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LEGAL CONDITIONS IN THE ASPECT OF POLLUTANT EMISSIONS FROM EXHAUST SYSTEMS OF RAIL VEHICLES ENGINES

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Abstract

One of the main objectives of the European transport policy is to increase the share of alternative modes of transport – revitalization of rail transport, promotion of water transport and development of intermodal transport, which will help to reduce the dominance of road transport. The adverse impact of transport can be felt both in the natural environment and in society, where the dynamic development of this sector has enabled significant civilization development, with the effects varying depending on the level of economic development, the degree of advancement and use of the various transport sectors, geographical location (including climate), and also the sensitivity of the elements of the environment. Considering contemporary transport hazards, it is important to prevent them from occurring, and when that is not possible – limiting their impact on the environment and reducing the scale and extent of negative impacts. The impact of rail transport on the environment and safety is much lower compared to road transport. The impact of rail transport on the environment mainly comes from the emission of noise and vibration, pollution (from diesel locomotives) and land occupation. The article presents information on the current legal conditions regarding the emission of pollutants from rail vehicles. Information with reference to research tests and emission limit values was included. The subject of tests in real traffic conditions was also mentioned as the direction of changes in vehicle homologation tests.

Keywords: *rail vehicles, combustion engines, exhaust emission, research tests, transport, environmental protection*

1. Introduction

Modernization of diesel locomotives in domestic conditions is a method of reducing exhaust emissions [8]. Exhaust emissions from railway vehicles constitutes a small share of the total emissions from means of transport [9, 10, 12]. Studies conducted by XX [11] indicate various energy consumption levels for rail transport. The analysis of years 1990–2014 indicates an energy consumption reduction in rail transport in Western Europe by 18%, and in Eastern Europe by as much as 45%. The results of the analyses indicate a more than 50% reduction in the consumption of fossil fuels. Rail transport is responsible only for 1.7% of energy consumption in road transport (in Western Europe) and 2.5% energy consumption in Eastern Europe (Fig. 1).

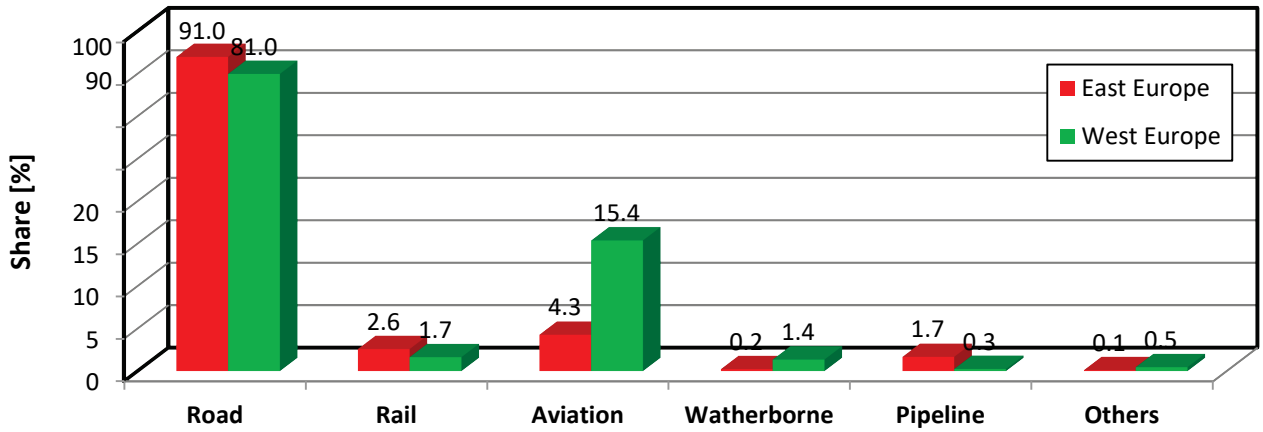

Fig. 1. Share of transport means in total transport energy consumption in Europe in 2014 [11]

2. Development of railway vehicles exhaust emissions regulations in Europe

Exhaust emission limits for non-road mobile machinery (NRMM) equipped with compression-ignition engines, introduced on 16.12.1997 by Directive 97/68/EC [1], have been divided into Stage I and Stage II standards. These standards included engines with a power range of 37-560 kW. This division did not apply to railway vehicle engines, however.

The Directive 2004/26/EU [2] introduced in 2004 amending the previous directive, includes rail vehicles and locomotives. This directive contains a breakdown into the following stages:

– Stage III A – for vehicle engines introduced to the market after 1.1.2006; it covers engines with power of 19-560 kW including engines of rail vehicles and locomotives,
– Stage III B – for engines produced after 1.1.2011 including engines of rail vehicles and locomotives,
– Stage IV – in force since 1/14/2014, covers engines with the power of 56-560 kW, but it does not apply to rail vehicles.

The Stage III A and III B emission limits were adapted for engines with power above 130 kW used for driving rail vehicles of several categories: R – rail, RL – rail locomotive, RH – rail haul and RC – railcars. Exhaust emission limits are presented in Tab. 1 (for Stage III A) and Tab. 2 (for Stage III B).

Tab. 1. Stage III A Standards for Rail Traction Engines [2]

Category	Net Power	CO	HC	HC + NO_x	NO_x	PM
	kW	g/kWh				
RC A	130 < P	3.5	–	4.0	–	0.2
RL A	130 ≤ P ≤ 560	3.5	–	4.0	–	0.2
RH A	560 < P	3.5	0.5*	–	6.0*	0.2
* HC = 0.4 g/kWh and NO_x = 7.4 g/kWh for engines of P > 2000 kW and D > 5 litres/cylinder						

Tab. 2. Stage III B Standards for Rail Traction Engines [2]

Category	Net Power	CO	HC	HC+NO_x	NO_x	PM
	kW	g/kWh				
RC B (railcar)	130 < P	3.5	0.19	–	2.0	0.025
R B (locomotive)	130 < P	3.5	–	4.0	–	0.025

The introduction of the Stage III B limit changes the division of engines: only two categories have been adopted, for engines below and above 130 kW. The new norm reduces the particulate

matter mass emission limit 8-fold. For engines below 130 kW, separate HC and NO_x emission limits have been introduced. For engines over 130 kW, the total sum emission limit for HC and NO_x remains.

The latest Stage V emission standard includes locomotive engines (RLL) and railcars (RLR) of any power and fuel ignition method. Emission limits are included in Tab. 3. Auxiliary engines used in locomotives or wagons should meet emission standards for the NRE or NRS category (Tab. 4).

Tab. 3. Stage V emission standards for rail traction engines [4]

Engine category	Ignition type	Net Power	CO	HC[a]	NO_x	PM	PN
		kW	g/kWh				#/kWh
RLL (Locomotives)	CI/SI	P > 0	3.50	4.00[b]		0.025	–
RLR (Railcars)	CI/SI	P > 0	3.50	0.19	2.00	0.015	1×10^{12}

[a] A = 6.00 for gas engines
[b] HC + NO_x

Tab. 4. Stage V emission standards for nonroad engines (NRE) and NRS used as auxiliary units of locomotives or rail vehicles [5]

Category	Ignition	Net Power	CO	HC	NO_x	PM	PN
		kW	g/kWh				#/kWh
NRE-v/c-1	CI	P < 8	8.00	7.50[a,c]		0.40[b]	–
NRE-v/c-2	CI	8 ≤ P < 19	6.60	7.50[a,c]		0.40	–
NRE-v/c-3	CI	19 ≤ P < 37	5.00	4.70[a,c]		0.015	1×10^{12}
NRE-v/c-4	CI	37 ≤ P < 56	5.00	4.70[a,c]		0.015	1×10^{12}
NRE-v/c-5	All	56 ≤ P < 130	5.00	0.19[c]	0.40	0.015	1×10^{12}
NRE-v/c-6	All	130 ≤ P ≤ 560	3.50	0.19[c]	0.40	0.015	1×10^{12}
NRE-v/c-7	All	P > 560	3.50	0.19[d]	3.50	0.045	–
NRS-vr/vi-1a	SI	0 < P < 19	610	10[a]		–	–
NRS-vr/vi-1b	SI	0 < P < 19	61	8[a]		–	–
NRS-v-2a	SI	19 < P < 30	610	8[a]		–	–
NRS-v/v-2b	SI	19 ≤ P ≤ 56	4.40[e]	2.70[a]		–	–

[a] HC+NO_x
[b] 0.60 for hand-startable, air-cooled direct injection engines
[c] A = 1.10 for gas engines
[d] A = 6.00 for gas engines
[e] Alternatively, any combination of values satisfying the equation $(HC + NO_x)* CO^{0.784} \leq 8.57$, as well as the following conditions: CO ≤ 20.6 g/kWh and $(HC + NO_x) \leq 2.7$ g/kWh
where: v – variable speed, c – constant speed.

The analysis of regulations concerning the modern exhaust emission limits standards of rail vehicles indicates that attempts to significantly simplify them have been made. The division of these vehicles is limited – only two categories remain in the Stage V standard: locomotives and railcars. The separation based on engine power for these vehicles has been completely eliminated, even though spark ignition type engines are also included (Tab. 5).

The simplification of rail vehicles division into two categories (Stage III B and Stage V) means that locomotives and rail vehicles only meet the same emission limits for carbon monoxide. Emission limits for other exhaust components are different for locomotives and for rail vehicles (railcars). For locomotives with combustion engines PM, limits are higher (than for engines of

railcars) and engines of such vehicles must meet the combined HC + NO_x emission limits (Fig. 2). Railcars must meet separate HC and NO_x limits. In addition, numerical limits for particulate emission have been introduced for these engines.

Tab. 5. The effects of introducing new emission limits Stage III A, Stage III B and Stage V

Norm	Stage III A	Stage III B	Stage V
Vehicles division	Railcars RC A, P < 130 kW	Railcars RC B, P < 130 kW	Railcars RLR, CI/SI; P > 0 kW
	Locomotives RL A, 130 kW < P < 560 kW	Locomotives R B, P > 130 kW	Locomotives RLL, CI/SI; P > 0 kW
	Haul RH A, P > 560 kW		

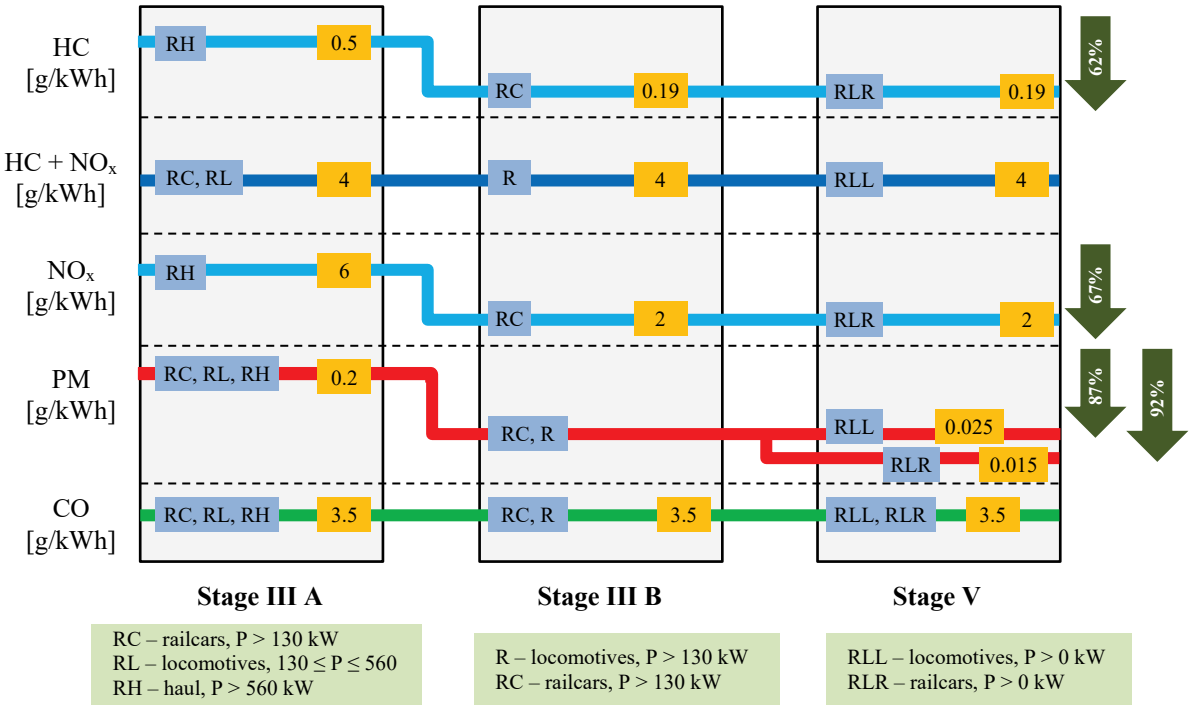

Fig. 2. A simplified visualization of the exhaust emission standards for diesel locomotives

Stage V emission limits have been reduced relative to the Stage III limits, for some exhaust components even by several dozen percent: for HC – by 62%, for NO_x by 67%. The mass emission limit of particulate matter was reduced the most: by 87% or by 92% depending on the rail vehicles group. The Stage V standard is already in force for new type approvals (1.1.2018), however, the launch date of these engines into the market is subject to an annual delay period (Fig. 3).

The procedure for railcar testing is identical to C1 cycle in the norm ISO 8178. The locomotive procedure is identical to the F cycle of ISO 8187. The emission durability period (EDP) for stage V rail vehicles is 10,000 hours. The emission durability period is the number of hours used to establish the deterioration factors (it means a set of coefficients indicating the relationship between emissions at the beginning and the end of the emission durability period).

The NRSC cycle (Non-Road Steady Cycle – stationary cycle for non-road machinery) is used to measure the exhaust emissions in Stages III A and III B from engines used for propulsion of railcars and locomotives [3].

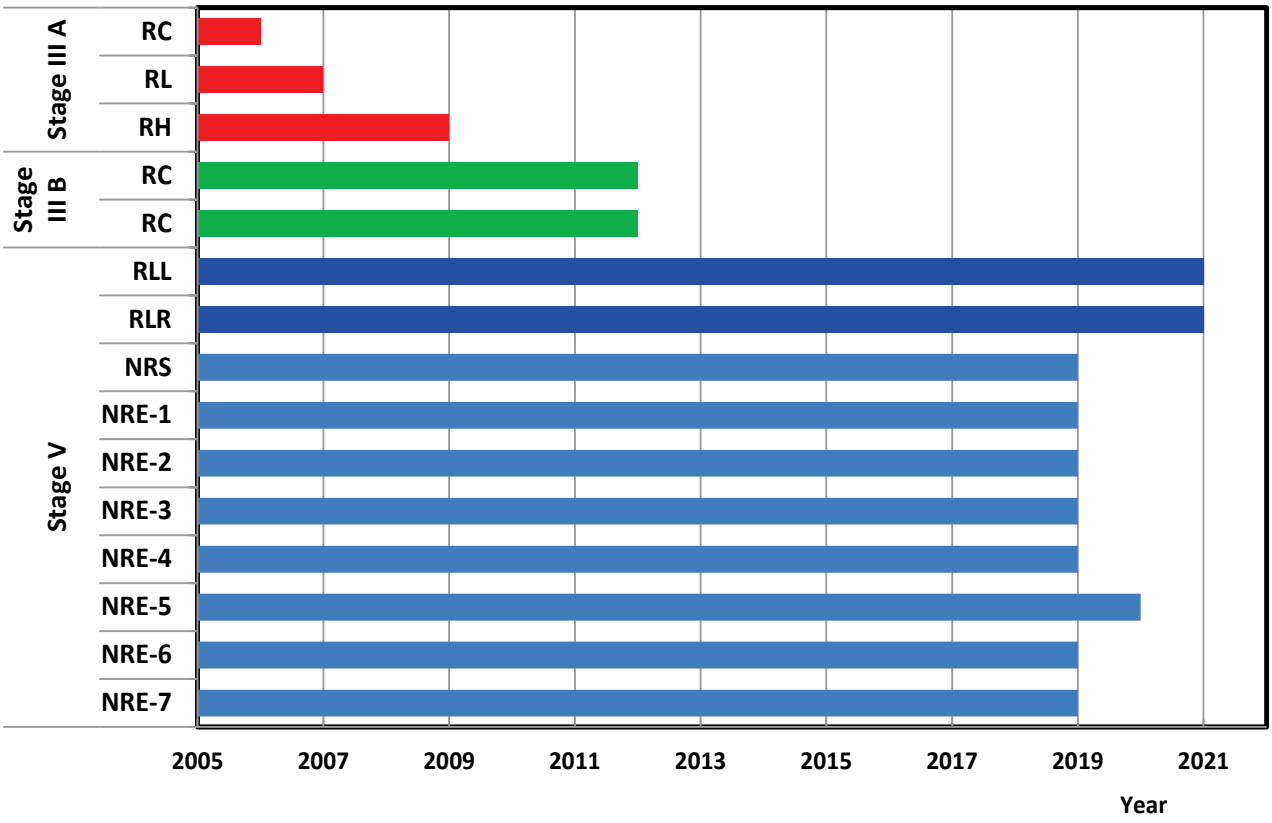

Fig. 3. The dates of various the rail vehicles exhaust emissions regulations coming into effect

3. Type approval testing

Tests of emissions of harmful pollutants in exhaust gases, carried out in typical laboratories testing vehicles and engines, can be divided into developmental and control ones. As part of the former, various works are carried out related to the development of new models of vehicles and engines, including primarily their injection systems, timing, or systems reducing the content of harmful substances in the exhaust. For this type of research, extensive measuring equipment is used that allows continuous exhaust gas analysis and modal analysis, which allows measurements to be made practically in every phase of the relevant test.

The following tests can be distinguished as part of follow-up tests:

– homologation (NTA – New Type Approval),
– conformity of production (COP; tests of vehicles taken at random from serial production to conformity with the approved type),
– periodic tests at vehicle inspection stations (in the case of motor vehicles).

The newly constructed vehicle must obtain a homologation certificate that allows it to move. Certification procedures are a time-consuming and complicated process. The exhaust gases toxicity tests of railway vehicle engines are carried out in stationary tests. Regarding locomotives, this is the ISO 8178-F test (Fig. 4). The load in the test is given by using, for example, electric brake.

As part of the control tests, already after the engine is installed in the vehicle, after a given period of operation, tests of the toxicity of exhaust gases are performed on a station equipped with, among others, a water resistor. Emission parameters – concentration of individual toxic components in the exhaust – are determined using suitable gas analysers. The tested values of exhaust parameters are obtained after the sample gas is delivered to the measuring device (probe mounted in the exhaust system of the locomotive engine). Engine operating parameters, including its power, are determined from the driver's interface – control panel in the cabin.

Fig. 4. Methodology of research on a water-based resistor (ISO 8178-F test)

4. New RDE test methods

Internal combustion engines of railway vehicles, in the aspect of exhaust emissions, are type approved only using stationary dynamometers. The work carried out in recent years indicates that the qualitative and quantitative measurements of exhaust emissions from internal combustion engines performed in laboratory conditions may significantly differ from the actual emission of a given category vehicle, which also holds true for rail vehicles. Therefore, continuous activities are being undertaken to develop detailed and universal methods for assessing vehicle exhaust emissions in real operating conditions. For passenger cars and heavy vehicles, such activities are qualified as RDE measurements (Real Driving Emissions), which do not replace the WLTP laboratory test, but are instead added to complement it. Recently, work has begun on defining a methodology for this type of tests for rail vehicles. RDE guarantees that cars deliver low emissions in real driving conditions. Europe is the first region in the world to introduce such on-road testing, marking a major leap in the testing of car emissions. In 2015, the European Union adopted the first two legal acts aimed at implementing a new procedure for testing vehicle exhaust emissions in real RDE driving conditions. The RDE testing applies to all new passenger cars as of 1 September 2017. Research conducted in recent years by research centres has clearly shown that tests conducted in stationary conditions differ significantly from the results of tests carried out in real traffic conditions for all vehicle categories. Determining the exhaust emissions in the road conditions requires the use of PEMS (Portable Emission Measurement System) devices, and is performed in 3 sections: urban of up to 60 km/h, rural between 60-90 km/h and motorway over 90 km/h. These testing methods are gradually being implemented into rail vehicles as well as road--rail machines and devices, along with determining the appropriate operating conditions to ensure the test results reliability, as shown in Fig. 5.

5. Conclusions

Contemporary emission limits for rail vehicles mean that combustion engines are equipped with systems similar to those of motor vehicles. The Stage V limits are a bit stricter than the Stage III B standard for mass emissions of particulate matter. Even though the remaining Stage V emission limits did not change compared to Stage III B, the binding power ranges of rail vehicle engines were changed.

The global harmonization of emissions legislation also covers rail vehicles. The division of the power ranges of these vehicles is limited, with consequent expansion of the scope of their research. The testing proposals for such vehicles include both static tests on the dynamometer (engines or vehicles) and road tests. The latter are a novelty introduced in Heavy Duty Vehicles in 2013 (Euro VI; Conformity Factor), currently in motor vehicles (WLTP test). This approach means that the proposals for introducing road tests for rail vehicles will appear ever more partial.

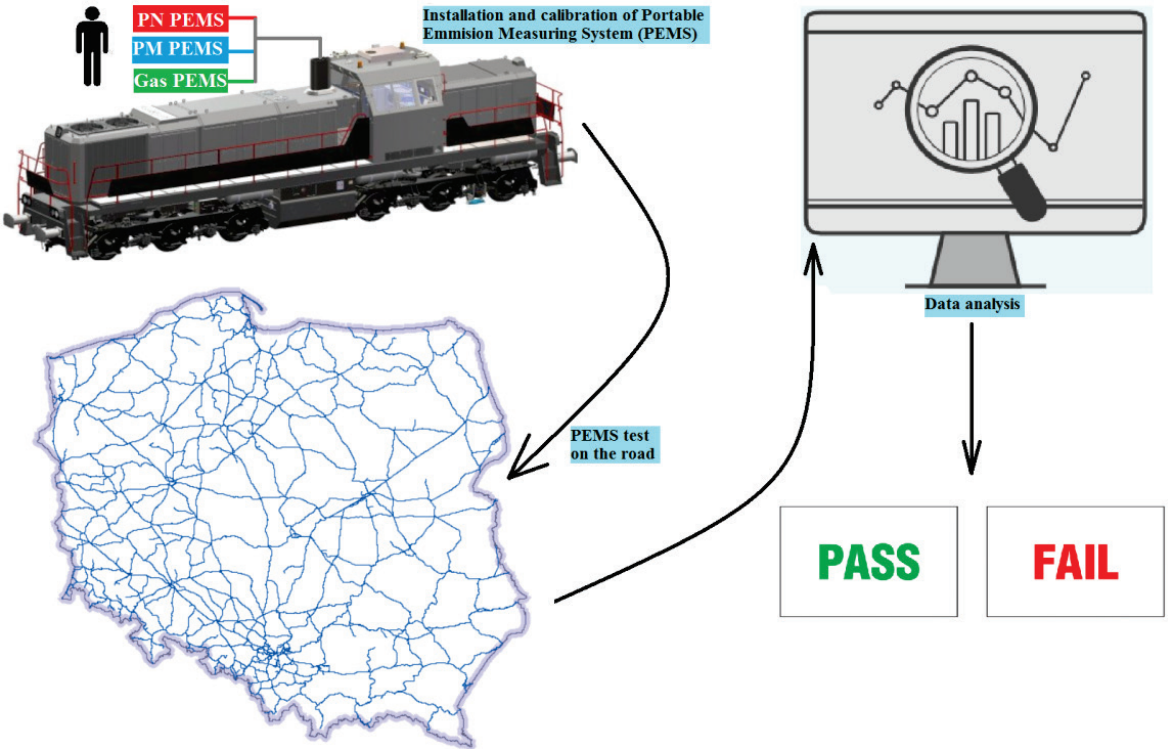

Fig. 5. Real Driving Emissions test procedure for rail vehicles

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