

Sensor & Actuator Component House

Developing, Integrating, Testing, Analyzing



Engineering for the Entire Vehicle

IAV is one of the leading engineering providers to the automotive industry and employs over 3,000 members of staff worldwide. Our long-standing clients include virtually all automobile manufacturers and their system suppliers. Together we work on advanced solutions for powertrains, electronics and vehicle development.

Our attention at all times focuses on the entire vehicle - and not just on individual components. Guided by this approach, IAV provides vehicle manufacturers and suppliers with independent support in developing production-ready sensors & actuators for:

- ▶ Drives
- ▶ Safety
- ▶ Comfort

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Quality Verdict on Sensors & Actuators: Sentenced to Life - With no Pardon

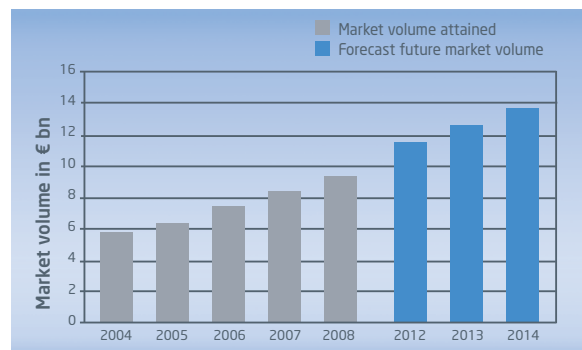
The advent of electronics in the motor vehicle has given rise to a wide range of mechatronic systems with new functions. Many of these system functions are made possible by sensor signals. Measuring engine speed, vehicle speed, pressure, temperature and other influencing variables, for example, sensors register driver requests or detect the state of the engine. These components are the automobile's "sensory organs". The system of actuators controls and switches these functions. Working as the "muscle of the electronics", it ensures occupant protection, enhances ride comfort and provides driving fun while keeping emission levels low.

Numerous innovations in the field of electronics have made the market for sensors & actuators grow more than the automobile market itself. One in every four sensors produced worldwide is installed in a motor vehicle. A typical sensor or actuator is produced in quantities of no fewer than 100,000, a figure that can also run into the millions.

The growing number of sensors & actuators in the vehicle increases both the probability of failure as well as system complexity on a disproportionate scale. Many of these components being relevant to safety, they are required to guarantee life-long reliability over more than 15 years or at least 240,000 km.

Malfunctioning sensor & actuator systems or their complete failure can lead to vehicle breakdowns. To avoid costly recalls, the quality of these small components must be "sentenced to life - with no pardon".

Satisfying this demand on quality goes a long way toward maintaining automobile manufacturer competitiveness. IAV takes up this challenge as an internationally recognized development provider with over 15 years of experience and expertise in the field of sensors & actuator systems.



Market volume for sensors & actuators

Development methods

Project management
Supplier management
Analysis
Quality assurance
System optimization
Validation, verification & testing
Risk analysis
Process organization
Planning methods



Development process

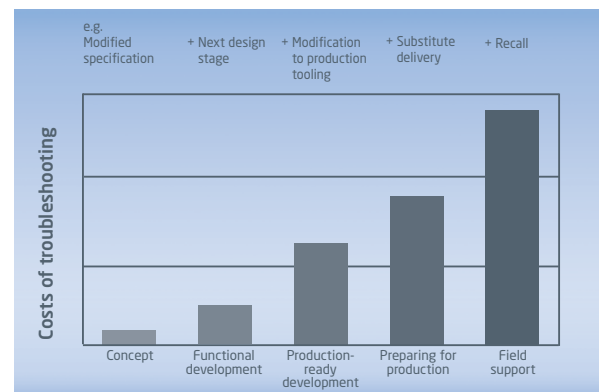
Process Expertise from IAV: From the Idea to the Start of Production and Beyond

The requirements placed on sensors & actuators have grown with the expectations made on the vehicle of today. Demands on the part of the legislator to reduce CO₂ emissions have added dynamism to the developments taking place in the field of underhood sensor & actuator systems. The desire for greater active safety and higher comfort demands are necessitating far-reaching improvements to these components. High operational reliability and long life, coupled with consumption, weight and package restrictions at minimal cost: This is where sensor & actuator systems are often pushed to the limits of technical feasibility.

In terms of sensor technology, the vehicle manufacturer relies on tried and proven components from the supplier. The supplier, in turn, is primarily a specialist in sensor technology and does not always have a grasp of the overall vehicle. IAV can support both automobile manufacturers and suppliers at every stage in the development process with its wealth of process and technology-related expertise. In particular, this covers:

- ▶ Generating ideas
- ▶ Concept phase
- ▶ Functional development
- ▶ Mass-production development
- ▶ Preparing for production
- ▶ Field support

Preparing ourselves for future challenges posed by the motor vehicle as a means of transport and the new solutions and technologies these will demand in the field of sensors & actuators, we cooperate with higher-education institutes and target investment in our own development activities to gain an understanding now of the production components for tomorrow.



Costs of troubleshooting in the product creation process



Our team takes you to your goal

What We Do: Take You to Your Goal!

IAV is available as a development provider to vehicle manufacturers and suppliers alike. We possess a high level of expertise in the process of developing sensors & actuators. Never losing sight of integration in the overall vehicle, we provide our clients with IAV's entire range of competencies. At the interface between vehicle manufacturer and component supplier, we facilitate the development process to the point of perfection.

Flexible project structures provide the capability of calling in our specialists for specific activities wherever they are needed. Our engineers are able to work on individual aspects or specifically defined subject blocks detached from the overall process without losing their focus on the whole. This system thinking helps us identify relationships between cause and effect.

Our expertise in the development process encompasses:

Preparatory activities

- ▶ Verification of availability of technology
- ▶ Feasibility analyses
- ▶ Strengths/weaknesses analysis

Managing requirements and compiling specifications

- ▶ Definition of testing concept
- ▶ Safety analyses
- ▶ System, product and process FMEA

Design reviews of samples and their evaluation

- ▶ Computation/simulation
- ▶ Verification in the concept vehicle
- ▶ Initial-sample testing

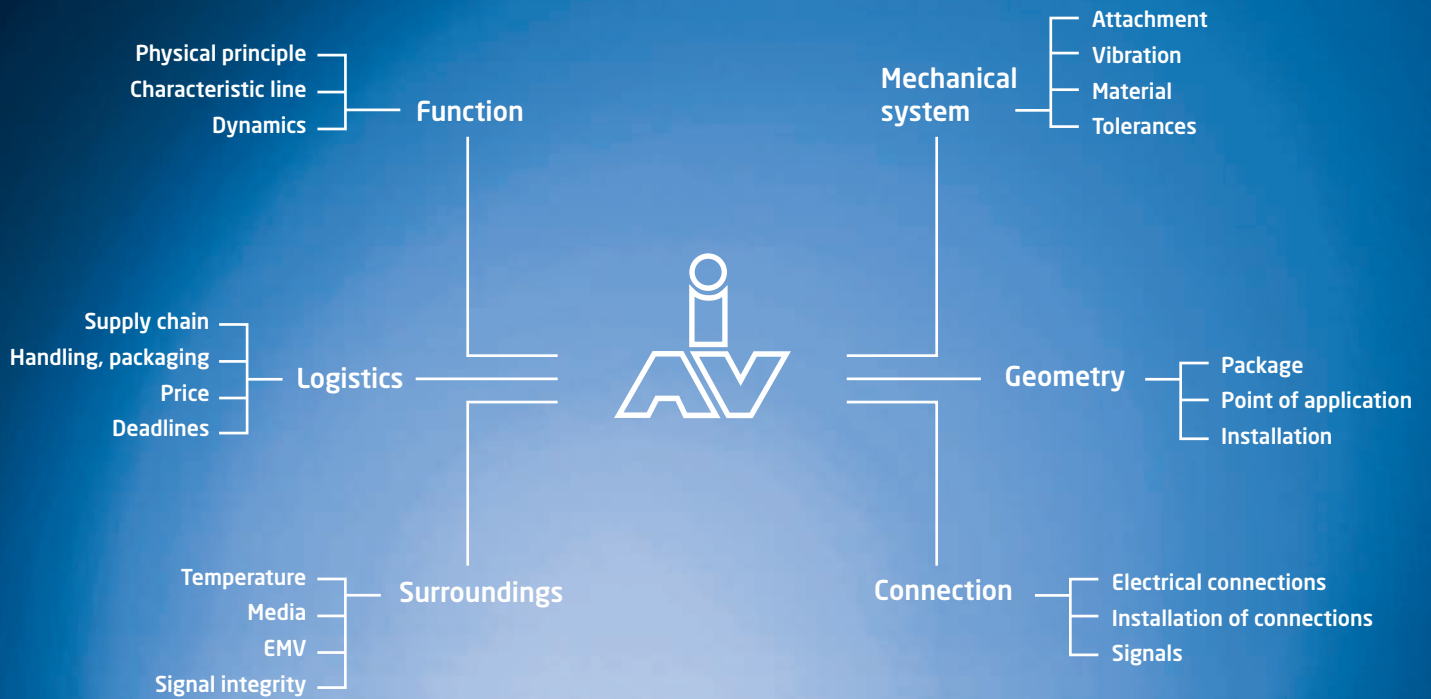
Component testing and validation

- ▶ Definition of test methods, test equipment
- ▶ Function and endurance testing
- ▶ Vehicle testing

To minimize failure rates, warranty costs and damage to their image, we provide our clients with support at production level and in matters of quality assurance:

Fact finding/analysis of faulty components/failure analysis

- ▶ Fault statistics
- ▶ Validation methodology, preventative quality work
- ▶ Product monitoring
- ▶ End-of-line inspections
- ▶ Task force



Fields of action for carry-over parts (COP)

Integration: The COP Trap

Why do validated sensors & actuators not function as carry-over parts (COP) in the next vehicle generation? Tried and tested components do not always meet the specific boundary conditions of the various vehicle models and must therefore be adapted accordingly.

The aim is to carry over validated components into the next vehicle generation at minimal cost while maintaining their operating precision and reliability with little modification work. In this process, the many different disciplines - from quality and package to algorithm development and calibration - work hand in hand.

Our engineers systematically perform a delta analysis on carry-over parts under the changed conditions. Proceeding from the requirements analysis, our teams detect the problem and action fields that need to be analyzed in the context of project and component. Fields meeting the requirements on COPs and involving no need for action are excluded.

Keeping costs low and involving as little work as possible, the aim is to obtain a precise basis on which to define further action, such as component modifications or additional validation tests.



Component damage analysis in our own laboratory



Analysis: The Fault Is a Matter of Detail

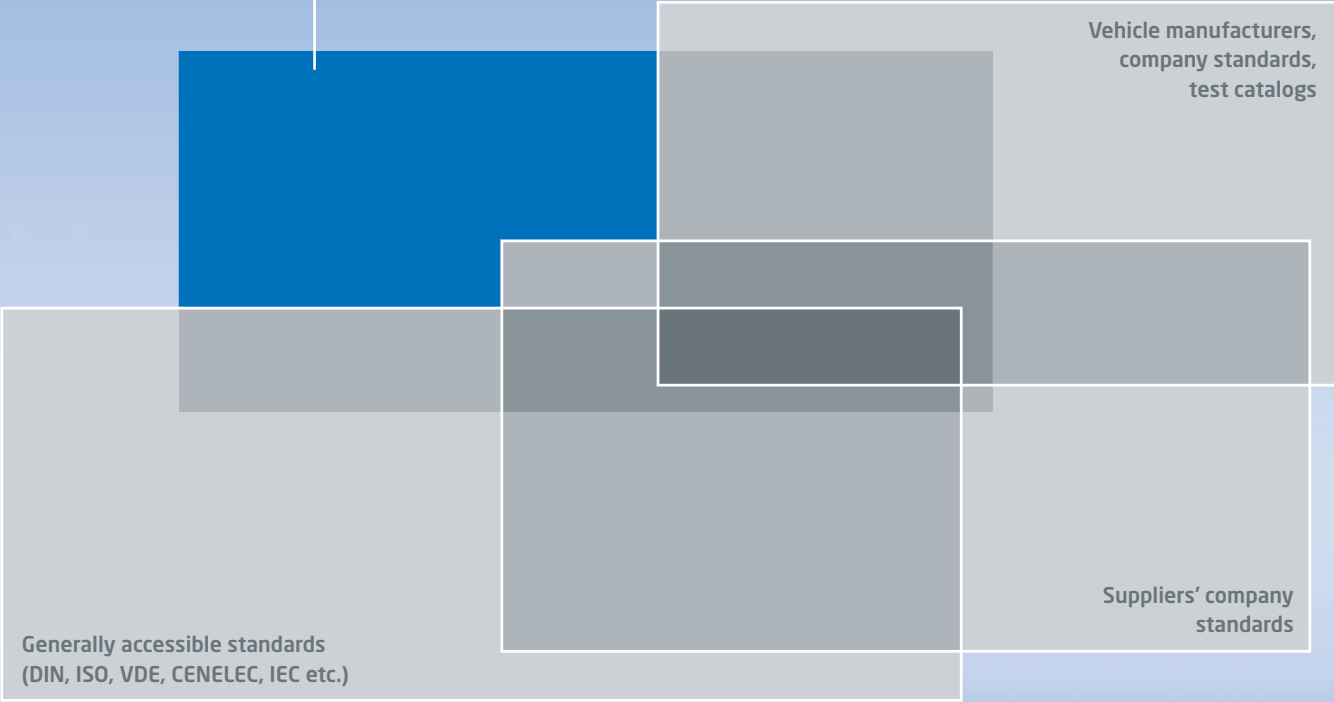
IAV provides its clients with support in promptly identifying, swiftly localizing and permanently rectifying any faults that occur during the development process, the validation phase or within mass production. This is where our experts stand apart with their detailed knowledge of components and systems. Our many years of experience enable us to localize the relevant problems quickly and provide rapid solutions.

We collect fault messages from testing and use them for identifying fault patterns. Our teams reproduce fault patterns on the test bench and in the vehicle, conduct component damage analyses and push forward research into fault causes. Together with car manufacturers and component suppliers, we define immediate action and provide permanent solutions.

We will be pleased to provide you with support in the field of analysis focusing on the following aspects:

- ▶ Fault recording/fault tracking
- ▶ Fault localization
- ▶ Fault processing (8D report)
- ▶ Component damage analysis in our own laboratories
- ▶ Consultancy regarding component damage analysis through specialized laboratories
- ▶ Fault reproduction
- ▶ Defining remedial action

These "marginal areas" are covered by special tailored tests developed and conducted by IAV on request



Special IAV tests complement standardized measuring programs

Test Definition: Who Tells the Tester How to Test?

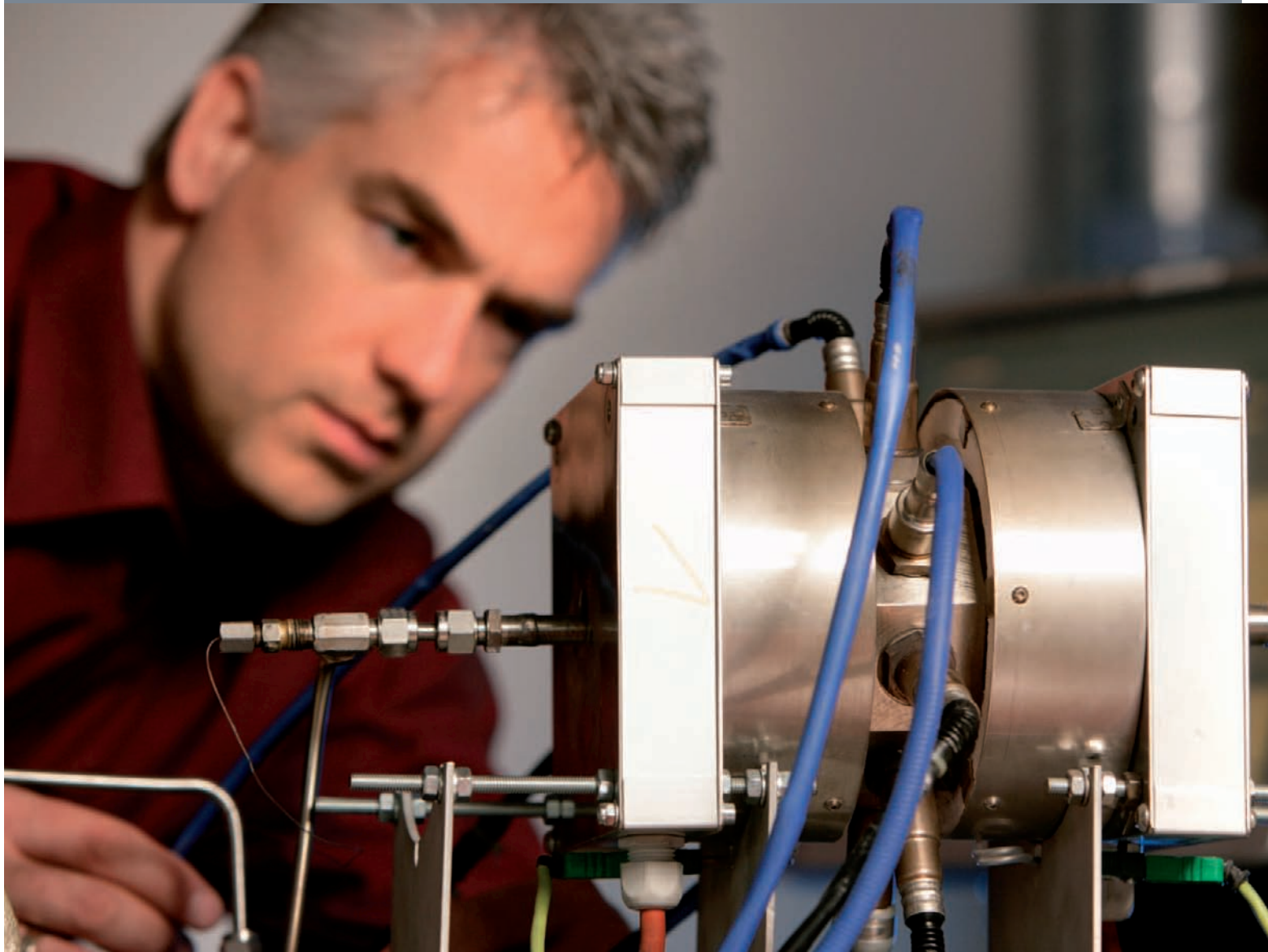
For a component to go into mass production, it must first undergo a process of comprehensive testing. In the case of sensors & actuators, this involves specific test activities, such as environment simulation or service life tests that are usually performed by test houses. The scope of testing is defined by the vehicle manufacturer in the requirements specification. Component qualification is the responsibility of the supplier - where it is in exactly the right hands.

IAV is in full command of all test domains in the V-model. Meeting the requirements and challenges of our clients, we can offer tailor-made solutions to quality problems not identified at the component qualification stage. This also involves developing specific tests that extend beyond or complement the existing standards.

Devised in-house, we can draw on a whole range of testing and inspection facilities, some of which have been developed specifically for this verification activity (you will find a brief overview at the end of this brochure). To meet these specifications, we work together with test houses who then include them in their tests. We also provide the vehicle manufacturer with support in incorporating these demands in the requirements specification.

We assist our clients in validating components for mass-production use in the following areas:

- ▶ Definition of testing concept
- ▶ Test specification, description and planning
- ▶ Test-bench assembly, test-bench automation
- ▶ Testing and evaluation
- ▶ Coordination/assessment of testing with internal/external partners
- ▶ Coordination of test specimens
- ▶ Trials in the vehicle and on test benches
- ▶ Definition of HALT/HASS (Highly Accelerated Life Test/ Highly Accelerated Stress Screen)



Assessing the analysis quality of exhaust-gas sensors

Reference Example: Assessing the Analysis Quality of Exhaust-Gas Sensors

As a result of ever-lower exhaust emission ceilings in EU and US emission standards, together with the high level of aging stability that is also demanded, exhaust-gas sensors hold a key position in powertrain development. Without them, optimum exhaust-gas aftertreatment would not be possible because they provide the means to control the system and are also indispensable for monitoring functions.

An exhaust-gas sensor can only ever be optimized in the context of the overall emission picture. The injection system, combustion process and exhaust-gas aftertreatment system are key components that must be taken into consideration in this context. The complexity of these components, however, often makes it difficult to optimize the overall system.

Automobile manufacturers are extremely keen for independent facilities to exist for testing exhaust-gas sensors. As the suppliers of these sensors are often unable to simulate the entire vehicle in its complexity, IAV has been commissioned to set up a multifunctional measuring facility for assessing the analysis quality of exhaust-gas sensors.

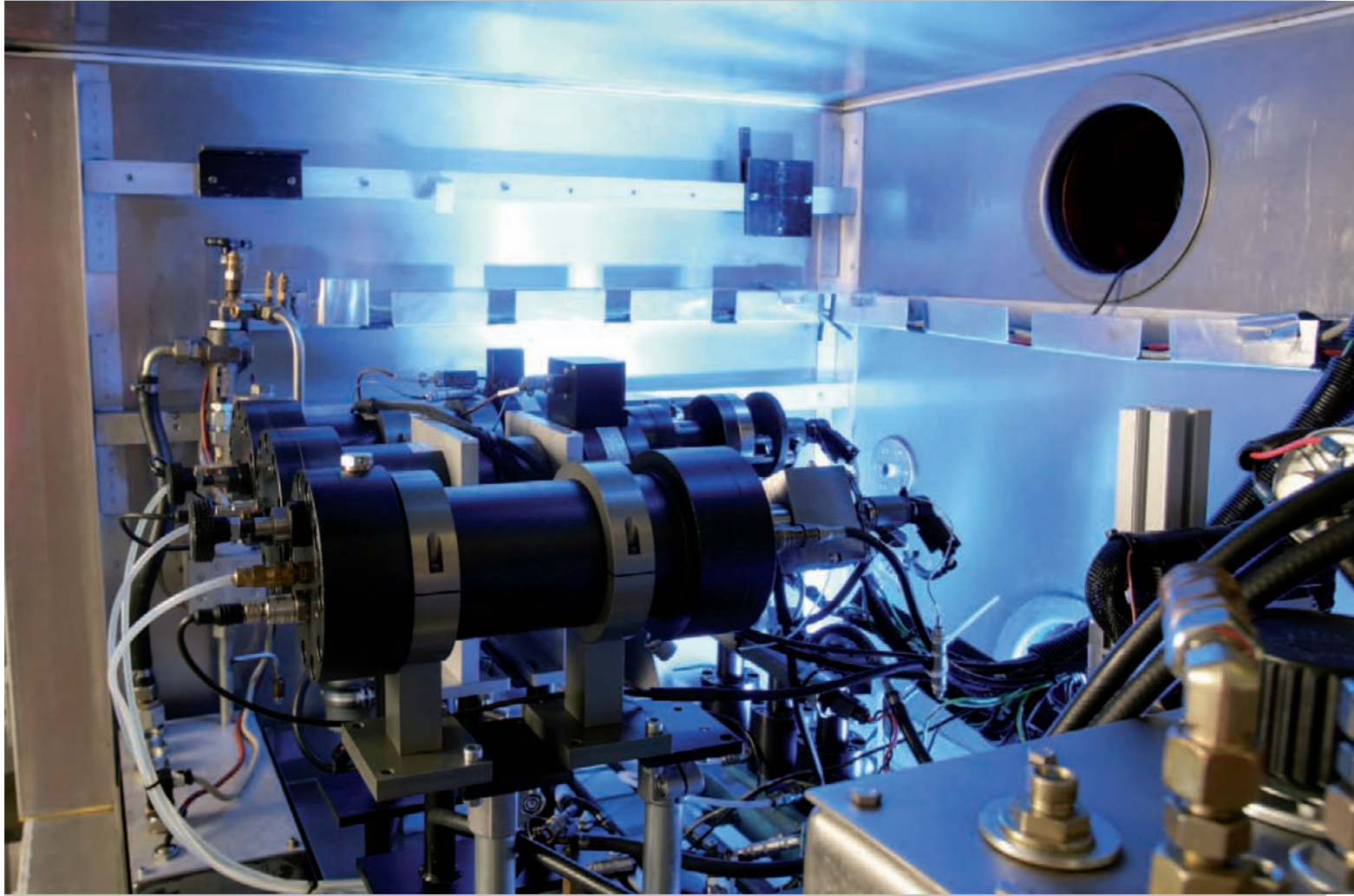
Using this measuring facility, different brands of various probe types (lambda probes, nitrogen-oxide sensors or ammonia sensors) can undergo independent assessment. We have propane-gas burners, a test bench for dynamic pressure analysis and a variety of synthetic-gas test benches at our disposal for this purpose. They allow us to examine exhaust-gas sensors in respect of the characteristic values specified by the manufacturer. In particular, their suitability can be assessed under real-life ambient conditions. It is here that our exhaust-gas analysis, exhaust-gas calibration and sensor-system specialists work together very closely.

One of IAV's synthetic-gas test benches provides the unique capability of conducting dynamic measurements in a synthetically reproduced hot flow of gas at full throttle. The relevant parameters for this can be varied independently of each other. The test bench also offers the possibility of testing several probes simultaneously under identical conditions (benchmarking). On account of the high degree of reproducibility, all of the synthetic-gas test benches can be used for determining individual effects, for conducting comparative as well as before/after measurements or even for developing new testing methods in conjunction with the client.

IAV is ideally positioned with this multifunctional measuring facility. Take advantage of the services we can offer.



Gas flows can be synthetically reproduced



Injection Analyzer



Reference Example: Under Pressure - Developing Fuel and Injection Systems

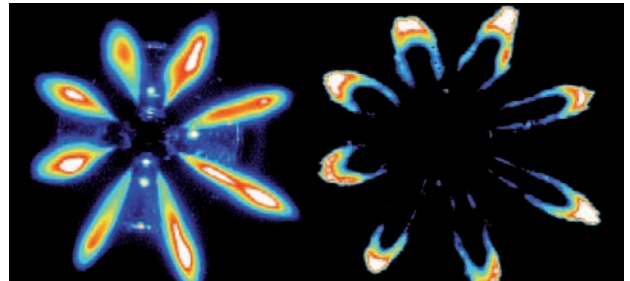
The rapid advances made in fuel injection systems over recent years have significantly contributed to the development of energy-saving and low-emission engines. The injection system itself is of high complexity and with every step forward (such as elevated injection pressure) comes up against technological limits in terms of material and function. At the same time, the injection system has a major influence on the combustion process and exhaust-gas aftertreatment.

To avoid development mistakes with far-reaching repercussions, the injection system with all of its components must be optimized early on in the process. It is here that we take into account both the requirements of the engine manufacturer as well as the situation at the supplier. Our engineers constantly need to strike the right balance between costs, lower emissions, consumption and durability.

Facilitation and development support by our specialists is based on investigations and actual results from IAV's function and endurance testing stations designed specifically for injection systems. Our experts do not restrict themselves to investigating injection-system components in isolation but are able, by following an all-embracing approach, to reproduce the requirements of the entire powertrain or whole vehicle in their testing facilities. This way, consideration is not only given to aspects inside the engine but also to the overall supply of fuel downstream of the tank, to market or country-specific fuel properties as well as to exhaust-gas aftertreatment, acoustics or packaging.

To implement the findings gathered from detailed analysis, we have a highly specialized team dedicated specifically to designing injection systems as well to providing assistance with the processes required to produce them. Consequently, support can be given as far as the production operations of injection-system suppliers.

In addition to its comprehensive range of testing facilities, IAV also benefits from special measuring techniques and equipment that are integrated in a continuous process of adjustment and improvement to satisfy the changing requirements of its clients - e. g. for analyzing injectors.



Visualization of injection quality in false color imaging



Time to act - our experts respond immediately

Reference Example: Risk of Breaking Down From Losing Coolant

Fingers were quickly pointed to the electric water pump as the possible cause - a component that was currently being used in large numbers of production vehicles from several manufacturers. The supplier of this component, on the other hand, suspected the fault in the overall system. Immediate action was necessary to avoid damaging the vehicle manufacturer's image.

IAV received the contract to localize the fault. A small IAV team was put together to find the root of the problem. Our engineers established that water-pump failure was indeed the cause of the fault. They identified two potential fault patterns. Quickly reaching agreement with the supplier about one of the fault sources, it immediately initiated measures to rectify the problem.

The other fault remained a bone of contention with the supplier. Following an exact analysis of the data in hand, our team drew up specifications for a test bench to verify the fault and set it up within two days.

The electric water pump was integrated in the test bench and fitted out with measuring equipment and a camera. During the course of testing, the camera was able to record the processes taking place inside the pump. This made it possible to determine the exact position of the rotor at the moment of failure. An automated cycle was employed for testing the component and recording the data measured when the fault occurred. Within just three days, our engineers had managed to verify the fault. The component was modified on the basis of these results.

Roof node cluster

Infrared sensors plus camera

- ▶ Lane-departure warning
- ▶ Traffic-sign recognition
- ▶ ACC with stop & roll
- ▶ Parking assistant (extended)
- ▶ CV sensing (extended)
- ▶ Emergency-brake assistant (extended)

Rear-end cluster

24-GHz radar plus camera

- ▶ Lane-changing assistant (long range)
- ▶ Parking assistant (rear)

Front cluster

77-GHz radar

- ▶ Stop-&-Go
- ▶ ACC
- ▶ Emergency-brake assistant

24 GHz short-range radar plus camera

- ▶ Stop-&-Go
- ▶ Parking assistant (extended)
- ▶ CV sensor and pre-crash
- ▶ Emergency-brake assistant

Side cluster

Active IR sensor plus camera

- ▶ Lane-departure warning
- ▶ Blind angle monitoring
- ▶ Lane changing (short range)
- ▶ Parking assistant (parallel)

Surrounding field sensor system and a selection of possible functions

Reference Example: Surrounding Field Sensor System - The Vehicle's Electronic Eyes

Surrounding field sensors are being used in a constantly growing number of vehicles to enhance comfort and safety. This is where our engineers face the challenge of getting the huge range of sensor types ready for production use in numerous vehicle models in ever-shorter development times.

We structure every stage of this development process efficiently and cost-effectively from concept to pilot series and start of production.

On the one hand, we consistently employ intelligent test methods developed at IAV in-house. For instance, our experts use a reference environment for testing and analyzing different surrounding field sensors in the overall vehicle. The results of these benchmarking activities are channeled into the overall validation concept together with the results of test drives. Compared with conventional methods, this means we can significantly reduce the number of test drives that are necessary in the open.

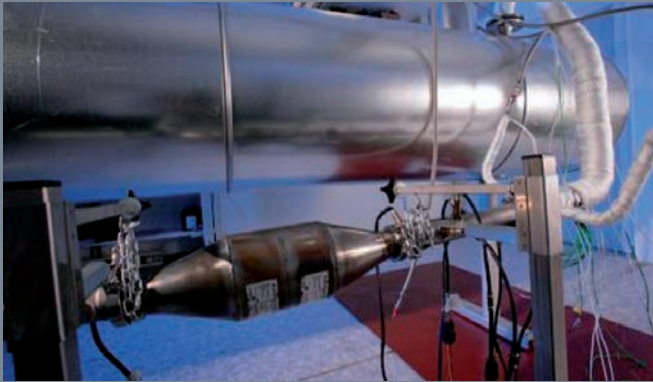
On the other hand, we optimize development costs as early as the concept phase. While planning the packaging, for example, our specialists were able to identify that the package defined by the vehicle manufacturer for a reversing camera in some models was not appropriate from a technical point of view. The positions designated for installing the cameras restricted their field of vision too much.

Using a test set-up, our specialists quickly managed to prove that in all vehicle models the angle of vision from some of the positions planned for mounting the reversing cameras was insufficient for completely imaging the contours of an adjacent vehicle. In some cases, the intended camera position was so low that the reversing camera was only able to capture the underfloor of other vehicles.

Checking all vehicle models early on in the concept phase, our experts were able to prevent huge modification costs in the later stages of vehicle development.

Overview of Testing Infrastructure

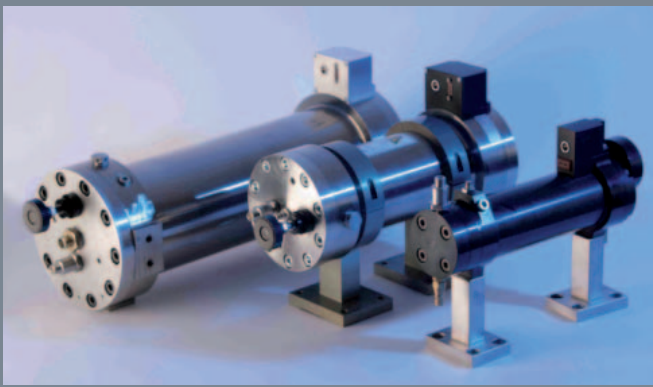
Test bench for exhaust-gas sensors



Test bench for exhaust-gas sensors

- ▶ Dynamic pressure test bench
- ▶ Synthetic-gas test bench with constant gas mixture
- ▶ Synthetic-gas test bench for steady-state operating points
- ▶ Synthetic-gas test bench for dynamic operating points

Development of special measuring equipment for injection systems



Injection Analyzer - measurement tool for developing injection systems

- ▶ Injection Analyzer
- ▶ Determining the point of cavitation reversal for nozzles
- ▶ Spray force measurement
- ▶ Needle-stroke measurement, WSG etc.

Testing injection system operation



Function testing of injection systems

- ▶ Pumps, injectors, pressure/volume control valves
- ▶ Underhood set-up of overall systems
- ▶ Optical spray analyses, hydraulic nozzle measurement
- ▶ Calibration/ECU data feed

Endurance testing/validation of injection systems

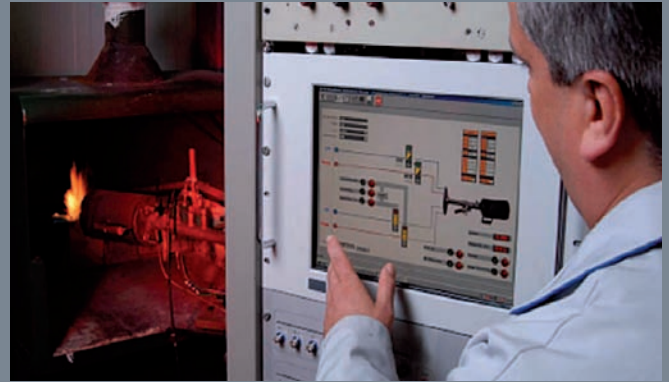


Endurance testing of injection systems

- ▶ Pumps, injectors, entire systems
- ▶ Actual fuels (diesel, gasoline, worst-case fuels etc.)
- ▶ Capability of calibrating ambient temperature up to 140 °C
- ▶ Time-lapse studies

Propane-gas burner for checking technical admissible tolerance for O₂ sensors

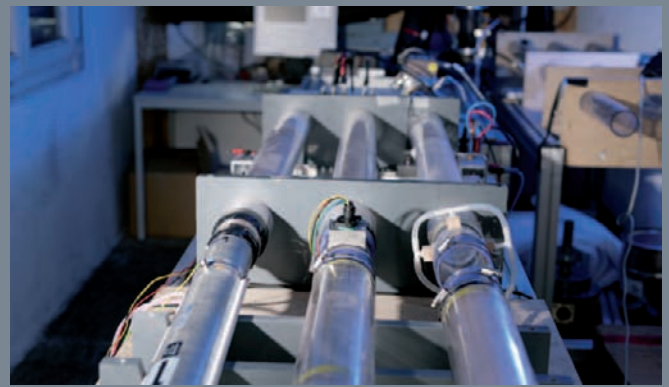
- ▶ Benchmarking
- ▶ Rich and lean-mixture voltage in defined atmosphere
- ▶ Response times
- ▶ Internal resistance
- ▶ Heater current requirement
- ▶ Test for the absence of rich gases



Propane-gas burner

Air-mass sensors

- ▶ Hot-film air mass and hot-wire mass measurement
- ▶ Life-cycle tests
- ▶ Comparative tests
- ▶ Measurement with selective fouling



Air-mass sensors

Test bench for flaps and valves

- ▶ Function tests
- ▶ Variation of actuation signals
- ▶ Break-away torque
- ▶ Static and dynamic friction



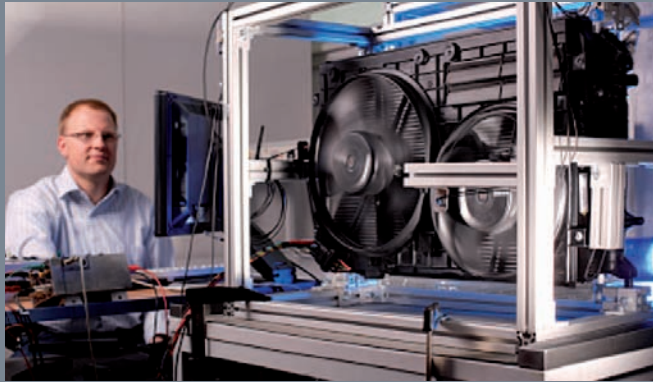
Test bench for flaps and valves

Test bench for electric water pumps

- ▶ Function tests
- ▶ Hydraulic and electrical characteristic line measurement
- ▶ Temperature-controlled endurance tests
- ▶ Contamination tests
- ▶ Benchmarking



Test bench for electric water pumps



Test bench for radiator fans



Field-of-vision identification



Switch test bench

Test bench for radiator fans

- ▶ PWM-controlled fan motors
- ▶ Testing of electrical variables
- ▶ Power output range from 200 W to 1000 W
- ▶ New/aged comparative tests
- ▶ Tests for protection concepts

Test center for surrounding field sensor systems

- ▶ Calibration of camera systems
- ▶ Sunlight and night-light simulation
- ▶ Validation and benchmarking of driver-assistance and comfort systems
- ▶ Determination of sensor parameters in the vehicle
- ▶ Sensor simulation

Test bench for mechanical stress loading on switches and controls

- ▶ Fatigue testing of controls and switches
- ▶ Mechanical qualification of controls with extremely precise simulation of later in-vehicle use
- ▶ Realization of individual test requirements using universally applicable and user-programmable robot modules

