ACTUAL AND FUTURE EUROPEAN MOTOR VEHICLE EXHAUST EMISSIONS REGULATIONS

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INTRODUCTION

The mobility is one of the main characteristics of modern life. Comprehensive transport is precondition for intensive mobility, developed economy and normal human activities. Motor vehicle is one of the most important factors in transportation. However, sometimes it can be heard that transports sector, i.e. motor vehicles are the human environments enemy number one. Though this is unfair, in some cases it can be truth. But let us start from the beginning.

The invention of wheel and the creation of the first wheeled vehicle in the distant past improved man's mobility and caused a technical revolution with far-reaching consequences. Probably our distant ancestors who found it did not know how much trouble it will cause in the future. Actually, there were not much of problems for a long time in the past when the main vehicle propulsion was animal power. This vehicle was relatively slow, it could not even carry either a lot of people or a lot of goods, but it could not cause major traffic accidents or create major environmental problems. But when in the second half of the nineteenth century the first internal combustion engine was invented, and when it was incorporated into the vehicle, the situation has changed significantly. So created vehicle was significantly faster, could move to far distances in a short time to and carry more people and cargo.

The potential advantages of motor vehicles have rapidly increased the number of light and heavy vehicles. However, the increased number of vehicles has created several problems. One of the biggest problems is air pollution caused mainly by their exhaust gases. Road transport often appears as the most important source of urban pollutant emissions. In current decade, road transport is likely to remain a large contributor to air pollution, especially in urban areas. In current decade, road transport is likely to remain a large contributor to air pollution, especially in urban areas.

To prevent further pollution and eventually to reduce it, legislation on permissible emission of toxic components in the vehicle exhaust has been introduced.

EUROPEAN VEHICLE EMISSION REGULATIONS

First vehicle emission regulations were introduced in US and Japan at the beginning of second half of last century. Europe followed through UN Economic Commission for Europe where its administrative body WP.29 adopted Agreement 1958 on uniform technical prescriptions for wheeled vehicles, so called ECE Regulations. There is now 133 adopted ECE regulations and 7of them are directly related to exhaust emissions of motorcycles (ECE 40), mopeds (ECE 47), passenger cars and light commercial vehicles (ECE 15 and 83), heavy commercial vehicles (ECE 24 and 49) and non-road mobile machinery (ECE 96).

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The Agreement 1958 has currently more than fifty Contracting Parties and they are (with their ECE code) [1]: E1 GERMANY, E2 FRANCE, E3 ITALY, E4 NETHERLANDS, E5 SWEDEN, E6 BELGIUM, E7 HUNGARY, E8 CZECH REPUBLIC, E9 SPAIN, E10 SERBIA, E11 UNITED KINGDOM, E12 AUSTRIA, E13 LUXEMBOURG, E14 SWITZERLAND, E16 NORWAY, E17 FINLAND, E18 DENMARK, E19 ROMANIA, E20 POLAND, E21 PORTUGAL, E22 RUSSIAN FEDERATION, E23 GREECE, E24 IRELAND, E25 CROATIA, E26 SLOVENIA, E27 SLOVAKIA, E28 BELARUS, E29 ESTONIA, E31 BOSNIA & HERZEGOVINA, E32 LATVIA, E34 BULGARIA, E36 LITHUANIA, E37 TURKEY, E39 AZERBAIJAN, E40 THE F.Y.R. OF MACEDONIA, E42 EUROPEAN COMMUNITY, E43 JAPAN, E45 AUSTRALIA, E46 UKRAINE, E47 SOUTH AFRICA, E48 NEW ZEALAND, E49 CYPRUS, E50 MALTA, E51 REPUBLIC OF KOREA, E52 THAILAND, E53 MALAYSIA, E54 ALBANIA, E56 MONTENEGRO, E58 TUNISIA, E62 EGYPT. Serbia has very low code (E10) since it succeeded Yugoslavia who signed the agreement between first. USA did not sign the agreement, but they participate in the work of WP.29. Canada, China and India did not sign the agreement, but they participate in the work of WP.29 and they are applying several UN/ECE Regulations.

Main characteristics of 1958 Agreement (amended in October 1995) are [2]:

- UN/ECE Regulations establish uniform provisions for mutually recognized type approval of vehicle systems, equipment and parts
- UN/ECE Regulations are optional
- UN/ECE Regulations become legal instruments only when incorporated into the national legislation
- Parties are obliged to accept for marketing or registration products type approved by any Contracting Party to the same Regulation
- Parties have privilege to type approve products if they have expertise
- Administrative Departments and Technical Services designated by Contracting parties share information about type approvals
- Administrative Department issuing type approval retains responsibility for conformity of the series production with the type approved

ECE Regulations on exhaust emissions define testing procedures, measurement methodology and permissible limits of pollutants. Appropriate EU Directives have accepted procedures and methodology from UN/ECE Regulations but the limits were tighten gradually from 1990 up to the present in the form of so-called Euro standards. These standards are then incorporated in appropriate ECE Regulations in the form of new amendments. EU Directives and UN/ECE Regulations for certain types of vehicle are practically identical.

THE EMISSION LIMITS FOR PASSENGER CAR

The emission limits for passenger cars from 1992 to 2014 are shown in Fig. 1. Euro 5 and 6 emission limits for conventional (multi point injection – MPI) gasoline engines are only with small reduction and do not require significant technological changes. The only novelty is that gasoline direct injection engines require particle emission measurement. However, diesel engine emission limits involve important changes. Particulate matter PM mass emission Euro 5 limits are extremely low, as well as Euro 6 emission limits for NOx. However, the important novelty is introduction of particle number emission limits.

			EU-1	EU-2	EU-3	EU-4	EU-5	EU-5+	EU-6	EU-6+
			1992	1996	2000	2005	2009	2011	2014	2017
Test Cycle			ECE 15.04	ECE 15.05	NEDC	NEDC	NEDC	NEDC	NEDC ? WLTP ?	
Positive Ignition Engines (Gasoline)	CO	mg/km	2720	2200	2300	1000	1000	1000	1000	
	HC	mg/km			200	100	100	100	100	
	HC + NOx	mg/km	970	500						
	NOx	mg/km			150	80	60	60	60	
	NMHC	mg/km					68	68	68	
	PM only GDI	mg/km					5	4,5	4,5	
	PN	#/km							6E12	6E11
Compression Ignition Engines (Diesel)	CO	mg/km	2720	1000	640	500	500	500	500	
	HC + NOx	mg/km	970	700	560	300	230	230	170	
	NOx	mg/km			500	250	180	180	80	
	PM	mg/km	140	80	50	25	5	4,5	4,5	
	PN	#/km						6E11	6E11	

no change | change | important

Figure 1 EU emission limits for passenger cars [3]

Actually, extremely low particulate matter mass emission is with high measurement error. Fig. 2 shows typical repeatability (obtained results in same laboratory) and reproducibility (obtained results in different laboratory) of heavy duty diesel engine particulate matter mass measurement [4, 5, 6]. Evidently, measurement method of particulate matter mass measurement should be improved. But it is concluded that measurement of PM mass concentration is not only important factor since in low PM mass emission can exists a high number of small particles. At the same time, health experts have concluded that small particles are more dangerous than great ones. Actually, big particles can be retained in the nose, but small particles go in the human lung, penetrate in the blood and then deposit in the brain or heart.

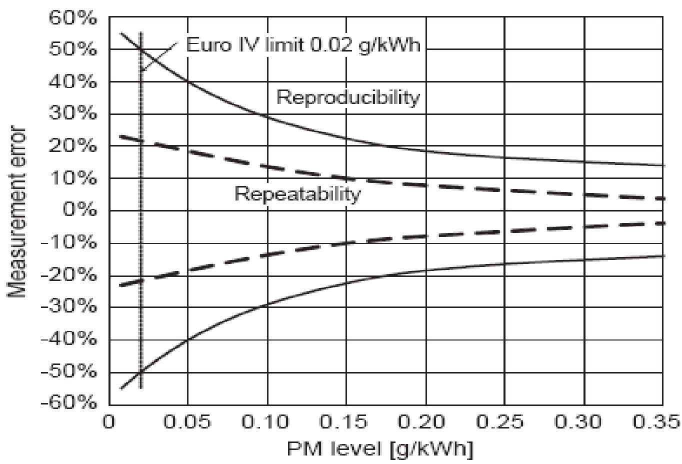

***Figure 2** The effect of low particulate matter emission*

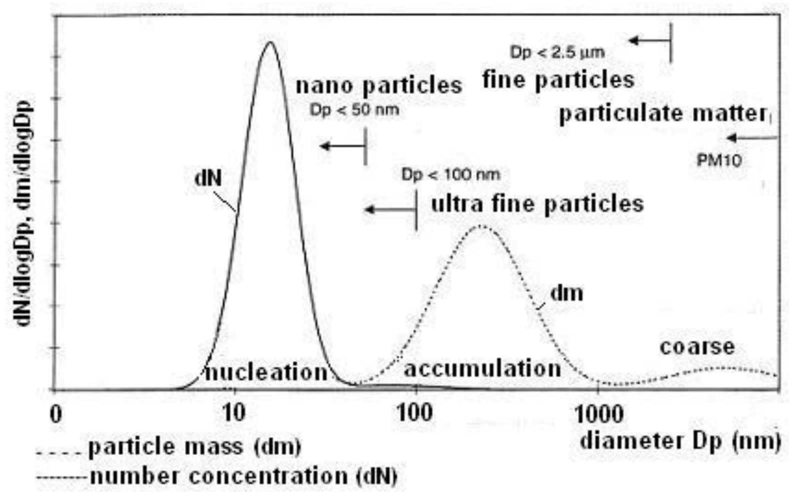

Figure 3 *Particle number and mass distributions*

Fig. 3 shows typical particle number (dN/dlogDp) and mass (dm/dlogDp) distribution in the function of particle diameter [6, 7]. Three typical phases of particle formation can be noticed. In the first phase are nano particles from nucleation phase. The second phase involves fine particles from accumulation phase and the third are coarse particles (which are eliminated in the modern diesel engines with high pressure injection, so their number is considerably low as well as mass). Total mass of emitted particles comes mainly from accumulation phase with fine particles smaller than 2.5 μm, but their number can be small (depending on applied technology and exhaust gas after treatment system). As concerns number concentration, nano particles are dominant. The composition of fine particles is mostly solid carbon and the composition of nano particles is mainly liquid compounds and volatile hydrocarbons. Particles from the first phase are the biggest problem. They are mostly unstable and almost without mass, but enormous by number. The correct measurement of their number concentration is not possible.

To solve the problem of particle number measurement, PMP group of UN/ECE/WP.29/GRPE has proposed approval methodology shown in Fig. 4 [6, 8]. According to this proposal standard CVS dilution tunnel should be used. The exhaust gas sample, taken from the tunnel, goes to the cyclone pre-classifier which remove particles bigger than about 2.5 microns. After dilution with hot air (PND1), sample is driven through heated evaporation tube HT (heated up to 150 C) where volatile components are removed. As the sample has to be cold at the entrance of particle counter, and to prevent condensation, the sample is again cold diluted (PND2) and then it is driven to particle number counter (PNC) where only number of solid particles is measured, which enables satisfactory repeatability and reproducibility. Condensation particle counter (CPC) is used as PNC device.

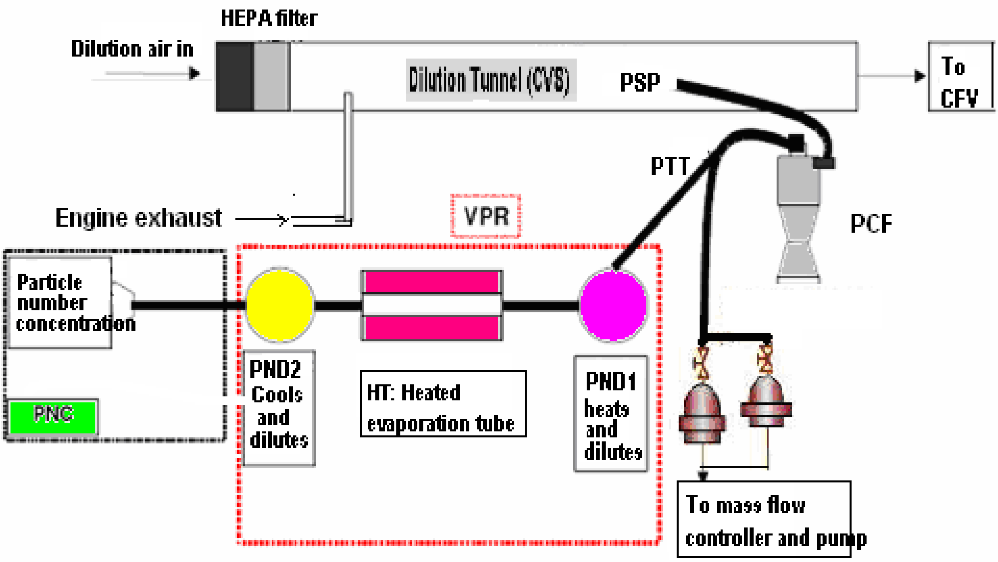

Figure 4 *Sheme of particle emission measurement*

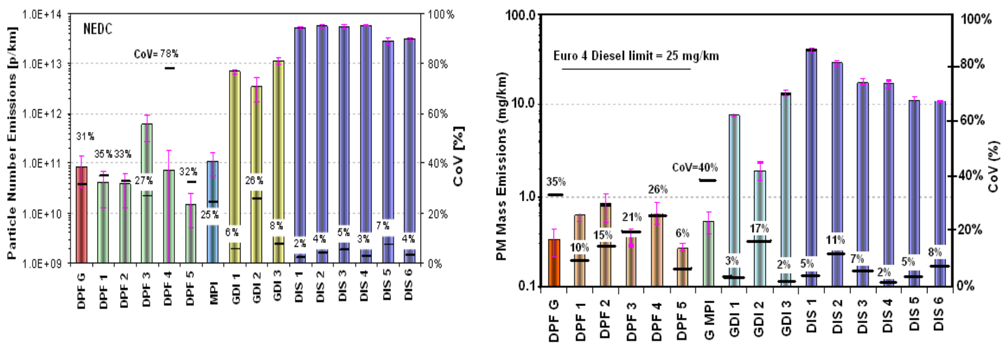

Figure 5 *Particulate mass (left) and particle number (right) emissions for vehicles with different engine technologies*

The results of particulate matter mass and particle number emissions of passenger cars with different engine technologies, obtained during Inter-laboratory Correlation Exercise (ILCE) to verify PMP proposed procedure, are shown in Fig. 5 [7, 9]. Particle mass emissions for all vehicles with particulate filter (DPF) are always very low: much bellows 1 mg/km. The particle mass emissions repeatability (coefficient of variations – CoV) of DPF diesel vehicles is very high and its average is about 20%. Mass particulate emission of multi point injection gasoline engines (G MPI) is at the same level with DPF engines and, also, its repeatability is very bad with high CoV (about 40%). The particle mass emission of direct injection gasoline engines (GDI) is almost ten times higher than the PM emission of DPF diesel engines, but the repeatability of test data is much better (CoV ranges from 2% to 17%). The particulate mass emissions of conventional Euro 4 diesel (DIS) engine (without particulate filter) is almost hundred times higher than emissions of DPF engines, but the results repeatability is much better with CoV mainly bellow 10.

Particle number emissions of diesel DPF vehicles were on level of gasoline engine with MPI injection. It can be expected that number emissions of these vehicles should be max. 10^{12} particles/km in NEDC test. Direct gasoline injection engine had ten times higher particles number concentration in comparison with diesel DPF and gasoline MPI engines. Their emissions is bellow 10^{13} particles/km. Diesel Euro 4 cars without DPF had hundred times higher particle number emissions than DPF vehicles. Their number emissions are bellow 10^{14} particles/km in NEDC test. Test results repeatability (CoV) is almost perfect for conventional diesel non-DPF vehicles and their CoV is mainly under 5%. However, the repeatability of DPF vehicles is much worst and their CoV was over 30%.

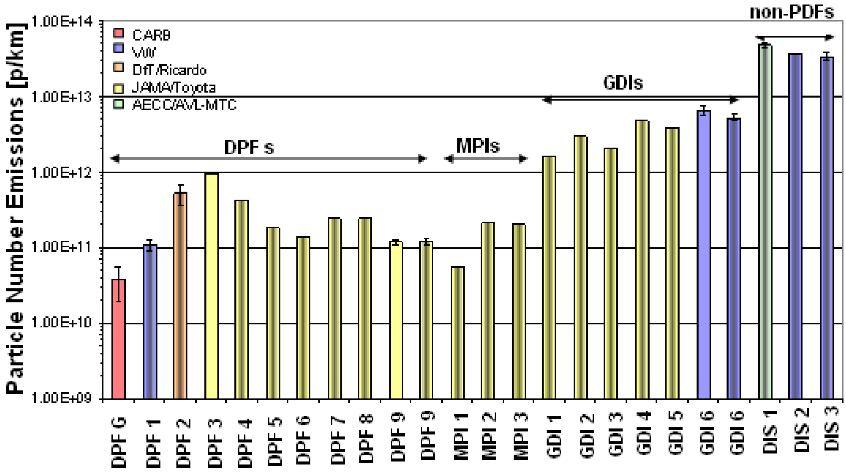

Figure 6 *Particle number emissions for vehicles tested outside PMP*

Fig. 6 shows some results of particle number emission measurements outside of PMP inter-laboratory correlation exercise in different laboratory and with different engine technologies, but using PMP measurement procedure in NEDC. The results are almost identical as in PMP testing. Particle number emission of DPF vehicles ranged from 1011 to 1012 p/km, for MPI gasoline engines it ranged from 5x1010 p/km to 5x1011 p/km, for GDI engines it was from 1012 to 10 13 p/km and for conventional diesel engines without DPF it ranged from 1013 to 1014 p/km [7, 10].

THE EMISSION LIMITS FOR HEAVY-DUTY ENGINES

The emission limits for heavy-duty engines from 1992 to 2014 are shown in Fig. 7. Actually Euro IV standards introduced very low limits for particulate mass emission (five times lower than Euro III) and not so strict limits for NOx. However, Euro VI standards reduced emission limits for NOx several times and particulate matters PM emission for more than double compared with Euro IV standards. At the same time Euro VI standard introduced particle number measurement with similar PMP procedure as for passenger cars with very low limits corresponding to the emission of diesel DPF engines. This procedure also includes counting of solid particle in engine exhaust.

Test cycles			I 1992	II 1996	III 2000	IV 2005	V 2008	VI 2013
Test cycles EU-I+II 13-Mode EU-III+IV ESC EU-VI WHSC	CO	g/kW-h	4,50	4,00	2,10	1,50	1,50	1,50
	THC	g/kW-h	1,10	1,10	0,66	0,46	0,46	0,13
	NMHC	g/kW-h						
	CH4	g/kW-h						
	NOx	g/kW-h	8,00	7,00	5,00	3,50	2,00	0,40
	PM	g/kW-h	3,60	0,15	0,10	0,02	0,02	0,01
	NH3	ppm				25	25	10
	PN	#/kWh						8 E11
	CO2, FC	g/kW-h						no
	NO2	g/kW-h						?
Test cycles EU-III+IV ETC EU-VI WHTC	CO	g/kW-h			5,40	4,00	4,00	4,00
	THC	g/kW-h						0,16
	NMHC	g/kW-h			0,78	0,55	0,55	
	CH4	g/kW-h			1,60	1,10	1,10	
	NOx	g/kW-h			5,00	3,50	2,00	0,46
	PM	g/kW-h			0,16	0,03	0,03	0,01
	NH3	ppm				25	25	10
	PN	#/kWh						6 E11
	CO2, FC	g/kW-h						no
	NO2	g/kW-h						?

Moderate Reduction (<30%) Large Reduction (>30%)

Figure 7 *Emission limits for heavy-duty engines* [3, 11, 12]

Some results of particles number emission measurement in different tests for a DPF 6 cylinder HD engine are shown in Fig. 8 [13]. The PMP system consists of a pre-classifier/cyclone sampling directly from the constant volume sampler (CVS) with a 2.5 μm size cut, a volatile particle remover (VPR) for volatile species control, and a CPC. The VPR includes an initial hot dilution (150◦C) stage, where the liquid volatile concentration is reduced, followed by a tube heated to 300◦C, where volatiles are evaporated, followed by a second diluter to prevent subsequent nucleation. Fig. 8 shows tailpipe particle number emissions from European (ETC), US (FTP) and Japanese (JE05) regulatory cycles, the World Harmonized Transient Cycle (WHTC) and the Non-road Transient Cycle (NRTC). For those cycles with cold- and hot-start portions, results are shown for the cold- and hot-start cycles separately. In addition results are shown for the hot-start WHTC with the 5, 10 and 20 minute soak periods. All tailpipe emissions measurements are the average of at least three tests. It is very interesting and important that all results are very similar and that the differences are very small.

WORLD HARMONIZATION OF TESTING PROCEDURE

Current legislations on exhaust emissions of motor vehicles are so strict that the further reduction of emission limits is impossible. At the same time, these reduced emissions are not accompanied by corresponding improvement in air quality. A reason for this is that the emission testing procedures, prescribed by existing legislations, do not correspond to the actual driving conditions. An additional problem is the lack of uniformity of vehicle emission control procedures in different regions of the world. Therefore, it is concluded that it is necessary to harmonize the emission testing procedures which should be adjust to the real driving conditions.

In 1994 the United States of America initiated and negotiated in cooperation with the EU and Japan in view of establishing a transparent process for improving global safety, decreasing of environmental pollution and consumption of energy through globally uniform technical regulations. Agreement on Global Technical Regulation (GTR) was concluded and opened for signature on 25 June 1998. The United States of America first signed the Agreement 1998 and it entered into force on 25 August for 8 Contracting Parties. Unfortunately U.S. of America has withdrawn sponsoring GTR in 2010. Also, it should be mentioned that in 2000, WP.29 becomes a Global Forum (March, 120th session) called World Forum for Harmonization of Vehicle Regulations [2, 15].

Global Technical Regulation (GTR) Agreement 1998 currently has 33 Contracting Parties (year of signature in bracket) [14]: AUSTRALIA (2008), AZERBAIJAN (2002), CANADA (1999), P. R. CHINA (2000), CYPRUS (2005), EUROPEAN UNION (1999), FINLAND (2001), FRANCE (1999), GERMANY (2000), HUNGARY (2001), INDIA (2006), ITALY (2000), JAPAN (1999), KAZAHSTAN (2011), R. KOREA (2000), LITHUANIA (2006), LUXEMBURG (2005), MALAYZIA (2006), R. MOLDOVA (2007), NETHERLANDS (2002), NEW ZEALAND (2001) NORWAY (2004), ROMANIA (2002), RUSSIAN FEDERAT. (2000), SLOVAKIA (2001), SOUTH AFRICA (2000), SPAIN (2000), SWEDEN (2002), TAJIKISTAN (2011), TURKEY (2001), TUNISIA (2007), UNITED KINGDOM (2000), U. S. OF AMERICA (1998). Serbia did not sign Agreement 1998.

There is now 15 adopted GTRs. Between them, 6 are on emission problems [15]:

GTR No. 2 - Motorcycles emission (adopted 2005)

GTR No. 4 – Heavy-duty engines emission (adopted 2006)

GTR No. 5 – On-board diagnostic systems (adopted 2006)

GTR No. 10 – Off-cycle emissions (adopted 2009)

GTR No. 11 – Non-road mobile machinery emissions (adopted 2009)

GTR No, 15 – Passenger cars emission (adopted 2014)

UN GTR NO. 2

Title of this GTR is “Measurement procedure for two-wheeled motorcycles equipped with a positive or compression ignition engine with regard to the emission of gaseous pollutants, CO2 emissions and fuel consumption” (ECE/TRANS/180/Add.2) [15]. It defines procedure and reference testing cycle: World-wide Motorcycle Transient Cycle (WMTC).

Reference cycle (WMTC) is not unique, but is composed of three parts, which are used depending on the class of motorcycle defined by engine volume and maximum speed of the vehicle. These three parts define different driving conditions and roads, as follows: part 1 simulates city driving, part 2 suburban and ordinary roads, and part 3 highway driving. The characteristics of classes are shown in Table 1. The scheme of WMTC is shown in Fig. 9.

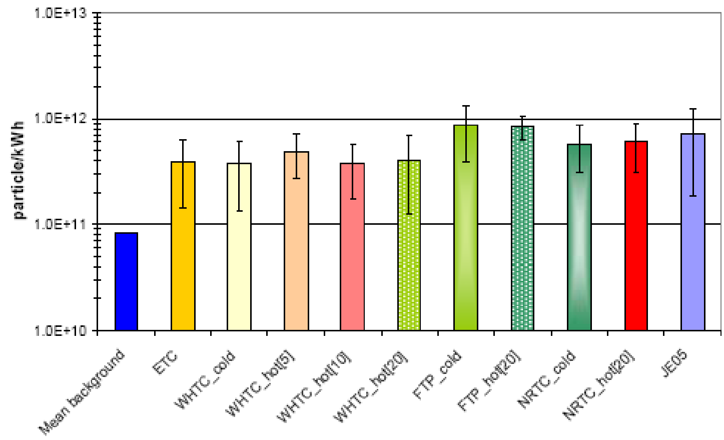

Figure 8 *Particle number emission of HD engine in different tests*

Table 1. *Classes of motorcycles*

Vehicle class	Characteristics	Cicle	Weighting factor
Class 1	Vh≤50 ccm, 50<Vmax<60 km/h or 50<Vh<150 ccm, Vmax≤50 km/h or Vh<150 ccm, Vmax<100 km/h	Part 1, cold	50 %
		Part 1, hot	50 %
Class 2	Vh<150 ccm, Vmax<100 km/h Vh≥150 ccm, Vmax<130 km/h	Part 1, cold	30 %
		Part 2, hot	70 %
Class 3	Vh≥150 ccm, Vmax≥130 km/h	Part 1, cold	25 %
		Part 2, hot	50 %
		Part 3, hot	25%

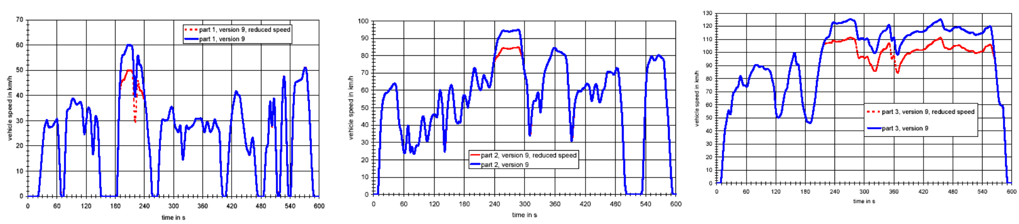

Figure 9 *Scheme of World-wide Motorcycle Transient Cycle (WMTC)*

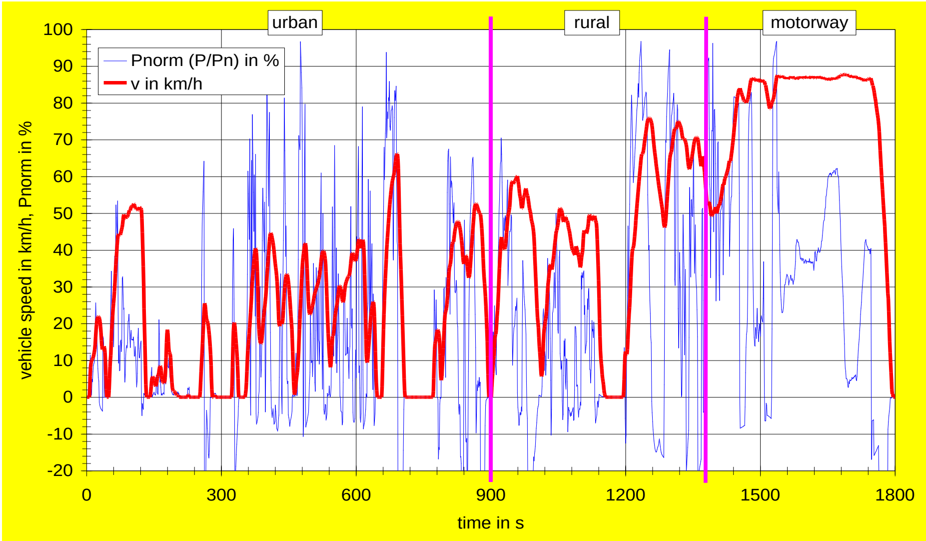

Figure 10 *Worldwide Transient Vehicle Cycle (WTVC)*

UN GTR NO. 4

The title of this GTR is "Test procedure for compression-ignition (C.I.) engines and positive-ignition (P.I.) engines fuelled with natural gas (NG) or liquefied petroleum gas (LPG) with regard to the emission of pollutants (WHDC)" (ECE/TRANS/180/Add.4) [15]. Worldwide harmonized Heavy Duty Certification (WHDC) is composed of three test cycles. The fundamental cycle is so-called Worldwide Transient Vehicle Cycle (WTVC) created from typical driving data recorded in USA, EU and Japan (Fig. 10) [16]. This cycle simulates driving in urban, suburban and road conditions with a constant change of load and speed. It is common for all vehicles. Since it is not possible to test a heavy vehicle on chassis dynamometer, this basic cycle serves for generation of control test for engine approval at dynamometer.

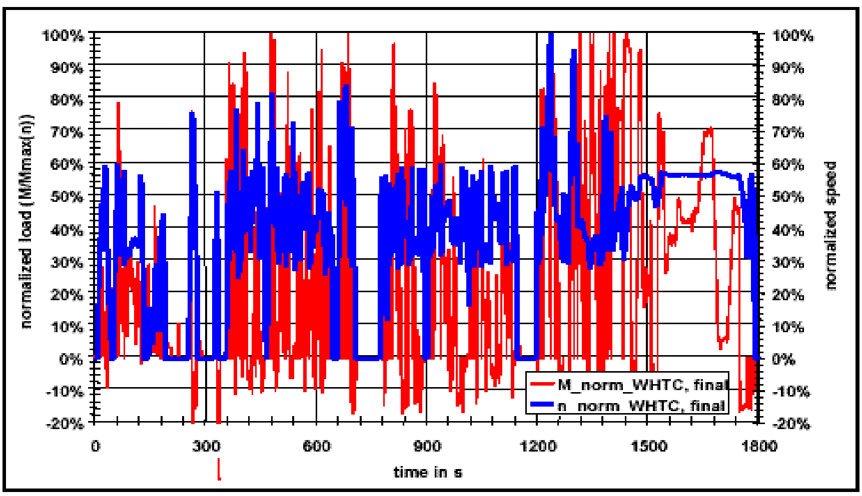

Figure 11 *Worldwide Harmonized Transient Cycle (WHTC)*

Worldwide Harmonized Transient Cycle (WHTC) uses normalized load and speed data from WTVC. Therefore, for each engine, test cycle should be first denormalized using real engine torque and power data. The normalized WHTC is shown in Fig. 11 [16]. WHTC is performed twice, as cold and hot test with soak period (5 or 20 s) between them. The results of cold and hot test are weighted as 5 or 14 % and 86 or 90 % respectively.

Using frequency distribution of load and speed of WTVC, the Worldwide Harmonized Steady-state Cycle (WHSC) is created using normalized load and speed data (Fig. 12). WHSC is quasi-stationary cycle called “ramped steady-state cycle”. Actually, transition from one regime to another is done through “ramp” – period of 20 s. Collection of data is not done mode by mode, as in old steady-state cycle, but continuously for whole cycle [16].

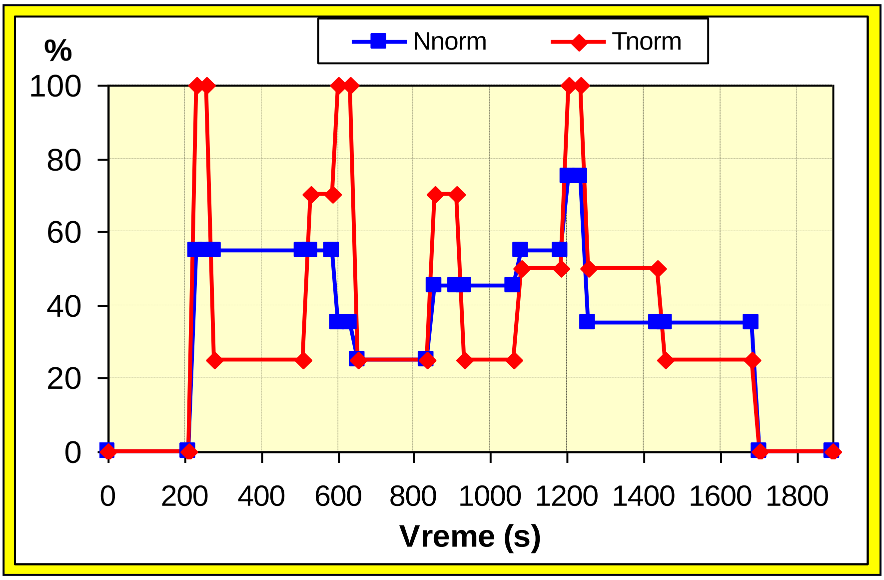

Figure 12 *Worldwide Harmonized Steady-state Cycle (WHTC)*

UN GTR NO. 5

The title of this GTR is “Technical requirements for on-board diagnostic systems (OBD) for road vehicles” (ECE/TRANS/180/Add.5) [15]. OBD system must detect a malfunction of either engine or after-treatment systems of exhaust gases. Also, he needs to show other information which should to be exchanged between the vehicle and power train. The proposal is based on technologies that are industrially available and in particular take due regard to the condition of the electronics in the period around 2008, as well as expected the latest technology of engines and exhaust after-treatment systems.

GTR proposal also defines the following items:

- Errors should be detected by the OBD system
- The information should provide OBD system and
- The process of approval OBD system

UN GTR NO. 10

The title of this GTR is “Off-cycle emissions (OCE)” (ECE/TRANS/180/Add.10) [15]. At the initiative of the United States, the discussion started on the problem of vehicle toxic emissions at engine regimes which are not covered by the procedure of light and heavy vehicles control testing. It was noted that the effects of improvements in vehicle emissions are not reflected in direct extent on reducing air pollution. One reason is that although the engine has satisfactory level of exhaust emission at approval testing, the increase of toxic emissions occurs in the use because the engine is not running the regimes in which the emissions was checked, and because the conditions of the engine in operation (temperature and ambient pressure) differ from those defined for the control test.

In the early considerations on this issue, in addition to the analysis of parameters and operating conditions that may affect the increased emission of the regimes which do not correspond to the control test, the effects of applying different tests on so called "off-cycle" emissions were analyzed and compared . It was pointed out that with regard to this problem, the advantage gives dynamic (transient) test WHTC that better covers the work area of the engine and harder it can be harder misused. This GTR is designed to be applicable to engines certified or type approved under the test procedures of GTR No. 4 on the Worldwide harmonized Heavy Duty Certification (WHDC).

The Off-Cycle Emissions (OCE) GTR includes two components. First, it contains provisions that prohibit the use of defeat strategies. Second, it introduces a methodology, termed the World-harmonized Not-to-Exceed (WNTE) methodology, for limiting off-cycle emissions. According to this GTR, Emission Limits are defined by next relation:

WNTE Emission Limit = WHTC Emission Limit + WNTE Component

where WNTE Component is:

for NOx: WNTE Component = 0.25 x EL + 0.1
for HC: WNTE Component = 0.15 x EL + 0.07
for CO: WNTE Component = 0.20 x EL + 0.2
for PM: WNTE Component = 0.25 x EL + 0.003

Off-cycle emissions can be checked in two ways:

- World-harmonized Not-To-Exceed in-use testing
- World-harmonized Not-To-Exceed laboratory testing

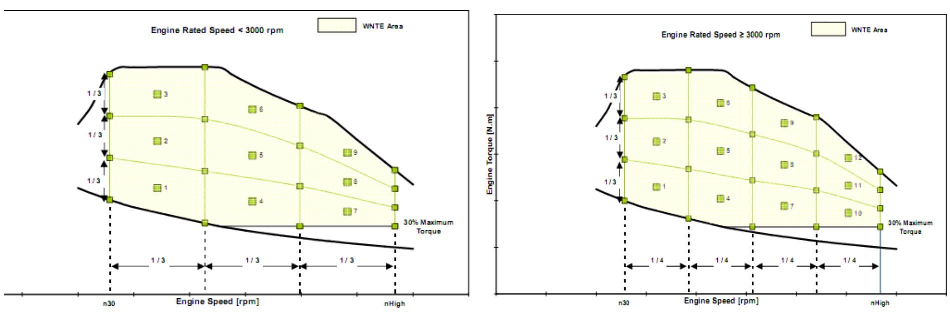

Figure 13 *WNTE control area grid for high (left) and super high (right) speed engines*

The GTR defines World-harmonized Not-To-Exceed (WNTE) laboratory testing. The specific mass emissions of regulated pollutants shall be determined on the basis of randomly defined test points distributed across the WNTE control area. All the test points shall be contained within 3 randomly selected grid cells imposed over the control area. The grid shall comprise of 9 cells for engines with a rated speed less than 3000 rpm and 12 cells for engines with a rated speed greater than or equal to 3000 rpm (Fig. 13).

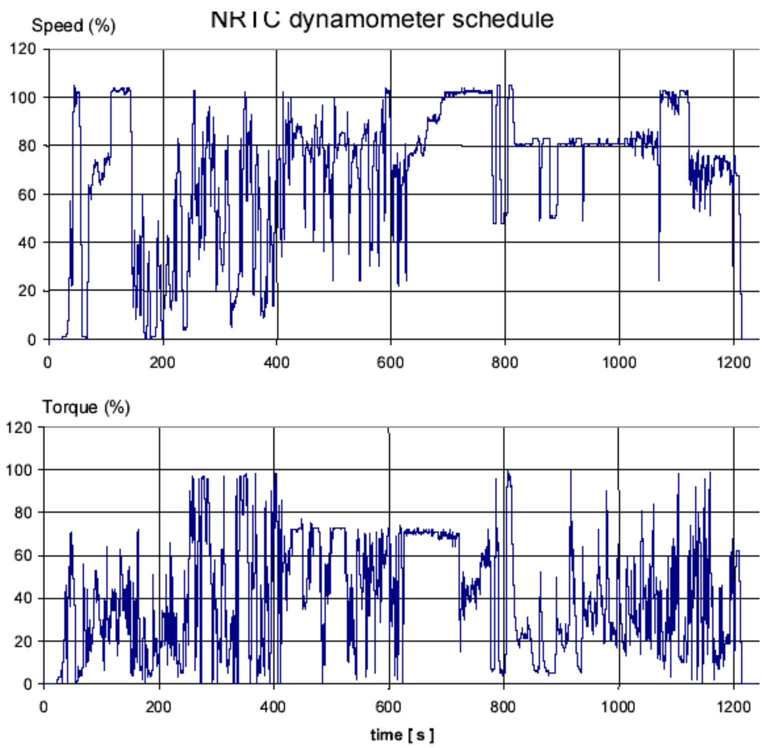

Figure 14 *NRDC driving schedule*

UN GTR NO. 11

The title is “Test procedure for compression-ignition engines to be installed in agricultural and forestry tractors and in non-road mobile machinery with regard to the emissions of pollutants by the engine” (ECE/TRANS/180/Add.11).

This regulation aims at providing a world-wide harmonized method to the determination of the emissions of pollutants of compression-ignition engines with a maximum power not smaller that 19 kW and not larger than 560 kW to be used in category T vehicles and in non-road mobile machinery.

The proposal is based on the EU directive that defines the dynamic cycle intended for emission testing of diesel engines for non-road vehicles (NRTC - Non Road Transient Cycle), which corresponds to the typical operating conditions of these engines. In fact it contains three 400 seconds sections with data of normalized values of engine torque and speed (Fig. 14). It is suggested that the NRTC cycle is performed twice: the first time with the start of cold engine (at room temperature) and the second time with a hot engine start (20 minutes after the first cycle). Then every cycle is weighted (first cycle with 10% and second with a 90%) to afford the reference emission per test.

UN GTR NO. 15

The title of this GTR is “Worldwide harmonized Light vehicle Test Procedures (WLTP)” (ECE/TRANS/180/Add.11) [15]. This global technical regulation (GTR) aims at providing a worldwide harmonized method to determine the levels of gaseous, particulate matter, particle number, CO2 emissions, fuel consumption, electric energy consumption and electric range from light-duty vehicles in a repeatable and reproducible manner designed to be representative of real world vehicle operation. The results will provide the basis for the regulation of these vehicles within regional type approval and certification procedures [17].

According to this GTR, all vehicles are classified in three classes:

- Class 1 vehicles have a power to unladen mass ratio (Pmr) ≤ 22 W/kg.
- Class 2 vehicles have a power to unladen mass ratio > 22 but ≤ 34 W/kg.
- Class 3 vehicles have a power to unladen mass ratio > 34 W/kg.

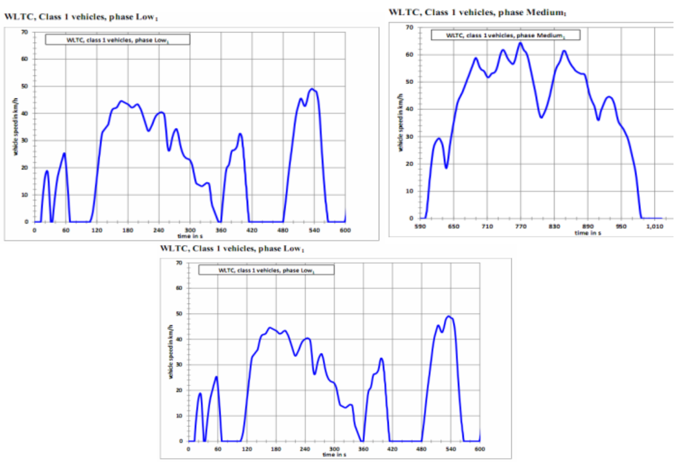

Figure 15 *Class 1 vehicles driving schedule*

A complete cycle for Class 1 vehicles (Fig.15) shall consist of a low phase (Low1), a medium phase (Medium1) and an additional low phase (Low1).

A complete cycle for Class 2 vehicles (Fig. 16) shall consist of a low phase (Low2), a medium phase (Medium2), a high phase (High2) and an extra high phase (Extra High2). At the option of the Contracting Party, the Extra High2 phase may be excluded.

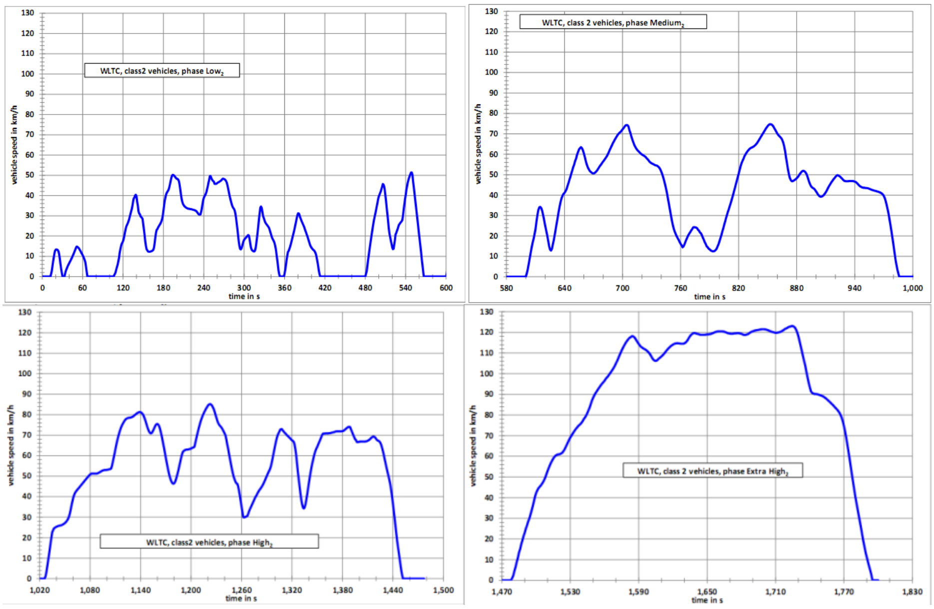

Figure 16 *Class 2 vehicles driving schedule*

Class 3 vehicles are mainly passenger cars. A complete cycle for Class 3 vehicles (Fig. 17) shall consist of a low phase (Low3) with driving speeds bellow 60 km/h, a medium phase (Medium3-1) with driving speeds bellow 80 km/h, a high phase (High3-1) with driving speeds bellow 100 km/h and an extra high phase (Extra High3) with max. speed ove 120 km/h. At the option of the Contracting Party, the Extra High3 phase may be excluded. Main characteristics of this cycle are: Time – 1800 s. Length – 23,26 km, Idle – 13 %, Vmax – 131,6 km/h, Vm – 46,3 km/h.

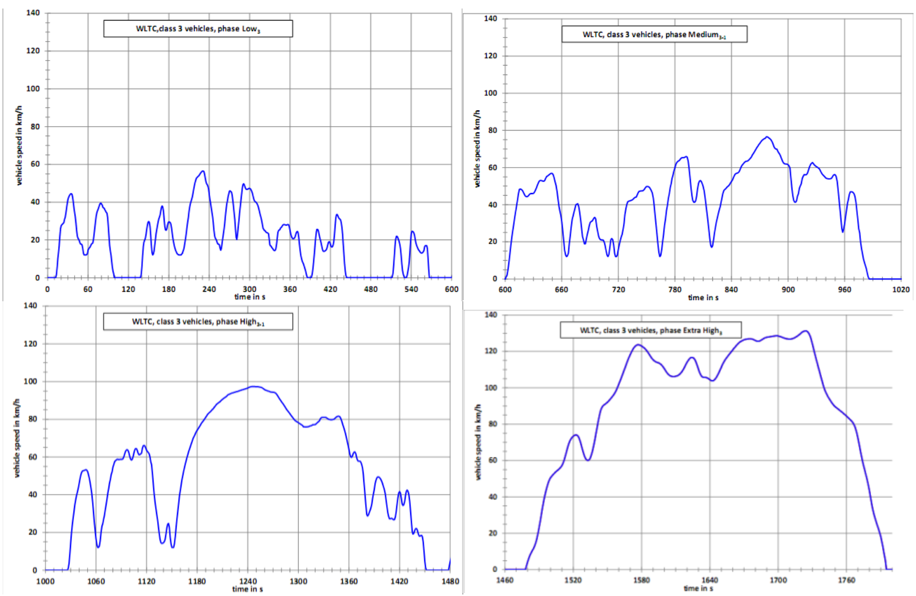

Figure 17 *Class 3 vehicles driving schedule*

REAL DRIVING EMISSIONS

Current tools and methods for evaluating pollutant emissions from road transport are mainly based on knowledge of specific vehicle emissions. Usually these emissions are measured on a test bench using test or driving cycles, or speed vs. time curves. The representativity of these cycles and their descriptive quality under real-world driving or vehicle operating conditions are thus of prime interest for the assessment of pollutant emissions and their evolution in an appropriate manner, in particular with newly developed technologies or fuels, the implementation of new regulations, or simply in function of the changes observed in trips and mobility [18].

The measurement of emissions in real-world driving situations will play an increasingly important role in vehicle and engine development in the future. New tehnologies for extra low engine emissions put new question: does emission testing in standard laboratory corresponds to real life emission of vehicle in-use? This is important since it has been noticed that vehicle emissions in real driving conditions is considerably higher than emissions measured in laboratory. The results collected previously on Euro 3-5 vehicles show that real-driving NOx emissions of light duty diesel vehicles did not change much over the last decade, despite the increased stringency of the limit values (Fig. 18) [19].

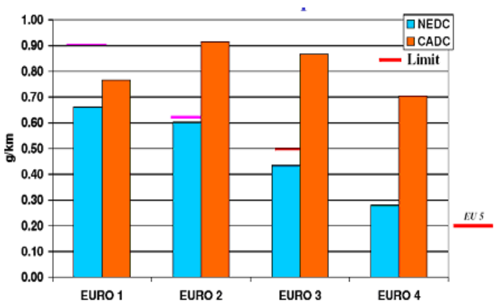

Figure 18 *Approval (blue) and real (red) emission results*

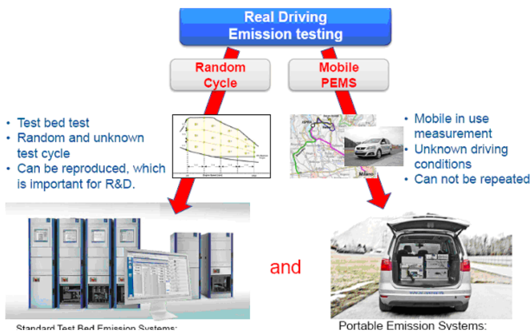

Figure 19 *Possible real emission measurement.*

There are two possibilities to check real emission level (Fig. 19):

- Random cycles in the test bed
- Mobile testing in the road

Main characteristic of test bed test is random and unknown test cycle schematically shown in Fig. 19 [3]. This cycle can be reproduced what can be important for research and development.

A main characteristic of mobile in use testing is unknown driving conditions. This cycle cannot be repeated.

Laboratory testing is preliminary proposed by UN GTR No. 10 on Off-Cycle Emissions. Mobile testing on road will be able after definition of Portable Emission Measurement Systems (PEMS).

PORTABLE EMISSION MEASUREMENT SYSTEM - PEMS

Portable Emissions Measurement Systems (PEMS) have been already included in U.S. legislation to control exhaust emissions of vehicles. EU supports for several years a project that should point to the most suitable methodology for measuring in-use emissions and its introduction in the regular procedure [18].

There is no problem with portable measurement of gaseous emission, but measurement particulate matter, especially particle number (PN) emission, is much bigger problem. Therefore, EU has undertaken PEMS project to validate potential instruments which can be used in mobile testing [6].

Potential instruments for particle number in-use measurement are shown in Table 2.

Table 2 *Potential portable emission instruments*

Company	**PEMS**
Control Systems	m-PSS
AVL	Micro Soot Sensor
Dekati	DMM 230
Dekati	ETaPS
Sensors	SEMTECH PPMD
Horiba	OBS-TRPM
Pegasor	PSS M
Matter Aerosol	Nanomet M3

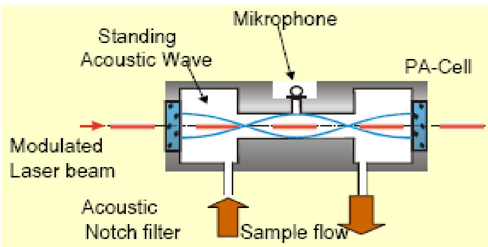

Figure 20 *Working principle of AVL MSS*

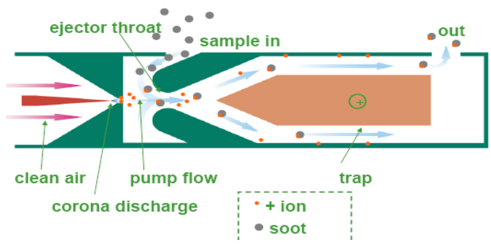

Figure 21 *Working principle of Pegasor PSS M*

More information on these instruments can be found in literature [6, 20, 21]. Only two of them will be shortly presented here just to have certain idea how they work.

The AVL Micro Soot Sensor (MSS) [22] is a system for continuous measurement of soot (not total PM) concentration in diluted exhaust from IC engines using The photoacoustic measuring principle. Fig. 20 shows its working principle. Highly absorbent soot particles is irradiated with modulated light. The periodic warming and cooling and the thus-resultant expansion and contraction of the carrier gas can be viewed as a sound wave and detected with microphones. Clean air does not produce a signal. With soot-laden air or exhaust gas, the signal increases proportionately with the concentration of soot in the measured volume.

Pegasor Particle Sensor (PPS) very compact and small instrument, which does not need special dilution (Fig. 21) [23, 24]. It uses raw exhaust gas and can be installed near to the exhaust pipe in the vehicle or at the test bench. At the entrance of sensor active part, fresh clean air is ionized by ~2 kV high voltage discharge at platinum corona needle. Positive ions are pushed through ejector nozzle which generates under pressure for the suction of sample gas with particles. After the ejector, turbulent mixing ensures a good connections between ions and particles and deposit of certain quantity of ion on particle surface. Positive free ions (not deposited on particles) are removed from sample flow by positive trap voltage from central electrode. The generated electrical field pushes free ions towards the wall of sensor's body where they are collected and only ionized particles leave the sensor [6]. An electrometer measures the difference between charge before (sample in) and after (sample out) faraday cup. This difference is proportional to the quantity of particles (total mass or number) in exhaust sample.

EU project on PEMS is still in active phase and different instruments are under investigation and comparison. Final decision on emission in-use testing should be done by 2017. PEMS will be introduced in Euro 6+ standard probably in the form of conformity of production check. The usage of most advanced technology makes it possible to reduce negative environmental effects of automobile and mobile machinery to minimum.

CONCLUSIONS

Permissible emission levels defined by existing standards are so severe that further reduction is practically impossible. Special problem is the inclusion of particle number limits for diesel engine and direct injection gasoline engine emission certifications.

Further reduction of air pollution by motor vehicle will be done by the improvement of testing procedure which should correspond to the real driving conditions. Global Technical Regulations enable World harmonization of vehicle regulations and creation of uniform provisions for certification testing procedure.

Real driving emission testing is under consideration and it will be included in emission certification procedure after definition of portable emission measurement systems.

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