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LABORATORY MEASUREMENTS OF LIGHT-DUTY VEHICLE POLLUTION AND FUEL CONSUMPTION

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Abstract:
The present paper present a method used in simple applications in order to determine the fuel consumption of a light-duty vehicle starting from the exhaust gases quantity and depending the testing cycle type. Are covered the EU, US and Japanese cycles and are presented the mesurements done on a twin-roll dynamometer.
Keywords:
fuel consumption, dynotest, driving cycles, carbon balance method

1. INTRODUCTION

Many countries have regulations on the measurement of exhaust gas emissions of passenger cars and light trucks. Pollution regulations define measurement conditions and the limit values for emissions of the following pollutants: carbon monoxide (CO), unburnt hydrocarbons (HC), nitrogen oxides (NOX), and particulate matter for diesel engines (compression-ignition engines). "Fuel consumption" regulations define the measurement conditions for both consumption and carbon dioxide (CO_2) emissions for passenger cars.

These measurements are taken on chassis dynamometers that can simulate different regulatory driving cycles: urban and extra-urban cycles in most countries and also motorway cycles, especially in the United States. Trucks, earth-moving vehicles and farm vehicles do not have to comply with any regulations on pollution or fuel consumption once fully assembled. Only their engines are subjected to laboratory pollution measurements with upper limits on the following emissions: CO, HC, NOX, particulate matter and exhaust fumes. As these engine measurements do not include tyre rolling resistance, we will not investigate them any further in this document. However, just as for passenger cars, progress in truck engine, vehicle and tyre design is helping lower pollution levels.

2. TEST PRINCIPLES

The vehicle is set up on a chassis dynamometer which simulates the resistance to forward movement experienced when driving on roads. During the test, the exhaust gases are collected then analyzed to determine:

- for pollution measurements: the mass of carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOX) and, for diesel engines, particulate matter. The results are given in g/km.
- for fuel consumption measurements: the mass of carbon monoxide (CO), total hydrocarbons (THC) and carbon dioxide (CO_2) in g/km. Fuel consumption is then calculated using the "carbon balance method".

3. POLLUTION AND FUEL CONSUMPTION MEASUREMENTS

- Speed (tolerance of ± 2 km/h with respect to the theoretical speed)
- Time (tolerance of ± 1s)
- Braking effort
- Temperature in the test chamber (between 20 and 30 °C)
- Air humidity
- Engine tuning: as per manufacturer’s specifications
- No heating, lighting or air-conditioning

- Fuel: reference fuel as defined by the Directive
- Vehicle: run in for at least 3,000 km and kept at between 20 and 30 °C for at least 6 hours before the test.

Pollution measurements

- Size: the widest size specified as original equipment by the automobile manufacturer. If more than 3 sizes are certified, it is choosed the second widest. The model is not indicated in the test report.
- Run in at the same time as the vehicle or with between 50 and 90 % of original tread depth.
- Tyre pressure specified by the manufacturer, as used for the preliminary road test to adjust the dynamometer. Important: May be raised by up to 50 % if the measurements are recorded on a twin-roll dynamometer.

Measured parameters:

- Mass of CO, HC, NO_X, and, for diesel engines, particulate matter.

Fuel consumption measurements

- One of the tyres specified as original equipment by the automobile manufacturer. Tyre pressure as recommended for the load and speed, adjusted if necessary to test bed operation.

Measured parameters:

- Mass of CO, THC, CO2.

Calculated parameters:

- Fuel consumption in l/100 km.

4. DYNAMOMETER ADJUSTMENT

The dynamometer must be able to reproduce all the forces to which a running vehicle is subjected:

- rolling resistance forces,
- inertial forces,
- internal frictional forces,
- aerodynamic forces.

The dynamometer is calibrated either using data obtained from a road coastdown test or from calibration tables stipulated in the Directive.

There are two types of dynamometer: single-roll and twin-roll.

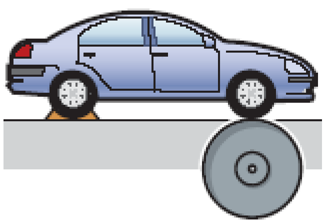

Figure 1. Car on a single - roll dynamometer

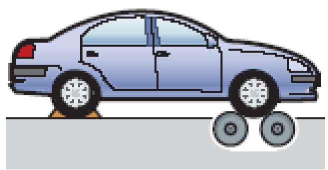

Figure 2. Car on a twin - roll dynamometer

Note: Tyre deformation is greater on a single-roll dynamometer than on a road, and still greater on a twin-roll dynamometer. Dynamometer-generated rolling resistance is greater than road-generated rolling resistance. At a normal tyre pressure, the deformation inflicted by a twin-roll dynamometer could even damage the tyre. European Directives therefore allow the tyre to be inflated up to an extra 50 % for twin-roll dynamometer tests.

5. DETERMINING FUEL CONSUMPTION BY THE CARBON BALANCE METHOD

The **carbon balance method** may be used to calculate fuel consumption from the quantity of carbon found in the exhaust gases collected.

Even with the complex chemical transformations taking place in an internal combustion engine, the relationship between fuel consumption and carbon emissions can be stated relatively simply:

- The main four fuels currently used are made almost exclusively of saturated hydrocarbons (alkanes). Saturated hydrocarbons are composed of carbon (C) and hydrogen (H) only, in known proportions.
- When combustion takes place, all the carbon from the fuel is emitted in the exhaust gases, combined with oxygen from the air in the form of carbon dioxide (CO_2), carbon monoxide (CO) or as unburnt hydrocarbons (HC, also referred to as VOC – Volatile Organic Compounds).

The calculation formulae are given in the following relations:

Fuel consumption calculation (according to Directive 1999/100/EC):
Petrol Vehicles :

$$C = \frac{0{,}1154}{\rho} \cdot \left[(0{,}866 \cdot THC) + (0{,}429 \cdot CO) + (0{,}273 \cdot CO_2)\right] \qquad (1)$$

Diesel Vehicles :

$$C = \frac{0{,}1155}{\rho} \cdot \left[(0{,}866 \cdot THC) + (0{,}429 \cdot CO) + (0{,}273 \cdot CO_2)\right] \qquad (2)$$

Liquefied petroleum gas (LPG) vehicles :

$$C_{norm} = \frac{0{,}1212}{0{,}538} \cdot \left[(0{,}825 \cdot THC) + (0{,}429 \cdot CO) + (0{,}273 \cdot CO_2)\right] \qquad (3)$$

Natural gas vehicles (NGV) :

$$C_{norm} = \frac{0{,}1136}{0{,}654} \cdot \left[(0{,}749 \cdot THC) + (0{,}429 \cdot CO) + (0{,}273 \cdot CO_2)\right] \qquad (4)$$

where:
C - fuel consumption in litres per 100 km (for petrol, LPG or diesel) or in cubic metres per 100 km for NGV
THC - total hydrocarbon emissions measured, in g/km
CO - carbon monoxide emissions measured, in g/km
CO_2 - carbon dioxide emissions measured, in g/km
ρ - test fuel density measured at 15 °C. A reference fuel density is used for LPG and natural gas.

6. CARBON AND CO2 EMISSIONS PER LITRE OF FUEL CONSUMED

Even if the exact amount of CO_2 produced by one litre of fuel depends on various factors such as temperature, ambient pressure and fuel quality, the following may be considered typical values:

- 1 litre of petrol used produces 2.35 kg of CO_2, i.e. 0.64 kg of carbon;
- 1 litre of diesel used produces 2.66 kg of CO_2, i.e. 0.72 kg of carbon.

E.U. DRIVING CYCLE

The European regulatory driving cycle is the same for both fuel consumption and pollution measurements. Automobile manufacturers thus take both sets of measurements during a single test. The cycle simulates 4.052 km of urban driving (part ONE) and 6.955 km of extra-urban driving (part TWO – driving on expressways and bypasses).

Specifications:

Maximum speed: 120 km/h
Average speed for part one: 18.7 km/h
Average speed for part two: 62.6 km/h
Total simulated distance: 11.007 km
Total duration: 19 min 40 s

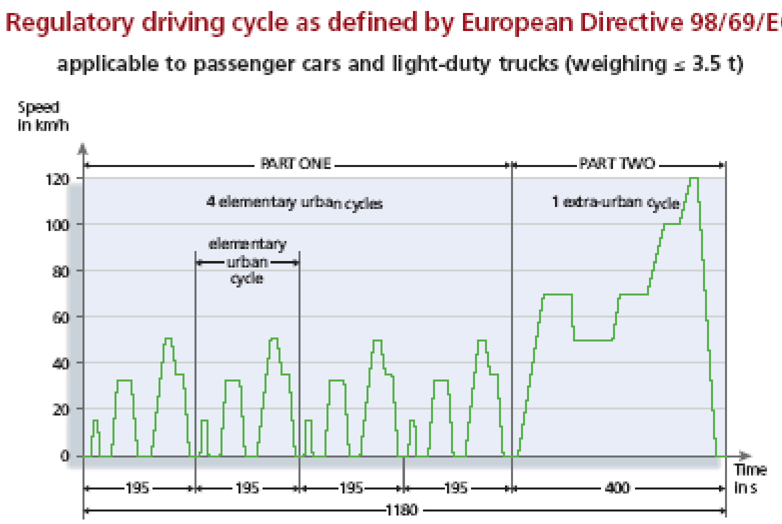

Figure 3. EU driving cycle

- Part ONE comprises four "elementary urban cycles", each made up of 15 successive phases (idling, acceleration, steady speed, deceleration, idling, etc.).

The urban cycle was drawn up in 1958 after following a Renault Dauphine car in Paris. It therefore represents a very slow urban cycle.

- Part TWO comprises one extra-urban cycle made up of 13 phases.
- Exhaust gases are collected continuously throughout the cycle.

U.S. DRIVING CYCLES

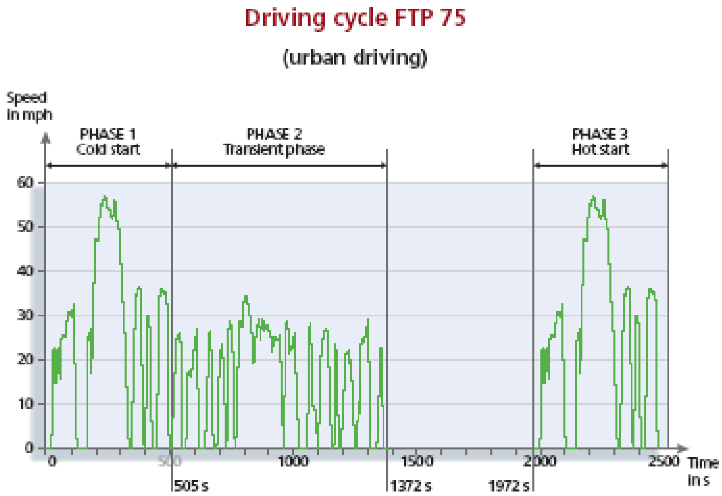

Figure 4. US driving cycle

Specifications:

Average speed: 21.2 mph (34.1 km/h)
Maximum speed: 56.7 mph (91.2 km/h)
Total rolling time: 31 min 17 s (1,877 s)
Stopping time: 10 minutes
Distance travelled: 11.04 miles (17.8 km)
Weighting factors: PHASE 1 = 0.43
PHASE 2 = 1
PHASE 3 = 0.57

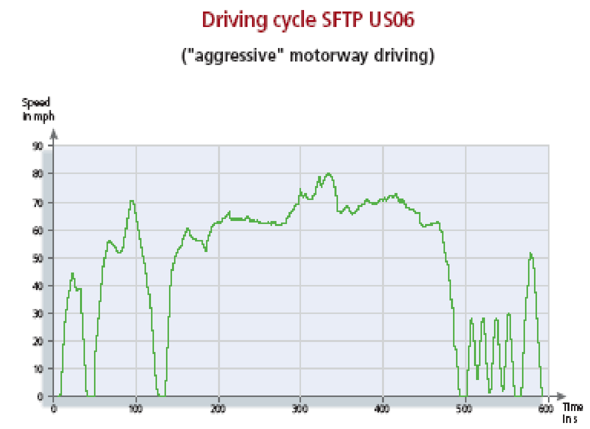

Figure 5. US driving cycle – aggressive motorway driving

Specifications:

Average speed: 48.4 mph (77.9 km/h)
Maximum speed: 80.3 mph (129.2 km/h)
Total rolling time: 9 min 56 s (596 s)
Distance travelled: 8.01 miles (12.9 km)

Figure 6. US driving cycle – normal motorway driving

Specifications:

Average speed: 48.3 mph (77.7 km/h)
Maximum speed: 60 mph (96 km/h)
Total rolling time: 12 min 45 s (765 s)
Distance travelled: 10.26 miles (16.5 km)

There are three American regulatory driving cycles used in the certification of passenger cars and lightduty trucks with respect to pollutant emissions:

- **FTP 75**: cycle simulating urban driving from a cold start followed by a hot-start urban cycle;
- **SFTP-US06**: "aggressive" motorway driving;
- **SFTP SC03**: urban driving with air-conditioning on (not shown here).

Fuel consumption measurements are based on the **FTP 75** cycle and the normal motorway driving cycle **HWFET**.

JAPANESE DRIVING CYCLES

There are currently two Japanese regulatory driving cycles:

- One hot-start cycle known as 10-15 mode for measuring the pollution and fuel consumption of passenger cars and light trucks.
- One cold-start cycle known as 11 mode applied in addition to 10-15 mode for measuring the pollution of petrol-driven passenger cars and lightduty trucks. 10-15 mode simulates urban driving (three "10-mode" elementary cycles) followed by peri-urban driving (one "15-mode" elementary cycle). It is a hot-start cycle, with the measurements only beginning after 15 minutes of rolling at 60 km/h, a measurement during idling then a further 5 minutes' rolling at 60 km/h and finally a "15-mode" elementary cycle, which means a total warm-up time of more than 20 minutes. Measurement results are given in g/km.

11 mode simulates another urban trip, this time from a cold start. Measurement results are given in g/test.

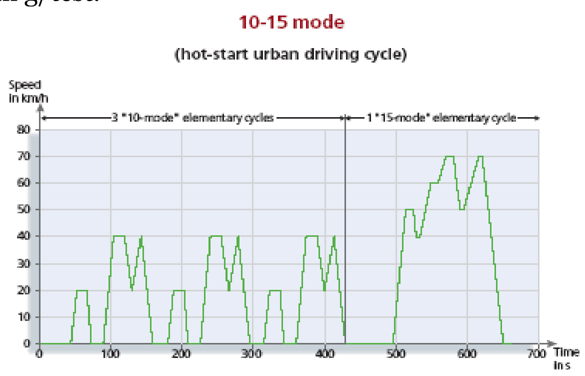

Figure 7. 10-15 mode Japanese cycle

Specifications:
Average speed: 22.7 km/h
Maximum speed: 70 km/h
Total rolling time: 11 min (660 s)
Distance travelled: 4.16 km

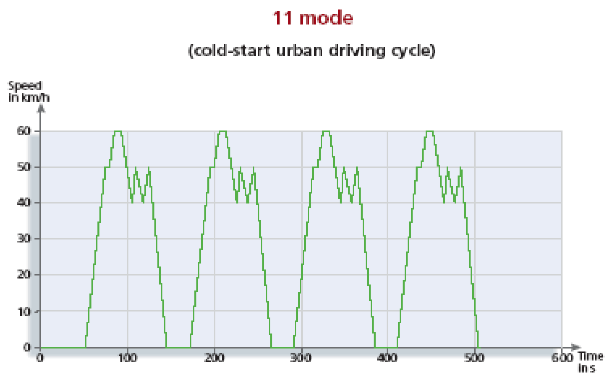

Figure 8. 11 mode Japanese cycle

Specifications:
Average speed: 29.1 km/h
Maximum speed: 60 km/h
Total rolling time: 8 min 25 s (505 s)
Distance travelled: 4.084 km

7. PRACTICAL APPLICATION

On the MAHA LPS 3000 dynamometer is loaded the correspondent driving cycle (figure 9) and when all the mesurement devices are set and the exhaust gas analyser are ready, the mesurement is started and datas are saved in tables and displayed as graphics (figure10).

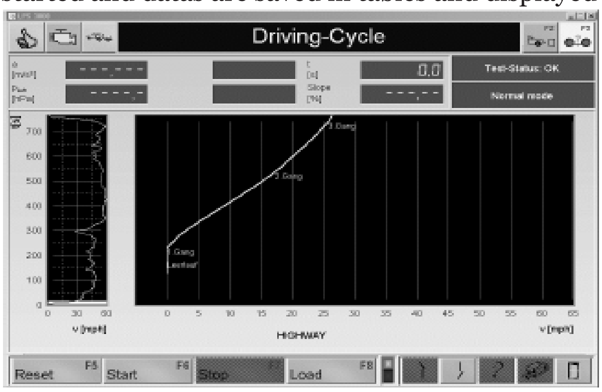

Figure 9. Loading the corresponding driving cycle for light-duty vehicle

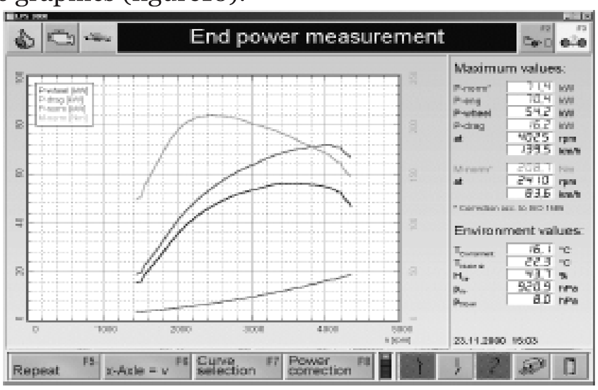

Figure 10. Graphics for analyzing the performances of the vehicle's engine

Applying the formulas 1 – 4, depending the engine's type, we have the values for fuel consumption, values that could be compared with official datas from car manufacturer, or could be used for analyzing the working of the engine.

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