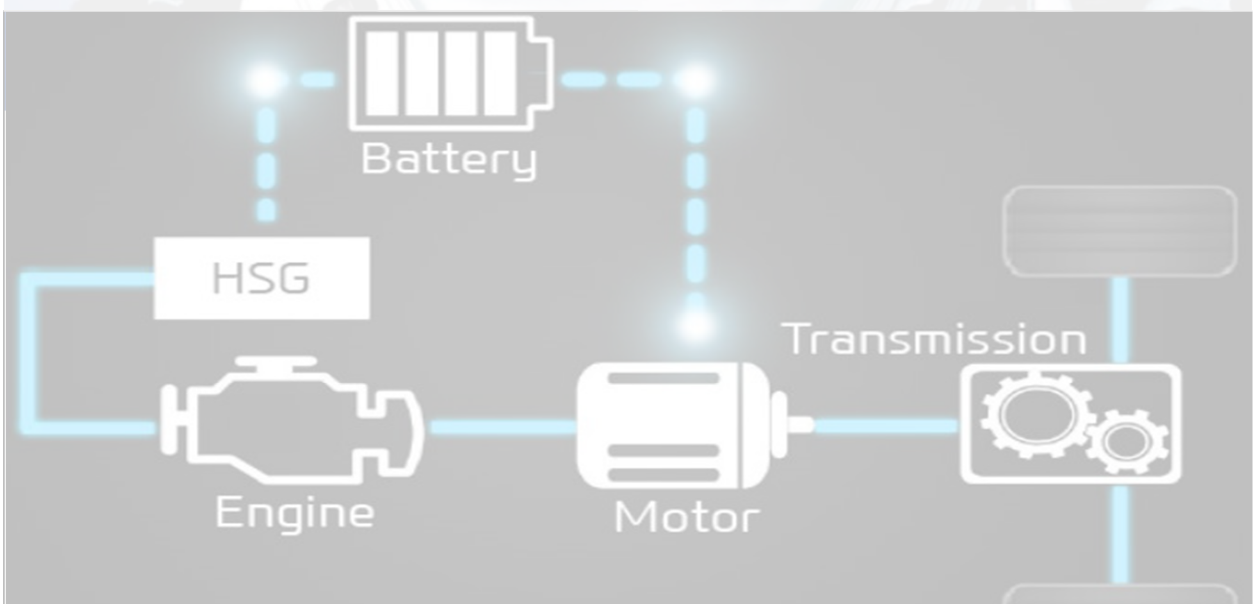
A REVOLUTIONARY HOMOGENEOUS CHARGE COMPRESSION IGNITION ROTARY ENGINE WITH VARIABLE COMPRESSION RATIO CONTROL



Foreword

Since 1875 when Siegfried Liepmann Marcus a German Jew invented the internal combustion engine, and the first practical automobile in Vienna. Marcus was born on September 18, 1831 in Malchin, Germany and was in the driver's seat when the World's first practical motorcar made debut in 1875 on the streets of Vienna, Austria.

Since then, we have been looking for the "Holy Grail" in an internal combustion engine. Why is POWER DENSITY the Holy Grail? Clean, Efficient and Lightweight Propulsion System for a Better World.

Today we have many inventors searching for this "Holy Grail". TwinSpin has looked at various designs. However, US Patent Number 9,435,257 integrates HCCI and VCR solutions in a compact, simpler and less expensive engine architecture.

Roberto Fanara, inventor at Customachinery will test and develop this unique engine design at Queen's University. However, TwinSpin has done a Simulation Performance Behavior showing also specific fuel consumption as presented in the graphs herein.

Benjamin A.S. Shannon
President/CEO TwinSpin Engine Consultants, USA

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Preface

This technical paper analyses two key features of an innovative internal combustion engine design (US Pat No 9,435,257): its unique combustion chamber and a novel roller seal system.

Customachinery's proprietary technology allows a real-time adjustment of the engine compression ratio and of the amount of trapped residuals. These are two key parameters to control Homogeneous Charge Compression Ignition, a scientifically proven low temperature combustion able to deliver higher efficiencies and lower emissions.

Homogeneous Charge Compression Ignition (HCCI) and *Variable Compression Ratio* (VCR) are regarded among the most promising solutions to meet the US 2025 CAFE standards and future European vehicles CO_2 emission limits. Indeed, both these technologies have been recently commercialized by Mazda and Nissan, respectively.

Customachinery's HCCI-VCR rotary engine overcomes the drawbacks of the notorious Wankel engine and promises a substantial increase in efficiency while reducing greenhouse gases emissions and harmful tailpipe pollutants (PM and NOx).

Nevertheless, given its simpler and more compact architecture, it features higher power density and lower manufacturing costs compared to current turbocharged reciprocating engine technologies.

Introduction

As of today, an extensive knowledge has been acquired relatively to reciprocating engines, either four or two-strokes, gasoline or diesel. Notably, only one rotary engine has ever been mass produced: the Wankel. It never gained the same public acceptance as its reciprocating counterpart, partly due to the sealing problems plaguing the first designs and partly to the very poor thermal efficiencies resulting from its oblong combustion chamber (Figure 1). The Mazda RX-8, the last mass-produced car powered by a Wankel engine, was finally discontinued in 2012 due to the tightening emissions regulations.

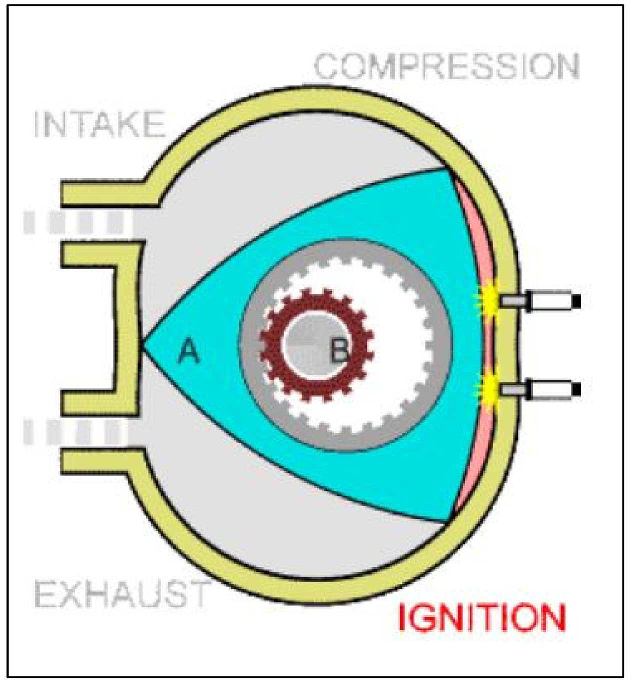


Figure 1 – Wankel engine

Customachinery has developed an innovative engine design able to substantially improve the current state of the art in terms of efficiency, performances and emissions. Its patented gates system creates a unique combustion chamber (Figure 2) having very low surface to volume ratios. Furthermore, the ability to adjust its volume and to retain variable amounts of trapped residuals promises a reliable and effective control of the cleaner HCCI combustion process.

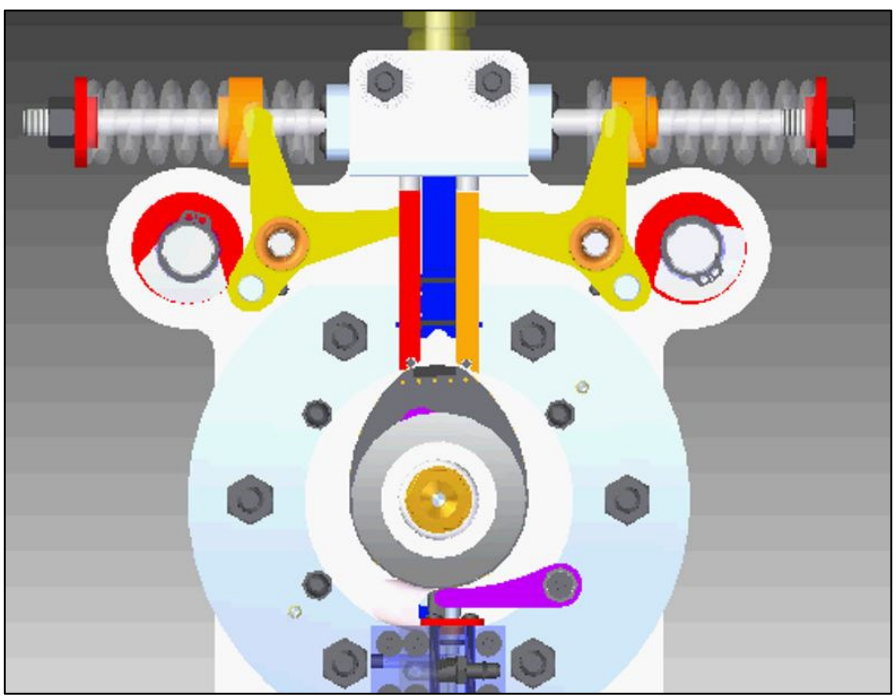


Figure 2 – HCCI-VCR rotary engine CAD model

The schematic on the next page explains the engine working principles and its functionalities.

The single lobe rotor and single combustion chamber arrangement above is conducive to one combustion event for every shaft rotation, similarly to a single cylinder two-stroke reciprocating engine.

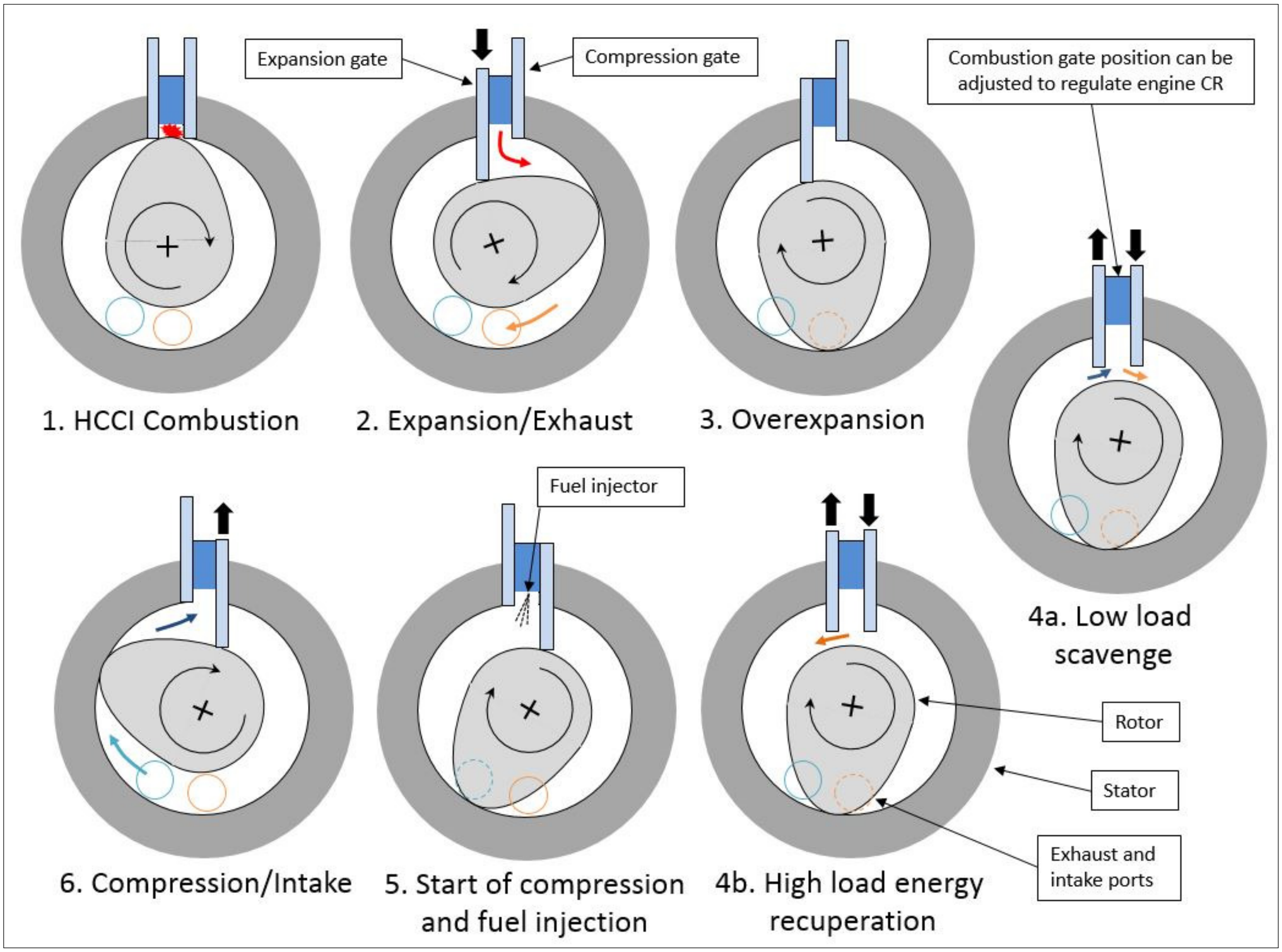


Figure 3 – HCCI-VCR engine schematic and working principles

But quite differently from that one, a HCCI-VCR rotary engine draws the fresh air inside the combustion chamber simultaneously to the compression stroke and expels the exhaust gases simultaneously to the expansion stroke, greatly reducing pumping losses. Furthermore, overexpansion is readily attainable by adequate positioning of the intake and exhaust ports and, at high load operations, it is also possible to recuperate part of the residual energy of the exhaust gases. As first guessed by Dr. Ciccarelli at Queen's University, lifting the expansion gate before the exhaust port is uncovered allows the exhaust gases to pre-compress the fresh air. This, in turn, reduces the work necessary for the subsequent compression phase and increases the rate of trapped residuals, allowing to use lower compression ratios at high load operations.

Better breathing characteristics with reduced pumping losses, overexpansion capabilities, possibility to recuperate exhaust gases' residual energy without the need of an external turbocharger, are all key features of this unique engine design.

The innovative high-turbulence combustion chamber

Any new engine technology needs to be validated, making sure it is conducive to an efficient combustion. In this regard, any novel design unable to adequately prepare the combustible charge is doomed. More in particular, the "art of charge preparation" can be further decomposed in its two main components: liquid fuel evaporation and subsequent mixing with air (only the second aspect is of course relevant for gaseous fuels).

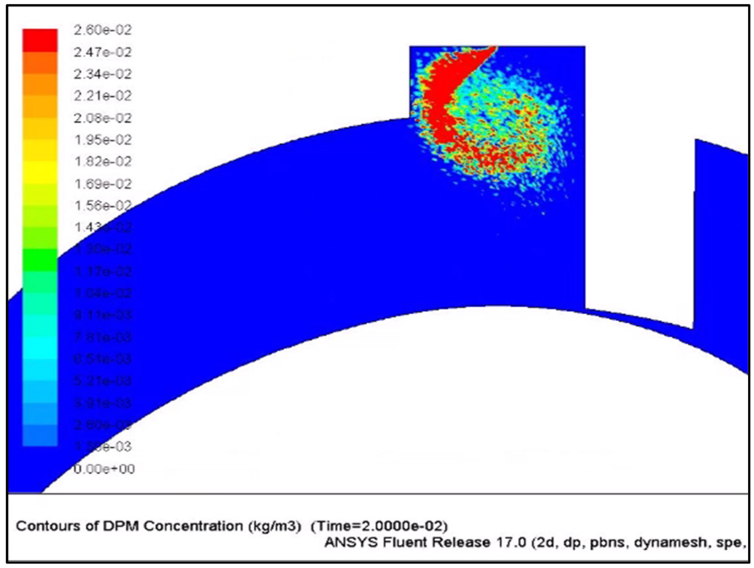


Figure 4 – Direct fuel injection strategy

Customachinery's unique design has undergone a systematic validation via Computational Fluid Dynamic (CFD) analysis. The methodic approach allowed to identify the ideal fuel injector location and the optimum spray angle, improving evaporation and minimizing wall wetting (Figure 4). The results of the analysis show a very high turbulence generated by the synergic interaction of the fuel injection coupled to the "plowing" motion of the rotor lobe (Figure 5). This, in turn, produces an excellent fuel/air mixing. Simulations based on two-dimensional meshing clearly show the two main mixing mechanisms: a tumble, followed by a final squish at the time of combustion (Figure 6).

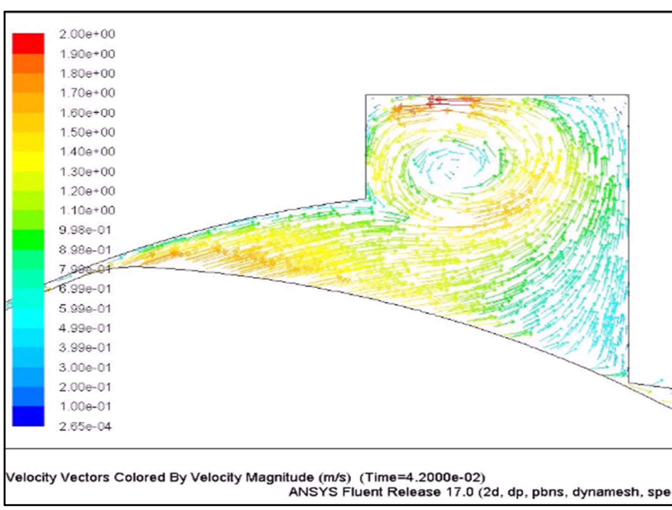


Figure 5 – Internal turbulence: tumble

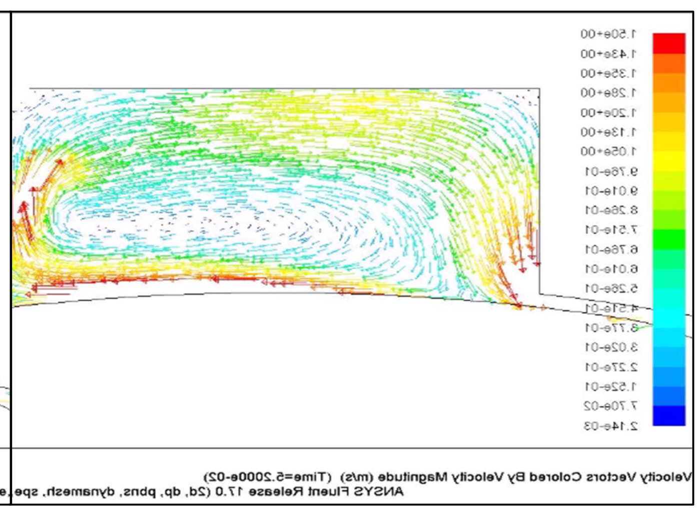


Figure 6 – Internal turbulence: squish

Noteworthy, the injection strategy and the turbulent mixing also produce a highly desirable temperature stratification in the combustion chamber (Figures 8 and 9). This, in turn, is fundamental to achieve a more gradual combustion process avoiding the typical "knock" issues plaguing HCCI at high load operations.

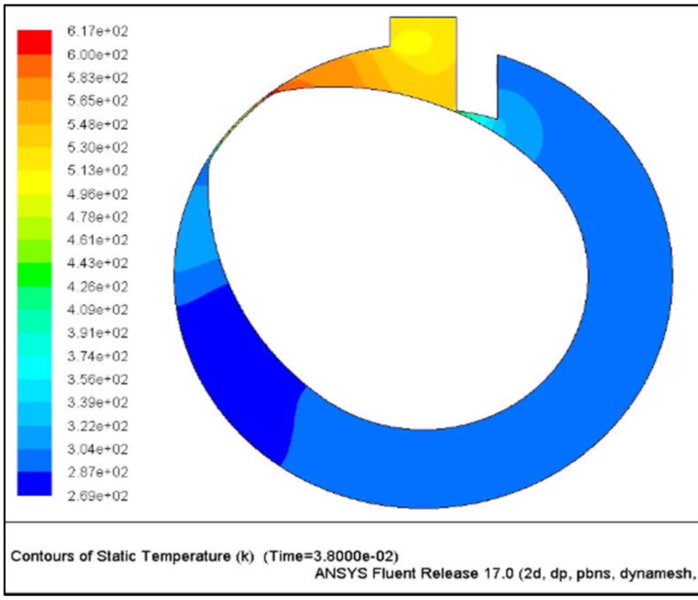


Figure 7 – Early compression temperature field

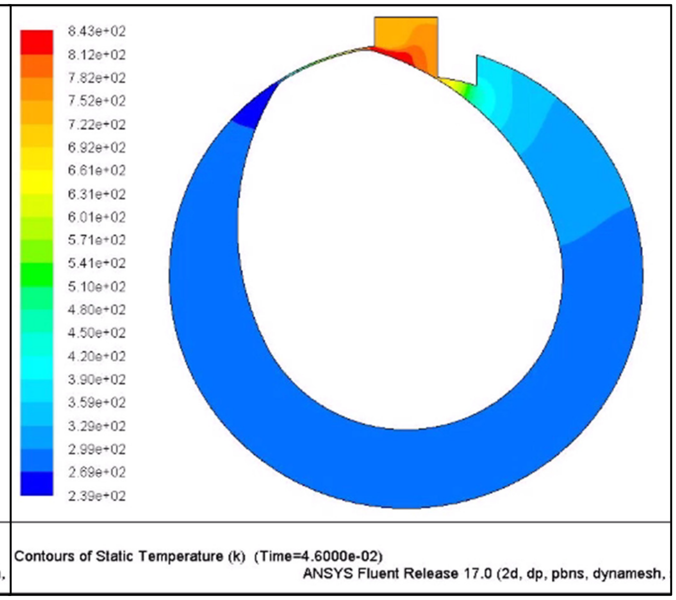


Figure 8 – Late compression temperature field

Detailed chemistry CFD analysis prove the capability of this engine design to effectively control a stoichiometric combustion of heptane fuel. Indeed, the adjustment of the compression ratio (CR) optimizes the start of combustion timing, maximizing efficiency while maintaining the rate of pressure rise, responsible for engine "knock", within acceptable limits (Figures 10, 11, and 12).

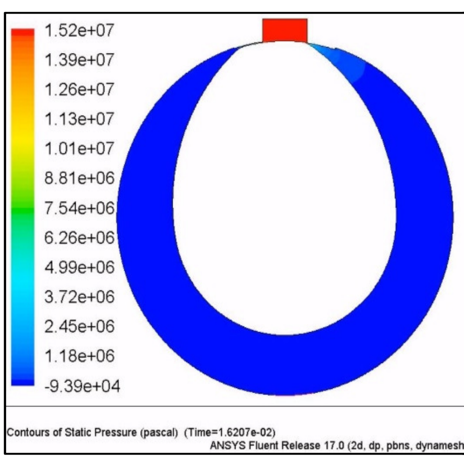


Figure 9 – Engine "knock"

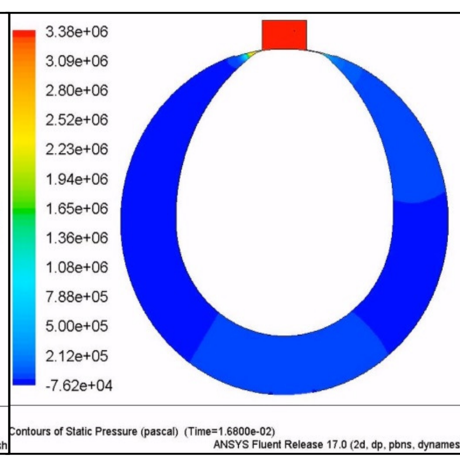


Figure 10 – Misfire

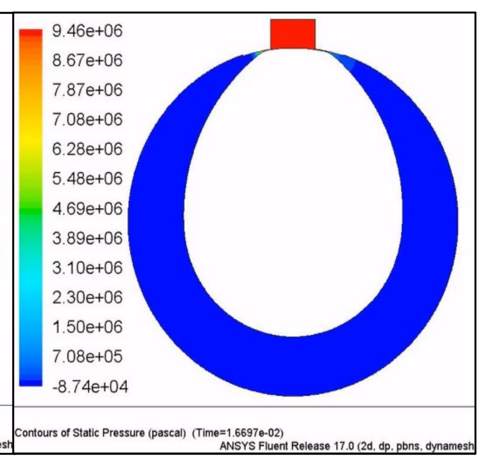


Figure 11 – Optimum CR

The novel low-friction roller seal system

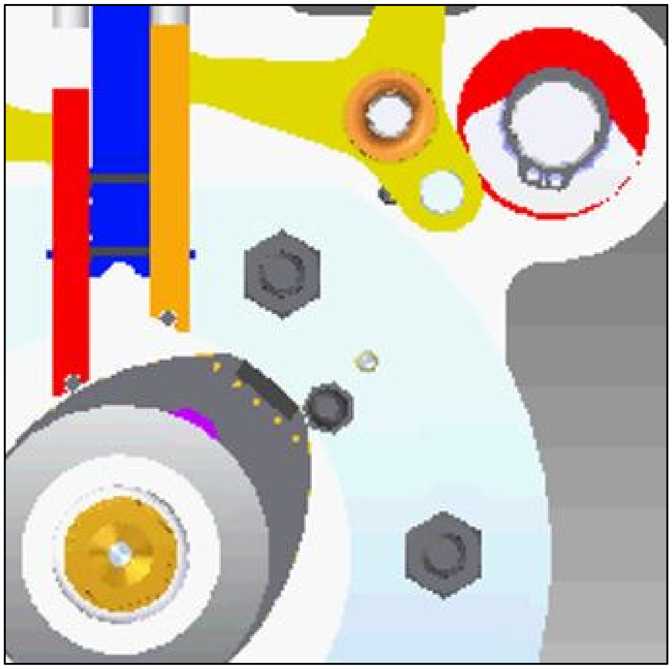


Figure 12 – Apex and roller seals

Differently than a Wankel, a HCCI-VCR rotary engine has a fixed angle of contact between the apex seal and the stator. This, in turn, allows to have a sliding surface instead of a line of contact, and it also drastically reduces the apex seal movements/vibrations, a prominent factor causing the premature seal failures for which the Wankel engines have been sadly renowned.

Another notable difference is the presence of roller seals between the newly design gates and the lobed rotor. Their main purpose is to reduce internal frictions, therefore increasing mechanical efficiency. Regarding their lubrication, three non-mutually exclusive solutions are possible:

1. addition of small amounts of oil (~1% by volume) to a gasoline fuel or use of fuels that presents inherent lubricating properties such as diesel, bio-diesel, or a blend of them;
2. specialty tribological coatings of the roller groove surface; more in particular, DLC coatings exhibit excellent low friction and wear resistance capabilities even under lack of lubrication;
3. catalytic decomposition of gaseous hydrocarbons to create a graphitic tribo-layer on the roller wear surfaces; several references from the literature show this is possible under high temperature and pressure conditions in the presence of metal catalysts (i.e. nickel and copper) or over the surfaces of materials such as silicon carbide (SiC) and silicon nitride (Si_3N_4).

Given the significant presence of hydrocarbon species inside an internal combustion engine, it is not unreasonable to imagine Si_3N_4 rollers with a self-replenishing graphitic lubricant tribo-layer. This, in turn, would greatly reduce internal frictions and seals' wear. Moreover, a DLC coating applied onto the roller groove surface would add an additional protection to counteract occasional lack of lubrication.

The above concepts are in line with a recent discovery by Argonne National Laboratory: "Carbon-based tribofilms from lubricating oils", Ali Erdemir, 2016 Macmillan Publishers Limited.

Notable differences compared to other engine designs

Several differences compared to the notorious Wankel engine have already been reported in the previous pages. There are additional differences compared to other designs as well. The following list is a compendium of the benefits and strengths of Customachinery's novel engine technology:

- gates defining a unique combustion chamber which features
    - extremely low surface to volume ratios, therefore reducing heat dissipation
    - variable volume, hence offering variable compression ratios capabilities
    - ability to trap variable amounts of residuals to optimize combustion
- possibility of adjust gate timing/phasing to realize overexpansion and to recuperate exhaust gases' residual energy without the need of an external turbocharger
- roller seals between the newly design gates and the lobed rotor to reduce internal frictions
- possibility to regulate the pressure between said gates and the rotor lobe, which is fundamental to establish a self replenishing graphitic tribolayer onto the ceramic roller seals
- fixed angle of contact between the apex seal and the stator, which allows to have a sliding surface instead of a line of contact as for the Wankel
- sealing perimeter that reduces as the rotor lobe approaches the combustion chamber and reaches its minimum when it aligns with said chamber, during the combustion event
- rotor tip constantly spinning at max speed, therefore minimizing blow-by compared to a piston engine that reaches a standstill position at TDC while the combustion is occurring
- eventual blow-by mixes back with the fresh charge that will combust in the subsequent cycle
- possibility to cool the reciprocating gates similarly to sodium filled exhaust valves of a piston engine

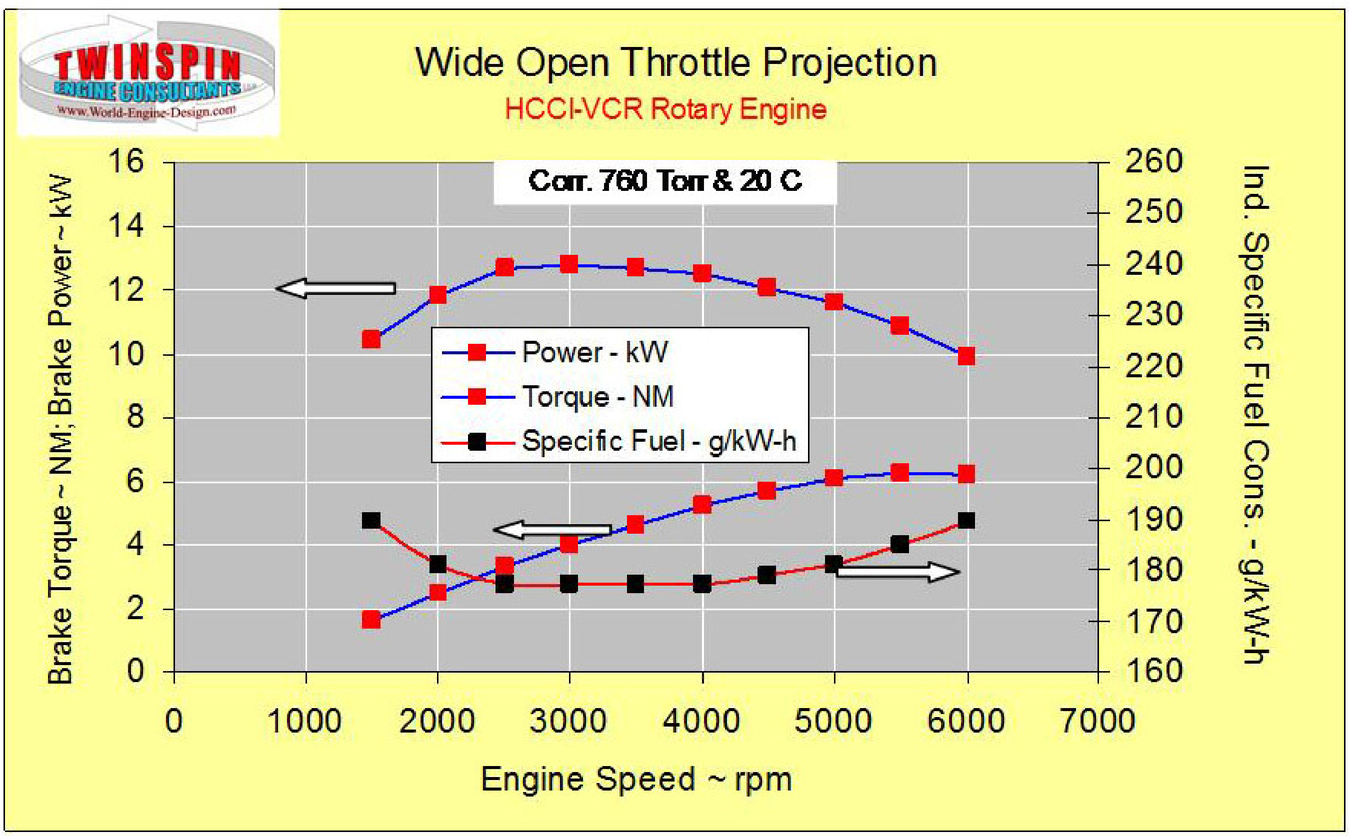
First performance projections

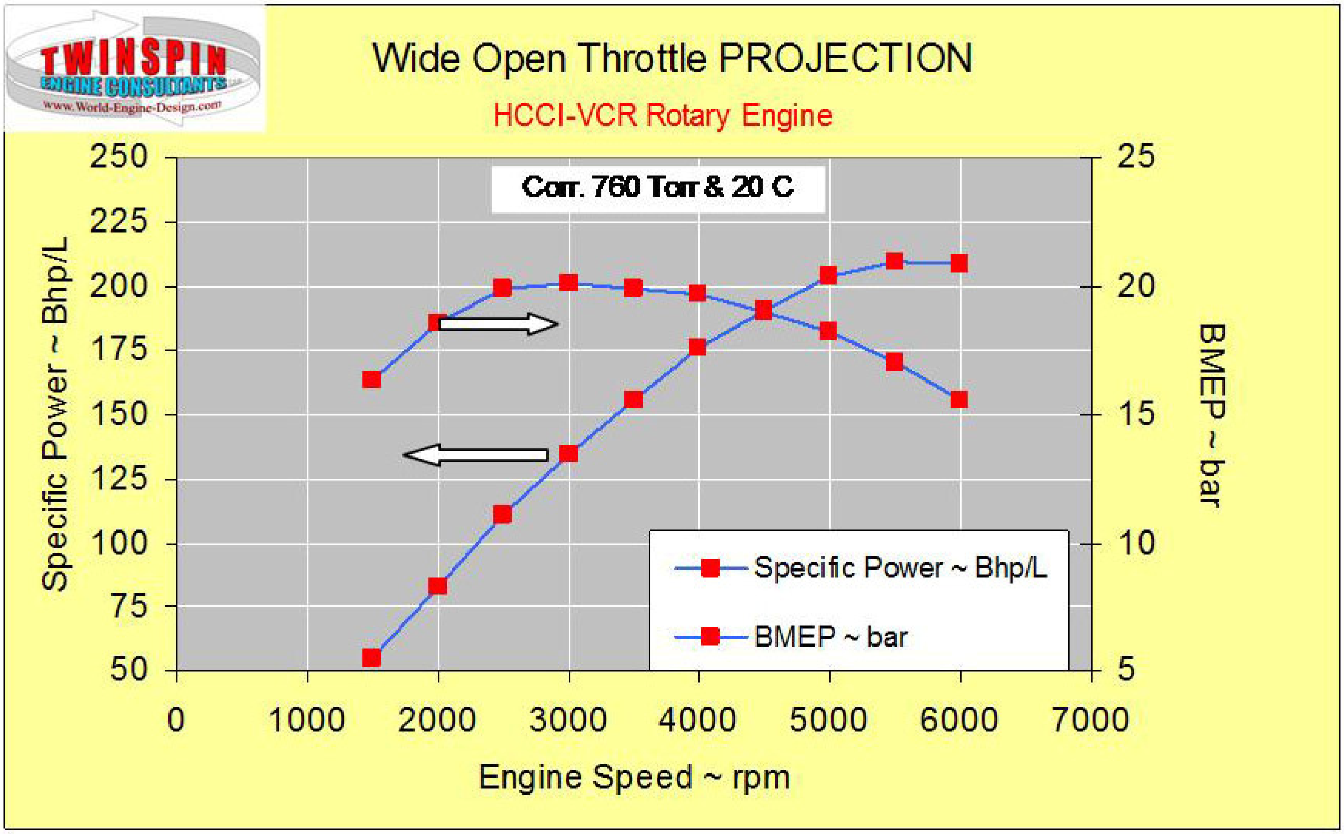
Two graphs reporting the first performance projections are shown in the next page. The work has been carried by Ben Shannon, President of TwinSpin Engine Consultants.

The results are quite exceptional and confirm that this innovative technology is certainly worthy of investments focused to the production of a first working prototype.

Indeed, a considerable amount of work is still required to validate the novel engine in a simulated environment and also to demonstrate it in a relevant application.

Capacity	40	[cm^3]
Compression Ratio	20:1	[-]
Weight	? Kg	Cast iron
Max. Torque	12.8 Nm	@ 3000 rpm
Max. BMEP	20.1 bar	@ 3000 rpm
Specific Power	209.4 Bhp/L	@ 5500 rpm
Specific Fuel Cons.	177.12 g/kW-h	@ 3000 rpm
Humidity 68%	Air Temperature 40.6°C	Air Pressure 745 mm
Max. Horsepower	8.4 Bhp	@ 5500 rpm
Humidity 68 %	Air Temperature 42.7°C	Air Pressure 745 mm
Corrected to: 760 Torr & 20 deg. C		





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- Ben Shannon, President of TwinSpin Engine Consultants (USA) and engine design expert.