Technology testbed

How an Audi A4 quattro is being used to test innovative technologies in endurance races on the Nürburgring

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A team of IKA, Tuning Akademie, and other industry partners are concentrating their core competencies to develop innovative technologies and teach students and young engineers the practical aspects of engineering.

In 2007 the Institute for Automotive Engineering (IKA) of the RWTH Aachen University and the Tuning Akademie Ingolstadt had the idea to design and develop a vehicle for the endurance championship at the Nürburgring (VLN). The university's desire to inspire young engineers in research and development of vehicles will be fulfilled by this project. In addition, innovative technologies can be developed and tested at the Nürburgring. With the support of a large number of industry partners, an Audi A4 quattro with a 3-liter TDI engine was built. The industry partners supported this project with components as well as with know-how; in return they received information and data from the testing of their components.

Following completion of the vehicle build, beginning with the body-in-white and a large quantity of individual components, the vehicle was tested and further developed with some races in the endurance championship. During the winter of 2008/9 its aerodynamics, lightweight design, engine cooling and chassis settings were improved.

The first races of the 2009 season showed the potential of the vehicle. In the first race on April 4, the team won the class for diesel vehicles with 2.5- to 3-liter capacity (D3T). The highlight of this year's season, the 24-hour race on the Nürburgring, was finished with a third place, followed by a second place in the following 6-hour race.

The vehicle was designed using the body of an Audi RS4 (B7) fitted with a certified safety cage. This body was combined with the drivetrain components of an Audi A4 3.0 TDI and some further components from an Audi RS4. A second application vehicle was used for the development of the ABS/ESP software and the chassis components.

The vehicle races against high-powered vehicles like the Porsche GT3 in other classes. Therefore competing in class D3T requires consistent exploitation of the

Race car genesis 1) Body-in-white; 2) Assembly; 3) Chassis assembly; 4) Screen assembly; 5) First race, 2008; (overleaf) 6) CFRP/steel doors; 7) Testing 2008; 8) Chassis optimization; 9 & 10) Aero changes; 11) Testing 2009

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diesel's fuel consumption advantage. The design of the drivetrain concepts should enable a maximum travel time of 2.5 hours per driver without any intermediate stop. Under these limit conditions the compromise between maximum power and optimized fuel consumption has to be evaluated with consideration of the maximum allowed volume of the fuel tank. ContiTech manufactured an FT3 tank with a volume of 100 liters for the 2008 season. Because of changes in the technical regulations for 2009, this volume had to be reduced to 70 liters by using filling balls. This reduced the driving time per driver to 110 minutes.

The ratio of the gearbox and the engine characteristics were optimized for the Nürburgring Nordschleife in cooperation with the company MTM. The gearbox setting considers the Le Mans-type starting procedure of the endurance championship and the 24-hour race. The slowest sector on the track (Wehrseifen) is driven in second gear. To reach the optimal acceleration at the exit of this curve without shifting in the apex of the next curve, some changes to the gearbox were required. The second gear ratio was increased from i = 2.05 to i = 1.46 and the spread of gears 3 to 6 was reduced. Additionally the gears were equipped with carbon-reinforced synchronizers to allow precise synchronization during fast changes.

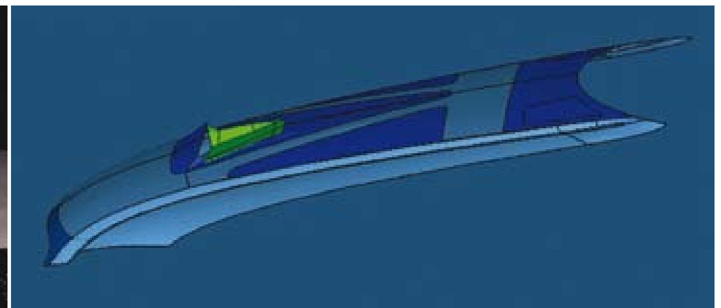
In the engine, specially developed oil by Rowe is used, which has been adapted to give optimized lubrication up to the maximum engine rotation speed (rpm) during the race. The exhaust system is made from stainless steel by BN-Pipes and includes a diesel particle filter by HJS.

The chassis of the race car is based on the series production chassis of the B7-generation Audi RS4. The combination of the Audi four-link front axle with the line-guided wishbone rear axle is a good, adjustable basis for a motorsport chassis.

To optimize the chassis components for durability in an endurance race, all moving chassis components (steering arm, upright, wishbone, and hub) have been shot-peened by Metal Improvement. In this controlled shot-peening, procedure the outer surface of the chassis components are shot with small glass pellets. This increases the resistance of the material against fatigue fractures, corrosion fatigue, strain-cracking corrosion, and embrittlement.

The conventional springs and dampers are substituted with a racing suspension system manufactured by KW Automotive. At the rear axle, combined spring damper elements were used instead of the separated spring and damper components. These combined elements enable a simple exchange of the components in case of an accident or failure. They also have a better adjustability. The dampers are based on the principle of a monotube damper using parameters that are optimized for motorsport usage. These dampers have a dual compression and a single rebound-damping mode. This suspension system also enables adaptation of the driving characteristics and the aerodynamic settings to the required boundary conditions by a variation of the ground clearance. In addition to that, a Heggemann stabilizer improves the drivability at the front axle.

The optimized chassis setup was verified using the servo-hydraulic test bench of KW Automotive. In addition, the kinematic and



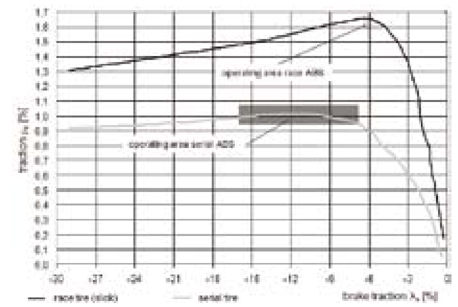
Design of the CFRP hood with integrated air outlet including aerodynamic optimization in SC/Tetra (above, right) and wind tunnel testing the aero settings for 2010 at FKFS in Stuttgart (left)

elastokinematic characteristics of the axles were analyzed within the adaptation of the chassis system. As a result of this testing, the rubber-metal and hydraulic-damping bearings of the front and rear axles have been changed to rigid ones. The line and camber characteristics are achieved using an adjustable arm in the upper wishbones of both axles. The settings were optimized to match the spread of the tire's contact force during cornering, to ensure homogeneous tire wear for the complete lap. Adams software was used for multibody simulations and OPT-Tool for numeric calculation, to optimize the axles' kinematics.

The race tires (Dunlop DTM Slick 265/660-18) were analyzed on the tire test bench of IKA at different operating points (camber, drift angle, velocity and temperature). The slip parameters were determined and the resulting operational areas for the antilock braking system (ABS) are implemented in the software. Moreover, it was possible to evaluate optimized parameters for the line and the camber values for these tires in the race, by using the tire test bench and the simulation tools.

An important topic in the area of driving dynamics was adapting the ABS/ESP software to the race tires. In the series development of a vehicle, the manufacturer has to consider that different types of tires will be used. Nevertheless, the slip control system has to harmonize 100% with the tire in case of emergency braking. Under no circumstances may a driving condition occur in which the braking force is too low. For that reason the defaults for the slip value are higher to allow automatic control, up to the tires' maximum traction coefficient.

Because the exact behavior of the tires was known from the experiments on the tire test bench, the operating point of the ABS was applied to the maximum of the slip curve. Thus the great fluctuations of brake pressure, which occur normally if a series ABS is used in combination with race tires, were eliminated and the utilization of the longitudinal force was optimized. Additionally the reduced slip requirements



Left: Plot of ABS/ESP operating areas of street and race car tires at equal temperature

of the race tires were considered in the parameterization of the ABS. Hence the reduced command slip value was realized in the ABS control unit with the support of the automotive supplier Bosch. Following the parameterization of the ABS, the operation limits for the electronic stability program (ESP) were modified. The adapted system only intervenes at high yawing impulses, e.g. in the case of contact with another car.

To reduce the body mass, an outer skin for the doors was developed, made from fiber-reinforced plastics (CFRP). For this the team was supported by the Institute of Plastics Processing (IKV) at RWTH Aachen University. In addition, a hood made of CFRP was developed. A reverse engineering approach was chosen to design these components. In the first stage the doors and the hood were digitized and transferred into a FE model for the numerical optimization of the structure. Different iteration stages were necessary to optimize these components, taking into account mass with a comparable stiffness level.

The side screens and the rear screen of the car are made from plastics by Evonik Roehm. All screens are joined to the body by adhesive bonding with a one-component glue by Henkel. This glue is based on silane-modified polymers, and was tested for compatibility with the materials used in the race car. The durability of the adhesive bonding was tested in a laboratory to determine the long-term bonding characteristics under the influences of temperature and humidity.

As a highlight in lightweight design, hybrid doors with an outer skin made of CFRP and an inner sheet made of steel are used at the race car. The outer skin is joined with the inner sheet by adhesive bonding. In comparison with a conventional steel door, the new hybrid door is 24% lighter. A much greater decrease of mass would be possible by realizing an integral design door completely made of CFRP.

This technology and procedure was also used to design the hood and optimize its inner structure to cope with the expected loads of race conditions. Sealing was applied to the contact area with the water box. Use of a single CFRP component eliminates the joining of two steel components as in conventional construction. The hood is reinforced to fulfill the requirements of stiffness and strength. Within this, rounded hat profiles are used to reinforce the structure. To realize these reinforcements, a special rigid foam (Polymethacrylimid by Evonik) is used. This material is best suited to this application because of its strength and temperature resistance. An overall mass reduction of 60% was achieved by the virtual optimization of the hood.

The integral CFRP doors are 63% lighter than the conventional steel doors in FE simulation with HyperWorks software by Altair. In addition, a CFRP trunk lid using sandwich material as reinforcements was analyzed. FE simulations on this component promise a mass advantage of up to 72% in comparison with the conventional steel component. All CFRP components were

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analyzed in mini and master theses at IKA. The manufacturing of the CFRP hood for the 2010 season has been started, and the manufacturing of the other components is still under discussion.

In the process of designing the CFRP hood, an air outlet for the engine cooling system had to be integrated into the hood design. This was done during the hood structural optimization process. By the application of computational fluid dynamics (CFD) an aerodynamic model of the car was created, using CFD simulation software SC/Tetra by Cradle. The complete outer skin of the vehicle was combined with an alternative model of the engine to analyze the airflow around and through the vehicle. This method enables the best design to be found for the air outlet in the hood under consideration. Before manufacturing the CFRP hood, a prototype made of aluminum was tested in the race and in a wind tunnel.

As additional aerodynamic measures, an underbody covering, a splitter in the front area, and a rear spoiler were attached to the vehicle. The underbody covering reduces the aerodynamic drag and, in combination with the rear spoiler, increases the downforce on the rear axle. It is made of an aluminum-sandwich material by Metawell. The splitter under the front bumper increases the downforce on the front axle and ensures the required balance between front and rear axle. This component is made from a fiber-glass reinforced sandwich material. The best setting for the aerodynamic components of the vehicle was evaluated in the wind tunnel at the University of Stuttgart.

> "Use of BTL biodiesel will give a new focus to the drivetrain concept regarding conservation and other green issues"

The series battery has to fulfill a wide range of requirements (number of power users, boundary conditions, cold start, etc). In a race car, this range of requirements is clearly reduced. Hence a mass reduction of 38% is possible by the application of a smaller race battery. The design of the battery was selected for the warm start of the engine after an incident during the race.

Additionally, the adoption of a cable harness made to the requirements of a race car offers the potential for a large weight reduction. Only the basic components required for racing, such as headlamps, screen washers and engine electrics have been integrated in the reduced-mass cable harness. The control unit network is based on the series components used in the Audi RS4. The number of control units has been minimized, taking into consideration the necessary signals and information required to be available to ensure faultless communication across the network. The control unit network of the race car was designed and manufactured based on measurements taken from the application car. Along with the instrument cluster, engine and brake system electronics, other components from the comfort electronics (e.g. control of the headlamps) were implemented in the race car.

All important vehicle/powertrain signals are monitored during the race to give indications of potential damage. Thus, in the case of any incident, the driver is able to adapt his driving behavior to protect the car and powertrain. Detailed evaluation of the recorded data after a pit stop offers the possibility to take adequate preventative measures and resolve any problems.

After the vehicle was completed and tested in the first races of 2008, a process of continuous optimization began. The successful completion of races in 2009, including one victory in class D3T, confirmed the car's potential and rewarded the team for their optimization work.

Further races are planned to be completed in the 2010 VLN and the 2010 24-hour race at the Nürburgring. The continuous improvements to the car will also continue; a cooperation with DiNaWa, a manufacturer of biomass-to-liquid (BTL) biodiesel, will give a new focus to the drivetrain concept regarding conservation of the environment and other green issues.