

Recent Developments in BMW's Diesel Technology

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1. Introduction

The image of BMW is very strongly associated to high power, sports biased, luxury cars in the premium car segment, however, particularly in the United States and some parts of Asia, the combination of a car in this segment with a diesel engine was up until now almost unthinkable. I feel sure that many people in the USA are not even aware that BMW produces diesel-powered cars.

In Europe there is a completely contrary situation which, driven by the relative high fuel price, and the noticeable difference between gasoline and diesel prices, there has been a continuous growth in the diesel market since the early eighties. During this time BMW has accumulated more than 20 years experience in developing and producing powerful diesel engines for sports and luxury cars.

BMW started the production of its 1st generation diesel engine in 1983 with a 2,4 l, turbocharged IDI engine in the 5 series model range. With a specific power of 35 kW/l, this was the most powerful diesel engine on the market at this time. In 1991 BMW introduced the 2nd generation diesel engine, beginning with a 2,5 l inline six, followed in 1994 by a 1,7 l inline four. All engines of this 2nd BMW diesel engine family were turbocharged and utilized an indirect injection combustion system.

With the availability of high-pressure injection systems such as the common rail system, BMW developed its 3rd diesel engine family which consists of four different engines. The first was the 4-cylinder for the 3 series car in the spring of 1998, followed by the 6-cylinder in the fall of 1998 and then in mid 1999 by the worlds first V8 passenger car diesel with direct injection.

Beginning in the fall of 2001 with the 4-cylinder, BMW reworked this DI engine family fundamentally. Key elements are an improved core engine design, the use of the common rail system of the 2nd generation and a new engine control unit with even better performance. Step by step, these technological improvements were introduced to production for all members of this engine family and in all the different vehicle applications.

In the next slide you can see the production volume of diesel engines by BMW. From the 1st family we produced ~ 260 000 units over eight years and from the 2nd family ~ 630 000 units were produced also during an eight year period. How successful the actual engine family with direct injection is can be seen in the increase of the production volume to 330 000 units for the year 2002 alone.

The reason for this is that, in addition to the very low fuel consumption, this new engines provide excellent driving characteristics and a significant improvement in the level of noise and vibration.

In 2002, 26% of all BMW cars worldwide, and nearly 40% in Europe, were produced with a diesel engine under the hood. In the X5 we can see the biggest diesel success rate. Of all the X5 vehicles produced, 35% Worldwide and 68% in Europe are powered by a diesel engine.

2. Actual BMW diesel engine family

Today's BMW diesel engine family includes a 2,0 l, 4-cylinder engine, two 6-cylinder engines, of 2,5 l and 3,0 l displacement, and ultimately a 3,9 l V8.

The 4-cylinder engine features different power versions for the 3 and 5 series cars. The 6-cylinder with 2,5 l is available only in the 5 series, while the 3,0 l 6-cylinder is available in the 3, 5, and 7 series as well as the X5.

The most powerful engine, the 3.9 l, V8 is currently only used in the 7 series car.

4-cylinder power ranges from 85 kW to 110 kW, the 6-cylinder, from 120 kW to 160 kW and the V8 providing 190 kW with an impressive 600 Nm of torque.

3. Technical features

What is it about the technology that makes Diesel engine so powerful while efficient at the same time?

There are four essential parameters.

First is a very robust, well-optimized core engine design. To achieve high power output, good efficiency and low raw emissions, the core engine must deal with high cylinder pressures of up to 180 bar and must have a high thermal resistance. On the other hand the friction losses should be as low as possible.

Second, the design of the combustion chamber and the inlet ports is critical.

Third is the injection system, not only is the maximum fuel pressure important but also the influence of the hydraulic efficiency of the system and a high flexibility in the engine management for a sophisticated application strategy.

Last, but not least, the air and exhaust management with well optimized turbochargers and well-designed intercoolers are very important.

BMW always tries to combine the optimal solutions; this is true of every engine, car and transmission combination.

Two examples of our core engine design. We use special aluminum alloys with specific developed thermal treatment for the cylinder head. The design is based on well-developed and proven simulation methods as well as the casting and the manufacturing process. For the crankcase we use gray cast iron. While the inline engines have a standard material, the V8 BMW was the first to use a high strength vermicular cast iron for such an application. In combination with "cracked" main bearings, this material allows the best compromise between weight and stiffness. Compared to nearly all other V-engine crankcase designs this BMW solution needs only two main bearing bolts per cap, even with cylinder pressures of around 180 bar.

On the next chart you can see the combustion chamber design. All of our DI Diesel engines have 4 valves, a central, vertical injector nozzle and a piston with a symmetrical combustion chamber.

Very important is the optimisation of the inlet air swirl, therefore the inline engines utilise two separated ports, one is designed as a swirl port coming from the top of the cylinder head, the other comes from the side. This is a relative expensive solution, but in combination with the small distance between the cylinders it leads to the best functional results.

In the V8, with more space resulting from its increased distance from cylinder to cylinder, it is possible to achieve similar results with a more conventional port design.

Besides the geometry of the combustion chamber, the functional characteristics of diesel engines are essentially shaped by the injection system. In addition to high injection pressure, key characteristics of these systems are speed, flexibility and long-term stability.

Bosch's second-generation common rail system is used in the new engines with injection pressures up to 1600 bar. The chart shows how the most important components of the 6 and 8 cylinder engines are arranged.

In addition to higher pressure, reduced scattering and the potential for very small pilot injection quantities, the inlet metering of the high-pressure pump is key element in reducing fuel consumption. By raising only the required quantity of fuel to high pressure, fuel consumption benefits of up to 6% are obtained in part load conditions with this latest common rail generation.

With the improved flexibility it is possible to optimise the injection strategy such that; under idling conditions we use two pilot injections and one main injection, for a significant range of the engine map good results were achieved with one pilot and one main injection and for high engine speeds, one main injection gives the best results. In other areas we applied one or two pilot, one main and an additional post injection.

According to the increased demand the capabilities of the ECU had to be enhanced significantly. In the figure, the developments over time of its specifications are shown. An increase in computing power by factor 10 compared with the predecessor, the 1 Mbyte of memory and 7800 applicable labels are impressive proof of this development.

Another feature of the reworked engines is the spontaneous preglow system. The new glow plugs are designed for 6 Volt, but for an extremely short preglow time, it is possible to overload them for a limited period, also the mass to be heated has been dramatically reduced.

This new preglow system delivers approximately 150 degrees higher temperature at the glowplug tip and occurs in less than 3 seconds.

The effect for the customer is that in the new engine there is no preglowing necessary at temperatures above minus 5° Celsius (23° Fahrenheit). The maximum preglow time at minus 25° Celsius (-13° Fahrenheit) is reduced from 9 to 2.5 seconds compared with the predecessor.

The next slide shows the intake and the exhaust system for the 6-cylinder engine.

The "dirty" air is drawn through the right hand side mounted air filter, to the compressor of the turbocharger. The compressed air travels, via a large intercooler, to the intake manifold.

The exhaust manifold is made of double-skinned steel and uses air as an insulating medium. This double-skinned structure ensures a significant reduction in weight and allows the catalyst to reach its optimum temperature more quickly. The closed coupled oxidation catalyst directly after the turbocharger ensures very low HC and CO emissions under all operating conditions.

All BMW diesel engines also have a water-cooled EGR system to reduce NOx emissions. This compact but efficient EGR cooler is located in the front of the engine.

To combine low exhaust emissions, high power output and best efficiency, we use turbochargers with variable nozzle geometry in all of our diesel engines. The 4 and 6 cylinder engines are fitted with a pneumatic actuator for the turbine housing nozzles. Whereas the V8's turbochargers are electrically actuated.

On the next chart you can see the major changes we achieved with the actual engine rework on the 6-cylinder unit.

The maximum cylinder pressure has risen from 160 to 180 bar in combination with a slight reduction in the compression ratio.

Instead of 1350 bar injection pressure we can now apply up to 1600 bar with the number of injections during one combustion cycle increased to four.

Very important for the trade-off between noise and NOx emission is a small, stable pilot quantity. The new injectors now allow pilot quantities down to 1 mm³.

Maximum boost pressure increases from 2,1 to 2,3 bar and the new turbocharger has a improved efficiency.

4. Results

With the revised 6-cylinder engine, we will raise the maximum power output in the X5 from today's 135 kW to 160 kW.

The maximum torque increases from 390 Nm to 500 Nm. This increased engine performance in combination with a newly developed 6-speed automatic gearbox improves the driving performance significantly. Acceleration from zero to 100 km/h (62mph) takes 8,8 seconds compared with 10,5 seconds for the predecessor. Maximum speed rises to 210 km/h (130mph) but fuel efficiency is maintained at 27 mpg.

When you compare this data with the 3,0 l gasoline engine in the X5, you also see a 20% lower CO₂ emissions for this diesel powered unit.

On the next slide you can see the exhaust emissions improvements in the over the last 10 years for the 6 cylinder in the 5 series cars.

Both, NOx and PM, could be reduced dramatically. The new engine has the potential to fulfill the EU4 limits for 2005. And, as we informed the press some weeks ago, in combination with a particulate filter, we will be able to reduce the PM emission close to zero.

The situation for the X5 with the 3,0 l diesel in the USA can be seen on the next chart. It is possible to achieve the EPA Bin 10 without additional exhaust after treatment and with the use of a particulate-filter it is also possible to achieve all future PM emission limits. Against this the future NOx limits are very challenging and the development of new technologies is necessary.

5. Conclusion

Modern diesel technology offers very powerful, clean and economical engines and, especially in the light duty car segment, large benefits are achievable when compared to gasoline engines.

While the HC, CO, and in the near future the PM emissions are at an extremely low level, the only remaining short term handicap of the diesel are the NO_x-emissions.

Although there are promising attempts for NO_x reduction in development, the time scale for conforming to the US legislation is very demanding.