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QUASITURBINE
LOW RPM HIGH TORQUE PRESSURE DRIVEN TURBINE
FOR TOP EFFICIENCY POWER MODULATION (*)

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ABSTRACT

The Quasiturbine turbo-machine is a pressure driven, continuous torque and symmetrically deformable spinning wheel. Excluding conventional turbines, the next step in the world of engine research is to make the gas engines as efficient as the diesel engines and the diesel engines as clean (or better) as the gas engines. Turbine characteristics help achieving this goal. The Quasiturbine (Qurbine or Kyotoengine) is a new engine technology that was conceived in early 1990 and patented in 1996 and later. The Quasiturbine is inspired by the turbine, perfects the piston and improves upon the Wankel engine. Efficient and compact, the Quasiturbine is also an engine concept optimization theory based on « volume pulse shaping » at design. While current technologies adapt combustion processes to engine design, the Quasiturbine theory tends to adapt the engine design to combustion processes. It is a non-eccentric crankshaft, true rotary engine (no piston like movement), that uses a 4 face articulated rotor with a free and accessible center, rotating without vibration nor propulsive dead time and producing a strong torque at low RPM under a variety of modes and fuels. The Quasiturbine goes along the best modern engine development strategy, which is to get as many ignitions as possible per minute, with a mechanical device rotating as slowly as possible.

Quasiturbine allows designs with up to « 7 conceptual degrees of freedom », substantially more than conventional turbine or piston engine, permitting to better shape the compression and relaxation volume pulse and further improved optimization. Taking full advantage of its unique short and fast linear ramp volume pulsed properties, its AC Model is a natural HCCI « detonation - knocking » engine. Such a detonation Quasiturbine has very little low-power-efficiency-penalty, is multi-fuel compatible (including direct hydrogen combustion), offers a drastic reduction in the overall propulsion system weight, size, maintenance and cost. Because Quasiturbine cycle is pressure driven instead of aerodynamically driven, it has a comparatively flat high efficiency characteristic in regard to RPM, load and power, which makes it most suitable for power modulation applications like in transportation and windmill energy storage and recovery systems. Used in Stirling and Brayton cycles, the Quasiturbine offers new ways to recover and transform thermal energy.

INTRODUCTION

The objective of this paper is to give an overview to the engine community of a new technology conceived in early 1990, patented in 1996 and later and called Quasiturbine. Why the name Quasiturbine? Because just like the conventional turbine, Quasiturbine has a (quasi) continuous flow at intake and exhaust, propulsive dead time is zero and torque impulses are consecutively jointed for uninterrupted torque. The Quasiturbine turbo-machine is a pressure driven, continuous torque and symmetrically deformable spinning

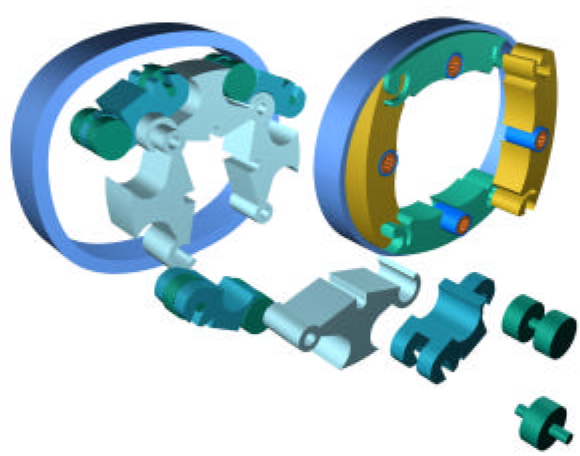

Figure 1. Two of the Quasiturbine family designs: Model AC (with carriages) on the left and SC (without carriage) on the right.

wheel. The Quasiturbine is inspired by the turbine, perfects the piston and improves upon the Wankel. This paper gathers the most significant concept developments of the last 15 years. Preliminary experimental data on fairly well built prototypes closely supports the Quasiturbine theory (comprehensible results will be published in the near future by independent sources).

Much information about the Quasiturbine (or Kyotoengine) is available in public patents [1-4], in the inventor's book [5] (in French) and on the official website [6]. Fragmented Quasiturbine information has been featured in international magazines and conferences as in European Automotive Design [7], Eureka Innovative Engineering [8], Prototype presentation at the SAE Small Engine Technology Conference USA [9], GHG Alberta Solutions [10], Diesel Progress North American Edition [11], Carol Crom Engine Comparison White Paper [12], Myron D. Stokes White Paper presented at the 2004 Global Power train Conference (GPC) [13], HowStuffWorks Encyclopedia [14], Engine Technology International [15] and more. Quasiturbine got some early recognition in the SRC 2000 French Canadian Broadcasting Corporation « Découverte » TV Science program [16], was semi-finalist to the Discover Magazine 2000 Awards [17], winner of the Énergia R&D Awards [18] and more. Application research projects are publicly ongoing in some universities, including Concordia in Montréal. The Quasiturbine is promoted by citizen groups in several countries [19]. Several prototypes have been delivered worldwide to customers generally interested in discreet early strategic application evaluations.

In the international environmental context and resources depletion discussions such as the Kyoto Accord and taking into account the general population conviction that climate changes are currently endangering our planet, there is a new sense of urgency mandating that no energy technologies can be discarded; this is particularly true of any sound engine concept breakthroughs.

QUASITURBINE THEORY

The Quasiturbine is both an engine optimization theory and a family of devices, which shares with the conventional turbine the most valuable characteristic of torque continuity (even if not constant, there is no propulsive dead time), that very few other engine concepts offer. While current technologies adapt combustion processes to engine design, the Quasiturbine theory tends to adapt the engine design to combustion processes. The Quasiturbine theory values the optimum shaping of the volume pulse (and consequently the pressure pulse) for each particular application. The Quasiturbine is a positive displacement engine. Descriptive equations are detailed in [1, 2].

Conventional turbine offers only one degree of freedom: Rotation. Piston engines present at design two conceptual degrees of freedom: Linear piston motion and crankshaft Rotation, both generally linked by a solid connecting rod offering no flexibility to shape the volume pulse. Once fitted into a proper Saint-Hilaire confinement profile [1] (from the physicist who first calculated it in the most general configuration), all the conceptual degrees of freedom get linked, and the Quasiturbine rotor is left, like in any other engine, with only one degree of freedom: Rotation. The mathematical rotor problem is to calculate a confinement profile, which ultimately leaves only the rotation as kinetic degree of freedom. Furthermore, the Saint-Hilaire confinement profile is generally not unique and to some extent can be selected according to thermodynamic considerations.

Fuel mixture thermodynamic combustion chemistry does not fit too well with the sinusoidal movement of the piston, and especially in regard to the high expectation of HCCI [23] and supersonic detonation mode (including volumetric radiative photo-detonation mode). A machine design with more conceptual degrees of freedom allows to better shape the compression and relaxation volume pulse and permits optimization compared to conventional engines.

In their search for an engine with high conceptual degrees of freedom, while still physically feasible, the Quasiturbine inventors had been looking to bring in one plane the compressor turbine and the hot power turbine of turbo-shaft helicopter like engines, but where compression and power stroke alternate. In order to do that, they found that the blades could not be attached anymore to the power shaft, but had to be chained to one another. To increase the number of conceptual degrees of freedom, they have introduced a set of carriages at each blade jointure. Doing so, they made an innovative design defined by a set of 7 parameters (degrees of freedom), which can be individually selected at design to shape the engine volume pulse almost at will. This set of 7 parameters allows generating an infinite number of machine designs of which one call Model AC (Avec Chariot) is shown in the left of Fig. 1. A special case geometry where the distance between the two wheels of a carriage is set to zero, called the Model SC (Sans Chariot) is shown in the right of Fig. 1 and also in Fig. 2. As indicated in Fig. 2, the Quasiturbine has four closed peripheral chambers (two compression - relaxation circuits, usable in parallel or serial), that a compressed fluid can use simultaneously, making it effectively 2 engines in one. The high efficiency of the power Quasiturbine is controlled by the optimum setting of the intake cut-off port closing (no similarity with cylinder deactivation). While conventional turbines need to convert initial pressure into high velocity fluid (aero-dynamic), the Quasiturbine responds directly to that internal pressure. When used in internal combustion mode, the Quasiturbine Model AC is intended for detonation mode, where the high surface to volume ratio is an attenuating factor of the violence of the detonation. Detonation self-fires similarly to Diesel, but burn homogeneously, faster and cleaner. This mode uses a « detonation chamber » instead of a « combustion chamber ».

Because the Quasiturbine does not require the pressure energy to be converted into the intermediary form of kinetic energy, it has some advantages over the conventional turbines, including efficiency at all regimes and the ability to digest saturated steam and dust without as much erosion. Because the Quasiturbine cycle is pressure driven, instead of aero-dynamically driven, it can run at very low RPM and high torque, and has a comparatively flat efficiency characteristic in regard to RPM, load, and power which makes it most suitable for power modulation application like in transportation. Near static modelization is, in all cases, close to a long tube in which there is a moving theoretical piston.

Why was this engine not invented before? As trying to square the circle, the exact Quasiturbine Saint-Hilaire confinement profile [1] does not exist in the general concept. However, it has been demonstrated that the residual play for a 12 cm (5 inches) diameter rotor is only 0,003 cm (0,0012 inch), which is of no practical limitation. The Quasiturbine goes along the best modern engine development strategy, which is to get as many ignitions as possible per minute, with a mechanical device rotating as slowly as possible. Reduction of propulsive dead time spreads the torque more uniformly over time and reduces the engine robustness requirement. Like the delta-plane and other modern concepts, the Quasiturbine is complex to design, but simple to execute.

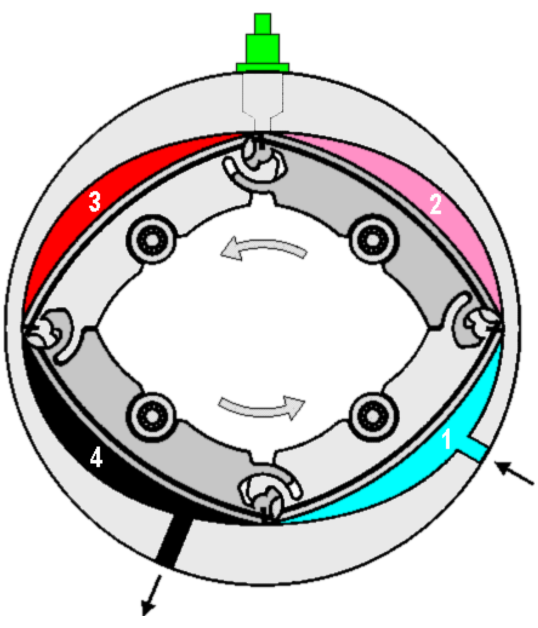

Figure 2. Quasiturbine Model SC in Internal Combustion mode. Intake (aqua 1), Compression (fuchsia 2), Combustion (red 3), Exhaust (black 4). A spark plug is located at the top (green).

HOW IT WORKS

Quasiturbine Model SC shown in Fig. 2 has no valve or eccentric crankshaft, only ports located either radially on the stator contour, or axially in the stator lateral covers. As the articulated 4-face rotor turns, its motion and the shape of the housing cause each side of the housing to get closer and farther from the rotor, compressing and expanding the chambers similarly to the "strokes" in a reciprocating engine. Each of the 4 rotor pivoting blade is radially supported by a set of wheelbearing in its center, rolling on two central circular tracks within each of the lateral side covers, such as the rotor is perfectly centered at all time. Rotor motion can be linked to a central main shaft in several ways [1-2].

Each Quasiturbine rotor face rocks back and forth in reference to the engine radius, but stays at a constant distance from the engine center at all time, producing only pure tangential rotational forces, with no piston like radial movement. Because the Quasiturbine has no eccentric crankshaft, the internal volume variations do not follow the usual near sinusoidal engine volume movements. The rotor motion thus provides very different characteristics from the piston or the Wankel engine. Absence of propulsive dead time justifies the name Quasi- and it is not surprising that the Quasiturbine has properties of both the piston and the turbine. Quasiturbine acts as a double sealed rotary valve.

DIFFERENCES WITH CONVENTIONAL ENGINES

While the Brayton turbines set compresses and expands, a single Quasiturbine does both in sequences, compressing 2 chambers during a quarter of a turn and relaxing them the next quarter of a turn. It is like two engines in one. Hydraulic, pneumatic, steam, gas and fuel combustion... produce primary energy in the form of pressure. Being a hydro- aerostatic device, the Quasiturbine directly transforms this pressure energy into mechanical rotation motion with optimum efficiency, almost regardless of the pressure level (The Quasiturbine idles with only a few psi!). Conventional turbines are hydro- aero - dynamic and they cannot handle directly the pressure energy that must be first converted into kinetic energy. For a given blade geometry, the efficiency of conventional turbine falls rapidly if the flow condition and velocity moves away from the optimum design value. Fig. 3 compares several engines for the transportation sector.

The Quasiturbine is not a « vane type » of engine (not easily scalable in size, torque, RPM and power due to their large seal extension), because the seal extensions are near zero at all times just like in the piston and the Wankel, and its geometry enables 2 quasi-independent circuits as well as very high compression ratio and power torque. While the Wankel engine has an eccentric crankshaft and its triangular rotor makes a piston like radial movement, the Quasiturbine is not in this category of « rotary piston engine » because it has no eccentric crankshaft and its pivoting blades are not moving radially. The eccentric crankshaft machines reach their

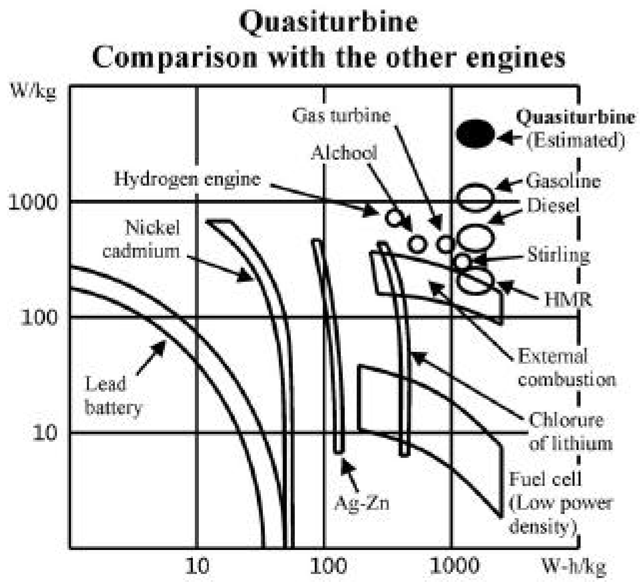

Figure 3. RAGON diagram for transportation applications [20] with the Quasiturbine positioned for Beau de Rochas (Otto) mode. Detonation mode is still further up due to higher efficiency and rpm.

maximum and minimum mechanical extension in synchronization with the pressure strokes, while in the Quasiturbine, the rotor reaches it maximum and minimum extension at half-stroke, producing a smooth kinetic transition near Top and Bottom pressure Dead Center. The Quasiturbine is rather a « true rotary engine » alike the conventional turbines. There are also other rotary concepts of compressors and blowers with different characteristics, like roots and screw types, as well as impulse stages or reaction stages turbine.

Contrary to the Wankel of which the main shaft turns 3 times for every revolution of the rotor and fires once per shaft revolution, the Quasiturbine shaft rotates at the same RPM as the rotor and fires 4 times per shaft rotation, producing a quasi-continuous torque, with little need for a flywheel. The stator irregular shape limits the Wankel geometric compression ratio, while the Quasiturbine has no such limitation. It is important to observe that the Quasiturbine contour seals are almost perpendicular to the housing contour wall at all times, avoiding the early Wankel like sealing problematic. An extensive Wankel differences discussion is given in reference [6].

Whereas a 4-stroke piston engine produces one combustion stroke per cylinder for every two revolutions, the chambers of the Quasiturbine rotor generate 8 combustion «strokes » per two rotor revolutions; this is 8 times more. The 4-stroke piston has a long propulsive dead time, its average torque is about 1/7 of the peak torque. These peaks dictate the need for extra robustness in piston engines. Since the Quasiturbine has no propulsive dead time (torque continuity), peak torque is within 20% of the average torque; for this reason, the relative piston robustness needs to be 5 times (7 / 1.2) higher than the Quasiturbine. This can further reduce the Quasiturbine weight... In this perspective, for the same shaft RPM as a piston 4-stroke engine, the Quasiturbine strokes are twice as fast and 8 times more frequent, for a substantial torque and power gain. Furthermore, the Quasiturbine has no valve, while the piston exhaust valve is a limitation in thermal optimization.

In addition to the intrinsic power modulation characteristics, the Quasiturbine when used in any of the pneumatic, steam, hydraulic, compressor or Brayton modes, offers unique extra flow and power modulation capabilities by using one or both of its double internal quasi-independent circuits, without affecting the torque continuity or the efficiency of the chambers. This is especially important for windmill energy storage and recovery systems and also to allow power modulation of the Quasiturbine operating in the Brayton, Rankine, or other engine cycles.

QUASITURBINE CHARACTERISTICS

Multi Modes – Multi Fuels

Not every one in the world has easy access to quality fossil fuels. Quasiturbine can be made switchable to internal natural gas, gasoline or diesel combustion, compressed air or steam engine (accepting saturated steam), with some local strategic interest for third world countries and elsewhere. The Quasiturbine is also most suitable for hydrogen internal combustion because it has a fixed cold intake area, and furthermore allows for stratification intake of air and hydrogen on each side of the engine, efficiently preventing unwanted detonation in Otto mode. It can be use in thermal Stirling [21] and Brayton [25-26] modes, as compressor, hydraulic motor or pump. It can act as a linear rotary dosing valve and expander, applicable to enhance the refrigeration cycle efficiency or to recover gas pipeline pressure energy.

Low RPM

At comparable piston power, because there is no propulsive dead time and the propulsive force is positive at all time, there is no need for a high RPM flywheel to smooth the rotation. It could idle under 100 RPM and a current power regime can be well under 1 or 2 thousands RPM. Notice that the low RPM keeps the ignition frequency high, because 4 chambers fire every revolution. In the Quasiturbine, everything is going fast while the rotation is going slowly.

High Torque

Contrary to the Wankel engine of which the main shaft turns 3 times per revolution of the rotor and fires only once per shaft revolution, the Quasiturbine shaft rotates at the same RPM as the rotor, and fires 4 times per shaft rotation, producing a quasi continuous torque, with little need for a flywheel. Even better, the Model AC (with carriages) generates a near square torque pulse still with no propulsive dead time, which gives very low shaft harmonic similar to the conventional turbines.

Light Weight and Small Size

Engine propulsive dead time is the enemy of specific power, in weight and size. Four stroke pistons are propulsive only 17% of the time. At comparable piston power, the Quasiturbine is 4 to 5 times more compact and light. Since it has no oil pan requiring gravity drain, the Quasiturbine can be operated in any orientation.

Efficiency and Environment

Better efficiency means saving the resources and protecting the environment. When used with compressible fluids like air, efficiency is competing with power like in any positive displacement engine, where efficiency can be regulated by the intake cut-off port closing adjustment, in principle to near reversibility (but adiabatic heat), which is an optimization not available in conventional turbine concepts. The Quasiturbine in Beau de Rochas (Otto) mode presents improvements over the Wankel because the strokes are non-truncated and the combustion chamber is 30 % shorter. Contrary to the piston engine where the same physical chamber is used for cold intake and hot combustion, the Quasiturbine gets cold intake in a different location from the hot combustion, allowing for better thermal conditions and combustion cleanness, while improving the overall engine thermodynamics.

Because there is no propulsive dead time, high temperatures heat loss to the cooling system (detrimental to pressure) are substantially reduced compared to long propulsive dead time and intake cylinder cooling with piston engine. Because the ports are at the opposed far ends of the chambers, ports overlap minimizes the intake mixture flowing straight to the exhaust. Shaping the volume pulse adds further optimization. Weight and size reduction (by a factor 4 to 5) provides indirect efficiency improvement in transportation applications, where direct drive with fewer ratios or no gearbox is also an improvement factor, while Combined Cycle Quasiturbine [10] optimizes the overall efficiency. Detonation mode (see below) further increases the efficiency by permitting higher compression ratio and by suppressing the intake butterfly valve responsible of the engine manifold vacuum (fuel consuming) and compression braking. A detonation engine removes the needs for anti-detonation additives (acting has radiation absorbers) which further improves the cleanness.

Scaling Up

Being a balanced configuration with near zero seal extension engine, nothing foreseeable prevents the scaling up of the Quasiturbine to the 10 megawatts range or more. Stacking several units side by side can be done through ratchet coupled on a common shaft (rotor not in movement while not firing) for efficient power modulation (cylinder deactivation or shut-off attempts the same while still keeping the piston in movement). As most engines, the larger it is, higher is the efficiency and lower is the RPM. Scaling down or miniaturization is also feasible in most modes, down to fuel combustion plasma minimum size limit. Other concepts have foreseeable objectable scale-up limits (The oscillating free-piston concepts are unbalanced and complex to scale-up, while the Holzwarth turbine scale-up problematic is not due to its turbine per se).

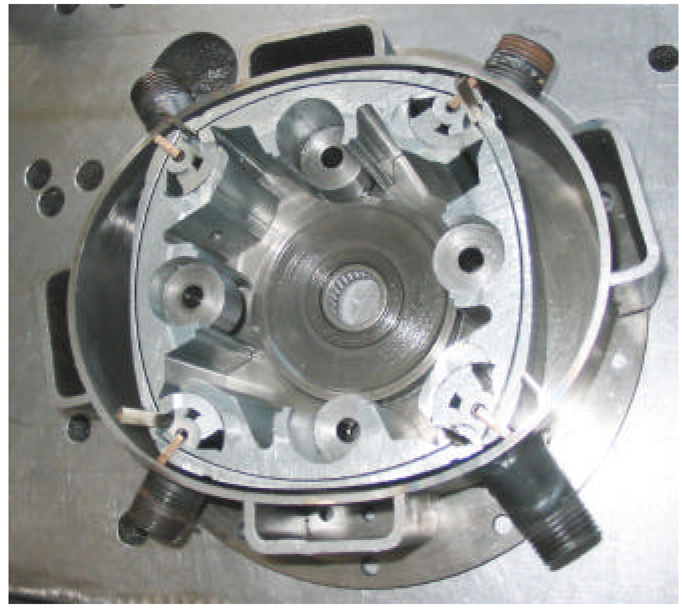

Figure 4. Photo of the interior of a Steam Quasiturbine

Low Cost

Fig. 4 shows the interior of a steam Quasiturbine. Engine manufacturing cost is function of weight, material sophistication, availability, internal stress, robustness, centralized technology and manufacturing complexity. All these factors are favorable to a low cost Quasiturbine. For example, the 4-stroke piston peak torque is 5 times its average value, while the peak torque of the Quasiturbine is within 20% of its average value, which reduces the robustness criteria (and further the weight) and to a major extent, the manufacturing cost. The Quasiturbine has no gear, no valve train and no eccentric crankshaft. All its components benefit from conventional engine developments, which are mainly in the public domain and on-the-shelf technologies. Small steam and pneumatic units can be mass-produced of cheap plastic or cast metal. Its low specific weight and size makes it even more competitive. In modern context, complexity is no longer synonymous with high cost; however, the Quasiturbine simplicity is welcomed today as an argument for local technology spreading, maintenance, training and general reliability. Quasiturbine cost reductions also involve suppressing the need of an expensive gearbox in many applications and removes specialized maintenance and adjustment. But the main economic consideration is the operating cost and particularly the impact of efficiency on fuel savings (which could make the engine cost effectively free over its life time). Of course, there will also be room for expensive advanced high temperature Quasiturbine at material limits, like ceramic or crystalline blades…

TOWARDS DETONATION

Engines generally fail to be « all in one » compact, low weight, low noise, zero vibration, high torque at low RPM, efficient on a wide power range, while having homogeneous clean combustion and being multi fuel capable... With today's Beau de Rochas (Otto) mode piston gas engine, about half the gasoline used in the transportation sector is literally wasted to fight the intake atmospheric vacuum depression [22-23] generated by the carburetor or injector manifold butterfly-valve (the engine-braking effect, which also occurs in the Otto Quasiturbine mode). This is half the pollution of the transportation activities. Detonation is the ultimate combustion mode, even faster and more homogeneous than the thermo-ignition shock wave mode referred to as "knocking". Quasiturbine Model AC unique short and fast linear ramp volume pulse properties allow what is almost impossible with the eccentric crankshaft piston engine.

The supersonic detonation (including volumetric radiative photo-detonation mode) auto-ignites similarly to that of a Diesel, but burns homogeneously, faster and cleaner. Mixture detonation does not present the relatively long ignition delay observed in the non-homogeneous Diesel mode. This mode uses a « detonation chamber » instead of a « combustion chamber ». The detonation Quasiturbine AC (See left of Fig. 1) makes the gas engine as efficient as the diesel engine and the diesel engine as clean (or better) as the gas engine, by conciliating both gas (homogeneous) and diesel (non-homogeneous) engines in one efficient and clean detonation mode, a major efficiency and cleanness objective. Contrary to the Wankel geometric compression ratio limitation and its piston like sinusoidal volume shape, the Quasiturbine Model AC produces volume pulses with a tip shaped as the cursive letter « i », with duration 15 to 30 times shorter than that of a piston and most suitable for detonation mode, because it permits fire self-timing on the rapid compression slope, early mechanical energy conversion and further extends the torque angle on a wider plateau. Detonation permits 2 gains in efficiency: the removal of the butterfly intake vacuum valve (engine compression breaking - which exists at all times within the Otto gas engine); and the increase of the compression ratio (well over the diesel and the knocking level) that increases the engine efficiency at full throttle as well. Because the combustion is homogeneous and occurs in excess of air, it is almost as clean as an external combustion.

Hydrogen is a fuel particularly well suited for the detonation mode. Since detonation engines have very little low-power-efficiency-penalty and require low octane additive-free gasoline or diesel fuel, they suppress the need of hybrid engine concepts, essentially attempting to get similar results by maintaining piston engine at their optimum - near full power - efficiency. At this time, large utility plants convert energy more efficiently than small distributed units and should be favored when possible, but on the long term, the Quasiturbine detonation engine is one of very few means to match the utility efficiency, in a distributed way while being as chemically clean. Only then, distributed electric generation will become reality and because of fuel mobility specific energy and power advantages, efficient internal detonation combustion engines will then have almost no substitute.

POWER MODULATION

Efficient power modulation characteristics are essential to many applications, like land transportation and windmill systems. Conventional hydro- or aero- dynamic turbines lack large range of efficient power modulation capability. Because the Quasiturbine cycle is pressure driven, rather than aero-dynamically driven, it can run at very low RPM as well and has a comparatively flat efficiency characteristic in regard to RPM, load and power. Detonation mode further enhances the efficiency by reducing the low power penalty of the Beau de Rochas (Otto) gas engine and enhances the power modulation by elevating the maximum RPM barrier. Stacking several units side by side is a well-known piston power modulation technique, but it becomes unique with the Quasiturbine because each stage can be ratchet coupled on a common shaft (rotor not in movement while not firing) for efficient power modulation on demand per stage (pistons cannot individually easily be ratchet coupled due to the eccentric crankshaft, but cylinder de-activation or shut-off attempts the same while still keeping the piston in movement).

Windmill Energy Storage is a good example of power modulation application needs and advantages. Because it does not make sense to store an electrical energy which is needed right away, consider a windmill having also on the generator shaft, a reversible Quasiturbine compressor - air motor, which can be made to run freely when power production equals demand. When the windmill power exceeds the electrical demand, the Quasiturbine can run as a variable flow compressor link to multiple storage tanks at different pressures and efficiently store the excess energy production (mechanical pressure amplifiers can be used to optimize air power management). Conversely, when the demand is slightly higher than the production, the air flow can be reversed to assist and supplement the windmill power. If the windmill power goes too low (in a no wind condition), then the windmill can be un-clutched and air-power alone can drive the generator to the actual power demand level and could even be made to provide power in excess of the windmill capability for a short period of time. Such a windmill performance enhancement application system using a modest short term air-energy-storage capability allows some windmill size scale down for specific needs, while improving the available power match with the fluctuating demand.

Apart from the intrinsic power modulation characteristic, since the Quasiturbine has two quasi-independent circuits, either compression load or relaxation power can be modulated by using either one or both circuits simultaneously. Additional modulation could be obtained by using a stack of 2 Quasiturbines of different size on the same shaft (As an example, a QT50 cc with a QT100 cc would offer an incremental torque or power spread over 6 levels: 0 / 50 / 100 / 150 / 200 /250 / 300 cc per quarter of a turn, or from 200 to 1200 cc per shaft revolution - Same size « binary identical Quasiturbines package » would reduce it to 4 levels). Multi chambers engine selection is the most efficient way to modulate power, because it maintains the same pressure drop within the engine, regardless of the power output. Using an efficient power modulated reversible Quasiturbine allows for optimum windmill energy production management and could provide direct economic benefit if the storage system is settled for « peak power sale at premium cost » (even with a reduced efficiency with low intake cut off port closing regime - no similarity with cylinder de-activation).

Figure 5. Photo of a Steam Quasiturbine Model QT5LSC, having 600 cc per chamber, and expanding 4.8 liters per revolution. The rotor diameter is 21 cm (11 inches), by 11 cm (4 inches) thickness. Idle with only 1/15 of a bar (1 psi).

With the Brayton thermal cycle, the compressor flow volume is less than the expanded power flow volume, which generally calls for a small compressor and a large hot power unit. However, the Quasiturbine Brayton cycle can work with only one « binary identical Quasiturbine package » [26] by using one of the quasi-independent circuits as a compressor and the other 2 or 3 circuits as the expander for the output. This provides for a flow modulation of 1 unit of volume in, and 2 or 3 units of volume out. The Quasiturbine compressor circuit (which can be allowed to run faster than the power only Quasiturbine unit) is then almost driven by its parallel output circuit (little power coming from the shaft) and leaves almost all the hot Quasiturbine power output available for the external drive. Using two identical power Quasiturbines instead of one on the same shaft as the compressor would extend the range up to 5 volumes out. The high efficiency of the power Quasiturbine is controlled by the optimum setting of the intake cut-off port closing. This shows how flexible the « efficient engine power modulation characteristic » offered by the Quasiturbine can be.

QUASITURBINE PROTOTYPES

In the mid 1990's, the prototypes QT50 (50 cc per chamber) had been built, both in Model AC (with carriages) and Model SC (without carriage), followed by Model QT75SC. Since 2005, the scale up to Model QT600SC shown in Fig. 5 has been built. Units are currently tested running under pneumatic and steam toward reliability and certification. Combustion version is in advanced development stage as of early 2007 and small detonation prototypes work is currently ongoing. The fact that the Quasiturbine center is empty allows for suppression of shaft alignment, as for example when the Quasiturbine is slidden directly over a generator shaft holding the coupling device.

Since 2005, academic and pre-commercial QT75SC and QT600SC pneumatic and steam prototypes are available for application research and demonstration projects. Most buyers prefer to keep it strategically confidential at this time, but remarkable attention has been given by some universities, including Concordia in Montréal for application evaluations.

QUASITURBINE APPLICATIONS

Hybrid Concepts Alternative

The future of energy strategies involves resources, efficiency, distribution and mobility. Hybrid technologies are viable approaches for the near term because they are the best practical ways to avoid the low-power-efficiency-penalty of nowadays high power vehicle engine, used with only 15% average load factor. But getting extra efficiency this way requires additional power components and energy storage, with associated counter-productive increases in weight, space, maintenance, cost and environmental recycling process. The detonation Quasiturbine with very little low-power-efficiency-penalty is more environment friendly, as it re-

Figure 6. Quasiturbine Air Car [24] first releases in 2005 by APUQ - Association de Promotion des Usages de la Quasiturbine.

quires low octane additive-free gasoline or diesel fuel. It is multi-fuel compatible, including direct hydrogen combustion, and offers a drastic reduction in the overall propulsion system weight, size, maintenance and cost. This would tend to make the hybrid concept much less attractive on the long term.

Because large utility energy station transforms fuel into electricity with a higher efficiency than the small distributed stations or your car engine, there will be a period during which hybrids, fuel cells (also thermal machines), batteries and electricity from the grid (electric power train will still be suitable with onboard efficient generator) will tend to substitute the simple internal combustion Otto engines. However, as more efficient and detonation engines come on the market, small engines will become as efficient and clean as large utility stations. Then, these kinds of substitution will have no reason.

A vehicle wheel rotates on the highway in the range of 800 to 1200 RPM, a perfect regime for direct Quasiturbine drive. In addition, steam or compressed air car as shown in Fig. 6 is also a possible hybrid way or an alternative to it. The Quasiturbine induces a true vehicular design and engineering paradigm shifts and may provide impetus to eventually retire the piston engine from some applications.

The Return of Steam Engine

Conventional positive displacement steam engines are expensive, cumbersome and have poor power to weight ratio. Solar, geothermal, biomass, cogeneration and heat recovery are natural applications for the Quasiturbine steam engine due to its simplicity, low price and low maintenance cost. While high pressure steam can be very dangerous, pressure less than 60 psi (often saturated steam) is generally much less regulated and most suitable still for the Quasiturbines. Flashing water (steam keep in liquid state in the supply line to ensure maximum heat transfer) into a hot Quasiturbine is also a very safe technique removing the need of a boiler.

Engine Exhaust Heat Recovery

As an engine exhaust heat is being transformed into useful mechanical energy on the same engine shaft or otherwise, the fuel consumption of that engine can be reduced while maintaining the same overall power level, but at a higher efficiency. Quasiturbine Stirling [21] and Quasiturbine Brayton [25-26] thermal cycles offer enhanced possibility for efficient moderate temperature heat conversion into mechanical energy. A 30 % engine heat recovery efficiency (not easy to achieve, but feasible [26]) would out-perform most hybrid concepts. A simple way is to heat a steam Quasiturbine engine block by placing it in or around the exhaust pipe (corrosive condensation will not affect the inside) and flashing hot pressurized water steam (steam kept in liquid state in the supply line to ensure maximum heat transfer) directly into the chambers. This way, the Quasiturbine acts simultaneously as the boiler and the expander all in one and suppresses the danger associated with steam reservoir. The Quasiturbine offers a unique flow and power modulation by alternate use of one or both of its double internal quasi-independent circuits, which allows power modulation of the Quasiturbine Ranking and Brayton cycles and also other important thermal cycles (See POWER MODULATION section). This technique could also apply to geothermal, solar and co-generation heat recovery.

Pipeline Pressure Energy Recovery

Conventional fossil energies are great, the renewable energies are better, but why not some free energies? The pressure energy of gas pipeline is considerable and it is not harvested in pressure reduction stations; this is a precious mechanical energy that Quasiturbines can recover without any gas combustion and pollution. While natural gas pipeline national distribution is done at up to 100 bars (1500 psi), final customers use the gas at less than 1 bar. The Quasiturbine is most suitable for gas pipeline pressure energy recovery at pressure reduction stations [27], where it can regulate the gas flow. This is an important source of free mechanical and electrical energy, both at the utility and consumer locations. This solution is available in the heart of cities and industrial parks and is even better than renewable (as no gas is combusted, economic is similar to a fossil fuel electric generation station where the fuel cost is set to zero. It is free energy until the utilities start to charge for it and make an extra income). Pipeline pressure potential reaches hundreds of MW in many industrialized countries, which corresponds to hundreds of large modern windmills. Efficient engine power modulation is key to this application. Hydrogen storage tank high pressure energy could be recovered in a similar way.

Refrigeration Regulator and Pump

Replacing the pin-hole expansion valve by a Quasiturbine rotary expansion valve allows recovering of pressure energy in refrigeration systems, enhancing its efficiency by removing gas kinetic energy otherwise dissipated in heat and reducing the amount of cold produced [28]. As an example, the QT600SC expands 2,4 cubic meters per minute at intake at 500 RPM, for up to 12 kW of output shaft power under 60 psi differential; this removes 300 joules of heat per liter (or 300 watts out of a 1 liter/sec flow) at intake (60 psi). The exhaust gas cooling efficiency is consequently enhanced compared to the use of a simple valve or pin-hole, even if the Quasiturbine expander shaft output power is simply dissipated and lost. However, this shaft power can be re-used, possibly to recompress part of the gas, for a double efficiency gain. Furthermore, using the Quasiturbine in turbo-pump mode allows to use the recovered energy to compress back some of the expanded gas. This application can be extended to heat pump and air conditioning systems, removing the mechanical pressure energy which destroys the cooling efficiency, while offering some compression capability. A double win situation.

Distributed Energy Generation

Because the Quasiturbine does not require the pressure energy to be converted into the intermediary form of kinetic energy, it has the ability to digest saturated steam without much erosion. Steam Quasiturbine is suitable for several megawatts units steam station and in particular for medium and low temperature grade steam like in co-generation heat recovery, geothermal or nuclear plants. It does idle with a pressure differential of only a fraction of a bar (few psi) making it suitable for less dangerous and regulated private steam system, including direct flash steam within the heated Quasiturbine engine body. Internal combustion Quasiturbine can also be used for electricity generation in remote areas and for advanced combined heat system [10].

Compressed Air Energy Storage and Recovery

See POWER MODULATION section for detail and windmill application.

Other Applications

Quasiturbine is suitable for general engine substitution with advantage in size and weight reduction and particularly for low noise and vibration sensitive applications like electrical generation in RV and pleasure boats or in urban area. It is most appropriate in applications nearby users, like in zero vibration hand tools, chainsaws, go-karts, busses and where efficiency is critical. Fuel cell generates a lot of heat and could eventually be well coupled with Brayton [25-26] or Stirling [21] Quasiturbine for thermal energy recovery. Reduced engine drag section and low weight and vibration makes it most practical for airplanes, while large units can be most promising in boats and locomotives [28]. The Quasiturbines are highly suitable as air compressor and water pump, hydraulic pump and motor, turbo-pump…

CONCLUSION

The Quasiturbine (or Kyotoengine) turbo-machine is a pressure driven, continuous torque and symmetrically deformable spinning wheel. It is a new engine alternative with some characteristics simultaneously common to the turbine, Wankel and piston, offering top efficiency power modulation capability, which makes it most suitable for land transportation and windmill systems. The Quasiturbine goes along the best modern engine development strategy, which is to get as many ignitions possible per minute, with a mechanical device rotating as slowly as possible. For the same shaft RPM as a piston 4-stroke engine, the Quasiturbine strokes are twice as fast and 8 times more frequent, for an impressive torque and power gain. By opposition to several new engine designs, the Quasiturbine is not a piston equivalent engine and notwithstanding its multi-mode (including steam and air motor) and multi-fuel capability, the foremost important characteristic is the fact that it does support detonation (HCCI [22]), where piston engine has not succeeded over the last decades. The detonation auto-ignites similarly to what happens in Diesel, but burns homogeneously, faster and cleaner.

The future of energy strategies involves resources, efficiency, distribution and mobility. As more efficient and detonation capable engines get on the market, small engines will become as efficient and as clean as large utility stations. Only then the distributed power generation will become reality and because of fuel mobility, specific energy and power advantages, efficient internal combustion engines like the Quasiturbine will then have almost no substitute. Considering fossil fuel depletion, is this technology coming too late? If the availability of fossil fuel becomes rationed, everyone will like to use the precious liquid left in the most efficient and clean engine possible. This is why it is important to develop better engines today regardless of the depletion of the fossil fuel, to attenuate the effect of the inevitable transition to synthetic replacement fuel, including hydrogen. The closer we will get to the end of the fossil era, the more highly efficient engines will be necessary and appreciated. The Quasiturbine is one more tool to tackle the energy and environment concerns.

Nevertheless, the resources availability will have to be addressed; but the most likely efficient solution will be toward synthetic fuel (from bio-solar ... or nuclear) similar to conventional fuels, because the best and most convenient way to store hydrogen today is to bond it with carbon atoms and make hydrocarbon (will we then enter a carbon depletion era?). For these reasons, no foreseen technology is on the long term going to substitute efficient combustion engines, toward which research and development must continue.

REFERENCES

1. Quasiturbine AC (With carriages), December 1996, USA Patent USA 6,164,263.
2. Quasiturbine SC (Without carriage), February 2003, USA Patent USA 6,899,075.
3. Quasiturbine SC (Without carriage), February 2003, PCT World Patent WO2004070169.
4. Quasiturbine SC (Without carriage), February 2003, European Patent Office no. 03815671.7.
5. Saint-Hilaire, R., et al., 2003, "La Quasiturbine Écologique, le meilleur du Piston et de la Turbine", Book in French, 292 pages, ISBN 2-922888-00-2, Promci Éditions, Montréal Québec.
6. Official "Quasiturbine - Kyotoengine website", www.quasiturbine.com or www.kyotoengine.com , Technical papers at www.quasiturbine.com/ETechnicalQTPapers.htm .
7. Fletcher, M., 1999, "Quasiturbine Rotary turbine torques of more power", European Automotive Design, **3**[6], cover and pp. 72-73.
8. Fletcher, M., 1999, "Quasiturbine Rotary turbine torques up the power factor", Eureka Innovative Engineering Design, **19**[9], pp 29-30.
9. Saint-Hilaire, G., et al., 1999, "Quasiturbine Presentation", SAE Small Engine Technology Conference, Wisconsin USA.
10. Marchetti, G., and Saint-Hilaire, G., 2002, "Ultra-low Emissions and High Engine Efficiency Fuel Interest In the Combined Cycle Quasiturbine", Alberta GHG News Solutions www.quasiturbine.com/GHGAlberta0205.html .
11. Bode, D., 2000, "Quasiturbine: An Engine for the New Millennium", Diesel Progress North American Edition, 65th Anniversary Edition, pp 84-86.
12. Crom, C., 2005, "Technical Discussion Comparing the Quasiturbine with Other Common Engines", White Paper published in Energy Central, www.quasiturbine.com/QTCromWP0510.doc .
13. Stokes, M. D., 2004, "Quantum Parallel: The Saint-Hilaire "Quasiturbine" As The Basis For A Simultaneous Paradigm Shift in Vehicle Propulsion Systems", White Paper published in www.eMOTIONREPORTS.com and presented at the 2004 Global Powertrain Conference (GPC) Advanced Powerplants & Vehicles Session, Dearborn, Michigan, USA.
14. How Stuff Works, 2005, "Quasiturbine on the Web Encyclopedia", www.howstuffworks.com/quasiturbine.htm .
15. Cowan, B., 2006, "Quasiturbine: Unusual Engines - Turbine Tale", Engine Technology International Magazine, September 2006, pp 58-62, www.quasiturbine.com/Presse/EngineTechIntl0609.htm, and host of the Annual International Engine of the Year Awards www.ukintpress.com/engineoftheyear .
16. CBC, 2000, "Découverte TV Science Program", SRC French Canadian Broadcasting Corporation www.quasiturbine.com/ERelationVideoDecou0004.htm.
17. Discover Magazine Awards, 2000 "Semi-finalist", www.discover.com/issues/jul-01/features/01awards .
18. AQME, 2002, "Quasiturbine Winner of the Énergia R&D Awards", La Maîtrise de l'Énergie, **17**[2], Cover and pp 13-18.
19. Citizen groups "Promoting the Quasiturbine in several countries" www.quasiturbine.org .
20. Susuki, T., 1997, "The Romance of Engines", Book, 488 pages, SAE Publishing.
21. "Quasiturbine Stirling", www.quasiturbine.com/ETypeStirling.htm.
22. Steven, A., 2001, "A Low-Pollution Engine Solution - New sparkless-ignition automotive engines gear up to meet the challenge of cleaner combustion - HCCI", Scientific American, June 2001.
23. Westbrook, C. K., 2000, "Innovative engine concept known as Homogeneous Charge Compression Ignition - HCCI", Lawrence Livermore National Laboratory, www.llnl.gov/str/Westbrook.html .
24. "APUQ Air Car", 2005, www.pureinvention.com/apuq .
25. Ruiz, J. R., 2005, "Waste Heat Recovery in Automobile Engine Potential Solutions and Benefits", Master degree thesis, Massachusetts Institute of Technology, https://dspace.mit.edu/handle/1721.1/32832 .
26. Crom, C., 2006, "Engine Exhaust Heat Recovery with Quasiturbines", Published in Energy Central www.quasiturbine.com/QTPapiers/QTCromExhaustWP0612.doc .
27. Valentine, H., 2005, "Using the Quasiturbine to Regulate Natural Gas Pipeline Pressure and Flow-rate", Published in Energy Pulse, www.energypulse.net/centers/article/article_display.cfm?a_id=1105 .
28. "Quasiturbine Refrigeration Rotary Expander", www.quasiturbine.com/ETypeExpander.htm.
29. Valentine, H., 2002, "The Steam-Powered Quasiturbine in Direct-Drive Railway Locomotive Propulsion", www.quasiturbine.com/QTLocoVapeurValentineH.htm.

(*) The paper presentation includes a demonstration of an air-flow running Quasiturbine.