Modern diesel engine technology

The diesel engine has undergone a technical revolution over the last twenty years. With the benefit of modern technology, a present-day diesel with a rating of 150 hp delivers basically the same performance, in terms of acceleration and effective top speed, as a turbocharged, petrol-engined car of up to 200 hp. With significantly lower fuel consumption and carbon dioxide emissions.

The four-stroke petrol engine was invented by Nikolaus August Otto in 1867, while the diesel was the invention of Rudolf Diesel in 1898. Thus, both principles are old, well proven and are used in engines that have all undergone further development.

However, whereas the petrol engine underwent stage-by-stage development over more than a century, the diesel was developed more slowly over a 50-year period, initially with the addition of two-valve precombustion chamber technology and mechanical, low-pressure fuel injection. This provided relatively modest specific performance compared with the Otto engine.

Lead overhauled

Until now, the diesel has been the less preferred option in terms of performance and environmental impact – regarded as a noisy, smelly unit using a messy fuel. Nevertheless, it has long enjoyed considerable popularity in large parts of Europe for its high fuel efficiency. However, opposition to the diesel still exists in other countries, such as Greece, Sweden and in particular, the USA and Japan, and some of these negative perceptions probably remain there.

Since the modern diesel is completely different from its forerunners, some of these prejudices have probably lived on as myths. In the last 10–15 years, there has been a strong swing towards the direct-injection diesel with turbocharging and four-valve technology, and the lead held by the petrol engine has been practically overhauled in a short time.

The diesel engine develops a considerably higher specific torque than a petrol engine. In many cases, this means that it delivers higher effective tractive power and acceleration than its petrol-driven counterpart.

Today’s diesel cars boast excellent acceleration, as well as high cruising and top speeds – important in some European markets. Diesel ‘knock’ is discernible only when the engine is cold or idling. Diesels are fun to drive and their drivers are happiest of all when they realise how seldom refuelling is needed.

On the open road, a Volvo V70 D5 automatic with an output of 185 hp can return a fuel consumption of 5 litres per 100 kilometres – running just as quietly and comfortably as a petrol-engined Volvo V70.

Compared with petrol, emissions of the greenhouse gas, carbon dioxide, are approximately 20% lower per unit of fuel consumed. Together with the engine’s lower fuel consumption and efficient combustion with excess air, emissions as a whole, including other exhaust emissions, are low. As new diesels are equipped with particulate filters, emissions of particulate matter have been reduced to more or less the same level as from petrol engines, although NOx emissions are still somewhat higher.

Key technologies

Mechanically, the diesel is basically of the same design as the petrol engine, although somewhat more rugged in construction to withstand the higher combustion pressure. Rather than a mixture of air and fuel, air only is drawn in
through the intake manifold, which is designed to impart a powerful swirl to the air to suit the diesel’s specific combustion process. A glow plug is used to initiate combustion when starting from cold – which is now as fast as in a petrol engine.

Unlike the petrol engine, in which a spark plug is used to ignite the petrol/air mixture, the diesel fuel self-ignites on injection into the hot, rapidly swirling compressed air. Once the initial charge has been ignited, diffusion combustion of the further injected fuel continues. A diesel runs on excess air at all times and does not require a throttle – the load is controlled simply by varying the quantity of fuel.

A flexible ‘common rail’ injection system equipped with a high-pressure fuel pump and a pressure accumulator is a key technology in the modern diesel. The pressure can be controlled from 500 to upward of 1,500-2,000 bar and fuel injection is fully electronic. Combustion is initiated by pilot injection, permitting low emissions and gentler combustion, as well as lower noise, to be achieved. Modern injectors are provided with 5-7 extremely small and carefully machined holes to ensure optimum atomisation in the cylinders and, as a result, efficient utilisation of the air.

At least 20% more efficient

Advanced turbocharging is another key technology. Variable turbine geometry and adjustable guide vanes upstream of the turbine ensure maximum efficiency and a higher boost pressure across the full range of revs. In the turbo, the guide vane angle is altered with the aid of a pneumatic or electrical actuator. The system permits efficient turbocharging and air charging, enabling more fuel to be injected. This can yield higher performance at higher efficiency, as well as lower exhaust emissions!

A diesel engine is 20-30% more efficient than a petrol engine. In other words, it performs more work per unit of fuel. Since diesel fuel does not suffer from the same knock limitation as petrol, diesel engines can operate at a higher compression ratio close to the optimum value of 16-19:1, compared with about 10.5:1 for the petrol engine.

In the petrol engine, the mixture is first ignited by means of a spark plug and combustion continues progressively as the flame front expands. The load is controlled with the aid of a throttle and the stoichiometric mixture is controlled by an oxygen sensor (Lambdasond). This, together with a three-way catalytic converter, ensures highly efficient purification of the NOx, (nitrogen oxides), CO (carbon monoxide) and HC (hydrocarbons) in the exhaust gases.

An example can be provided using current values for a couple of different Volvo cars. At present, the summated emissions of nitrogen oxides and hydrocarbons (NOx + HC) from a petrol-engined car are 0.05 g/km compared with 0.22 g/km from a diesel. Emissions of hydrocarbons alone are comparable. In the case of carbon monoxide (CO), the Volvo D5 engine currently emits 0.205 g/km, compared with 0.216 g/km for the equivalent 2.5T turbo petrol engine.

EGR reduces NOx

Nitrogen oxides (NOx) are formed during combustion when oxygen (O2) is bonded with nitrogen (N2) at high temperature. The process is dependent on the occurrence of ‘local’ temperature peaks and increases with load; in other words with the car’s acceleration, speed and load.

The nitrogen oxides are reduced in three ways – by controlling the fuel injection and combustion, by adding incombustible exhaust gas through exhaust gas recirculation (EGR) and, to a lesser extent, by post-treatment using oxidising catalytic converters.

In the EGR system, a proportion of the exhaust gases is returned to the engine intake. This means that even though the resultant mixture is hotter than the outside air, the specific heat rises and the relative oxygen content is lowered, accompanied by a reduction in the intake mass air flow. The net result is a combustion process that is somewhat slower and cooler at an lower overall temperature. As a result, the exhaust gases are cleaner in terms of nitrogen oxide content. Cooled EGR enables the admixture of exhaust gases to be further increased, further lowering the combustion temperature and reducing the NOx level even further.

The quantities of hydrocarbons (HC) and carbon monoxide (CO) are reduced significantly when an oxidising catalytic converter is added to the system.

Particulate filter the latest

Basically all modern diesels are equipped with the features described above. The most recent advance in diesel technology is the particulate filter. This is available in two main types – ADPF and CDPF. In each case, the three last letters stand for ‘Diesel Particulate Filter’, while ‘A’ indicates ‘Additive’ and ‘C’ denotes ‘Catalysed’.

Each of these devices is provided with a substrate similar to that in an ordinary catalytic converter and, as in the latter, the gases are conducted through a large number of small passages. The difference is that the rear end of each passage is closed and the gases are forced to flow through the porous walls into the other half of the filter, whose passages are closed at the front end. In this way, the soot particles are bonded to the channel walls.

As noted above, the letter ‘C’ in CDPF denotes ‘Catalysed’ (catalyst-coated), while the ‘A’ in ADPF stands for ‘Additive’. In the latter case, the fuel is dosed with a special, non-hazardous additive which, together with EGR,
produces the same clean exhaust gases as the CDPF system. The catalytic coating or additive, as appropriate, reduces the temperature to allow the soot to be burned off.

The accumulated soot particles are burned off at regular intervals in an automatically controlled burnoff/regeneration process. This takes place about every 500 kilometres unnoticed by the driver.

The life of the catalysed type of particle filter is almost equal to that of the car itself (240,000 km), while the additive type requires service at intervals to remove unburned material and to top up the additive reservoir.

With a particulate filter, the concentration of large and small particles is reduced to the same or a lower level than from a petrol car. This also applies to the harmful fine fractions.

It is clear, therefore, carmakers are working comprehensively to reduce the particulate content of diesel exhausts. This applies both to the development of even more efficient combustion systems and post-treatment technologies. In addition, oil companies are likely to make a contribution in terms of developing better and cleaner fuels. As an example, trials of synthetic diesel indicate the feasibility of reducing NOx and particulate levels by a further 20% and 30% respectively.

Captions:

1. The principle of a catalytic diesel particulate filter (CDPF) in simplified form. From the engine, the gases pass first to a close-coupled oxidising catalytic converter, then to the filter. The entire process is monitored by temperature and pressure sensors, as well as an oxygen sensor (Lambda-sond). P2005_2833

2. The principle of a diesel particulate filter (DPF). Every second passage at the inlet end is closed, while the remaining passages are closed at the outlet end. This forces the gases to pass through the porous walls of the substrate, trapping over 95% of the soot, including the fine particles. P2005_2834

3. European legislation governing the maximum permissible levels of various emissions has been tightened in several stages over the years. The percentage reduction figures refer to 1990 as base year. The figures for hydrocarbons (HC) and nitrogen oxides (NOx) are combined. Blue figures are values for petrol-driven cars. All values are expressed in g/km. NOx+ HC emissions from a diesel are almost double that from a petrol-engined car, while the opposite applies to carbon monoxide (CO). P2005_2831


5. The fuel injection system in the latest version of Volvo’s D5 diesel engine features injectors with seven extremely small spray holes, compared with five before. This affords better atomisation, resulting in more efficient combustion. Injection can now be controlled precisely in three stages: pre-injection, injection proper and post-injection. The last of these is important to the efficient burnoff of soot in the exhaust gases. P2005_2096

6. As before, the swirl imparted to the induction air in the combustion chamber is utilised in the D5 engine. However, the swirl can now be controlled steplessly with the aid of a new type of damper, enabling combustion to be adjusted very precisely to the prevailing driving conditions and the current load on the engine. P2005_2093

7. The variable guide vanes in Volvo’s new D5 engine feature a flow-optimised wing profile and a greater angle of adjustment, promoting more efficient gas flow and higher turbo efficiency. These improvements contribute both to faster acceleration and improved high-speed resources. P2005_2094

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