Special AVL

The Chassis Dynamometer as a Development Platform

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A Common Testing Platform for Engine and Vehicle Testbeds

In order to achieve time-savings during vehicle development, companies are increasingly looking to run the same tests on the engine test bed as on the chassis dynamometer. The aim is to correlate results in order to highlight differences and their influencing factors, as well as to verify the engine test bed results, and to achieve the additional benefit of reusing existing tests. A common test automation and data platform is required. The article describes an application in which this has been achieved for emissions certification testing and discusses the value of upgrading the chassis dynamometer to a higher level of automation.

1 The Synergies between Engine, Driveline and Vehicle Testbeds

The product development processes at OEMs and the component development process of tier 1 suppliers rely on extensive testing phases of the different powertrain components and of the complete vehicle. The testing is carried out using various types of test benches: hardware-in-the-loop benches, component testbeds, engine testbeds, driveline testbeds and vehicle testbeds. Finally, fleet testing of prototypes takes place on the test track or road for the final adjustments.

In each of these test environments, various testing tasks are carried out. For instance, an engine testbed is used during the development phase to verify the engine durability and its thermodynamics. It is also used to set up the base calibration of the ECU and predict the engine emission behavior using vehicle simulation.

The OEMs are coming under ever-increasing pressure to reduce the time to market of new vehicles while saving on development costs. This translates into a need for an efficient and shorter product development process. A key element in reducing development time is front-loading the testing of vehicle characteristics earlier in the process. Front-loading not only allows time-savings and a reduction in the number of vehicle prototypes needed; it also supports a reduction of development costs by addressing unplanned design changes much earlier in the process in a cost-efficient manner, as the later a component failure is detected the more expensive the fixing will be.

However, this requires a state-of-the-art development tool chain that fulfils the following requirements:

– the ability to accurately simulate the missing vehicle components on the testbed (e.g.: the vehicle powertrain on an engine testbed)
– the ability to reproduce environmental conditions realistically
– the ability to support iterative development loops efficiently between the different stages of the process.

This last point is the key for delivering the desired efficiency improvements since it must allow the correlation of similar testing tasks carried out at different stages in the process for the purpose of validating results obtained using simulation, or to comply with legislative requirements.

For example, emission tests are carried out on an engine testbed and repeated on the vehicle testbed for certification; drivability assessment and powertrain calibration optimization are carried out on engine, driveline and vehicle testbeds and verified later in the vehicle on the road; climatic testing takes place on the engine testbed and again later on the vehicle testbed; durability testing takes place on the transmission testbed and again later on the road or on the vehicle testbed, **Figure 1**.

One well-known way of facilitating the correlation is the use of a common simulation platform which also avoids the need to develop and maintain multiple models.

Another source of productivity gains is the use of a common automation platform across all types of testbeds.

2 The Common Automation Platform

The automation test system can be split into three different layers in terms of software functions, **Figure 2**:

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Figure 1: Simulation across the product development process

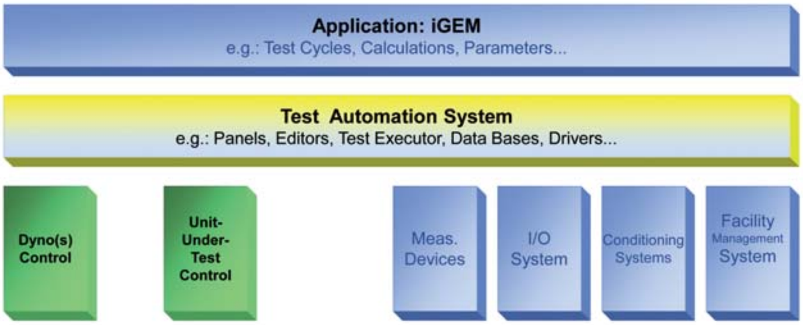

Figure 2: The architecture of a common automation platform

- the controller – for testbed and unit-under-test control
- the test automation system (TAS) – for data acquisition and test automation
- the application (e.g. an emission test run such as FTP 75).

If the controller is specific to the different types of testbed, the TAS is not. Therefore, provided consistent system architecture on engine, driveline and vehicle testbeds, the same TAS can be used on all types of testbeds and, if it successfully abstracts the application from the controller, the application is then portable from one type of testbed to another.

Being able to port the application from one testbed type to another allows the synergy potential between the different testing steps of the product development process to be efficiently leveraged. Result data can be correlated, test specifications can be reused (e.g.: shift quality and drivability assessment on a powertrain testbed and on a vehicle testbed). Parameters can also be reused (e.g.: vehicle parameters for the simulation on an engine testbeds and the parameters for the chassis dynamometer).

In addition, significant benefits can be derived from the effects of scale and standardization, which contribute to reducing the total cost of ownership of the TAS.

For instance, the "one window" approach reduces training needs and maintenance costs; a common data handling and IT infrastructure is used across the whole product development process; common process management tools are used across the whole product development process for scheduling, equipment management and supervising.

While the need for vehicle testbeds may have been challenged by front-loading many testing tasks, its use remains more crucial than ever for verifying the results obtained earlier in the process while also enabling the execution of traditional in-vehicle activities in a more deterministic manner in a testbed environment rather than on the road. One example is the shift quality and drivability assessment application. Being able to automate such an application on a vehicle testbed may bring significant productivity gains and address the increasing effort required for transmission calibration.

All this requires the vehicle testbed TAS to be able to: transfer testruns and correlate test results between the engine and the vehicle testbeds (e.g.: for emission testing); transfer testruns and correlate test results between the driveline and the vehicle testbeds (e.g.: for powertrain calibration optimization); transfer road profiles recorded in the vehicle and replicate them on the vehicle testbed (e.g.: for endurance testing); provide the frameworks and interfaces to the calibration tool chain (e.g.: automatic calibration software, direct access to the xCU and the application systems); provide the connectivity to the vehicle testbed subsystems (e.g.: dynamometer, emission benches, driver-robots, measurement devices, in-vehicle buses, facility and conditioning systems).

Up to now, automation of the chassis dynamometer was often limited to data acquisition while the testbed control was left to the chassis dynamometer controller and the human driver or robot system. However, to fulfill the above requirements, one requires a TAS for the vehicle testbed which is able to fully automate the testbed and provide the required compatibility with the TAS of other testbed types in terms of architecture and data formats.

3 The AVL Solution

AVL's solution is to use PUMA Open as the automation platform for rig testing: from the component testbed to the engine, powertrain and vehicle testbed. While PUMA Open is well-known and well-established as the TAS for component, driveline and engine testbeds, its extension to vehicle testbeds was required to fulfill the requirements of a common automation platform.

Thanks to its modular design and its scalability, PUMA Open can be tailored for a wide range of vehicle testing applications, from simple data logger to ad-

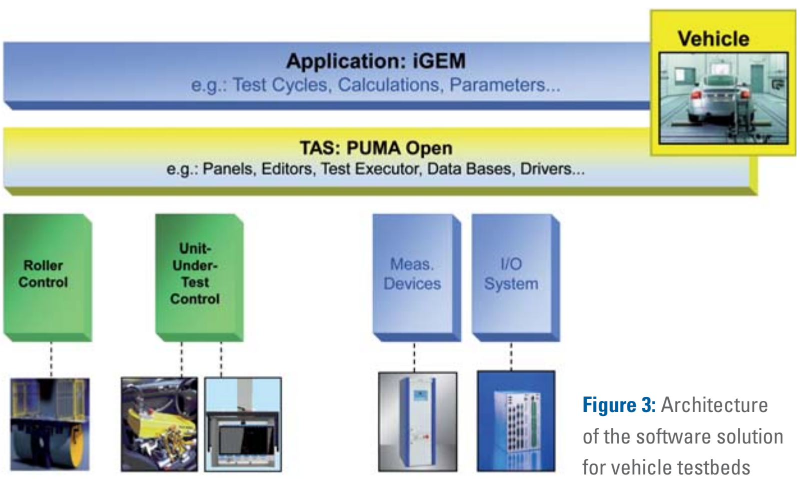

Figure 3: Architecture of the software solution for vehicle testbeds

Table: Automation of the vehicle test bed with PUMA Open

Data acquisition	PUMA Open supports industry-standard bus technology such as CAN, Profibus or FireWire and state-of-the-art ASAM compliant interfaces for ECU/TCU application and diagnostic systems (MCD3MC and MCD3D) or for automatic calibration tools (ACI).
Real-time execution	The parameterization of a test run is made easy through a graphical block sequence editor, thus avoiding the need for programming skills. Even complete road profiles can be directly imported in the test run enabling a real-time replication of road data. The real-time platform makes it also possible to carry out residual bus simulation, very much needed for development activities.
Real-time monitoring	Not only limited to channel monitoring with user-definable reactions, PUMA Open also features advanced monitoring functions such as reference cycle monitoring or online classification which makes it easy to analyze the behavior of a particular vehicle along its entire testing life.
Integration	Due to the availability of numerous device drivers, standard measurement devices, such as fuel meter or emission benches, can be easily connected to the TAS and their control and operation synchronized with the test run execution. Also, PUMA Open features a Configurable Device Handler which allows the user to connect any AK-based device using a wizard to create a dedicated driver. In addition, through a state-machine based real-time Test Cell Controller, conditioning systems such as fuel filling devices, environmental control systems and other PLCs can be closely integrated and controlled by the application, thus guaranteeing an accurate control of the test conditions.
Result evaluation	Using ASAM-ODS as a data backbone results can be centralized on a data HOST shared between different testbeds or test fields making the results available not only on the testbed but also in the office for evaluation and automatic report generation.
Data integration	The PUMA HOST system provides a central data repository for all parameters: vehicle parameters, robot vehicle specific configurations, test runs and test profiles, etc. The key benefit of centralization is the ability to start a test on one vehicle testbed and finish it on another one, transferring automatically all the necessary information and appending the results as appropriate.

vanced powertrain calibration optimization, while bringing its demonstrated performance and high level of automation on to the vehicle testbed.

3.1 Integration with the Chassis Dynamometer Controller

Depending on the application and the level of automation required, a close integration of the chassis dynamometer controller with the TAS may be required. For applications such as emission certification, where the chassis dynamometer is mostly used in road-load simulation mode, the AK interface provided by PUMA Open allows it to be connected to chassis dynamometers from various manufacturers without the need for complex integration.

However, for applications where a number of different control modes must be used and a dynamic switch between them is required, a closer integration of the chassis dynamometer controller with the TAS is needed. This is achieved through a high performance interface between the AVL Zoellner chassis dynamometer controller, VECON, and PUMA Open, **Figure 3**.

VECON is the latest version of AVL Zoellner's controller software. It leverages the same technologies used by other AVL software, in particular running all its advanced control algorithms under the AVL Real-Time Environment (ARTE) thus providing stunning control performance in terms of speed, accuracy and stability. Combining VECON with PUMA Open through a real-time interface allows the same degree of automation and dynamic control performance to be achieved on a vehicle testbed as on an engine or driveline testbed – especially raising the repeatability and reproducibility of tests on the vehicle testbed. These performance gains are a must for new innovative applications on the vehicle testbed: drivability assessment, TCU calibration optimization or maneuver based testing using advanced road & driver simulation. Thanks to a generic dynamometer interface via hybrid or Profibus DP to the cabinet, the combination of VECON and PUMA Open can also be used to modernize existing chassis dynamometers while keeping the required investment low.

3.2 Control of the Vehicle

Here again, various set-ups are possible depending on the application. In case of a human driver, like for emission certification, PUMA Open transfers the profile to be executed to the drivers-aid and synchronizes its execution with the data acquisition and the device control tasks. Having the TAS as the master for the profile execution guarantees a perfect synchronization between profile execution, data acquisition and control & commands sent to devices and subsystems.

If the vehicle testbed is fully automated like on a mileage accumulator, PUMA Open integrates a vehicle controller, EMCON, which replaces the human driver, taking care of throttle, brake and gear selection actuation. The controller is abstracted from the actuation itself which can be realized either through mechanical actuators or using drive-by-wire.

As mentioned above, if the controller layer is testbed specific, the common automation platform demonstrates the exact same automation capability at the TAS level on all types of testbeds. Therefore, PUMA Open on a vehicle testbed provides advanced automation and integration capability, **Table**.

The availability of high level automation functions on the vehicle testbed not only provides the benefits of a common platform from a product development process perspective but also supports the trend towards one-man operation of several vehicle testbeds.

The use of PUMA Open as the integration platform for AVL's chassis dynamometer controller VECON and the robot system centralizes the automation tasks, thus simplifying the overall system architecture and its operation and maintenance. For example, today, the same test profile can be defined in multiple places using different formats and editors: on the driver's aid, the chassis dynamometer controller, the robot driver or the emission automation system. By having one automation system centrally controlling all the other subsystems, the test profile like all other parameters are defined once and stored centrally. This also provides the ability to cover multiple applications with one vehicle testbed: a mileage accumulator, sharing parameters with the costly emission certification testbeds, can be used to carry out so-called prep cycles or, a highly automated NVH vehicle testbed can be used for shift quality optimization.

4 Emission Testing on Chassis and Engine Test Beds

The new emission and test bed automation technology AVL iGEM, **Figure 4**, is used in engine and vehicle development to carry out automated emissions tests and can be used for both light and heavy duty engines, following a common automation platform and seamless data exchange approach.

The iGEM emission automation software comes on top of the common automation platform PUMA Open. The engine test bed automation system as well as the emission equipment fulfils the new US legislation EPA CFR Part 1065.

Thanks to an innovative architecture which enables a complete abstraction of the application from the testbed, the iGEM application packages are fully independent of the testbed type and configuration. The software solution built around PUMA Open consists of the following components:

- iGEM Vehicle on the vehicle testbed
- iGEM Engine on the engine testbed
- graphical editors for test cycles and testruns
- PUMA HOST system: for data centralization
- iGEM Offline for offline emission calculation
- CONCERTO for report generation
- Emission Bench Handler for intelligent emission bench control
- iGeneration Emission Equipment Controller.

On the vehicle testbed, iGEM Vehicle communicates with the chassis dynamometer via the AK interface of PUMA Open. iGEM Vehicle prepares the chassis dynamometer for the test run by setting the chassis test bed parameters such as inertia and road load coefficients retrieved from a central database.

To ensure accurate emission data iGEM Vehicle communicates in 10Hz with the chassis dynamometer controller during the test run. For certification testing by the end of the test run the chassis dynamometer performs a coast down test confirming the right parameter setting.

5 Conclusion

The common automation platform strategy efficiently supports the need for shorter development processes. By bringing the vehicle testbeds closer to the engine and driveline testbeds, it enables significant savings by reusing test specifications, correlating test results and standardizing testing tools and methodologies. But it also significantly increases the capability of vehicle testbeds, making them suitable for relatively new applications, such as shift quality and drivability assessment or powertrain calibration optimization.

Figure 4: The PUMA Open automation system with iGEM Vehicle for vehicle emission certification

Total Energy Efficiency Testing
The Chassis Dynamometer as a Mechatronic Development Platform

Individual mobility today implies – in addition to comfort and safety – above all energy efficiency. An energy-efficient vehicle places high demands on automatic control systems because the functions are often divided up on to many controllers and the objectives defined in the requirements specification can only be achieved by means of optimized interplay between the controllers. So the further development of the classical chassis dynamometer into a powerful "vehicle-in-the-loop" test bed as pursued by AVL is a logical consequence. This article describes how a chassis dynamometer becomes a mechatronic development platform and helps automotive engineers to put "green" technology on the road in a cost-efficient and rapid manner.

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1 Introduction

The objective of "total energy efficiency testing" is the realistic measurement, assessment and optimization of energy consumption in real-world use by means of development carried out on the test bed. A wide variety of operating and ambient conditions for the following tasks have to be considered here:

- What is the real consumption of the vehicle in comparison with the statutory cycle?
- What consumption is measured in the tests by the popular press and the technical press? What measures enable a good rating here? For tests carried out by automotive journalists, such as the consumption group of "auto motor und sport", great importance is attached to real consumption, and therefore it is an important criterion for deciding what vehicle to buy [1].
- What are the effects of different friction contact conditions (tires/roadway), tire versions (summer/winter) and side wind behavior on fuel consumption?
- What are the effects of driver behavior? What design results in a high "fuel economy robustness" with regard to the driver behavior?
- What are the effects of different loads and their distribution (front/rear axle load)? Here, the driving maneuver catalogs differentiate between different tare weights due to equipment and types of construction, the test weight, the number of passengers as well as roof loads and towed loads.
- How can Advanced Driver Assistance Systems (ADAS) such as Adaptive Cruise Control (ACC) be used for reduced fuel consumption?
- How can fuel consumption be optimized with a view to "space and time", meaning optimized for a certain route which is often used by certain drivers at certain times of day, week and year, often regularly recurring as in a commute? In other words: Is it possible to realize a route memory? What will the future contribution of digital maps and GPS be with a view to a farsighted operating strategy?

The objective of the development and testing environment described in this article is to operate the vehicle under realistic conditions in the entire driving maneuver parametric space (as far as possible) by means of driving tests on a chassis dynamometer in order to cover the consumption-relevant situations that occur during everyday real-world use. The determination of an "energy fingerprint" is, against the backdrop of early determination of CO_2 emission and fuel consumption, a main concern of this test method developed by AVL. Furthermore the method makes a significant contribution towards the shortening of the development period. For one thing is clear: vehicle development engineers may have achieved a lot today, but as demands keep increasing, development tools and techniques have to keep improving as well.

2 Maneuver- and Event-based Testing

The method for implementing test cases on the AVL chassis dynamometer with AVL InMotion is called "maneuver- and event-based testing". This method is essentially based on the following idea: driving a vehicle, the ultimate driver of vehicle development, is a sequence of events and maneuvers. For this reason, such a maneuver- and event-based test description should be a highly efficient "lingua franca" for the vehicle development process. In the end, a maneuver- and event-based development environment also enables the merging of traditionally separate fields of development (chassis/drive train), which enables the exploitation of additional cross-linking potentials. The unique integration of the four test environments office, laboratory, test bed and road in a common user interface and data management system also enables a new level of quality within the development process.

Over the past ten years, there has been much talk about "synergies" – too much talk. But as a result of the combination of technological maturity (for example, of assistance systems, electrical horizon) and today's economic necessity of sustainable mobility, we know that CO_2 optimization has to be achieved across all functions and fields of work. With appropriate modifications, the AVL chassis dynamometer enables efficient testing of the interaction of the highly cross-linked individual systems within the complete system.

3 Absinth Control Strategy

According to the current state of the art, the rolling resistance on chassis dynamometers is computed by means of a polynomial formula

$$F_x = F_{x0} + C_0 \cdot v + C_2 + v^2 \quad (1)$$

Figure 1. This approach is insufficient to comprehensively evaluate the energy balance and the tasks described in the introduction [3]. What is the contribution of the walk resistance of tires, for example? What are the effects of ambient conditions (e.g. tire temperature and tire inflation pressure)? How significant is the impact of unevenness of the road and the dynamic wheel loads? How great is the influence of a wet- or snow-covered road (resistance due to water displacement, increased slippage) or bad road conditions? How large is the loss due to the axle geometry – in particular toe-in and camber – when driving straight ahead too? How great is the power loss when curves are negotiated (combined rotational slip and side slip, restoring torques, etc.) and during transient tire response? What contribution can the chassis development (suspension design) make towards CO_2 reduction? To date, it has not been possible to answer these and many other questions that are pivotal in the determination of the "energy fingerprint" and therefore the comprehensive and realistic assessment of the power loss and, as a result, the fuel consumption, of a vehicle on a chassis dynamometer.

AVL chassis dynamometers in combination with the "Absinth control strategy", for which the authors have applied for a patent, can be used to take remedial action here. The basic idea behind this is to move the frictional connection (power bond) from the tire-road contact zone to the axle shafts or even before the axle drive (differential gear). By definition, the real world and the virtual world exchange the performance quantities on the test bed via defined interfaces (so-called power bonds). For this purpose, the driving torques and speeds in the power bond are determined either from the tractive force measurement on the test bed or by means of torque measuring wheels. By doing so, the tire is no longer part of the unit under test, but becomes a part of the test bed. If the power bond is moved to the input side of the axle differential, axle shafts and the axle differential are also part of the test bed and not part of the unit under test. As far as simulation goes, the tire losses are simulated on the AVL chassis dynamometer with AVL InMotion by means of powerful, real-time tire models, **Figure 2**. As a result of the large number of active parameters (wheel load, slip angle, camber, rotational slip, inflation pressure, tire temperature, road conditions, friction coefficient etc.) and the distinct non-linearity and dynamics of the physical tire properties, very detailed tire models are used, such as TaMeTire, a thermo-mechanical tire model developed by Michelin [4]. Other standard formats such as TYDEX, Pacejka MagicFormula, or customer-specific tire models are integrated in the tire model library via standard interfaces.

Several additional 3D mechanical coupling effects between the real drive train (unit under test) and the whole vehicle (simulated) are also considered by AVL InMotion: restraining torques (unit bearing, bogie bearing), time-variant bending of the cardan shafts (including the effects of wheel travel) as well as gyroscopic effects which act, for example, on a yawing vehicle during steering operations in particular [5].

Furthermore the control strategy has the advantage that the tire is eliminated as a disturbing quantity (variation of the measurement results due to heating-up and tread wear). Tires have to be changed less often in test operation because their behavior has no influence on the test results any more – which saves you money and time. If a wheel-force measuring hub is not used, the tire model is operated in the "Absinth mixed mode": the force FX is really measured (in the vehicle longitudinal axis), and the other force/torque components of the tire are simulated. If tractive force measurement is also not available, and only the torque of the drum, it is not possible to differentiate between FX and rolling resistance torque in the wheel contact point (My) with measurement techniques. In this case, My is separated by means of suitable estimation methods. Then Fx and My are taken from the measurement, and the four other forces/torques come from the simulation. If the tire is operated within the limits of the power transmission potential and especially in combined slip-

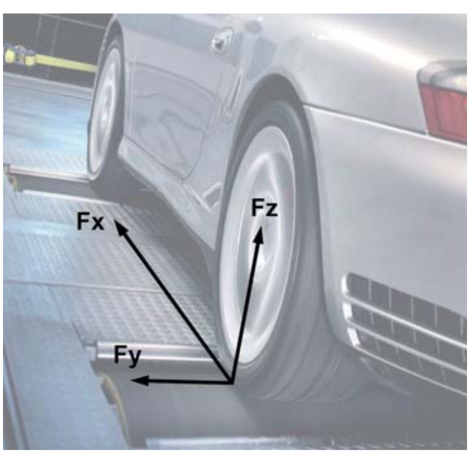


Figure 1: Forces acting on tires

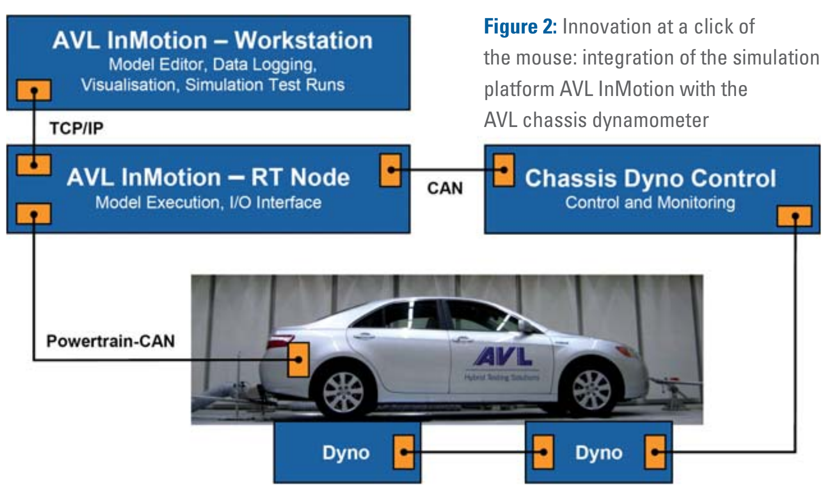


Figure 2: Innovation at a click of the mouse: integration of the simulation platform AVL InMotion with the AVL chassis dynamometer

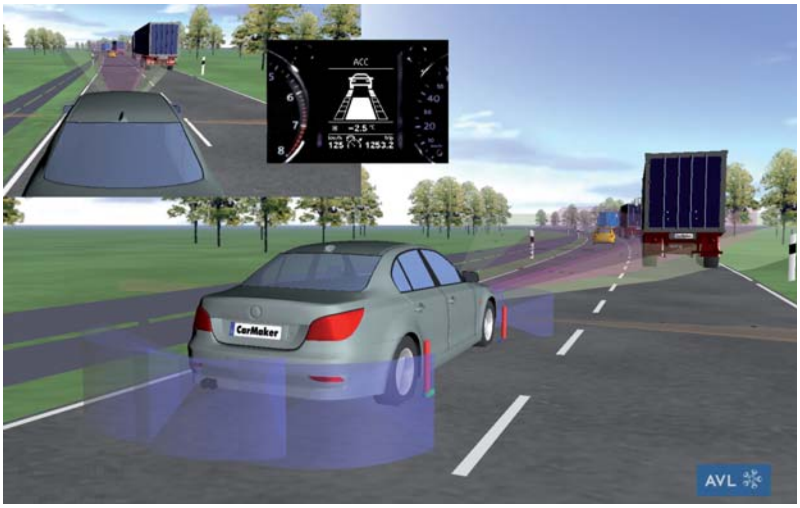


Figure 3: Traffic simulation on the chassis dynamometer: The integration of driving assistance systems and drive train control enables reduced fuel consumption

page during the maneuver, it is highly recommended to use a wheel-force measuring hub.

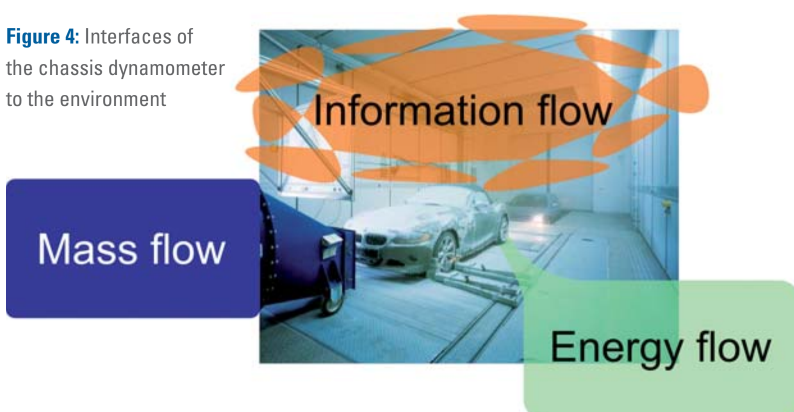
4 Simulation and Test Bed Dynamics

In general, it can be said that chassis dynamometers are operated in a manner similar to drive train test beds with a focus on control engineering. The power bond is identical in both cases. On drive train test beds, the power coupling between the unit under test and the test bed is of the positive-action type, while on chassis dynamometers, it is of the power-grip type. This is the main difference. This creates different test bed dynamics. Another variable between the two types of test beds is the different inertias of the load units. For many application tasks – especially for the optimization of fuel consumption – the dynamics of modern chassis dynamometers are sufficient, **Figure 3**. Tire sidewall stiffness and damping as well as the first normal vibration modes of a tire (tire / belt rigid body mode [6]) are simulated in a sufficiently realistic manner "in the first order" for most testing tasks.

Here a widespread misunderstanding has to be cleared up: a simulation-based development and testing environment does not necessarily require a highly dynamic test bed. For example, the speed/torque set points of a highway cruise at constant speed may originate from a powerful, realistic 3D real-time vehicle simulation. However, a highly dynamic test bed is not necessary for the physical simulation of this maneuver.

At the other end of the spectrum, there are dynamic driving maneuvers such as shock loads or jump starts. These can only be reproduced in a realistic manner on highly dynamic drive train test beds [7]. In the virtual universe, any speed/torque gradients can be generated, even those that will only rarely occur in the later area of application of the vehicle or not at all. The conclusion drawn from this is that not every test bed can cover the entire driving maneuver range (which the proving ground test site cannot do either), but that quasi-stationary, transient as well as highly dynamic test beds can be operated on the basis of the maneuvers and events it can properly simulate.

Figure 4: Interfaces of the chassis dynamometer to the environment



5 Operating Modes in the Simulation Mode

An operating mode during which the unit under test is operated in a closed-loop control system via the power bonds with the virtual vehicle and environment model is referred to as "free mode". However, no test bed can – as already discussed above – obtain any bandwidth, so it cannot implement any gradients and frequency characteristics requested by the simulation environment with a view to control engineering. In part, the speed and torque are also intentionally limited in order to protect the unit under test. However, in most cases the test bed dynamics are very well known in advance. So the requested speeds can be checked for feasibility of the test bed by means of suitable online test bed models. These considerations have resulted in a strategy for which a patent has been applied for by AVL that aims at influencing the simulation in such a way that the simulation and the test bed are "synchronous" and do not diverge. The simulation is carried out in the so-called "servo mode" in this case.

This is realized either by applying suitable servo torques or by means of rheonomic speed control (as defined by classical mechanics) with constraining torques. The term "servo mode" is derived from the "servo constraints" introduced by H. Beghin [8]. Switching between the "servo mode" and the "free mode" is realized smoothly between two integration steps. The virtual additional torques impressed on the model in the servo mode are recorded and made available to the user. The simplest example of "servo mode" operation is a limitation of speed.

„Easy and Objective Benchmarking“

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Christoph Schmidt

Uwe Schmidt

Will we still really need chassis dynamometers if we can test components and systems „in the loop" with much less effort?

Modern development processes are characterised by the intensive use of simulation, replacing many tests particularly at the beginning of the process. Yet at the same time tests are being transferred from the road into the chassis dyno lab, which means that the vehicle test bed is increasingly being used for additional and new development and validation tasks. The advantage of the chassis dyno in these cases is that results are objective – reproducible environmental conditions that can be simulated at any time and guarantee efficient testing and measurement. Tests are no longer limited due to bad weather, travelling time or working hours. Replacing road tests by a chassis dyno that is situated very close to where the development is taking place enables complex measurement equipment to be used „on the road". The increasing complexity and interrelated nature of components and systems in the complete vehicle also put a limit on how far components can be developed purely „in the loop". Both methods are valid, their use depending on the development phase. An additional benefit of the chassis dyno is that it can be used for easy and objective benchmarking of variants, further developments and competitive products, as the vehicle is tested as a closed system.

How high are the gains in productivity when you can control all test beds in the same manner and guarantee consistent data availability?

Merely introducing a consistent development platform for engine and vehicle tests does not lead to an increase in efficiency. In addition, processes need to be adapted and implemented in order to leverage the potential that the platform offers. We believe that development times, which have been significantly reduced over the last few years, will be shortened further, or at the very least kept at their current level, in spite of increasing complexity – in hybrid development for example. AVL provides customers with the necessary environment to enable a consistent development process. AVL can also support the customer in designing and rolling out processes so that the tools will be used to the optimum.

Will driveability assessment on the chassis dyno ever completely replace the test driver's subjective rating?

No, but it does spare some of the routine work and provides a rational test result. The test driver is freed up for more challenging tasks such as validation. But it won't replace the CEO's test drive.

What role does the chassis dyno play in configuring new powertrain concepts – such as partial electrification, for example?

After the road itself, the chassis dyno provides the most realistic environment, as it is where the least is simulated. Vehicles with any kind of powertrain system – whether conventional, hybrid or electric – can be tested there, making it a universal development environment. And as powertrains become more diversified the chassis dyno will become even more important.

AVL Zöllner enjoys an excellent reputation as test bed supplier. How important are the close links to other areas of AVL such as simulation or application development?

AVL Zöllner develops and provides reliable and modern vehicle test bed technology for applications such as NVH, EMC, MACD, Emission development and calibration of vehicles of any kind or size. Being an integral part of AVL, with its modern instrumentation and application tools, allows us access to new ideas that can be built into the test bed and provide the customer with additional benefits.

6 Application as a Mechatronic Development Platform

6.1 Interfaces

In hybrid and increasingly also in conventional vehicle models, interlinked control units take over the functions that are relevant to energy in a consistent and powerful integrated system. For testing, this implies the need for powerful interfaces used by the unit under test to communicate with the test bed. As everybody knows, the three central mechatronic interfaces are "matter", "energy" and "information" [9], **Figure 4**. Control over the interface "matter" is ensured on AVL performance test beds by means of a powerful oil, water and fuel conditioning systems as well as climatic chambers and altitude chambers.

Control over the interface "energy" is realized by means of dynamometric brakes with the respective measurement and control equipment and, for hybrid and electric vehicles, by means of battery simulators. It is astonishing that the realistic simulation of the interface "information" is not yet paid the attention that it deserves considering its importance as an innovation carrier and market driver. The "vehicle-in-the-loop" approach that is consistently pursued by AVL fills this gap. So the classical chassis dynamometer further develops into an integrated mechatronic development and testing platform in an evolutionary manner. Such a platform should be regarded as the master plan for the optimization of product development.

In the following, selected examples are used to show the application possibilities of a "vehicle-in-the-loop" chassis dynamometer.

6.2 Examples of Application

In one-axle chassis dynamometers, the wheels that are not driven by the vehicle powertrain do not turn. As a result, the wheel speed of the stationary wheels is not consistent with real driving operation. Any wheel braking torque of the axle that is not driven is not considered either. Realistic wheel speeds are generated from the simulation. AVL enables the simulation of inductive, magneto-resistive or "intelligent" wheel speed signals via IO-modules. If there are braking operations during the requested maneuver, the forces and pressures are directly measured in the brake body piston and played back to the model online. The use of plug connectors from series production and of mass-produced instrumented brake discs results in short setup times. The result is that, for example, it is now possible to simulate the "rock cycle" (rocking out of a depression in the snow) or driving away uphill from rolling backwards with very smooth braking and controlling interventions on the chassis dynamometer. It is important for an energy-efficient design that the instrumented brake discs also determine the residual braking torques that remain after the brake pedal has been released and make them available to the simulation. Residual braking torques are up to 50% of the rolling resistance torque and so are relevant for consumption development.

Especially in city traffic, but also in single-lane traffic with changing speeds, ACC systems (Adaptive Cruise Control) offer a significant potential for reduction of fuel consumption, and not nearly enough attention is paid to that at the moment. The wide variety of possible scenarios that result from the interactions between the driver, the vehicle, the traffic situation and the environment constitute a special challenge here. The most important scenarios have to be identified as test cases and implemented in the simulation in a reproducible manner.

With AVL InMotion, ACC can now be tested on the AVL chassis dynamometer under realistic conditions. Freely configurable traffic situations with any number of movable objects are created. The sensor information from the radar is created by the test system and transmitted to the real vehicle. Superordinate driving dynamics controllers coordinate the interventions in the engine control and also actively modulate the hydraulic brakes if necessary.

Map and GPS information are not yet used in any applications that reduce fuel consumption, but they offer great potential. Future navigation systems ("electrical horizon") will provide information about gradients, curve radii, speed limits, other traffic restrictions and even information about the smoothness of the road. Furthermore they calculate the route that the vehicle will probably follow. Forward-looking systems adapt the drive management to the course of the expected route. Learning systems record and recognize constantly recurring "paths of usage" of the vehicle (traffic density, driving style) and so reduce the average and the variance of the cycle for which the estimation is carried out. Especially for hybrid and electric vehicles, this technology offers the potential of significantly reduced fuel consumption.

In order to enable the practical application of such developments on the road in a faster and more cost-efficient way, AVL will equip future chassis dynamometers with additional functions: simulation of the "GPS antenna", Road-Importer (importing and mapping of the GPS route in the test system), preconfigured ADASIS interface and preview sensor.

7 Summary

The examples given show that the continued development of the classical chassis dynamometer into a mechatronic development and testing platform pursued by AVL enables cost- and time-efficient development methods. The complete vehicle becomes an "embedded system" of the virtual environment in which it is tested. The continuously expanding possibilities in sensor technology, mechatronics, data processing and communication will enable the simulation of a wide variety of functions in the future. The increased system integration in the vehicle brings about synergy effects, but it also results in a major increase in complexity at the same time. In the real vehicle, the individual systems are integrated and can so be tested in combination. So the ViL (Vehicle-in-the-Loop) test bed is a key to complexity control and the protection of the entire functional integrated system; undesired system interactions and conflicts between the individual systems with effects that often overlap are detected on the ViL test bed early and in a cost-efficient manner and are eliminated by means of a suitable adaptation of the controller software in a targeted manner. The handling of the growing variety of versions is facilitated as well.

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Innovative Use of Chassis Dynamometers for the Calibration of Driveability

One of the most time-intensive calibration tasks in vehicle development is the optimisation of driveability. In order to guarantee brand and variant specific driveability, a great number of parameters relevant to vehicle handling must be calibrated. AVL has developed a new approach to driveability calibration that makes an objective, robust and efficient calibration possible on the chassis dynamometer.

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1 Introduction

The continuing pressure to reduce costs is leading OEMs towards a growing focus on "front loading". The front loading process shifts tests that would traditionally be run on chassis dynos to engine or component test beds. Simultaneously, road testing, trials and recently quality testing are being transferred from the road to the chassis dyno. This is particularly true for calibration of engine and transmission control systems for the desired driveability. This paper will discuss an approach for such calibration tasks to be completed using chassis dynos.

2 Model-based Approach for the Calibration of Driveability

The classic manual calibration of driveability of the vehicle on the road is carried out by the application engineer using subjective evaluation criteria. These criteria consist of the perceived vehicle's longitudinal acceleration (absolute value, gradient, oscillations and consistency) and the analysis of the signals corresponding to the driveability functions in the control unit. The signals for load change manoeuvres are torque build-up, whereas for shift procedures in automatic transmissions the signals are engine torque and clutch pressure behaviour. The set values are filter parameters, with which the torque build-up or interventions are affected and other parameters such as fill time, fill pressure or clutch shift pressure. Using expert knowledge of the relationship between the set values and the evaluated signals, the application engineer is able to optimize driveability in terms of driving comfort and dynamic behaviour.

The manual approach is limited not only by the mainly subjective evaluation of data but also by additional difficulties such as: differing environmental conditions (road, weather, traffic) leading to low reproducibility of test conditions. Tests cannot be easily run overnight or over weekends: which combined with short development times leads inexorably to a higher number of prototypes. Due to the increasing complexity of the set values, the application engineer finds it more and more difficult to achieve an overview of the complete system.

An objective evaluation of driveability on a chassis dynamometer is both beneficial and pragmatic in order to obtain higher flexibility in terms of test environment, level of automation and efficient utilization of the test object. Since the vehicle longitudinal acceleration is not available due to the vehicle being locked in position on a chassis dyno, the acceleration signal must be derived from other sources, in this case, via the force applied by the vehicle on the restraint or via the tractive force applied by the vehicle's wheels on the rollers. These physical signals make it possible to judge subjective driveability based on objectively measured values.

AVL-DRIVE, used for the objective evaluation of driveability, contains more than 400 criteria for more than 80 different driving manoeuvres (such as „tip-in", tip-out, shift manoeuvre, full load and partial load acceleration, drive-away manoeuvre). These manoeuvres are automatically recognised during a test run and evaluated online. AVL-DRIVE calculates physical characteristics for each driving manoeuvre from pre-defined evaluation criteria such as kick, jerks or response delay for the "tip-in". These individual criteria are rated from 1 (no function) to 10 (excellent). An overall rating for a manoeuvre is calculated from the individual criteria (for example for full load acceleration out of motoring) and an overall vehicle rating is calculated from all the manoeuvre ratings. These calculations reduce the driveability relevant signals to scalar values, whereby a single manoeuvre corresponds to a single measurement point.

By running the test on a chassis dynamometer and employing tools to objectivise the driveability, the whole process can now be automated.

By doing so, pre-defined driving manoeuvres can be run more efficiently and reproducibly. Despite an increase in the reproducibility of the manoeuvres, there is still a spread in the evaluation of the driving events. This is dependent on many factors such as the current oscillatory state of the powertrain or the clutch due to the previous shift [1].

However, the spread of subjective evaluation is considerably higher than that of the objective evaluation as shown in **Figure 1**.

Figure 1: Comparison of subjective and objective driveability ratings from 5 tests with 5 different application engineers and AVL-DRIVE

A large population of tests is necessary in order to provide a statistically firm statement in view of the deviation. In order to be able to run a large number of tests in the shortest possible time, the chassis dyno is run in different control modes for the shift quality optimisation. An operating point, defined by speed, load and gear number is run via a fast speed ramp. The chassis dyno is only run in road load simulation during the actual driving manoeuvre. This requires that the chassis dyno is capable of a "bump less" transition between control modes and stable control after the transition has been completed. This then enables successive shift manoeuvres to be run every 12 seconds and load change cycles to be run every 15 seconds. This results in a total test time between 10 and 70 hours of unmanned operation, independent of the calibration task.

The general work process is shown in **Figure 2**. A DoE test plan is created then run in automatic mode on the chassis dyno. Global models are then generated in the office for drive comfort and dynamic behaviour. A manual calibration is performed in local operating points, whereas the automated process follows a global approach, which includes not only the measured signals, but also the set values. This global data set contains all pertinent information concerning driveability. This data set makes it possible to generate optimized calibrations for various driveability modi such as comfort, sport or super-sport modes, without the necessity of further data gathering loops. Today, where individual brand definition means that each OEM currently has up to seven such driveability programmes, the effort required to calibrate these programmes is considerably reduced – as is the number of prototype vehicles required for the calibration work. The completed data sets are then verified conventionally in the vehicle on the road.

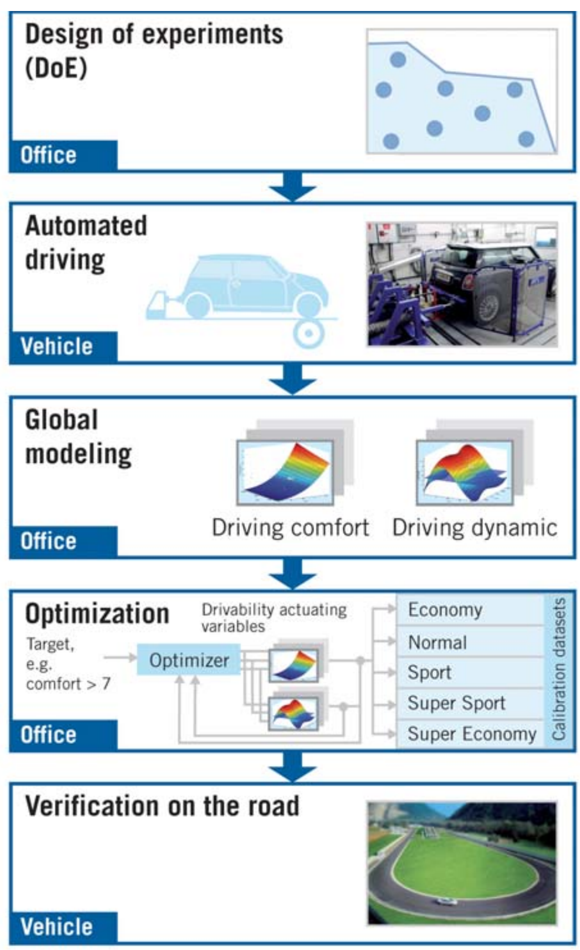

Figure 2: General work process of the model-based calibration of driveability

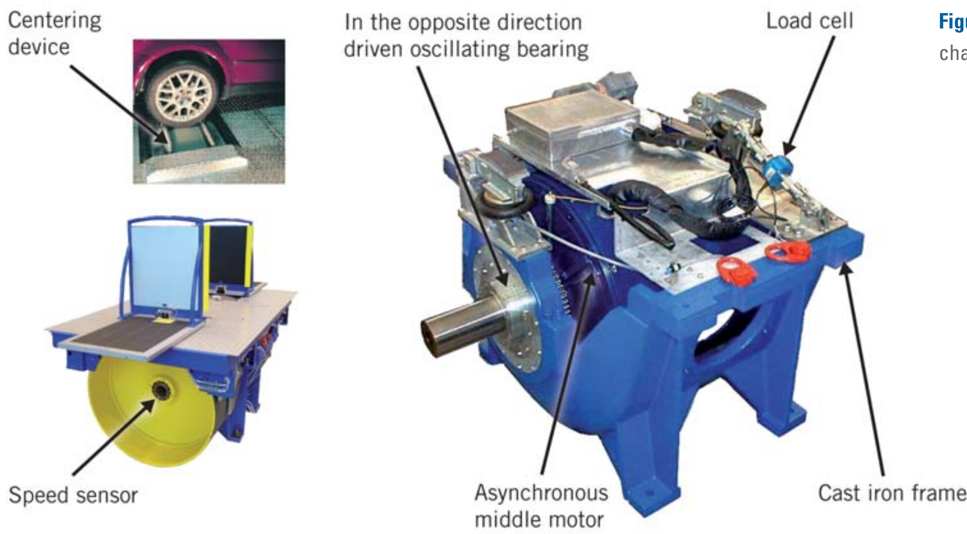

Figure 3: Hardware components of the chassis dynamometer

3 System Configuration

The vehicle is fixed on the chassis dyno via a load cell with a very stiff clamp, since the longitudinal forces can only be measured by the load cell. This upgrade variation was used for the tests in this article. The possibility of using the acceleration signal directly from the chassis controller on the AVL-Zöllner chassis dyno avoids extra mechanical systems and promises high dynamic response and measurement repeatability. This signal is transmitted to the AVL-DRIVE system, other necessary signals, such as vehicle speed, engaged gear, accelerator pedal position are taken from the vehicle's CAN bus.

The layout and control of the chassis dyno are of paramount importance for the application. A chassis dyno with high dynamic response is necessary for the reproduction of driveability test manoeuvres. In addition, if the requirements for emissions specification C100081T1 are fulfilled, then the chassis dyno offers a wide field of application beyond driveability calibration: amongst other things emissions calibration, endurance testing or fuel consumption reduction testing, and at the same time cost efficient.

Two 48" rollers with centering device, coupled directly to an asynchronous centrally mounted motor, form the roller assembly for an axle (simulation unit), **Figure 3**. The active centering device guarantees that tyre contact with the roller is horizontal during vehicle installation.

Multiple axle test beds use two of these devices mechanically connected via a frame construction, whereby one is adjustable in the vehicle longitudinal direction. A torsionally rigid cast frame is used to mount the asynchronous motor and

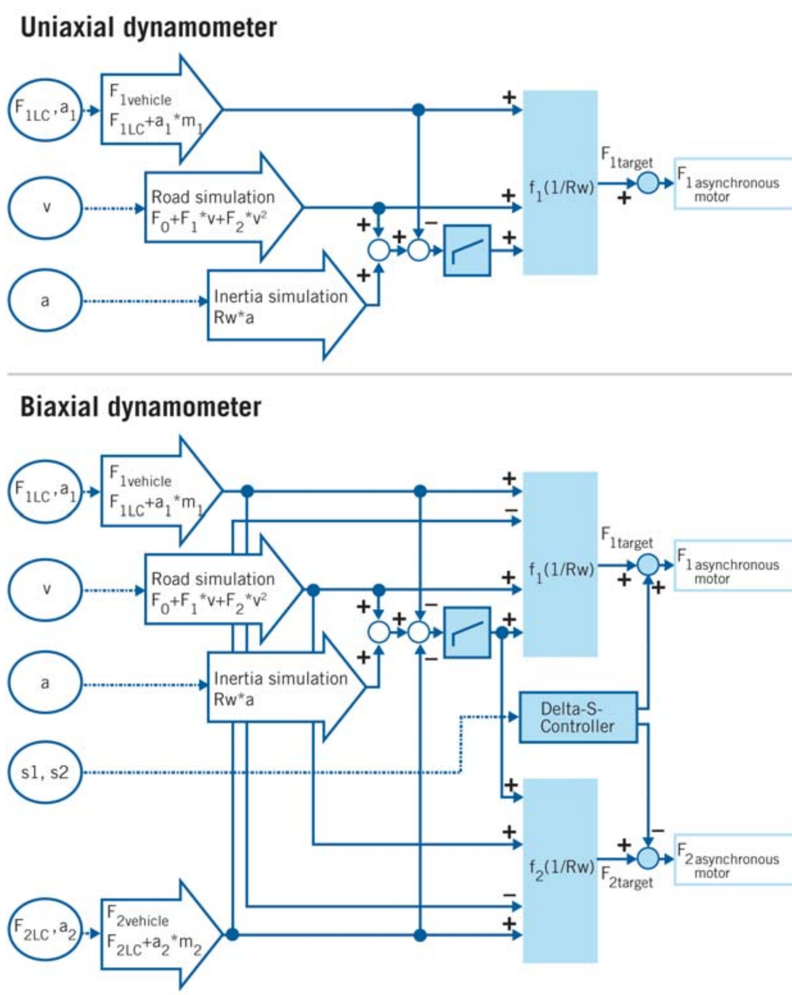

Figure 4: Controller configuration for single and twin axle test beds

provides exact and fast reaction torque even when subjected to dynamic conditions. The cradle bearings, located within the torque measurement system, are motorized to avoid pressure points and the related breakaway torque. This also means that temperature dependent bearing losses are automatically compensated for and do not influence the accuracy of the torque measurement. The precise measurement of the torque itself is done via a temperature-compensated load cell. The load cell and pivot arm are rigidly mounted leading to a high natural frequency.

This then permits the full dynamic response of the fast current control of the motor and converter to be exploited. Control times of below 10 ms are possible.

The calculation and control of the road load applied to the vehicle is done in realtime. Deterministic and fast reaction time is guaranteed by the deployment of an ARTE environment (AVL Real Time Environment), which provides the pre-requisite for stable control, **Figure 4**. The simulation takes into account stiction, kinetic friction and the aerodynamic resistance in the form of coefficients F0, F1 and F2 of the road load equation. The missing mass inertia of the fixed vehicle is reproduced by the rotating mass of the rollers. The difference between the vehicle mass and the roller mass is compensated for by mass simulation. The force of the vehicle applied to the road surface (FxVehicle), the force of the road load simulation and the force derived from the mass simulation are calculated using the measured vehicle speed (v), acceleration (a) and force signals (Fx-LC) of the test bed motor. Using feed forward control of the forces from the road load simulation and the vehicle FXVehicle in combination with the control of all forces that act additively on the feed forward loop, it is possible to apply the necessary force FXDemand to the wheels via the AC motor within milliseconds. This type of control guarantees a fast and deterministic reaction by the test bed. For vehicles driven by two axles, symmetrical controllers on both axles maintain the calculated total force and identical speed of both rollers.

In order to compensate for inaccuracies of the simulation model and to reduce the angular difference between the rollers to below 0.2°, the system uses an overlying delta-s controller to reduce differences between the roller speeds and positions (s1, s2). This guarantees a high synchronicity between the rollers for an arbitrary force distribution by the vehicle.

In addition to the controllers described here, the AVL Zöllner chassis dyno supports "bumpless" transition between controller modes speed control and road load simulation providing a major pre-requisite for an effective automation of the system.

Figure 5 shows the complete system layout with the roller controller AVL-VECON, the automation system AVL-Dricon/PUMA-Vehicle, the evaluation system AVL-DRIVE, the optimisation system AVL-CAMEO, the applications systems and the fixed vehicle. Using either AVL-Dricon or PUMA-Vehicle, the vehicle's accelerator pedal and the shift lever for automatic or DCT transmissions can be controlled purely electronically.

The advantages of the electronic control are:

- can be used in both development vehicles and those in series production
- lower cost, shorter setup times and the required faster conversion of control signals than a robot
- identical layout for both road and chassis dyno.

The AVL DriCon/PUMA Vehicle receives the commands for the current driving manoeuvre from the AVL-CAMEO optimisation system via an Ethernet UDP interface. These commands are converted into ramps for the accelerator pedal and the roller speed and then sent together with the control mode and road gradient to the vehicle and the roller controller.

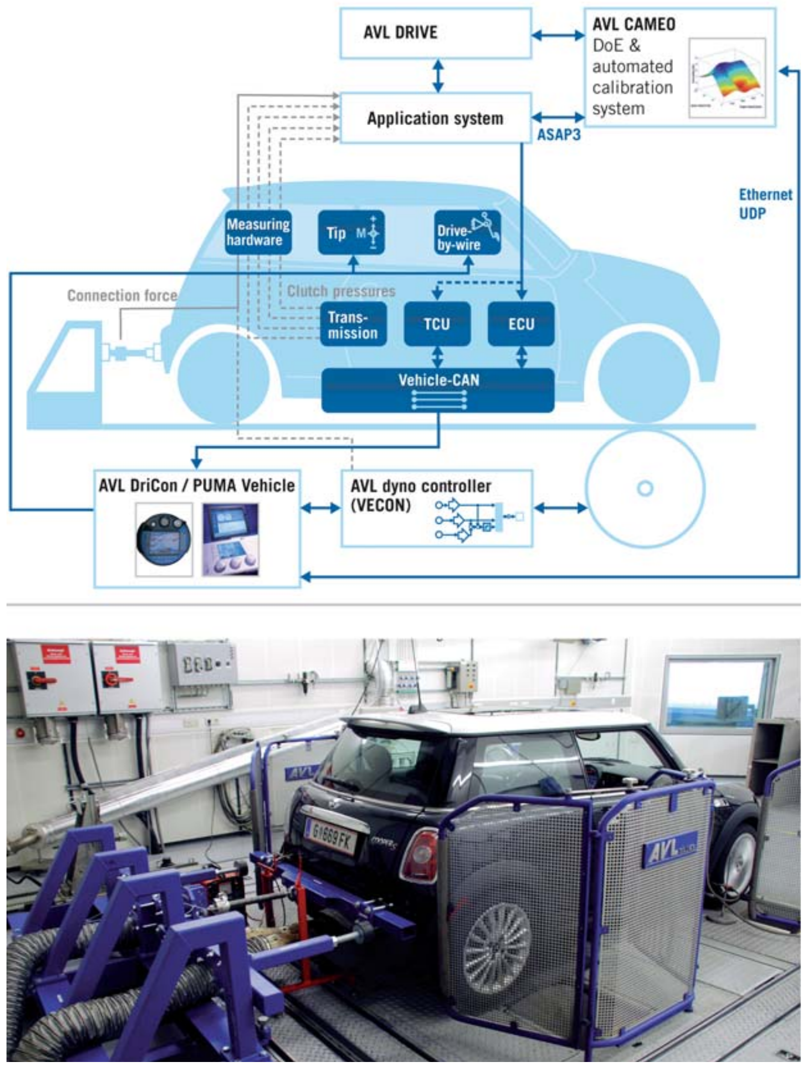

Figure 5: System layout, test vehicle on the high dynamic chassis dyno

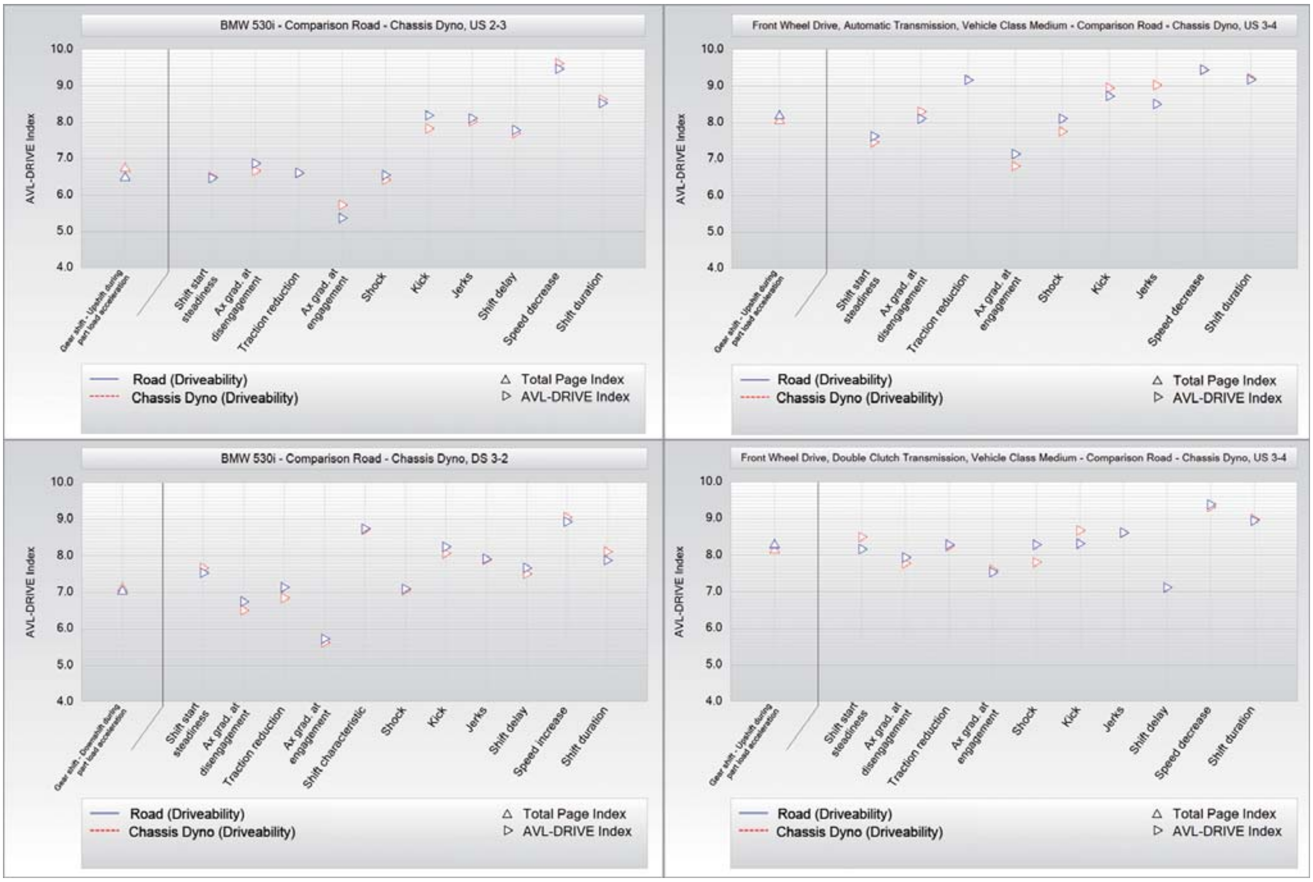

Figure 6: Comparison of driveability ratings for shift quality between road and chassis dyno

AVL-CAMEO is used not only for the overall control of the test sequence but also for the test plan, data modelling and control map generation. The system uploads all relevant ECU/TCU demand values via an ASAP-3 interface to the application system. The ratings and physical characteristics of the driving manoeuvre as calculated by AVL-DRIVE are transmitted online to AVL-CAMEO and stored together with the demand values in a database.

The complete measurement log with tractive force and other signals such as clutch pressures, emissions and fuel consumption values is generated by the applications system using appropriate hardware.

In order to run continuously unmanned, it is necessary to monitor relevant vehicle CAN bus signals and to prevent damage by fire and overheating by the engine and transmission, by overspeed or overtorque conditions, tyre damage and excessive vehicle movement, diagnostic errors or fuel leakages. Automated refuelling systems must also be implemented. Detailed correlation tests were carried out with this system configuration in order to be able to guarantee the portability of the test results from the chassis dyno to true road conditions.

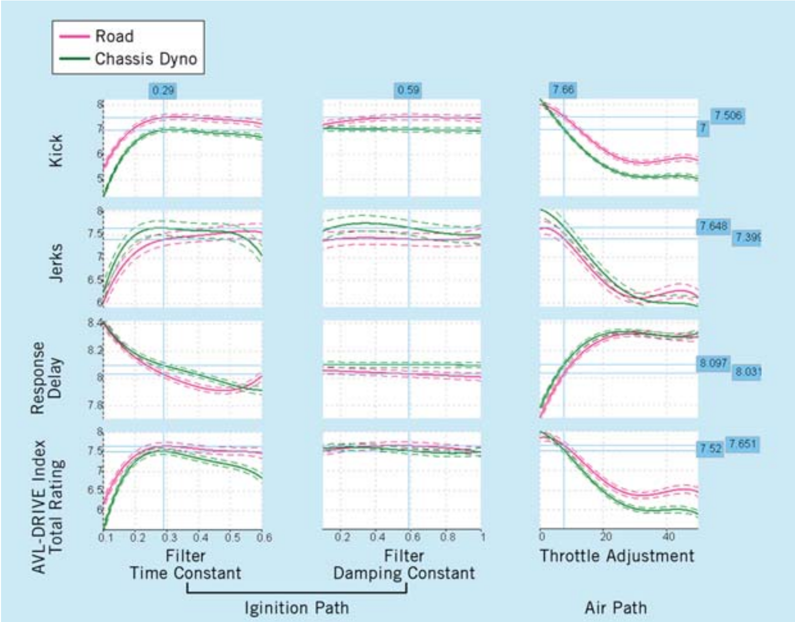

Figure 7: Comparison of the driveability rating models for „tip-in" between road and chassis dyno

4 Correlations Test between Road and Chassis Dynamometer

A BMW 530i with automatic transmission (AT), a front-wheel drive vehicle with automatic transmission and a FWD vehicle with DCT transmission were selected for the comparison tests of gear shift quality measurements. The measurement plan consisted of sets of 10 operating points defined by turbine speed against turbine torque (AT) and engine speed against engine torque (DCT), applied to gear shifts from 2nd to 3rd and from 3rd to 4th gear. A downshift from 3rd to 2nd was also analysed. Each operating point was run with series production calibration and repeated 5 times. The measurements were run on the road and on a high dynamic AVL Zöllner chassis dynamometer.

The comparison values for each driveability criteria for the shifts are shown in **Figure 6**.

The difference in the ratings is 0.5 [-] at the most and is firmly within the scatter band of the AVL-DRIVE evaluation, Figure 1. The „tip-in" comparison uses variations in driveability relevant set values with a grid-test plan (343 variations) in the road and on the chassis dyno:

Table: Operating ranges and set values for „tip-in"

Load	Pedal steps: 0 – 20, -30, -50, -75, -100 %
Engine speed	1000 – 3000 rpm in steps of 250 or 500rpm
Gear	1st, 2nd, 3rd, 4th
Set value 1	gain factor anti-jerk function
Set value 2	filter damping constant for torque demand (ignition path)
Set value 3	filter time constant for the torque demand (ignition path)
Set value 4	pedal position for the torque demand (air path)

- operating point 1500 rpm (engine), pedal step from 0-50 % in 2nd gear
- set point variation: pedal, filter constants for torque rise.

The set values for the „tip-in" are split into those for the fast torque demand via spark advance (ignition path) in the form of filter constants and the slow torque demand via the accelerator pedal (air path). The model shape in **Figure 7** is qualitatively very similar for both road and chassis dyno. The optimisation leads to equivalent demand values and the difference in ratings is in the range of 0.5[-]. The pre-requisite for portability of optimisation results from the chassis dyno to the road environment is thus fulfilled.

5 Usage in Driveability Calibration

The following example for the application of a model based methodology for driveability calibration will limit itself to a „tip-in" for a gasoline engine (results for shift quality calibration have

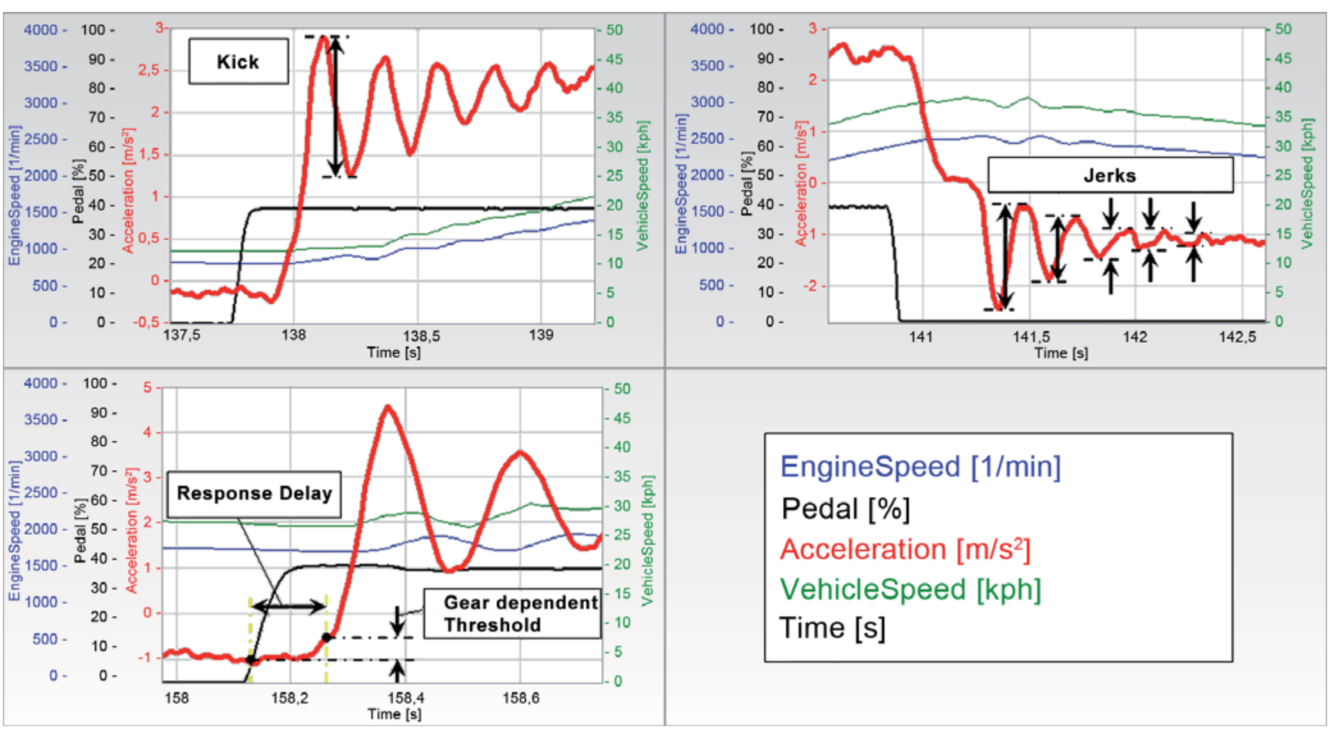

Figure 8: Significant factors for the "tip-in" rating: multiple oscillations, single jerk event, delay

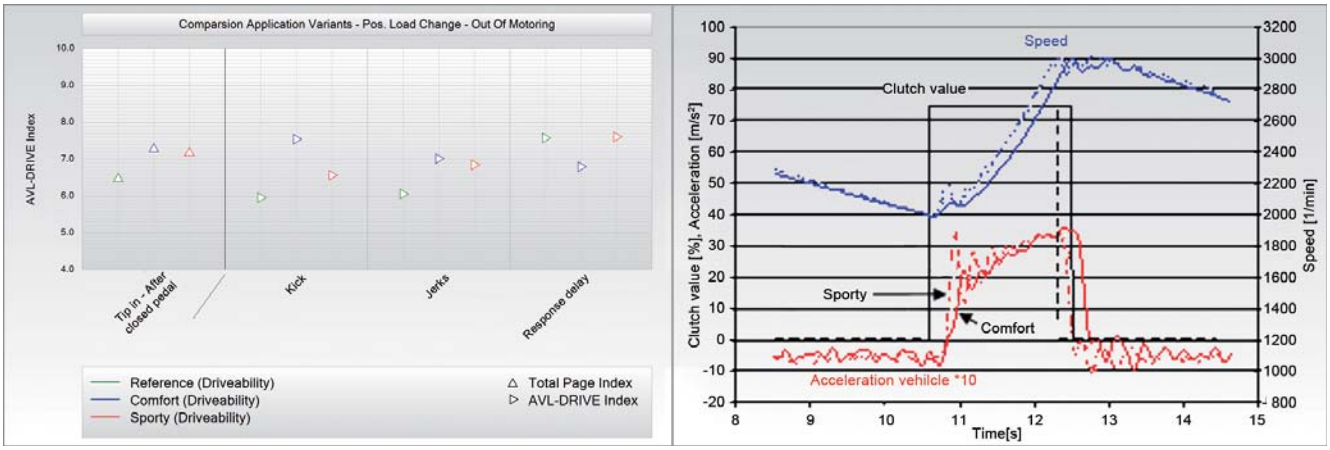

Figure 9: Comparison of calibration variants, effect of limiting physical signals
(the signal traces correspond to a "tip-in" of 0-75 % pedal position in 2nd gear at a speed of 2000 rpm)

already been published in [3]. In addition to the set values mentioned for the „tip-in" for the correlation tests, the gain factor for the anti-jerk function was varied. The anti-jerk function in the ECU is used to recognise and dampen undesirable oscillations in speed in the powertrain. The **Table** shows the operating ranges and the set values.

After the automated test had gathered the data, AVL-DRIVE built global models for the most relevant AVL-DRIVE detail evaluations and the overall rating for the „tip-in", refer to **Figure 8**.

The overall rating for a „tip-in" results from the weighting of the detail ratings: jerks are weighted at 25 %, a kick 20 % and the response delay 15 %. A high overall rating is achieved above all by low jerks and a low kick, which, from a driver's perspective, corresponds to high driving comfort. Other detail ratings contributed only 5-10 % to the overall rating and were considered insignificant and therefore not modelled.

Two different driveability variations were optimised in AVL-CAMEO. A "sport" calibration was generated by maximising the overall driveability rating while limiting the maximum delay (the smaller the response delay, the better the rating). Optimising the overall rating with no further limitations generated a "comfort" calibration.

After optimisation and data set generation, the first validation test was performed on the test track. **Figure 9** shows the AVL-DRIVE ratings for the evaluated reference calibrations and example signal traces for a "comfort" and "sport" calibration.

As expected, the rating for the delay with a "comfort" calibration is the lowest. The gentle and harmonic torque rise leads to better ratings for jerks and kick compared to the reference. The "sport" calibration shows improved ratings for kick and jerks with simultaneous response delay.

6 Summary

AVL has responded to the increasingly demanding market requirements in the domain of vehicle calibration by developing a new method for driveability calibration. The main focus of the methodology lies in the automated data gathering process on a chassis dynamometer, the model-based approach and the inherent avoidance of multiple calibration loops.

Since data is gathered at night and at weekends, a significant increase in chassis dyno productivity is achieved. The subsequent data evaluation and generation of all driveability calibration variants in the office environment makes it possible to simultaneously use vehicle prototypes for other calibration tasks. The sum of these factors leads to considerable savings in time and costs. This approach is a significant step in being able to cope with the future demands of driveability calibration.

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