Innovative Engine Technology – Future Directions

a report by

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The automobile has been providing individual mobility for more than 100 years. This mobility is made possible first and foremost by combustion engines drawing their power from fossil energy carriers, which, even today, provide the foundation in generating mechanical drive power in the automobile.

Created millions of years ago, these fossil carriers of energy are being burnt at an ever-increasing rate and the oxidation of carbon contained in organic compounds leads to the release of large amounts of carbon dioxide (CO_2) into the atmosphere. The primary objectives in developing drive systems are therefore to curb fuel consumption and reduce CO_2 emissions. In an effort to meet this challenge, the automotive industry is developing suitable new engines. The voluntary commitment assumed by the European Automobile Manufacturers Association (ACEA) is to reduce the fleet emission average of all newly introduced cars to 140g of CO_2 per kilometre by 2008 (see *Figure 1*).

Minimising CO_2 emissions is a demanding, high-tech process, during which development engineers must solve various conflicts of interest. The driving force in this course of development is to achieve the highest conceivable level of efficiency in thermodynamic processes. The demands and criteria that are being faced in this development are, however, very complex and even preclude each other to a certain extent.

The first objective is to minimise emission components such as hydrocarbon, CO_2 and nitrogen oxides (NOx) subject to specific limits. At the same time, manufacturers are seeking to minimise fuel consumption and, accordingly, CO_2 emissions. All of this should be achieved with a maximum standard of comfort and safety on the road.

In the homologation of motor vehicles, Europe, Japan and the US apply different driving cycles to determine emissions and fuel consumption. However, it is the individual customer who ultimately decides on his/her particular style of motoring and up to 30% of a car's fuel consumption depends on how it is driven and the style of motoring that is preferred by the driver. Clearly, the development engineer is unable to influence these external parameters – all that he/she can do is change the basic functions and control factors in the car and its drivetrain. The amount of energy required for driving a vehicle also drops with decreasing driving resistance provided by, for example, a reduction in roll and air resistance.

To make more efficient use of the energy in fuel, the actual process of using energy must reach a higher standard of efficiency.

Despite modern engine technology, the process of on-going development has not yet come to an end. Looking at the overall concept of a vehicle, the development engineer must therefore optimise the efficiency chain formed by all of the car's individual components. For example, a car with a state-of-the-art spark-ignition engine uses only about 20% of the energy consumed to actually generate driving power and mobility in the EU test cycle. This alone demonstrates the remaining potential (see *Figure 2*).

The losses that are capable of being influenced are composed primarily of the following:

- a combustion process not yet ideal;
- the charge cycle;
- friction; and
- thermal losses through the walls.

Optimisation in these areas in driving cycles with low loads and engine speeds provides the greatest improvements in fuel economy. Quite generally, steps taken to reduce the throttle effect have a greater potential for saving fuel than the reduction of friction in the drivetrain (see *Figure 3*). Precisely with this in mind, BMW has developed a fully variable valve drive referred to as Valvetronic, a system offering improvement in fuel consumption comparable in virtually all driving cycles to the latest spark-ignition engines with direct fuel injection (DFI) and lean-burn operation.

After making significant progress with electronic control and management systems in recent years, BMW have introduced new variables and combustion processes improving the properties of

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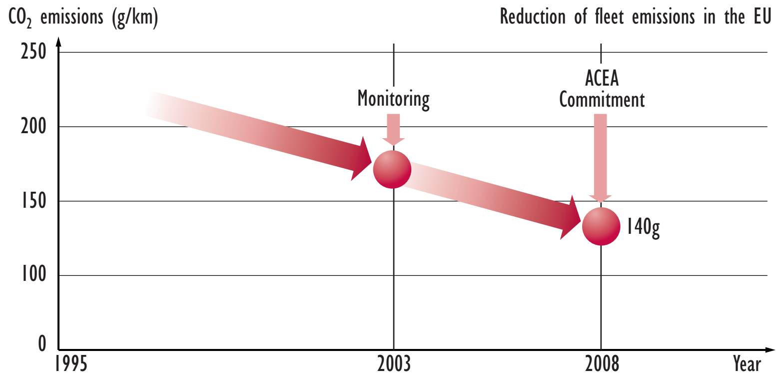
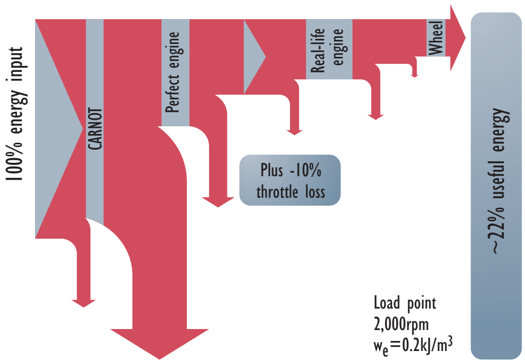
Figure 1: CO_2 Fleet Average Challenge – Commitment by ACEA



Source: European Automobile Manufacturers Association.

Figure 2: Energy Loss in the Spark-ignition Engine



BMW engines. This was the prerequisite for developing an all-new generation of spark-ignition power units. A further strategic objective in choosing the right technology was to reduce fuel consumption by more than 10% versus the former model in each case, thus making a significant move in fulfilling the obligation assumed by European car manufacturers. A number of other important items were also included in the list of objectives:

- achieving dynamic performance, fuel economy, noise management and quality typical of BMW;
- having a flexible concept capable of fulfilling future emissions standards;
- creating a benchmark product in terms of its package, weight and cost of ownership;
- taking a modular approach in order to develop specific engine variants;
- ensuring a significant potential for on-going development; and
- providing the foundation for other engine variants, i.e. communality with future engines.

All of this led to the development of a fully variable valve drive system, BMW Valvetronic, helping to significantly reduce fuel consumption while maintaining stochiometric driving conditions with all the usual advantages.

Valvetronic allows the engine to run without a throttle butterfly, the cylinder charge being determined under part load as a function of the valve-opening period. The intake and outlet camshafts are driven by variable cam adjustment, BMW's Vanos technology. A further advantage of this concept is that it allows worldwide use of the proven three-way catalyst for emissions management, thus meeting even the strictest emissions standards in the US.

Innovative technology was essential in order to reach the demanding objectives and functional requirements desired. However, at the same time, this concept demanded the utmost of the electronic control and management systems in the engine. This new development does not only involve the introduction of a new engine series, rather, the challenge was to launch an entirely new technology on a large-scale production level, at the same time making it the fundamental technology for a new family of engines.

BMW has successfully completed this quantum leap in technology, even in the light of a demanding product development process. An important task in this process is to reduce the product development period to just 30 months. This applies to all new products. A further objective is to reduce the amount of hardware required and provide a broad knowledge base for the new Valvetronic technology, the know-how acquired in this process serving to develop this technology to an even higher standard with new functions. Computer-aided exercise (CAx)-based methods and three-dimensional calculations were applied consistently in this project, ensuring successful application of the new technology in the car despite the high level of product complexity. This new mechatronic system calls for multi-parameter load management requiring the introduction of new control algorithms and new, even more efficient, engine management.

Facing such a high standard of software and hardware complexity, a manufacturer obviously also runs a greater risk of making mistakes. It is essential to acquire a sufficient stock of data under all kinds of operating conditions in order to understand how such a new system behaves. However, such data cannot be provided by the usual sequential test runs.

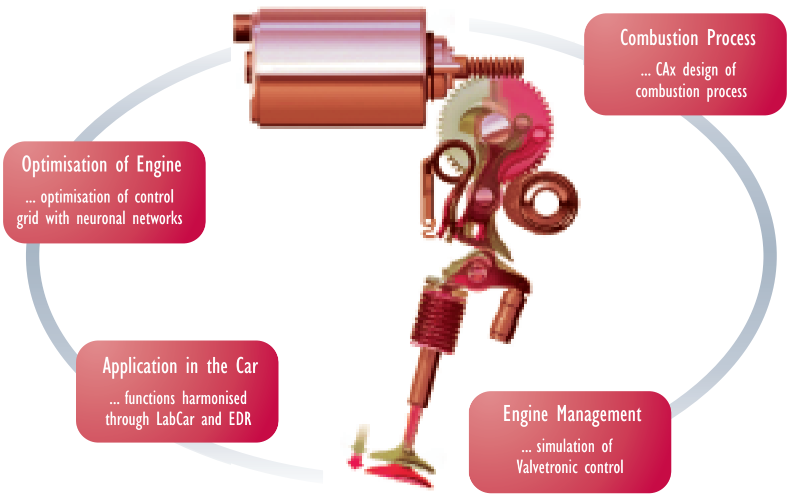
The consequence of this challenge was to introduce and implement a development data transfer philosophy subsequently checked out in various test vehicles run by various development specialists at various locations worldwide. Data compiled in this way automatically goes through the Global System for Mobile communications™ network into a database for further processing and evaluation.

The first BMW model to enter the market in 2001 with a large-production spark-ignition engine featuring fully variable Valvetronic and Vanos valve control was the 316ti Compact. In turn, the first representative of this newly developed family of engines was a four-cylinder four-valve spark-ignition power unit displacing 1.8 litres, developing maximum torque of 175 Newton metres (Nm) and maximum output of 85kW (see *Figure 4*). BMW's new Valvetronic four-cylinder power units come with 1.8-litre and 2.0-litre capacities.

Despite the reduction in engine size by 100 cubic centimetres, compared with the former generation of power units, torque is up from 165Nm to 175Nm, with output increasing from 77kW to 85kW. With displacement of the 2.0-litre engine being increased by 5%, torque was up by no less than 11% from 180Nm to 200Nm, engine output increasing from 87kW to 105kW, resulting in specific torque of 100Nm/litre and specific output of 52.5kW/litre.

The driver senses this enhanced performance through the more powerful torque curve, the car's dynamic behaviour on the road clearly proving the advantages of this extra torque. More than 90% of the engine's torque comes at just 2,000 revolutions per minute (rpm), with torque peaking at 3,750rpm.

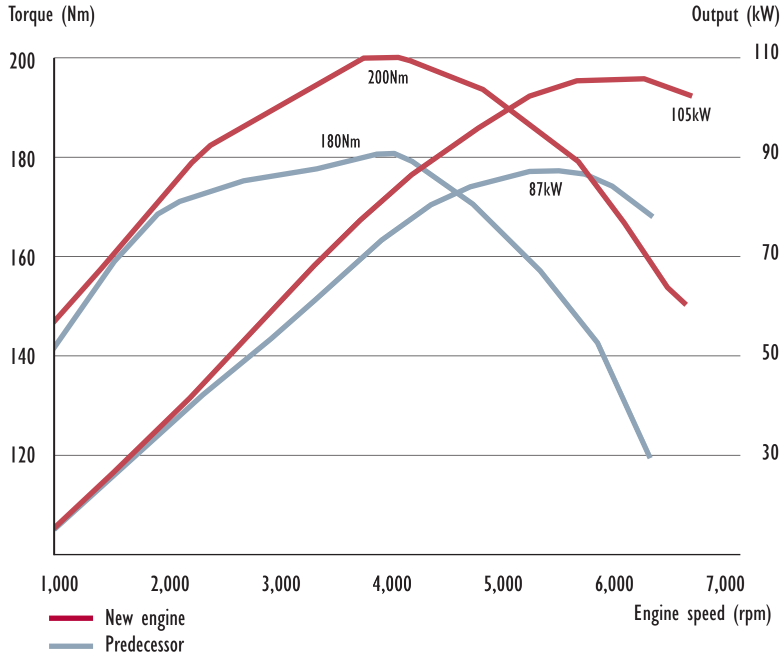
Figure 3: Valvetronic



Engine output, in turn, remains consistently at its near-maximum throughout a wide speed range.

One of the most important objectives from the start was to reduce fuel consumption. These engines offer a particular enhancement of fuel economy above all at low loads. When idling, fuel consumption is down by approximately 25% and the overall improvement in the European fuel consumption test cycle is 12%. The customer will also experience this improved economy and fuel efficiency in everyday motoring

Figure 4: Full Load Data 2.0-litre Valvetronic Versus 1.9-litre Predecessor



on the road. Using the power of the engine in full, on the other hand, the driver does not have greater fuel efficiency than with a conventional power unit. The reason for this is that, under these conditions, the engine runs like a throttle butterfly power unit with its butterfly fully open. Under normal driving conditions, however, throttle-free load management significantly reduces fuel consumption in practice.

Apart from reducing fuel consumption and fulfilling the strictest emissions standards, the targets in developing the new V8 engine were to minimise weight, improve the level of dynamic performance and offer the customer other important benefits. A further requirement was to create a V8 engine with significant potential for further development. This process of development has already commenced, with the control systems already described being joined by a fully variable intake manifold and a toothed chain used for the first time in engine management. Although the eight-cylinder is the first V-engine in this family, it shares more than 40% of common components with the four-cylinder engine.

The introduction of the world's first intake manifold providing infinite variation in manifold length serves to improve the torque level, which is already very good to begin with. A particular highlight of engines with Valvetronic load management is the significantly improved fuel/air mixture guaranteeing minimum fuel consumption, maximum spontaneity and optimum refinement. Furthermore, this V8 engine features a secondary air-control system to reliably fulfil the world's strictest emissions standards. Another important feature of the exhaust system is the newly developed air-gap-insulated exhaust gas manifold with its main catalysts close to the engine.

In summary, these innovative developments provide a combination of product features thus far inconceivable with a spark-ignition engine.

The 4.4-litre power unit develops a maximum output of 245kW with a fuel consumption of only 10.9 litres/100km (or 25.9 miles per gallon) and already complies with the EU4 standard, which does not become obligatory until 2005. The oil service intervals, in turn, have been extended up to 40,000km or 25,000 miles.

In the process of renewing the entire range of spark-ignition engines, BMW developed an all-new 12-cylinder power unit for the 760i model introduced in series production in January 2003. Displacing six litres, the new engine comes in a classic, uncompromising 60º V-configuration. It is also the first engine in the world to combine fully variable Valvetronic valve control with DFI. DFI with a stochiometric air/fuel ratio provides the highest level of specific output as well as a combustion process helping to fulfil all exhaust emissions standards worldwide.

Valvetronic combines a significant improvement of fuel consumption with excellent engine response and control, allowing optimum valve timing under all running conditions. The result is smooth and free operation of the engine under part load with very little throttle effect. Optimised fuel/air mixture management ensures significant advantages in fuel efficiency compared with a conventional four-cylinder engine, reaching the same standard as today's lean-burn concepts. Since such an engine with Valvetronic does not require an NOx removal catalyst, it can be used worldwide with all types and grades of fuel.

The greater fuel economy achieved by the new 12-cylinder engine is rounded off by the interaction of DFI and Valvetronic. On the road, with the right kind of engine control map, this means an improvement in fuel efficiency in the double-digit percentage range.

In years to come, BMW will be introducing Valvetronic in all of its engine families. All-round, general use of the latest direct-injection technology, in turn, faces some significant drawbacks such as costs, the need to make the combustion process very robust and the potentials in exhaust emissions treatment. BMW is therefore following a consistent and clear-cut philosophy of the best technology currently available not just being offered in specific models and various markets, but will be introduced worldwide as quickly as possible in all models and in all markets. ■

This article has been abridged from a longer article, which can be found in the Reference Section of the CD-ROM accompanying this business briefing.