

# Ultra high Efficiency Hydrogen fuelled Combustion engine with water injection

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**ABSTRACT :** Aumet Oy (Reference 1) has developed a new type of 2-4 stroke fully valve controlled hydrogen fuelled combustion engine with water injection, called Z-engine, working with Z-engine-Rankine combine process. Z-engine produces work at every crankshaft rotation, Figures 1a, 1b. It has a very rapid high -pressure gas exchange (tested with a test engine) at 120-130 deg. ABDC, after the exhaust period between 30 deg. BBDC – 120 deg. ABDC has occurred. The adjustable throttle valve in the turbo bypass duct adjust the amount of EGR remaining in the work cylinder after exhaust period Figure 2b. The intake air is compressed with turbocharger to 2.5 bar. at full load, then inter cooled, then compressed to 10bar. with a water-cooled piston compressor, then inter cooled and led to the working cylinder with a rapid valve system. After the gas exchange the air pressure in the work cylinder is 10.3 bar and the temperature 378K. After this the gas exchange about 35% water of the gas mass of the work cylinders gas is injected into the work cylinder between 165 – 195 deg. ABDC.to cool the gas in the cylinder and to prevent too early ignition of the at 122 – 190 deg. ABDC injected hydrogen. The injected water lowers the compression work in the cylinder. As the temperature in in cylinder is quite low at this point and the pressure is quite high, the injected water droplets don't evaporate during the end compression to TDC Figure 5. Evaporation occurs first after TDC. when spark ignition at full load occurs at 8 deg. ATDC, Figure 3 The evaporated water increases the volume of working gases at about 30% thus increasing the efficiency of the engine to 50% at full load. Modern simulation tools were used in this project.

**KEY WORDS:** combustion engine, hydrogen, water injection, efficiency, 4-2 stroke, turbulence.

## 1. INTRODUCTION

The need to reduce CO<sub>2</sub>emissions has forced car industry to search for new fuels, bio methanol and hydrogen to lower CO<sub>2</sub> emissions. Production of hydrogen has increased in the last years because of the lowering prices of electricity, produced by solar cells and wind turbines. The lowering price of carbon fibre tanks, in near future 5-7 Euro pro kWh /700 bar. tank makes hydrogen fuelled cars more compatible. Hydrogen fuelled combustion engine has at least the same efficiency as hydrogen fuel cells, but is much cheaper to produce (Reference 2) and the hydrogen must not to be so high purity class as in fuel cells. In the last years some universities have made research from water injection of different temperatures in combustion engines (Reference 4) and from hydrogen fuelled combustion engines with water injection (Reference 3). The injected water lowers the temperature in compression and combustion and protect the engines from too early ignition and too high pressures and too high Nox. It also lowers in some cases the fuel consumption even 15% (Reference 5).

## 2. THE WORKING PRINCIPLE OF Z-ENGINE

The working principle of Z-engine is presented in Figures 1-6. Figures 1a, 1b presents the gas exchange of Z-engine. The very rapid intake gas exchange mechanism, Figure 6, is more detailed presented in Reference 1. In order to keep the intake valve

control systems contact pressure low enough between the silicon nitride cam follower roll and the special steel Cronidur 30 cam, the cam diameter is chosen to be 120 mm. and its broadness is 10 mm. At max. rotation speed = 2650 rpm. the max. contact pressure is about 2GPa when max. allowable value is 2.8GPa. (FAG).

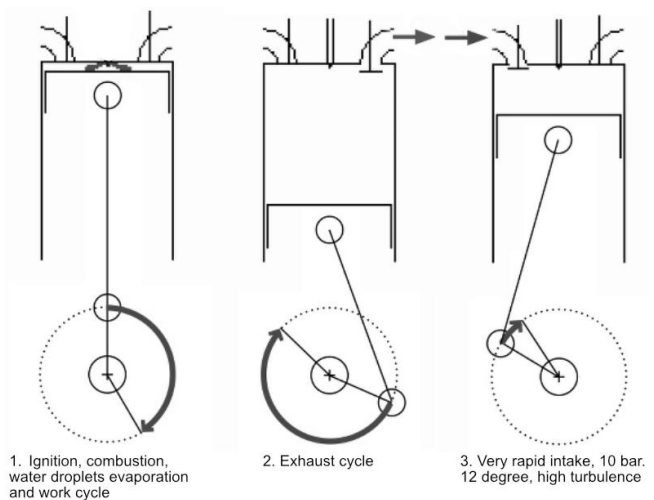
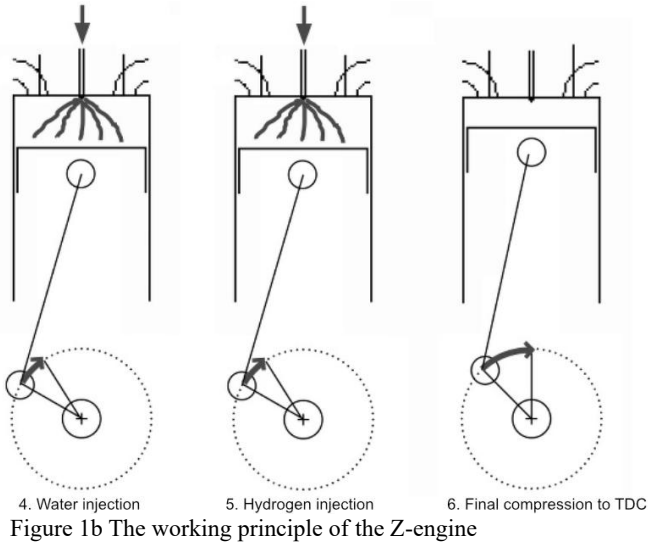


Figure 1a The working principle of the Z-engine

The injected water has temperature of 645K, about the critical temperature water, so its evaporation heat is about zero. The injection pressure of the water is 350 bar.

The combustion duration at full load is 15 deg., max. pressure is 240 bar. max. temperature is 1800K, BTE 50%,  $C_r=27:1$ ,  $\lambda=1.0$ , BMEP = 36bar., 2cyl.:80\*80 mm., 2650 rpm, about 129KW., expansion ratio at full load 13:1 (late ignition), at part load 27:1. At high loads the downwards rapid moving piston limit max. pressure- and temperature when late ignition.



The exhaust gases are pushed out from the cylinder with piston. The intake gas and exhaust gas cant mix with each other because of the fully valve controlled gas exchange, like in 4-stroke engines. Because of the high inter cooling rate (2 inter coolers), the average temperature level is lower than in normal combustion engines. This lowers the heat losses as well as the water injection. The high turbulence after the gas exchange, Figure 4, mixes the gases well in the work cylinder and also increases the heat transfer to the water droplets during compression to TDC.

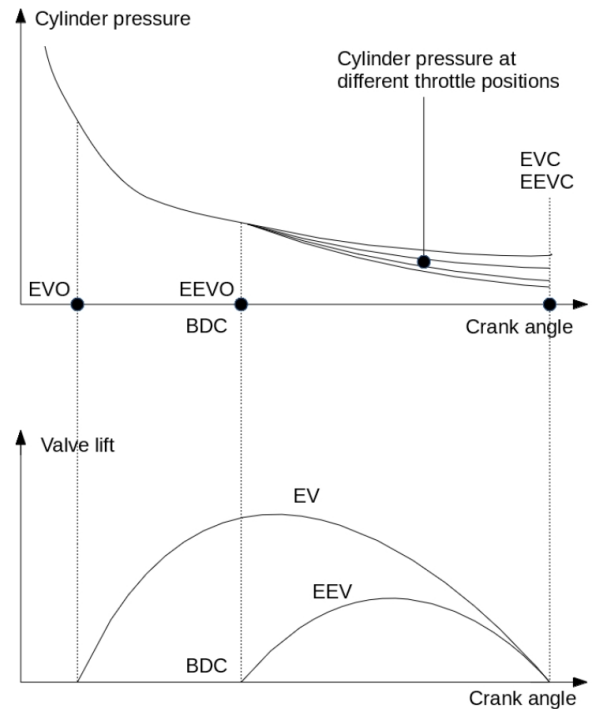


Figure 2b Z-engine with adjustable turbochargers bypass system

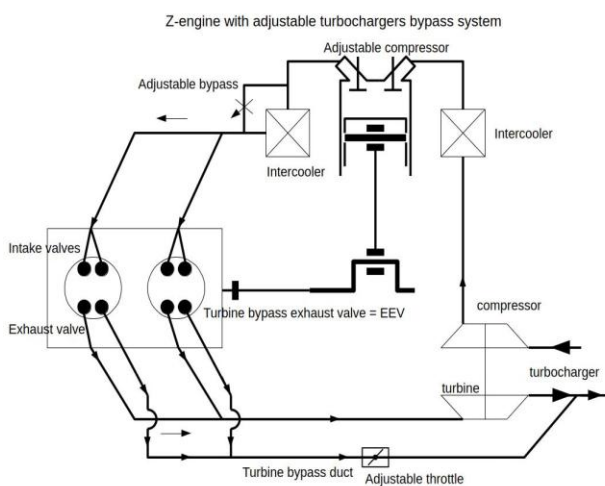


Figure 2a Z-engine with adjustable turbochargers bypass system

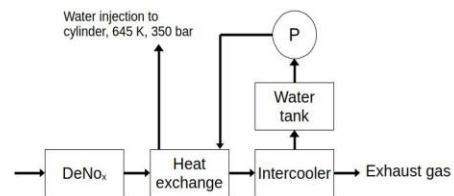


Figure 2c NO<sub>x</sub> and water treatment

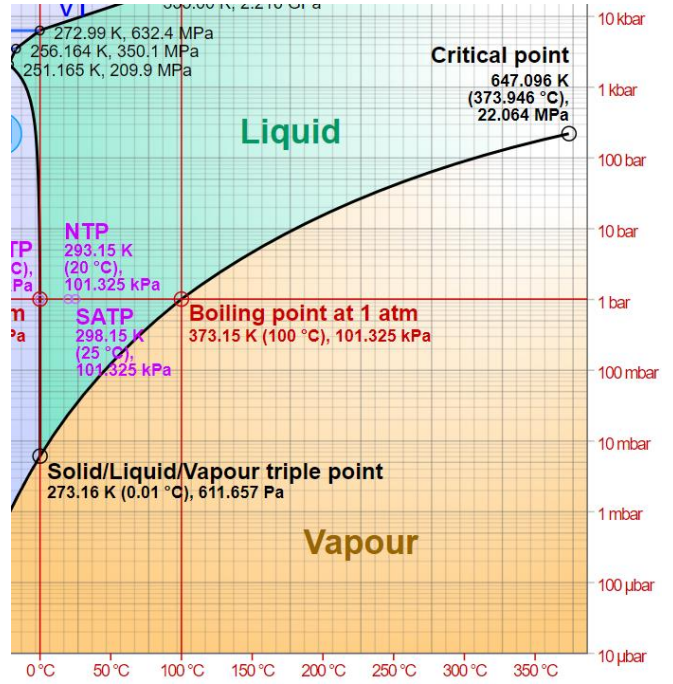
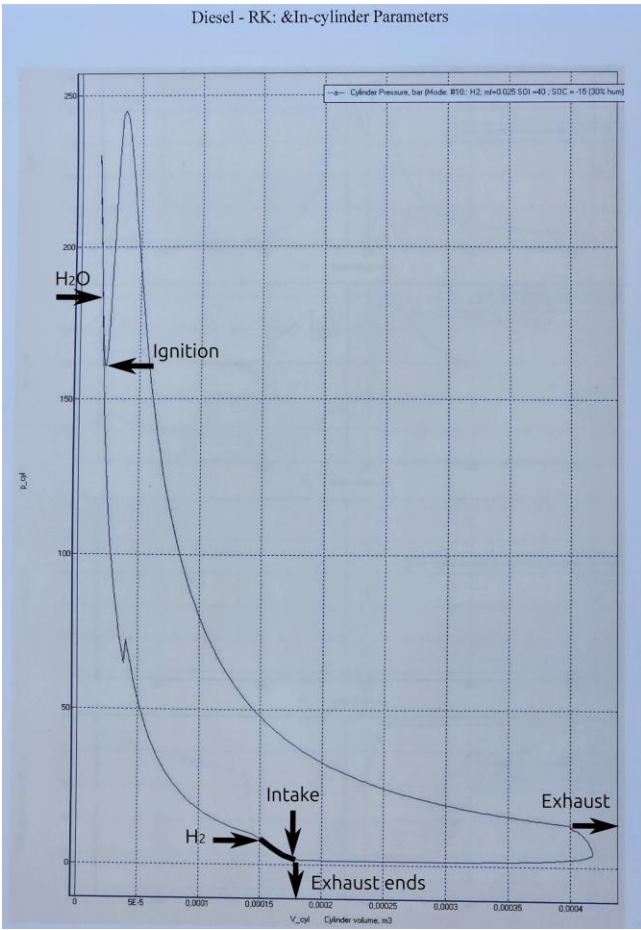


Figure 5 p-T diagram of water

Figure 3 p-V diagram of the Z-engine at full load

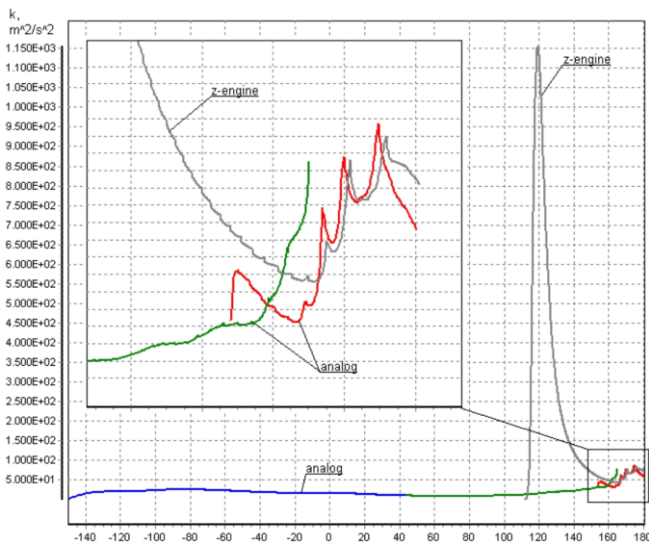


Figure 4 Turbulence energy in cylinder of the Z-engine

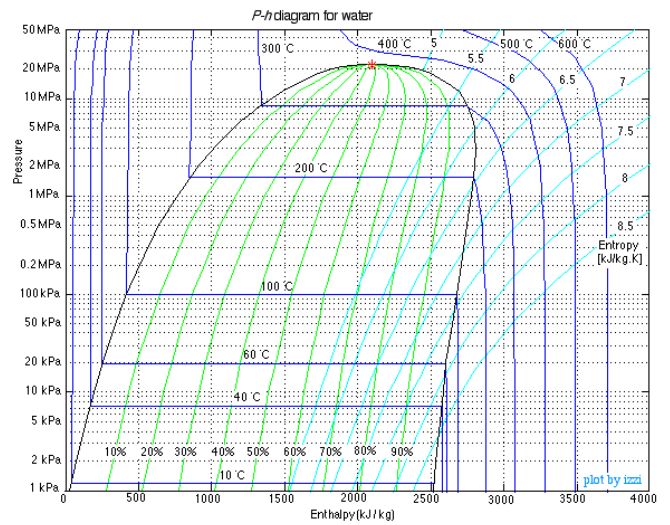


Figure 6 p-H diagram of water

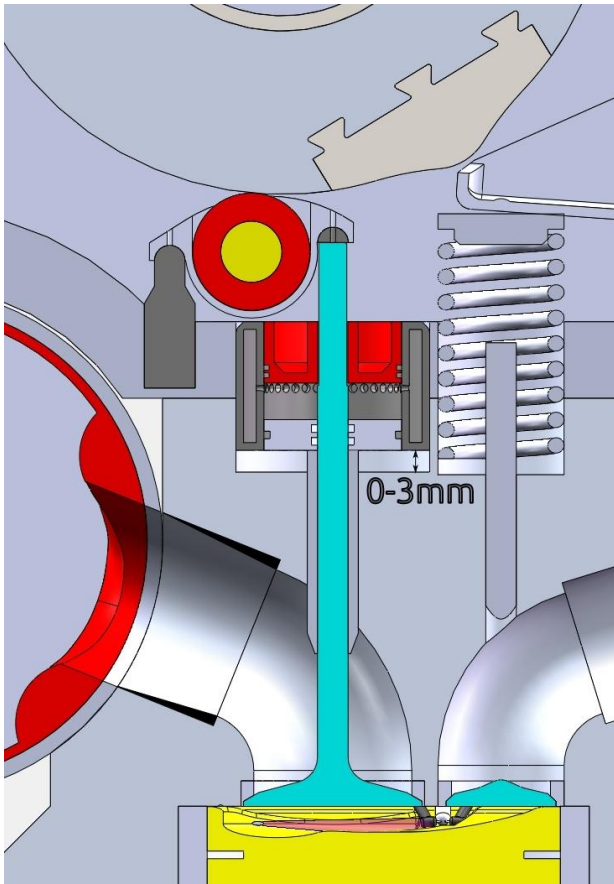


Figure 7 The intake cam mechanism

## CONCLUSION

The new method in Z-engines gas exchange and the water injection during the compression in the work cylinder increases the efficiency of the combustion engines. In some researches the injected water has been heated in the exhaust gas heat exchanger, for example to 600K (Reference 4), but in the described Z-engines water injection system the water is heated in the exhaust gas heat exchanger to about 645K. The water droplets act as neutral particles and they don't influence the ignition of the mixture, but their evaporation lowers the combustion temperature and lower ROHR. As the water droplets don't evaporate before the ignition, they don't increase the pressure during the end compression to TDC, but they lower the compression work by lowering the temperature during the end compression. This increases the efficiency of the Z-engine as well as the higher adiabatic coefficient of the expanding gas, because of the higher adiabatic value of the water steam in the working gas. This increases also the power of the turbocharger.

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