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Czech Technical University in Prague, Faculty of Mechanical Engineering

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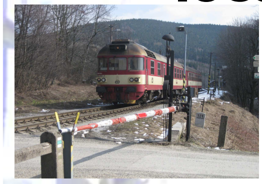
On-track measurements of diesel motorized car and locomotives during line-haul passenger service



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Background:

Real driving emissions are often higher than those during laboratory certification tests as they include conditions for which some engines are not optimized. They are monitored on heavy on-road vehicles in the EU and U.S., with likely extension to non-road mobile machinery (NRMM).

Testing of **non-road engines over 560 kW** is difficult – there are few laboratories, removing and transporting engines is expensive. Diesel-electric locomotives can be tested at standstill using a load bank. **Diesel-hydraulic vehicles need to be moving in order to maintain load on the engine.**

Portable on-board emissions monitoring systems (PEMS) can be used, but surprisingly, given safety and operational constraints, there is not much available space on many types of machinery including rail vehicles.

Goal: Evaluation of real driving (rolling?) emissions of diesel rail vehicles during regular service.

Approach:

- On-board monitoring system fitted into the non-through isle of the engine compartment during periodic service of the car/locomotive at the depot.
- Instrumented vehicle put into scheduled passenger service on Czech Railways Prague-Tanvald line.
- Miniature PEMS used by the authors since 2009 (presentation 2010 and poster 2015 at ETH). Similar system used by Graver et al. (2015, 2016) in United States.
- "High-end" PEMS including FTIR and NanoMet used in anticipation of aftertreatment after repowering.

Vehicles tested:

- CKD series 749 locomotive, diesel-electric, 1100 kW engine
- CKD series 754 locomotive, diesel-electric, 1460 kW engine
- Series 854 motorized car, diesel-hydraulic, 588 kW engine

All high mileage engines from 60-90's near their useful life.

Calibration of speed-density equation:

Diesel-electric: Control system-reported electric power output, published engine and generator efficiency.

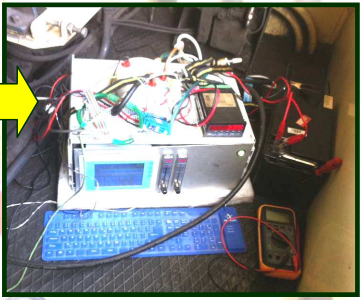
Diesel-hydraulic: Manufacturer-provided intake air flow data.

U.S. 2-stroke diesel-electric: fuel consumption measurement during load bank testing (Graver 2015 and 2016)

Instrumentation & installation

Mini-PEMS ("Poor man's PEMS")

CO, CO2: NDIR - NO, NO2: electrochemical cells
PM mass: proportional sampling gravimetric
Indicative online PM mass: light scattering
Particle length: measuring ionization chamber



All PEMS options:

Position & speed: GPS

Intake air flow: calculated using speed-density method from measured engine rpm and measured intake air pressure and temperature

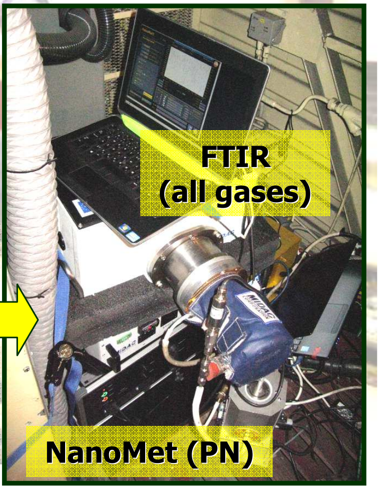
Exhaust flow: calculated from intake flow (direct measurement difficult – space constraints)

Severe environment: 0-55°C, vibrations, "rail dust" (a mixture of soot, oil, grease, iron oxide brake dust), lack of access during most of the train run

High-end PEMS (engines w/aftertreatment)

FTIR, 0.5 cm-1 resolution, 6 m path length:
- **Greenhouse gases CO_2, N_2O, CH_4**
- **Reactive nitrogen NO, NO_2, NH_3**
- **CO, formaldehyde, acetaldehyde, ...**

Particle number: NanoMet3
Heated line 130 C
~ 100 kg incl. batteries, ~ 400 W consumption



Low-profile installation due to overhead traction lines

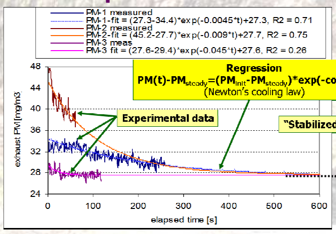
Installation of exhaust flow measurement module difficult or impossible.

Lack of space: Confinement into "dead-end isle" of engine compartment (nothing can be put outside of the train, no opening to conductor cabin, one isle to remain free for train engineer to walk through during turnarounds).

Conclusions & take-home

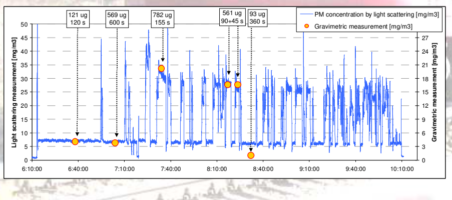
- **PEMS measurement of rail vehicles challenging but feasible, and useful.**
- **Emissions per passenger relatively low**

Calculation of steady-state conditions comparable to the laboratory



(Vojtisek-Lom ASME 2012)

Calibration of online particle measurement with gravimetric sampling during steady-state operation



Overall exhaust emissions are low compared to road transport due to higher efficiency and far less transient operation of rail transport. The relative health risk is lower as fewer people live near railroads.

Summary results per train

	g/km					Fuel	
	CO	NO	CO2	PM [g]	PN [#]	kg/km	L/100km
Locomotive 754, 4 cars, average load 150 passengers assumed							
Praha-Tanvald	3.0	93	4506	0.68	8.5E+13	1.42	171
Tanvald-Praha	13.8	66	3201	0.44	5.6E+13	1.01	122
Route avg	8.4	79	3853	0.56	7.0E+13	1.22	147
Locomotive 749, 5 cars, average load 150 passengers assumed							
Praha-Tanvald	24.1	93	5361	1.10		1.71	206
Motorized car 854, 1-3 cars, average load 150 passengers assumed							
All routes	8.2	43	2835	0.14		0.89	107

Summary results per passenger

	g/km/passenger					fuel per passenger	
	CO	NO	CO2	PM [g]	PN [#]	kg/km	L/100km
Locomotive 754, 4 cars, average load 150 passengers assumed							
Praha-Tanvald	0.02	0.62	30	0.0045	5.6E+11	0.009	1.14
Tanvald-Praha	0.09	0.44	21	0.0029	3.7E+11	0.007	0.82
Route avg	0.06	0.53	26	0.0037	4.7E+11	0.008	0.98
Locomotive 749, 5 cars, average load 150 passengers assumed							
Praha-Tanvald	0.16	0.62	36	0.0073		0.011	1.37
Motorized car 854, 1-3 cars, average load 70 passengers assumed							
All routes	0.12	0.61	40.49	0.0020		0.013	1.53

NO_x, PM comparable to EU 5 cars!

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