Draft data evaluation procedure for vehicle emissions testing with Portable Emissions Measurement Systems (PEMS)

This document is provided for information only and does not represent any official statement of the European Commission. Once completed, it could serve as a basis to draft an appendix of the regulatory text on Real Driving Emissions of Light Duty Vehicles.

Colour codes:
Always to be checked and/or discussed
Options

Scope and contents of the document:
- The proposed document shall be generic and describe Verification of trip dynamic conditions with method 1 (Moving Averaging Window).
- The (introductory) annex shall detail the general testing requirements (pollutants, conformity factors, route selection, boundary conditions, fuels, etc…). This shall allow the regulator to modify the requirements without changing the measurement and data evaluation protocols.
- The present document applies to conventional powertrains. The adaptation of the method to hybrids shall be developed at a later stage until September 2015

Appendix 5. – Verification of trip dynamic conditions with method 1 (Moving Averaging Window)

5.1 Introduction

The Moving Averaging Window analysis provides an insight on the real driving emissions occurring during the test at a given scale. The test is divided in sub-sections (Windows) and the following subsequent statistical treatment aims at identifying which windows are valid and suitable to assess the vehicle RDE performance.

The 'normality' of the windows is conducted by comparing their CO_2 emissions[1] with a reference. The completeness of the test is judged when a sufficient number of normal windows, covering different speed areas (Urban, rural, motorway) is achieved.

The present section shows the different steps of the data evaluation. Further details of their application to different are given in the following sections.

Step 1. Segmentation of the data and exclusion of cold start emissions;
Step 2. Calculation of emissions by sub-sets or "windows" (section …);
Step 3. Identification of normal windows; (sections … to …)
Step 4. Verification of test completeness and normality;
Step 5. Calculation of conformity factors using the normal windows.

5.2 Abbreviations and main symbols

Index (i) refers to the time step
Index (j) refers to the window
Index (k) refers to the category (t=total, u=urban, r=rural, m-=motorway) or to the CO_2 characteristic curve (cc)
Index 'gas' refers to the regulated exhaust gas components (e.g. NO_x, CO, PN…)

M_{gas}…….integrated mass of the exhaust gas component "gas" [g]
$M_{gas,j}$ .....integrated mass of the exhaust gas component "gas" in window j
$M_{gas,d}$ .....distance-specific emissions for the exhaust gas component "gas" [g/km]
$M_{gas,d,j}$ .....distance-specific emissions for the exhaust gas component "gas" in j^{th} window
t_i .....Total time in step i, [s]
t_t.....duration of a test, [s]
v_i .....actual vehicle speed in time step i, [km/h]
$\bar{v}_j$…….Average speed of j^{th} window, [km/h]
h_j…….Distance of j^{th} window to the CO_2 characteristic curve, (%)
w_j…….Weighing factor of j^{th} window
tol_1……..Primary tolerance for the vehicle CO_2 characteristic curve, (%)
tol_2……..Secondary tolerance for the vehicle CO_2 characteristic curve, (%)

[1] For hybrids, the energy consumption shall be converted to CO_2. The rules for this conversion will be introduced in a second step.

5.3 Moving Averaging Windows

5.3.1 Definition of averaging windows

The instantaneous emissions in calculated according to Appendix 2 shall be integrated using a moving averaging window method, based on the reference CO_2 mass. The principle of the calculation is as follows: The mass emissions are not calculated for the complete data set, but for sub-sets of the complete data set, the length of these sub-sets being determined so as to match the CO_2 mass emitted by the vehicle over the reference laboratory cycle. The moving average calculations are conducted with a time increment Δt equal to the data sampling period. These sub-sets used to average the emissions data are referred to as "averaging windows" in the following Sections.

Any Section of invalidated data for:

- The periodic verification of the instruments and/or after the zero drift verifications;
- The cold start emissions, defined according to Appendix 2, section 2.3 to this Annex;
- The zero vehicle ground speed;
- Any section of the test during which the combustion engine is switched off, defined according to Appendix 2, section 2.4 to this Annex.

Shall not be considered for the calculation of the CO_2 mass and the emissions of the averaging windows. Any Section of data for regeneration events of the emissions control system may be excluded for the calculation of the CO_2 mass and the emissions of the averaging windows.

The mass emissions $M_{gas,j}$ (mg/window) shall be determined as described in Appendix 2 to this Annex.

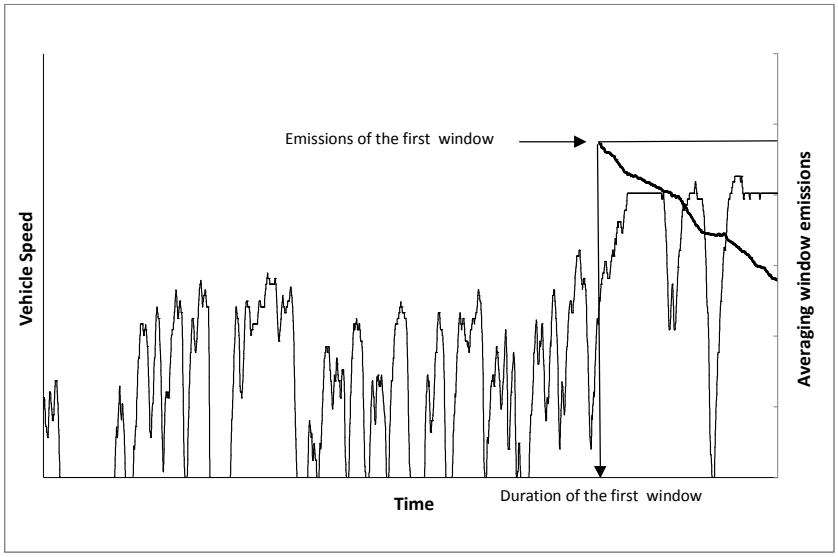

Figure ... Vehicle speed versus time- Vehicle averaged emissions versus time, starting from the first averaging window.

Comment [PB1]: Similar section shall be introduced for CLEAR

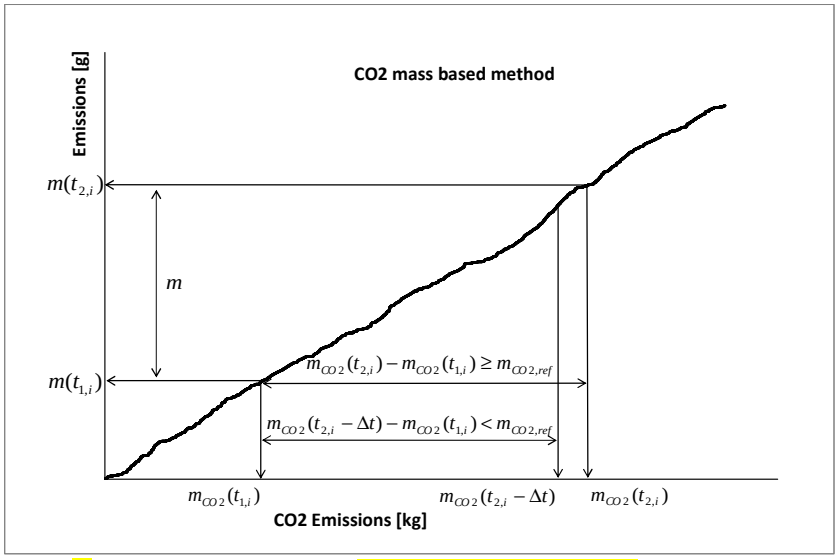

Figure ... CO_2 mass based method. (Symbols will be modified)

The duration $(t_{2,j} - t_{1,j})$ of the j[th] averaging window is determined by:

(E1). $$M_{CO_2}(t_{2,j}) - M_{CO_2}(t_{1,j}) \geq M_{CO_2,ref}$$

Where:
$M_{CO_2}(t_{i,j})$ is the CO_2 mass measured between the test start and time $(t_{i,j})$, kg;
$M_{CO_2,ref}$ is the half of the CO_2 mass emitted by the vehicle over the WLTP cycle (Type I test, including cold start) , kg;

$t_{2,j}$ shall be selected such as:

(E2). $$M_{CO_2}(t_{2,j} - \Delta t) - M_{CO_2}(t_{1,j}) < M_{CO_2,ref} \leq M_{CO_2}(t_{2,j}) - M_{CO_2}(t_{1,j})$$

Where Δt is the data sampling period, equal to 1 second.

The CO_2 masses are calculated in the windows by integrating the instantaneous emissions calculated according to the requirements introduced in Appendix 2.

5.3.2 Calculation of window emissions and averages

From the windows defined according to the principles laid down in section 5.3.1:
- The distance specific emissions $M_{gas,d,j}$ for all the pollutants specified in this annex;
- The distance –specific CO2 emissions $M_{CO2,d,j}$;
- The average vehicle speed $\bar{v}_j$.

shall be calculated for each window.

5.4 Evaluation of windows

5.4.1 Introduction

The reference dynamic conditions of the test vehicle are defined from the vehicle CO2 emissions versus average speed measured at type approval and referred to as "vehicle CO2 characteristic curve".

5.4.2 CO_2 Characteristic curve reference points

The reference points P_1, P_2 and P_3 required to define the curve shall be established as follows:

5.4.2.1 Point P_1

$\overline{v_{P1}} = 19\ km/h$ (Average Speed of the Low Speed phase of the WLTP cycle)
M_{CO_2,d,P_1} = Vehicle CO2 emissions over the Low Speed phase of the WLTP cycle x 1.2

5.4.2.2 Point P_2

$\overline{v_{P2}} = 56.6\ km/h$ (Average Speed of the High Speed phase of the WLTP cycle)
M_{CO_2,d,P_2} = Vehicle CO2 emissions over the High Speed phase of the WLTP cycle x 1.1

5.4.2.3 Point P_3

$\overline{v_{P3}} = 92.3\ km/h$ (Average Speed of the Extra High Speed phase of the WLTP cycle)
M_{CO_2,d,P_3} = Vehicle CO2 emissions over the Extra High Speed phase of the WLTP cycle x 1.05

5.4.2.4 CO_2 Characteristic curve Curve definition

Using the reference points defined in section 5.4, the characteristic curve CO_2 emissions are calculated as a function of the average speed using two linear sections (P_1, P_2) and (P_2, P_3). The section (P_2, P_3) is limited to … km/h.

Comment [PB2]: Maximum speed value as specified in Annex IIIa

The characteristic curve is defined by equations as follows:

For the section (P_1, P_2):

(E3). $M_{CO_2,d}(\bar{v}) = a_1\bar{v} + b_1$

(E4). $with: a_1 = \left(M_{CO_2,d,P_2} - M_{CO_2,d,P_1}\right)/(\overline{v_{P2}} - \overline{v_{P1}})$

(E5). $and: b_1 = M_{CO_2,d,P_1} - a_1\overline{v_{P1}}$

For the section (P_2, P_{32}):

(E6). $M_{CO_2,d}(\bar{v}) = a_2\bar{v} + b_2$

(E7). $with: a_2 = \left(M_{CO_2,d,P_3} - M_{CO_2,d,P_2}\right)/(\overline{v_{P3}} - \overline{v_{P2}})$

(E8). $and: b_2 = M_{CO_2,d,P_2} - a_2\overline{v_{P2}}$

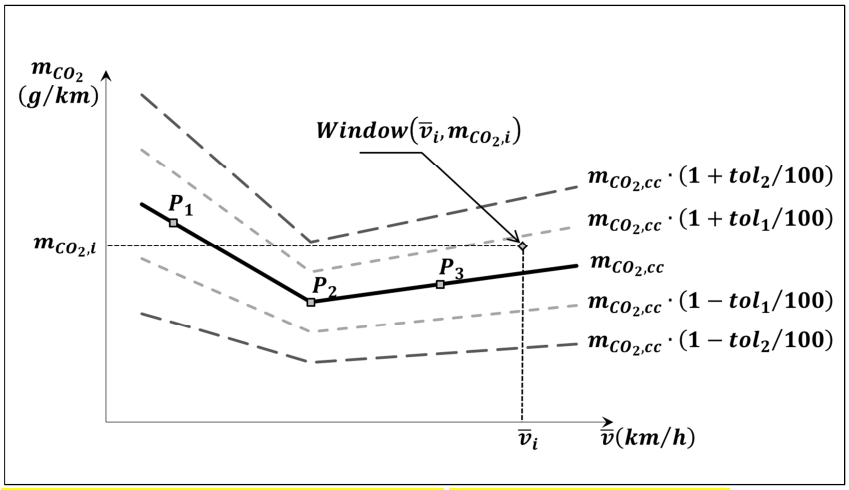

Figure ... Vehicle CO2 characteristic curve (Symbols will be modified)

5.4.3 Urban, rural and motorway windows

5.4.3.1 Urban windows are characterized by average vehicle ground speeds $\bar{v}_i$ smaller than 45 km/h,

5.4.3.2 Rural windows are characterized by average vehicle ground speeds $\bar{v}_i$ greater than or equal to 45 km/h and smaller than 80 km/h,

5.4.3.3 Motorway windows are characterized by average vehicle ground speeds $\bar{v}_i$ greater than or equal to 80 km/h and smaller than ... km/h

Comment [PB3]: To be decided, will depend upon the maximum speed value as specified in Annex IIIa

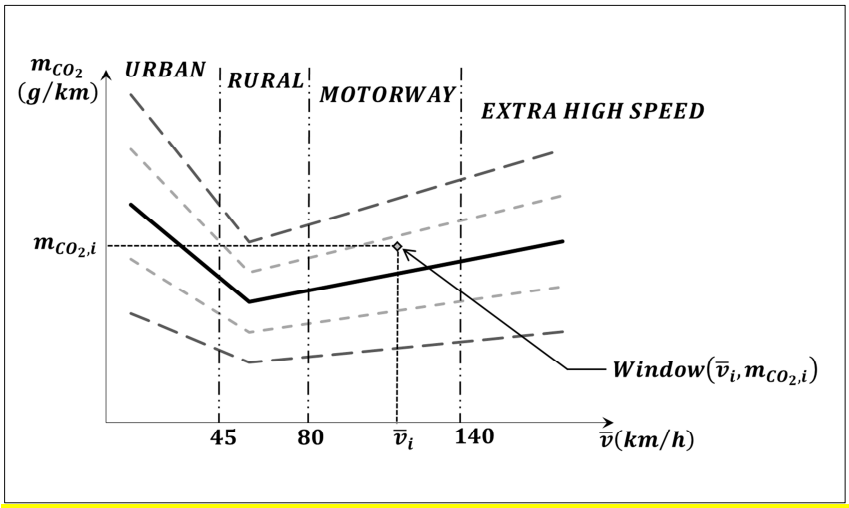

Figure ... Vehicle CO2 characteristic curve, urban, rural and motorway driving definitions (Symbols will be modified)

Comment [PB4]: This figure shall be made consistent with the notation for distance specific CO2 emissions (eCO2 instead of mCO2)

5.5 Verification of trip completeness and normality

5.5.1 Principle

The valid windows CO2 emissions at a given average speed shall fall within the primary and secondary tolerances of the vehicle CO2 characteristic curve.

5.5.2 Verification of test completeness

The test is complete when it comprises at least 15% of urban, rural and motorway windows, out of the total number of windows.

5.5.3 Verification of test normality

The test is complete when it comprises at least 50% of the urban, rural and motorway windows are within the primary tolerances defined for the characteristic curve.

5.5.4 Numerical examples

Table ... Checking the windows normality and evaluating the trip - Numerical examples (To be added)

5.6 Calculation of conformity factors

5.6.1 Calculation of weighted distance-specific emissions

The emissions shall be calculated as a weighted average of the windows distance-specific emissions separately for the urban, rural and motorway categories and the complete trip.

(E9). $M_{gas,d,k} = \frac{\sum w_i M_{gas,d,i,j}}{\sum w_i}\ k = u, r, m$

The weighing factor w_j for each window shall be determined as such:

(E10). If $M_{CO2,d,CC}(\bar{v}_j).(1 - tol_1) \leq M_{CO2,d,j}(\bar{v}_j) \leq M_{CO2,d,CC}(\bar{v}_j).(1 + tol_1)$

Then $w_j = 1$

If $M_{CO2,d,CC}(\bar{v}_j).(1 + tol_1) \leq M_{CO2,d,j}(\bar{v}_j) \leq M_{CO2,d,CC}(\bar{v}_j).(1 + tol_2)$

(E11). Then $w_j = k_{11} h_j + k_{12}$

(E12). $with\ k_{11} = 1/(tol_1 - tol_2)$

(E13). $and\ \ k_{12} = tol_2/(tol_2 - tol_1)$

If $M_{CO2,d,j}(\bar{v}_j).(1 - tol_2) \leq M_{CO2,d,j}(\bar{v}_j) \leq M_{CO2,d,CC}(\bar{v}_j).(1 - tol_1)$

(E14). Then $w_j = k_{21} h_j + k_{22}$

(E15). $with\ k_{21} = 1/(tol_2 - tol_1)$

(E16). $and\ \ k_{22} = k_{21} = tol_2/(tol_2 - tol_1)$

If $M_{CO2,d,j}(\bar{v}_j) \geq M_{CO2,d,CC}(\bar{v}_j).(1 - tol_2)$ or $M_{CO2,d,j}(\bar{v}_j) \leq M_{CO2,d,CC}(\bar{v}_j).(1 + tol_2)$

(E17). Then $w_j = 0$

Where:

(E18). $h_j = M_{CO2,d,CC}(\bar{v}_j) - M_{CO2,d,j}(\bar{v}_j)$

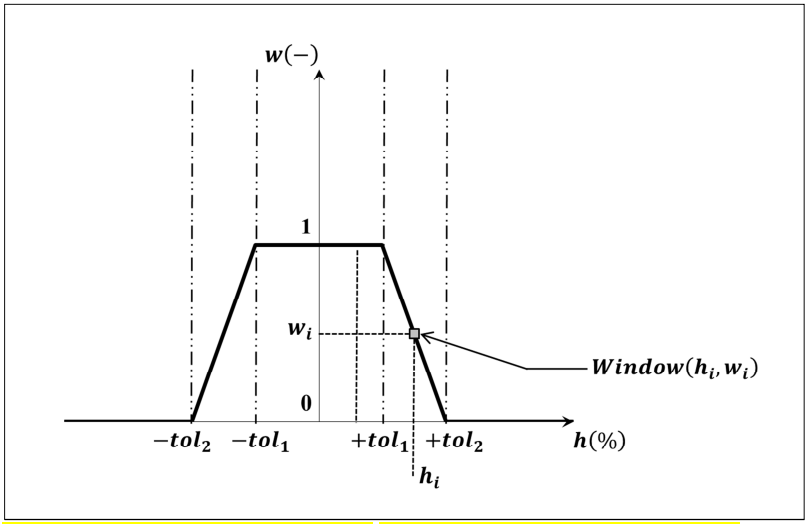

Figure – Window weighing function (Symbols-indices will be modified)

5.6.2 Calculation of severity indices

The severity indices shall be calculated separately for the urban, rural and motorway categories.

(E19). $\bar{h}_k = \frac{1}{N}\sum_j h_j \;\; k = u, r, m$

and the complete trip:

(E20). $\bar{h}_t = \frac{1}{3}(\bar{h}_u + \bar{h}_r + \bar{h}_m)$

5.6.3 Calculation of emissions for the complete trip

Using the weighted distance-specific emissions calculated under section 5.6.1, the conformity factors shall be calculated each pollutant in the following way:

Option 1 (Take the trip ‘as such’, with the shares of ‘realized’ urban, rural and motorway driving)

Option 2 (Re-balance the shares of urban, rural and motorway driving with weighing factors)

(E21). $M_{gas,d,t} = \frac{f_u \cdot M_{gas,d,u} + f_r \cdot M_{gas,d,r} + f_m \cdot M_{gas,d,m}}{(f_u + f_r + f_m)}$

Where f_u, f_r, , f_m are respectively the shares of urban, rural and motorway driving specified in Annex IIIA, section…