Increasing the Efficiency of a Two-Stroke Car Diesel Engine

The innovative two-stroke car diesel engine concept from Aumet Oy is based on a very rapid gas exchange through poppet valves in the cylinder head when the piston approaches top dead centre. This rapid gas exchange is achieved by high-pressure scavenging air that is produced externally.

Ways of improving the two-stroke car diesel engine

From 1990 to 2000, many car manufacturers examined ways of improving the two-stroke car diesel engine. The aim was to produce a lighter, smaller and more economical engine. In principle, a two-cylinder, two-stroke engine with 1litre cylinder displacement is equal to a 2-litre, four-cylinder, four-stroke engine. Thus, it would be possible to halve the number of engine parts while also significantly reducing weight, volume and production costs. However, there were still problems that were not solved for this type of engine, namely, HC emission and the excessive wear of the piston rings.

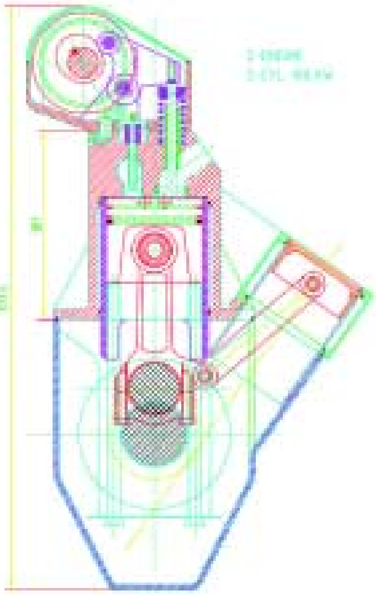


Figure 1: 1.3-litre, two-cylinder, two-stroke car diesel engine with 100 kW.

Project Z Engine

In 1999, Aumet Oy started to research a two-stroke car diesel engine called the Z engine, in co-operation with the Internal Combustion Engine Laboratory at Helsinki University of Technology (HUT) and the Energy Technology Department at Lappeenranta University of Technology (LUT). So far, two Masters theses have been completed on the subject and a third is underway. The first dealt with the simulation of the process and the emissions, while the third examined very rapid gas exchange. Modern simulation tools such as Star CD and GT-Power were used in those theses. Aumet's research project is part of the Finnish Engine Technology Programme, ProMotor, and it is supported by the National Technology Agency of Finland, TEKES. There are plans to run a test engine in 2003. For reference, a 1.3-litre, two-cylinder, two-stroke car diesel engine with 100 kW output has been designed, Figure 1.

Combination

The Z engine contains several new features. It is a combination of a four-stroke and a two-stroke engine. The piston pushes the exhaust gases out of the cylinder through the exhaust valves in the cylinder head. The high scavenging pressure of the air is produced with an integrated piston compressor. The new charge that is controlled by the temperature, pressure and mass flows enters the cylinder through the scavenging valves in the cylinder head. There, before fuel is injected, a secondary compression of the air takes place in the cylinder. The geometrical compression ratio of the Z engine is between 30–50 and the expansion is very long, as in the Atkinson cycle. This positively affects the efficiency of the engine. As the inlet valves are small, it is possible to place the fuel injection nozzle in the middle of the cylinder head and still have all the valves parallel with the cylinder. This enables a monobloc construction to be achieved without a cylinder head gasket. Due to this advantageous construction, the cylinder head can be thinner than in a normal design. There is one camshaft in the Z engine. It rotates at the same speed as the crankshaft and can therefore be used as a balancer shaft. The mechanical efficiency of the Z engine is high, as the pistons work at every stroke. According to simulations, the efficiency of the engine was 45–48 % with a turbocharger.

Z Process

A modern 4-cylinder, turbocharged TDI engine was used as the standard for comparison and the Z engine achieved a better fuel consumption than it. The results of this simulation are presented in Figure 2.

The process of the Z engine can use spark or compression ignition. Internal EGR is easy to implement.

In normal engines, the peak compression pressure and temperature are tied to the geometrical compression ratio of the engine. This is not the case with the Z engine. It is possible to separately control the peak compression pressure and temperature by using an intercooler with an ECU-controlled (Engine Control Unit) by-pass valve. Thus, the mass flow over the engine can also be controlled; for example, if the mass flow to the working cylinder is 1 g/stroke and its temperature is 300 K, or the mass flow is 0.5 g/stroke and its temperature is 600 K, the final compression pressure stays the same in the working cylinder. In the latter case, the temperature rise caused by the burning of the fuel is twice as high, as the mass of the gas is only 50 %. This increases the efficiency of the engine, especially at part load. In the simulations, the value of the maximum compression pressure was 160 bar and the value of the maximum mean temperature was limited to 1800 K to keep the NOx formation level low. A 10° shift in the inlet (and exhaust) cam timing makes it possible to choose how much compression occurs in the cylinder. The amount of internal EGR is easy to control. The EGR is additionally used as an "internal heat exchanger". The rapid expansion caused by the high compression ratio shortens the high-temperature period by about 50 %. This influences the NOx formation and the heat losses, Figure 3. The process parameters are shown in the simulation results in Figure 4.

Z Combustion

The high scavenging pressure enables this new combustion method to be implemented in the Z engine. The shape of the combustion chamber is toroidal and it is located on the piston crown. The maximum speed of the gas coming into the cylinder is above 500 m/s. The pressure of the gas varies between 7–25 bar. The swirl number of the new charge is about 10. The turbulence energy is very high, about ten times higher than that of normal diesel engines.

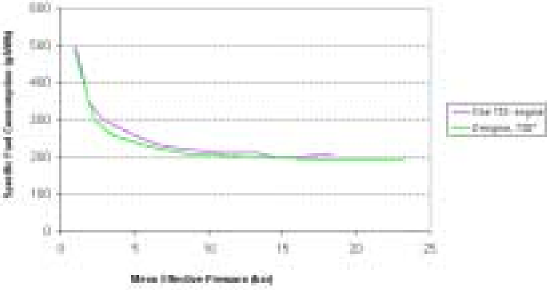


Figure 2: Simulation results.

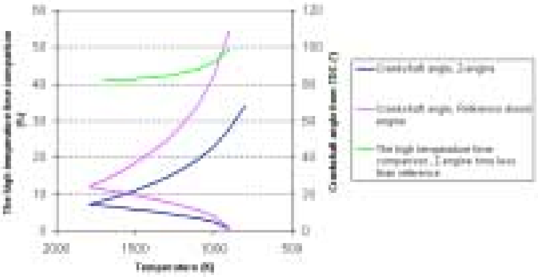
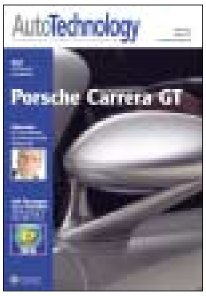


Figure 3: NOx formation and heat losses.



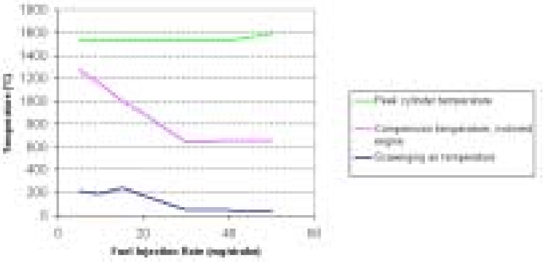


Figure 4: Process parameters.

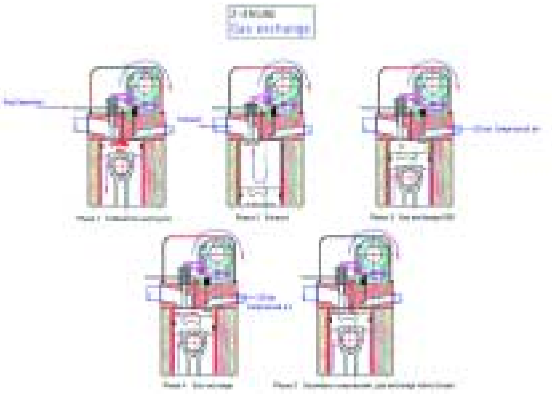


Figure 5: Z-process.

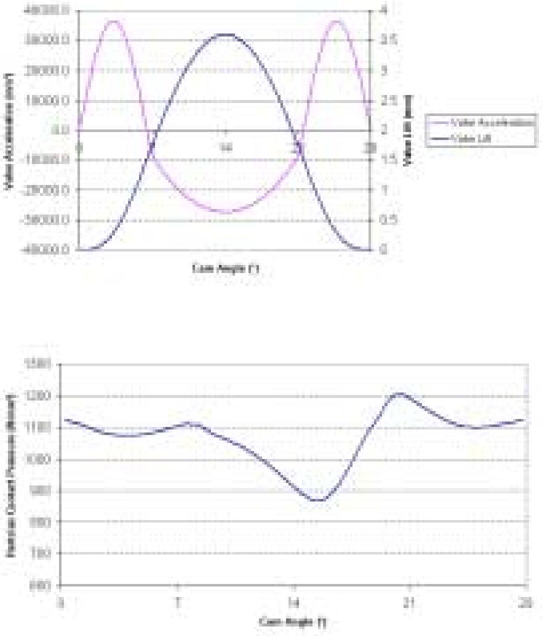


Figure 6a + 6b: Data of the valve system.

The high turbulence energy makes it possible to mix the charge effectively as well as to keep the temperature difference between the burned and the unburned charge small, thus enabling rapid and soot-free combustion. The fuel injector does not need to have any transport function in the Z combustion process as the high-velocity air takes care of the transportation of the droplets. All the air passes the fuel injector when the air rotates in the groove on the piston crown. This makes a controlled distribution of the fuel to the air possible, as in an oil burner. For this reason, it is possible to optimise the atomisation of the nozzle. The nozzle produces very small droplets. The size is about one micron. The nozzle produces a homogeneous mixture with the lambda, ignition and ROHR controls. The droplets evaporate and form a homogenous mixture with the air before they burn. No fuel injection occurs to the flame in the Z combustion process and the amount of particulates is therefore very low, Figure 5. The design of the nozzle means that it has no sac volume, thus lowering HC emissions. The fuel injector can, for example, be like the CAV Microjector, which was used in some USA-made swirl chamber diesel engines in the 80s.

Valve Mechanism

The gas exchange of the Z engine takes place during a period of 20–30° crank angle. This means that, when the engine rotates at 3600 rpm, the gas exchange takes place within a period of only about one millisecond. The maximum acceleration of the inlet valve is 4000 g, which means that each gram in the valve line produces a force of 40 N. In order to keep the contact stress on the cam within acceptable limits, the inlet cam has a basic diameter of 100 mm. The Hertzian contact pressure is about 1200 N/mm_. The material of the cam follower roll is silicone nitride and the cam is through-hardened. In this case, the maximum allowable contact pressure is 2500 N/mm^2. The lift of the inlet valve is small, only 3.6 mm, and the valve spring is a combination of a mechanical spring to start the engine and a pneumatic spring to run it. The force of the pneumatic spring can be adjusted depending on the speed of the engine. The behaviour of the valve mechanism is simulated with a valve train simulation programme. The data of the valve system is shown in Figure 6a and 6b.

Compressor

An adjustable turbocharger (or a supercharger) is used as a precompressor. It defines the mass flow over the engine. A piston-type compressor is used to raise the scavenging pressure to 20–25 bar. The maximum pressure ratio of the piston compressor can be 10 when using a typical compressor head design. The drive for the piston compressor is taken from one connecting rod of the engine. The side force of the compressor piston is small, due to the very elliptical movement of the lower end of the connecting rod of the compressor piston. The force of the compressor piston is only 10–15 % of the force of the working piston, thus allowing the compressor to be made lighter. The cost of the integrated compressor is about 30 % of the cost of one working cylinder. There is an intercooler with a controllable by-pass valve after the piston compressor. The size of the intercooler can be small, as the pressure of the compressed air is high.

Conclusion

By using the Z engine, it is possible to reduce the manufacturing costs of vehicles. All the components used in the Z engine are like those used in normal engines and compressors. For this reason, there is no need to make many changes to the component supply chain. It is possible to have a diesel car without an NOx catalyst or a particulate filter when using the Z engine.

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