REPRODUCTION OF CHASSIS DYNAMOMETER DRIVING CYCLES ON THE ROAD AS A MEANS OF ACHIEVING REPEATABLE ON-ROAD EMISSIONS TESTS

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Abstract

Efforts to reduce vehicle emissions, a prime source of air pollution in many metropolitan areas, require emissions measurements throughout the useful life of the vehicle. A chassis dynamometer is typically used for the measurement of emissions from light-duty vehicles, and often also from in-use heavy-duty vehicles. Chassis dynamometers are, however, relatively few and far between, notably for heavy vehicles, due to their complexity and cost. In many cases, portable, on-board systems are thus used, and the vehicle is tested on the road, in lieu of on a dynamometer. On-road testing is generally not repeatable and subject to many influencing factors, and as such. has the capabilty to cover a wide range of real-world operation. Sometimes, however, repeatable tests are called for. This paper discusses various methods of reproducing chassis dynamometer driving cycles on a test track or other suitable area. Examples are given from measurement of emissions at a local airport. A simple portable, on-board system was used to measure mass emissions of NOx, CO2 and PM, and a GPS device with a fast (5 Hz) update rate was used as a source of the actual road speed data given as a feedback to the driver. The repeatability of data was generally good, with coefficients of variance of under 10% among multiple runs of each test. While more accurate transient speed data are available using other devices, GPS offers minimal installation time and universal use on any type of vehicle.

Keywords: *Real-world emissions, portable on-board monitoring systems, emissions test repeatability*

1. Introduction

Efforts to reduce vehicle emissions, a prime source of air pollution in many metropolitan areas, require emissions measurements throughout the useful life of the vehicle. As emissions vary even among seemingly identical vehicles, and are a function of many factors, measurements on a large number of vehicles under a variety of atmospheric, operating and other conditions are necessary to understand the real-world emissions of a given fuel, technology, or vehicle group. While some measurements can be accomplished in ordinary operation, repeatable tests are also necessary. Currently, repeatable tests are conducted on chassis or engine dynamometers. Transport of heavy-duty vehicles to chassis dynamometer facilities, or removal of their engines for engine dynamometer tests, are expensive and time-consuming tasks. Moreover, a very small number of heavy-duty chassis dynamometers are in operation.

As an alternative, chassis dynamometer driving cycles can be driven on a suitable test track, while emissions are measured with a monitoring system installed on board of the tested vehicle. To repeat the cycles, a vehicle speed signal with sufficient accuracy and update rate is necessary. Vehicle speed signal can be sourced from the engine control unit [1] or various sensors sensing driveshaft or wheel rotational speed, or directly the road speed. One option is to use a global positioning system receiver. Traditional GPS units with one-second update rate are, however, too slow to reproduce transient cycles. The paper describes reproduction of drive cycles using a fast, 5 Hz update rate GPS system, and results obtained while conducting emissions tests of a van at a local airport, in preparation of a larger study of heavy vehicles powered by alternative fuels or retrofitted with exhaut gas aftertreatment systems.

2. Experimental

The tests were carried out on a former military airport near Ralsko, Czech Republic. The airport features a 2.4-km runway, with taxiways on both sides of the runway. The maximum speed at which the vehicle could be safely turned around was determined experimentlly to be 30-40 km/h. Three common driving cycles were selected: City portion of the ECE light-duty vehicle cycle, and two transit bus cycles recommended in SAE J-2711 [2]: Manhattan Bus Cycle and Orange County Bus Cycle. These cycles were selected because they could all be driven within the constraints of the airport.

A Renault Master van with a 2.0-liter common rail turbodiesel engine and a 6-speed manual transmission was used as the test vehicle. The van was equipped with a commercially available 5 Hz GPS receiver, coupled with an in-house written software allowing replication of driving cycles. Emissions were measured by a simple portable, on-board emissions monitoring system. Undiluted raw exhaust was sampled from the vehicle's tailpipe using a 6 mm diameter unheated sampling line. CO and CO2 concentrations were measured by a thoroughly tuned and calibrated NDIR bench of the type commonly used in garage-type emissions analyzers, NOx concentrations by electrochemical cells, and a semi-condensing low-angle dynamic laser beam scattering device was used for PM concentrations measurement. Hydrocarbons were not measured. The exhaust gas flow was computed from engine operating data[1].

The installation of the monitoring system and the process of cycle reproduction are demonstrated on Fig. 1.

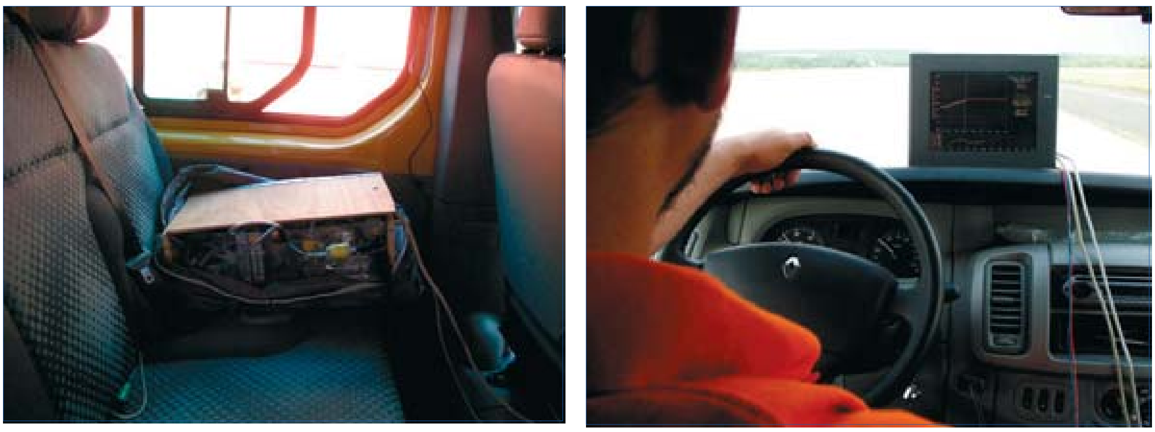

Fig. 1: Portable, on-board monitoring system (left) and drive cycle reproduction (right)

3. Results

Prior to the measurements, the accuracy and stability of the NDIR system was verified by comparing its readings to traditional laboratory instruments during an engine dynamometer test that happened to be underway at the departmental engine laboratory using a direct injection turbodiesel engine running on EN 590 compliant diesel fuel which was also used in the test van. The results from this comparison are shown in Fig. 2. Real-time concentrations of NO_x and PM were not measured by the laboratory instruments.

The instruments were then loaded into the van, and emissions were measured continuously during the trip to the airport, repeated runs of the driving cycles at the airport, and return trip to the university. Not counting pre-conditioning and practice runs, two sets of four and five runs of the

ECE cycle, and two runs each of Manhattan Bus and Orange County Bus cycles were performed. The real-time results for the ECE cycles are shown in Fig. 3.

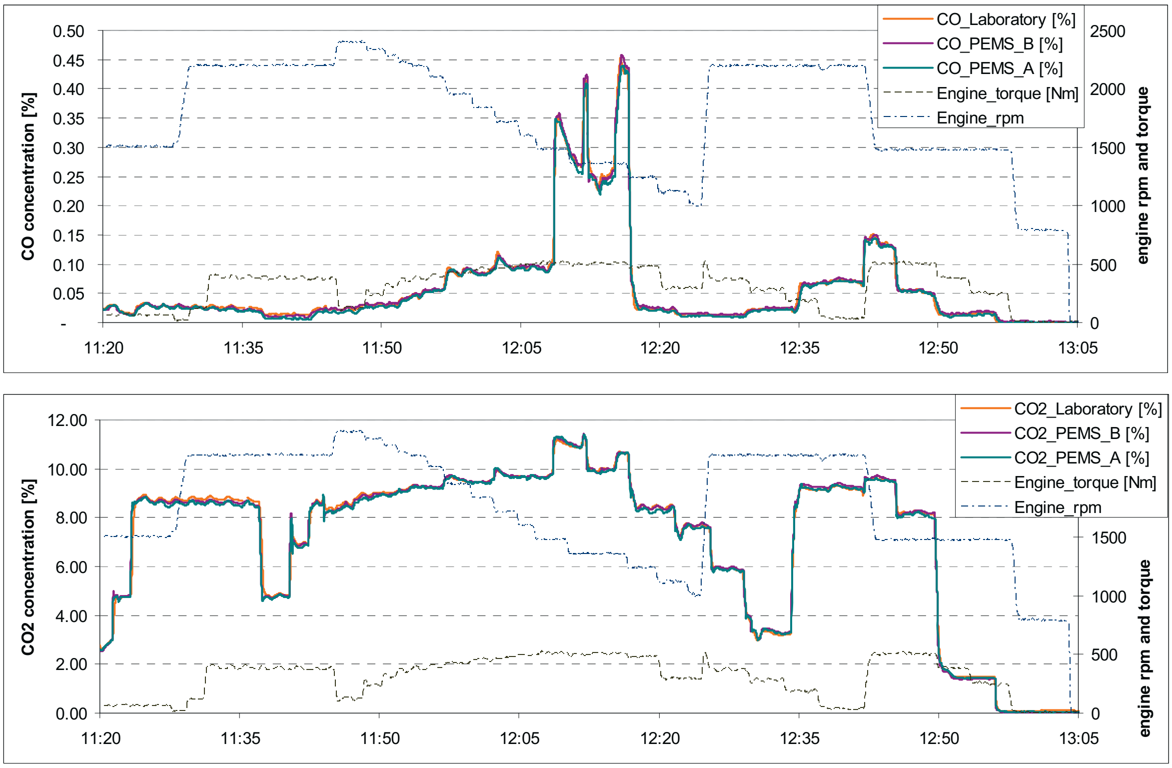

Fig. 2. Comparison of CO and CO_2 concentrations measured by two independent NDIR systems (PEMS A, PEMS B) used in the portable unit with traditional laboratory instruments on an engine dynamometer fitted with a direct-injection turbodiesel engine.

CO emissions during these tests were very low and are were considered to be insignificant, but they are plotted nonetheless in Fig. 4, as they were of interest for several reasons. First, the concentrations were higher during first, preconditioning run of the cycle, than during four subsequent measurement cycles. This demonstrates the need for careful preconditioning of the engine, preferrably using the same cycle as used for the test cycle. Second, the stability of the zero readings was used for checking for drift of the analyzer readings and for evaluating the effect of operating conditions on the emissions. Third, higher „off-cycle“ CO emissions were measured during cold operation of the engine at the very beginning of the trip, and during transients in mountain driving, where CO concentrations up to several hundred times higher than during the ECE cycle runs were observed, as shown in Fig. 4.

4. Discussion

The 5 Hz GPS signal was observed to offer a reasonable compromise. It allowed better replication than a 1 Hz GPS signal or EOBD signals with update rate on the order of 1 Hz, but was judged to be less „user-friendly” than a 10 Hz road speed signal from heavy-duty engine interfaces (SAE J-1939) or an optical speed sensor. Still, given the driver lacking day-to-day experience in cycle driving, relatively good test-to-test repeatability was achieved. The principal benefit of the GPS device is its easy installation and independence of vehicle and engine type and road surface.

The on-board monitoring system has performed well and produced relatively highly repeatable results. The stability of the miniature NDIR system, originally designed for garage measurements of emissions of high emitting petrol-powered vehicles, was excellent. This represents not only technological advances, but is also to a large extent a result of preparation, operation and quality control by qualified personnel. The absolute accuracy of NOx and PM readings was not verified and for certification measurements is certainly of concern, given known issues associated with both electrochemical cells and light scattering instruments. For such purposes, however, different instruments can be chosen; some elaborate on-road instrumentation packages fill the entire bus [3] or a truck trailer [4]; as with all field measurements using portable, on-board systems, the choice of equipment should be made carefully and thoughtfully, after thorough assessment of the needs of the project and resources available. This study demonstrates that repeatable results can be achieved even with simple instruments; therefore, same or better repeatability would be expected should the runs be made with higher-grade instrumentation.

A fast-response GPS might not be the best source of speed signal for this purpose, but offers a relatively good cost/performance ratio and can be used, with minimal efforts and costs, on all vehicles. Likewise, the on-board system utilized might not offer the highest accuracy, but features low cost and simplicity, and ease of use.

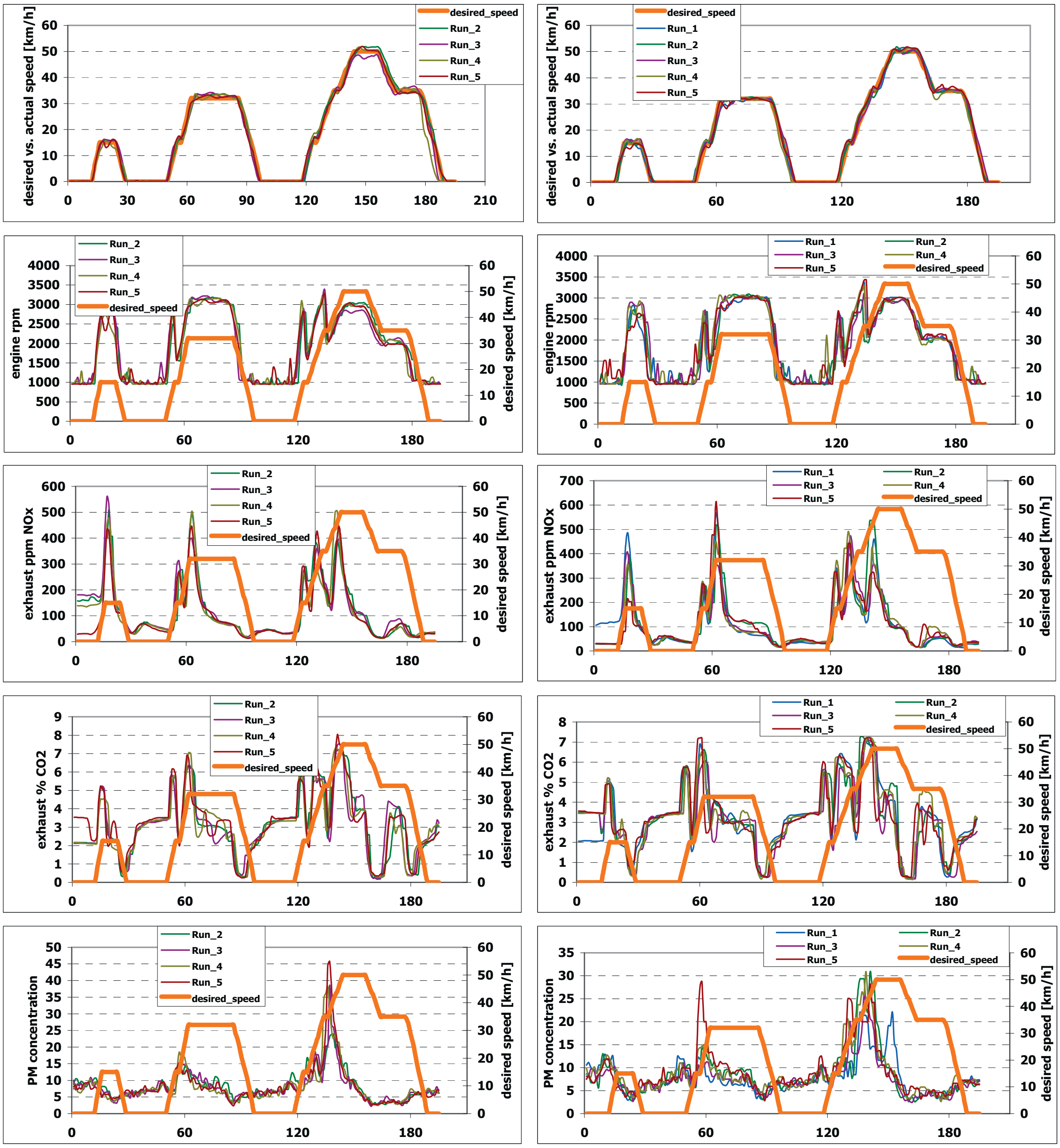

Fig. 3. Comparison of real and desired speed, traces of engine rpm and concentrations of NOx, CO2 and PM along two sets of four (left) and five (right) runs of the ECE cycle

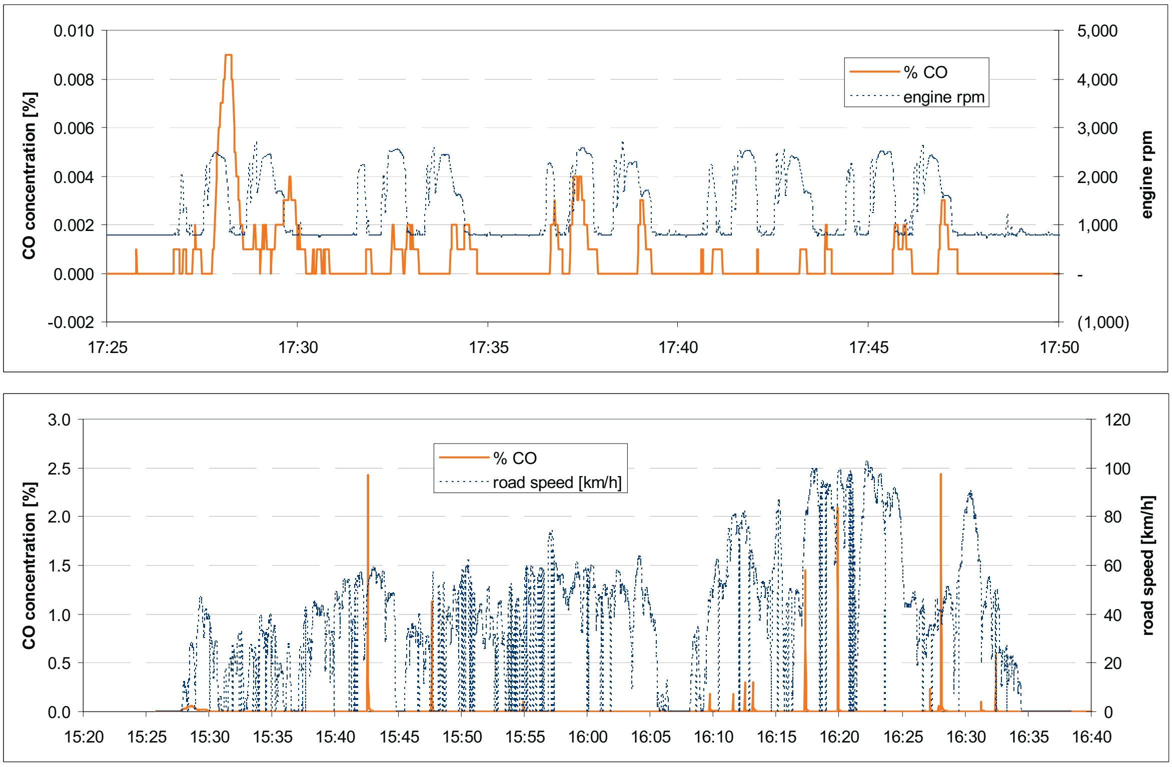

Fig. 4. CO concentrations measured during ECE cycle runs (top) and during the trip to the airport (bottom) show that the levels were very low, with most CO emissions occurring during cold operation and transients. Graphs also suggest that the detection limit and stability of the NDIR analyzer was significantly better than the typical 0.02-0.04% limit of garage-type gas analyzers.

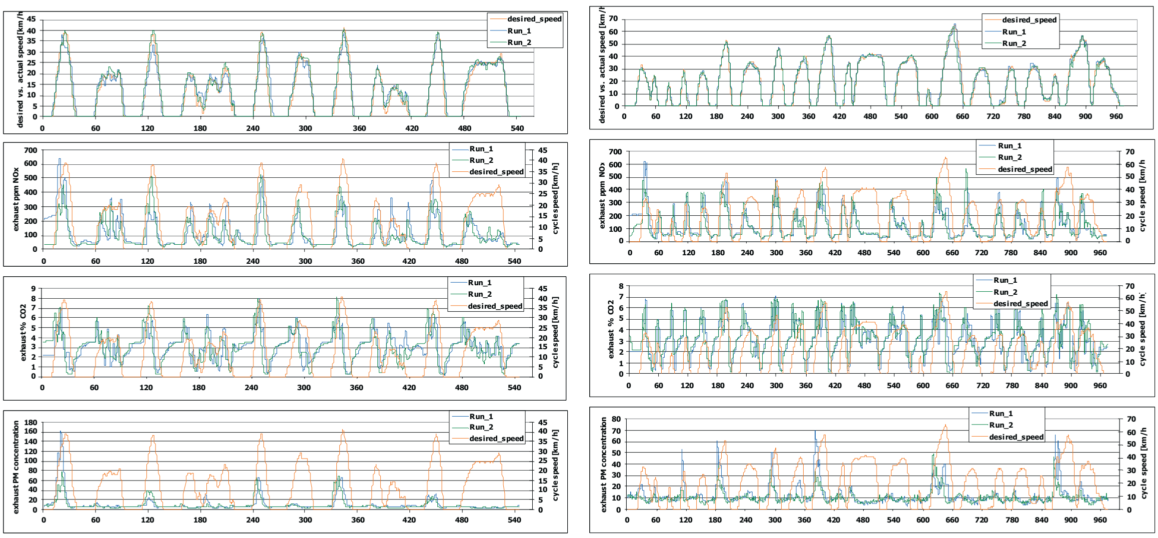

Fig. 5. Comparison of real and desired speed, traces of engine rpm and concentrations of NOx, CO2 and PM along two consecutive runs of Manhattan Bus Cycle (left) and Orange County Bus Cycle (right). These are presented primarily for demonstration purposes.

5. Conclusions

A speed signal from a fast-response GPS was used to reproduce chassis dynamometer driving cycles at a local airport. Emissions measurements, conducted with a relatively simple on-board monitoring system, were reasonably reproducible, with coefficients of variance generally under 10%. The project demonstrates that chassis dynamometer drive cycles can be reproduced on the road, with a reasonable test-to-test repeatability, with a relatively simple, universal system.

Tab. 1. Test summary results for replicated driving cycles

ECE urban - Set A			
	NOx [g]	**CO2 [g]**	**PM [mg]**
Run 1	0.554	128.8	2.22
Run 2	0.548	127.3	2.10
Run 3	0.518	128.0	2.13
Run 4	0.500	132.4	2.19
Average	***0.53***	***129***	***2.16***
COV	***4.8%***	***1.8%***	***2.6%***

ECE urban - Set B			
	NOx [g]	**CO2 [g]**	**PM [mg]**
Run 1	0.509	129.2	2.04
Run 2	0.520	131.0	2.25
Run 3	0.489	123.8	1.99
Run 4	0.517	133.9	2.37
Run 5	0.507	129.4	2.46
Average	***0.51***	***129***	***2.22***
COV	***2.4%***	***2.8%***	***9.2%***

Manhattan Bus Cycle			
	NOx [g]	**CO2 [g]**	**PM [mg]**
Run 1	1.235	264.3	4.08
Run 2	1.165	251.6	3.69
Average	***1.20***	***258***	***3.89***
COV	***4.1%***	***3.5%***	***7.1%***

Orange County Cycle			
	NOx [g]	**CO2 [g]**	**PM [mg]**
Run 1	2.891	652.7	11.85
Run 2	2.841	647.1	11.51
Average	***2.87***	***650***	***11.68***
COV	***1.2%***	***0.6%***	***2.0%***

Acknowledgments

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