Ricardo Motorcycle
Conference 7.0

Dream six

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Dream SIX

RQ MOTORCYCLES & PERSONAL TRANSPORTATION

Soon after winning a contract to upgrade the BMW four-cylinder motorcycle engine family in 2006, Ricardo was awarded an even more prestigious task – to design a new, six-cylinder engine, from scratch, to power a new, best-in-the-world sports tourer. **Jesse Crosse** takes up the story.

Designing a new sports touring motorcycle will always be a challenge, but designing a radically new one to be the very best in the world is a tougher one than most. So for its new top of the range 1600GT and 1600GTL bikes, BMW Motorrad drew inspiration from the heritage of its automotive sister by choosing a straight-six engine configuration that would deliver a level of refinement unmatched by any four-cylinder motorcycle engine in existence.

Although a number of six-cylinder motorcycles have appeared over the years, they are rare – and the length and bulk of these engines presents major challenges when it comes to packaging and handling. The new BMW would be no American-style straight-road cruiser: instead, it would need to offer world class levels of agility, handling and steering.

Ricardo has enjoyed a close relationship with BMW Motorrad for a number of years and had already undertaken a number of smaller motorcycle projects for the Munich-based manufacturer. Then in 2006 Ricardo was invited to re-engineer the four-cylinder K1200 engine to produce a new family of K1300 motorcycles for 2009 [*see RQ Q2 2009*]. It was a substantial task, quickly and successfully undertaken by Ricardo drawing on expertise at its sites across Europe in the UK, the Czech Republic and Schwäbisch Gmünd in Southern Germany.

Yet even while the K1300 development was still underway, Ricardo

was awarded a top-secret project to support the design of a new, compact, lightweight six that would rewrite the rulebook of motorcycle engine design. Remarkably, perhaps, Ricardo was awarded the six-cylinder project almost in parallel with the four-cylinder. The two programmes ran in tandem, the six cylinder work benefiting from experience gained during the early design activities with BMW on the K1300 programme. Again, the project was directed from Ricardo's division in Schwäbisch Gmünd, where the top end of the engine was also designed. The bottom end was designed at the Shoreham and Prague Technical Centres, with the gearbox designed and produced at the Midlands Technical Centre in Leamington, England. The procurement, build, development and validation testing of the engine were all carried out in Schwäbisch Gmünd, together with BMW. The later stages of the programme such as refinement of the engine in the vehicle, smooth driveability, engine management application and industrialisation were BMW's responsibility.

Key targets were smoothness, impressive fuel economy and NVH characteristics, driveline refinement and shift quality; substantial engine torque (175 Nm) would take precedence over outright power. While six cylinders would be ideal for delivering the exceptional levels of refinement for which BMW is famous, the bikes would still need to corner well: with the six-cylinder engine arranged transversely in the frame, guaranteeing sufficient ground clearance would pose a challenge from the outset. Earlier in-line six-cylinder bikes had been too wide, and manufacturers eventually confined themselves to a maximum of four cylinders for that reason. The target weight for the power train was also challenging, important not just for the agility and handling, but for fuel consumption too.

Packaged to minimize width

The vehicle package layout allowed for six cylinders inclined forward, much like the four-cylinder K1300 engine, the basic vehicle layout being similar to the proven and very successful K1300GT bike.

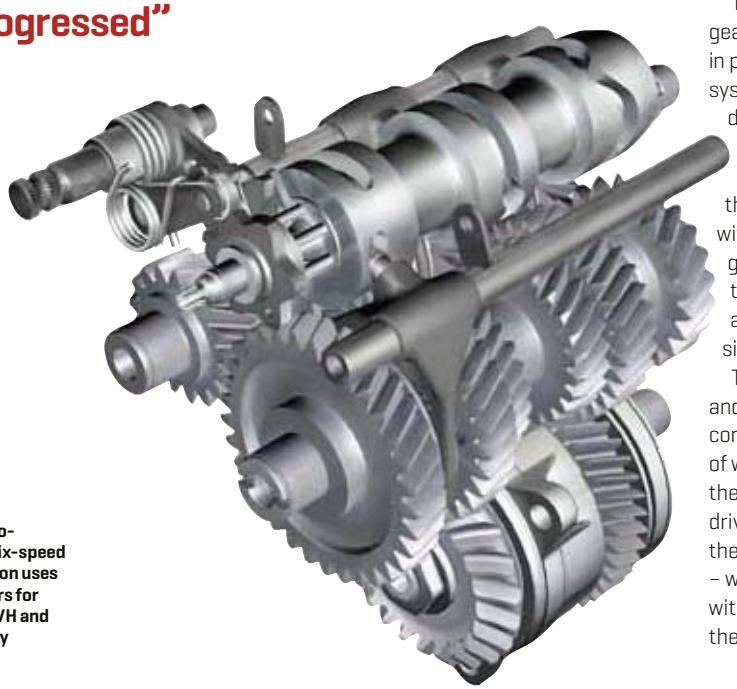
"Ricardo was selected as a partner primarily on account of the fact that the development philosophies of BMW Motorrad and Ricardo are very similar. This was confirmed as the project progressed"

Heinz Hege,
project leader,
powertrain,
BMW Motorad

The project began with detailed concept layout drawings from BMW, outlining how the engine should look and defining the basic package for the engine. "We worked very closely with the BMW team to achieve the look they wanted as well as the technical targets," explains the Ricardo project chief engineer, Paul Etheridge. The four-cylinder is already a proven package from the point of view of ergonomics, weight distribution and power delivery, so it made sense to maintain those essential characteristics. But surprisingly, the 160 hp six-cylinder 'drive-by-wire' engine is very pure in its design and, although it has four valves per cylinder, the cam timing is fixed and the cylinders are fed through a single throttle body with multipoint injection and long ram pipes. This helps to promote torque and flexibility. This is an ideal configuration for a touring bike, which must deliver fuss-free and accessible performance to the rider for hours on end.

The engine drives through a six-speed gearbox with the usual dog engagement in preference to the synchromesh system found in cars. The gearbox is designed as a separate module which can be removed without the need to split the engine crankcase. Rather than being straight-cut in common with most other motorcycles, the gears are helical like those in a car transmission. This design is quieter and leads to a lighter gear shift, both significant benefits for a touring bike.

To achieve the ultimate in refinement and shift quality there are three compliant elements in the driveline, two of which are a torsional spring pack in the clutch and a torsional damper in the driveshaft. There is a third, too, inside the gearbox and fitted to a third shaft – which means the gearbox is equipped with a total of three shafts rather than the usual two. In the later stages of the



The Ricardo-designed six-speed transmission uses helical gears for superior NVH and shift quality

programme the gearbox was redesigned by the production supplier to suit their specific manufacturing requirements.

The overall package is very compact, especially across the width of the bike. Normally, the crankshaft length of a six-cylinder engine would mean having a torsional vibration damper (TVD) fitted within the shaft or at its end. But Ricardo was given precise specifications based on the maximum lean angle of the bike, which placed a restriction on the length of the crankshaft and also the size of any counterweights incorporated in the webs of the crank. One way of minimizing width is to keep the bores small and close together, and in this case they are separated from one another by only 5 mm.

Repositioned ancillaries

Ancillaries like the alternator and starter drives that would normally be mounted on the end of the crank are mounted behind the engine in a cassette assembly. This is easily removed for servicing and driven by a separate drive from the back of the clutch. Yet it was clear that some advanced crankshaft design would be necessary to meet the required targets. Six-cylinder car crankshafts always have TVDs fitted and the longer the crankshaft, the more torsional vibration it is likely to suffer. Resonances that can be noisy or damaging to the crankshaft always appear somewhere in the speed range, so the team knew they were faced with an unusually difficult task. To keep the natural torsional frequency of the crankshaft high and out of the usable speed range, a good approach is to minimize the size of the counterweights. Larger counterweights would only lower the natural frequencies and amplify torsional vibration, but counterweights do two important jobs – they reduce the loading on the individual main bearings and also prevent bending of the crankshaft. So there is a trade-off and a compromise to be found – something that was achieved with extensive analysis using Ricardo's ENGDYN software.

The crankshaft was originally designed to be manufactured using the 'forged flat and twisted' method, but Ricardo liaised with suppliers to adopt the 'forged in position' method. This, while more complex, gives a better-quality end result.

Efficient combustion

The valve train is a four valve per cylinder, double overhead cam system. Designed for simplicity and robustness, it is a very straightforward 'direct attack' layout with chain-driven camshafts and the cam lobes acting on graded bucket tappets. The cams are made of built-up, hollow steel, designed in this way to save weight, a unique feature on a motorcycle engine.

The camshaft profiles are not an

Co-operation with Ricardo: the BMW view

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BMW provided detailed information (specifications for suppliers / drawings / 3D models) in which the engine package and the installed position in the motorcycle were described. Ricardo bore sole responsibility for designing and modelling the basic engine including gearbox and clutch, but the work was carried out in close co-operation with BMW. Some important Tier 2 suppliers were integrated into development; production-related boundary conditions were agreed with these parties. Ricardo also bore responsibility for procuring and building the prototype B0 engines (10 parts sets) and the B1 engines (20 parts sets). Functionality and durability were tested on the engine test beds in Schwäbisch Gmünd and, partly with assistance from BMW, the basic Motronic application and power development were progressed.

Development of the intake and exhaust systems and the vehicle cooling were BMW responsibilities, with optimization being undertaken in close contact with Ricardo's modelling results. B1 engines were installed in vehicles (10 off) at BMW, and BMW used these vehicles to conduct functional trials and endurance tests in the course of which areas for further development emerged in the oil supply, engine acoustics, and in the durability of the gearbox.

Pre-release of the component drawings for the basic engine (not including gearbox and clutch - BMW continued modifying these components together with the series suppliers) marked the conclusion of Ricardo's involvement in development. The task of incorporating minor adjustments into the drawings up to production release was entrusted to a Ricardo designer. Further development and preparation for industrial production from pre-release onward was continued by BMW, with the major issues being the optimization of engine operation, engine acoustics and power development.

Co-operation with Ricardo was very positive overall. It was characterised by mutual understanding and trust. The durability of the basic engine components designed by Ricardo was always unproblematic; component rig tests and endurance runs received positive confirmation with series-production parts. Even closer co-operation would be desirable for future projects, with a higher degree of interaction between designers / test engineers. Similarly, responsibility for development activities up to series-ready status (production release) should be shifted more effectively to Ricardo for future projects."

Heinz Hege
Project leader, powertrain,
BMW Motorrad

Technical data: BMW 1600GT/GTL

Engine

Type	Oil/water cooled 4-stroke in-line 6-cylinder engine, two overhead camshafts, four valves per cylinder
Bore x stroke	72mm x 67.5mm
Capacity	1,649cc
Rated output	160 hp at 7,750 rev/min
Max. torque	175 Nm at 5,250 rev/min
Compression ratio	12.2:1
Mixture control /engine management	Electronic intake pipe injection, digital engine management (BMS-X)
Emission control	Closed-loop 3-way catalytic converter, emission standard EU-3

Performance / fuel consumption

Maximum speed	Over 200 km/h
Fuel consumption per 100 km at constant 90 km/h	4.5L (GT) 4.6L (GTL)
Fuel consumption per 100 km at constant 120 km/h	5.7L (GT) 5.9L (GTL)
Fuel type	Unleaded super, octane number 95 (RON)

Electrical System

Alternator	Three-phase alternator 580W
Battery	12V/19Ah, maintenance free

Power transmission

Clutch	Multiple-disc clutch in oil bath
Gearbox	6-speed, helical gearbox
Drive	Cardan Shaft

The new 6-cylinder engine goes into production at BMW

'aggressive' design, says Etheridge, but have been designed to be as efficient and durable as possible – as befits a touring bike engine. Valves sit in a well-proven pent-roof design of combustion chamber and the inlet ports are not symmetrical, but narrow towards the rear of the engine to fit the external dimensions of the engine and vehicle package.

Cylinders are Nikasil-plated with a slightly over-square bore and stroke of 72 mm x 67.5 mm. The engine was designed with a dry sump in order to keep the centre of gravity as low as possible but, unlike the four-cylinder K1300 engine which has a plastic oil tank behind the engine, the new six has an integral oil tank inside the crankcase. This gave BMW more opportunities with the motorcycle package.

Efficiency was the watchword throughout the development programme, with the choice of bore and stroke yielding an effective surface-to-volume ratio for optimum combustion characteristics. A six-cylinder engine is inherently smooth and, unlike a four-cylinder, requires no balancer shafts to achieve high levels of refinement. This reduces frictional losses and gives fuel economy benefits.

Substantial task

While the four-cylinder programme was an upgrade, the clean-sheet design of the six was clearly a much more substantial task. Ricardo had full responsibility not just for the design of the six, but also the development during two stages of prototyping. The task was to deliver prototype engines in two separate phases; also included was all the component procurement. During the programme Ricardo operated as a department of BMW. Indeed, Ricardo is the only BMW supplier with full access to its product development database, using a satellite workstation.

With prototypes complete, says Etheridge, "we were responsible for the base engine development, finally supplying validated prototype

powertrains to BMW for vehicle development."

Powertrain testing included performance development, combustion development and basic mechanical development with engine tests and component rig tests for the prototypes. At this stage Ricardo's work was essentially complete, although its remit included maintaining a presence for any detail design changes that were needed, as well as the validation of subsequent production-intent units. First manufacturing integration was incorporated at the design stage, and Ricardo was also on hand to update manufacturing drawings as required during industrialization.

Rave reviews

The K1600 engine has already been a hit with the press. The UK *Daily Telegraph* said of the 1600GT, "just a silky delivery of power unlike any four-cylinder rival, with immense strength, too. It's enormously satisfying, especially as the bike powers forward so rapidly when you spin the motor close to its 8,500 rev/min red line."

Ride magazine was similarly impressed, saying, "It is an amazingly smooth engine, untroubled by intrusive vibes, rattles or shakes." *Motorcycle News* simply declared it "one of the most intoxicating engines in motorcycling".

Fitting tributes, perhaps, for what has to be one of the most refined and neatly packaged motorcycle engines in the world.

As with the K1300 four cylinder engine project, the new K1600 engine and transmission is another very high profile testimony to one of the most effective engineering collaborations in the global motorcycle industry. Bearing all the hallmarks of a truly great bike engine, the six-cylinder K1600 takes premium motorcycling into a new and exciting dimension in which engineering sophistication combines with genuine rider appeal to set new standards in the elite segment. RQ

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Project chief engineer,
Ricardo

Ricardo's Motorcycle Centre of Excellence

Uwe Moser was project director for both the K1300 and K1600 engine programmes at Ricardo and, together with the support of Paul Etheridge, he founded the Motorcycle Centre of Excellence in Schwäbisch Gmünd. His focus is on continuing to build this group into a world-leading engineering partner for motorcycle OEMs: "From the first of June we have appointed additional Chief Engineers and Ricardo is very serious about growing in this market."

The Motorcycle Centre of Excellence has grown steadily over the last few years and while based in Germany, it is a global focus for activity in this market for Ricardo. "Worldwide, the emphasis continues to be on fuel consumption and CO_2," Moser continues. "In Asia, customers are focused on cost of ownership for smaller bikes, and we see a growing demand in this market for an improved quality of small bikes and mopeds."

The global market is evolving in other ways too. "The market is moving from two directions; in Asia from the simple commuter bikes to a higher level and, for the established European and Japanese brands, a trend for offering smaller bikes as an entry level in the developed markets, and a high end bike for developing markets." With a global convergence towards motorcycles of 200 cc to 250 cc growing, it seems a dramatic shift in the world market for motorcycles is about to begin.

The development of the Motorcycle Centre of Excellence has proven to be a Ricardo success story as demonstrated not least by the two recent and very high profile BMW programmes, which have been so well received in the market. The team continues to work with its customers in Germany and around the world, with investment in new, motorcycle-specific personnel and new facilities to support the expansion of this important business for Ricardo.

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