Technical Information

– Optimization focus: Thermodynamics –

Variable valve train for greater engine efficiency—Solutions for an optimal charge exchange

Stuttgart/Germany, September 2009—Combustion engines of the future will have to be even more compact, lighter, more fuel-efficient, and cleaner. The "breathing cycle" of the cylinders—the charge exchange—will play a key role in such engines. MAHLE has developed a number of solutions for the valve train that optimize the charge exchange. Common features of these solutions include greater variability in the valve train and fine-tuning of the "breathing" to the current operating state of the engine. Alongside greater fuel economy, reduced CO_2 output, and lower NO_x emissions, these solutions also improve torque in the low rpm range, making it possible for even compact, high-efficiency engines to deliver excellent driving performance.

Today, gasoline engines are more fuel-efficient and powerful than ever before. But there's still plenty of room for improvement. By continuing to improve and, in particular, vary control of events before, during, and after combustion, it is possible to achieve even greater optimization of gasoline engines. These engines can either deliver better performance in proportion to their weight and size, or they can be built lighter and more compact while maintaining the same performance. In any case, it is essential to achieve the best possible fuel economy in a clean-burning engine. But in order for such engines to find large-scale acceptance, they must deliver excellent driving performance and remain affordable, efficiency aside: This means they must provide enough torque even at low rpms to allow on-demand acceleration of the vehicle.

Improvements in this regard can be achieved through more precise control of events taking place in the valve train. This involves adjusting the inflow of fresh air into the cylinders—an important prerequisite for combustion and for the subsequent expulsion of combustion gases destined in part for use in the exhaust gas recirculation system—to the driving condition at any given moment. Another feature of the MAHLE solutions in this area of thermodynamics is that they can be integrated into current engine concepts with only minor changes. In other words, these solutions are readily available, offer a favorable price-to-end-result ratio due to low adaptation costs, and significantly improve engine fuel economy: When intelligently combined with different engine concepts, the MAHLE technologies presented here enable fuel efficiencies of up to 17 percent.

For conventional vehicle concepts as well as modern engine concepts like hybrids, high-efficiency gasoline engines and even next-generation diesel engines will continue to be in demand as the engine technology of personal mobility. Optimal valve train technology is a fundamental prerequisite in this regard.

CamInCam® technology: two camshafts in one

In the past, there was no way to individually adjust the opening times of the intake and exhaust valves in relatively "simple" gasoline engine designs with one central camshaft in the engine block (overhead valve train—OHV) or one camshaft located above the cylinder head (single overhead camshaft—SOHC). Actuation times in these engines are fixed and therefore always present an obstacle to achieving high rated power or low fuel consumption. Because these engines exist in large numbers and many are high-displacement models, any additional freedom to adjust control times would quickly and noticeably affect the CO_2 emissions of entire vehicle fleets. With its CamInCam® (CIC) technology, MAHLE has brought variable valve technology to OHV and SOHC engines, making its series production debut in the Chrysler Dodge Viper sports car.

CIC technology can also be used to improve turbocharger response on the exhaust side of modern turbocharged four-cylinder engines. And when outfitted on the intake side of an engine with four-valve technology, CIC serves to independently control each of the two intake valves to generate a load-dependent, variable vortex in the air stream, promoting intermingling of the air-fuel mixture and thereby optimizing subsequent combustion.

CamInCam® technology combines a camshaft within a camshaft: The outer element is a shaft with fixed cams. Within this shaft, there is an inner camshaft connected to the outer shaft with adjustable lobes. This design enables independent control of the lobe separation angle between the intake cams and exhaust cams. CamInCam also offers a weight reduction of some 30 percent compared to two conventionally built camshafts. Moreover, this design requires bearings to be fitted for only one camshaft, thus eliminating the second bearing seat and also the frictional loss associated with a second bearing. And finally: Two camshafts are integrated into the packaging space of just one. Control times can be varied.

Variable timing makes it possible to achieve a number of objectives: Because the intake and exhaust time can be adjusted independently in the CIC camshaft, it is possible, for example, to open the intake valves at full load while the exhaust valves are still open. During this "big" overlap of valve opening times, fresh air purges residual combustion gases from the cylinder, cooling the combustion chamber in the process. This effect, also known as scavenging, can be utilized to achieve greater torque. In the partial load, by contrast, optimized valve timing can be used to increase internal EGR rates. Large quantities of residual exhaust gas in the cylinder have a thermal dethrottling effect on the engine, resulting in greater fuel efficiency with a concurrent reduction in NO_x emissions.

On a European-designed inline four-cylinder SOHC engine—the type found today in thousands of vehicles—MAHLE measured the following improvements on a live test bench after retrofitting the engine with the CIC camshaft:

- 16 percent greater maximum power
- 7.5 percent greater maximum torque
- 3–8 percent fuel savings and 5 percent fewer CO_2 emissions on average (from 133 g/km down to 126 g/km)
- significantly reduced NO_x emissions
- faster catalytic converter response times on cold start

In an American OHV V8 engine, a torque gain of nine percent and fuel savings up to seven percent were achieved after retrofitting with CIC.

By outfitting a turbocharged four-cylinder four-valve engine with CIC on the exhaust side, it is possible to use variable timing on the valve train to delay the opening of the exhaust valve during a large valve overlap in the low-end torque range (when the risk of turbo lag is high), thus retarding the exhaust gas pressure surge. Because the valve opening time is shorter than the firing interval of the engine (180°), the pressure surge of the next cylinder in the firing sequence misses the freshly scavenged combustion chamber and shoots directly for the turbine inside the turbocharger. When combined with the influx of scavenged air, the total mass flow increases—the turbocharger kicks in earlier and the engine generates high torque even in the low rpm range, something that was previously possible only with cost-intensive twinscroll turbochargers or two-stage pressure-charging systems. Using relatively large turbochargers and CIC on the exhaust side, a high engine output can be achieved at the same time. This opens the gates for further downsizing and downspeeding potential in turbocharged gasoline engines and therefore also additional strides in reducing CO_2 emissions.

<u>Cylinder shut-off</u>
In the partial load range, an effective strategy for increasing fuel efficiency—particularly in engines with a large (even) number of cylinders—is to shut off individual cylinders. However, the basic principle of cylinder shut-off also shows potential for four-cylinder engines. When cylinders are shut off, the associated valves are closed, and fuel is not injected into these cylinders. Therefore, the shut-off cylinders do not require the application of valve actuation

forces, and consequently, the frictional losses of the engine are reduced. The remaining cylinders operate at a higher load point, where combustion is more efficient. At the same time, the induction process is dethrottled and the ignition conditions improve. This results in reductions in fuel consumption of up to eleven percent in the New European Driving Cycle (NEDC) in six- and eight-cylinder engines.

The switchable roller-type cam follower used for cylinder shut-off was developed at MAHLE. Unlike conventional roller-type cam followers, it comprises two lever arms. In active, locked mode, this component operates like a conventional roller-type cam follower. When deactivated, the coupling bolt between the two lever arms—which normally acts as a locking mechanism—is open, and force is no longer transferred from the cam lobe to the valve. However, roller actuation between the cam lobe and the lever still takes place. This is of importance because it ensures that the friction at the contact always remains even and low, owing to physical characteristics at play here.

The MAHLE Group is one of the top 30 automotive suppliers and the globally leading manufacturer of components and systems for the internal combustion engine and its peripherals. Around 45,000 employees work at over 100 production plants and eight research and development centers. In 2008, MAHLE generated sales in excess of EUR 5 billion (USD 7.3 billion).

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