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Brake abrasion

Procedure for the Value Determination of Vehicle Parameters with Significant Impact on Brake Abrasion

Test Procedure

September 2025

CONTENTS

1. INTRODUCTION

Abrasion from vehicle brakes is a significant contributor to environmental pollution. Green NCAP's approach of assessing it focuses only on vehicle properties, which result from design and strategy characteristics and directly impact the level of brake abrasion. No direct emissions measurements are conducted, but relevant vehicle parameters are evaluated instead. The results of this evaluation present proxies of brake abrasion behaviour. The vehicle parameters with the highest impact on brake abrasion, addressed by Green NCAP, are:

- Availability of brake abrasion reducing equipment (e.g. brake dust filters)
- Type of brake system – open (discs) or closed (drums)
- Share of friction braking.

1.1. Availability of brake abrasion reducing equipment (e.g. brake dust filters)

Brake abrasion reducing equipment (e.g. brake dust filters) are not yet a widely used technology for the reduction of brake abrasion emissions, but an available one. Green NCAP rewards the use of technology innovations for brake abrasion reduction.

1.2. Type of brake system – open (discs) or closed (drums)

Closed brake systems (like drums) do not emit significant abrasion emissions into the environment, while open systems (like open disc brakes) provide no barrier between the brake abrasion and the environment. Vehicles equipped with closed brake systems are rewarded for brake abrasion reduction.

1.3. Share of friction braking

Electrified vehicles with the possibility to reduce speed by recuperating kinetic energy and convert it to electrical energy stored in a battery reduce the usage of friction brakes. The more such vehicles use their electrical machine(s) for braking instead of their mechanical brakes, the less brake abrasion is produced due to the reduced mechanical friction of the brake components. The share of recuperative braking depends on the component properties and the vehicle's strategy at given conditions. Green NCAP's rating assesses the friction braking share in the warm start *WLTC+ Warm* test (see under **https://www.greenncap.com/test-procedures/**). This procedure can as well be applied to the other *WLTC+* tests performed by Green NCAP, but the accuracy of the calculations is limited for tests with high auxiliaries energy usage, e.g. cold weather tests. The rating system awards vehicles for using less friction braking throughout the *WLTC+ Warm* test. Vehicles without any recuperation possibilities rely 100% on friction brakes and cannot be awarded for brake abrasion reduction through recuperation use.

2. APPLICABILITY

As of 2025, the provisions made in this procedure are applicable to all Green NCAP tested vehicles without exceptions.

3. TEST EQUIPMENT

3.1. Availability of brake abrasion reducing equipment (e.g. brake dust filters)

Based on inspection or information materials, it shall be indicated whether the test vehicle is equipped with such systems. No measurement equipment is needed.

3.2. Type of brake system – open (discs) or closed (drums)

Based on inspection or information materials, it shall be indicated what type of brake system the vehicle is equipped with and at which axle the position of the corresponding system is. No measurement equipment is needed.

3.3. Share of friction braking

The procedure makes use of time-resolved values recorded in the *WLTC+ Warm* test. No further measurement equipment is required.

4. PROCEDURE FOR THE DETERMINATION OF THE SHARE OF FRICTION BRAKING

4.1. Share of friction braking for non-pure electric vehicles

Fixed friction braking shares are considered for non-pure electric vehicles, such as conventional cars, hybrid electric vehicles and plug-in hybrids. The values are adopted form UN GTR No. 24 (Laboratory Measurement of Brake Emissions for Light-Duty Vehicles)[1], Table 1.

Table 1 Friction braking share coefficients for all vehicle types (source: UN GTR No. 24)

Brake type	Vehicle type	Friction Braking Share Coefficient (c)
Full-friction braking	ICE and other vehicle types not covered in the non-friction braking categories in this table	1.0
Non-friction braking	NOVC-HEV Cat. 0	0.9
	NOVC-HEV Cat. 1	0.72
	NOVC-HEV Cat. 2	0.52
	OVC-HEV	0.34

Table 2 explains the abbreviations used in Table 1.

Table 2 Abbreviations used in Table 1

ICE	Internal Combustion Engine (vehicle), to be understood as “conventional” vehicle
NOVC-HEV Cat. 0	"*Not off-vehicle charging hybrid electric vehicle – Category 0*" means a hybrid electric vehicle that features a traction REESS with a nominal voltage higher than 12V and lower than or equal to 20V that cannot be charged from an external source.
NOVC-HEV Cat. 1	"Not off-vehicle charging hybrid electric vehicle – Category 1" means a hybrid electric vehicle that features a traction REESS with a nominal voltage higher than 20V and lower than or equal to 60V that cannot be charged from an external source.
NOVC-HEV Cat. 2	"*Not off-vehicle charging hybrid electric vehicle – Category 2*" means a hybrid electric vehicle that features a traction REESS with a nominal voltage higher than 60V that cannot be charged from an external source.
OVC-HEV	"*Off-vehicle charging hybrid electric vehicle*" means a hybrid electric vehicle that can be charged from an external source (plug-in hybrid).

1 https://unece.org/transport/standards/transport/vehicle-regulations-wp29/global-technical-regulations-gtrs

4.2. Share of friction braking for pure electric vehicles (PEV)

The friction brake share calculations shall be based on the actual dyno speed given in discrete time sample points. For the calculation, the time between two sample points shall be interpreted as a time period *Δt*. The duration of this time period shall be 1 second.

The identification of events takes place discrete, second by second.

4.2.1. Definition of a deceleration event

A deceleration event is defined as such, where speed v_{i+1} is lower than v_i

$$v_{i+1} < v_i$$

where:

v_i is the measured speed at point of time i

v_{i+1} is the measured speed at point of time i+1

4.2.2. Definition of a braking event

The calculations of friction and recuperation braking share require the identification of braking events. These are events, in which the vehicle actively applies braking force to reduce its speed. Speed reduction caused by vehicle driving resistance is not a braking event. The definition of a braking event is based on the comparison of real speed values and theoretical speed values for a hypothetical case that the vehicle would reduce its speed only due to driving resistance forces. A braking event results in a speed reduction higher than the theoretical speed reduction due to driving resistance forces only.

The analyses can be performed based on speed reduction, deceleration values or calculated forces. This procedure uses the difference between the measured speed reduction and the theoretical speed reduction due to driving resistance forces only.

A braking event is identified when

$$v_i < v_{th.\_resist_{\mathrm{i}}}$$

where:

v_i is the measured vehicle speed at time point i [km/h]

$v_{th.\_resist_{\mathrm{i}}}$ is the theoretical speed at time point i, resulting from deceleration caused by driving resistance forces only [km/h]

4.2.2.1. Calculation of the theoretical speed resulting from speed reduction due to vehicle driving resistance forces only

$$v_{th.\_resist_{\mathrm{i}}} = v_{i-1} + a_{th.\_resist_{i-1}} * \Delta t * 3.6$$

where:

$v_{th.\_resist_{\mathrm{i}}}$ is the theoretical speed at time point i, resulting from deceleration caused by driving resistance forces only [km/h]

v_{i-1} is the measured speed at the previous point in time i-1 [km/h]

$a_{th.\_resist_{i-1}}$ is the theoretical acceleration value at the previous point in time i-1, which would result due to the deceleration by vehicle driving resistance forces only [m/s^2]

Δt is a time step with duration of 1 s

3.6 is a conversion factor

4.2.2.2. Calculation of the theoretical acceleration, which would result due to the deceleration by vehicle driving resistance forces only

$$a_{th.\_resist_{i-1}} = \frac{F_{decel\_resist_{i-1}}}{TM * 1.03}$$

where:

$F_{decel\_resist_{i-1}}$ is the driving resistance force during a deceleration at time point i-1 [N]

TM is the test mass, [kg]

1.03 is a factor to consider the additional inertia of rotating masses, according to *WLTC+_Test_Procedure* (see under **https://www.greenncap.com/test-procedures/**)

4.2.2.3. Calculation of the driving resistance force during deceleration

The driving resistance force is calculated only in deceleration events, which are defined by

$$v_i < v_{i-1}$$

For

$$v_i \geq v_{i-1}$$

$$F_{decel\_resist_{i-1}} = 0$$

For v_i < v_{i-1}, $F_{decel\_resist_{i-1}}$ is calculated as follows:

$$F_{decel\_resist_{i-1}} = f_0 + f_1 * \left(\frac{v_{i-1} + v_{i-2}}{2}\right) + f_2 * \frac{(v_{i-1} + v_{i-2})^2}{4}$$

where:

f_0, f_1, f_2 are the rod load coefficients for the test vehicle under consideration in [N], [N/km/h] and in [N/(km/h)^2] respectively.

Caution: For the *WLTC+ CAT* tests, f2* - a modified value of f_2 - is to be used according to the provisions in *GNT_WLTC+_CAT_Test_Procedure*! (see Green NCAP procedures under **https://www.greenncap.com/test-procedures/**)

4.2.3. Calculation of the total deceleration energy during braking events

The calculation of the deceleration energy demand E_{decel_i} shall be performed for braking events, i.e. v_i < $v_{th.\_resist_i}$. For v_i ≥ $v_{th.\_resist_i}$, E_{decel_i}= *0.*

The total deceleration energy demand E_{decel_total} during braking events for the whole cycle shall be calculated by summing E_{decel_i} over the corresponding cycle time between t_{start} and t_{end} :

$$E_{decel\_total} = \sum_{i=t_{start}}^{t_{end}} E_{decel_i}$$

where:

t_{start} is the time at which the applicable test cycle starts, [s]; for WLTC t_{start} = 0

t_{end} is the time at which the applicable test cycle ends, [s]; for WLTC t_{end}= 1800

E_{decel_i} is the total deceleration energy during time period from (i-1) to (i) in [Ws], calculated as follows:

$$E_{decel_i} = F_i * d_i$$

where:

F_i is the total longitudinal force during time period (i-1) to (i), calculated as below, [N];

$$F_i = (1.03 * TM) * a_i$$

where:

1.03 is a factor to consider the additional inertia of rotating masses, according to *WLTC+_Test_Procedure*

TM is the test mass, [kg];

a_i is the acceleration during time period (i-1) to (i) in [m/s²], calculated as follows:

$$a_i = \frac{(v_i + v_{i-1})}{2 * 3.6 * (t_i - t_{i-1})}$$

where:

v_i is the actual velocity at time point (i), [km/h];

t_i is the time at point (i), [s];

and

d_i is the distance travelled during time period (i-1) to (i) in [m], calculated as follows:

$$d_i = \frac{(v_i + v_{i-1})}{2 * 3.6} * (t_i - t_{i-1})$$

For the chosen approach of 1Hz data resolution:

$$t_i - t_{i-1} = 1\ [s]$$

4.2.4. Calculation of the deceleration energy due to vehicle driving resistance during braking events

The calculation is performed for identified braking events, i.e. for v_i < $v_{th.\_resist_{\text{i}}}$. For v_i ≥ $v_{th.\_resist_{\text{i}}}$, E_{decel_resist} = 0.

$$E_{decel\_resist} = \sum_{i=t_{start}}^{t_{end}} E_{decel\_resist_i}$$

where:

t_{start} is the time at which the applicable test cycle starts, [s]; for WLTC t_{start} = 0

t_{end} is the time at which the applicable test cycle ends, [s]; for WLTC t_{end}= 1800

$E_{decel\_resist_i}$ is the rolling resistance energy during time period from (i-1) to (i) in [Ws], calculated as follows:

$$E_{decel\_resist_i} = F_{resist_i} * d_i$$

where:

d_i is the distance travelled during time period (i-1) to (i) in [m]

F_{resist_i} is the force during time period (i-1) to (i) in [N], calculated as follows:

$$F_{resist_i} = f_0 + f_1 * \left(\frac{v_i + v_{i-1}}{2}\right) + f_2 * \frac{(v_i + v_{i-1})^2}{4}$$

where:

f_0, f_1, f_2 are the rod load coefficients for the test vehicle under consideration in [N], [N/km/h] and in [N/(km/h)^2] respectively.

Caution: For the *WLTC+ CAT* tests, f2* - a modified value of f_2 - is to be used according to the provisions in *GNT_WLTC+_CAT_Test_Procedure*! (see Green NCAP procedures under **https://www.greenncap.com/test-procedures/**)

4.3. Calculation of the amount of recuperated kinetic energy

4.3.1. Determination of the WLTC+ idling phase electric energy consumption level

The time resolved (1 Hz) electric energy consumption values of the *WLTC+ Warm* test recording are to be used. A baseline idling electric energy consumption level is to be calculated. For that purpose, the electric power at discrete WLTC time points is to be recorded. The choice of the discrete time points is arbitrary and follows only the purpose of estimating the base electric energy consumption at idling, which is assumed to be representative for the base energy used by all auxiliaries and standby systems when the vehicle is driving. As this part of the energy consumption cannot be distinguished within the total consumption reading when the vehicle is moving, the interpolated idling consumption in several phases is used as an estimation for the base consumption of auxiliaries and standby. When kinetic energy is being recuperated, the electricity gained first covers for the consumption by auxiliaries and other base systems, before the reading indicates an energy flow going into the high voltage battery.

The Figure 1 shows the position of these time points on the WLTC time axis.

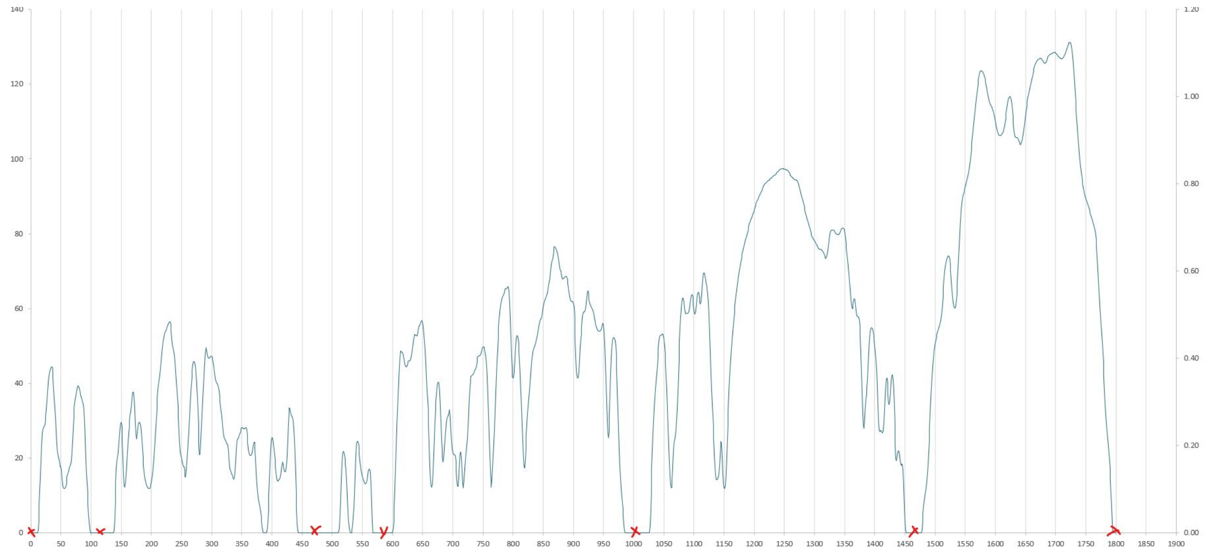

Figure 1 Position of time points 5; 125; 480; 590; 1000; 1465; 1797 on the WLTC time axis

- The abbreviation “rip” is used for “reference idling point”.
- The abbreviation “ph” is used for “phase”.

Table 3 shows the position of the seven reference idling points rip_j on the time axis of the WLTC cycle and introduces the time definition of each of the phases ph_j

Table 3 Position of the reference idling points (rip_j) on the time axis of the WLTC cycle and definition of the base consumption interpolation phases (ph_j)

Reference idling points (rip_j)	Phase (ph_j)	Time point t_i at rip_j and ph_j on x-axis, (seconds)	Phase ph_j definition
1	1	i=5	ph_1 < 5s
2	2	i=125	5s ≤ ph_2 < 125s
3	3	i=480	125s ≤ ph_2 < 480s
4	4	i=590	480s ≤ ph_2 < 590s
5	5	i=1000	590s ≤ ph_2 < 1000s
6	6	i=1465	1000s ≤ ph_2 < 1465s
7	7	i=1797	1465s ≤ ph_2 < 1797s

An interpolated value of the electric energy consumption in each of the phases is to be calculated, where negative values indicate that electric energy is being consumed:

For phase j=1 (phase 1, ph_1):

$$E_{idling\_ph_j\_i} = E_{idling\_rip_j}$$

where:

$E_{idling\_ph_j\_i}$ is the idling electric energy consumption for time point i in phase j [Ws]

$E_{idling\_rip_j}$ is the idling electric consumption at reference idling point rip_j

$$E_{idling\_rip_j} = P_{idling\_rip_j} * \Delta t$$

where:

$P_{idling\_rip_j}$ is the electric power at idling at time point rip_j [W]

and

Δt is a time duration of 1 s

$$P_{idling\_rip_j} = I_{idling\_rip_j} * U_{idling\_rip_j}$$

where:

$I_{idling\_rip_j}$ is the electric current during reference idling point rip j [A]

$U_{idling\_rip_j}$ is the electric voltage during reference idling point rip j [V]

For phases 1< j ≤ 7 (i.e. phases 2 to 7), an interpolation value of the idling consumption at the two next closest (previous and following) reference idling points should be built:

$$E_{idling\_ph_j\_i} = E_{idling\_rip_j} - (E_{idling\_rip_j} - E_{idling\_rip_{j-1}})/(t_{rip_j} - t_{rip_{j-1}}) * (t_{rip_j} - t_i)$$

where $E_{idling\_rip_j}$ is calculated as shown above.

Table 3 defines the basic consumption interpolation phases (ph_j) through the time on the x-axis of the WLTC cycle. Therefore, if the phase ph_j is not of explicit interest, the following simplification can be introduced:

$$E_{idling\_ph_j\_i} = E_{idling_i}$$

where:

E_{idling_i} is the electric idling energy at time point i [W]

4.3.2. Calculation of approximated electrically recuperated kinetic energy

Using the measured electric energy flow from and into the high voltage battery, the recuperated energy is to be calculated, assuming that all electric energy consumption values higher than E_{idling_i} during braking events are due to recuperation.

For $P_{el_i} \leq P_{idling_i}$, $P_{el\_recup_i}$ =0:

$$P_{el_i} = I_i * U_i$$

where:

P_{el_i} is the electric power measured at time point i [W]

I_i is the electric current at time point i [A]

U_i is the electric voltage at time point i [V]

$$P_{idling_i} = \frac{E_{idling_i}}{\Delta t}$$

where:

P_{idling_i} is the electric idling power at time point i [W]

The calculation of the electrically recuperated energy E_{el_recup} shall be performed for braking events.

For $v_i \geq v_{th.\_resist_i}$, $P_{el\_recup_i}$ = 0.

For $v_i < v_{th.\_resist_i}$ and $P_{el_i} > P_{idling_i}$:

$$P_{el\_recup_i} = P_{el_i} - P_{idling_i}$$

For $P_{el\_recup_i}$ < 0, $E_{el\_recup_i}$ =0.
For $P_{el\_recup_i}$ ≥ 0:

$$E_{el\_recup} = \sum_{i=t_{start}}^{t_{end}} E_{el\_recup_i} = \sum_{i=t_{start}}^{t_{end}} P_{el\_recup_i} * \Delta t$$

where:

t_{start}	is the time at which the applicable test cycle starts, [s]; for WLTC t_{start} = 0
t_{end}	is the time at which the applicable test cycle ends, [s]; for WLTC t_{end}= 1800
$P_{el\_recup_i}$	is the electric recuperation power at time point i [W]
$E_{el\_recup_i}$	is the electric recuperation energy at time point i [Ws]
E_{el_recup}	is the recuperated electric energy [Ws]
Δt	is time duration of 1 second

The approximated recuperated kinetic energy E_{recup_kin} in [Ws] is calculated as follows:

$$E_{recup\_kin} = \frac{E_{el\_recup}}{0.95}$$

where:

0.95	is an assumed efficiency factor of the recuperating path from the wheel to the battery terminals

4.4. Determination of the approximated friction braking share

The total deceleration energy is a sum of driving resistance, brake energy recuperation and friction braking.

$$E_{decel\_friction} = E_{decel\_total} - E_{decel\_resist} - E_{recup\_kin}$$

The energy potentially available for recuperation $E_{recup\_potential}$ is:

$$E_{recup\_potential} = E_{decel\_total} - E_{decel\_resist}$$

The recuperation braking share r_{recup} of the energy potentially available for recuperation is:

$$r_{recup} = \frac{E_{recup\_kin}}{E_{recup\_potential}} * 100\ [\%]$$

The friction braking share $r_{friction}$ of the energy potentially available for recuperation is:

$$r_{friction} = \frac{E_{decel\_friction}}{E_{recup\_potential}} * 100\ [\%]$$

5. DATA PREPARATION

- Based on inspection or information materials, the availability of brake abrasion reducing equipment (e.g. brake dust filters) is to be indicated in the rating template.
- Based on inspection or information materials, the type of brake system – open (discs) or closed (drums) and their position (axle) is to be indicated in the rating template.
- For non-pure electric vehicles, the vehicle type and system voltage level are to be provided.
- For pure electric vehicle PEV, a set of calculated data is to be provided.

  The time resolved values [1 Hz] of

  E_{decel_total},

  E_{decel_resist},

  E_{el_recup},

  E_{recup_kin},

  $E_{decel\_friction}$,

  $E_{recup\_potential}$

  as well as the electric energy demand readings E_{idling_i} for every i and explicitly at idling time points 5, 125, 480, 590, 1000, 1465, 1797;

  and the values of

  r_{recup}

  $r_{friction}$

  are to be submitted in a common office software format (e.g., .csv, .xlsx) with clear labels, for all *WLTC+* tests.

Green NCAP's test results reporting template implements all calculations, data preparation and reporting steps for pure electric vehicles described in this procedure.