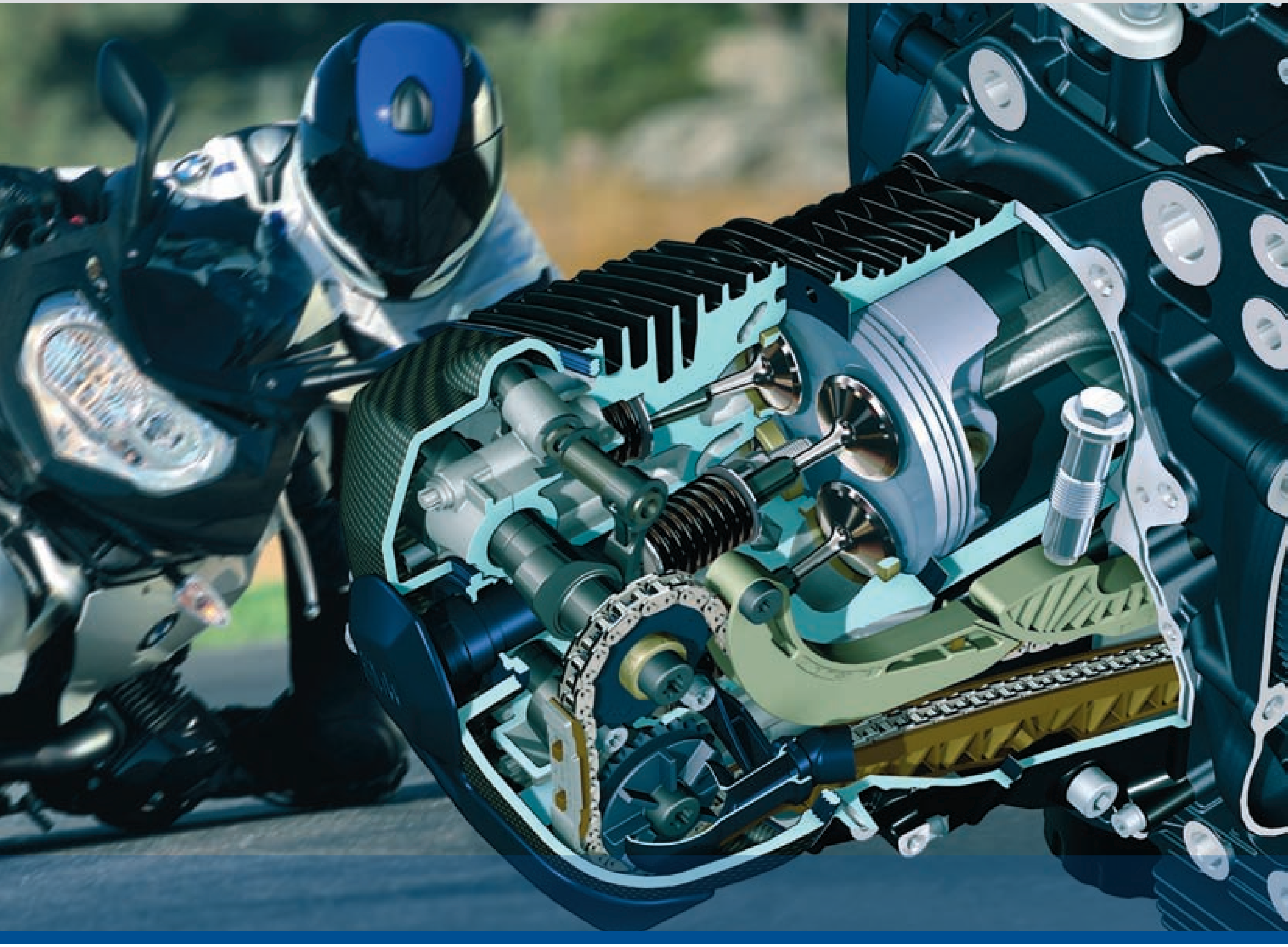

The New Boxer Engine of the BMW HP2 Sport

No other engine has dominated a motorcycle brand like the two-cylinder boxer engine from BMW. For 85 years now it has been the driving force behind a wide variety of motorcycles. As the power behind the BMW HP2 Sport, the completely redesigned engine with newly developed DOHC cylinder heads ensures a strong torque in the lower rpm range, continuously rising peak performance and a broad usable rpm band. The performance capabilities of the concept have been proven with prototypes during the Endurance World Championship. The experience gathered there has been incorporated directly in the HP2 Sport. This makes the BMW HP2 Sport the strongest, most sporty Boxer of all time from BMW Motorrad.

1 Introduction

Notwithstanding the limits for engine performance because of the principles applied and the disadvantages in terms of aerodynamics due to the layout of Boxer cylinders, BMW Motorrad has consciously decided to develop this long-standing engine concept for a street sports bike with the capabilities of a racer. A completely redesigned four-valve cylinder head with double overhead cam shafts enables the moved mass in the valve train to be reduced while at the same time increasing the size of the valves, opening up new opportunities in terms of charge exchange and rpm performance. A slightly radial arrangement of the valves with finger followers and conically shaped cams enables a central spark plug to be accommodated. Requirements in terms of mechanical stability for the revised timing drive and the basic engine with its unchanged shaft layout pose an enormous challenge. The greatly increased thermal stress makes optimized oil cooling necessary and ensures the stability of the cylinder head. One of the major challenges was the charge exchange because the port design was subject to a number of geometrical constraints. Sophisticated optimizations of the intake port, the combustion chamber and improvements in the preparation of the mixture nonetheless permit high mean effective pressure, excellent fuel consumption figures and low emissions. An optimized airbox system, adjusted throttle valve housing, new exhaust system with exhaust valve and a newly applicated motor management yield excellent engine response in a very broad usable speed range with a much higher torque in the lower speed range and increased peak performance. A refined, emotionally appealing sound, allied with moderate vibrations underline the general characteristics of this engine.

2 Basic Engine Concept

The basis for the development of the basic engine was provided by the engine of the strongest boxer motorcycle to date, the R 1200 S. The objective was to re-use the fundamental layout and features. This applies, for example, to the stroke/bore ratio and the layout of the shafts in the crank housing. The key engine parameters in comparison with the engine of the R 1200 S are shown in **Table 1**.

2.1 Crank Case, Crank Gear, Mass Balancing Mechanism

It was possible to keep the necessary changes to the vertically divided die cast

Table 1: Main technical data

		R 1200 S	HP 2 Sport
Design	Flat twin	2-cylinder	2-cylinder
Displacement	ccm	1170	1170
Bore/Stroke	mm	101 / 73	101 / 73
Cylinder spacing	mm	42.4	42.4
Number of valves	–	4	4
Valve angle IV/EV	°	19 / 22	Radial
Diameter IV	mm	36	39
Valve lift IV	mm	10.73	10.86
Diameter EV	mm	31	33
Valve lift EV	mm	10.73	10.97
Main bearing diameter	mm	60	60
Conrod big/small end bearing diameter	mm	48 / 22	48 / 22
Conrod lenght	mm	125	128.1
Max. engine speed	1 / min	8800	9500
Average piston speed	m / s	21.4	23.1
Compression ratio		12.5	12.5

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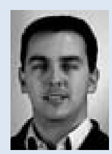

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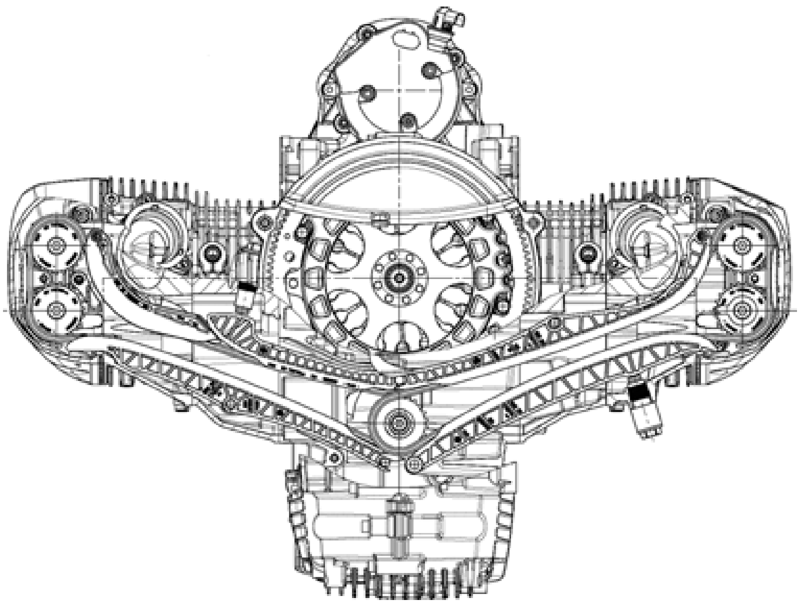

Figure 1: Engine cross-section

aluminium crank case so small that there was no need for a new die cast mold, **Figure 1**. Because of the new cylinder head design and need to increase the thickness of the cylinder liner wall due to the increase engine speeds, the cylinder studs had to be moved outwards and shortened. Partial increases in wall thicknesses were also necessary. The cylinders also had to be adjusted slightly in the area of the chain drive so as to make space for the new timing drive. Because of the optimized thickness of the liner wall and the adjusted cylinder bolt positions and screw forces, the result is a cylinder face that has very little warping, so that the oil consumption is very small. The minimum-friction Nicasil coating was retained.

The bore diameter of 101 mm and the 73 mm stroke were also retained. It was possible to re-use the crankshaft without changes, while the same went for the main bearing and conrod bearing. The conrod, which is subject to much greater stresses is a new design made from the high-strength crackable material 36MnVS4. The forged piston with reduced compression height enables the length of the conrod to be increased by 3,1 mm, **Figure 2**. The tried-and-tested method of mass balancing using a balance shaft in the engine‘s auxiliary shaft was retained, although the bearing concept was modified. The front bearing in the engine cover was placed inside the auxiliary shaft, creating a „shaft-in-shaft“ bearing. This does away with the need for the previous bearing point in the front engine cover.

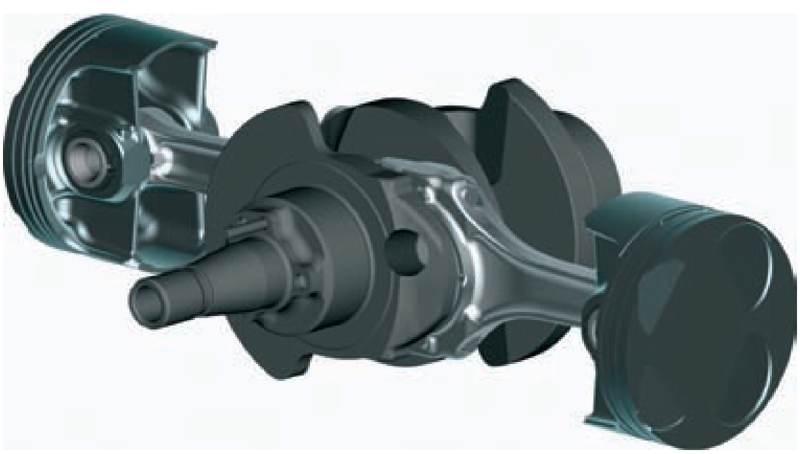

Figure 2: Crankshaft, conrod and piston

2.2 Cylinder Head, Valve Gear, Control Gear

It was only possible to meet the requirements for significantly improved charge exchange by completely redesigning the timing and valve drive, **Figure 3**, and cylinder head, **Figure 4**. Considerably enlarged valves and a valve lift and lift pattern adjusted to thermodynamic requirements could only be shown with actuation by means of a cam follower and two higher cam shafts. The design permits a maximum speed of 9,500 rpm and offers sufficient reserves for over speeding in the event of shift-ins. The valves are arranged in a radial layout to create space for the central spark plug. Consequently the cams are conically shaped. Because of the horizontal flow through the cylinder head, the intake cam and the exhaust cam is placed on one cam shaft.

The finger followers, which are also arranged in a radial layout, have already proven themselves in several BMW Motorrad engines and their small moving mass ensure optimum dynamic conditions. As a result of this and due to the DLC coating on the investment-cast follower, the friction loss on the valve gear is very low. The cam shafts are carried in a cam shaft bearing screwed to the cylinder head. The FEM-optimized cylinder head/cam shaft bearing module ensures that there is very little distortion of the bearing holes, and therefore the friction and wear and tear are kept low. The valve shaft diameter is 5.5 mm. The intake valve is a solid shaft valve, while the output valve is hollow with a sodium pellet inside. The small dimensions of the valve ensure bearable forces when touching down, while the nitration guarantees the necessary friction resistance. An extremely friction-resistant sintered material in the valve seats leads to excellent tribological behavior by the valve/sit-ring pairing and only causes minor changes in the valve clearance in the maintenance interval. Because of the ergonomic design of the vehicle as a whole, the position of the throttle valve housing and thus the intake flange of the intake ports in the cylinder head had to be retained. Together with the necessary banking freedom, this resulted in very congested and difficult conditions for the chain drive. Small chain wheels with minor slippage on the cam shafts are thus unavoidable. Multi-body simulation with flexible elements enabled a careful, dynamic layout of the tension and guide tracks (some of which involved two parts and two components) for optimum rigidity, as well as the hydraulic chain tensioner and a lasting, friction-optimized and low-noise control assembly. Overall the basic layout of the engine allows a very appealing and unassuming sound from the entire engine mechanism thanks to the extremely quiet valve drive.

The increase in performance and speed also causes the heat input in the cylinder head to rise dramatically. In order to keep the component temperatures within a reasonable range both for mechanical stresses and for the charge exchange and combustion, it was necessary to dramatically intensify the oil/air cooling of the cylinder head, **Figure 5**. Coupled FEM/CFD simulations [2] were used to revise the precision coolant channel in the cylinder head with the aim of complying with the permissible temperature values and material stresses under all operating conditions.

In order to stabilize the top of the combustion chamber around the spark plug the diameter of the spark plug was also decreased to 10 mm and the screw engagement length was increased to 18 mm. Thermally sensitive primary alloy AlSi7Mg was chosen as the material for the gravity-cast cylinder head. This has high temperature strength, particularly in the high temperature range, and a high thermal conductivity in comparison with other cylinder head alloys, which is particularly beneficial for the component temperature in the area of the spark plug.

2.3 Oil Circulation System, Crank Case Ventilation, Friction

It was largely possible to retain the tried-and-tested oil circulation system with integrated dry sump – all that was necessary was to raise the oil pressure slightly by half a bar and to increase the oil intake holes for the main bearings in order

Figure 3: Valve train

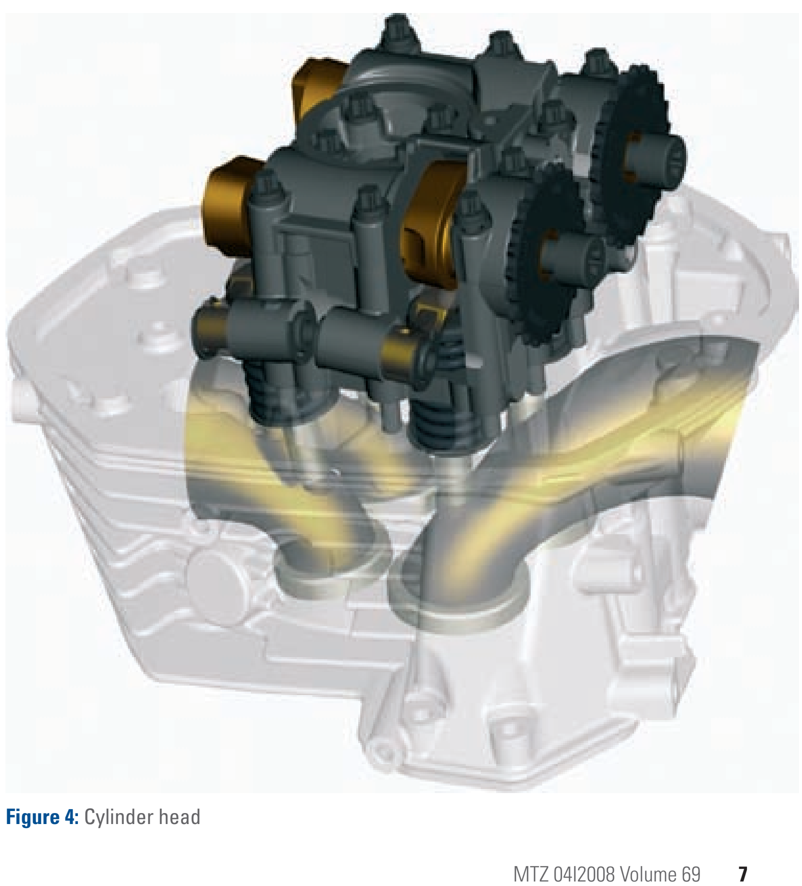

Figure 4: Cylinder head

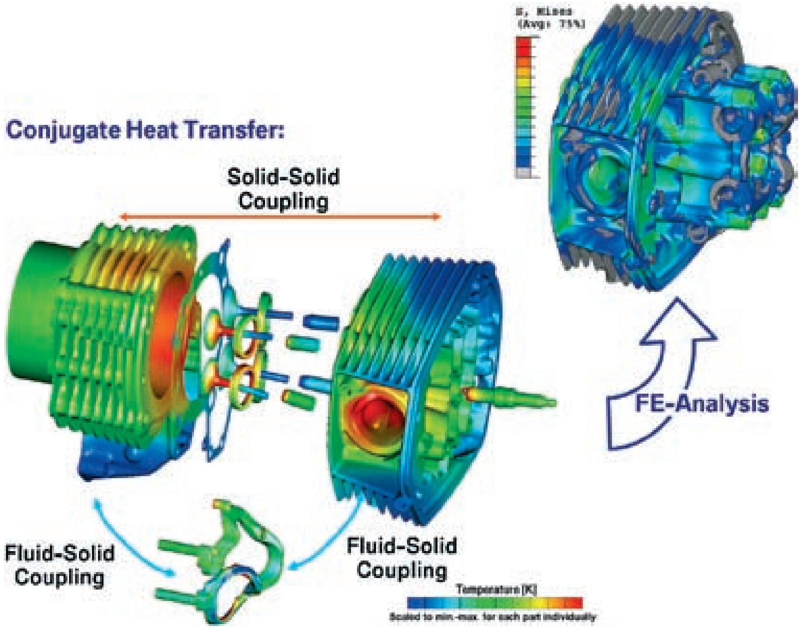

Figure 5: Cooling oil jacket

to meet the higher requirements resulting from the increase in speed. The crank case is ventilated in the usual way by means of a centrifugal disk, while the blow-by gases are channeled through a continuously rising line into the plenum chamber. The already familiar separation of the crank case from the oil chamber by a diaphragm valve, **Figure 6**, offers further benefits, through low level pump losses and oil foaming, particularly at high speeds.

Overall it has proven possible to retain the excellent friction performance of the original engine and the improvements in the valve gear are balanced against slight deterioration in the chain gear, while the rise in friction and pump losses in the speed ranges over 8,600 min-1, not considered before, are as expected.

3 Charge Exchange, Combustion

The general construction conditions described require an asymmetrical intake channel in the cylinder, which also features a strong deflection from the throttle valve housing to the flow into the cylinder, **Figure 7**.

The consequence is an asymmetrical distribution of mass flow on the two intake ports [3]. Because of the required leg room, the injection valve injects across the intake valves, so that it is not possible to distribute the injected fuel specifically to the upper and lower intake tubes in all load ranges, but rather the penetration depth of the droplets changes in accordance with the load and speed, also changing the formation of a film on the chamber wall and therefore the distribution of the mixture to the individual ports. A further difficulty arises because of the long injection times required to supply sufficient fuel for the individual lift volumes of almost 600 cm^3 with just one nozzle at almost standard fuel pressure conditions. The roughly 12 % higher load mass in the upper intake tube, **Figure 8**, during stationary flow and the tangential flow in the lower intake port lead to contrary swirling flows in the cylinder, although a pronounced tumble does not occur, **Figure 9**. Despite the deficits in the distribution of mixtures, this generally leads to good combustion, **Figure 10**, and is thus responsible for the good torque in the lower speed range.

The large valves, the valve lifts and control times and massive de-throttling of the aspiration and exhaust system facilitated by the rigid valve drive still achieve passable filling at high speeds, despite the disadvantageous flow, but cannot completely compensate for the package-related disadvantage in the port guide. In addition to the disadvantages when filling at high speed, the now indifferently weak charging motion leads to long combustion and late centers of combustion mass.

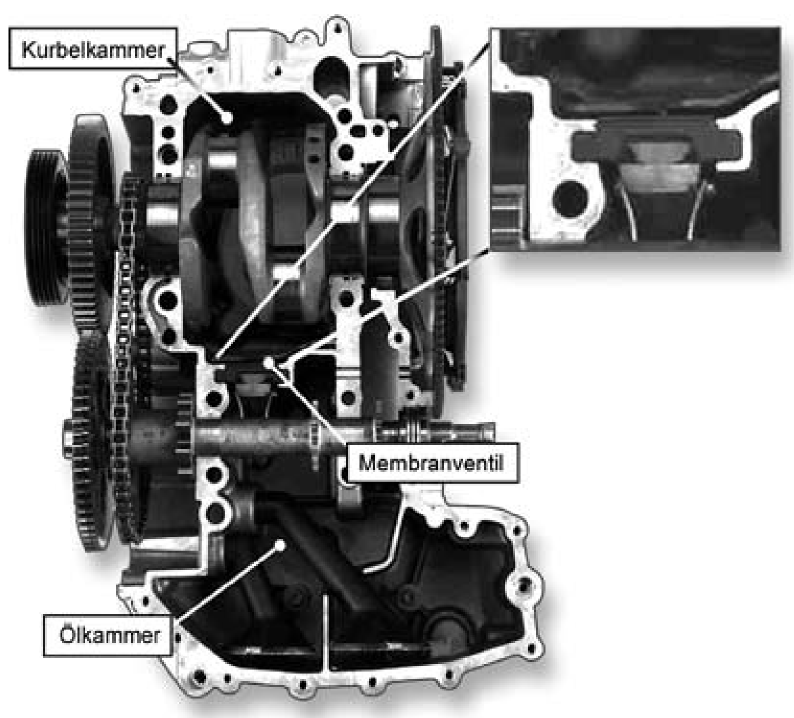

Figure 6: Crank case/oil sump seperation, reed valve

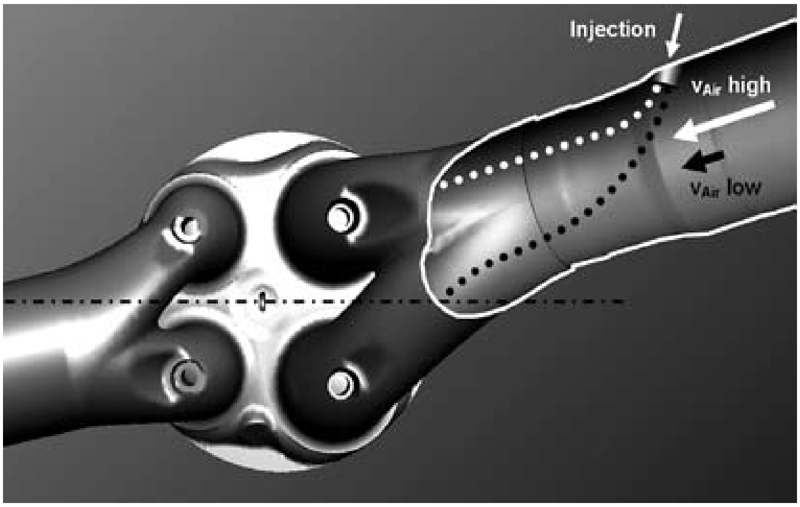

Figure 7: Spray penetration for different mass flows

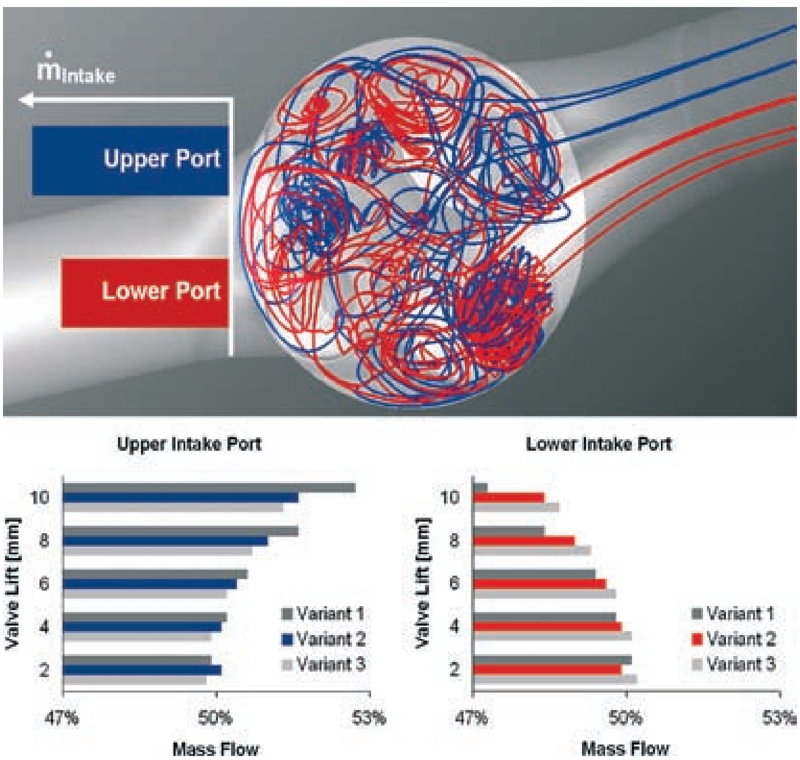

Figure 8: Mass flow intake ports

4 Engine Peripherals

4.1 Aspiration System, Fuel System, Throttle Valve Housing

The aspiration in the vehicle takes place at a cool point in the back pressure area at the front of the fairing. The lengths and diameters were coordinated though charge exchange calculations and the system was de-throttled as technically possible. The injection valves, whose through-flow was adjusted to the higher requirements, sit inside the throttle valve housing, which has a diameter of 52 mm. The valve is linearly activated by means of a pulley. The fuel supply is by means of an in-tank pump and features a system pressure of 4 bar.

4.2 Cooling System

Much of the heat is naturally dissipated through the surface of the engine and cooling fins on the cylinders and cylinder heads. The increased cooling required for the engine oil as a result of the optimized transmission of heat in the cylinder head is assured by a twin-row shell oil cooler. This ensures oil temperatures of about 140 °C even at full load.

4.3 Exhaust System

The exhaust system, **Figure 11**, is divided into a manifold with interference pipe, Cat Box with catalytic converter and silencer with exhaust valve. The pipe lengths of the manifolds to the Cat Box, which determine output, were again adapted to the overall system by calculating the transfer of charge. The current manifold lengths represent the optimum for attainable shaft dynamics in the available space between the cylinder outlet and the positioning of the catalytic converter as far back as possible in front of the rear wheel. The position and cross section of the interference pipe were also kept in the lower speed range in terms of idling and torque pattern by trial and error. The most complete de-throttling possible was required for good filling in the back end. The increase in the exhaust back pressure was kept as small as possible by means of a 105 x 74.5 mm metal bed catalytic converter with 200cpsi and a reflection silencer with two chambers. The key design criterion was the achievement of a sound suited to the segment. At the same time, compliance with the noise abatement regulations is ensured by an exhaust valve activated by an actuator.

A racing exhaust system is available for use in competitions or on closed tracks. Because the catalytic converter can be omitted in this case, the manifold length, which dictates the shaft length, can be optimized, improving filling. The further reduction of flow resistance leads to further increase in performance and to a flattening of the torque pattern in the medium speed range. The use of titanium yields a weight reduction of over 2 kg.

5 Functional Properties

5.1 Performance and Torque, Drivability

The key element in increasing performance was the described redesign of the valve gears. This means that valve accel-

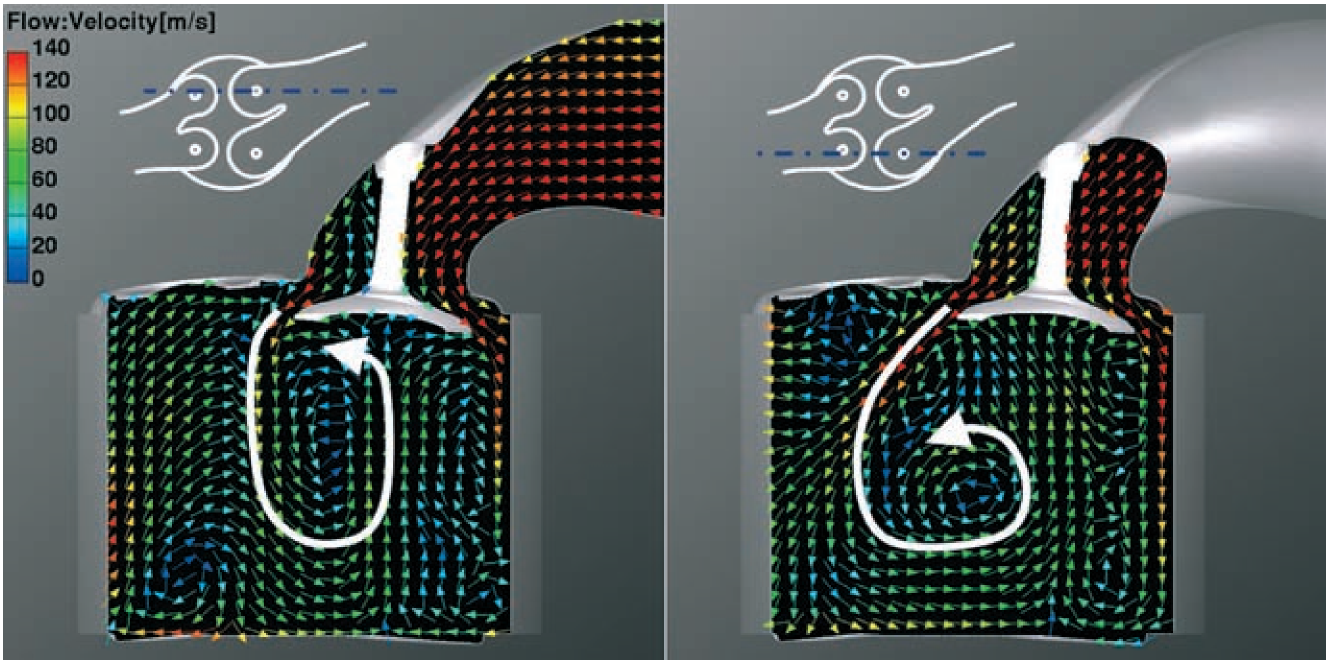

Figure 9: Flow pattern, intake stroke, piston in BTDC

erations of up to 70 mm/rad² are possible. The consequence is correspondingly full, yet speed-resistant valve lifts.

Naturally, particular attention was paid to optimizing flow in the intake port, which was developed in several iteration loops through calculation and blow trials. In its final form, the intake port is fully machined to minimize tolerance spread. The valve guide on the side facing the channel was reduced as much as possible while still maintaining mechanical durability, so as to further improve flow coefficients. Compression is 12.5 : 1. The design of the combustion chamber and quench areas in conjunction with a knock control system also allows fuel with ROZ 95 to be used, although performance is reduced.

The stationary performance achieved is over 10 % higher than R1200S, **Figure 12**. The open racing version is approx. 5 % better again. This is particularly noticeable because of the very high engine torque in the lower and medium speed range due to the special features of the charge exchange. It was possible to dramatically improve the slight decrease in torque typical of large-volume twin-cylinder engines in the medium speed range, while this was completely eliminated in the version with racing exhaust system by optimizing the exhaust tract.

In addition to sheer performance, the key elements in drivers' perception are excellent dosage control and response from thrust and partial load. Specially developed functions have been integrated in the engine control software devel-

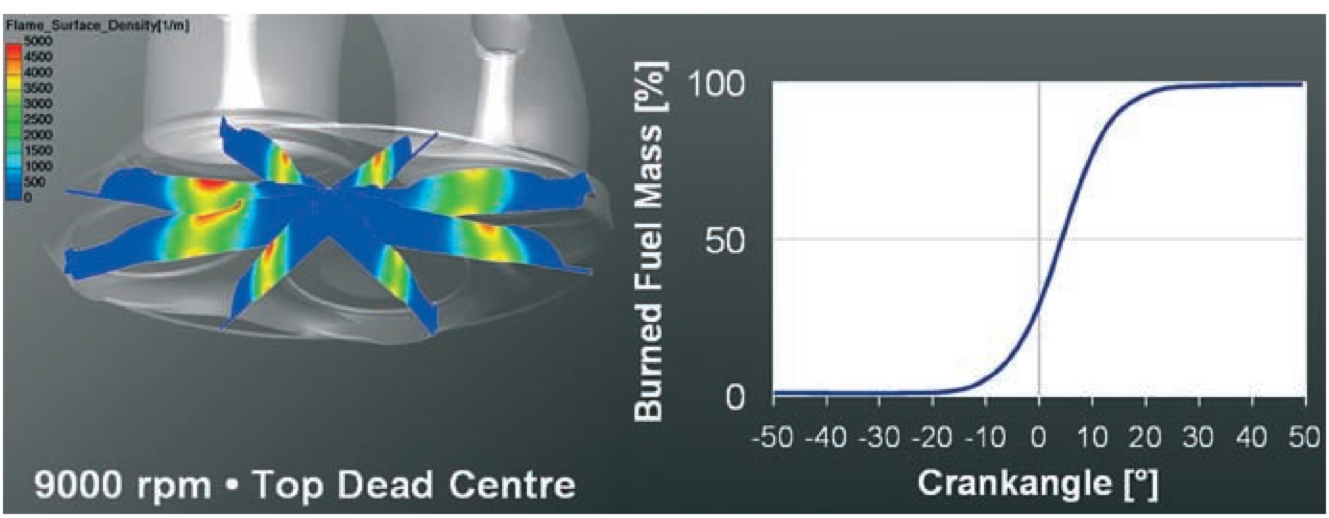

Figure 10: Flame surface density and combustion at 9000 rpm

Figure 11: Exhaust system

oped by BMW Motorrad for this purpose. It was possible to omit the twin ignition familiar from standard engines because the small amount of residual gas due to the charge exchange layout enables an acceptable level of cycle variation to be achieved for the application, so that a constant surge is also possible with single ignition.

5.2 Fuel Consumption and Exhaust Emissions

The implemented performance-enhancing measures are certainly not counterproductive when it comes to emissions and consumption. All boxer models from BMW Motorrad draw attention to themselves for their excellent fuel consumption figures. The HP2 Sport is no exception. The ignition and delay angle are optimized in terms of consumption, exhaust and drivability, despite contradictory influences. Additional special functions also enable excellent response even in long thrust phases. Comparative measurements both in the exhaust-related cycle and on the open road indicate a level comparable with the R 1200 S and R 1200 R. Because of a wide range of functions in the engine controller, the two lambda sensors and the temperature-stable catalytic converter with Trimetall coating, the exhaust values are much lower than the limits set. The catalyst function is sufficient for high operational performance.

6 Summary

The BMW HP 2 Sport from BMW Motorrad is the sportiest, strongest and, at the same time, lightest boxer of all time. The capability of the air-cooled boxer concept has also been demonstrated in international endurance racing (open class winner in the Endurance World Championships 2007). This further underlines the versatility of the Boxer concept. This is the first time that speeds of 9500/min and output of 98 kW have been achieved on a sustainable basis, as well as being approved for road use. The special features in charge transfer and the combustion of the boxer engine were particularly apparent in the motor sports application when probing the potential of this concept. Intensive development work was required in order to achieve balance both in torque/response and drivability. The understated sound from the basic engine and an emotionally attractive charge transfer- and exhaust system noise underline the sportiness and superiority of the vehicle, which is an exhilarating drive, on both the street and the racetrack.

References

[1] Peter Mueller, Franz Berkmann, Joerg Schneppenheim „Die neue BMW HP2 Sport", ATZ 03/08
[2] Dr.rer.nat. Dipl.-Ing. Achim Gordner, Dipl.-Ing. Dr. techn. Georg Unterweger, Dipl.-Ing. Dr. techn. Christian Landerl "Conjugate Heat Transfer including Solid-Solid Coupling" MTZ Conference – Simulation 2007 "Virtual Powertrain Creation" München, 2007
[3] Dr.-Ing. Peter Bohn, Dr.-Ing. Joachim Post, Dipl.-Ing. Dr. techn. Georg Unterweger, Dipl.-Ing. Dr. techn. Christian Landerl, Dipl.-Ing. Markus Märkl „Simulation instationärer Ladungswechselvorgänge am Zweizylinder-Boxermotor" 11.Tagung „Der Arbeitsprozess des Verbrennungsmotors" Graz, 2007

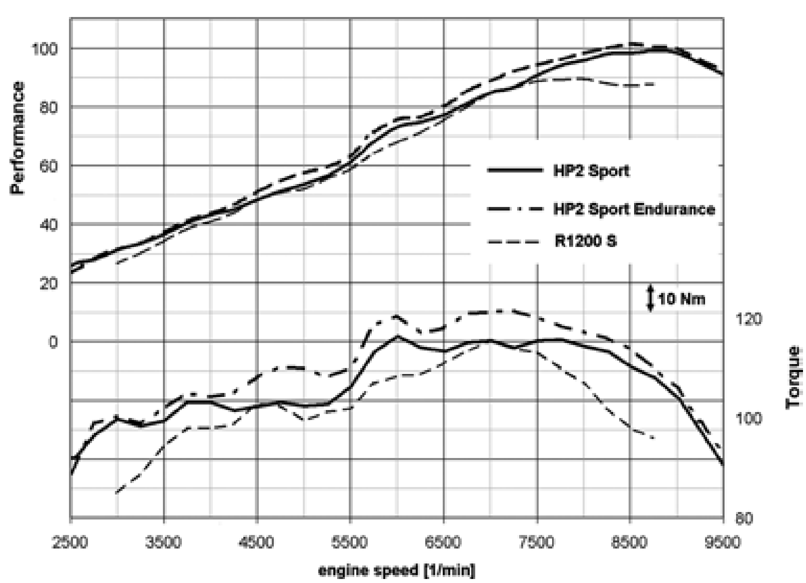

Figure 12: Comparison of full load curves