

ATZ extra

September 2015

Offprint

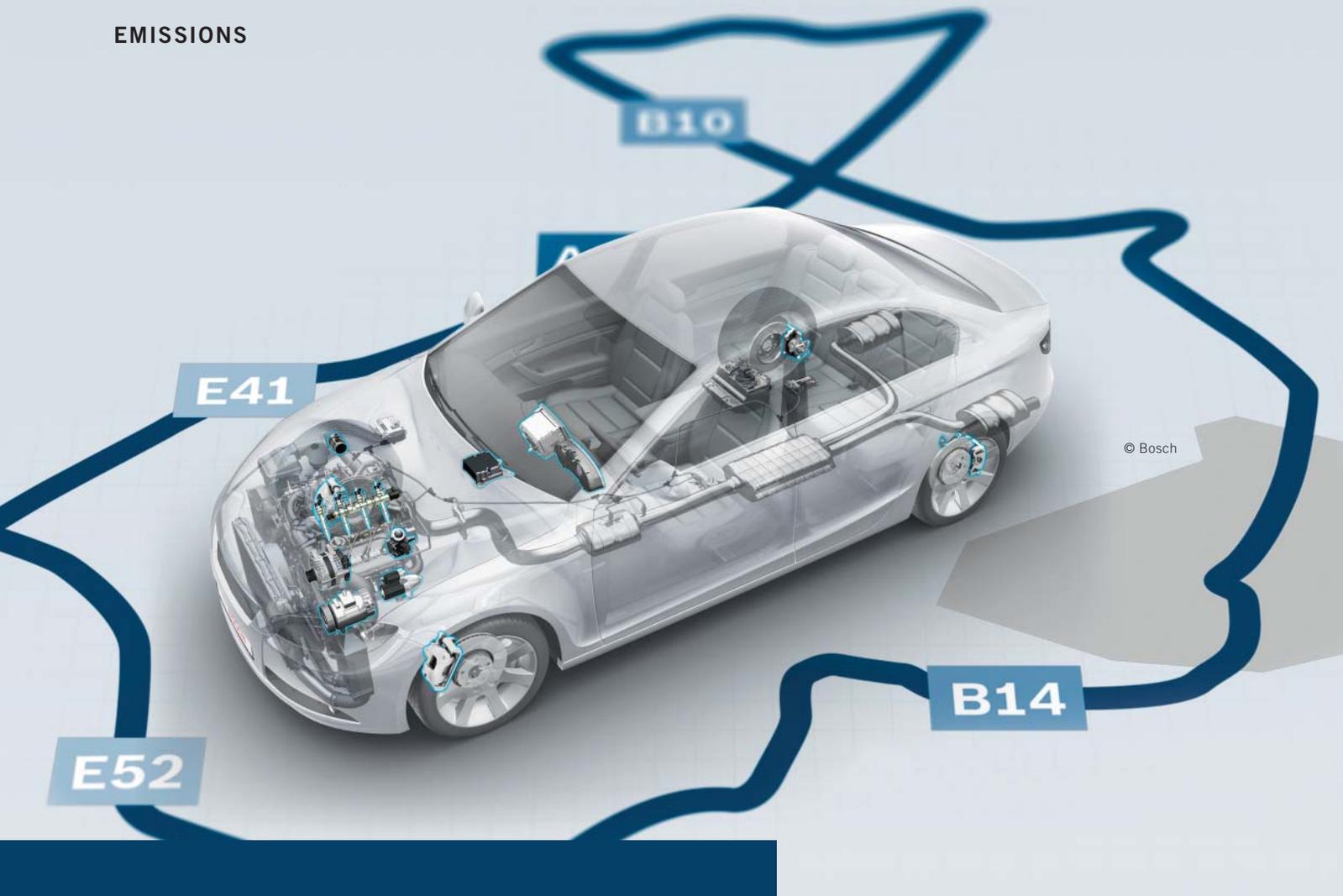
from ATZextra 09/2015

Springer Vieweg

Springer Fachmedien Wiesbaden GmbH



**RDE ENGINEERING ENVIRONMENT
ON A DYNAMIC ENGINE
TEST BENCH**



RDE engineering environment on a dynamic engine test bench

With the implementation of the Real-Driving-Emissions legislation in 2017 and its monitoring phase starting in 2016, the technical challenges regarding the reduction of emissions as well as the scope of development will continue to rise. This sharpens the focus of the EU on the exhaust emissions during real driving. The Bosch Engineering GmbH has realized a new tool-chain at the engine test bench to examine the Real-Driving-Emissions conformity of engines “in-the-loop” with different simulated chassis and gearbox variations.

AVOIDING ADDITIONAL COSTS AND DEVELOPMENT TIME

The European Union considers the Real-Driving-Emissions (RDE) legislation as the key to a reliable measurement of a vehicle with its resulting emissions through so-called Portable-Emission-Measurement-Systems (PEMS) [1]. The discrepancies between cycle emissions and emissions in dynamic real driving have led to this decision of the EU improving the air quality [2]. Even if not all details of the RDE legislation are determined so far, the certification of vehicles in Europe will change. According to these changes manufacturers, suppliers and development providers have to develop new technologies on the one hand and establish efficient development processes on the other hand. The introduction of the RDE-tests will revoke the previous separation between the areas of internal reduction of emissions, after-treatment, gearbox control,

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driving characteristics, combustion noise and on-board diagnosis (OBD). Those cannot be considered separately any longer due to their impact on emissions results. Furthermore, the comple-

xity of the emission development increases through RDE because different environmental conditions such as temperature, road-tracks and driver are taken into account. According to this, it is the task of the development department to prepare all engine, vehicle and transmission combinations in time for RDE to be able to avoid later adjustments in the development process which would cause additional costs and time.

CHALLENGES AND TARGETS

RDE tests under real driving conditions on the road challenges the development because the situational environmental conditions such as temperature, traffic and the behavior of the driver are not reproducible. But constant conditions are necessary to investigate influences of hardware and software on the emission performance. In addition, the development department is faced with rising costs, shorter development times and an increasing number of models. In opposition to that costs lead to a reduction of testing vehicles and to a decreasing availability of test vehicles for the engineering teams. Due to this situation the roller- and engine test benches will remain an essential part of the engine development. But they have to develop technologically due to the new requirements.

Moreover, the RDE legislation raises further questions:

- How often does a gear-box-chassis-combination have to be checked in

order to avoid emission over limit during certification?

- How can emission results coming from soft- and hardware-changes be separated from the influences from the driver, the road track and the environment
- Which development departments should get involved into the RDE issue and at what time?

The Bosch Engineering GmbH, the Engineering Service of the Bosch Group, has realized a tool-chain based on vehicle and environment simulation, combined with an engine-in-the-loop process. With this system real driving can be displayed on engine test benches. So, numerous environmental conditions such as slopes, traffic and driver's behavior as well as city, rural and motorway driving are tested regarding exhaust emissions of different vehicle models to derive further development steps. With the new methodology, emissions of engine platform concepts can be ensured under RDE conditions to avoid hardware or software changes right before the start of production (SOP). In addition to that, the engine test bench is considered as an efficient development tool to face the increasing calibration effort (Fig. 1). The emission measurements on the roller test bench (NEDC & WLTC) will remain and they will be complemented through unreproducible real driving tests on the road. To support this situation the high reproducibility of the engine test bench, the known and fully-developed measure equipment and the

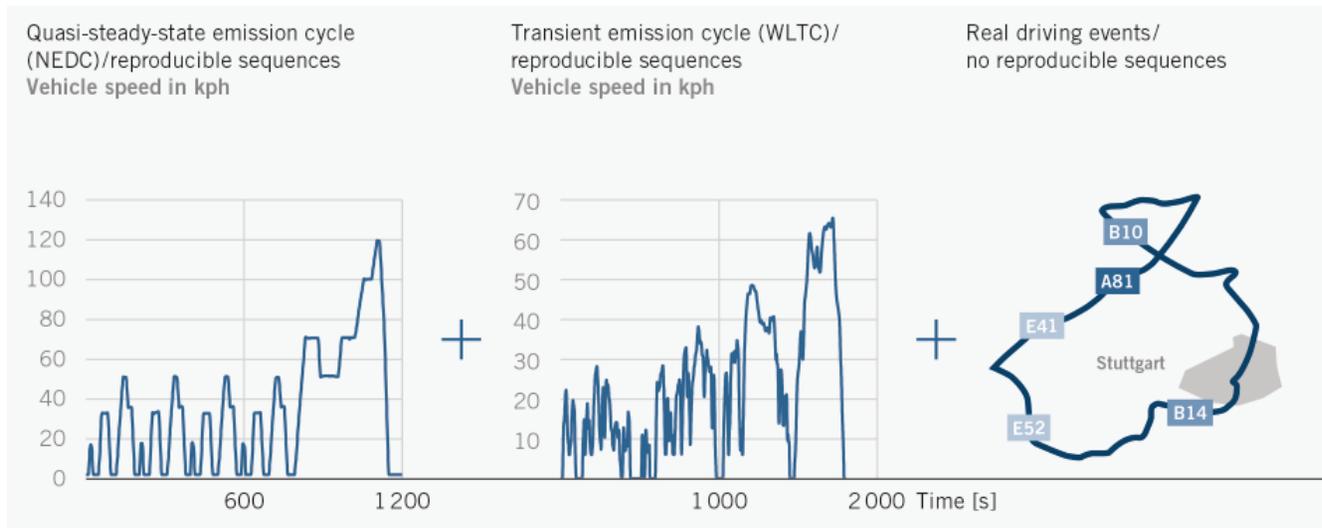


Fig. 1: EU 6c emissions cycles and RDE (© Bosch)

EMISSIONS

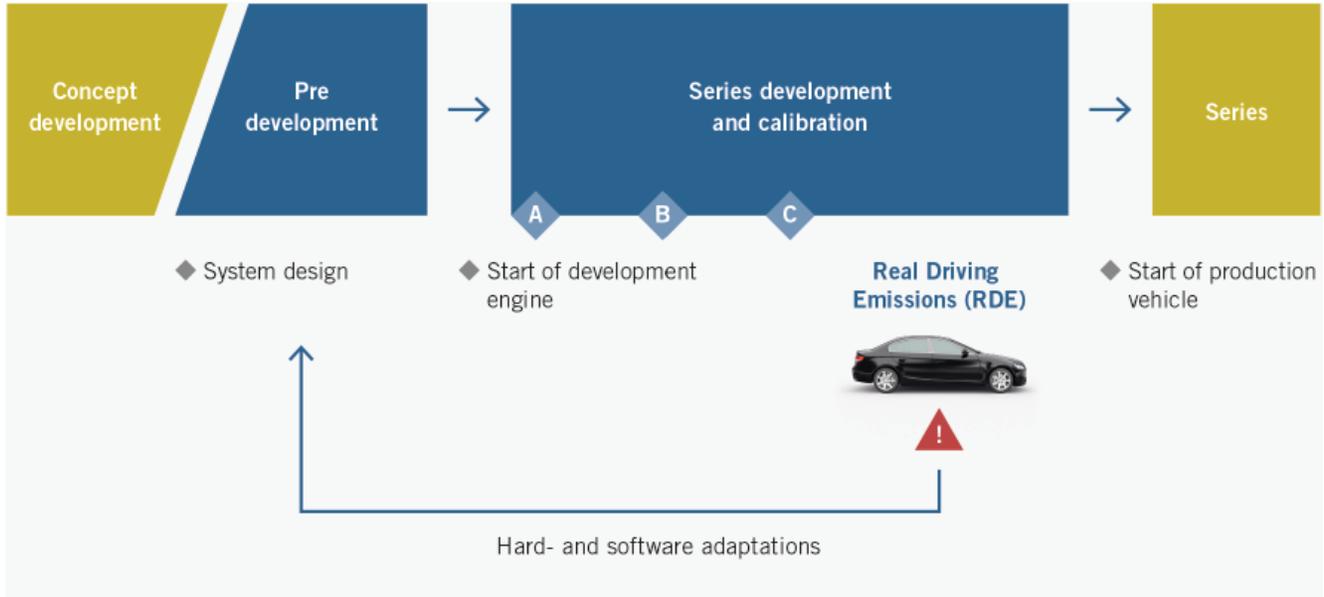


Fig. 2: Project schedule for combustion process development and series calibration (© Bosch)

advantage to perform automatically numerous tests during the night is set. Combined with a fast cooling of the engine even more RDE tests variations can be added to a single overnight run. Through an early check of the emissions performance of the engine regarding future load, speed-operating points and a variation of environmental conditions on the engine test bench, a so-called “frontloading” is implemented in the development process which leads to a higher maturity of the complete system at time of the first PEMS measurement with the different test- vehicles. Furthermore, “frontloading” minimizes

the risk of a recursion right before the SOP (Fig. 2).

DIFFERENTIATION OF THE OPERATING CONDITIONS BETWEEN THE EMISSION CYCLE AND THE REAL DRIVING

Real driving leads to operating conditions that deviate from the already known exhaust cycles (New European Driving Cycle and Worldwide Harmonized Light Duty Test Cycle). In these emission cycles on the roller bench, the thermal behavior of the engines is reproducible. The emissions result from

the combustion process, the thermal condition of the combustion chamber and the after-treatment system. During real driving, no thermal reproducibility can be realized even using the same road-track. Due to traffic a speed-load operation point can be initiated after a long overrun phase or after a performance phase on the motorway. These differences in the emission results are realized due to a cold or a hot combustion chamber of a diesel engine. These circumstances can change the NO_x-Soot trade-off of up to 70% [3]. This must be considered when designing the exhaust gas treatment.

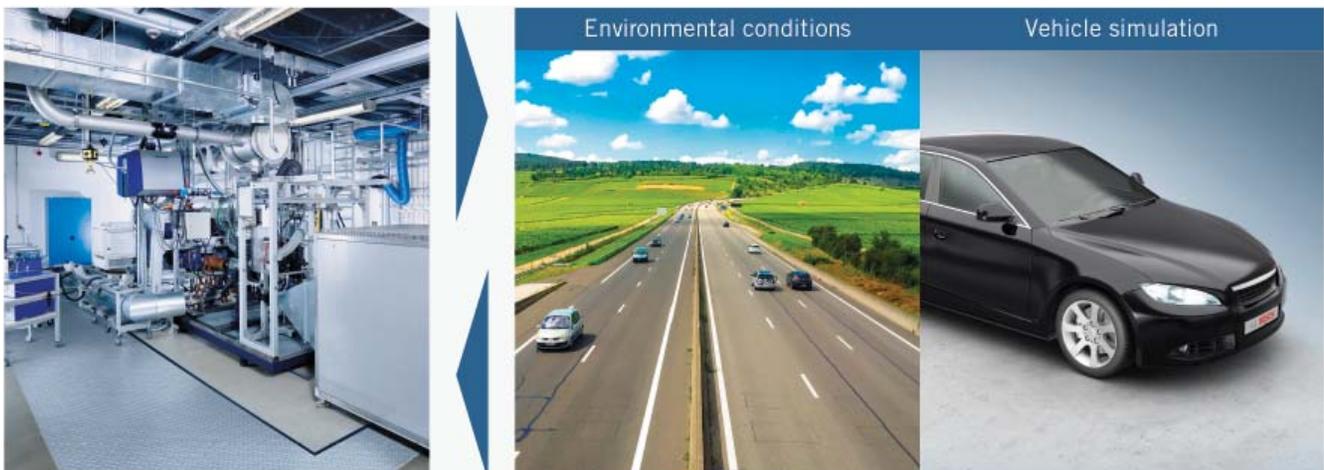


Fig. 3: Visualization of real driving on the engine test bench (© Bosch)

SELECTING THE ROUTE

The choice of the road track has a direct impact on the vehicle's emissions. Measurements show that especially up and down gradients along a track have a dominant influence on the emission behavior. The measurement data is realized in a lab environment that visualized a chosen track by a road map, a movie of the real road and the GPS-based route information including up and down gradients. Due to that, the engineer can refer emissions peaks to the real driving event and focus on optimizing the engine behavior to this situation (Fig. 3).

DRIVER ANALYSIS

The driver's acceleration behavior on the road can, as shown in **FIGURE 4**, be analyzed and transferred to the simulated driver. In the diagram, the engaged gear, the vehicle speed and areas of equal acceleration are displayed in the form of shell scheme. A "soft" driving style is characterized by a maximum acceleration of 2 m/s² between 10 to 35 kph. An "aggressive" driving style, in contrast, involves an acceleration of 2.5 m/s² from 30 to 50 kph and shows an expanded range for 2 m/s² from 10 to 85 kph. These characterizations permit different, yet precisely-defined kinds of acceleration behavior to be transferred to the engine test bench. These are complemented with constant driving measurements. The simulated driver behavior is modified to act like a real driver with all its undefined movements on the accelerator pedal.

REAL-LIFE DRIVING ON THE ENGINE TEST BENCH

TABLE 1 shows the analysis of a middle-class vehicle with a turbocharged diesel engine, high and low-pressure exhaust gas recirculation (EGR) and diesel oxi-

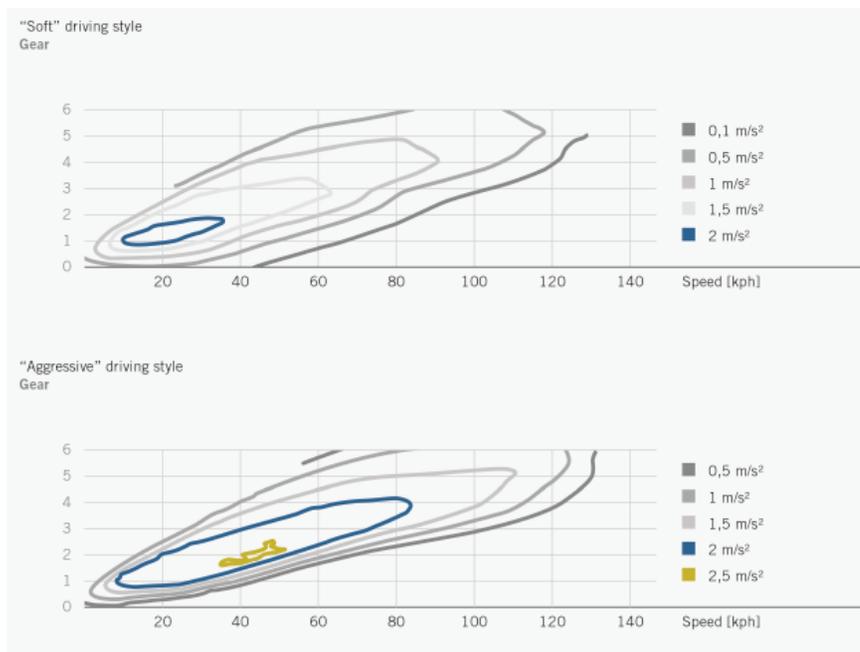


Fig. 4: Analysis of driving styles during road trips (© Bosch)

dation catalyst (DOC). The raw emissions were examined at urban traffic according to verify the chosen exhaust after-treatment systems. The **table 1** shows that the NO_x (nitrogen oxides) emissions created by an "aggressive" driving style and a "soft" driving style in urban driving environments with little traffic vary between 220 and 260 mg/km. With a NO_x-after-treatment system and suitable exhaust temperatures, the vehicle variant can be defined as robust regarding NO_x emissions in this event. With a conformity factor (emissions factor on the exhaust test, CF) of 1.5, 120 mg/km NO_x are the limit for vehicles under the RDE legislation EU 6c. Thus, at a NO_x conversion rate of 60%, a safety distance of 16 mg/km to the critical limit can be realized, even with an aggressive driving behavior. In stop-and-go traffic, however, significantly higher NO_x raw emissions can be observed. The engine emits between

430 and 620 mg/km NO_x depending on a "soft" and "aggressive" simulated driving behavior. So, for an aggressive driving style, a total NO_x reduction efficiency of 83% is therefore required to obtain the same safety margin to the emission limit as with little traffic. The tests also included other variations in which the defined road track was driven twice on the engine test bench by a simulated driver; on the second trip, however, with a 200 kg heavier vehicle (**Fig. 5**). Regarding the environmental conditions, a "soft" driving style, traffic jam influences and 20 °C ambient temperature were set. The NO_x-emissions from the first test differed by 16 mg/km from the second journey with a heavier vehicle. Among other reasons for the differences that part of the route had a 6% slope. **FIGURE 5** shows a trip at 60 kph on a route with a 4 - 7% slope. During acceleration on this section of the route, NO_x peaks up to 0.015 g/s

	NO _x [g/km]	HC [g/km]	CO [g/km]	CO ₂ [g/km]
"Soft" driving style, little traffic	0,22	0,07	0,22	129
"Soft" driving style, traffic jam	0,43	0,06	0,19	190
"Aggressive" driving style, little traffic	0,26	0,05	0,16	132
"Aggressive" driving style, traffic jam	0,62	0,05	0,07	199

TABLE 1: Excerpt multidimensional emission information in city traffic (© Bosch)

EMISSIONS

(route point 14.75 km) were measured, which is equal to a difference of 50% between the light and the heavy vehicle variant. These driving event with the heavy vehicle variant have to be carefully analyzed with respect to the raw emissions and the required efficiency of NO_x after-treatment system to prove the feasibility. In addition, overrun periods and the resulting cooling of the combustion chamber or the exhaust after-treatment systems are also a challenge. To illustrate this point, a stop-and-go situation on the motorway is examined (Fig. 6). Once again, both a “soft” and an “aggressive” driving style are simulated. This part of the track slopes downhill until the track point at 27.5 kilometers. After the stop-and-go phase

on the downhill slope, the car is accelerated to 80 kph. At the kilometer point 28.3, a breakthrough of the HC- (hydrocarbon) emissions, which was not oxidized by the DOC, was measured. In contrast to conventional exhaust cycles on the engine test bench, the studies show that a repeated falling below the light-off temperature of a DOC is certainly one of the scenarios which has to be dealt with. At stop-and-go traffic on slopes, the exhaust gas temperature T₄ (after DOC) cools down to 75 °C, regardless of the driving style.

EVALUATING THE DATA

Depending on the CF emission factor to be defined by the EU, each vehicle vari-

ant needs to be prepared for RDE events. Raw engine emissions, as well as the efficiency levels of the exhaust after-treatment systems, which can be represented in real driving situations, are the criteria for appropriate measures to optimize hardware, customize software or change the parameters (Fig. 7). Bosch offers with the Boost Recuperation System (BRS), an electrically-supportive belt generator that can handle high torque in order to reduce NO_x peaks [4]. Increasing the injection pressure up to 2,700 bar and/or digital rate shaping help to further reduce engine-out emissions [5].

SUMMARY

With the newly developed test environment, Bosch Engineering has created the possibility to carry out engine measurements based on a simulation of all transmission and chassis models, with regards to RDE. The customer’s engine development phase can be supported by early tests regarding the future combination of chassis, gearbox and engine variants. On the one hand, the utilization of test vehicles can be minimized and, on the other hand, challenges posed by certain chassis and transmission models can already be pointed out at an earlier stage thanks to the new testing methodology. In addition, in a reproducible RDE testing and engineering environment, customers’ engines can be attended in the development time with regards to their real driving emissions, hardware and software adjustments and feature developments.

BIBLIOGRAPHY

- [1] Vlachos, T. G.; Bonnel, P.; Weiss, M. (2014): Evaluating the real-driving emissions of light-duty vehicles; 36. Internationales Wiener Motorensymposium.
- [2] o. V. (2015): Neues Emissionsmessverfahren - Der Realty-Check, Spiegel Online.
- [3] Wirbeleit, F.; Hartlief, H.; Gerstenberg, J. (2014): Realisierung von Hochdynamik auf einem Motorprüfstand, VPC+ Conference Hanau.
- [4] Wüst, M.; Krüger, M.; Naber, D. (2015): Operating strategy for optimized CO₂ and NO_x emissions of diesel-engine mild-hybrid vehicles, In: 15. Internationales Stuttgarter Symposium Automobil- und Motorentechnik, p. 93-111.
- [5] Wintrich, T.; Hammer, J.; Naber, D.; Raff, M (2015): Advanced diesel technology to meet multi-dimensional challenges of the diesel engine, In: 15. Internationales Stuttgarter Symposium Automobil- und Motorentechnik, p. 337-351.

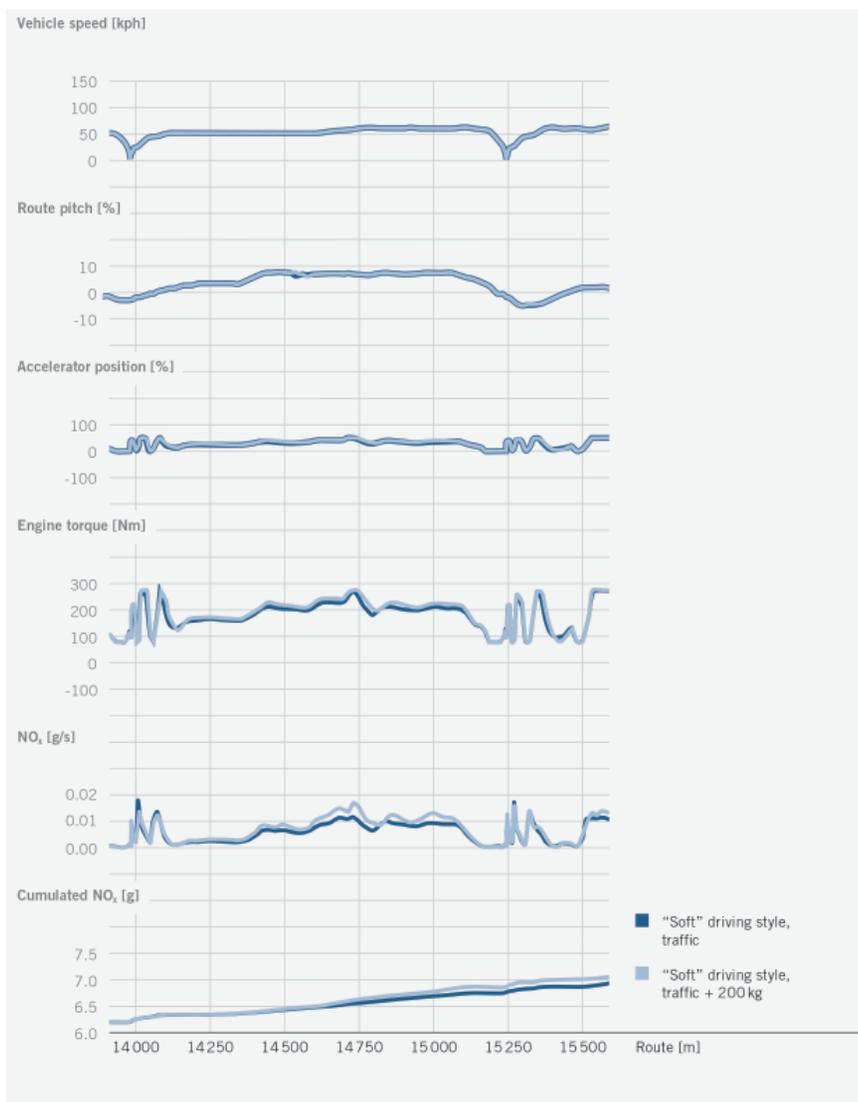


Fig. 5: Part of the road-track facing variants testing (© Bosch)

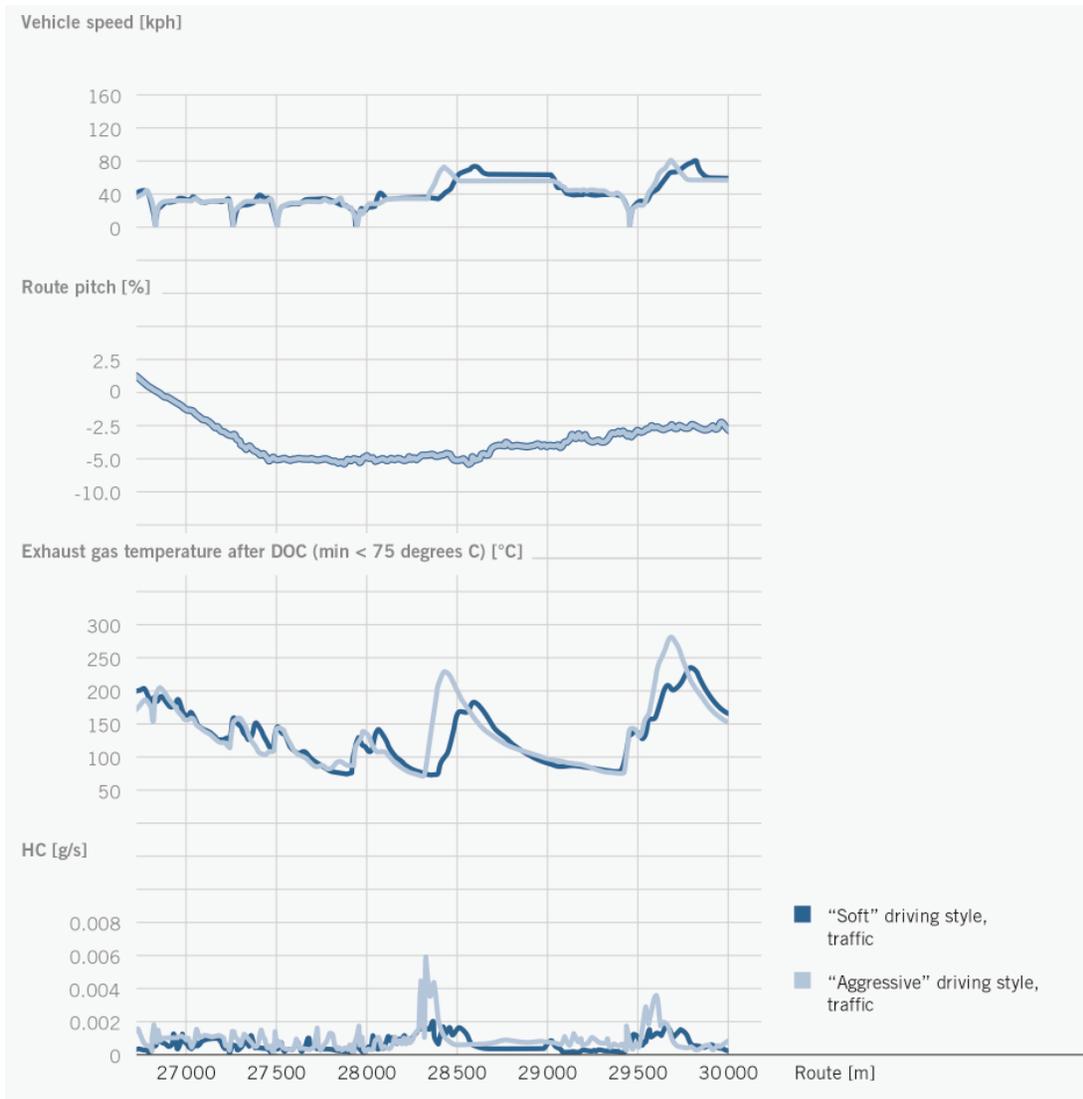


Fig. 6: Emissions during a downhill driving at traffic (© Bosch)

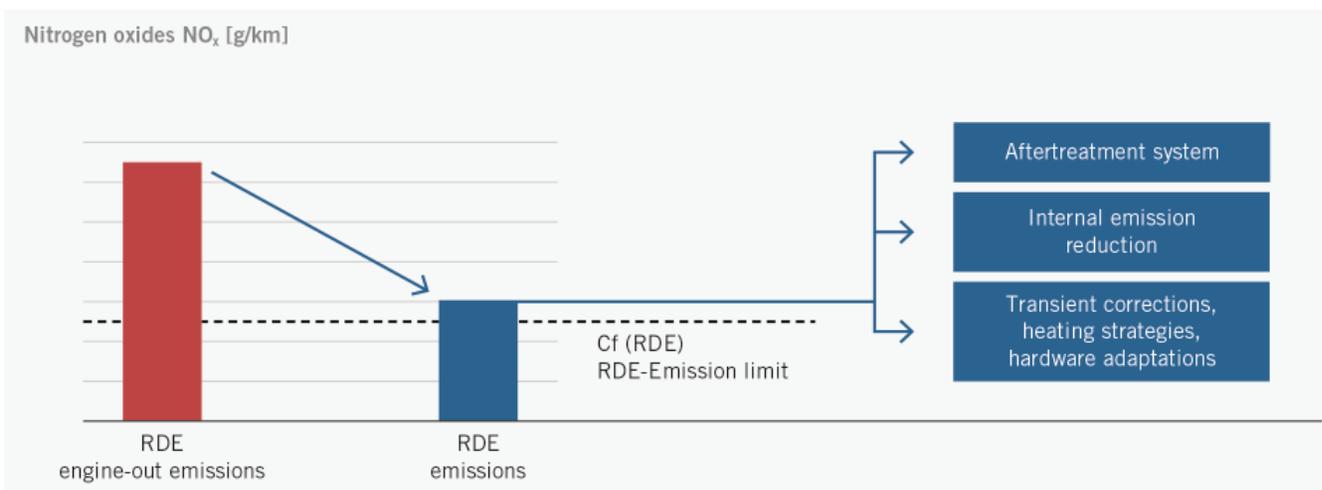


Fig. 7: Deriving strategies for RDE (© Bosch)



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