or at right and TDC at over and below. That is twice the piston volume speed at same RPM.
- Furthermore, the QT being a low RPM high torque device, it requires little or no gearbox in many system integration applications, which is an add up value to its high-power density characteristic, compare to other solution calling for a large and complex step down gearbox.
- Contrary to Piston, QT does not need power shaft to run, offering empty central area for more optional applications.

Due to a variety of geometries and combustion managements, different engine types with same Displacement could have different instantaneous torque and RPM, making direct comparison difficult or hazardous. Over all, QT understanding requires to know how many compression and expansion strokes there is during one complete rotation? This question deserves distinct discussions for each operating 2-or 4-strokes modes due to diverse ports configurations.

4. The 2-Strokes in a Single Rotation QTL-PE Pump-Expander

Pump-expander are 2-strokes devices, they have only intake and expel strokes. The quasi-symmetrical Quasiturbine QTL-PE counterclockwise stator of Fig.3presents 2 diametral opposed low volume areas (up and below) ready to intake, and 2 diametral opposed high volume areas (left and right) ready to expel. In a quarter of a turn, each of the 4 pivoting-blades goes from one area to the other, completing one stroke each (2 intakes and 2 expels). That is 4 strokes per quarter of a shaft rotation, for a total of 16 strokes per rotation. In half a rotor turn, each of the 4 pivoting-blades make one intake and one expel stroke, that is 4 intakes and expelled pumping volumes, but with duplication (2-strokes, dual sequential circuits) in the following half rotation, a total of 8 pumping volumes cycles is achieved in 16 strokes per shaft rotation.

On the pump-expander Quasiturbine QTL-PE (2-strokes, dual circuits, 4 ports, 1 rotation) of Fig.3, let's focus on the right blade pivot at its maximum volume chamber (BDC) and follow the counterclockwise pivoting-blade movement:

- As the blade 0 degree pivot blade progresses toward 90 degrees, the chamber volume contracts and the fluid get expelled outside (exhaust stroke) at OUT-R until the blade movement reaches the 90 degrees position (TDC) where all the fluid has been ejected from the QT.
- Keep focusing on that same pivoting-blade during its pivot move from 90 to 180 degrees where the chamber volume starts to increase (TDC) and intakes the fluid (intake stroke) at IN-L until the chamber is completely filled when the pivoting-blade pivot gets to 180 degrees (BDC).
- Up to this half a rotation of the rotor, the selected blade has accomplished 1 exit stroke and 1 intake stroke for 1 chamber volume fluid flow. The same will repeat from 180 to 270 and 270 to 360, as this is the dual sequential design, making each pivoting-blades complete 4 strokes

Paper ID: SR22704112446 DOI: 10.21275/SR22704112446

per rotation (2 intakes and 2 expelled). Each 3 others pivoting-blades add up the same to the flow.

- In pump-expander, the QTL-PE (2-strokes, dual circuits, 1 rotation) makes repetitive use of sequential chambers: intake, exit, intake, exit (2 quasi-independent circuits, each with its own intake and exhaust ports).

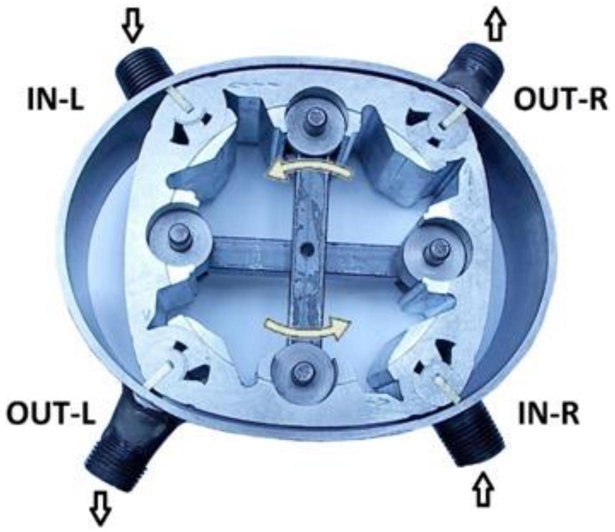

Figure 3: The Quasiturbine QTL-PE (2 strokes, dual circuits, 4 ports, 1 rotation) as pump-expander with stator 4 ports configuration, different from QTL-IC (2-strokes, 4 ports, 2 sparkplugs, configuration not shown), making counterclockwise strokes-volumes in square configuration. On the upper: Intake ready at top IN-L, and on the left expel ready at OUT-L, while on below: Intake ready at IN-R and on the right expel ready at top OUT-R. Maximum strokes-volumes shown left and right (BDC), and minimum residual strokes-volumes shown over and below (TDC). In 1 rotation, the sequential dual circuits intake together a QTL-PE2 Displacement of 8 strokes volumes (out of 16 strokes total), exactly what a Piston8-PE (8-cylinders, 2-strokes, 1 rotation) pump-expander does in 1 rotation.

To properly configure the Quasiturbine QTL-EP (2-strokes) pump-expander stator, an intake port must be located on the QTL stator where chamber volume starts to increase, and there are 2 such diametrical positions. Similarly, exit port must be located where the chamber volume starts to decrease, and again there are 2 such diametrical positions. As the rotor turns, 2 sets of interlaced intakes and exits ports constitute 2 full pumping circuits. In the 2-strokes mode, what a pivoting-blade is doing, the diametral opposed pivoting-blade is doing the same, no matter if either in pump, compressor or expander. Nearly also true for the QTL-IC (4-strokes, no dual circuit) internal combustion engine (IC) considering the stator has only 2 ports and strokes have different names: intake, compression, combustion, exhaust.

The Quasiturbine QTL-PE (2-strokes, dual circuits, 1 rotation) has 2 quasi-independent pump-expander circuits which means both circuits add up their pumping flow, and in expander mode, both circuits add up their torque to the rotor. A special application could use one circuit as an air/steam expander to drive the rotor, and the other circuit could be used as a fluid/water pump. Notice that in such a case, the differential and central shaft is not necessary for the expander-pump device to run, leaving the QT central area empty… reducing some total external device volume, and increasing its effective power density.

The QTL-PE (2-strokes, dual circuits) design can also be the starting point to design a QTL-IC (2-strokes, dual circuits, 2 sparkplugs, 1 rotation) internal combustion engine (known as a more polluting engine than the 4-strokes, but more compact). (See QT substituting Piston section 6.).

The Displacement cycle of the Quasiturbine QTL-PE (2-strokes, dual circuits, 1 rotation) is not completed until a full shaft-rotor rotation, since to visit all the ports, each of the 4 pivoting-blades have to make a full rotation and 16 strokes total. The Displacement being the sum of all intake (only) strokes in a complete cycle (regardless the mode), TDV is equal to 8 (half the total strokes number) multiplied by the maximum chamber volume (static geometrical volume at BDC). This 2-strokes dual sequential design highly impacts the QTL (2-strokes, dual circuits, 1 rotation) total Displacement, leading to higher Displacement ratio DispR « over QTL external volume and weight », and in supporting a higher flow rate at reduced RPM. The QTL-PE (2-stroke, dual circuits, 1 rotation) completes in 1 shaft rotation its dual circuits cycle, for a total of 16 strokes of which half are intakes defining the TDV.

5. The 4-Strokes in a Single Rotation QTL-IC engine

An important landmark for Quasiturbine technology is the internal combustion in 4-strokes mode. As a stand-alone QTL-IC (4-strokes, 2 ports, 1 rotation) internal combustion IC devices, each stroke has its own name: intake, compression, combustion and exhaust. The quasi-symmetrical QT-stator Fig.4 contains the rotor in mid-stroke position, and presents 2 diametral opposite mall chambers volume areas (TDC at over and below), and 2 diametral opposite large volume areas (BDC at left and right). In a quarter of a turn, all 4 pivoting-blades go from one area to the other, completing each 1 stroke per quarter of a rotor turn. That is 4 strokes per quarter of a shaft rotation, for a total of 16 strokes per rotation, the same number as Piston4-IC (4-cylinders, 4-strokes, 2 rotations) but in only one rotation, revealing a mismatch as the QT is twice as fast as the Piston cycle for the same RPM.

On the stand-alone Quasiturbine QTL-IC (4-strokes, 2-ports, 1 rotation) IC of Fig.4, let’s focus on the pivoting-blade at IN-R making its counterclockwise way through a complete rotor rotation, starting from its mixture intake IN-R. To make each pivoting-blade volume accomplish its 4-strokes cycle:

- The stator must have one and only one mixture intake port, located forward the pivoting-blade where the rotor intakes stroke from IN-R.
- As the pivoting-blade pivot gets toward 0 degree inits first quarter of a turn, the mixture gets all in.

- In its second rotor quarter of a turn as the pivot of that same pivoting-blade moves toward 90 degrees, the mixture gets compressed while moving into the minimum volume stator area (at the top) where a sparkplug is located on the stator to ignite near the end of that stroke.
- Up to this half rotor rotation, the selected blade has accomplished 1 intake stroke and 1 compression stroke (unlike for the 2-strokes mode, the following will not duplicate the first two strokes).
- In the third quarter of a turn of that same pivoting-blade, the pivot is moving from 90 degrees toward 180 degrees, where no port is required as the combustion-expansion stroke progresses and produces mechanical energy conversion as rotor torque.
- As the fourth quarter of a turn is initiated toward 270 degrees, the unique exhaust port OUT-L must be positioned on the stator for the burned combustion gas to be exhausted.
- Then back to the initial position for the next intake strokes-cycle.

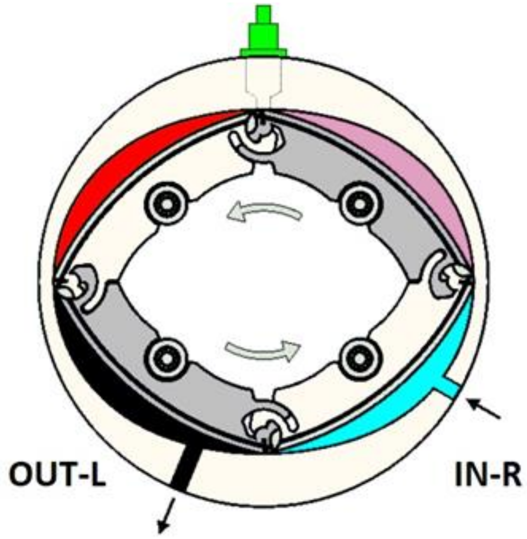

Figure 4: The stand-alone single QTL-IC (4 pivoting-blades, 4-strokes, 2 ports, 1 rotation) IC combustion engine (different from pump-expander) with 2 ports configuration, showing counterclockwise intake stroke-volumes IN-R on the right; and the exhaust stroke OUT-L at bottom left). Maximum stroke-volumes occur at left and right sides at BDC, while minimum stroke-volumes do upper and below at TDC. This stand-alone single QT makes a total of 16 strokes per rotation, and intake 4 strokes-volumes for a total Displacement TDV of 4 intake strokes, like a Piston4-IC (4-cylinders, 4-strokes, 2 rotations) IC engine does in not 1, but 2 rotations. This stand-alone Quasiturbine does not match the Piston4-IC (4-cylinders, 4-strokes, 2 rotations) engine due to RPM (and power) mismatch, but considered as a double rotation engine, the QT-IC2R does match perfectly with Piston8-IC (8-cylinders, 4-strokes, 2 rotations) in RPM and Power.

While 1 pivoting-blade accomplishes the shaft rotation and its 4 strokes in the Quasiturbine QTL-IC4 (4-strokes, 2-ports, 1 rotation), the other 3 pivoting-blades make the same, which completes the QT16 strokes volumes cycle per shaft rotation (out of which 4 are intake strokes defining the Displacement TDV). In the QTL-IC (4-strokes, 2-ports, 1 rotation), there are only 2 ports, intake and exhaust, neither located symmetrically, nor diametral across the stator. In the 4-strokes mode, there is no pump-expander mode duplication (dual circuits) as all the different strokes are needed for the internal combustion IC engine process. Notice that the differential and central shaft is not necessary for the engine to run, but a practical way to extract the engine power. In special application, like engine central fan or impeller, the rotor differential and shaft would be useless, leaving the QT central area available for application… and reducing somewhat the total external device volume, increasing as such its effective power density.

About the Quasiturbine QTL-IC (4-strokes, 1 rotation) Displacement, the QTL-IC strokes cycle is completed after a full shaft-rotor rotation, after all 4 pivoting-blades have visited all the ports, with a total of 16 strokes. The Displacement being the sum of all intake strokes volume in a complete cycle (regardless the mode), TDV is equal to (here 1/4 the total strokes numbers) 4 maximum chamber volumes (static geometrical volume at BDC), just like Piston4-IC (4 cylinders, 4-strokes) engine would do in not 1, but 2 rotations (constituting the RPM and Power mismatch). This single 1 rotation QT high Displacement impacts positively the mixture flow through the QT, the highest Displacement ratio DispR « over size and weight », and allows supporting higher torque and power output at reduced RPM.

RECALL –Note about the QT 2R rotations with Piston 8-cylinders: TVD = 8 QTL-IC2R (4-strokes + 4-strokes, 2R rotations) IC engine: About the Quasiturbine stroke chamber being faster than the piston chamber, comparison of a (4-pivoting-blades) against a (8-cylinders piston engine) may require the Quasiturbine (stand-alone) TVD = 4 QTL-IC (4-strokes, 1 rotation) IC engine to make an additional rotation. In such a situation, a double rotation 2R device must be considered as a distinct QT engine defined as TVD = 8 QTL-IC2R (4 -strokes + 4-strokes, 2R rotations) instead of 1 rotation, with its own characteristics.

6. Substituting a Quasiturbine to Piston Device

The objective here is not to compare the power density of Quasiturbine to Piston in term of device volume or weight (which could be geometrically straightforward– See section 2.), but is about understanding the QT substitution concerns which are essential in term of design and mechanical characteristics, to appreciate the power density gain of QT technology thereof. The extensive comparison of QT with Piston pump-expander or internal combustion IC engines having a different number of pistons (not 4, or 8) would involve complex situations, out of the scope of this work, but would still benefit from the present methodology, see Case: ALL (cycle angle on the shaft) below.

The total engine Displacement being at the center of this work, let consider a side-by-side Piston and QT having the same total Displacement volume TDV, and look in detail how both strokes-cycles and shaft angle evolved. This can be quite complex in general, but considering the fact that QT has a fixed number of 4 pivoting-blades (piston equivalent), comparison is much simpler with the Piston8 (8-cylinders) device. Parameters selection is key in making a simplified comparison between different types of operation. The following selection works for pump, expander and engine operation mode. Note: The Piston4-IC (4 cylinders, 4-strokes, 2 rotations) IC, has similitude with the Quasiturbine QTL-IC (4 pivoting-blades, 4-strokes, 2-ports, 1 rotation) IC but is not a perfect fit because of RPM and power mismatch.

The Quasiturbines do compare differently with their Piston counterpart, depending if a pump-expander QTL-PE (2-strokes, dual circuits, 1 rotation) in Fig.3, or an internal combustion IC, either QTL-IC (2-strokes, 1 rotation), or QTL-IC2R (4-strokes + 4-strokes, 2R rotation) in Fig.4. The 2-strokes and 4-strokes are compared with Piston device separately, mainly because the QTL-IC (4-pivoting-blades, 4-strokes, 2 rotations) need to run twice to match the Piston8-IC (8-cylinders, 4 strokes) total Displacement TDV, flow and power output. Displacement ratio DispR « over device sizes and weight » is covered in the following sections. Comparisons are limited to selected compatible device models (of equal Displacement, strokes number, stroke volume, and same number of rotation). Parallel discussion for Quasiturbine and Piston devices differences and similitudes are presented, where:

Piston8 (8 cylinders) is having 8 pistons attached to a single crankshaft.
Piston stroke volume (1 chamber volume) = 1 cylinder volume.
Piston total Displacement TDV = 8 intake strokes (= 8 cylinders volumes)
The selected QT total Displacement TDV = Piston reference total displacement TDV
The QT 4 pivoting-blades rotor, attached or not to a single differential central shaft.
The QT stroke volume is being constructed = Piston reference stroke volume.
The QT RPM is always = RPM of the Piston reference

The EP (2-strokes), IC (4-strokes), IC (2-strokes) and ALL (strokes-cycle angle on the shaft) cases are presented separately. BEWARE while reading: While the Piston strokes occur in one location, the Quasiturbine rotor pivoting-blades are attached together, and the QT strokes are spread on the stator internal peripheral. While focusing on one stroke in movement, keep remembering that the 3 others are simultaneously evolving elsewhere. Remember that reducing the sizes of an engine by a factor of 2, cut the volume (and weight) by a factor of 2^3. Also, « RPM and power interchangeable » device does not mean they are identical, and so many other criteria may have to be considered as well.

--- CASE: PE (2-STROKES) PUMP-COMPRESSOR-EXPANDER

The Piston reference device = Piston8-PE (8-cylinders, 2 strokes, 1 rotation):

* A complete 2-strokes mode cycle of 16 strokes, executed in 1 shaft rotation. The Quasiturbine QTL-PE (4-pivoting-blades, 2-strokes, dual circuits, 4 ports, 1 rotation)
* A stroke volume (1 chamber volume) equal to a QT pivoting-blade moving 1 quarter of a turn.
* A Stator having 2 intake ports and 2 exit ports (2-strokes, dual circuits)
* A complete 2-strokes dual circuits with 16 strokes cycle, executed in 1 shaft rotation.

COMPARISON PE pump-expander: Fluid flow considerations. To pump, the Piston8-PE (8-cylinders, 2 strokes, 1 rotation) uses 2-strokes cycles (intake-expel), and only 1 shaft rotation is needed by each piston to accomplish its full 1 rotation cycle, concurrently with the 7 other pistons, for a total of 16 strokes, of which 8 are intake strokes volumes add-up as the total Piston device Displacement. The same arrangement allows the Piston expander mode, where air/steam is pressure forced into the device intakes producing 8 power strokes and 8 exhaust strokes, with the same Piston device total Displacement of 8 strokes (cylinders) volumes.

To pump, the Quasiturbine QTL-PE (4 pivoting-blades, 2-strokes, dual circuits, 1 rotation) uses also 2-strokes cycles (intake-expel), and because the 4 pivoting-blades load 2 quasi-independent sequential circuits, only 1 shaft rotation is needed to accomplish the 4 + 4 intake strokes and 4 + 4 expel strokes, for the same Piston total of 16 strokes per full cycle. QT and Piston device match in number of strokes, and in total Displacement TDV as well, since QT has been selected with equal Piston stroke volume, both supporting the same RPM and the flow rate. The same arrangement allows the Quasiturbine expander mode, where air/steam is pressure forced into the QT intakes producing 8 power strokes and 8 exhaust strokes, with the same Piston device total Displacement TDV of 8 strokes (cylinders) volumes.

Quasiturbine external envelop volume and weight is less than its Piston counterpart, and in addition of being vibration free by design, pivoting-blades act both as piston equivalent, and as flywheel (with no add up) for smooth torque continuity (low harmonic).

Fact PE (2-strokes): On fluid flow (and RPM) consideration: One single Quasiturbine QTL-PE (4 pivoting-blades, 2-strokes, dual circuits, 1 rotation) is interchangeable with an equal Displacement Piston8-PE (8-cylinders, 2-strokes, 1 rotation) pump and/or expander, with QT reducing the volume and weight.

--- CASE: IC (4-STROKES) INTERNAL COMBUSTION

The Piston reference engine = Piston8-IC (8-cylinders, 4 strokes, 2 rotations):

- A complete 4-strokes mode cycle of 32 strokes, executed in 2 shaft rotations. The Quasiturbine QTL-IC2R (4-pivoting-blades, 4 strokes, 2 ports, 1 sparkplug, 2R rotations). Note: The Quasiturbine QTL-IC4 (4 pivoting-blades, 4-strokes, 2-ports, 1 rotation) IC has similitude with the Piston (4-strokes, 2 rotations) IC, but is not a perfect fit because of RPM and power mismatch. The

Piston8-IC (8-cylinders, 4 strokes, 2 rotations) is the reference.

- A stroke volume (1 chamber volume) equal to a QT pivoting-blade moving 1 quarter of a turn.
- A Stator having 1 intake port and 1 exhaust port (4-strokes, 2R additional 2 rotations)
- A complete 4-strokes with 16 strokes cycle, executed in 1 shaft rotation.

Comparison 4-strokes (IC) engine: A Piston8-IC (8-cylinders, 4-strokes, 2 rotations) IC engine accomplishes its complete strokes-cycle in 2 shaft rotations, with 8 pistons X 4 strokes each, for a total of 32 strokes per full cycle, of which only 8 are intake strokes volumes summed up as the Piston engine total Displacement. The Quasiturbine QTL-IC (4-pivoting-blades, 4-strokes, 1 rotation) in internal combustion IC mode accomplishes its complete stroke-cycle in 1 shaft rotation, with 4 intake strokes, 4 compression strokes, 4 expansion strokes, and 4 exhaust strokes, for a total of 16 strokes per full cycle, of which only 4 are intake strokes volumes summed up as the QT engine total Displacement. This is half the Piston. In 1 rotation, QTL makes half the strokes number and the Displacement of the Piston8IC (8 cylinders, 4-strokes, done in 2 rotations). To match, the QTL-IC2R (4-strokes, 2R 2 rotations) needs to make an additional rotation, that the Piston8 IC (4-strokes, 2 rotations) cycle needs to do anyway. Consequently, the match in strokes numbers and Displacement is reached at the same RPM. Said otherwise, the added rotation extends the QTL Displacement angle shaft from 360 to 720 degrees (2 rotations).

In 2 shaft rotations: The Piston8-IC (8-cylinders, 4-strokes, 2 rotations) IC engine intake-compress-fire-exhaust 8 strokes volume, while the Quasiturbine QTL-IC2R (4 pivoting-blades, 4-strokes + 4-strokes, additional 2R 2 rotations) also intake-compress-fire-exhaust 4 + 4 QTL BDC strokes volumes. The total QT and Piston Displacements TDV are equal, both are compared at same RPM, same shaft power, both accomplish complete intake-compression-fire-exhaust 32-cycle in two Piston shaft rotation. QTL-IC2R is used twice in the 2 rotations (without adding a second QTL engine block). Piston8-IC (8-cylinders, 4-strokes, 2 rotations) makes a total of 32 strokes per cycle, and the same for QTL-IC2R double rotations. Total Displacements are equal at 8 strokes volumes each.

The Piston4-IC (4-cylinders, 4-strokes, 2 rotations) strokes are executed in 2 rotations, while an additional QTL-IC (4-strokes, 1 rotation) does it in 1 rotation destroying the match in RPM and Displacement. With Piston8-IC (4-strokes), the QTL-IC2R is used twice in the 2 rotations (without adding a second QT engine block). Quasiturbine external envelop volume and weight is less than its Piston counterpart, QT is vibration free by design, and the pivoting-blades act both as piston equivalent and as flywheel (with no add up) for smooth torque continuity (low harmonic).

Fact IC (4-strokes): On shaft power (and RPM) consideration: One single Quasiturbine QTL-IC2R (4 pivoting-blades, 4-strokes, additional 2R 2 rotation) is interchangeable with an equal Displacement Piston8-IC (8-cylinders, 4-strokes, 2 rotations) IC engine, with QT reducing the volume and weight.

--- CASE: IC (2-STROKES) INTERNAL COMBUSTION

The Piston reference device = Piston8-IC (8-cylinders, 2-strokes, 1 rotation):

- A complete 2-strokes mode cycle of 16 strokes, executed in 1 shaft rotation. The Quasiturbine QTL-IC (4-pivoting-blades, 2-strokes, dual circuits, 4 ports, 2 sparkplugs, 1 rotation)
- A stroke volume (1 chamber volume) equal to a QT pivoting-blade moving 1 quarter of a turn.
- A Stator having 2 intake ports and 2 exit ports (2-strokes, dual circuits, 1 rotation)
- A complete 2-strokes dual circuits with 16 strokes cycle, executed in 1 shaft rotation.

Comparison 2-strokes IC engine: A word about the poor environmentally-friendly IC engine 2-strokes mode. This will probably never be a great breakthrough for this QT technology neither, but worth to mention as Piston IC (2-strokes) are still in used… While the Piston8-IC (8-cylinders, 4-strokes, 2 rotations) IC cycle requires 2 shaft rotations, the Piston8-IC (8-cylinders, 2-strokes dual circuits, 1 rotation) IC engine has a different strokes management that inserts both exhaust and mixture intake (no strokes per say) in a feed through port between truncated expansion and compression strokes, for achieving almost full Piston Displacement in 1 single Piston rotation (using an external fan to force-in the gas mixture while expelling-out most exhaust, a quick intrusion between 2 strokes). The Piston8-IC (8 cylinders, 2-strokes) achieves nevertheless combustion with only 16 strokes total per shaft rotation.

In a similar way, the Quasiturbine QTL-IC (4-pivoting-blades, 2-strokes, dual circuits, 2 side feed-through in-out ports, 2 stator sparkplugs, 1 rotation) in Piston equivalent 2-strokes mode has a sideway feed-throughout port across the QTL 2 side covers (intake flow pushing simultaneously the exhaust out) for each of the dual circuits. There is no port on the confinement stator itself, but 2 sparkplugs located opposite one another (on the 2 Top Dead Center locations-at top and below). Since there are 2 sequential combustion zones (top and below) within the stator peripheral, each QT rotor blade executes the standard 4 strokes per rotation, times 4 blades, for a total of 16 strokes per rotor rotation, while subject to the quick side-way inter-stroke intrusion. Still in this IC case, the QT matches the Piston8-IC (8-cylinders, 2-strokes, 1 rotation) strokes-cycle, its RPM and its total Displacement. Nevertheless, this does not make the QTL-IC (2-strokes) IC cleaner than its similar Piston8-IC (2-strokes) IC. Worth to say in their advantages, both QT and Piston8-IC (2-strokes) IC are more compact and weight less than any 4-strokes, while the 2-stroke IC has serious handicaps of polluting, and being less fuel efficient.

Fact IC (2-strokes): On shaft power (and RPM) consideration: One single Quasiturbine QTL-IC (4 pivoting-blades, 2-strokes, dual circuits, 1 rotation) IC is interchangeable with an equal Displacement TDV Piston8-IC (8 cylinders, 2-strokes, 1 rotation) IC engine, with QT reducing the volume and weight.

--- CASE: ALL (CYCLE ANGLE ON THE SHAFT)

The Piston reference device = any Piston device, any mode:

- A known Piston total strokes-cycle angle on the shaft. The Quasiturbine = any design, any mode
- A known QT total strokes-cycle angle on the shaft.

COMPARING displacement regardless of type, design or mode: This important insertion relates to advanced Displacement concept rarely mentioned. The simple total Displacement definition (based on the total intake volume per comparable stroke-cycle) restricts inter-types devices comparison to well selected compatible device models (of equal stroke number, stroke volume, and full strokes-cycle with same number of rotations, or fractional). More generally, not all types of devices intakes the Displacement volume TDV at the same speed (read same shaft angle), nor grouped the same way, and this means equal Displacement TDV « does not then » produce equal power output. To prevent such a confusion, the reference to a device Displacement TDV is incomplete without spelling-out its full strokes-cycle angle on the shaft (ex.: for 2 rotations, the Displacement being spread on 720 degrees angle on the shaft…).

Theoretically, it is possible to construct a QTX to match any PistonY or Othertype Z of devices in regards to RPM and power, regardless of type or mode, but if the device and the QT total strokes-cycle angle on the shaft differs (Displacement spread on different shaft angle), then the Displacement volume TDV has to be inversely proportional to preserve equal power output, or all Displacement must be normalized to a standard 360 degrees shaft angle. In this situation, Displacement to external volume Ratio DispR needs interpretation.

FactALL (strokes-cycle angle on the shaft): By adjusting the relative displacement, it is generally possible to construct a QTX to match any PistonY or Other type Z of devices in regards to RPM and power, regardless of type or mode, with QT reducing the volume and weight.

7. Piston versus Quasiturbine Complementary Comments

The fundamental reasons why the Quasiturbine matches so well with the Piston8 (8-cylinders) is a fortunate rule of nature: 1) In the pump-expander cycle, the QTL-IC (4-pivoting-blades, 2-strokes) catches-up the number of Piston8 (8-cylinders, 4-strokes, 2 rotations) with a physical dual circuit; and 2) In the internal combustion IC engine cycle, the QTL-IC2R (4-pivoting-blades, 4-strokes, 2R 2 rotations) catches-up the number of Piston8-IC (8-cylinders, 4-strokes, 2 rotations) strokes with an extra rotation. Consequently, some comparison results may look at first surprising. The following comments could help to further clarify Piston-Quasiturbine differences and similitudes.

Q1-Interchangeability: How come « any mode Pistons8 (8-cylinders) devices » can be interchangeable with a single Quasiturbine QTL of equivalent mode and Displacement, while both are being so different?

The Quasiturbine QTL « 4 pivoting-blades acts like 4 pistons in modulating » the volume of the pressure chambers, but for the same piston crankshaft RPM, the QTL (4 pivoting-blades) is not sufficient in number to match the Piston8 (8 cylinders) device. For IC engine 4-strokes, thanks to a second QTL rotation at the same RPM. For the 2-strokes, the total Displacement and power output being equal, thanks to the QTL dual sequential circuits, which matches the Piston RPM. There exists no Piston8 (8-cylinders) device making 32 strokes in 1 rotation (its needs 2 rotations), and there exists no Quasiturbine QTL device making 32 strokes in 1rotation (its needs 2 rotations). A match exists at the same RPM when QTL-IC2R (4-strokes, 2R 2 rotations) does an additional rotation.

FACT Q1: One single Quasiturbine QTL-IC is interchangeable with an equal stroke-volume Piston8 (8 cylinders) device in the same mode, with reduced volume and weight.

Q2-Why not a second Quasiturbine block instead of a second rotation?
In 4-strokes comparison, can the second QTL-IC2R rotation be replaced by a second distinct QTL engine block? No, the Piston8-IC (4-strokes) requires 2 rotations any way, and the single QTL needs to make this second rotation at the same RPM in order to match the total Piston Displacement, even if all the 4-strokes cycles of each 4 pivoting-blades are done in a QTL single rotation (which is not the case with Piston 2 rotations). Because this does not require a second QT engine block, QTL power density becomes exceptionally high. Furthermore, this makes the Piston8-IC (8-cylinders, 4-strokes) engine comparison straight forward, and the QTL looking as a natural compact design alternative for Piston devices.

Fact Q2: A second QTL-IC2Rrotation does the match, with no extra hardware, preserving the total Displacement and power, and with engine reduction in volume and weight.

Q3-About Piston4-IC (4-cylinders, 4-strokes) engine: Why is the QTL-IC (4-pivoting-blades) not equivalent?
The Quasiturbine QTL « 4-pivoting-blades acts like a piston in modulating » the volume of the pressure chambers, but accomplishes full strokes cycle in 1 rotation (The Piston needs 2). Let's recall that two colinear Piston4-IC (4-cylinders, 4-strokes) engines are equivalent to a Piston8-IC (8-cylinders, 4-strokes) engine, but two colinear QTL (4-pivoting-blades, 4-strokes) are not equivalent to a Piston8-IC (8-cylinders, 4-strokes) engine, only 1QTL-IC2R does it at the Piston RPM.

Looking otherwise breaks the equal displacement assumption: Referring to a standard Piston4-IC (4-cylinders, 4-strokes) device with a total Displacement TVD of 4 intake cylinders volumes (in 2 rotations cycle, of 16 strokes total), the QTL with equal total Displacement would have to be built with a half cylinder's chamber volume each (out of assumption). Then the Piston would fire (full power stroke) 4 times in 2 rotations, while at same Piston RPM, QTL would fire (half power stroke) 4 times in the first rotation and 4 times in the second. Here, Piston and QTL single stroke volume would not be identical (but the total

Displacement TDV over the Piston cycle would be). Another way would be to use a transmission gearbox to lower the QTL RPM.

Fact Q3: QTL pivoting-blades act like piston, but at twice the piston frequency. With Piston8 (8-cylinders), the Piston and the QTL single stroke volumes are equal, as well as their total Displacement TDV, which cannot be simultaneously the case for thePiston4-IC (4-cylinders, 4-strokes).

Q4–Displacement: Is the definition of the device total Displacement TDV strictly respected in the QTL-IC (4-strokes, 2R 2 rotations)?
Since a Quasiturbine QTL-IC2R (4-strokes, 2R 2 rotations) IC needs to be rotated twice (at the same Piston RPM) to match the total Piston8-IC (4-strokes, 2 rotations) Displacement, it does respect the total intake volume per complete device strokes-cycle, which justifies the RPM and power integration and confirms a complete match.

Fact Q4: The simple definition of Displacement restricts the comparison to equal cycle shaft (angle) rotation. The double rotations of QTL-IC2R provide that equality. The total device intake volume per complete stroke cycle matches.

Q5-Torque matters: Is its usual that a small and compact engine can match the torque of a large size Piston device? It is rather exceptional. For efficiency consideration, most vane rotary engine design cannot use high eccentricity which limits their torque and power. The Piston comparison contributes to establish the Quasiturbine as a high torque engine, which is currently recognized.

Fact Q5: A single Quasiturbine QTL is a small and compact high torque engine, generally matching the Piston8 (8-cylinders) device torque, with reduced volume and weight.

Q6-Useless QT central area: Why can this central volume be occasionally discarded from total engine volume?
The Quasiturbine concept can usually run without anything in its central area. In some situation the QTL central area can contain an external application device (and its volume legitimacy subtracted from the overall QT engine size). For example, when a propeller screw is inserted into the QTL central area for a specific integration, or when a QT-PE (2-strokes) dual circuits expander has one circuit fed with compressed air or steam, to drive the second circuit as a pump or otherwise, the central area is free for flow rate sensor, or else. Most engines need central area to run, or at least to link an external fly wheel with their Pistons components to smooth the movement, while in the QT, the pivoting-blades inertia already assumes a low level of harmonics.

Fact Q6: The Quasiturbine QTL central area is left free by the kinetic of the concept, and is available for insertion of some special applications, which would occupy space elsewhere anyway. Options not offered by Piston device.

Q7-A word about the WANKEL engine?
A rotary engineWankel3-IC (triangle, 3-4-strokes, 1 rotor rotation, 3 shaft rotations) attempting to make 4-strokes cycle out of the 3 faces of an unbalanced triangle rotor, with unavoidable strokes overlaps that are detrimental to efficiency (engine still being a fan's hope?). The shaft turning at 3 times the rotor RPM makes the Wankel a high RPM, low torque engine, by opposition to the QTL where the perfectly balanced rotor drives directly the high torque shaft.

Fact Q7: The high torque Quasiturbine QTL has a balanced rotor turning at the same RPM as the central shaft, and does not have the Wankel strokes-overlap and single rotor vibration limitations.

8. Current QTL-PE Displacement Ratio to Piston8-PE

The main purpose of this paper is to provide a method to compare through the mean of TDV Displacement, the Quasiturbine, power, weight and sizes with other types of engines. Globally a complex subject with different types of devices, due to weakness of the definition. The «Displacement » simple definition is the total geometric volume a device can intake (flow, expel, burn or exhaust) once all their strokes-cycles are completed. This definition fails to make the total Displacement of all categories of devices proportional to their power output, due to the different shaft spread or cycle speed. In order to make comparison the Quasiturbine chosen ReferencePiston8 (8-cylinders) device imposes to select Quasiturbines with equal stroke volume, and with condition of operation making 8 intake strokes in 2 rotations (at the same Piston RPM). Then the comparisons are valid for all modes, with or without IC internal combustion. The total volume Displacement of the Quasiturbine is then equal to 8 chambers Piston8 or QT stroke volume, in1 or 2 rotations.

What is the Current Quasiturbine DispR Ratio for QTL-PE (2-strokes, 1 rotation)?
Let's pick up a Piston device compatible current Quasiturbine Model QTL-IC Internal combustion (excluding ports) of Fig.3 and copy the stator shape in Fig.7 where the rotor, the stator and the strokes chambers are superposed on an arbitrary grid for surface comparisons which are proportional to QT volumes. The Displacement ratio DispR to the « overall QT stator volume » (excluding ports and sparkplug), is a simple ratio of corresponding surfaces over the grid.

On Fig.7, the QTL-PE surface data (regardless of the QT uniform thickness) gives:
QTL-PE Displacement TDV = 8 normalized (to a single stroke chamber, defined as= 1)
QTL-PE stator enclosure volume = 12,4 chambers
QTL-PE Stator empty central area volume = 2,7 chambers
DispR = 8 chambers Displacement / (QTL stator volume)
DispRi QTL-PE including the central area
= 8,0 / 12,4 = 0,65
DispRe QTL-PE excluding the central area
= 8,0 / (12,4 - 2,7) = 0,82

The Displacement volume power density ratio of 0,65 (equal to 65 % of the QT external volume-excluding ports…) is impressive for high compression-able device, having a small residual volume at TDC. For application where the Quasiturbine central area is not an active part of the engine (unlikely possible with other engine concepts), the ratio increases to 0,82.

HOW DOES THE PISTON8-PE (2-strokes, 1 rotation) DispR RATIO compare to current QTL-PE?
QTL-PE (2-strokes, 1 rotation) Displacement TDV = 8
Piston8-PE (8-cylinders, 2-strokes, 1 rotations) Displacement TVD = QTL = 8
DispR Piston8-PE = (Displacement / Piston envelop volume)
DispR Piston8-PE Typical values = Range from 0,2 to 0,4 (arguable?)

The Piston8-PE and QTL-PE 2-strokes have the same full cycle of 16 strokes in 1 rotation, for the same Displacement of TDV = 8. With a DispR ratio of 0,65 to 0,82 the QTL-PE is already at least 2 to 3 times more compact (and lighter) than Piston8-PE (8-cylinders) device of equivalent Displacement. Furthermore, the Quasiturbine DispR ratio can still be considerably improved (and its power output as well, with no stator volume increase) from theoretical stator eccentricity consideration, see QTD-PE (2-strokes, 1 rotation) on Table 1. Note: Comparison between QTL-IC2R (4-strokes, 2 rotations) and the Piston8-IC (4-strokes, 2R 2 rotations) is unique, since the QTL-IC2R is allowed to make a second rotation, 4 + 4 QT intake strokes are achieved without additional QTL-IC2R hardware. The QTL and QTD DispR Ratio are respectively doubled in Displacement by not adding external QT volume (QTL-IC2R and QTD-IC2R stator volume still equal to 1, not 2).

9. QT Eccentricity for Optimum Displacement Ratio

The current manufactured Quasiturbine base on QTL (same as QT-LSC) with moderate eccentricity stator designs are already impressive with Displacement DispR ratio of 0,65 to 0,82, but there is still substantial gain possible toward« QT Displacement exceeding the device volume » linked to confinement stator eccentricity analysis [5].

Quasiturbine higher stator eccentricity QTD means larger intake chamber (almost double of QTL), with the same stator internal volume, and higher Displacement DispR to stator volume ratio. However, there is no benefit to select an eccentricity which makes a stator inflexion (dual lobes), as this reduces the maximum compression ratio (and captures a useless residual volume within the pivoting-blades). Consequently, there is an optimum eccentricity for top Displacement ratio DispR, which is when the stator reaches a rectilinear straight junction between the left and the right stator lobes (Referred in patents as the Saint-Hilaire skating rink confinement [3]). See the QTD optimum rotor design for maximum Displacement on Fig.5, with the rotor shown in mid-stroke position.

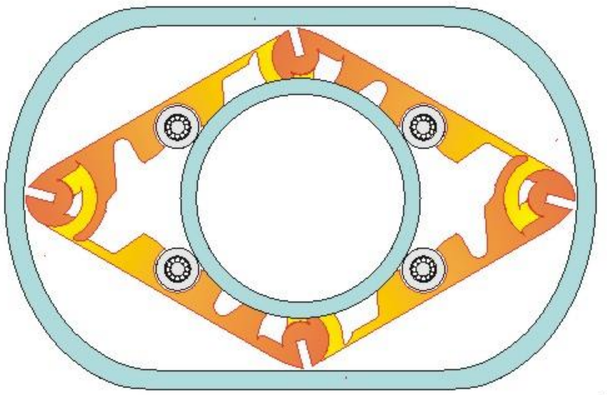

Figure 5: The Quasiturbine QTD stator optimum design gives the maximum QTDispR ratio of « total Displacement over stator volume (grid surface of Fig.7) », with the rotor shown in mid-stroke configuration as one of several design possibility. Notice that the little wheel-bearings supporting the pivoting-blades are not travelling all around the central shaft, as the shaft turns as well (the wheel-bearing oscillates only slightly in relative movement from behind and ahead).

In order to explore this Quasiturbine rotor optimum eccentricity « Displacement to engine volume » ratio, the QT geometrical parameter set of the rotor must be reviewed to allow for extra rotor deformation. Fig.6 presents the QTD stator with rotor in square configuration, and a possible rotor solution inspired from previous QTL rotor design, where pivot-to-pivot length is maintained, as well as the pivot hinge diameters (still meeting the high compression criteria - a small residual pivoting-blade volume at TDC). This limit rotor design is one of potential interest, but has not actually been tested.

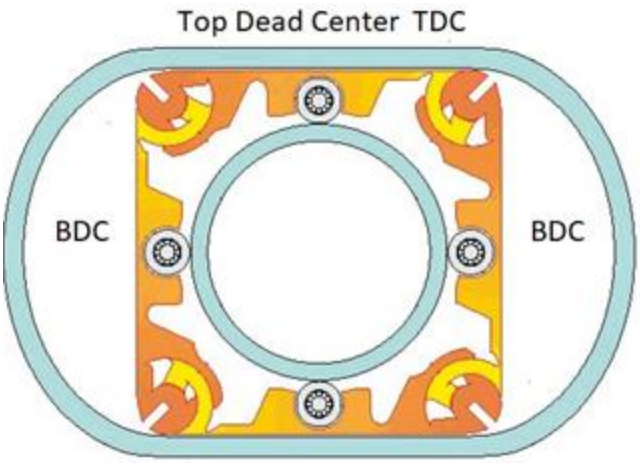

Figure 6: The Quasiturbine QTD (optimum stator eccentricity) with the rotor shown in square configuration. This is the optimum stator shape for the highest QT Displacement ratio DispR, while still being a high compression-able device. The left and right rotor pivoting-blades are at Piston equivalent BDC (maximum chamber volume), while the upper pivoting-blades and below are at TDC (minimum residual chamber volume).

The QTD optimum eccentricity stator confinement profile is not unique [5], and pivoting-blades geometry with central differential can have multiple designs. The main characteristics of the Quasiturbine come from the grid on Fig 7, where all surfaces are given in fraction of the total stator reference surface =1. Notice the QTD (solid line) on the right side with the long arrow from the rectilinear pivoting-blade to the stator internal surface. The maximum chambers volume (stroke) is shown at BDC in left and right. In the context of comparison (interchangeable) with reference Piston8 (8-cylinders), the total displacement is TDV = 8 strokes chambers (exception in out of context, not interchangeable, Piston4 (4-cylinders) TDV=4). From the right side QTD and the left side QTL of the grid on Fig.7, data can be obtained:

TVD Displacement # of strokes
QDT = 8 QTL = 8
One single stroke volume (stator fraction)
QDT = 0.15 QTL = 0,08
Stator internal volume (including central area)
QDT =1 QTL = 1
Stator internal volume (excluding central area)
QDT = 0,73 QTL = 0,78
DispRi (including central area)
QDT =1,2 QTL = 0,64
DispRe (excluding central area)
QDT = 1,6 QTL = 0,82

The moderate stator eccentricity QTL is also superimposed (broken line) on the grid Fig.7, where the short QTL arrow on the left side from the curved pivoting-blade to its own stator can be compared to the longer arrow of the QTD on the right side (almost double).

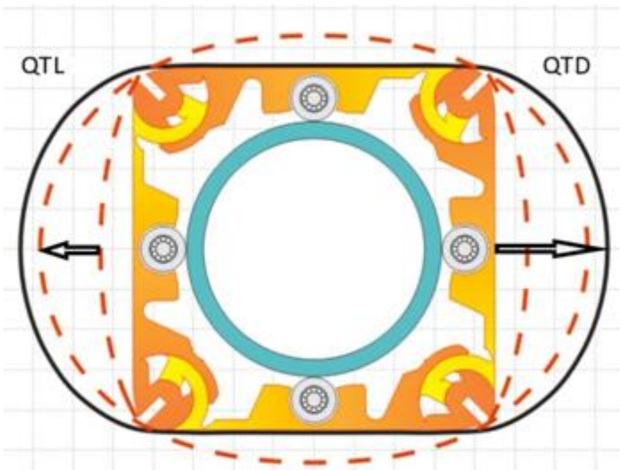

Figure 7: QUASITURBINE Displacement DispR ratio versus stator eccentricity. Superposed over an arbitrary grid with rotors of equal pivot-to-pivot lengths, the QTL (moderate rotor eccentricity) on the left, and the QTD (rectilinear side) stator for optimum DispR ratio on the right. The stator volume is nearly unchanged by eccentricity, while the QTD single stroke volume is 1, 90 X larger than the QTL one. Notice that vane motors cannot use such high eccentricity without important overlap or back-leak flow, compromising their efficiency.

TABLE 1
QUASITURBINE STATOR ECCENTRICITY
EFFECT ON POWER DENSITY
Stator QTL - versus - Stator QTD
Source: Grid Fig.7
All volumes in fraction of the stator volume.
Central area volume (surface) QTL = 0,22; QTD = 0,27
Single stroke volume (surface) QTL = 0,08; QTD = 0,15
Notice that increased eccentricity QTD
nearly doubles the QTL displacement TDV.

Devices description (Similar for QTD stators series):
QTL-PE (2-strokes, dual circuits, 1 rotation) QT pump and/or expander (air, steam, gas…).
Interchangeable with the Piston8-PE (8 cylinders, 2-strokes, 1 rotation).
QTL-IC (2-strokes, dual circuits, 2 side feed-through, 1 rotation) QTIC 2-stroke engine.
Interchangeable with the Piston8-IC (8 cylinders, 2-strokes, 1 rotation).
QTL-IC (stand-alone, 4-strokes, 2 ports, 1 rotation) QT IC 4-strokes engine.
(Not direct interchangeable) with Piston4-IC (RPM and power mis-match).
QTL-IC2R (4-strokes + 4-strokes, 2 ports, 2R rotations) QT IC2R4+4-strokes engine.
Interchangeable with the Piston8-IC (8 cylinders, 4-strokes, 2 rotations).
QTD Stator series have similar descriptions…

Device Model	Cycles TDV#	Rot.	Displacement Volume	Stator volume (Less Central)	DispRi ratio (DispRe)	Relative Power
			----- 2-strokes -----			
Piston8-EP	8 / 16	1	8 X 0,08	4 (4) +/-	0,16 (?)	53 %
QTL-PE	8 / 16	1	8 X 0,08	1.0 (0,78)	0,64 (0,82)	53 %
QTD-PE	8 / 16	1	8 X 0,15	1,0 (0,73)	1,2 (1,6)	100 %
QTL-IC	8 / 16	1	8 X 0,08	1,0 (0,78)	0,64 (0,82)	53 %
QTD-IC	8 / 16	1	8 X 0,15	1,0 (0,73)	1,2 (1,6)	100 %
			----- 4-strokes -----			
Piston8-IC	8 / 32	2	8 X 0,08	4 (4) +/-	0,16 (?)	53 %
QTL-IC	4 / 16	1	4 X 0,08	1,0 (0,78)	0,32 (0,41)	27 %
QTD-IC	4 / 16	1	4 X 0,15	1,0 (0,73)	0,60 (0,82)	53 %
QTL-IC2R	8 / 32	2	(4+4) X 0,08	1,0 (0,78)	0,64 (0,82)	53 %
QTD-IC2R	8 / 32	2	(4+4) X 0,15	1,0 (0,73)	1.2 (1,6)	100 %
Piston4-IC	4 / 16	2	No fit with QTL-IC (4-strokes) (mis-matches in RPM - power)			
ALL (shalt angle)			No need with these selected devices.			

TABLE 1 - In the context of comparison with Piston8 (8-cylinders), a total Displacement TDV of 8, not only the current Quasiturbine QTL Displacement to device volume DispR ratio of 0, 60-0, 82 becomes QTD 1, 2-1, 6 but it does double the relative power output as well from 53 to 100 % (top QTD reference), with no stator volume increase. The QTL-IC Displacement equal Piston4 for 4-strokes, which is half the QTD-IC2R. Remember about Power density: Reducing the sizes of an engine by a factor of 2 cuts the volume (weight and cost…) by a factor of 2^3.

Increasing the eccentricity has a major impact on the engine Displacement volume, not only because higher eccentricity provides extra volume in the chamber (QTD almost double of the QTL), but also because it affects the external surface of the pivoting-blades, while becoming rectilinear, which further increases the stroke volume in the right side on Fig.7. Notice that accentuating the stator profile does not change significatively its surface, which has then no direct impact on the Displacement ratio DispR. In addition, the design and mechanical conception of the rotor is more complex.

The Table 1 is done in the context of Piston8 (8-cylinders) comparison to expose interchangeable possibilities « Piston 8-cylinders-QT » with total Displacement TDV = 8, and to give an idea of relative power (no strict values). For a total Displacement of TDV = 4 for Piston4 (4-cylinders, 4 rotations), there is no direct interchangeable QTL possibility (not even the QTL stand-alone), and the displacement is half the QTD-IC2R with QTL-IC DispRi of 0,32 - 0,41 becoming DispRe QTD 0,60 - 0,82, with a relative power doubled-up from 27 % to 53 %.

In the comparison between different QT stator eccentricities, the relative QT power is also affected in the same ratio than the single stroke volume is, which is substantial as it goes for Displacement TDV = 4 from QTL of 27 % to QTD of 50 %, and for Displacement TDV = 8, of 53 % to 100 % (being the optimum QTD stator reference). Excluding the stator central area volume from QT volume is an option the Piston engine cannot offer (when this central area is used as an external application, like impeller…). Stator volume reduction by central exclusion increases the Displacement Ratio respectively from QTL DispRi 0,60 to 0,82 and QTD DispRe from 1,2 to 1,6 times the stator volume.

10. Conclusion

The Quasiturbine (QT) is a recent engine concept [2] currently available as air-steam-gas motor-expander, which has been reviewed by numerous labs and experts worldwide [6] and is steadily improving in terms of design and manufacturing techniques, and where the timing for a framework contribution is appropriate. The QT « pivoting-blades acts like a piston » in modulating the volume of the pressure chambers in-between the inner-stator wall. The Piston8 (8-cylinders) and the QT (4 pivoting-blades) devices produce the same number of 16 strokes per rotation, but with execution grouped differently, which explain their operational similitudes.

Like most engine concepts, the Quasi turbine is characterized by its positive volume Displacement, RPM, torque, power, efficiency and its power density, expressed as Displacement ratio DispR « over external engine volume ». For matter of simplicity, the present work relates to comparison with QT of equal stroke volume and total Displacement as Piston8 (8-cylinders) devices. Like in the Piston8-PE (8-cylinders) pump and expander (… and 2-strokes IC as well), the QT has a complete cycle of 16 strokes per rotation (where 8 intakes are defining the total Displacement). Similarly, the Piston8-IC (8-cylinders, 4-strokes, 2 rotations) internal combustion IC engine, and the QT (4-strokes, with not 1 but 2 rotations) have complete cycle of 32 strokes (of which 8 intakes strokes are defining the total Displacement). While the QT fires all its strokes-cycle in each of its 2 rotations, the Piston8-IC (8-cylinders, 4-strokes, 2 rotations) needs absolutely 2 rotations to end the cycle. For Piston (8-cylinders) devices, it is shown that the Quasiturbine matches exactly the same in term of stroke size, stroke number, total volume Displacement and RPM shaft rotation, regardless of the 2-or 4-strokes modes, QT doing the same 2 rotations. The QT can typically be 3 to 5 times lighter and more compact than the Piston8 (8-cylinders) of equivalent Displacement and power at moderate RPM.

For pump-expander-engine, the Displacement ratio DispR «to external device volume or weight » is one of the most valuable criteria to express the output power density. In addition to its intrinsic high Displacement capability, the Quasi turbine makes use of its pivoting-blades rotor as a no-add-up integrated flywheel, its cylindrical geometry helps for power density, and its low RPM high-torque characteristic suppresses the need of large and heavy gearbox in many applications. Not only in reference to light airplane engine, this set of potential gains is valuable for improving portable equipment, as for onboard hybrid vehicle, but also for strategic efficiency as the QT « uniflow rotary steam engine » (where used steam does not cold the intake hot areas), as high flow fluid pump and thermal energy recovery in geothermal heat-pump, air conditioning, refrigeration and temperature-controlled devices.

The total positive Displacement ratio DispR of the current Quasi turbine QTL design is already equal to 65 % of the QT external device volume, and this Displacement ratio can further be increased by accentuated eccentricity to a QT theoretical optimum of about1,2 to 1,6 over unity, while doubling the relative power output as well from 53 to 100 %, with no stator volume increased. How much smaller could the QT be in practice, compare to a Piston engine? It would depend of the Piston reference engine type, its number of cylinders, its cycle technology and the application involved (torque, RPM, vibration…). Answers are not in the scope of the present work, but one can expect substantial gain in reducing both engine volume and weight in most cases, and specially where smaller QT gearbox suppression can fit the application.

Not only a single Quasi turbine is (interchangeable) with a same mode Piston8 (8-cylinders) device of equal stroke volume and total displacement, but QT total Displacement ratio DispR could be greater than unity. At a time where hydrogen and synthetic fuels offer new perspectives, power density, high torque, low-cost manufacturing, and durability through perfectly balanced design are in demand, especially if sustainable locally and not high-tech dependent. The Quasiturbine is a step in that direction.

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Author Profile

Gilles Saint-Hilaire Ph. D. Paris, Thermonuclear Physics

Roxan Saint-Hilaire MBA Berkeley, Microchips design,

Ylian Saint-Hilaire M. Sc. Montréal, Meshcentral Principal

Françoise Saint-Hilaire M. Let. Sorbonne, Documentation.

Are all in Quasiturbine Académie,
Montréal Québec H2K 4J9, Canada

Definition / Abbreviation

IC-INTERNAL COMBUSTION

QT-QUASITURBINE

QTL-QT OF MODERATE ECCENTRICITY

QTD-QT OF OPTIMUM ECCENTRICITY

TDC-TOP DEAD CENTER

BDC-BOTTOM DEAD CENTERTVD-TOTAL VOLUME

TDV- DISPLACEMENT

DispR-DISPLACEMENT RATIO

Annexes TABLE 1

TABLE 1 (Is a photo in the text)
(HERE ARE THE NUMBERS FOR IMPORT IN MS-WORD)

QUASITURBINE STATOR ECCENTRICITY
EFFECT ON POWER DENSITY
Stator QTL - versus - Stator QTD
Source: Grid Fig.7

Device Cycles Displacement Stator
volume DispRi ratio Relative
Model TDV# Rot. Volume (Less
Central) (DispRe) Power

----- 2-strokes -----

Piston8-EP 8 / 16 1 8 X 0,084 (4) +/-0,16
(?) 53 %

QTL-PE 8 / 16 1 8 X 0,081.0 (0,78)
0,64 (0,82) 53 %

QTD-PE 8 / 16 1 8 X 0,151,0 (0,73)
1,2 (1,6) 100 %

QTL-IC 8 / 16 1 8 X 0,081,0 (0,78)
0,64 (0,82) 53 %

QTD-IC 8 / 16 1 8 X 0,151,0 (0,73)
1,2 (1,6) 100 %

----- 4-strokes -----

Piston8-IC 8 / 32 2 8 X 0,084 (4) +/-0,16
(?) 53 %

QTL-IC 4 / 16 1 4 X 0,081,0 (0,78)
0,32 (0,41) 27 %

QTD-IC 4 / 16 1 4 X 0,151,0 (0,73)
0,60 (0,82) 53 %

QTL-IC2R 8 / 32 2 (4+4) X 0,08 1,0
(0,78) 0,64 (0,82) 53 %

QTD-IC2R 8 / 32 2 (4+4) X 0,15 1,0
(0,73) 1.2 (1,6) 100 %

Piston4-IC 4 / 16 2 No fit with QTL-IC (4-strokes) (mis-matches in RPM and power)

ALL (shalt angle) No need with these selected devices.

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