REAL WORLD FUEL CONSUMPTION AND MANEUVER-BASED TESTING

Exhaust-gas chassis dynamometers are generally known as instruments for exhaust emission tests, primarily for homologation functions. In most cases, the executed Euro-6 experiments only slightly resemble real road drives or driving characteristics. Moreover, only simple vehicle models and rolling resistances are implemented. TÜV Hessen, TU Darmstadt and AVL Zöllner show how real road drives can still be transferred to the four-wheel chassis dynamometer for passenger cars with simulation environment.

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APPROACH

In this paper the features of the new "4×4 Chassis Dynamometer Advanced" from AVL during the innovative collaborative project between TÜV Hessen, TU Darmstadt and AVL Zöllner GmbH are presented. For the first time, an accurate transfer of road drives onto the test bench, applying real vehicle models, is possible [1, 2].

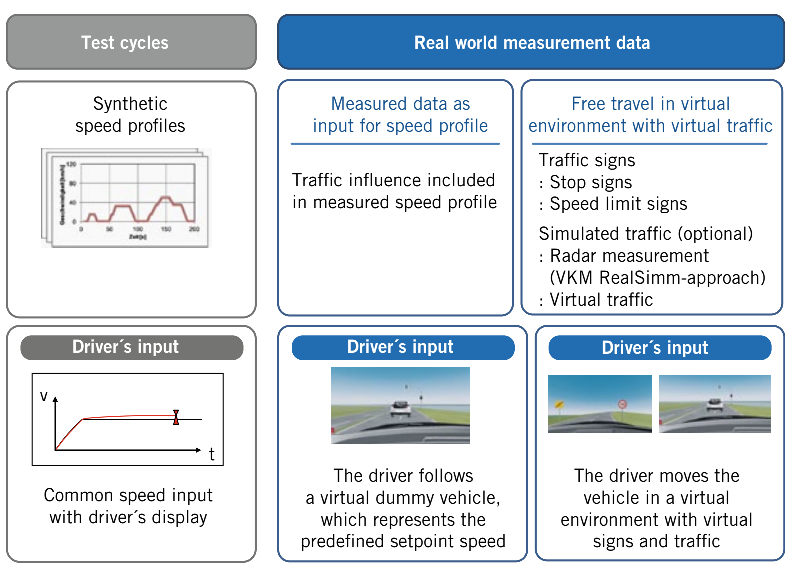
Concerning this, various road drives using different operational profiles are collected but also diverse vehicles (using different drivetrain concepts) and driver's characteristics are evaluated in order to enable the transfer onto the dynamometer afterwards. The aim of these emission and fuel consumption relevant real world measurements is the exact transfer of driving manoeuvres. Additionally, emissions and energy consumption can realistically be generated and analysed at the test bench.

With a view to the future emission standard Euro 6 for passenger cars concerning Real Driving Emissions (RDE) [3], passenger car manufacturers are confronted with new amounts of testing, which can be reproduced and operated at the dynamometer advanced with the aid of this new transfer approach.

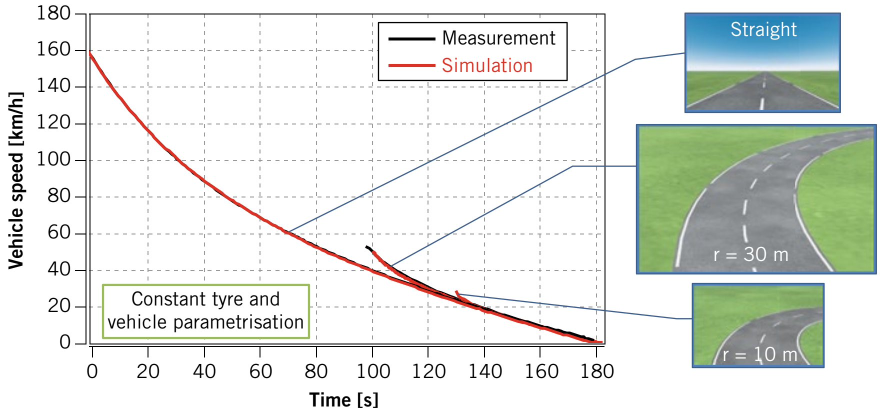
SIMULATION ENVIRONMENT AT THE DYNAMOMETER

The central instrument for manoeuvre based testing at the test bench is a vehicle-in-the-loop (ViL) simulation environment, which is called AVL InMotion and based on the IPG CarMarker product family. The key role is played by this open simulation environment according to X-in-the-Loop framework, concerning the interaction between vehicle, driver and road. Moreover, this environment is used in order to operate vehicle variations, driver's characteristics as well as road and traffic variations via different interfaces. The test engineer has the opportunity to test real driving situations at the test bench [4]. ❶ illustrates the enhanced possibilities of driver's presets connected to the 3D environmental simulation at the "4×4 Chassis Dynamometer Advanced" in contrast to conventional chassis dynamometers for test cycles.

In comparison to conventional road simulations on chassis dynamometers, which are based on coast down curves, the enhanced road simulation uses AVL InMotion. This includes a physical vehicle model which interacts with a virtual environment as well as virtual or real drivers. Dependent on the introduced pulling force on each wheel of the real vehicle, the driving speed is permanently calculated and adjusted at the test bench. As a result of that corners as well as mountain trails can be performed. Moreover, vehicle specific data as varying vehicle mass, changing driving resistances (aerodynamics, chassis), or for instance additional load by trailers can be simulated. Especially when driving along corners, not only the differential wheel speed, but also the additional resistances by the wheel's cornering behaviour are regulated. ❷ illustrates the comparison



❶ Present and new driving possibilities for dynamometers at real world drives



❷ Comparison of measured and simulated coast down experiments at different coast radii with r = ∞, 10 and 30 m (Lexus RX 400h)

between real and simulated coast down experiments (including coast down experiments when driving along curves).

At conventional road simulation, the parameterisation of the vehicle model is set up by adaptation procedures based on real coast down data (straight-on movement). At the advanced road simulation the load is calculated using a model-based simulation set up with physical parameters (frontal area, c_d value, rolling resistance etc.), which can also be varied during the run time. To use the detailed mapping, this information must be available. Due to the fact that each vehicle element is existent at the dynamometer, so called universal models are also usable. These can be created by a vehicle generator which restricts itself to the essential parameters (weight, wheelbase, vehicle type etc.).

ROAD DRIVES

The unique feature of the “4×4 Chassis Dynamometer Advanced” is the transferability of real road drives with individual speed and torque at each wheel from the road to the laboratory. Therefore several driving manoeuvres, which hitherto could only be performed either on real roads, test tracks or testing grounds, can now be transferred to a chassis dynamometer for the first time. This includes, for example, driving around corners or other complex driving manoeuvres, such as a ABS braking sequence or a start on µ-split. Basic requirements for the described dynamometer functions are the four separate controlled rollers as well as the outlined ViL simulation environment. This new approach, to operate vehicles close to the reality at the test bench, has to be validated with adequate correlation measurements in order to validate conform vehicle behaviour between road simulations and real road drives.

For this purpose, three vehicles using different drivetrain concepts are chosen:

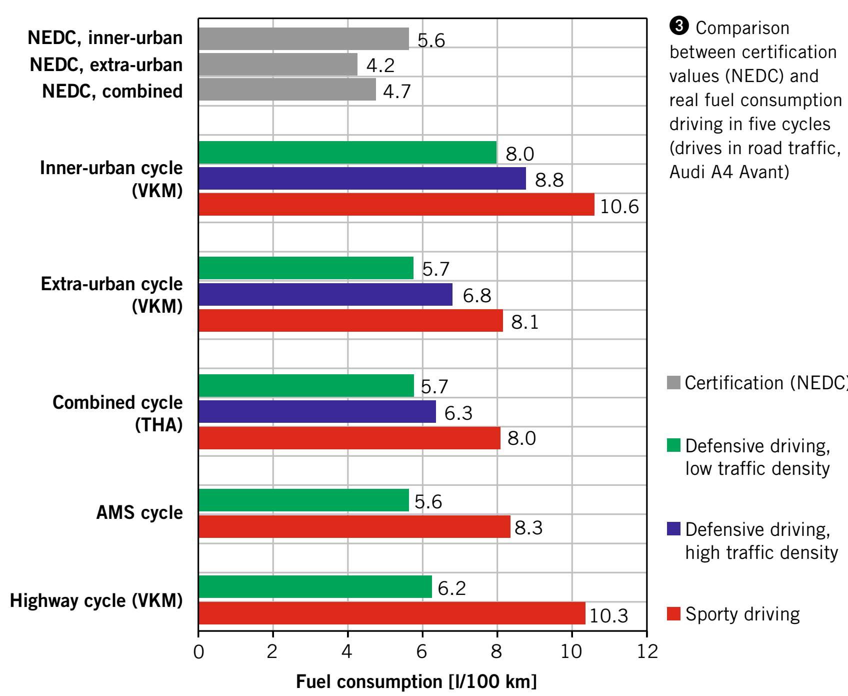
: an mid-class vehicle Audi A4 Avant with a conventional drivetrain and manual transmission
: a full-hybrid vehicle Lexus RX 400h with a four-wheel drive, continuously variable transmission and electrically operated rear axle
: the range extender vehicle Opel Ampera.

All vehicles are equipped with considerable instrumentation to acquire the fuel consumption and other important variables. Concerning the hybrid drivetrains, power output of the drive battery and especially for the Lexus RX 400h, speed and torque for all four wheels are captured with torque measuring rims made by Kistler.

At first all vehicles are measured on the road, in order to transfer the drives to the dynamometer afterwards. Hence, the operation between driving in road traffic and individual generic driving manoeuvres at test tracks is distinguished. While the focus during road traffic drives was on the test vehicle’s energy demand, generic driving manoeuvres are used as verification for the dynamometer’s proper function on a detailed level. The comparison of the driving manoeuvres is based on every four wheel’s measured speed and torque.

DRIVING IN ROAD TRAFFIC

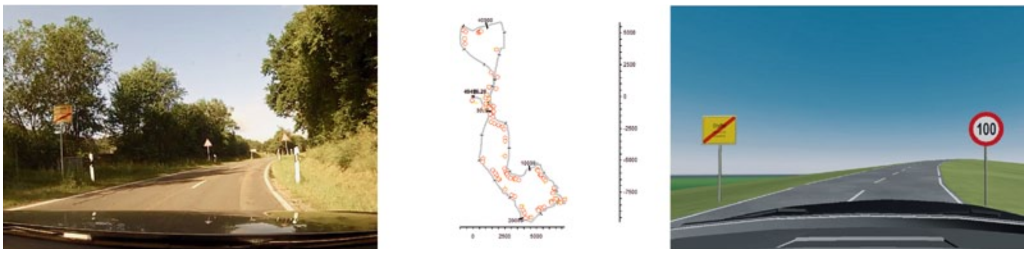
Drives in road traffic are focused on transferability to the dynamometer and the spreading of fuel consumption values in customer’s operation mode, which primary consist of traffic and driver effects. The traffic situation presents a non-reproducible factor with significant influence on the fuel consumption. For this purpose the drives were run at different traffic densities, which prove the traffic situation’s impact. At the test bench this



❸ Comparison between certification values (NEDC) and real fuel consumption driving in five cycles (drives in road traffic, Audi A4 Avant)

VEHICLE		NEDC	INNER URBAN CYCLE (VKM)		COMBINDED CYCLE (THA)		HIGHWAY CYCLE (VKM)	
		Combined (100 %)	Defensive	Sporty	Defensive	Sporty	Defensive	Sporty
	Audi A4 Avant	4.7 [l/100 km]	~ 177 %	~ 220 %	~ 129 %	~ 170 %	~ 131 %	~ 211 %
	Lexus RX 400h	8.1 [l/100 km]	~ 118 %	–	~ 104 %	~ 133 %	–	–
	Opel Ampera (electr.)	16.9 [kWh/100 km]	–	–	~ 96 %	~ 113 %	–	–

❹ Expansion of fuel and energy consumption during real road drives



❺ Real (left) and digitised (centre and right) THA cycle

❻ Vehicle in virtual (left) and real (right) environment (THA cycle)

uncertainty can be eliminated due to the fact that the virtual traffic is simulated in a repeatable manner. In addition, the spreading width of the consumption parameters taken from legal test cycles (NEDC) and real-live driving with different driver behaviour, in other words the "customer consumption", are compared.

Specific trained test drivers were instructed to complete the test runs in an anticipatory driving style ("defensive") as well as in a sporty way of driving ("sporty"). Predictive drives took place in low and high traffic density. Using the vehicle with a manual transmission – the Audi A4 Avant – gear changes happened according to the vehicle's switching demand, whereas the driver exploited nearly the entire speed range of the engine during a sporty way of driving. The maximum speed for predictive defensive drives was limited to 130 km/h at every section of the motorway, including also those without a speed limit. Goal in the sporty way of driving was to move the vehicle as fast as possible within legal speed limits.

All drives in road traffic are based on distinct driving routes/driving cycles with diverse route profiles. This includes an inner urban cycle, an extra-urban cycle, a highway cycle (in each case from TU Darmstadt, Institute VKM), a combined cycle provided by TÜV Hessen Automotive (THA) and the AMS cycle (from Auto, Motor, Sport magazine). ❸ illustrates the impact of driver behaviour and traffic density on energy consumption in road traffic using the example of Audi A4 Avant – in comparison to the NEDC.

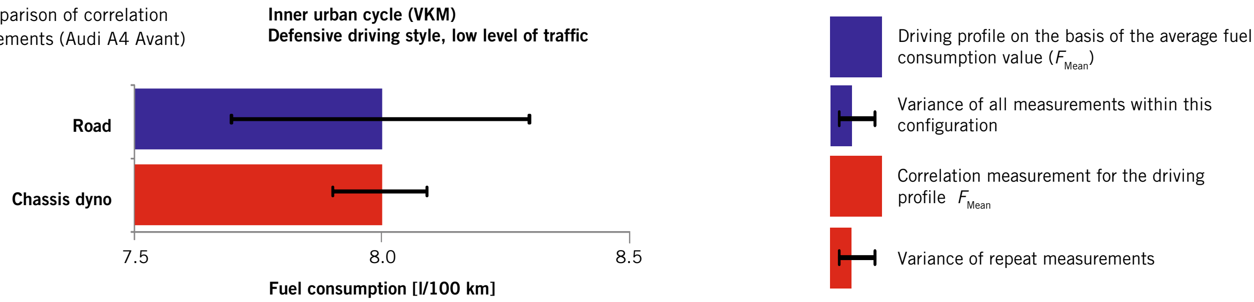
❹ illustrates the range concerning the energy consumption of all three test vehicles during real road drives in comparison to the type tested values at NEDC. It is important to note that all test drives were performed with the additional weight of the carried measurement devices. Furthermore, loads such as dimmed headlights and ventilation were turned on (Audi A4 Avant: deactivated start/stop operation).

In order to reproduce the tests at the chassis dynamometer, 3D courses of the road were recorded with aid of GPS sensors and combined with the data of a barometric height sensor. At the same time, the legal speed limits were recorded. Elicitation and processing of the measured data was based on the RealSimm approach, which was developed at the VKM institute [4]. With the help of this data and the appropriate parameter setting, it was possible to reproduce courses of roads at the new dynamometer. ❺ illustrates the THA cycle in real as well as digitised; ❻ illustrates the THA cycle with a vehicle in virtual and real environment.

Exemplarily the results of repeated measurements at the dynamometer are illustrated in ❼. They indicate a high conformity as well as a high reproducibility of the measured data.

GENERIC DRIVING MANOEUVRES

The research campaign's second part evaluated the transferability of typical generic driving manoeuvres to the dynamometer. With the aid of selected test drives, the accurate function of the test bench was verified. The experimental design includes manoeuvres and road variations, which are simulated at the chassis dynamometer. This includes for instance: full load and half load acceleration, braking sequences as well as a leap in accelerator pedal value (tip in). Variation parameters are the slope of the road (0 and 12 % gradient), the pavement variations (μ-high, μ-low, μ-split, roller tracks) as well as the vehicle mass, which has been varied by about 200 kg.



❼ Comparison of correlation measurements (Audi A4 Avant)

Using the example of a full load acceleration with the Lexus RX 400h, ❽, the transfer of road drives (generic driving manoeuvres) to the AVL "4×4 Chassis Dynamometer Advanced" is demonstrated. Both, the process of time concerning each wheel's torque as well as the wheel's numbers of revolutions shows a high correlation with the road measurements. ⑧ generically illustrates the torque curves at the right front and rear wheel.

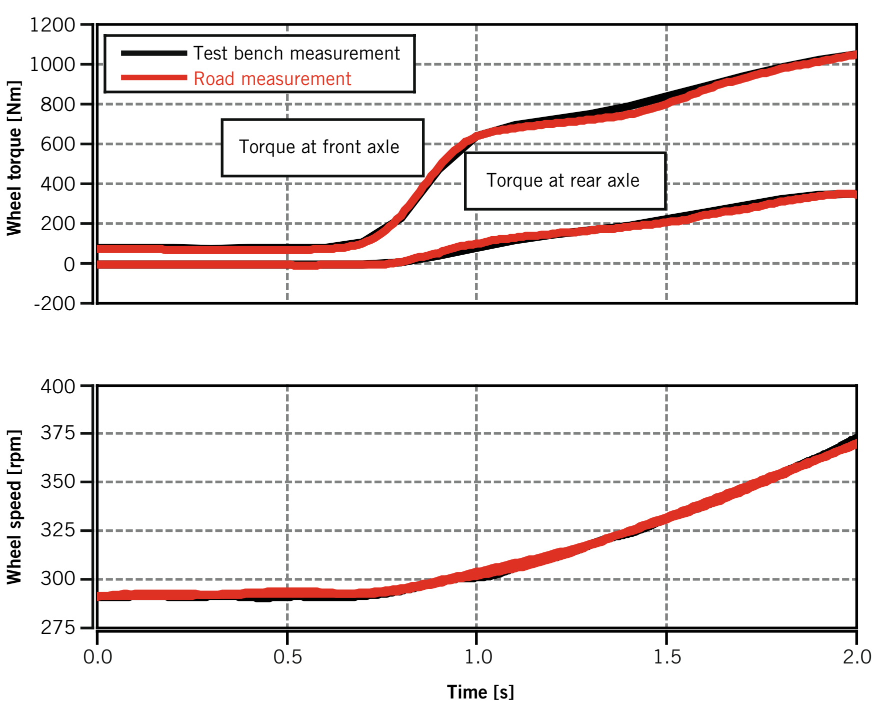
SUMMARY AND PROSPECTS

Within the scope of this article, a holistic system approach has been introduced, which makes the transfer of on road test drives to the chassis dynamometer possible. In order to transfer complex driving manoeuvres for any kind of drivetrain concepts, a chassis dynamometer with four separately controlled rollers is used. Moreover, the dynamometer is linked to a simulation environment.

This environment allows, among others, the depiction of driving along corners, driving up- and downhill, individual wheel-spin as well as the analysis of torque vectoring systems at the chassis dynamometer. In order to perform a systematic investigation of fuel consumption, exhaust gas emissions or the energy flow (electric motor and battery), including its designing strategy, fuel consumption dominating influence parameters are model-based varied. These parameters are, for example, traffic flow but also vehicle parameters, such as the vehicle mass or air resistance. Furthermore, the influence of different driver characteristics can be depicted.

In addition to standardised homologation and certification functions, this comprehensive ViL development platform supports the determination of real driving emissions (RDE) and real consumption either in synthetic routes or routes based on real test drives. Therefore, the ViL development platform is the ideal complement to PEMS measurements in road traffics [3]. Further applications are development and optimisation tasks concerning the complete vehicle such as drivetrain application, function and operation strategy optimisation of modern conventional as well as electrified drivetrains.

As a result, tasks of vehicle developers (application) can be transferred from the road to the test bench. Special advantages are the reproducibility of individual experiments and the flexibility to examine different real driving roads successively. Moreover, it is possible to describe different vehicle types (benchmarking) under identical driving conditions along any driving road chosen at the „4×4 Chassis Dynamometer Advanced". This happens in a repeatable manner which is not possible on the road, due to variations given by environmental and traffic conditions.



❽ Comparison between test bench measurement and road measurement (test track) relating to full-load acceleration (Lexus RX 400h, measured values of the right front and rear wheel)

REFERENCES

[1] www.tuev-hessen.de/tuz

[2] Düser, T.; Schmidt, C.; Schmidt, U.; Pfister, F.: Chassis Dynamometers for Vehicle and Powertrain Concepts of Tomorrow. In: ATZworldwide 114 (2012), No. 4, pp. 12 – 16

[3] Steininger, N.: Finalising Euro 6 and Reducing CO_2 Emissions of Light Duty Vehicles. 3. VDI-Fachkonferenz Abgasnachbehandlungssysteme 2012, Stuttgart, 5 and 6 December 2012

[4] Kluin, M.; Bier, M.; Weickgenannt, P.; Beidl, C.: Einsatz dreidimensionaler Umgebungssimulation in der Entwicklung von Hybridantrieben. ATZlive-Konferenz VPC Virtual Powertrain Creation, Esslingen, 25 and 26 September 2012

[5] Pfister, F.; Schick, B.: Die Zukunft hat einen Sensor: Location Awareness meets Powertrain Controls. 4. Internationales Symposium für Entwicklungsmethodik, Wiesbaden, 8 and 9 November 2011