The Z engine project

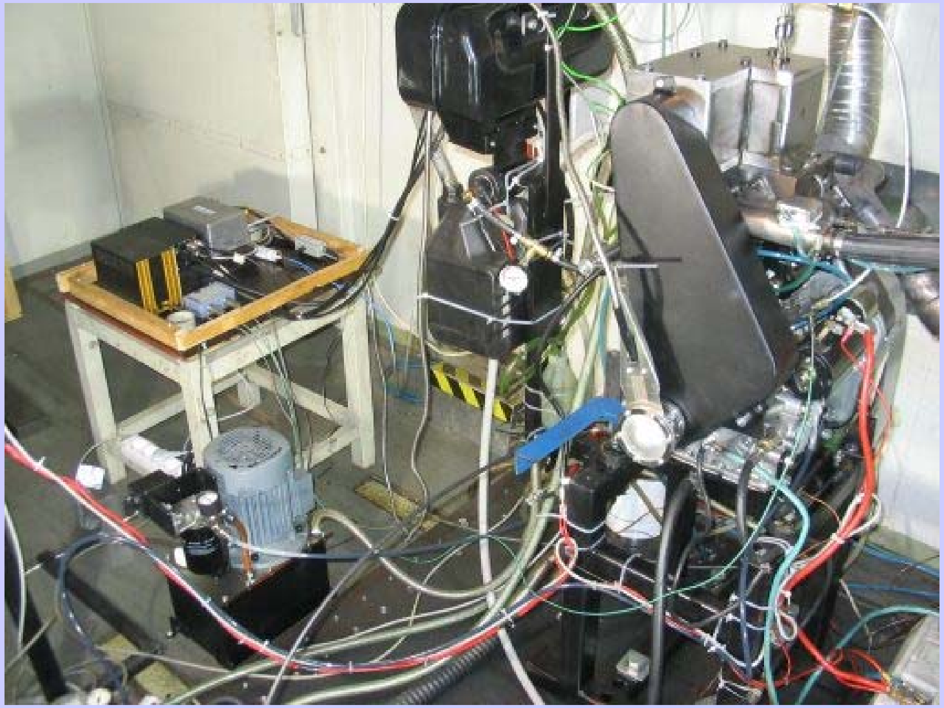
AUMET OY
The Z*-motor company

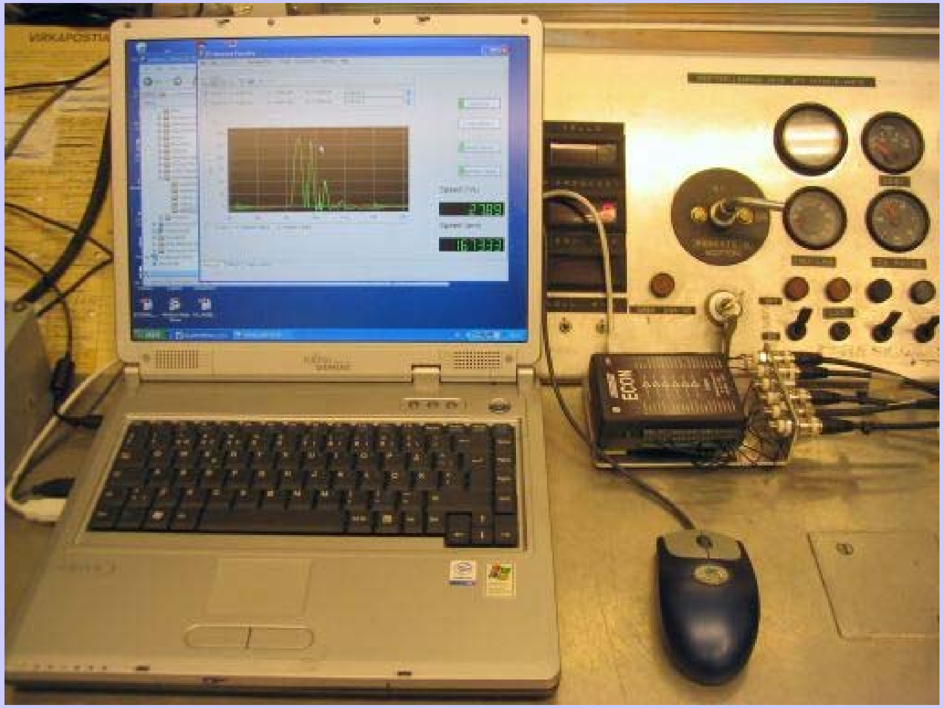
In 1999, Aumet Oy began to research a 4/2-stroke car diesel engine, called the Z engine, in co-operation with the Internal Combustion Engine Laboratory at the Helsinki University of Technology (HUT) and the Energy Technology Department at the Lappeenranta University of Technology (LUT). So far, three master's theses, two SAE-papers and one Fisita-paper have been completed on the subject. Modern simulation tools, such as Star CD, GT-Power and Diesel RK have been used. Aumet's research project was part of the Finnish Engine Technology Programme, ProMotor, and it is supported by the National Technology Agency Finland, TEKES. A prototype engine made its first start in December 2003 and testing of the engine started spring 2004. Since then the engine has been in a test bench at VTT (Technical Research Centre of Finland).

The NOx and efficiency measurements of the prototype engine was made at VTT at part load November 2006. The results were: NOx = 0,8g/KWh, efficiency = 35%.

The Z engine has got five international patents until now. Several international patents are pending.

The prototype engine

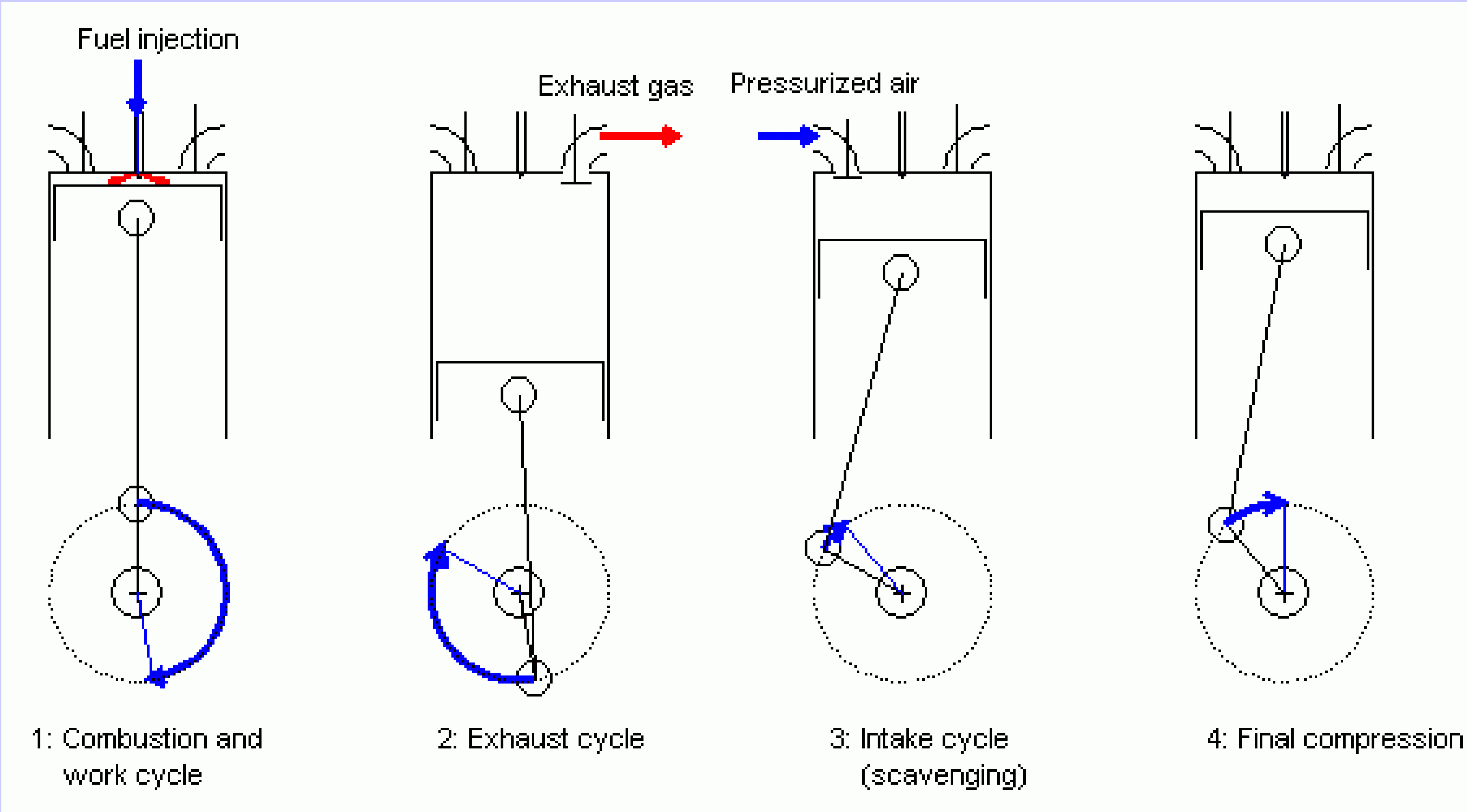

The prototype engine in the test bench



The data acquisition

The gas exchange of the Z engine

The Z engine is a 4/2- stroke engine producing work at every stroke of each piston. The gas exchange is controlled by means of poppet valves. The work cycle of the Z engine is identical to that of a 4-stroke engine.



The Z process

The main principle of the Z engine is to make a part of the compression outside of the hot work cylinders. This makes a very high inter cooling rate possible. The cold compressed air is lead into the work cylinder through the poppet valves when the piston approaches the top dead centre.

The compression is made by a two-stage compressor set. The first-stage is a pulse turbo charger and the second-stage is a piston compressor that is integrated into the engine.

There is an adjustable intercooler after each compressor stage for the control of the temperature. The pressure level of the external compression varies from 6 to 15 bar, depending on the speed and load of the engine.

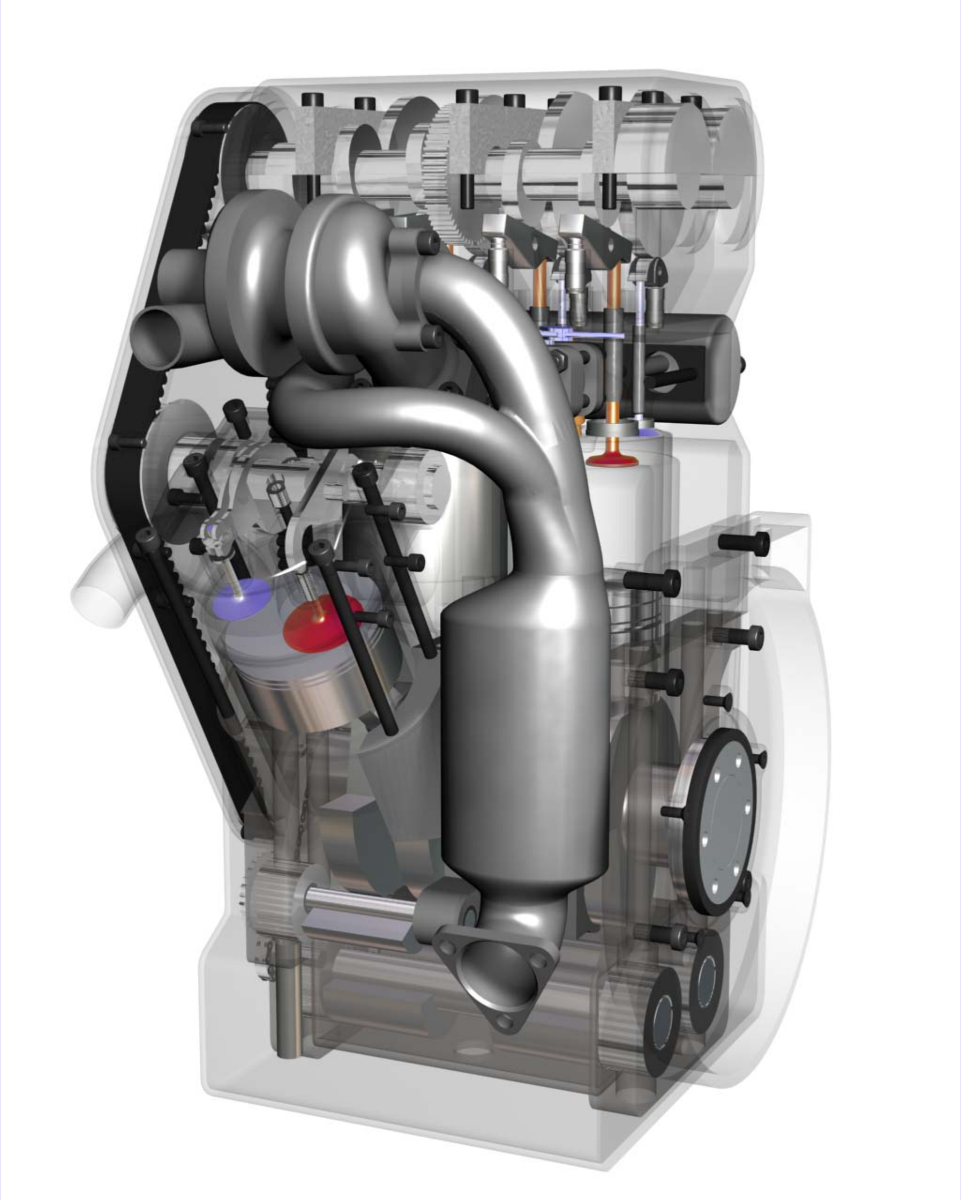
Thanks to the high intake pressure level, the intake cycle is very short, typically 20° of the crankshaft. After the intake/scavenging, the air is further compressed in the work cylinder.

The work cycle is like in a 4-stroke engine. The exhaust valves are opened about 60 ° before the bottom dead centre. Then the rising piston pushes the exhaust gases out of the cylinder until the exhaust valves are closed and the intake valves are opened, typically 60° – 40° BTDC.

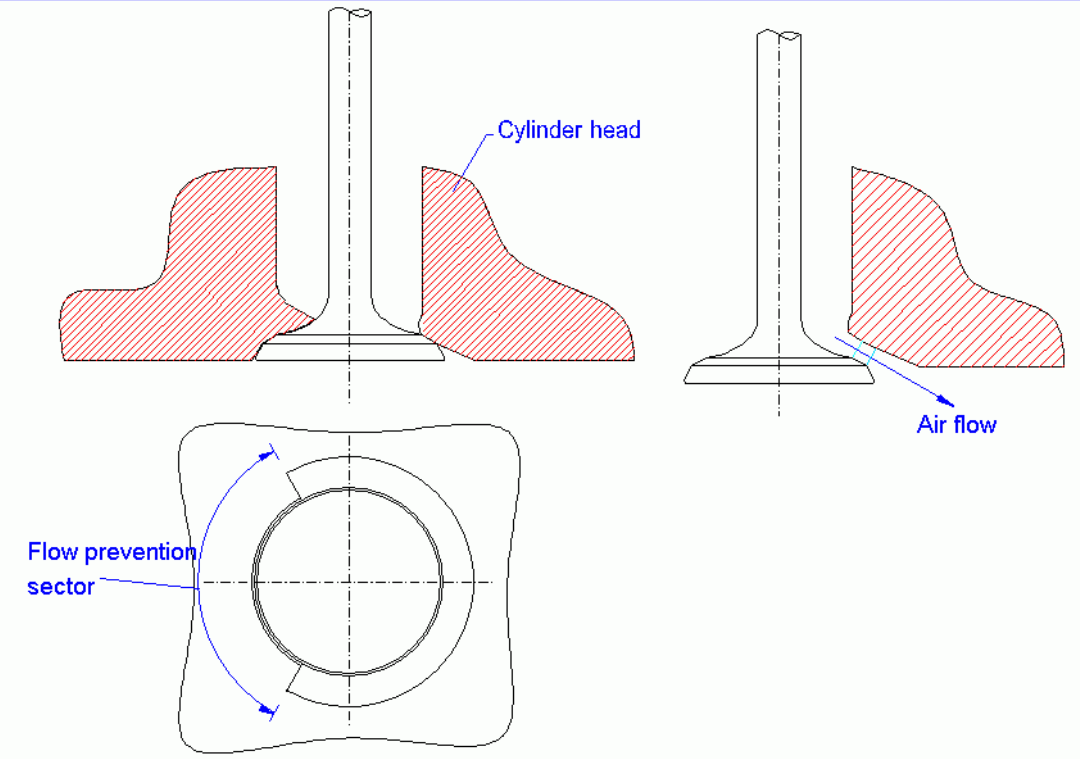
The amount of the internal EGR can be controlled easily. The hot EGR acts as an internal heat exchanger in the Z-process, as well as the heat isolated combustion chamber (Ricardo).

The Z engine, turbo and compressor

The Z engine has a pulse turbo charger and a super charger (piston compressor)

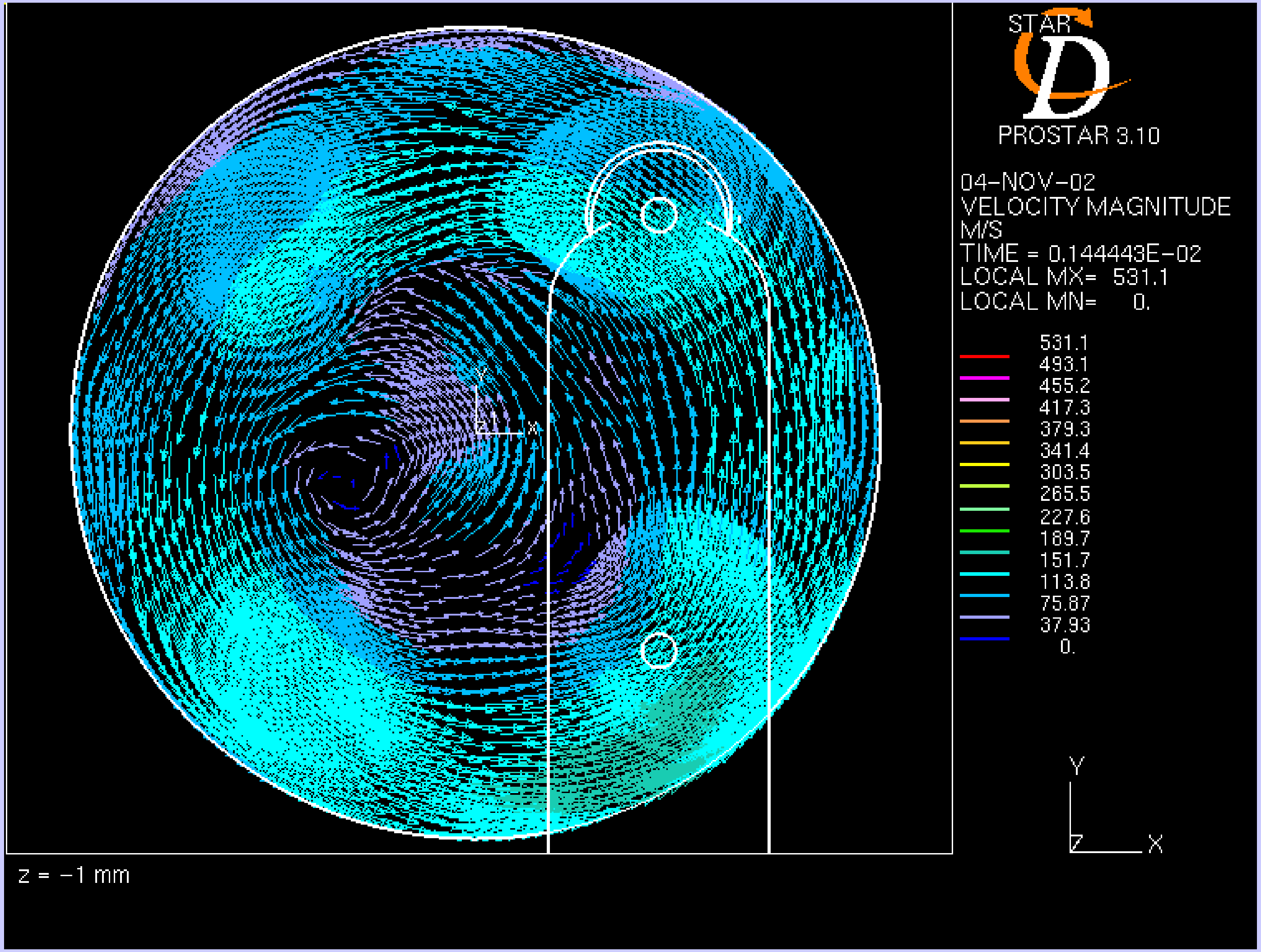


The high swirl intake valves of Z combustion



- The valves form a narrowing / widening nozzle that allows supersonic flow speed.
- The flow is prevented on certain sector to direct the combustion air tangentially into the cylinder to make a high swirl.

In cylinder flow simulation, intake valves closed



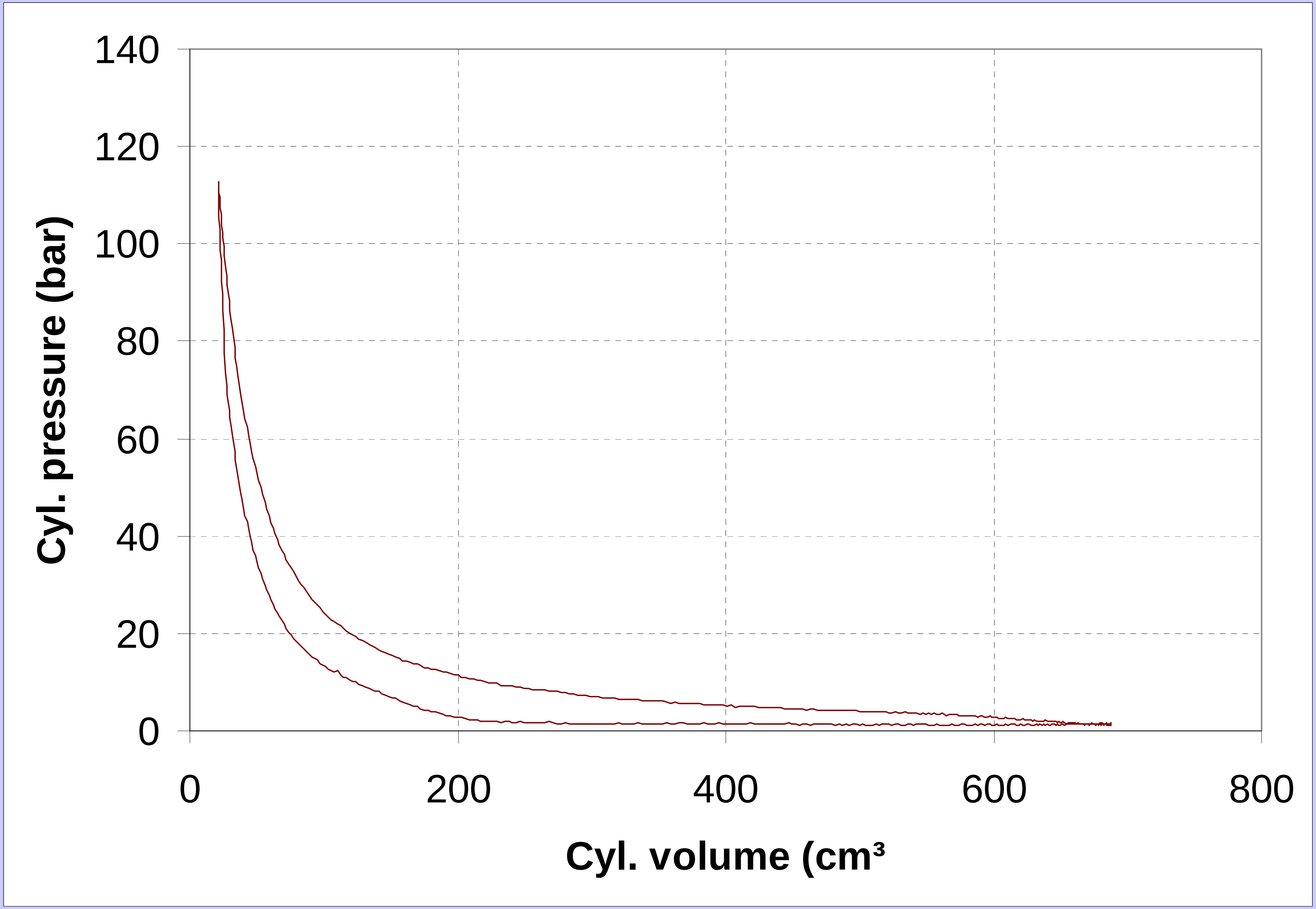
The Z combustion

The Z combustion chamber is a combination of the swirl combustion chamber and the "Perkins squish-lip" combustion chamber. It has also some common features with M combustion
The Z combustion works with an air/fuel ration of 1-1,6 independently of the load of the engine.
The swirl ration is 30 – 50 in the Z combustion chamber, like in the swirl chamber engines.
The high speed squish flow is generated by having a small opening diameter of the combustion chamber in the middle of the piston like in the "Perkins squish-lip" combustion chamber and by having a small piston – cylinder head clearance, about 0,1 – 0,2 mm. This is possible as the gas forces are always "downwards" in the Z engine and also the bearing clearances.
As the combustion chamber of the Z engine is very small and compact, it is possible to reach almost all the available air (90 – 95 % of the total intake amount) within the very short injection time. There is a good contact between the high speed, high turbulence air and the conical fuel sprays, making a rapid mixing possible. The duration of the injection is 5 °- 10 ° of crank angle, starting 20 ° BTDC. The nozzles, 1-3 pcs/cylinder are outwards opening conical nozzles (like CAV Microjector). There is enough flow area for a rapid injection even the gab between the conical needle and the injector frame is only 0,05 mm. The flow area is 5 – 10 times bigger than in an equal direct injection system. The injection pressure can be only 200 – 500 bar and this gives 2 – 3 % advantage in the fuel consumption, when compared with systems working at 2000 bar.

Combustion chamber

The insulated combustion chamber after tests.

Cylinder pressure at part load



Part load results

-n = 1600 rpm
-air:m = 0,47g
-total gas:m = 0,65g
-fuel:m = 18,3mg = 778 J
-W = 420J – friction – compressor work = 272J
-effective pressure:p = 4,1 bar
-e = 32
-lambda = 1,65
-efficiency = 35%
NOx = 0,8g/kWh

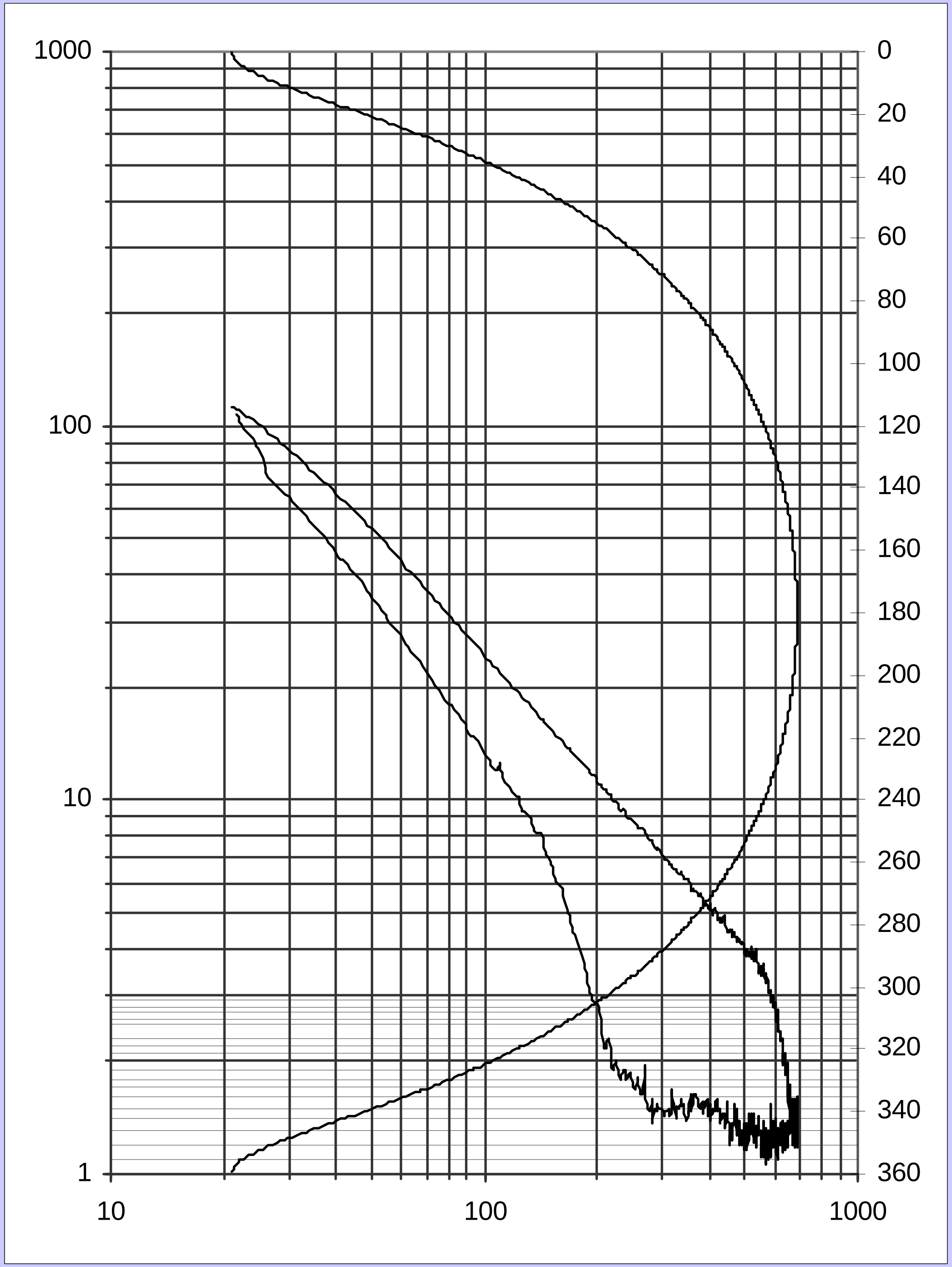
Precompression

-impulse turbo p = 1,5 bar
-piston compressor p = 7,8 bar

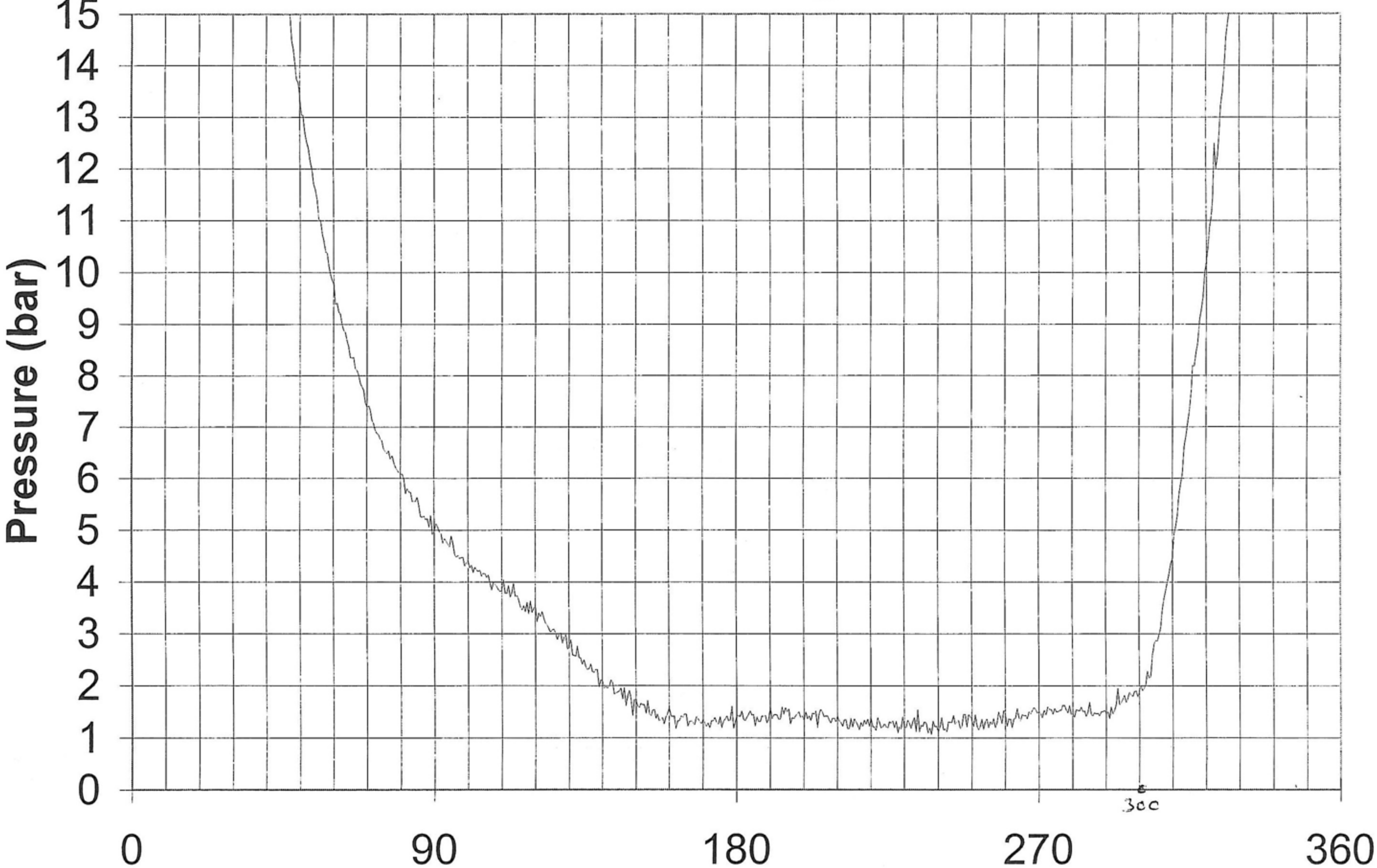
Gas exchange

-exhaust opens 60° BBDC
-exhaust closes 120° ABDC
-intake opens 120° ABDC
-intake ends 136° ABDC

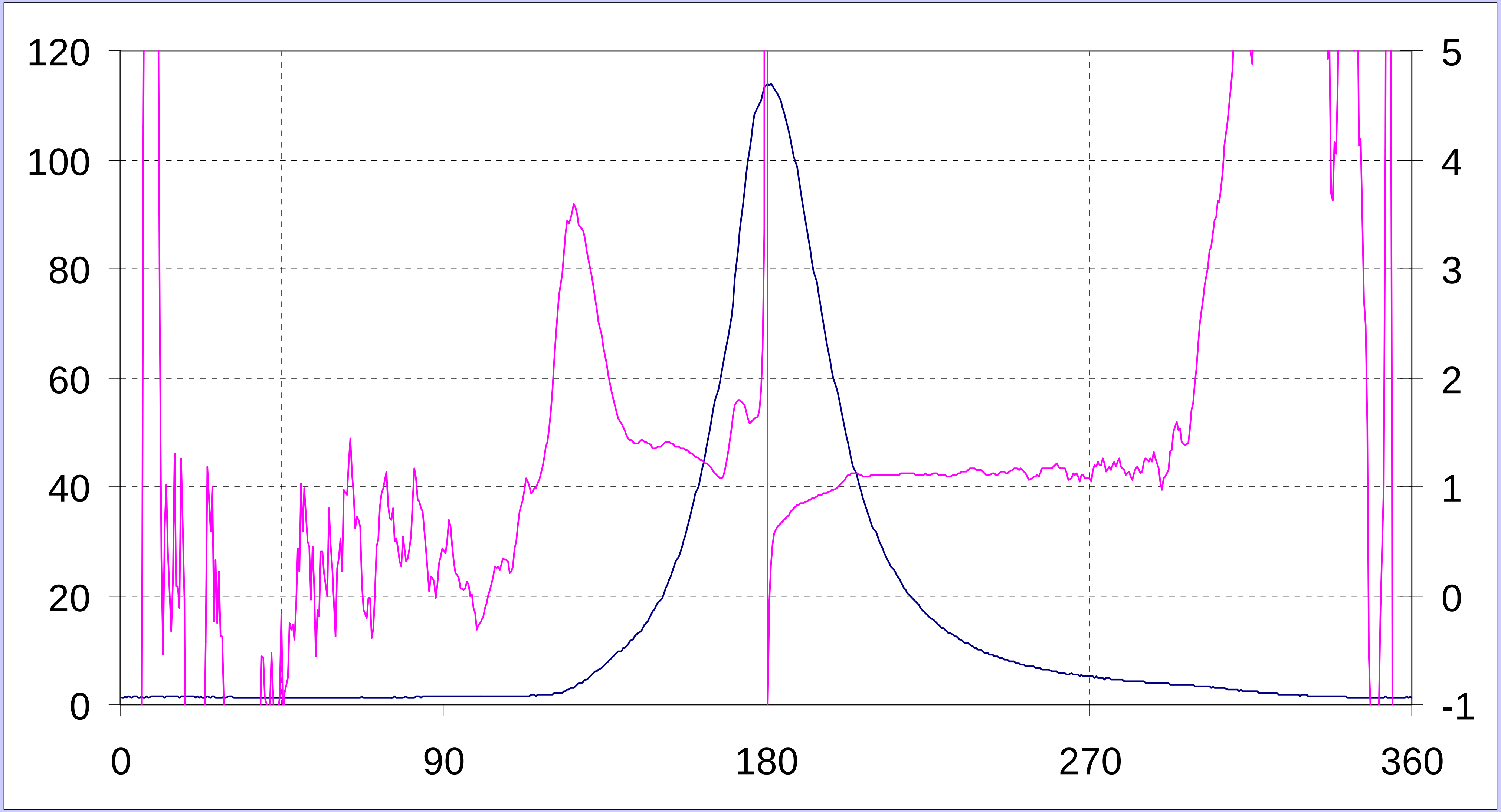
lgp, lgV diagram



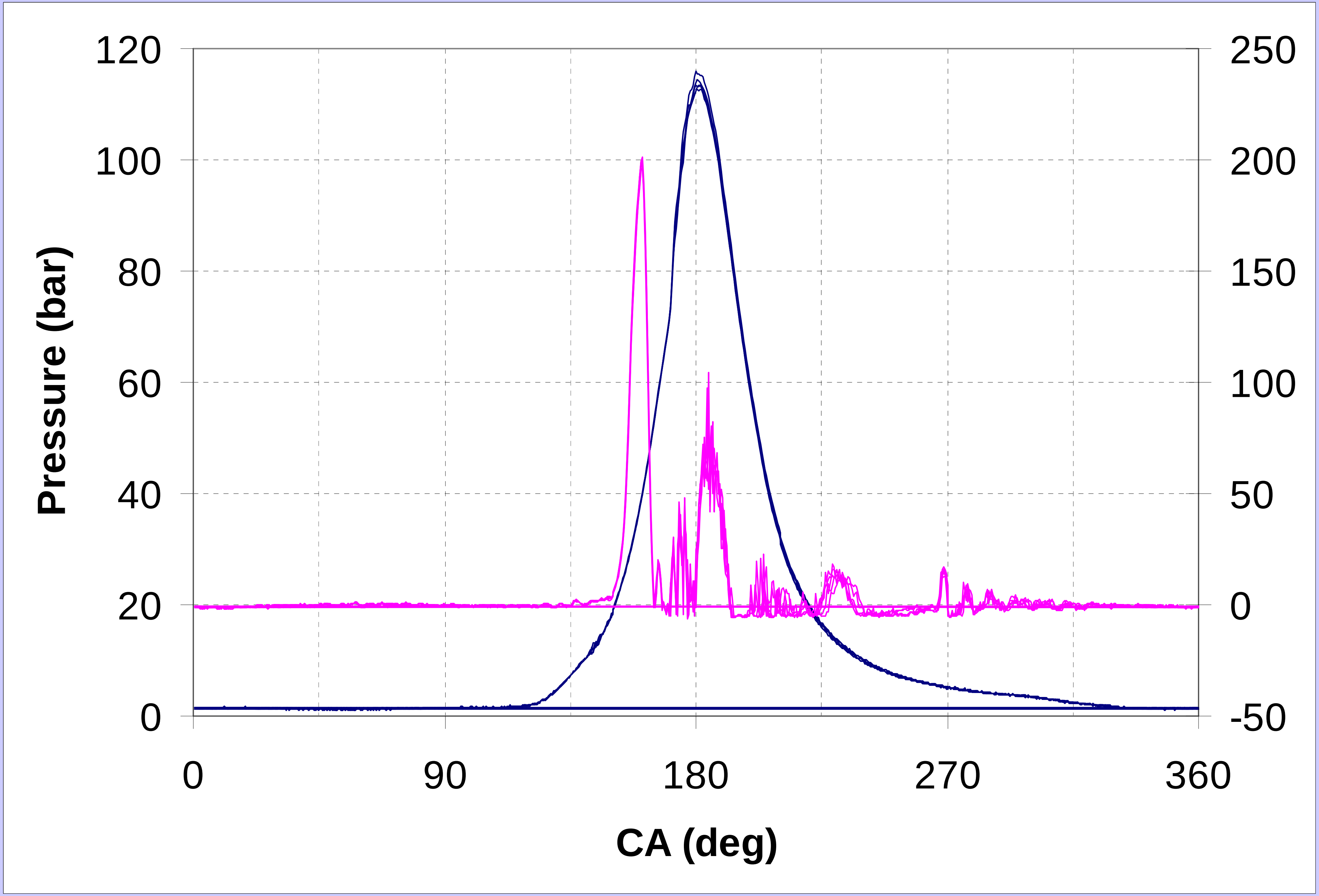
Gas Exchange



Cylinder pressure and polytropic exponent



Cylinder and fuel pressures



deNOx in Diesel Combustion

The low level of the NOx emission in the swirl chamber engines has been known for a long time and as an explanation has said to be the combustion in the fuel rich circumstances in the swirl chamber. This phenomenon has in the last years been more researched for example in some Japanese and Italian studies, in which the deNOx has been explained. In these studies the combustion chamber was located in the middle of the piston crown like in the Z engine.

In these studies have been measured about the same level of the NOx emissions as in the Z-engine (100 – 130 ppm). The hot, heath isolated squish lip type combustion chamber with a very high turbulence, located in the middle of the piston of the Z-engine supports the cracking of the fuel.

In one of these studies a numerical analysis was made by using Chemkin III with Plug. The calculated results were very close to those measured ones and they were about at the same level as measured in the Z-engine in the NOx tests.

See:

-NO reduction mechanism in a fuel-rich diesel-burning zone with swirl. JSAE 1998, Miwa, Ishiyama

-An Interpretation of High Swirl Diesel Combustion Based on Optical Diagnostics and 3D Numerical Calculations. COMODIA 1998, Astarita, Corcione, De Maio, Vaglieco, Valentino

-Effect of Rich and High Turbulence Combustion on NOx and Particulate Emissions from a High Speed Direct-Injection Diesel Engine. COMODIA 1998, Yang, Kidoguchi, Miwa

-Effect of High Squish Combustion Chamber on Simultaneous Reduction of NOx and Particulate from a Direct-Injection Diesel Engine, SAE 1999-01-1502, Kidoguchi, Yang, Miwa

-Reduction Mechanism of NOx in Rich and High Turbulence Diesel Combustion, COMODIA 2001, Kidoguchi, Miwa, Mohammadi

-deNOx Mechanism Caused by Thermal Cracking Hydrocarbons in Stratified Rich Zone during Diesel Combustion. COMMODIA 2004, Kidoguchi, Noge, Miwa

-A Study of NO Reduction Caused by Thermal Cracking Hydrocarbons during Rich Diesel Combustion. JSME International Journal No 2, 2006, Noge, Kidoguchi, Miwa

The advantages of the Z engine

- high turbulence combustion having a low NOx and particulate emission.
- low air/fuel ration independently of the load.
- high efficiency especially at part load (Atkinson cycle)
- good balancing, equal to a 4-cylinder, 4-stroke diesel engine
- small size, 30% smaller than an equal 4-cylinder, 4-stroke diesel engine
- low weight, 30% lower than an equal 4-cylinder, 4-stroke diesel engine
- low cost, 30% lower than an equal 4-cylinder, 4-stroke diesel engine
- quick warming
- good cold start behaviour (bypass of the intercooler after the compressor)
- short crankshaft, no torque vibrations
- normal components, no need to any changes in the supply chain

Comparison: the Z engine versus a hybrid system

- better overall efficiency, higher than 35% (hybrid system 25 – 28%)
- lower weight
- smaller size
- lower cost, less complex to manufacture

The Z engine, an economical alternative to a hybrid system