Written questions to BOSCH – EMIS hearing of 27 June 2016

Answers

Preliminary note: As is widely known, since September 2015, authorities in the U.S., Germany, and other countries have been investigating possible legal violations with regard to emissions from diesel vehicles, including those made by Volkswagen (VW).

Bosch is one of the world's biggest suppliers of injection technology. A large number of the engine control units for the VW diesel engines being investigated were supplied by Bosch. However, there are several other VW suppliers of these software products globally.

Bosch takes the allegations of manipulation of diesel software very seriously. Because of its role as a supplier, Bosch launched its own internal investigation immediately after learning of the allegations against VW. This is an ongoing process. Bosch is also in constant dialogue with the relevant authorities. Due to the sensitive legal situation, we cannot comment on individual details of the investigation or on our cooperation with the authorities. Moreover, restraint in our external communications will help our constructive cooperation with the authorities.

Some of the questions relate to strategies or motivation of manufacturers (OEM) and should be addressed to the OEM directly.

The subjects addressed by the questions from EMIS are complex and can only be explained within this document in a very simplified manner. We may only be able to address some of the aspects mentioned and would like to point out in advance that simplified description will by nature involve a certain degree of vagueness in that the background cannot reliably be described in all details. Therefore, please bear this proviso in mind when reading the following statements.

1	Can you confirm that it is a regular procedure that OEMs are adapting the electronic control unit (ECU) software to their special needs? Who has in the end the formal responsibility in this regard for the final (emission) performance of the vehicle? What are usually the contractual agreements between suppliers and OEMs in this regard?

1.1 Can you confirm that it is a regular procedure that OEMs are adapting the electronic control unit (ECU) software to their special needs?

As far as Bosch is able to assess this question, the ECU is adapted to the customers' special requirements via functionality and calibration. This is done by the OEM, or by the OEM commissioning Bosch (or, if applicable, a service provider) or directly by Bosch if, according to the contract, the responsibility lies with Bosch.

1.2 Who has in the end the formal responsibility in this regard for the final (emission) performance of the vehicle? What are usually the contractual agreements between suppliers and OEMs in this regard?

In his answer to question 8 at the meeting of 16 June 2016, Prof. *Borgeest* provided an essentially correct rough summary as to how ECU software in today's diesel passenger cars is normally structured and how tasks are typically allocated between the supplier of the control unit and the OEM.

Roughly speaking, in the development of control unit software, one must differentiate between the programming of the code on the one hand and its calibration (application), i.e. assigning values to individual labels, on the other hand.

Based on our experience, ECU software for modern diesel passenger cars today consists of approximately 35,000 labels (this is higher than the figure of 20,000 given by Prof. *Borgeest* in his answer to question 1 at the meeting of 16 June).

Additionally, as Prof. *Borgeest* already described, in the development of the program (of files and codes), one must also differentiate between the standard software (the platform with standard functions), which is developed by the individual supplier and represents the core of the supplier's software, and the customer-specific requirements which are customized to the individual OEM and specific vehicle. The customer-specific requirements complement or modify the platform. The proportion of customer-specific requirements relative to the specific platform functions varies greatly depending on the customer and the market. These customer-specific functions and labels are developed based on the OEM's instructions.

Furthermore, most OEMs themselves add functions and constructs they have developed to parts of the software, the exact content of which the supplier itself cannot see in most cases (like a "black box") and which it merely integrates in the status of the entire program. For such parts of the software, the supplier typically has no access rights and does not receive any software documentation. Some OEMs have their own large development departments whereas others transfer large parts of their software development to suppliers, in particular to further software providers.

The final calibration (application) of the program labels and codes is predominantly the responsibility of the OEM or performed in accordance with the OEM's detailed instructions. The reason for this is that proper performance of the calibration requires knowledge of the vehicle's entire engine and emissions technology and other performance data, which often only the OEM has and generally not the supplier. Without this knowledge, it is generally impossible to clearly identify the effects of the labels and functions and their calibration on the vehicle's emission behavior. Bosch especially designs "hardware proximate" functions to ensure that, for example, fuel injectors are capable of injecting without causing the motor to break down and without damaging the injectors, but, in the end, the customer's calibration determines when and how the hardware is actually activated.

As between the OEM and the supplier, it is as a general rule the OEM that is ultimately responsible for integrating the software into the vehicle's emission control system and for the effects of the software on the NOx emission behavior. There are, however, projects where the supplier also performs the entire calibration and is responsible for such calibration under the relevant contract. However, also in these cases responsibility for complying with the requirements of the type-approval procedure remains solely with the OEM. Bound by duties of confidentiality to the OEMs, Bosch cannot make any statements about the contractual agreements it has made with its customers without their consent.

2	How close is the cooperation with automotive suppliers when developing software? Does the car manufacturer know the structure and the proprietary code of the software developed by Bosch in detail? How many varieties does your company develop for the Electronic Diesel Control (EDC)? Are these varieties comparable or do they differ significantly from each other? Why do some car manufacturers prefer to feed software provided by automotive suppliers with the parameters of their engine (data!) and do not programme their own software?

2.1 How close is the cooperation with automotive suppliers when developing software?

Cooperation occurs in the form of joint project development. A project leader is appointed at both the supplier and the OEM. The OEM may also engage additional tiers of suppliers in the product development chain. The OEM project leader coordinates the OEM requirements and prioritizes them with a view to the timetable of implementation. They work with the tier one supplier to estimate the implementation effort, confirm the delivery dates and ensures compliance with such dates. The tier one supplier and sometimes the OEM then work with other suppliers on the details of development. During this process, the OEM has complete knowledge of the entire vehicle and all of its components. The various suppliers have partial knowledge of subsystems and components.

2.2 Does the car manufacturer know the structure and the proprietary code of the software developed by Bosch in detail?

Normally, the OEM is provided with the documentation on the calculations of signal characteristics in the form of sequence diagrams as part of the software documentation. In general, the OEM is not given access to the C-source code of the Bosch software. The automotive manufacturer's knowledge of the software strongly varies depending, among other factors, on the part of the software that it is providing, on the scope of application by the OEM, and the contractual agreements.

2.3 How many varieties does your company develop for the Electronic Diesel Control (EDC)

Every vehicle and vehicle configuration (e.g. automatic/manual transmission) constitute an individual software (code + data) variation. This means that each OEM project supplies one or more vehicles with a control unit hardware variation. The ECU hardware variant depends on the performance (computation speed/storage) required by the OEM and on the number of signal inputs and outputs designated for the car.

2.4 Are these varieties comparable or do they differ significantly from each other?

The various varieties are identical in that they use the same family of microcontrollers and the same or similar hardware components for the input and output signals. In addition, there are customer-specific and vehicle-specific hardware components.

Roughly summarized, the software comprises Bosch functions (i.e. functions for all customers) that are used at most of the OEMs. A large part of the software is specified by the OEM, however. Each OEM defines its own scope of functions consisting of

- OEM’s own functions (developed by the OEM itself or by third parties)
- functions developed by Bosch at the customer’s direction (customer platform)
- functions adapted from the Bosch platform at the customer’s direction
- Bosch platform functions.

Over the years and in the course of individual projects, this OEM-specific scope of functions forms the basis for the scope of further software development defined within the framework of the OEM commissions.

The details of the functions may be very different.

As already described, in order to protect expertise and differentiate themselves from competitors, many OEMs develop some own software functions, which Bosch are then given as the object code (machine code) for integration into the overall software. The functionality contained in the code is not disclosed to Bosch.

2.5 Why do some car manufacturers prefer to feed software provided by automotive suppliers with the parameters of their engine (data!) and do not programme their own software?

We, as suppliers, cannot validly answer the question as to the OEMs' motives and reasons not to develop their own software.

3	What are the technical potentials of software modifications? Which benefits can be achieved by the OEMs (e.g. delta kW of engine power, delta fuel consumption or CO_2) and what are the potential negative impacts to be expected for pollutant emissions? Could you provide us a range of possible options? Can the observed gaps for NO_x and CO_2 emissions from available RDE measurements (as documented by JRC, TNO and others) be explained by software modifications? If yes, to what extent?

The connections addressed by this question are – as we understand the question – extremely complex and can only be explained within this document in a very simplified manner. We will only be able to address some of the aspects mentioned and would like to point out in advance that such simplified description will by nature involve a certain degree of vagueness in that the background cannot reliably be described in all details. Therefore, please bear this proviso in mind when reading the following statements. We would also like to point out that we will only discuss the theoretical technical possibilities for software modifications and we will not speculate about possible application strategies of the OEMs. Any questions as regards possible application strategies would have to be addressed to the vehicle manufacturers.

It is unclear what is meant by "software modification".

In general, all physical functions of the engine are controlled by the effect of the "software" – meaning the logical link – in conjunction with the "calibration".

A simplified example: The engine's idle speed can be set based in part on the coolant temperature. When the coolant temperature rises, the engine's idle speed is lowered via a functional link. This ensures that the engine can reach its operating temperature as quickly as possible (and therefore runs in its typical working range), but runs optimally in terms of "ignition failures" when it is cold. In this process, the thresholds for temperatures or the temperature range in which the idle speed is changed are determined only by entering the temperature values, i.e. by way of calibration. The changes to idle speed and idle speed regulator are achieved by these logical links, also called functionalities.

This example shows that, in many cases, the software (in terms of the logical link) by itself has no functions yet. In these cases, it is only when the application data (= adaptation data with which the logic provided by the software is adapted to the specific engine or vehicle) has been entered that the software is given a function.

A function contained within the software can also be calibrated neutrally by way of the corresponding calibration so that the function has no effect at all.

Ultimately, through interaction of functional logic (software) and its adaptation by entering data (calibration, application respectively) almost any effect can be configured.

The connection for example between increased performance and higher emissions as suggested in the latter part of the question may exist but is by no means inevitable.

Several, in part opposing, goals are to be achieved simultaneously in the steering of the engine technology and of the exhaust gas treatment technology, for example, reduction of emissions with differing emissions limit values (NOx, CO2, HC, particulates, ...), low fuel consumption, vehicle safety, engine protection, durability of the components used, performance of the engine/vehicle. For example, reduction of certain emissions may result in an increase in other emissions or fuel consumption.

We understand the question about "observed gaps for NOx und CO2 emissions" to be a question about the "deviation between type approval result and street measurement".

In our opinion, the deviations discovered between EC-type approvals and street measurements may have different causes and need to be evaluated case by case. Causes may be:

(1) physically necessary and therefore inevitable differences in particular operating points and operating conditions
(2) impact of environmental conditions
(3) process-related influences that result in deviations between real driving and the depiction of real driving on a roller test bench

On (1)

In general, the drive cycles defined in the EC-type approval and other test conditions are designed to produce similar and repeatable results. The driving style is therefore defined by the drive cycle with a narrow tolerance during the test, and other test conditions such as ambient temperature, etc. are predefined and cannot be changed.

Necessarily, the test conditions during EC-type approvals on roller test benches in enclosed buildings necessarily differ from those in real traffic. Measurements in real traffic also show considerably higher variations than measurements under type approval conditions.

Examples of physically necessary differences which generally have inevitable effects on exhaust emissions and CO2 (respectively fuel consumption) are driving uphill (which is depicted neither in the NEDC (New European Driving Cycle) nor in the new cycle WLTC) and differing acceleration rates (often higher acceleration rates in particular compared with NEDC in real traffic). The physical consequence of the influence on consumption is the direct result of the energy balance since more energy is needed during greater acceleration and driving uphill. Consumption and CO_2 emissions will therefore increase.

The influence on emissions performance is somewhat more indirect but also physically inevitable: Higher energy consumption when driving uphill or for faster acceleration creates higher pressures and temperatures in the combustion chamber, both of which contribute to increased creation of nitrogen oxide resulting in increased emissions from the engine. This effect can be reduced to a great extent by after-treatment of exhaust gases downstream of the engine.

On (2)

Environmental conditions also have physically necessary effects on consumption and emissions. For example, at colder outside temperatures, the engine takes longer to warm up than is the case at the predefined room temperatures during type approval test. Due to factors such as greater engine friction, the longer warm-up phase results in corresponding greater (CO_2) generation.

On (3)

The current EC-type approval test describes driving conditions with very moderate accelerations and, for example, without significant electrical loads, such as radio or heated seats. Real driving conditions often deviate from these conditions.

Deviations in the test results would still have to be expected even if the type approval measurement was repeated on the street with the exact same driving profile on an even street and, for example, without additional electrical loads. This is to a large extent because the replication of driving resistances on the street currently has a relatively large tolerance and much room for optimization. This fact is known and will be neutralized to a large extent as part of implementing the new drive cycle WLTC which has substantially more precise definitions for the processes to set loads and conduct the tests. The future Real Drive Emissions (RDE) requirements are expected to result in considerable improvements in this area.

4	The components which are now the centre of a probe into rigged emissions were supplied by Bosch. Bosch designed the software to be used in testing applications and apparently it made clear to VW that the code would not be legal for production vehicles. Could you please tell what the purpose of such software is? Why it was designed in the first place? How is it used in testing applications?

As is widely known, since September 2015, authorities in the U.S., Germany, and other countries have been investigating possible legal violations with regard to emissions from diesel vehicles, including those made by VW.

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Bosch takes the allegations of manipulation of diesel software very seriously. Because of its role as a supplier, Bosch launched its own internal investigation immediately after learning of the allegations against VW. This is an ongoing process. Bosch is also in constant dialogue with the relevant authorities.

We cannot comment on individual details of the investigation or on our cooperation with the authorities.

We therefore trust you will understand that we cannot comment further on this issue.

5	Since it has been revealed that the defeat device software was produced by Bosch, and apparently you knew already in 2007 that its use to manipulate road tests would be illegal and warned Volkswagen about it, did you already have a clear idea then that that was exactly how Volkswagen would use it? Have you sold the same or similar software that makes defeating possible to big car manufacturers other than the Volkswagen Group and if so, did you give the same warning to those as well? While it may not have been illegal for Bosch to sell these kind of device software, but you nevertheless have been aware that it is illegal for example for Volkswagen to use your devices to manipulate road tests, where you not at all concerned about what it would do to your reputation, if and when car manufacturers were caught? What about the current software that you sell: have you been able to change it in a way that defeating is not possible any longer or is it still up to the buyer how it chooses to use it?

To begin with, we would like to refute the various statements and assessments contained in the question. Unfortunately, we are unable to comment on the facts that are the subject matter of currently ongoing investigation proceedings. In regard to these topics, Bosch is cooperating with investigative authorities.

6	In a previous EMIS hearing, the AECC argued that modern catalyst technology (emissions after-treatment after EGR) is fully functional-independent of ambient temperatures. Do you think it would be possible to ensure a correct functioning of abatement systems without intervening by switching them off at particular ambient conditions?

We would like to start by pointing out that Bosch itself is not a manufacturer of catalysts.

We do not agree with the absoluteness of the statement that the entire function of emissions after-treatment or even of the catalytic converters was "fully independent" of the ambient temperatures. In a cold environment, it is a physical necessity that there is increased energy discharge from the exhaust system into the environment (higher temperature differences). As a result, one can generally expect that somewhat lower temperatures set in in the catalytic converters, too. Since the catalytic converters have to reach a certain temperature level for maximum efficiency (significantly higher than "light-off"), the catalyst function may definitely be reduced, and at very high temperatures its efficiency may also be reduced.

However, it is correct that this effect is not the same as "shutting off" the catalytic converter.

Generally, emissions can be reduced efficiently in all ambient conditions occurring with relevant frequency.

7	In your professional opinion, why is there such a wide divergence of temperatures at which pollution controls are switched off by car manufacturers, with reported figures varying from below 17° to below 5°?

Since we do not know the details of the application strategies and motives of the individual manufacturers, we are unable to comment on them.

Generally, it can be said that, in certain driving situations, a correction to the exhaust gas recirculation (EGR) function depending on the ambient temperature might be reasonable. Such correction might be done, for example, by reducing the EGR cooler effect, possibly also by shutting off the cooler, or by switching from a so-called low-pressure EGR to a high-pressure EGR.

8	Do you produce EGR systems with different type and quality of materials/components and of different durability as regards the EGR operation in cold ambient temperature or high engine out temperatures? Do the EGR equipment you produce have safety limits as regards ambient air temperature or engine out temperature? If yes, is it possible to install additional equipment to ensure the EGR can be operational under all normal use? Do OEMs order EGR equipment of different quality and durability, for the same type of vehicles they sell on the US and EU markets? And within the EU market?

Bosch does not produce any EGR systems.

9	Regulation (EC) No 715/2007 states in its Article 4 that the tailpipe and evaporative emissions must be effectively limited throughout the normal life of the vehicles under normal conditions of use. How would you define "normal conditions of use"? Under which conditions do you undertake your testing, for example of the Common Rail technology? As soon as real drive emission tests are introduced, what conditions (such as air temperature) can be seen as extreme and therefore not admissible?

We are unable to comment on the legal assessment of the term "normal conditions of use" as referred to in Article 4 of Regulation (EC) No 715/2007. This question must be addressed to the vehicle manufacturers to whom this regulation is applicable in the context of the EC-type approval procedure.

We assume that the RDE requirements insofar as described in the adopted Packages 1+2 can be fully complied with ($t_{amb.}$ = -7…+35°C, elevation up to 1300 m). In connection with the other boundary conditions described in Package 1+2, more than 95% of the actual driving in diesel passenger cars occurring in the EU will thus be covered, according to our experience.

As to the question regarding Bosch components, using common rail as an example:

The permissible ambient temperature range for Bosch's current injection components is generally -40°C … +140°C. This is subject to the condition that the components must be fully operable at temperatures from -35°C … +120°C, and "survive" the remaining temperature range.

In concrete terms, this means for example on the "cold end":

The injection system is configured for engine starts at temperatures as low as -35°C (whether the engine actually starts will, in addition, depend on other boundary conditions such as starter, fuel, and so on). Full system functionality is to be ensured at temperatures as low as -20°C.

Start attempts are technically permissible at temperatures as low as -40°C without any damage being expected to occur to the injection system components. However, reliable starting cannot reasonably be expected in this range of temperatures.

10	On board diagnostic systems (OBD) are important to control emissions in vehicles. It seems that these systems do not record when emission limit values are exceeded. Otherwise, drivers and car dealerships could have been notified in the dashboard of their cars or would have been able to read out the measurements and would have noticed that emission limit values were not respected. Why was this feature not programmed into the software?

The purpose of the OBD system is to detect and identify faulty emissions-relevant components and systems. The OBD system does not serve to control emissions, but to monitor selected emissions-relevant components. According to statutory requirements, qualification is achieved by detecting individual faults in the OBD test procedure/cycle. Detection is accomplished, for example, by evaluating sensor signals or signal models in the control unit. This means that emissions are not measured. Instead, the proper working condition of selected components is checked.

11	Modern cars and their components are largely controlled by software. For the moment, software is not part of type approval, in-service-checks, in-production-conformity-checks or general inspections. Do you see any reason - be it technical or else - why software should remain excluded from those tests? Concerning engine control software: how difficult is it to re-engineer or manipulate that software? In what ways can "cheat-codes" be integrated and hidden/disguised in such software?

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Software is indeed key to the functioning of many complex automotive components and systems. This is also true of systems that are safety-relevant (e.g. electronic stability control) or emissions-relevant (e.g. exhaust gas treatment systems). We believe that additional clarification of the existing rules could prove worthwhile especially in the area of exhaust emissions. When setting regulatory requirements in this area, the purpose of such requirements should be kept in mind, i.e. preventing that software inappropriately reduces emissions reduction performance. Given the complexity of modern engine control units (ECUs), disclosure of the entire software would probably not serve this purpose. Disclosing the thousands of programs, tens of thousands of variables and hundreds of thousands of lines of source code of each individual ECU would present the type-approval authorities with enormous challenges in terms of both effort and capacity, which is why the effectiveness and meaningfulness of such a measure seems questionable. Moreover, disclosing the entire software would make proprietary know-how of ECU manufacturers available to competitors. Therefore, Bosch recommends an approach where OEMs have to disclose information on their emissions control strategy, similarly to the practice in the U.S. In the U.S., auxiliary emission control devices (AECD) have to be disclosed and their use justified to the Environmental Protection Agency (EPA) / California Air Resources Board (CARB). This is handled by the automobile manufacturers. In any case, a reasonable level of IP protection must be ensured.

11.2 Concerning engine control software: how difficult is it to re-engineer or manipulate that software? In what ways can "cheat-codes" be integrated and hidden / disguised in such software?

Bosch will not answer questions relating directly or indirectly to the ongoing investigations (see preliminary note).

First, we would like to summarize once again the connections and distinctions as described in the above answer to question 1:

ECU software developers distinguish between programming and calibrating the code. Functionality is ensured by combining the code and calibration data. The code of an ECU is comprised of software code of the supplier and customer-specific code (i.e., code developed on behalf of the OEM and code provided by the OEM that has been implemented by the OEM itself, by other first tier suppliers or by software service providers). Bosch develops code ordered by the OEM in compliance with the requirements of the OEM. Code provided by the OEM is merely adapted by Bosch within the status of the entire program. Calibration is largely performed by, or on behalf of, the OEM.

It is possible to protect the software (code and data) of state-of-the-art generations of ECUs from third-party manipulation using state-of-the-art automotive technology. Bosch's platform solution offers security functionalities with which any unauthorized manipulation of programs or data (e.g., fitting of cheat code) can be prevented or detected. Among other things, appropriate mechanisms prevent that content is read or written over; access keys (so-called software signatures) prevent the installation and activation of manipulated software and diagnostics access is deactivated or adequately protected.

The above security features are recommended by Bosch. However, ultimately, it is the OEMs who decide what safeguards are active in the control unit.

12	Bosch is an automotive supplier that serves both the European and American markets. Do you produce ECTs for diesel vehicles for use in both markets? Are these technologies identical? If so, why are there such discrepancies in what the cars emit in Europe and in the US if they use the same technologies? Why are cars in the US able to meet more stringent NOx limits compared to the EU?

Bosch sells ECUs for vehicles suitable to be sold in Europe as well as ECUs for vehicles suitable to be sold in the U.S.

Bosch is unable to comment on the engine strategies pursued by the OEMs.

Generally, we can comment on the exhaust emissions standards as follows:

There are differences between exhaust emissions standards applicable in the U.S. and in the EU. For example, the current test cycle in the U.S. (FTP75) is much more challenging in regard to driving dynamics than the European NEDC. At the same time, much lower CO emissions are permitted in Europe than in the U.S.. A manufacturer in the U.S. can select from a number of limit value-related formulas (given compliance with a fleet's average value), which differ considerably in their requirements.

The element of driving conditions deviating from the "standard cycle", which will be addressed in future by RDE in Europe, has already been addressed in the U.S. for more than 10 years with additional testing on the roller test stand.

In future, i.e., after the conversion to WLTP has been completed and RDE has been instituted, the test conditions in the U.S. and EU will be much more similar. The element of the U.S. additional test cycles will be covered in Europe by the RDE requirement.

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