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HEAVY-DUTY VEHICLE IN USE EMISSION PERFORMANCE

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ABSTRACT

Engines for heavy-duty vehicles are emission certified by running engines according to specified load pattern or duty cycle. In the US, the US Heavy-Duty Transient cycle has been in use already for a number of years, and Europe is, according to the requirements of the Directive 1999/96/EC gradually switching to transient- type testing.

Evaluating the in-use emission performance of heavy-duty vehicles presents a problem. Taking engines out of vehicles for engine dynamometer testing is difficult and costly. In addition, engine dynamometer testing does not take into account the properties of the vehicle itself (i.e. mass, transmission etc.). It is also debatable, how well the standardized duty cycles reflect real-life-driving patterns.

VTT Processes has recently commissioned a new emission laboratory for heavy-duty vehicles. The facility comprises both engine test stand and a fully transient heavy-duty chassis dynamometer. The roller diameter of the dynamometer is 2.5 meters. Regulated emissions are measured using a full-flow CVS system. The HD vehicle chassis dynamometer measurements (emissions, fuel consumption) has been granted accreditation by the Centre of Metrology and Accreditation (MIKES, Finland).

A national program to generate emission data on buses has been set up for the years 2002-2004. The target is to generate emission factors for some 50 different buses representing different degree of sophistication (Euro 1 to Euro5/EEV, with and without exhaust gas aftertreatment), different fuel technologies (diesel, natural gas) and different ages (the effect of ageing). The work is funded by the Metropolitan Council of Helsinki, Helsinki City Transport, The Ministry of Transport and Communications Finland and the gas company Gasum Oy.

The International Association for Natural Gas Vehicles (IANGV) has opted to buy into the project. For IANGV, VTT will deliver comprehensive emission data (including particle size distribution and chemical and biological characterization of particles) for up-to-date diesel and natural gas vehicles.

The paper describes the methodology used for the measurements on buses, the test matrix and some preliminary emission data on both regulated and unregulated emissions.

BACKGROUND

Engines for heavy-duty vehicles are emission certified by running engines in engine dynamometers according to specified load patterns, called duty cycles. Before modern electronically controlled engine dynamometers existed, the duty cycles used were steady-state cycles that did not represent well the real-world load patterns of road vehicle engines.

Transient engine testing, already used in the US for a number of years (US Heavy-Duty Transient Cycle), was introduced to the European legislation (Directive 1999/96/EC) beginning Oct. 1, 2000. The new ETC (European Transient Cycle) test represents real-world conditions much better than the former steady-state test cycle. In Europe, the ETC test has been required, since the date mentioned above, for all new gas engine types, and for all new diesel engine types utilizing advanced emission control technology, meaning NO_X and/or particulate aftertreatment. From year 2005 on, ETC will be required for all diesel engines.

In addition to ETC, all engines are subjected also to ESC (European Steady Cycle) and ELR (European Load Response) tests. ESC is a steady-state test utilizing three engine speeds and four loads at each speed. Also, idle conditions are also included. Additionally, when counducting an ESC test, the testing facility is required to check NO_X emissions at three randomly selected load points within a certain area in the engine map, to prevent cycle beating. ELR is a smoke opacity test measured at four constant engine speeds increasing the engine load rapidly from 10 % to 100 % several times at each engine speed.

RESTRICTIONS RELATED TO ENGINE TESTING

Even though the introduction of transient engine test cycles was, in terms of correspondence to real-world conditions, a clear step forward compared to steady-state cycles, still several matters remain unaccounted when testing engines only. The whole vehicle and its properties will not be accounted for. Foe example, the load conditions under which the engine in real-world service operates, can vary substantially from vehicle to vehicle, depending on the shape, weight, transmission properties etc. of the vehicle. Also, the usage of different vehicle types utilizing the same engine may alternate considerably. Moreover, in the worst case scenario, there is the risk that in some applications the engine does not operate significantly within the load ranges covered by the engine testing procedure.

The desire to evaluate in-use vehicles poses another problem. Dismounting engines from in-use vehicles and installing them to an engine dynamometer is time-consuming, costly and awkward. This is in most cases impossible, because heavy-duty vehicles can usually not be removed from regular service for such long periods of time.

ADVANTAGES OF TESTING COMPLETE VEHICLES

Most of the difficulties described above can be avoided if engine testing is substituted by complete vehicle testing on a chassis dynamometer. On a chassis dynamometer, the whole vehicle with all of its properties will be accounted for. Also, the time needed for testing is reduced substantially, because a complete vehicle is much simpler to mount on a chassis dynamometer than the work needed to install an engine in an engine dynamometer, Moreover, complete vehicle testing easily enables comparison of different real-world simulating driving patterns, including road gradient.

THE NEW HEAVY-DUTY EMISSION LABORATORY AT VTT

Based on the considerations above, a decision was made at VTT Technical Research Center of Finland to invest in a new heavy-duty emission laboratory. The construction of the new facility was completed in spring 2002. The instrumentation of the new laboratory consists of a transient type road-simulation chassis dynamometer, a transient type engine dynamometer, a full-size CVS system and a modern emission analyzer set for regulated emissions.

The main characteristics of the road-simulation chassis dynamometer are as follows:

- Roller diameter 2.5 m
- Inertia simulation 2 500 - 30 000 kg
- Max axle weight 20 000 kg
- Max wheelforce ±20 000 N (speed 0 - 54 km/h)
- Max power absorption 300 kW (speed 54 - 110 km/h)

The main characteristics of the transient engine dynamometer are as follows:

- Model Froude AC 570 F
- Max power 570 kW (1700 - 4000 rpm)
- Max torque 3200 Nm (150 - 1700 Nm)
- Fast and precise IGBT control for good transient load response

The main characteristics of the full-flow CVS system are as follows:

- Pierburg CVS-120-WT
- Multiple (3) CFV-venturi system
- Maximum flow 120m^3/min
- Secondary tunnel VT-458
- Particle collector PS2000 C

The exhaust analyses are performed with an AMA4000 analyzer set manufactured by Pierburg, Germany. The device is used by both dynamometers on a shared basis.

In addition to the research potential for regulated emissions, all the expertize and instrumentation that VTT has gained over the years in the field of unregulated emissions, and particulate characterization, can now be harnessed to benefit the work among heavy-duty vehicles.

All the emission and fuel economy measurements in the new laboratory are accredited in accordance with the EN ISO/IEC 17025 standard. The methods used are based on European Directives 98/69/EC and 1999/96/EC, and on SAE J2711 and J2264 recommended practices.

TRANSIT BUS EMISSION EVALUATION

At VTT, an extensive emission evaluation program for transit buses is underway. The program is scheduled for years 2002-2004. The emission factors for over 50 buses operating in the Helsinki area will be generated. With several emission cycles, repeats and follow up tests, the total amount of chassis dynamometer tests will peak at over 150.

The test vehicles selected represent different ages and technologies. The emission certification levels range from Euro 1 to Euro 5/EEV (Environmentally Enhanced Vehicle). In terms of fuels, both diesel and natural gas will be involved. Among diesel, there will be there will be individual buses with and without exhaust aftertreatment, whereas all the natural gas buses are equipped with catalysts. In the case of natural gas powerplants, both lean-burn and stoichiometric operating principles will be included.

IANGV (International Association for Natural Gas Vehicles) has bought into the project, and ordered additional measurements that did not belong to the original test matrix of the program. Originally, only regulated emissions (CO, THC, NO_X and total particulate mass) were planned, but the assignment from IANGV added a range of unregulated emission measurements to the program. These measurements include particulate size distribution, chemical and biological characterization of particulates, hydrocarbon speciation, and determination of aldehydes, semivolatile hydrocarbons as well as anions (sulfates and nitrates).

Moreover, the IANGV assignment added also some test vehicles. The amount of natural gas vehicles representing newest fuel distribution technology and exhaust aftertreatment, was increased to three. Also, newest technology diesel buses (Euro 3) will be measured without aftertreatment, with oxidation catalyst and with a CRT device as a reference for the natural gas vehicles.

The test vehicle matrix consists of three vehicle groups: basic vehicles, the so-called speciality vehicles and the vehicles representing the newest CNG technology. The basic vehicles include Euro 1, Euro 2 and Euro 3 diesels, which represent the majority of the fleet being used in Helsinki. The speciality vehicles include oxycat and CRT equipped vehicles as well as the oldest CNG technology buses (model year 1996).

In some cases, several buses of the same batch will be measured for evaluating emission consistence. Also, some buses will be measured repeatedly over the course of the program to define the deterioration properties of the vehicles.

METHODOLOGY

The program utilizes three driving cycles: the ECE15 cycle (Figure 1), which is the urban part of the official European certification cycle for passenger cars, the German originated Braunschweig bus cycle (Figure 2), and the Orange County bus cycle (Figure 3) recommended in the SAE standard J2711, representing a US bus cycle (Figure 3).

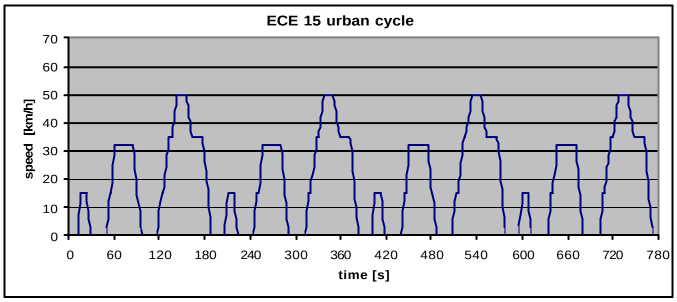

Figure 1. The ECE 15 urban cycle (duration 780 s, length 4.052 km, average speed 18.7 km/h, max speed 50 km/h, share of idle 31 %)

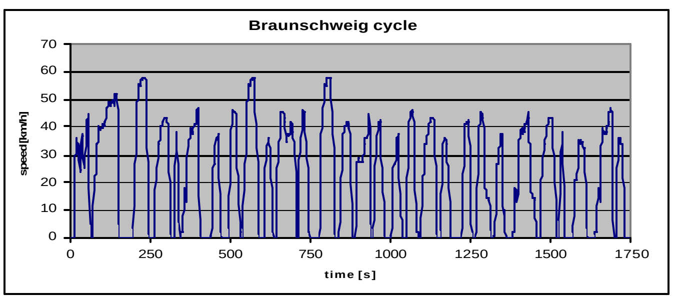

Figure 2. The Braunschweig urban bus cycle (duration 1740 s, length 10.873 km, average speed 22.5 km/h, max speed 58.2 km/h, share of idle 25 %)

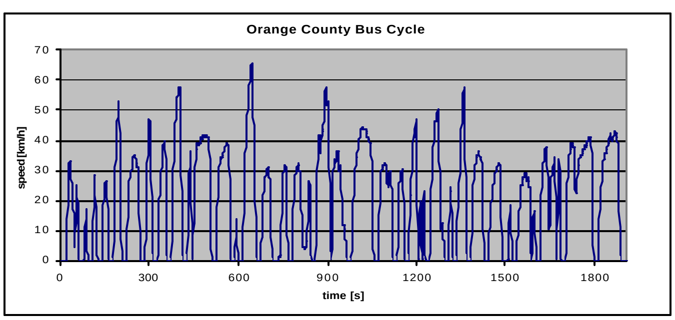

Figure 3. The Orange County bus cycle (duration 1909 s, length 10.526 km, average speed 19.9 km/h, max speed 65.4 km/h, share of idle 21 %)

Vehicle loading principles include tests with half-loaded vehicles as a basis. Additionally, some checkpoints will be generated measuring a few vehicles unloaded.

As test fuels, in the case of diesel, low-sulphur (about 30 ppm) low-aromatics (max 20 %) commercial Finnish reformulated diesel with cetane number over 50 is used. The natural gas used has high methane content (98 %), and is practically sulphur-free, even odorant that would contain sulphur is not used.

RESULTS AND CONCLUSIONS

The transit bus evaluation project at VTT runs for three years, and this paper deals with the background information and the preliminary results of the first year of the three-year project. More comprehensive understanding of the emission behavior of these vehicles will be gained later, along with the completion of the project. At this stage, the main conclusions that can be drawn are as follows:

Driving cycle (smooth ECE15 or harsh Braunschweig) has surprisingly small effect on emissions. Some vehicles emit less harmful compounds in the ECE15 cycle, others in the Braunschweig cycle.

NO_X results seemed to decrease along with newer Euro standards, just as would be expected.

One of the CRT equipped buses emitted high amounts of particulates. This is most likely due to poorly maintained CRT unit. Another high-mileage CRT bus gave low particulate results, as was expected.

The particulate emissions of all natural gas buses were extremely low. Some measuring problems were encountered due to diesel soot carryover from the dilution tunnel. Later, a separate dilution tunnel, dedicated to gaseous fuel use only, was constructed.

Significant reductions in particle number (a factor of 100) with both CRT and CNG were detected compared to the baseline diesel. Equivalent of slightly lower number of nanoparticles (below 60 nm) were detected with CNG compared to CRT equipped diesel.

THC emissions CNG may increase along with aging catalyst. This would probably not affect NMHC results, which were not measured at this stage.

There seemed to be no significant difference in CO_2 emissions between Euro 3 diesel and Euro 3 natural gas buses. As expected, CO_2 results were higher in Braunschweig cycle than in the ECE 15 cycle for all buses tested. This is caused by the higher power need of the Braunschweig cycle.