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PEMS BASED IN-SERVICE TESTING: PRACTICAL RECOMMENDATIONS FOR HEAVY-DUTY ENGINES/ VEHICLES

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Abstract :

This guidance document is a JRC technical support document, contributing to the development of best practices with PEMS. It shall be used primarily for the preparation, the execution and the follow-up of the emissions tests with PEMS on road heavy-duty vehicles (HDV) equipped with conventional combustion engines (gasoline, diesel, CNG, LPG).

The document does not substitute either the operation manuals of the instruments or safety rules and recommendations nor official regulatory texts regarding in-use emissions tests with PEMS. The intention of this guide is to clarify some operational points of the PEMS procedure and to provide a guide for the application of PEMS inside and outside the regulatory context (In-Service Conformity Testing of heavy-duty engines as foreseen in Regulations 582/2011 and 64/2012).

Acknowledge.

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1. Introduction

This guidance document is a JRC technical support document, contributing to the development of best practices with PEMS. It shall be used primarily for the preparation, the execution and the follow-up of the emissions tests with PEMS on road heavy-duty vehicles (HDV) equipped with conventional combustion engines (gasoline, diesel, CNG, LPG).

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The guide is intended for any type (types of tests listed below) of PEMS test on heavy-duty vehicles/engines. Each section therefore highlights what is specific to ISC EURO VI PEMS testing by introducing types of tests:

- ✓ Type A - Development of emissions factors
- ✓ Type B- Road vehicle technology assessment (A to B comparison of vehicles with different engine or emissions control technologies on the same road, e.g. for a Retrofit)
- ✓ Type C - Heavy-duty engine in-service conformity (ISC) testing

● Mandatory // ○ Recommended // ■ Ad-hoc rules must be developed

The installation and the operation of the instruments shall always be conducted in accordance with the local health and safety regulations.

2. List of acronyms

Acronym	Definition
CH4:	Methane gas
CO:	Carbon monoxide gas
CO2:	Carbon dioxide gas
ECU:	Engine Control Unit
EFM:	Exhaust Flow Meter
ESC:	European Steady state Cycle
ETC:	European Transient Cycle
FID:	Flame Ionisation Detector
FS:	Full Scale
GPS:	Global Positioning System
HDV:	Heavy Duty Vehicles
I/O:	Input / Output
LDV:	Light Duty Vehicle
NDIR:	Non-Dispersive Infrared analyser
NDUV:	Non-Dispersive Ultraviolet analyser
NO:	Nitric oxide gas
NO2:	Nitric dioxide gas
NOx:	Nitric oxides gases
O2:	Oxygen gas
PEMS:	Portable Emission Measurement System
PID:	Vehicle data Parameter Identifier
PM:	Particulate Matter
SAE:	Society of Automotive Engineers
THC:	Total Hydrocarbons

3. Portable instrument for gaseous emissions

ITEM	Applicable Requirements or recommendations	A	B	C
Portable measurement equipment	Regulation 582/2011, Annex II, Appendix 2	●	●	●

The PEMS systems to be used for the official HDV testing have to comply with general requirements, serving the regulatory purposes and detailed as below:

- To be small, lightweight and easy to install;
- To work with a low power consumption so that tests of at least three hours can be run either with a small generator or a set of batteries;
- To measure and record the concentrations of NOx, CO, CO2, THC, gases in the exhaust;
- To record the relevant parameters (engine data from the ECU, vehicle position from the GPS, weather data, etc.) on an included data logger.

4. Description of an in-use emissions test with PEMS [What shall I measure and how]?

ITEM	Applicable Requirements or recommendations	A	B	C
Test procedure - Test parameters	Regulation 582/2011, Annex II, Appendix 1 - Section 2.2	○	○	●

5. Instrumentation performance requirements [Which instruments shall I use, depending on the purpose?]

5.1. Gaseous Emissions[1]

ITEM	Applicable Requirements or recommendations	A	B	C
Equipment specification	Regulation 49, Annex 4 - Section 9.2 (Linearity) - Section 9.3.1. (Analyser specifications) - Section 9.3.2. (Gas analysers)	○	○	●
Equipment verification	Regulation 49, Annex 4	○	○	●

[1] Reference 1: UNECE Regulation 49, Annex 4, Section 9

	- Section 9.3.3. (Gases) - Section 9.3.4. (Leak check) - Section 9.3.5. (Response time check of the analytical system) - 9.3.6. to 9.3.11, only if applicable			

This section gives an overview of the test parameters to be measured, together with the associated authorised measurement techniques. The table lists the minimum set of parameters to be measured during a test for HDV. The parameters have been categorised into 4 families, namely:

- Exhaust gas;
- Engine;
- Vehicle;
- Ambient conditions.

Some parameters below are shown as 'secondary', as they do not directly provide input for the test verifications and the emissions calculations. Their documentation is however recommended for the development of the test protocol, and to check if the vehicle behaves 'normally' during a test.

The 'mandatory' or 'recommended' character is fully established for HDV testing, according to the protocol defined in the European regulation[2].

● Mandatory - ○ Recommended

Parameter	***Measurement technique***	***Alternative techniques***	
HC Concentration	FID Analyser	None	●
CO Concentration	NDIR Analyser	None	●
CO_2 Concentration	NDIR Analyser	None	●
NO_x Concentration	CLD or NDUV Analyser	None	●
Exhaust Mass Flow	EFM	Fuel or Air flow sensor + calculated A/F[3]	●
Exhaust temperature	Sensor	ECU	●
Engine Torque	ECU		●
Engine Speed	ECU or		●

[2] Commission Regulation (EU) No 582/2011 of 25 May 2011, Annex II, Appendix 1.

[3] It is required in the HDV protocol for data consistency checks.

	Sensor		
Coolant temperature	ECU		●
Intake air temperature	ECU or Sensor		●
Fuel rate	ECU or Sensor		●
Intake air flow rate	ECU or Sensor		○
Fuel Temperature	ECU		○
Boost Pressure	ECU		○
Oil pressure	ECU		○
Fault status	ECU		○

Ground speed	GPS	ECU	●
Latitude	GPS		●
Longitude	GPS		●
Altitude	GPS		○
Road grade	Inclinometer		○

Ambient humidity	Sensor		●
Ambient temperature	Sensor	ECU	●
Ambient pressure	Sensor	ECU	●
Head wind	Sensor	ECU	○

5.2. Particulate emissions

ITEM	**Applicable Requirements or recommendations**	**A**	**B**	**C**
Equipment specification	Regulation 49, Annex 4 - Section 9.2 (Linearity) - Section 9.4 (Measurement and sampling system) - Section 9.4.4 (Particulate sampling filters)	○	○	●
Equipment verification	Regulation 49, Annex 4 - Section 9.4.6 Special requirements for partial flow dilution system	○	○	●

The Particulate matter (PM) measurement requires the use of a PEMS PM instrument. A set of data will be produced by this instrument in addition to the data

acquired and produced by the gaseous PEMS. Parameters required to perform the PEMS PM analysis are listed in the following table.

Parameter	***Measurement technique***	***Alternative techniques***	
PEMS PM RT signal	PM analyser	None	●
Dilution ratio	PM analyser	None	●
Filter mass (PM on filter)	PM analyser	None	●
PM mass (g/test)	Post-processed data	None	●
Exhaust Mass Flow	EFM	Fuel or Air flow sensor + calculated A/F[4]	●
Exhaust temperature	Sensor	ECU	○

6. Test preparation [How do I select and prepare the vehicle for the test?]

6.1. Basic test set-up

The main components of the PEMS can often be installed as such:

- The main units[5] containing the components to measure gaseous emissions and/or PM are best installed in the cabin of the vehicles or at least in "semi-protected" environment (boxes), to avoid contamination, excessive vibrations, heating of the equipment or shocks.
- The exhaust flow-meters (in case of direct exhaust flow measurement) are attached to the vehicle's tailpipe;
- The ECU interface modules are connected to the appropriate vehicle interfaces, typically a CAN bus;
- GPS and weather station are installed on the body of the vehicle/machine.

Further recommendations for the installation of the various elements are detailed in chapter **Error! Reference source not found.**.

6.1.1. Engine, vehicle and ambient parameters from the vehicle interface

The required engine parameters must be obtained from the vehicle network. The measurements performed by different sensors installed on the engine and/or values calculated by the vehicle ECU are broadcasted and can be accessed through such a network.

[4] It is required in the HDV protocol for data consistency checks.
[5] Main units of gaseous or PM measurement instruments

Various hardware and software protocols have been established by the Society of Automotive Engineers (SAE) to standardise these vehicle interfaces. Two have been considered during the evaluation for the development of the test protocol using PEMS: J1939 and J1708.

The J1939 standard provides a torque estimator for diesel engines through the values of:

- Actual engine percent torque (%)
- Engine friction torque (%)
- Maximum engine torque (N.m)

The fuel rate can also be re-calculated from:

- Actual engine percent torque (%)
- Engine speed (rpm)
- Mass of fuel injected per stroke (g)

The assumptions behind the above calculations i.e. the linear relationship between torque and injected fuel quantity is only applicable to diesel engines.

Important Remarks:

- The choice of standards to communicate with the ECU implies no judgement on the quality of data.

- The choice of a standard is not exclusive: other standards can be considered by the users to address specific requirements, for instance ISO27145-Standard (WWH-OBD).

- There are differences in the implementation of the same protocol by various engine and vehicle manufacturers, which may impose a special set-up of the instrument used to record the ECU data.

- The protocol performance specifications may affect time-alignment procedures that are performed during post-test data reduction, as the sampling rates may vary for the different parameters coming from the ECU.

- Methods to derive torque and fuel rate from other types of engines (Otto engines such as Compressed Natural Gas (CNG) engines), are not part of the present document.

6.2. Vehicle selection and preparation

Performance/maintenance inspections of the test vehicle have to be performed prior to the installation of the PEMS. Any identified problem – once solved – must be documented.

The safety inspection of the vehicle must be conducted prior to any test. Some safety related issues are for instance:

- The equipment mounted outside for road vehicles, e.g. the exhaust flow meter on the vehicle tailpipe.
- The routing of tubes, cables and the heated line.
- The installation of pressurised gas cylinders, e.g. for the FID fuel.

The pre-test vehicle checks and safety inspections shall be recorded in the appropriate data sheets.

7. Test conditions [Under which conditions – ambient, route, payload – shall I test the vehicle?]

7.1. Ambient conditions

ITEM	Applicable Requirements or recommendations	A	B	C
Range of ambient conditions	Regulation 582/2011, Annex II, Section 4.2	○	○	●

7.2. Vehicle conditioning, fuels, lubricants, reagents

ITEM	Applicable Requirements or recommendations	A	B	C
Vehicle conditioning (Engine coolant temperature)	Regulation 582/2011, Annex II, Section 4.3 or ad-hoc requirements	■[6]		●
Fuel, lubricating oil, reagent	Regulation 582/2011, Annex II, Section 4.4 or ad-hoc requirements	■[7]		●

7.3. Operational requirements: Test routes and payloads

ITEM	Applicable Requirements or recommendations	A	B	C
Vehicle payload	Regulation 582/2011, Annex II, Section 4.1 or ad-hoc requirements	■[8]		●
Trip requirements	Regulation 582/2011, Annex II, Section 4.5 or ad-hoc requirements	■[9]		●
Operational requirements	Regulation 582/2011, Annex II, Section 4.6	○	○	●

[6] Vehicle 'cold start' emissions can be measured
[7] Use of market fuels
[8] Vehicle payload should be representative for the real vehicle usage - or tests can be conducted with different payloads
[9] It is recommended to test vehicles always on the exact same test routes, provided that they are representative for the average vehicle usage. Indicators should be used then to check the repeatability of the tests on these routes (e.g. average vehicle speed)

7.4. Recommendation for the test route selection

7.4.1. Route composition requirements for a Type C test (ISC)

- In the EU Directive 582/2011:
    - *Paragraph 4.5 Annex defines the requirements for the ISC PEMS trip composition:*
        - ISC PEMS route shall consist **of urban driving followed by rural and motorway driving according to the shares specified in points 4.5.1 to 4.5.4** of the same Annex (and repeated below).
        - A tolerance on target value **+/-5% applies to the urban, rural and motorway shares**
        - Vehicle speed ranges for heavy-duty vehicles: **Urban (0 - 50km/h), Rural (50 - 75km/h), Motorway (above 75km/h)**
        - Route composition for M1/N1/N2/M2/M3 vehicles: 45% urban, 25% rural and 30% motorway
        - Route composition for M2/M3 class I, II or A vehicles: 70% urban and 30% rural
        - Route composition for N3 vehicles: 20% urban, 25% rural and 55% motorway
        - Other parameters that may serve as additional guidance: **a) accelerating 26.9% of the time, b) decelerating 22.6%, c) cruising 38.1% and d) stop (0km/h) 12.4%**
    - *In addition to the trip requirements, the paragraph 4.6.5 Annex II* defines the length of the trip in terms of the work performed by the engine:
        - "The minimum test duration shall be long enough to complete five times the work performed during the WHTC or produce five times the CO2 reference mass in kg/cycle from the WHTC as applicable"

7.4.2. Route selection methodology to meet the minimum engine work requirement

In practice, the route selection process must ensure that the above requirements are met after the test. To achieve an efficient route selection process and to avoid an iterative and costly learning process, the following methodology may be used.

The methodology relies on on-road engine torque data to be able to estimate the approximate duration of the trip, it results in a good estimate of a route characteristics. However, uncontrolled elements such as traffic or variations in average speed depending on weather shall be taken into account during the real tests using good engineering judgement (i.e. lowering average speed to be taken into account for the calculations or allowing more time per share) the procedure is the following:

a. Step 1 – According to the roads to be considered for the test, the method base itself on a preliminary test on which the vehicle needs to be driven in constant speed for a period of 3-5minutes. The constant speed required depends on the road taken and the share that it belongs to, for example, if the road is an urban road, the vehicle should be driven on a constant speed/engine rpm/gear condition (as possible within the constraints of any uncontrolled element) within the urban speed range (0-50 km/h). This process has to be repeated for the urban, rural and motorway driving conditions, always with a constant speed that indicates better the expected average speed on the chosen road. For example, an estimation of the speed of the following roads intended to be used for a test is shown below (Figure 7-1).

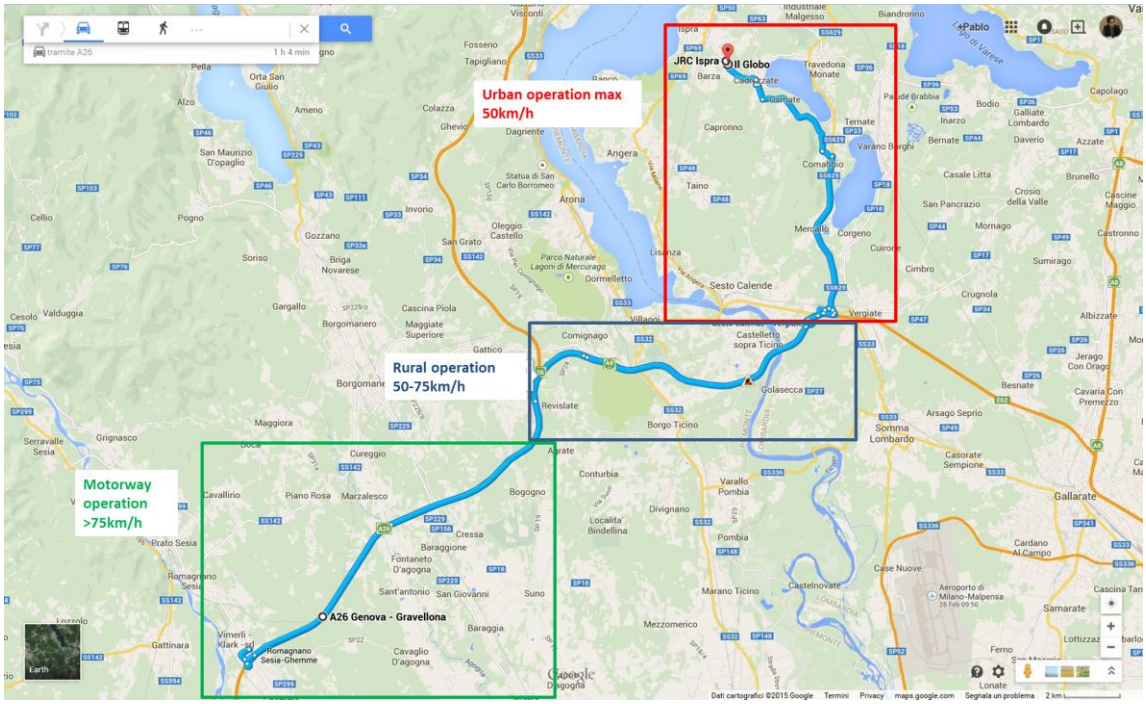


Figure 7-1

b. Step 2 – The preliminary test can be run at 40/50km/h (urban), 60/70km/h (rural) and 90km/h (motorway) representative speeds for 3- 5 minutes of steady state conditions operation. It can also be ran at two different gear sets to observe different engine speed (which will entail higher/lower torque) to be able to define the test strategy. During the preliminary test the following ECU parameters need to be monitored and logged:
   i. Engine speed [rpm]
   ii. Torque, in any form: torque[Nm] or actual/friction percent torque[%], load[%] as long as the torque in Nm can be calculated from the variables
   iii. Vehicle speed [km/h]
   iv. Gear

c. Step 3 – Once the parameters have been logged, a post processing of the data is required to have average values for engine speed and torque for the steady state conditions. Table 7-1 shows different speed/torque combinations depending on gear, speed and engine speed (in this case, actual/friction torque combined with the maximum indicated torque was used to determine the torque in Nm to be used in the next section).

Table 7-1 Operational data of the vehicle use in this example

Gear	Speed [km/h]	Act torque [%]	Friction torque [%]	Engine speed [rpm]
3rd gear	40	20.72	13.17	2756.30
4th gear	40	19.51	11.00	1890.33
4th gear	50	17.00	12.00	2290.45
5th gear	70	31.24	12.00	2352.75
6th gear	75	38.15	11.00	1988.35
6th gear	90	42.77	12.05	2399.60

d. Step 4 – Using the following general power equation, the power can be calculated for each constant speed as shown in Table 7-2:

$$P = \frac{M \cdot n}{9549}$$

Where:
P = power [kW]
M= torque [Nm]
n = engine speed [rpm]

Table 7-2 Operational data of the vehicle use in this example

Gear	Speed [km/h]	Act torque [%]	Friction torque [%]	Engine speed [rpm]	Power [kW]
3rd gear	40	20.72	13.17	2756.30	8.71
4th gear	40	19.51	11.00	1890.33	6.74
4th gear	50	17.00	12.00	2290.45	4.80
5th gear	70	31.24	12.00	2352.75	18.96
6th gear	75	38.15	11.00	1988.35	22.62
6th gear	90	42.77	12.05	2399.60	30.88

e. Step 4 – Reference work is required to calculate the amount of work (5 x WHTC work) to be completed during the trip. It is also advisable to forecast a time frame in which is desired to complete the test (usually 2.5-3 hrs).
The following example (Table 7-3) shows a vehicle which has a reference work of 10kW; in this test the desired time of completion is 3hrs.

Work on WHTC [kWh]	10
Work required for ISC [kWh]	50

Table 7-3 Calculation of duration of the trip dependant on the cumulative work

N2	%	Time [min]	Total time [sec]	Power [kW]	Speed [km/h]	Cumulative Work [kWs]
Urban	45	81	4860	4.80	50	23314.64
Rural	25	45	2700	22.62	75	61065.51
Motorway	30	54	3240	30.88	90	100046.07

Total Work performed by route: 51.23 kWh

As it can be seen, by defining the duration of the test and using the trip shares depending on the type of vehicle the minutes per share can be determined, further to this, the power calculated based on the constant speed test is used to calculated a cumulative work which comes from multiplying the seconds (of each share) times the power (at constant speed). By obtaining the cumulative power and adding it, the work [kWh] can simply be obtained by dividing the resulting addition of the cumulative power of the shares by 3600.

8. Test Protocol [How shall I conduct the test?]

8.1. Installation of instruments (Detailed by PEMS component)

Source 1: Appendix A – Section 6.2

ITEM	Applicable Requirements or recommendations	A	B	C
Test procedure - Installation of the measuring equipment	Regulation 582/2011, Annex II, Appendix 1 - Section 2.4	○	○	●

All STEPS under the present paragraph are to be made for every **Series of Tests**

8.1.1. Installation of the PEMS main units

It is recommended to install the main unit in the cab of the test vehicle to limit vibrations and movements and to keep the instruments in an environment where temperature is semi-controlled through the vehicle air-conditioning system. Temperature is the parameter that affects the most the stability of the analysers.

Keeping access to the test equipment is necessary – either for the installation or for the checks between the tests.

The main unit should be secured with load straps (Figure 8-1).

The mounting location should be chosen so that the unit's cooling fans are unobstructed. Sample stream exhaust lines should be routed outside of the vehicle's cab in order to prevent contamination of the vehicle cabin environment; other possibility is the installation of the equipment in other position to avoid contamination of the cabin environment. These lines should be routed in such a manner as to prevent pinching or rupturing and should be strain-relieved in order to prevent damage due to vibrations.

Figure 8-1 Example of secured installation of PEMS instrumentation

8.1.2. Exhaust Flow Meter

8.1.3. Selection of the exhaust flow meter range

To select the exhaust flow meter (EFM) range, please refer to the user's manual

8.1.4. Installation of the exhaust flow meter

The EFM must be attached to the vehicle's tailpipe. Different solutions are available, depending on exhaust configuration and expected exhaust temperatures.

Solution 1 (recommended): Clamping and fixation point (Figure 8-2 and Figure 8-3)

The first solution is to weld two identical flanges on the tailpipe and on one end of the EFM. These two flanges should then be clamped whereas a sealing material must be used to minimize exhaust leakage. This solution is safe, makes easy the installation and possible re-installation of the EFM and also eliminates the risk to see the alignment of the Pitot tubes modified because of vibrations.

Solution 2: Silicon tube, collars and fixation point

Another solution is to use silicon tubes, secured with collars.

A fixation point is always needed to secure the EFM

To prevent heating and possible damages, the outlet of the EFM should not be directed towards a tyre or other vehicle components.

Remarks:

- *The Pitot tubes must be correctly aligned, as shown in Figure 8-4.*
- *The clamps and the mounting of the EFM should be visually inspected before the initial test cycle and between each subsequent test cycle.*
- *The Pitot sensor should be placed between two pieces of straight tube whose length should be at least 5 times the Pitot diameter (upstream and downstream).*
- *The EFM shall be placed after the vehicle silencer, to limit the effect of exhaust gas pulsations upon the measurements.*

- *It is recommended to insulate the outlet of the Pitot tubes to limit water condensation.*
- *The EFM, once mounted should not prevent the access to important vehicle functions such as the spare wheel, fuses, etc.*
- *For dual exhaust configurations, a Y-connection shall be implemented so that the entire exhaust stream is sampled by the exhaust flow meter test section.*
- *The thermocouple to measure the exhaust temperature is part of the EFM.*
- *According to instrument manufacturers' specifications, EFM can stand exhaust temperatures of at least 500°C in continuous operation, if properly maintained.*
- *Exhaust clamps as seen in* Figure 8-2*, can damage the EFM if over tightened and/or due to expansion of the EFM. If the EFM is damaged, it has to be sent back to the instrument manufacturer for calibration, with the consequent cost and even more important down time of the PEMS system.*
- *If necessary the Flow Meter Coefficients of the selected EFM should be entered in the EFM tab in the appropriate software. This is very important as it is easily forgotten and can make a big difference in the calculated exhaust mass flow.*

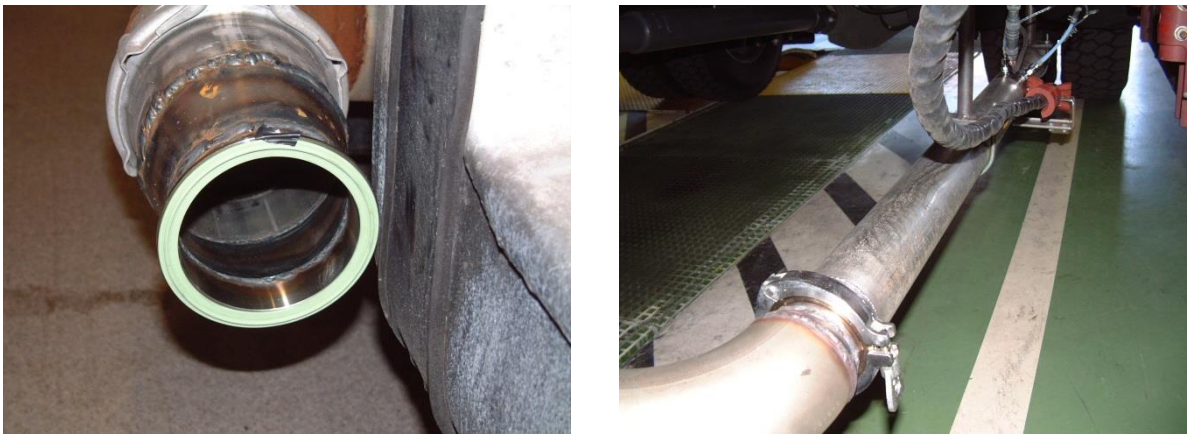


Figure 8-2 EFM Clamping: Flanges on tailpipe and exhaust flow

Figure 8-3 Examples of EFM installations

Figure 8-4 Alignment of EFM Pitot tubes

8.1.5. GPS

8.1.5.1. Mounting the GPS antenna

The antenna should be mounted at the highest possible location, without risking interference with any obstructions encountered during on-road operation. Mounting is accomplished with either a magnetic or fixed mount post (Figure 8-5).

[a] [b]

Figure 8-5 GPS Installation examples for the GPS antenna (picture [a] is an example of a correct installation, while picture [b] corresponds to a WRONG installation)

8.1.6. ECU communication

8.1.6.1. Identification of the ECU communication protocol

8.1.6.2. Preparation of the ECU communication cable

The type of adapter used for each vehicle test should also be recorded, and the appropriate cable prepared.

In many cases, the CAN bus of the vehicle is used to record the ECU data according to standard protocols like SAEJ1939 or J1708. In such a case, a two-pin cable (CAN-high + CAN-low) is sufficient.

8.1.7. Connection and installation of the ECU communication cable

The cable shall be routed in such a manner as to provide minimum interference to vehicle occupants. In addition, the unit should be securely mounted in the cab of the test vehicle in a location that does not permit unnecessary moisture, vibration, or excessive operating temperatures.

8.1.8. Power supply

8.1.8.1. Installation of the power supply

In order to accommodate the power requirements of a complete PEMS system, the following solutions are possible:

- A portable generator set (required for HDV), capable of providing at least 2.5 kW of 12 volts DC or 230 AC power;
- Batteries (silica gel or –better - lithium-ion).
- The power maybe supplied by the internal electrical system of the vehicle as long as the power demand for the test equipment does not increase the output from the engine by more than 1% of its maximum power and measures are taken to prevent excessive discharge of the battery when the engine is not running or idling.

Rechargeable batteries do not offer a great advantage in terms of volume, weight and flexibility. However, they are the only alternative for some applications like city buses or small vehicles, for which the noise and the exhaust gas from a generator would not be acceptable.

The use of a buffer battery between generator and PEMS equipment might avoid power excursions (voltage dips) during operation probably due to the thermal control of the heated line.

The generator set should be installed on the vehicle safely. The grounding strap should be securely attached to the vehicle chassis. Examples are shown in Figure 8-6.

Figure 8-6 Installation examples for the power generators

<u>Remark:</u> The heated probe is responsible for a significant part of the power consumption. For some configurations, cold ambient temperatures and highway driving conditions (forced cooling) may significantly affect the behaviour of the heated probe and its temperature control.

8.1.9. Weather station

8.1.9.1. Installation of the weather station

Install the weather station on the outside of the cab in a location that is shielded from direct air-flow and contamination from debris (Figure 8-7). The location should be as close to the intake air flow as possible. The temperature sensor should be shielded from any warm-up effects like sunshine or hot air coming from the vehicle engine or exhaust.

The ambient absolute pressure transducer shall be installed in the cab of the test vehicle/machine. The mounting location shall be selected such that air motion effects on the sensor are minimized.

Some instruments have a build-in absolute pressure transducer; in these cases an external ambient absolute pressure transducer is not required.

Figure 8-7 [a] Installation example for the weather station. [b] Shielding with aluminium tape

8.1.10. Routing tubes, cables and heated probe

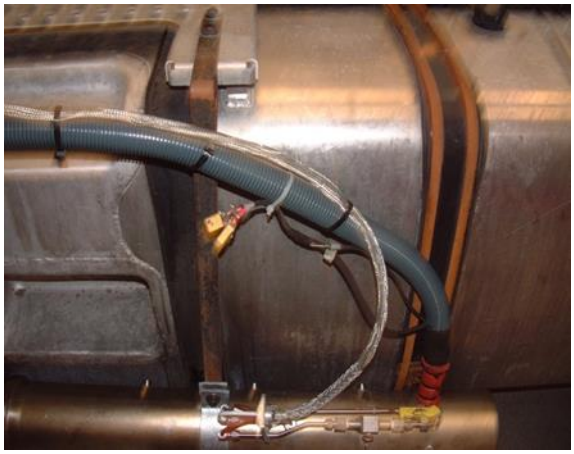
8.1.10.1. Connection of the heated probe (gas analysers)

Connect the inlet of the heated sampling line to the sampling probe port located on the exhaust flow rate measurement tube. Connect the outlet of the heated sampling line to the inlet port on the PEMS exhaust sample conditioning unit.

Any replacement involving a modification of the length of the heated probe should be avoided, due to the associated variations that would be observed in system transport times. It is recommended that the sampling line be routed through side access doors, as shown in Figure 8-8 [a] or through the passenger-side window of the vehicle's cabin.

Make sure that the heated probe is properly insulated, especially at the connection points: EFM and back of the analysers, to avoid 'cold spots' that could lead to wrong emissions measurements, especially HC (Figure 8-8 [b]).

[a]



[b]

Figure 8-8 [a] Routing heated probe through side access doors. [b] Connection of the heated probe on the EFM

8.1.10.2. Connection of other tubes and cables

Connect the different cables and tubes as described in the instructions manuals of the instruments.

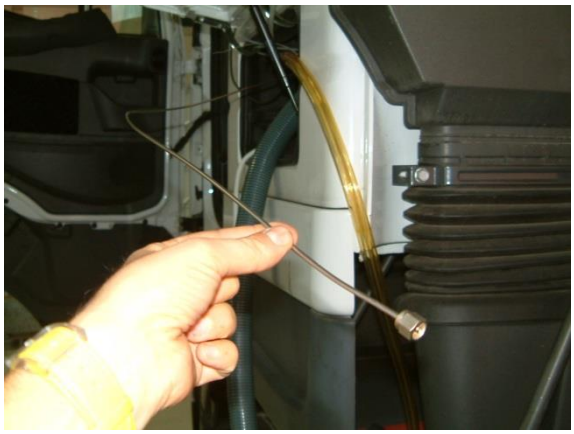
The wiring should be routed in such a manner as to prevent pinching and should be strain-relieved in order to prevent damage due to vibrations and relative movement between vehicle chassis/body components.

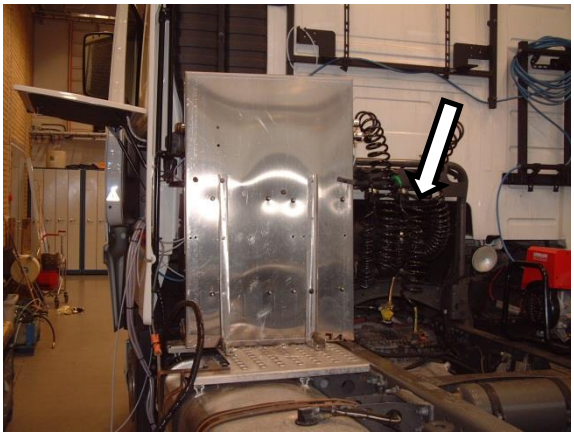
8.1.11. Operation gases

8.1.11.1. Installation of operation gas bottles

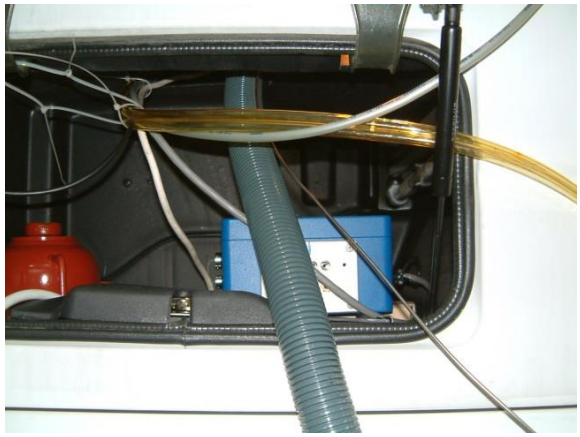
The type of gases depends on the analyser technique: The FID analysers require a mixture of Helium and Hydrogen ('FID fuel') whereas the CLD ones use Oxygen. The quantity of gas required to perform a test depends on the test duration, but small bottles of 5 litres are sufficient for 8 to 10 hours of operation.

Larger bottles (10 or 20 litres) may be used to avoid frequent substitutions: in this case, a storage compartment is needed to secure the bottles. An example is shown in Figure 8-9 [a].





[a]



[b]

Figure 8-9 [a] Example of gas storage (For 3 bottles of 20 litres) [b] Connection and routing of stainless steel tubes for FID fuel

The installation of gas and the presence on the vehicle of pressurised gas cylinders shall in any case be done in accordance with the local health and safety regulations.

The gas storage compartment should not be located into a hot zone, like the exhaust silencer.

Tubes for the FID fuel should be in stainless steel Figure 8-9 [b].

FID fuel bottle: 1 litre bottle, autonomy about 6 hours (which must include warm-up and calibration) – Larger bottles could be used

8.2. Pre-Test Procedures

ITEM	Applicable Requirements or recommendations	A	B	C
Test procedure - Pre-test procedures	Regulation 582/2011, Annex II, Appendix 1 - Section 2.5	○	○	●

8.2.1. Inspection of connections and wirings

8.2.1.1. Check connections and wirings

The check should be performed **every 3 to 5 Tests**

Prior to supplying power, visually inspect and touch all connections to check if they are loose, possibly due to vibrations on non-cushioned vehicle platforms.\

8.2.1.2. Power-up and warm-up

a. Verify the generator fuel tank level or the batteries charge level. This should be performed **every Single Test.**
b. (When using a power generator) **Start the generator**.

This should be done only if the vehicle remains outside. Otherwise, standard 230V electrical power should be used from a building

c. Power up the main units. To be made **every Day** (Better is to keep equipment in stand-by once installed)

Supply power to the emissions analyser components at least one hour prior to testing in order to allow temperatures to stabilize. (On heated FID and heated probe in particular).

d. Power-up main software. To be made **every Single Test**

8.2.2. Calibration and cleaning

8.2.2.1. Check of zero air.

When ambient air is used to zero the analysers, one should make sure that the air is not sampled near the exhaust of a running generator (To be made **every Single Test**).

8.2.2.2. Zero-span of the analysers.

The zero-span of the emissions analysers should be performed using the span-gas concentrations recommended by the instruments manufacturer (To be made **every Single Test**).

For a test scenario in which the vehicle is tested on a roundtrip, the span gas bottles can be stored in the workshop or near the vehicle parking spot, as shown in Figure 8-10.

Remarks:

- *Make sure that pressure regulator is fixed to the bottle.*
- *Only small amounts of span gas are used per test*

Figure 8-10 Calibration gas bottles nearby test vehicles/machines

8.2.2.3. Archiving zero-span data.

Zero-span records must be archived (To be made **every Single Test**)

8.2.2.4. Exhaust flow meter cleaning.

The EFM should be cleaned by purging at the pressure transducer connections with pressurized clean air or nitrogen. This back-flush procedure is used to remove condensation and diesel particulate matter from the pressure lines and associated flow tube pressure measurement ports (To be made **every Single Test**).

8.2.2.5. Exhaust flow meter leak check.

This procedure should be conducted according to the recommendations provided by the instrument manufacturer (To be made **every Series of Tests)**

8.2.2.6. Zero check of flow meter.

To be made **every Single Test**

8.2.2.7. Start the engine.

To be made **every Single Test**

8.2.3. Checks with running engine

8.2.3.1. Check ECU communication.

Check that the system is properly recording ECU "mandatory" data (To be made **every Series of Tests)**.

8.2.3.2. Check that data acquisition storage

Check that data acquisition storage media and backup have sufficient space. (To be made **every Single Test).**

8.2.3.3. Check GPS.

Check GPS signals and GPS status (To be made **every Single Test)**.

8.2.4. Qualification of measurements

8.2.4.1. Qualification of ECU Engine Speed

ECU engine speed broadcasts must be qualified with a secondary measurement device during each PEMS installation. After the secondary measurement device is installed the engine should be operated throughout the engine speed range. Data should be logged using the ECU verification procedure of the PEMS data acquisition program. Any observed inconsistencies between the ECU broadcast data and the measurements made with the secondary technique should be recorded in the pre-test data sheet(s) (To be made **every Series of Tests)**.

8.2.4.2. Qualification of ambient temperature and humidity sensors.

Ambient temperature and pressure measurements must be made with independent devices and compared to pre-test values measured with the weather station of the PEMS. (To be made every **Series of Tests)**

8.2.5. Pre-test runs

8.2.5.1. Verify temperature controllers

Verify that all temperature controllers are set at the correct operating values. To be made **every Single Test.** This should be done at least one hour after 8.2.1.2 (c) or strictly follow the recommendations given by the instruments providers.

8.2.5.2. Spot check.

Log onto the data acquisition computer and start the PEMS data acquisition program. Verify that all pertinent measurement data is being recorded (spot check). To be made **every Series of Tests.**

The following steps (8.2.5.3 to 8.2.5.5) are recommended only for series of tests conducted on the same vehicle.

8.2.5.3. Exhaust measurement at idling.

As a pre-test inspection, the exhaust flow rate measurement pressure transducers' signal and emissions measurement system integrity shall be verified by acquiring data for 30 seconds with the vehicle engine idling. This data should be examined for

any anomalies, and corrective measures should be initiated if any were identified (To be made **every Series of Tests**).

8.2.5.4. Pre-test (Optional).

The test vehicle/machine may be operated during a few minutes. All the data shall be recorded during this procedure and checked. (To be made every Series of Tests).

8.2.5.5. Verification of pre-test data.

The following data screening is recommended (to be made **every Single Test or Series of Tests)**:

- Analysers concentrations: check for the measured ranges, eventual range saturation and negative values;
- Vehicle ground speed, comparing the values from the ECU and from the GPS;
- Exhaust mass flow, comparing the direct measurement of the EFM to a 'backup' value (e.g. the exhaust mass flow recalculated from ECU fuel mass flow and A/F ratio);
- Ambient conditions, comparing the values from the weather station to the ones given by the vehicle ECU.

8.2.6. PEMS PM Pre-test procedures

Some specific PEMS PM procedures must be followed:

- Installation of the cable for the analog output from the EFM to the PEMS PM dilution and sampling system.
- PEMS PM instrument needs to be warmed up to allow the temperature set points specified by the equipment manufacturer.
- PEMS PM software settings for the EFM need to be calibrated.
- A set of filters must be weighted and conditioned (the type fo filters and condtinoning is specified in Regulation ECE49, Annex 4) prior to testing with a PEMS PM instrument. Filters must be kept on their protective cases until positioned on the filter holder.
- Filter need to be positioned on the filter holding system from the PEMS PM equipment with a set of tweezers. Special attention must be put when loading the filter to the holder, any particles collected by the filter if mishandled will influence in the result.

8.3. Test runs

Source 1: Appendix A – Section 6.4

ITEM	Applicable Requirements or recommendations	A	B	C
Test procedure - Emissions test run	Regulation 582/2011, Annex II, Appendix 1 - Section 2.6	○	○	●

Data logging and sampling shall be initiated 60 seconds prior to the start of the on-road test cycle. All measurement data shall be logged continuously throughout the test route and for a period of 60 seconds after the test route has been completed.

8.4. Post-test

8.4.1. Conclusion of a test run

8.4.2. Zero and span check of gas analysers.

Zero and span procedure should be performed on the emissions measurement sensors/analysers according to the pre-test procedures section (To be made **every Single Test)**

I. Zero drift

Zero response is defined as the mean response, including noise, to a zero gas during a time interval of at least 30 seconds. The drift of the zero response shall be less than 2 per cent of full scale on the lowest range used.

II. Span drift

Span response is defined as the mean response, including noise, to a span gas during a time interval of at least 30 seconds. The drift of the span response shall be less than 2 per cent of full scale on the lowest range used.

8.4.3. Removal of Filter from PEMS PM instrument

The removal of the filter is as important as the data acquisition; attention is needed when the filter is being removed from the holder not to drop the filter to the ground or to push the filter to any surface. The filter needs to be removed with a set of tweezers and placed safely in its protective case to be taken to the weight chamber.

8.4.4. Zero of exhaust flow-meter.

The values displayed by the exhaust flow meter shall be referenced against pre-test values and recorded. (To be made **every Single Test)**

8.4.5. Back up test data

8.4.6. Verification of test data.

To be made **every Single Test**

Same recommendations as for 8.2.5.5

8.4.7. Turn off the emissions sampling system and all measurement devices

8.4.8. Remove power from the instruments

8.5. Conclusion of Test Series

8.5.1. Dismount PEMS equipment and restore vehicle/machine to the original configuration.

Disconnect the heated sampling line from the exhaust sampling port, all data cables and transducer lines, remove instruments and restore the vehicle/machine exhaust system to its pre-test configuration. (To be made **every Series of Tests).**

9. Data processing [How shall I evaluate the measurements?]

9.1. Test data screening

Source 1: Appendix A – Section 7

ITEM	Applicable Requirements or recommendations	A	B	C
Test procedure - Verification of the measurements	Regulation 582/2011, Annex II, Appendix 1 - Section 2.7	○	○	●

9.1.1. For all the emissions calculations the test parameters have to be recorded and stored with at least 1 Hz (better 10 Hz) on a computer system.

The data may be processed using the PEMS post-processors. For EU 'legislative' in-use emissions testing, it is recommended to benchmark the results against the ones obtained with data processing reference tool developed in the EU-PEMS project (EMROAD). Such a benchmark can in principle be performed only on a limited number of samples.

9.1.2. At the end of a test or a series of tests, the following points must be checked:

a) Presence of mandatory parameters (See table in section 4.2)

b) Quality screening of mandatory parameters (check for the measured ranges, eventual range saturation and negative values)

c) Zero drift and span drift results for THC, CO, NOx (or NO/NO2) and CO2

d) Zero drift of EFM

e) Data consistency check results:

   i. ECU Fuel rate versus Calculated Fuel rate

   ii. Brake-Specific Fuel Consumption

   iii. ECU torque data

   iv. GPS speed versus ECU vehicle speed

f) Correctness of test conditions:

   i. Test duration

   ii. Ambient conditions

g) Supply of Documentation

   i. Vehicle / machine

   ii. Engine

   iii. PEMS Test equipment

   iv. Measured test data

   v. Calculated test data

9.2. Evaluation of test route composition (Rules, principles)

Under development – Analysis of existing ISC 'trip and driving' data (Data sources: JRC, TNO) [R9]

9.3. Calculation formula and principles

ITEM	Applicable Requirements or recommendations	A	B	C
Calculation of the emissions - Time alignment of data	- "Best practice approach" using the relevant tools provided with each PEMS system to adjust the delay times and, during pre-processing of the test data, application of Regulation 582/2011, Annex II, Appendix 1, Section 3.1	○	○	●
Calculation of the emissions - Data consistency checks	Regulation 582/2011, Annex II, Appendix 1 - Section 3.2	○	○	●
Calculation of the emissions - Calculation of the instantaneous gaseous emissions	Regulation 49, Annex 4B - Section 8.4.2.3 [NB: Valid only for the listed fuels]	○	○	●

10. References

R1. Commission Regulation (EU) 582/2011

R2. Directive 2005/55/EC of the European Parliament and of the Council on the "approximation of the laws of the Member States relating to the measures to be taken against the emission of gaseous and particulate pollutants from compression-ignition engines for use in vehicles, and the emission of gaseous pollutants from positive-ignition engines fuelled with natural gas or liquefied petroleum gas for use in vehicles"

R3. Commission Directive 2005/78/EC "implementing Directive 2005/55/EC of the European Parliament and of the Council relating to the measures to be taken against the emission of gaseous and particulate pollutants from compression-ignition engines for use in vehicles, and the emission of gaseous pollutants from positive ignition engines fuelled with natural gas or liquefied petroleum gas for use in vehicles and amending Annexes I, II, III, IV and VI thereto"

R4. Commission Directive 2006/51/EC "implementing Directive 2005/55/EC of the European Parliament and of the Council relating to the measures to be taken against the emission of gaseous and particulate pollutants from compression-ignition engines for use in vehicles, and the emission of gaseous pollutants from positive ignition engines fuelled with natural gas or liquefied petroleum gas for use in vehicles and amending Annexes I, II, III, IV and VI thereto"

R5. EPA Final Rule Part 1065 Test Procedures - Subpart J "Field Testing" - 40 CFR Part 1065, Subpart J

R6. Directive 2004/26/EC of the European Parliament and of the Council amending Directive 97/68/EC on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery.

R7. SAE Standard J1939 - Recommended Practice for a Serial Control and Communication Vehicle Network

R8. ISO Standard 16183 - Heavy duty engines – Measurement of gaseous emissions from raw exhaust gas and of particulate emissions using partial flow dilution systems under transient test conditions

R9. A. Perujo, P Mendoza-Villafuerte, " PEMS EMISSIONS TESTING OF HEAVY DUTY VEHICLES/ENGINES: ASSESSMENT OF PEMS PROCEDURES IN FULFILMENT OF ARTICLE 14(3) TO REGULATION (EU) 582/2011". JRC Technical Reports, EUR 27251

R10. P. Mendoza-Villafuerte, A. Perujo, P. Bonnel, M. Carriero, F. Forni, F. Riccobono "EU PEMS PM Pilot Program: Testing, data analysis and results". JRC Technical Reports, EUR 27326

11. Annexes [Useful documents]

11.1. Test Auditing Questionnaire

STEP	Description	
Selection of equipment and installation		
1	PEMS type	
2	EFM Measurement Range	_____ in kg/h _____ in % of max. engine exhaust flow
3	EFM Installation	According to Guide recommendations □ Yes □ No: Provide details
4	Position of GPS antenna	According to Guide recommendations □ Yes □ No: Provide details
5,6	Communication protocol for ECU data	□ SAE J1939 □ Other: Please specify
6,7	ECU data logger	□ PEMS □ Other: Please specify
8	Power supply	□ Power generator □ Batteries □ Other: Please specify
9	Position of weather station	According to Guide recommendations □ Yes □ No: Provide details
10	Operation gas bottles on-board	□ FID Fuel □ Oxygen □ Other: Provide details
	Installation issues not listed above	Please provide details
Preparation and Execution of tests		
11	Zero-span of analysers	□ Yes □ No
12	Archiving zero-span data	□ Yes □ No
13	EFM Purging	□ Yes □ No
14	Leak check	□ Yes □ No

15	EFM Zeroing	□ Yes □ No
16	Qualification of ECU Engine Speed	□ Yes □ No
17	Qualification of ambient temperature and humidity sensors	□ Yes □ No
18	Pre-test run	□ Yes Duration:_____ □ No
19	Verification of pre-test data	□ Yes □ No
20	Archiving pre-test data	□ Yes □ No
21	Archiving test data	□ Yes □ No
22	Audit of analysers	□ Yes □ No
23	Archiving audit data	□ Yes □ No
	Execution issues not listed above	Please provide details

11.2. Data Consistency Questionnaire

Item #	Description	Comment
1	Presence of mandatory parameters	Refer to section **Error! Reference source not found.** for the list of parameters for each application
2	Correctness of mandatory parameters	Check for the measured ranges, eventual range saturation and negative values
3	Zero drift and span drift results for THC, CO, NOx (or NO/NO2) and CO2	Refer to section **Error! Reference source not found.** for the allowed drift values
4	Zero drift of EFM	No specific requirement. Recommended: The drift of the zero response shall be less than 2 per cent of full scale on the range used.
5	ECU Fuel rate versus Calculated Fuel rate	Recommended: Slope of the regression line 0.9 to 1.1 Mandatory: Coefficient of determination r2>=. 0.90 – Important as well to check the correct time alignment of test data
6	Brake-Specific Fuel Consumption	HDV and NRMM ISC testing, consistency to be checked against declared type approval value
7	ECU torque data	HDV and NRMM ISC testing, consistency to be checked against maximum power curve
8	GPS speed versus ECU vehicle speed	No requirement – Important to check the correct time alignment of test data
9	Correctness of Test duration	HDV EURO V: 3 times the engine work or CO2 emissions on the ETC cycle HDV EURO VI: 5 times the engine work or CO2 emissions on the WHTC cycle NRMM and LDV: Not defined yet.
10	Correctness of ambient conditions	HDV: Defined in 582/2011 Annex II NRMM and LDV: Not defined yet. The recommendations are: - Altitudes below 1200 m - Ambient temperatures between -7℃ and 30℃
11	Supply of Vehicle/Machine Information	

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