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PRESS INFORMATION

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Introduction

Content

Premium quality in the digital age

Quality is a core competence of the brand with the four rings. To inspire with quality leadership in the premium segment is Audi's aspiration with regard to the mobility of the future. Audi customers have expectations for the function, comfort, value and reliability of their cars that are every bit as great as those of people using premium mobility and other services – and that will hold even more true in the future.

With its headquarters in Ingolstadt, Audi Quality Assurance is involved in the entire product process – from development through production in all factories worldwide to testing in international markets.

"The megatrends digitalization, sustainability and urbanization are changing the understanding of quality and influencing our work in Quality Assurance," said Werner Zimmermann, Head of Audi Quality Assurance. "We are moving from pure component analysis to a holistic system view. In doing so, we are increasingly turning to virtual and digital methods." Today already, the employees in this area already collect data during the entire product creation process. For Werner Zimmermann this results in a new way of working. "We at Quality Assurance are moving away from checking and towards controlling."

Quality has many facets and is particularly important where the customer can experience it with all their senses. There, where they see, feel and hear it. The precision of the suspension, the perfection of gap dimensions and utmost quality with respect to workmanship and materials are the traditional touchstones for a car's overall sense of quality. The reliability of the different vehicle functions also contributes to quality.

"Each of the approximately 2,800 employees in Quality Assurance is an ambassador for quality," said Zimmermann. His experts are involved in the development of new products at an early stage and provide input on concepts or coordinate material selection with the Design team. Quality Assurance accompanies the entire development process with the aim of implementing lessons learned, incorporating experience and perfecting new features. Early intervention avoids changes at a late stage of the process and the associated additional costs. According to the rule of ten, the cost of an undetected error during value creation increases by a factor of ten from step to step. "The sooner an error is discovered and eliminated, the more cost-effective it is for the company," said Zimmermann, adding: "Saving on quality is therefore always the most expensive solution."

Master Jig

Earlier, faster, more connected and more agile: Audi Quality Assurance makes consistent use of digitalization and is bringing the master jig into a new era too. The traditional array of instruments is continually being supplemented by virtual elements. Working with data records starts much earlier in the development process of each Audi today in comparison to previous times. “The so-called digital master jig today allows us to put our expertise into the product creation process up to as many as two and a half years before start of production,” said Marcus Hoffmann, Head of Master Jigs and Measurement Technologies, explaining the work of the quality assurance experts. “Much of what we used to check on physical components ten months before the start of production can now in principle be carried out much earlier on the basis of 3D models.”

New technologies in cars expand and change the face of the tasks which the master jig has to complete. A good example of this is the new Audi A8. Its touch displays with haptic feedback mean that there are much fewer classic controls to be checked. Besides decisions on the fit and feel of components, the daily work of the Quality Assurance experts also includes a variety of functional topics. That’s why Audi has electrified the interior master jig.

The distinction between physical components and digital data records is becoming increasingly blurred, both in terms of the interior master jig and the exterior master jig. Where previously just a manual surface check allowed the desired premium quality to be verified, today photometric cell robots with extremely precise optical sensors can now carry out the required steps. The resulting data records can then be compared with other components at the simple press of a button.

The journey to the virtual master jig has already begun – in the future, complex algorithms should be able to simulate force interactions between components which arise during their assembly and movement.

The basis for this: the traditional exterior and interior master jigs
The exterior master jig enables the assembly of components to be checked and optimized before the start of production. This involves coordinating the fits of all parts that are visible on the exterior with one another. These parts range from sheet metal panels such as doors, engine hoods and tailgates to exterior trim parts such as bumpers, headlights, tail lights, windows, mirrors, door handles, spoilers and trim strips. The experts from Audi Quality Assurance use more than forty measuring systems when working with the master jig. These offer measurements precise to more than 0.1 millimeter.

Other tools are used in this area before work is performed on the exterior master jig. The joints master jig, for example, is used to check for dimensional conformity of the underbody and its individual components, such as the front and rear floors, and to tailor them to one another. This ensures that all components can be assembled together without exerting any tension on one another and in the subsequent assembly process it ensures a high-quality body – a fundamental requirement for the premium feel of every Audi.

Using what are known as exterior function cubes, experts analyze the model's exterior trim parts in a local zero-reference environment – i.e. in an environment without deviations. Correction data is derived from this process, which is used to optimize components at an early phase. When the parts fit to the cubes, they are added to the exterior master jig for further fine tuning.

Work in the zero-reference environment of the exterior master jig begins around ten months before the start of series production. The employees install the previously inspected panel parts of the body's exterior skin and their attachments, such as doors, hoods and lids, on a reference body. Exterior trim parts are also installed to the assembly to analyze the interplay of all body parts. This puts the specialists in a position to employ a stepwise method for optimizing the dimensional tolerances of components, achieving flush fits and perfecting the lines of joints.

In an additional fine-tuning step, the experts equip reference bodies in a way similar to that of an exterior master jig. This is done so that the paint application can also be considered in a final detailing step. Although the paint is only about 15 hundredths of a millimeter thick, even this plays an important role in dimensional optimization.

However, the seam pattern of an Audi does not always follow exact mathematics. A sense of proportion is just as important. Take the front bumper, for example, which is slightly offset to the rear at its transition to the fender so that the customer always perceives a harmonious transition when looking at it from above, as is most often the case. Another example is the seams on the tank flap. Here, the upper seam is slightly narrower than the lower one to give the observer the subjective impression of a better fit.

Along with dimensional conformity, the exterior master jig also yields information on gloss level and the tactile feel of sheet metal, aluminum and polymer parts. In addition, it provides information on the firm seating of all components and their easy assembly. And so the developers recognize whether there is potential for optimization in the component concepts.

No rattling, no rustling and exact fits: Audi places great importance on maximum precision in the interior, too. The interior master jig is a body produced to a specific drawing status or specified size with no deviations at the points where interior components are mounted.

The quality assurance employees tailor the physical components precisely to one another ten months before the start of production. In the process, visual and tactile measurement processes are used.

In addition to the functional criteria (such as freedom of movement of attachments such as doors or tailgate, simple and time-saving installation, tight fit and harmonious actuation forces) the interior master jig also focuses on visual properties. All components are inspected for grooves, sink marks or bumps, as well as for flushness and joint running, for example on the center console and its numerous components. The Quality Assurance interior master jig lends its attention to even the finest of details. Whether minimal burrs on a trim strip or a visually uneven border along the perforation of a speaker cover – every little shortcoming is discussed with the suppliers and corrected in a bid to achieve the desired Audi quality.

The present: digitalization of the master jigs
Advancing digitalization offers totally new possibilities in measurement technologies – it has brought the work of the master jig up to a new level in the past years. For many of these new tasks, optical measurement cells form the technological basis. They allow automated and objective analysis of the surface quality of sheet metal and trim elements.

The latest addition to the master jigs, a photometric measurement cell the size of a double garage, represents an important step in the direction of the virtual master jig. Two robots with eight-axis kinematics and high-resolution optical sensors (16 megapixels) simultaneously capture the geometry and the surfaces of the bodywork. The length of time required to fully digitize an entire body thus decreases from 48 hours to a mere four.

An advantage of optical versus tactile measurement techniques is that, among other things, they can be done without touching the material. This allows even soft materials such as seals and seats to be precisely measured. What's more, it doesn't just measure individual points, rather it precisely measures the entire surface area. Data obtained through the photometric measurement cell serves as an important basis for further work steps on the master jig.

Virtual joining
The combining of available CAD data already takes place in the master jig at a very early stage of the product creation phase. So-called virtual joining also allows CAD data of the first individual components to be compared against the digitized measurement data. A further use case: two data records from completely digitized components can be collated in order to check the quality of the components and, if necessary, further optimize them.

Example: the fuel filler flap of the new Audi RS 4 Avant (combined fuel consumption in l/100 km: 8.8*; combined CO_2 emissions in g/km: 200 - 199*) is able to be demonstrate its various possibilities using virtual joining. In an early development phase, the bodywork component is only available as a CAD data record and is merged virtually with the digital measurement data of the physically available tank flap by means of a piece of software. Using interactive analysis of the facing surface curves as well as the outline and radius geometries, the Quality Assurance staff can identify the need for corrections much faster than before – and long before cars are assembled.

Digital reference samples

Components from the series production of a car must correspond to the qualification status of the master jig. So-called reference samples are stored for the life cycle of a model and beyond, and are available for comparison at any time.

For several years now, Audi has been increasing its use of digital reference samples in addition to these physical reference samples. These 3D data records documented at the end of component qualification serve as a reference, just like the previous physical reference samples. They represent a possibility for comparison, both in the suppliers' series production processes and in Audi's own production processes. Digital reference samples ensure fast availability as well as international compatibility and interchangeability between Audi sites worldwide. Contrary to components stored, they are not subject to change over a long period of time. In addition, space and shelves for the storage of physical parts are increasingly being eliminated – an efficiency gain that also benefits sustainability.

Electrification: functional interior master jig

Audi is taking its high quality standards into the digital age with a new operating concept. The number of conventional switches on the instrument panel will decrease drastically in the future. On the current Audi A4, there are still 22, but in the next generation of the Audi A6 which celebrates its premiere in 2018, there will only be a few of them left. This poses new challenges for Quality Assurance. The focus used to be on the haptic and acoustic coordination of knobs. Now everything revolves around the function
of the electronic controls in black-panel look.

To be able to fully evaluate digital controls and virtual processes, Audi electrified the interior master jig and thus created the functional interior master jig. All functions of a new interior with the latest parts can be modeled. The behavior of the electrical control elements when installed can thus be checked at an early stage of a new model's development.

* Figures depend on the tire/wheel set used

The functional interior master jig will be used for the first time as part of the development of the new Audi A6 and is equipped with the original cable harness of the model. This enables all interior functions of a new Audi model to be simulated – be it electrically powered windows, seat adjustment settings, ambient lighting, head-up display, Audi virtual cockpit or touch-sensitive screens.

The combination of acoustic and haptic feedback as well as familiar touch gestures such as swiping like on a smartphone allow particularly safe, intuitive and rapid operation. When the driver activates a function on one of the touch-sensitive screens or via one of the new glass-look buttons, he/she hears and feels a click as confirmation. The functional interior master jig can be used to check not only the new control elements, but also to fine-tune the digital representation and the accuracy of the graphical user interface.

During function tuning, the Audi Quality Assurance system also monitors the fit and gaps around the black panel control elements. Some joints in the interior today fulfill more than merely an aesthetic function. They serve, for example, to allow for expansion of the touch-sensitive displays in relation to the decorative trim elements in the case of extremes of temperature.

The ambient lighting in many Audi models strongly influences the perception of the entire interior. Therefore, the functional interior master jig also assesses scatter and leakage light – i.e. light escaping at undesirable places – as well as possible reflections. The aim is perfect interaction of the light guides with the geometry of the interior, both in daylight and at night.

The future: the virtual master jig

Tactile and optical measurements today already provide exact data records for individual components which can be compared with one another at any point by means of virtual joining. In the future, Audi will also convert various exerted forces, e.g. when opening and closing the hood, into digital data records and then use them for complex simulations. Soft seals, deformations caused by various force interactions during movement – in the future, there will be very complex algorithms which can then be made available for real-time analyses by powerful computers at the push of a button. We will continue on our journey into the future – Audi Quality Assurance is on the way to the virtual master jig.

Semiconductor Lab

Automated driving, powertrain electrification, and the increasing networking of cars with one other and their surroundings – all these innovations are based on powerful semiconductor technologies. “More than 80 percent of all innovations in today’s automobiles are made possible by microelectronics,” said Stefan Simon, semiconductor expert at Quality Assurance. “All told, a car today includes as many as 8,000 active semiconductors in up to 100 interconnected control units. Every single one of them has more computing power than the first moon rocket.”

The Audi Semiconductor Lab works according to the principle of preventive quality management. As a central point of contact for the topics of semiconductor quality and analysis as well as assembly and connection technology, it fulfills an important interface function. This applies both within the company and in contact with external partners from industry and research. As a competence center, the Semiconductor Lab supports the cross-business and interdisciplinary assessment of components and assemblies as well as manufacturing and production processes. Another core task is the qualification of employees in all specialist areas. This spectrum of topics makes Audi’s Semiconductor Lab unique in the European automobile industry.

The experts at the Semiconductor Lab assess the individual components – the inner workings of the control units – for suitability, reliability and production quality. Early in the development process, staff check the requirements that a semiconductor chip has to meet for use in automobiles. And these clearly differ from those for other applications. While the average life of a smartphone is two years, it is about 15 years for a car. What’s more, the use and strains to which a car is subjected cannot be compared to those of a smartphone. “A semiconductor has to be designed and manufactured differently to account for the temperature differences, moisture and vibrations that occur in an automobile,” explained semiconductor expert Oliver Senftleben.

Components can be tested in the lab for aging mechanisms as they can occur in the car. Aging in a climate chamber is one such a test. Physical analyses are also used to investigate aging behavior and production qualities. Among other things, the Semiconductor Lab is equipped with a modern x-ray machine and a scanning electron microscope. For special analyses of semiconductor chips, the experts work closely with the colleagues of the Lab for Materials Engineering, e.g. on sample preparation using the focused ion beam (FIB), a scanning electron microscope with a focused ion beam. This can be used to examine control units for possible series and process errors.

Digitization

Priorities have changed dramatically in recent years. Although drivers continue to compare the performance of vehicles whilst also keeping a close eye on design aspects, they also expect new technologies such as live traffic data via Audi connect, as well as problem-free connection of their smartphone with the vehicles and the latest driver assistance systems.

To meet these customer requirements, the automotive industry must increasingly turn to new, trendsetting technologies. Previously, components were only deemed suitable for use in the automotive industry after several years of use in consumer electronics. Nowadays, such components rapidly make their appearance in vehicles. To ensure that the electronics deliver the desired high performance, they are validated in advance. To safeguard Audi’s high quality standards, the Semiconductor Lab performs such tasks as the definition of requirements and a technology assessment. Standards that are customary in the consumer sector (0 °C to 40 °C) are compared with the standards of the automotive industry (-40 °C to 125 °C) and lifetime requirements are checked. For example, the Audi MMI connect app can be used to query the current status of the vehicle, operate the interior climate control system or check the charge status. The car is thus constantly connected to and in communication with the environment, resulting in significantly increased uptime of the connected components. These can be active for as many as 30,000 hours and more in a vehicle life cycle. And some future applications will have to be equipped as “always-on” solutions.

autoSWIFT – tailored electronic components for the automobile industry

In order to come up to the high innovation tempo in the industry and to be able to rapidly react to new developments, AUDI AG collaborates with leading partners in the semiconductor segment and the electronics industry. Together with FZI Forschungszentrum Informatik, Globalfoundries, HOOD GmbH, Infineon Technologies AG and Robert Bosch GmbH, the fundamentals for a standardized technology assessment will be established. The “autoSWIFT” research project stands for “rapid innovation cycles for electronics systems throughout the automobile added value creation chain”. It has set its sights on getting innovative and high-quality electronics components based on the latest manufacturing technologies much quicker and in a much more appropriate way than before into vehicles. For future requirements placed on this development process, it is currently being investigated how the value creation chain can be turned into a value creation network.

“The cross-company and interdisciplinary joint development of automotive components is intended to enable the suitability of future technologies to be assessed during their development phase and incorporated into the product development processes sooner than before,” explains Helmut Lochner, expert from the Semiconductor Lab and autoSWIFT overall project leader. This will bring the latest semiconductor technologies into harmony with the high quality standards of the automotive industry.

Lighting technology

For the new Audi A8 and the Audi TT RS (combined fuel consumption in l/100 km: 8.5 - 8.2*; combined CO_2 emissions in g/km: 194 - 187*), the brand with the four rings optionally offers tail lights with OLED technology (OLED: Organic Light Emitting Diode). Unlike single-point light sources, such as LEDs, OLEDs are so-called surface light sources. Their light takes homogeneity to a new level. They do not cast any harsh shadows and require no reflectors, light guides or similar optical parts. This makes the OLED units efficient and light – with minimal space requirements. The division of the OLEDs into small, individually controllable segments with a three-dimensional arrangement enables completely new lighting scenarios, which give the designers additional creative freedom in design and animation.

In each OLED unit, two electrodes – at least one of which is transparent – incorporate numerous extremely thin layers of organic semiconductor materials. A low voltage causes these layers, which are 200 times thinner than a human hair, to illuminate. This has allowed the traditional Audi genes to be transposed into a new technology.

The employees of the Semiconductor Lab were part of the multi-stage validation process to which this innovative lighting technology was subject prior to its series-production introduction. This ranged from the creation of specific implementation profiles to the validation of the basic technology and the OLED module, right up as far as the testing of the complete tail lights. The focus was on the unique aspects of use in the automotive sector, e.g. aging behavior due to environmental influences and passive aging.

The first-ever use of OLEDs in the automotive sector required the derivation and review of specific parameters of this technology. Audi's Semiconductor Lab, in conjunction with Technical Development, carried out a complete technology assessment for each application during the pre-development phase. Weak points in the technology and in the manufacturing process were identified and addressed. These specific requirements for OLED technology have been defined for future projects and anchored as a standard.

* Figures depend on the tire/wheel set used and the body variant

Electrification
Audi is pressing ahead with the electrification of its drive systems across a broad front and is developing sustainable mobility concepts. As part of this, the power electronics form the beating heart of every electrified vehicle. Their core is formed by the pulse width modulating inverter – from a technological point of view, this is one of the most demanding components. It converts the DC voltage from the high-voltage battery into three-phase alternating current for powering the electric motor. The high-performance semiconductors within the pulse width modulating inverter have a surface area of around 1 cm^2 *(0.4 sq in)*. Each of them must switch a current of more than 100 amps at a frequency of 10 kHz. Despite efficient cooling, the resultant in-chip power losses lead to rapid aging of the electrical contact connections.

Beginning with the Audi Q5 hybrid quattro (2011), then the Audi Q7 e-tron quattro (2016; combined fuel consumption in l/100 km: 1.9 - 1.8*; combined energy consumption in kWh/100 km: 19.0 - 18.1*; combined CO_2 emissions in g/km: 50 - 48*) and the up-coming fully-electric Audi e-tron (2018), the employees of the Semiconductor Lab have supported and ensured the progression of the technological development in the power electronics. Examples of their work include evaluating the technological connections between the individual chips and the heat sinks, and subsequently ensuring the necessary thermal connections. In doing so, the aging mechanisms were focused upon just as much as the specificities of the process involved in the individual technologies. Among these were soldering, wire bonding and sintering – the so-called mounting and connection technologies. The results were of fundamental importance for the creation of a Group-wide norm, which was partially converted into a German industrial standard in 2017.

RoBE – Robustness for Bonds in E-Vehicles
To enable a reliable service life prognosis for each individual bond during production, Audi has teamed up with partners from industry and research in the joint RoBE (Robustness for Bonds in E-Vehicles) project. The goal is to at least double the bond life typical for consumer electronics. The project, which also includes the Fraunhofer IZM and Fraunhofer ILT research institutes, strives for a deeper understanding of the variables and the mechatronic relationships of bonding technology. Alternative production techniques such as laser beam welding are being developed and new wire materials investigated in order to overcome today’s process limits.

The most important lever for the collaborative research of innovative solutions by industry and research institutes is the pooling of competencies along the entire development and creation chain. Assessment criteria and test standards for novel technologies often do not yet exist. The Semiconductor Lab is therefore involved in the development of Group-specific quality specifications at very early project and pre-development stages, and even drives their development across industries.

* Figures depend on the tire/wheel set used and the number of seats

Automated driving

The new Audi A8 is the world's first volume-production car to be designed for conditional automated driving at Level 3 in accordance with international standards. The Audi AI traffic jam pilot takes charge of driving in slow-moving traffic at up to 60 km/h *(37.3 mph)* on highways and multi-lane roads with a physical barrier dividing the opposing lanes. During piloted driving, a central driver assistance controller (zFAS) now permanently computes an image of the surroundings by merging the sensor data. In addition to the radar sensors, a front camera and the ultrasonic sensors, Audi is the first car manufacturer to also use a laser scanner.

The scanner expands the long-range radar's field of view from a narrow 35 degrees to 145 degrees. Thanks to the wide coverage, the car will be able to identify other road users and interpret their behavior, such as moving into and out of the lane, much sooner in the future. "You can think of the laser scanner as a beam of light scanning the car's surroundings in fractions of a second," said Robert Kraus, an expert in production technologies at the Semiconductor Lab. A rapidly rotating mirror inside the compact housing guides the beam of the powerful laser diode in small increments across the area to be scanned. The new laser scanner doesn't just detect obstacles, it can also determine the exact distance to them. It does this by measuring the time between the emission of a laser pulse to its detection at the photodiode.

The employees of the Semiconductor Lab have been preparing for the successful first use of the laser scanner in the new A8 since 2014. In collaboration with Technical Development, they defined comprehensive specifications and requirements of the part and its individual components. Before being used for the first time in the automotive branch and having previously only been used in consumer electronics, the laser diode was subject to numerous reliability tests and detailed analyses as part of complex laboratory trials. On the basis of these results, optimizations in the manufacturing process for diodes were brought about in order to fulfill the quality requirements needed of them.

Materials Engineering

With its know-how, the Materials Engineering unit at Audi Quality Assurance supports material challenges across the entire process chain, from product creation to product testing.

Focused ion beam (FIB) – innovative analysis tool
In addition to conventional analysis techniques, such as light-optical microscopy, Audi's materials experts also use scanning electron microscopes for analysis. These allow a significantly higher depth of analysis of the materials.

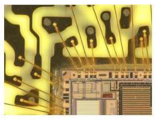
Scanning electron microscopy (SEM) provides high-resolution images of fracture surfaces or important insights into the concentration and distribution of chemical elements in the material being studied.

Materials Engineering has been using a focused ion beam (FIB) for four years now. This makes the brand with the four rings a pioneer among car manufacturers. The combination of an imaging scanning electron microscope and an ion gun as an abrasive tool makes it possible to create high-resolution, cross-sectional images of material systems.

The functional principle of the focused ion beam: the gallium ion beam of the FIB first digs a hole invisible to the human eye into the material under investigation. An integrated scanning electron microscope then provides a high-resolution, cross-sectional view below the material surface. The typical cutting depths of 5 to 50 micrometers – with widths of 50 to 100 micrometers – are achieved after two to five hours of cutting time. A major advantage is that the experts can follow the cutting process live with the scanning electron microscope.

At the same time, compared with mechanical preparation methods like the creation of grinding patterns, the FIB offers the big advantage in the case of complex material combinations (e.g. hard, thin coating of soft substrates) of only leaving behind minimal preparation artifacts. This refers to changes of a distorting nature, such as those on interfaces which result from such preparation.

In addition to the typical analyses in the field of surface technology, such as anti-corrosion coatings and paints, Audi uses FIB technology for almost all automotive-relevant raw materials and material systems: metal, glass, ceramics, polymers and even leather.

Engine	Suspension	Body	Interior	Exterior	Electronic
Hard material layers	Anti-corrosion coatings	Exterior paint finish	Chrome applications	Anodic coatings	LED technology
Sensors	Anti-wear coatings	Phosphating Hot shaping	Interior paint finish	Paint finish Trim elements	Power modules Power electronics
Deposits/ linings	SCR systems/ heating elements		Displays/ optical films	Decorative films	Microchip/ structural elements
Plain bearings	Paint finish for wheels		Leather		

Exemplary overview of areas of application for FIB analysis at Audi Materials Engineering; new fields of application with high potential for the future are highlighted in red

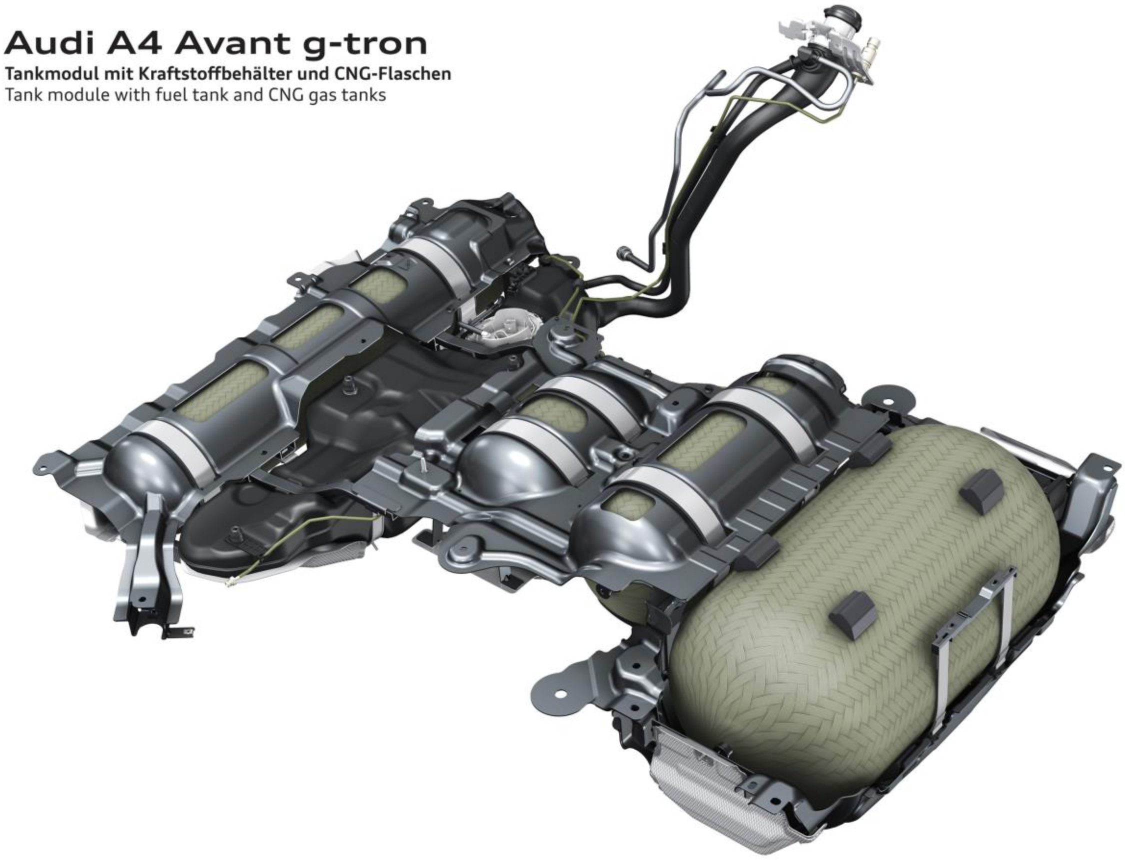
FIB analysis technology has particular potential for the new material challenges in electrification and digitalization. For example, a targeted and high-resolution SEM analysis of the individual layers of a touch-sensitive screen is only possible with an ion-based sample preparation. Possible weaknesses on interfaces of the individual layers which can lead to functional defects, can therefore be identified at an early stage in the development process.

CNG pressure tanks – analyses after shakedown testing

Audi customers can enjoy the A4 Avant g-tron (CNG consumption in kg/100 km: 4.3 - 3.8*; combined fuel consumption in l/100km: 6.5 - 5.5*; combined CO_2 emissions in g/km (CNG): 117 - 102*; combined CO_2 emissions in g/km (gasoline): 147 - 126*) and the A5 Sportback g-tron (CNG consumption in kg/100 km: 4.2 – 3.8*; combined fuel consumption in l/100 km: 6.3 – 5.6*; combined CO_2 emissions in g/km (CNG): 114 - 102*; combined CO_2 emissions in g/km (gasoline): 143 - 126*) as two sustainable drive variants. Both models are equipped with a bivalent 2.0 TFSI engine with a power output of 125 kW (170 hp). They can be powered, as with the A3 Sportback g-tron (CNG consumption in kg/100 km: 3.6 - 3.3*; combined fuel consumption in l/100 km: 5.5 - 5.1*; combined CO_2 emissions in g/km (CNG): 98 - 89*; combined CO_2 emissions in g/km (gasoline): 128 - 117*), either by means of climate-friendly Audi e-gas, normal CNG (Compressed Natural Gas) or regular gasoline. Their four high-strength, safe gas tanks are made from a mix of carbon-fiber reinforced polymer (CFRP) and glass-fiber reinforced polymer (GFRP). They are located underneath the rear of the vehicle. In order to achieve as high a range as possible when running on CNG (500 kilometers *(310.7 mi)*), the available installation space was optimally used. Each of the four pressurized tanks therefore has a different geometric shape to the next. Together, they store 19 kilograms *(41.9 lb)* of gas at a pressure of 200 bar.

* Figures depend on the tire/wheel set used and the transmission variant

The pressure tanks made of CFRP and GFRP fulfill the strict safety requirements prescribed by law. Before the start of series production, the materials engineering experts at Quality Assurance carried out elaborate analyses as part of shakedown testing. This ensures that the energy stores of the new g-tron models will function flawlessly even after many years and tens of thousands of kilometers in the hands of customers.



Material analysis in detail
For the material experts, computed tomography is the non-destructive testing method of choice in a first analysis step. This technology allows, for example, fiber damage within the composite material to be made visible and measurable.

Microsections are prepared for further investigations of the pressure tanks. A section of the tank is cut out, one of its edges finely polished and then examined under the microscope. With this method, the tank's composite material can be examined optically for pore size and distribution.

An additional thermal process (calcination) allows an exact determination of the porosity and a check of the proportion of glass fibers and carbon fibers. DSC analysis (differential scanning calorimetry) determines the softening temperature of the resin. This enables the experts to investigate the durability of the material after many thousands of kilometers.

In addition, the CNG tanks undergo further optical inspections and material analyses in the laboratory. One of these is tensile testing to determine the mechanical properties of the inliner, a special gas-tight blow-molded plastic part.

Sustainable: leather tanned using plant substances

Audi is a pioneer in the use of chrome-free tanned leather in the entire vehicle interior – and that since more than 20 years. Now follows the next step towards even more environmentally friendly use of resources: the brand with the four rings uses leather tanned using plant substances. This patented process uses olive leaf extract. The materials experts check and follow the diverse process steps from soaking to drying and staining, right up to the finished product – olive-leaf tanned leather.

Shakedown Testing

Before a new Audi model receives approval for series production, shakedown testing is performed with pre-series vehicles. The focus is on the total vehicle with all its connected functions. Audi experts examine and assess all aspects that could possibly lead to customer complaints.

Planning of the pre-series vehicles with regard to equipment, location and driving profile begin two years before the actual shakedown testing. Shakedown testing begins roughly half a year before the start of production, when all parts from series production tools and the complete software of the new model are available. This leaves enough time to solve unexpected technical difficulties together with Technical Development and Production.

The vehicles are driven worldwide as customers are expected to drive them and thoroughly tested, analyzed and assessed. Major technical innovations coming into series production for the first time are validated by Audi with specially tailored test programs. If all parts and functions are ready for approval, new vehicle projects such as the new Audi A8 will be presented during an acceptance road test. This is where models receive the official total vehicle release for series production.

Shakedown testing stations
Shakedown testing takes place at 17 stations worldwide. To simulate customer operation, Audi tests pre-production vehicles in all climate zones in a temperature range of -30 to +50 degrees Celsius. A wide range of road conditions and traffic situations is also important. In addition to the quality of fuel, the charging infrastructure for battery-electric models has been gaining importance as a further shakedown criterion for some years now.

During shakedown testing, approximately 600 pre-production vehicles are driven over 50,000 to 100,000 kilometers *(31,068.6 – 62,137.1 mi)* under real-world conditions. Some of the cars are driven as many as 200,000 *(124,274.2 mi)* kilometers over a two to three-year period. All cars are equipped with special measurement cabling and data loggers so that any issues raised by the experts can be subsequently traced.

With increasing urbanization and digitization, there is also an increased focus on operating hours in addition to numerous test kilometers. The cars are driven on public roads under the same conditions as the customers will experience them later. In addition to the ergonomic layout of the design, the experts also check the component quality, the acoustics and the proper functioning of the connected systems. As part of shakedown testing, Audi covers around 35 million test kilometers *(21,747,991.7 mi)* annually in various countries and climate zones. This distance corresponds to around 875 trips around the world and approximately 700,000 operating hours.

In doing so, the reliability of the models is tested under extreme conditions in places ranging from metropolitan centers of the world right up to the cold climes of Scandinavia and even the arid climate of the desert in both the USA and Africa.

Extended quality validation

To gain insights in an early phase, extended quality validation is performed in collaboration with Technical Development even before the actual shakedown testing. The focus here is predominantly on electronics and electrical systems, such as the infotainment system and the driver assistance systems. A team of experts from Development and Quality Assurance takes to the road with specially configured vehicles. One of the goals is to identify errors in the control units and in their communication.

The cars used in extended quality validation have complex instruments on board, some of them the size of a large suitcase. In pairs, the drivers and co-drivers work through a special functional checklist. As part of this, they put the car and its systems under the most extreme loads. In the background, the instruments document all available data, which are used as the basis for later analysis.

The focus is on the customer

Different types of drivers participate in shakedown testing. Seldom and frequent drivers, women and men, young and old, large and small people, sporty and rather restrained drivers. They glean general impressions and assess special topics relating to all aspects of the car.

The increasing number of challenges posed by digitalization have led to an expansion of validation coverage in recent years. The numerous new connectivity functions are checked, of course. No shakedown testing is performed today without a smartphone and SIM card. “Customers have high expectations of their Audi,” said Arnd von dem Bussche-Hünnefeld, Head of Quality Assurance Total Vehicle. If a smartphone does not immediately connect to the car, the customer usually first pins this on the car manufacturer rather than the smartphone – even if that is where the problem lies. Therefore, these functions are systematically tested by Audi.

Complex instruments for data analysis

Quality Assurance staff use data loggers to deal with the vastly increased complexity of in-car data processing. These are about the size of a shoebox. They are installed in the car at the start of shakedown testing and operated there over the duration of testing. The data loggers are used at all sites worldwide and continuously collect vehicle data. In line with this, some 80 terabytes of data were recorded during shakedown testing of the new Audi A8, for example.

This ensures that requirements of global validation can be met. The use of data loggers makes possible both an in-depth analysis of all abnormalities on the entire vehicle as well as the tracking of the respectively selected validation level. Such continuous recording is the only way to detect sporadic errors.

The data recorded are analyzed continuously and automatically. If a problem is detected, a detailed analysis is carried out by the Quality Assurance experts. Then they define corrective actions and check their effectiveness in an additional shakedown.

Digitization and innovations in shakedown testing – automated driving
With the new Audi A8, Audi is placing a large number of new driver assistance systems into volume production and thus on the road. Prior to release, Quality Assurance staff have validated the functionality of all systems over many thousands of kilometers and the execution of defined scenarios. The engineers are currently working intently on the intelligent park assist.
"To validate the park assist, we parked a few thousand times. As part of this, it wasn't a matter of how often, rather also about looking at as many different conditions as possible, such as the dimensions and orientation of the parking space, as well as the type of parking area. That's why we also validate parking at various stations worldwide," said Dr. Stefan Stümper from the Quality Assurance team for automated driving.

CarPad app
The use of mobile devices for data collection and the CarPad app make shakedown testing easier today. They allow an event-driven assessment and evaluation of complex vehicle systems. Where we previously had to fill in checklists partially by hand, the data entry now takes place by the quality experts using the dashboard tool of the CarPad app. Perpendicular spaces on the left, lane change assistant on the passenger side, maneuvering out of parking spaces – the driver can select the function which needs to be validated from a list and immediately display the result at the tap of a finger. He can record specifics of each individual driving maneuver in a comments field. The CarPad app synchronizes the data entered with Audi's quality assurance databases via mobile radio or WiFi.

Total Vehicle Acoustics
In the premium segment, acoustics is a classic core competence of Quality Assurance. New technologies, especially the electrification of the powertrain, affect the acoustics of the total vehicle in many ways and lead to new challenges. It pays to listen carefully: cars with an electric drive are not completely silent, but rather bring completely new noise phenomena. Vibration analysis, i.e. the investigation of the noises and vibrations that occur during driving, must be rethought in the age of electric mobility. Audi uses innovative analysis methods.

Total Vehicle Acoustics staff analyze the various vibrations penetrating the interior of the car during driving. Due to the comparatively quiet electric motor, noises come to the fore that in conventional cars are drowned out by the sound of the internal combustion engine. The challenge in shakedown testing is to assess and locate intrusive noises. To analyze the different acoustic transmission paths, the acoustics technicians use modern instruments such as microphones or an artificial head that is equipped with two highly sensitive microphones and simulates the human ear. Even an accelerometer is used regularly. Experimental modal analysis is used here to visualize intrusive vibrations of structures.

Following the analysis, the acoustics experts work with Technical Development to develop solutions to attenuate, eradicate or dampen these noises. “During shakedown testing, we actively shape the sound of each Audi,” explained quality expert Andreas Wolf, Acoustics Total Vehicle. “An electrically powered Audi must sound just as high-quality as an Audi with an internal combustion engine.”

The Rustle and Rattle team

The finest of leather and shiny high-gloss trim elements in the vehicle are important component parts of a high-quality, premium ambiance. Touching, smelling and feeling an Audi is an experience in the truest sense of the word. Even slight, intrusive noises can disturb this feel-good atmosphere. Preventing these is the task of the experts in the Rustle and Rattle team. Their expertise lies in finding an optimal configuration comprising material pairings, design and fit.

A well-trained ear and sound technical understanding are the most important tools. Alert ears, absolute quiet in the car and a poor-quality road surface are the essential prerequisites for finding the source of intrusive noise. Here again, vehicle electrification leads to new challenges: the internal combustion engine is eliminated as one of the typical primary noise sources.

What remains are vehicle vibrations due to road conditions. Different materials in the car rub together ever so slightly. The longer a car is on the road, the more prominent these sounds become. With their wealth of experience, Audi acoustics technicians track down possible rub points and challenging material pairings to help eliminate unwanted noise during the early phase of development. This creates a special form of premium quality: the peace of mind the customer expects in the car.

Service Technology

Service Technology is an integral part of Quality Assurance in the product testing process step. It forms an important link between the retail market and Audi AG. The strengthening of technological and analytical competence is in central focus. Findings obtained here flow directly into the upstream processes, such as development and production.

Service Technology works on a global scale – with the Technical Service Center (TSC) at strategically selected locations abroad, the team can optimally take into account regional specificities.

The technical vehicle analysis is a core task of this area. The analysis methods are subject to continual optimization and further development. Effective and innovative analysis tools are today already helping to build up the analytical competence in the retail market as well as helping to offer the customer an optimum service experience.

Mobile tools for the analysis of dynamic occurrences: CAR ASYST APP
Analyzing vehicle data on the go is as easy as updating the software on a smartphone. Rapid malfunction and fault analysis without stationary measurement technology is made possible by the CAR ASYST APP which was specially developed for Audi. For example, the smartphone becomes a professional diagnostics tool for workshops.

The CAR ASYST APP receives wireless access to the vehicle via a powerful WiFi Ethernet adapter. A connection is established between the WiFi interface of the smartphone and the Ethernet port on the vehicle diagnostic connector. Communication takes place via the Diagnostics-over-Internet Protocol (DoIP). In just a few seconds, the event memory and any necessary measurement data are read out, and the app displays the corresponding values in real time.

In addition to these basic vehicle analysis functions, vehicle measurement data can be combined with smartphone sensor readings. For example, the video function of the smartphone can be used while vehicle data are logged – a practical aid during the analysis. Thanks to the fast Ethernet interface with 100 Mbit/s, the entire communication of the control units can be recorded in parallel in so-called mirror mode with no additional cabling. Both the employees of Service Technology and the workshops use the CAR ASYST APP regularly for in-situ system analyses and rapid diagnostics.

NVH analysis to identify noises and vibrations
Vibrating, humming, crunching, whining, cracking, buzzing – people perceive noises very subjectively with their ears. Often audible perceptions cannot be generally summed up in easily understandable words. An analysis of noises and vibrations was previously a major challenge as even the evaluation of regular vehicle measurement data was not always able to establish the origin of noises or vibrations. For this reason, Service Technology has developed a unique approach for Audi workshops. The so-called NVH tool (noise, vibration, harshness) makes it possible to analyze and objectivize noises, vibrations and harshness directly at the vehicle.

The implementation of a mobile NVH tool makes it possible for employees of Audi workshops to record all vibration and noise levels as part of a joint test drive with the customer. The data collected can then be analyzed, evaluated or compared with data collected from other vehicles in the workshop or data from validation runs. The NVH tool is available worldwide and with it, noises can be globally visualized and evaluated. The analysis of the data recorded helps convert a subjective noise description into an objective characteristic and for abnormalities to be attributed to specific components with the help of the recorded conditions, e.g. engine speed and road speed. Audi Quality Assurance saves the evaluated noises in digital form within the measurement data management system for acoustics (MeDaMAk) and uses it for continuous product improvement. In the future, on the basis of the MeDaMAk database, an NVH analysis software might be created which, after just a few seconds of recording a noise, can already associate it with a known source – a little like it is already possible today for an app to recognize a music track currently playing.

Outlook – Vision 2025
Connecting several new technologies with one another leads to the classic focus of the customer being much broader in the future – the customer base no longer just focuses on the product itself, but on the interplay between the car, the infrastructure and digital products relating to mobility. This increasing complexity thus brings new challenges to Service Technology. In this respect, digitalization empowers and supports the Service and Technology areas.

An important component here is the “connected car”. Integrated vehicle sensors turn the car into its very own analysis tool with remote access – if desired on the part of the customer – which helps the team at Service Technology to access the measurement data in real time. Using special data analysis methods, future patterns can be detected and the vehicle behavior predicted in order to offer customers individual maintenance and preventive services.

With this digitalization initiative, Service Technology shapes the service experience for the customer with the aid of new technologies in as comfortable a way as possible and thus increasingly also creates personal freedom for the customer.