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Hybrid-electric road vehicles — Exhaust emissions and fuel consumption measurements —

Part 1: Non-externally chargeable vehicles

Véhicules routiers électriques hybrides — Mesurages des émissions à l'échappement et de la consommation de carburant —

Partie 1: Véhicules non rechargeables par des moyens externes

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 37, *Electrically propelled vehicles*.

This second edition cancels and replaces the first edition (ISO 23274-1:2013), which has been technically revised.

The main changes compared to the previous edition are as follows:

— the content of ISO/TR 11955:2008, *Hybrid-electric road vehicles —Guidelines for charge balance measurement* was merged with this document as Annex D.

A list of all parts in the ISO 23274 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Hybrid-electric road vehicles — Exhaust emissions and fuel consumption measurements —

Part 1:
Non-externally chargeable vehicles

1 Scope

This document specifies a chassis dynamometer test procedure to measure the exhaust emissions and the electric energy and fuel consumption for the vehicles.

This document applies to vehicles with the following characteristics:

— vehicles classified as passenger cars or light duty trucks, as defined in the relevant regional applicable driving test (ADT) standard;

— the nominal energy of the rechargeable energy storage system (RESS) is at least 2 % of the total energy consumption over an ADT;

— internal combustion engine (ICE) only using liquid fuels (for example, gasoline and diesel fuel).

NOTE In the case of the vehicles with ICE using other fuel [for example, compressed natural gas (CNG), liquefied petroleum gas (LPG), hydrogen], this document can apply except the measurement of consumed fuel; otherwise the measurement method for those using the corresponding fuel can apply.

This document proposes procedures for correcting the measured emissions and fuel consumption of hybrid-electric vehicles (HEVs), in order to obtain the values when the state of charge (SOC) of the RESS does not remain the same between the beginning and the end of an ADT.

It can also be applied to measurement procedures for exhaust emissions and fuel consumption of externally chargeable HEVs when a vehicle is not externally charged and operated only in the charge sustaining (CS) state, as described in ISO 23274-2.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 10521 (all parts), *Road vehicles — Road load*

ISO/TR 8713, *Electrically propelled road vehicles — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/TR 8713 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
applicable driving test
ADT
single driving test schedule which is specified for a relevant region

Note 1 to entry: Chassis dynamometer test schedules for a relevant region are the Worldwide Light-duty Test Cycle (WLTC) or the Urban Dynamometer Driving Schedule (UDDS), for example.

3.2
charge balance of RESS
change of charge in the *RESS* (3.10) during fuel consumption measurement

Note 1 to entry: Normally expressed in ampere hours (Ah).

3.3
coulomb efficiency
Ah efficiency
efficiency of the battery, based on electricity in coulomb for a specified charge/discharge procedure, expressed by output electricity divided by input electricity

3.4
energy balance of RESS
ΔE_{RESS}
change of *RESS* (3.10) energy state during an *applicable driving test* (3.1)

Note 1 to entry: Normally expressed in watt hours (Wh).

Note 2 to entry: For practical use, the energy balance of RESS is approximated by multiplying the *charge balance of RESS* (3.2) in ampere hours (Ah) by the nominal voltage in volts (V).

3.5
energy efficiency
Wh efficiency
efficiency of the battery, based on energy for a specified charge/discharge procedure, expressed by output energy divided by input energy

3.6
externally chargeable HEV
HEV (3.7) with a *RESS* (3.10) that is intended to be charged from an external electric energy source

Note 1 to entry: External charge for the purpose of conditioning of the RESS is not included.

Note 2 to entry: Externally chargeable HEVs are widely known as plug-in HEVs (PHEVs).

3.7
hybrid-electric vehicle
HEV
vehicle with both a *RESS* (3.10) and a fuelled power source for propulsion

EXAMPLE Internal combustion engine or fuel cell systems are typical types of fuelled power sources.

3.8
non-externally chargeable HEV
HEV (3.7) with a *RESS* (3.10) that is not intended to be charged from an external electric energy source

3.9
rated capacity
supplier's specification of the total number of ampere hours that can be withdrawn from a fully charged battery pack or system for a specified set of test conditions such as discharge rate, temperature and discharge cut-off voltage

3.10
rechargeable energy storage system
RESS
rechargeable system that stores energy for delivery of electric energy for the electric drive

EXAMPLE Batteries or capacitors.

3.11
regenerative braking
braking with conversion of kinetic energy into electric energy for charging the *RESS* (3.10)

3.12
state of charge
SOC
available capacity of a *RESS* (3.10) or RESS subsystem expressed as a percentage of *rated capacity* (3.9)

4 Test conditions and instrumentation

4.1 Test conditions

4.1.1 General

For test conditions, 4.1.2 to 4.1.4 apply. Otherwise, the test conditions of the relevant regional ADT standards apply.

4.1.2 Ambient temperature

Tests shall be conducted at ambient temperature of (25 ± 5) °C.

4.1.3 Vehicle conditions

4.1.3.1 Vehicle conditioning

Prior to testing, the test vehicle with RESS shall be stabilized as specified by the manufacturers, or the mileage shall be accumulated to above 3 000 km and less than 15 000 km.

4.1.3.2 Vehicle appendages

Vehicles shall be tested with normal appendages (mirrors, bumpers, etc.). When the vehicle is on the dynamometer, certain items (e.g. hub caps) should be removed for safety reasons, where necessary.

4.1.3.3 Vehicle test mass

The vehicle test mass shall be selected in accordance with the relevant regional ADT standards.

4.1.3.4 Tyres

4.1.3.4.1 General

The correctly rated tyres as recommended by the vehicle manufacturer shall be used.

4.1.3.4.2 Tyre pressure

The vehicle tyres shall be inflated to the pressure specified by the vehicle manufacturer in accordance with the test chosen (track or chassis dynamometer).

4.1.3.4.3 Tyre conditioning

The tyres shall be conditioned as recommended by the vehicle manufacturer.

4.1.3.5 Lubricants

The vehicle lubricants normally specified by the manufacturer shall be used.

4.1.3.6 Gear shifting

If the vehicle is fitted with a manually shifted gear box, gear shifting positions shall correspond to the relevant regional ADT standard. However, the shift positions should be selected and determined in accordance with the vehicle manufacturer's specification.

4.1.3.7 Regenerative braking

If the vehicle has regenerative braking, the regenerative braking system shall be enabled for all dynamometer testing except where specified in 4.1.4.4 determining the dynamometer load coefficient.

If the vehicle is tested on a single axle dynamometer and is equipped with systems such as an antilock braking system (ABS) or a traction control system (TCS), those systems may inadvertently interpret the non-movement of the set of wheels that are off the dynamometer as a malfunctioning system. If so, these systems shall be temporarily disabled for adjustment to achieve normal operation of the remaining vehicle systems, including the regenerative braking system.

4.1.3.8 RESS conditioning

The RESS shall be conditioned with the vehicle as specified in 4.1.3.1, or by equivalent conditioning.

4.1.4 Chassis dynamometer conditions

4.1.4.1 General

The vehicle should generally be tested on a single axle chassis dynamometer. A vehicle with four-wheel drive shall be tested by modifying the drive train of the vehicle. When the vehicle is modified, the details shall be explained in the test report.

Double axle chassis dynamometer testing should be performed if a modification for single axle chassis dynamometer testing is not possible for a specific four-wheel drive vehicle.

4.1.4.2 Dynamometer calibration

The dynamometer shall be calibrated in accordance with the specifications indicated in the service manual provided by the dynamometer manufacturers.

4.1.4.3 Dynamometer warm-up

The dynamometer shall be warmed up sufficiently prior to testing.

4.1.4.4 Determining the dynamometer load coefficient

The determination of vehicle road load and the reproduction on a chassis dynamometer shall conform to the ISO 10521 series Vehicles equipped with regenerative braking systems that are activated at least in part when the brake pedal is not depressed shall have regenerative braking disabled during the deceleration portion of coast-down testing on both the test track and dynamometer.

4.2 Test instrumentation

Test instrumentation shall have accuracy levels as shown in Table 1, unless specified differently by the relevant regional ADT standards.

Table 1 — Accuracy of measured values

Item	Unit	Accuracy
Time	s	±0,1 s
Distance	m	±0,1 %
Temperature	°C	±1 °C
Speed	km/h	±1 %
Mass	kg	±0,5 %
Current	A	±0,5 %[a]
Capacitor voltage	V	±0,5 %

[a] Accuracy for measure value: ±0,5% full scale deflection or ±1% of reading, whichever is greater.

5 Measurement of exhaust emissions and fuel consumption

5.1 General

The ADT procedure shall be selected according to the relevant regional ADT standards. Common requirements, if not described in the relevant regional ADT standards, are described below.

5.2 Test procedure

5.2.1 Vehicle preconditioning

Vehicle preconditioning shall be carried out in accordance with the relevant regional ADT standard, if necessary.

If necessary, the RESS SOC may be preadjusted by charging or discharging, to obtain a suitable energy balance of RESS between the beginning and the end of the test.

5.2.2 Vehicle soak

The vehicle shall be soaked in accordance with the relevant regional ADT standards.

5.2.3 Vehicle movement to the test room

When the vehicle is brought into the test room, and moved during the test if necessary, it shall be pushed or towed (neither driven nor regenerative recharged). The test vehicle shall be set on the chassis dynamometer after the chassis dynamometer has warmed up just before the test. The vehicle shall not be activated during soak until right before starting the test.

5.2.4 Measurement over ADT

Energy balance of RESS, consumed fuel and exhaust emissions shall be measured in each ADT. The conditions of the vehicle during the ADT shall follow the relevant regional ADT standards.

5.3 Correction of the test results

5.3.1 General

Measured fuel consumption and exhaust emissions shall be corrected if these test results are influenced by RESS energy balance during the test. However, the correction is not necessary if the RESS energy balance satisfies the conditions in 5.3.2. The guidelines for charge balance measurement are described in Annex D.

5.3.2 Allowable range of RESS energy balance

The correction is not necessary if RESS energy balance is within the following range [see Formula (1)]:

$$|\Delta E_{\mathrm{RESS}}| \leq 0{,}01 \times E_{\mathrm{CF}} \qquad (1)$$

where

ΔE_{RESS} is the energy change in RESS over the ADT in Wh;

E_{CF} is the energy of consumed fuel over the ADT in Wh.

Practical methods that apply to battery and capacitor are described in Annex B.

5.3.3 Correction procedure by correction coefficient

The vehicle manufacturer shall deliver the correction coefficient to calculate the fuel consumption and the exhaust emission at $\Delta E_{\mathrm{RESS}} = 0$. The correction coefficient can be obtained in accordance with Annex A. When the measured value is independent of ΔE_{RESS}, a correction is not required. See also Annex C for theory of the linear regression method (in case of batteries).

6 Calculations and expressions

To calculate the resultant exhaust emission and fuel consumption for an ADT, the relevant regional standards should be taken into consideration.

Annex A
(informative)

Linear correction method using a correction coefficient

A.1 General

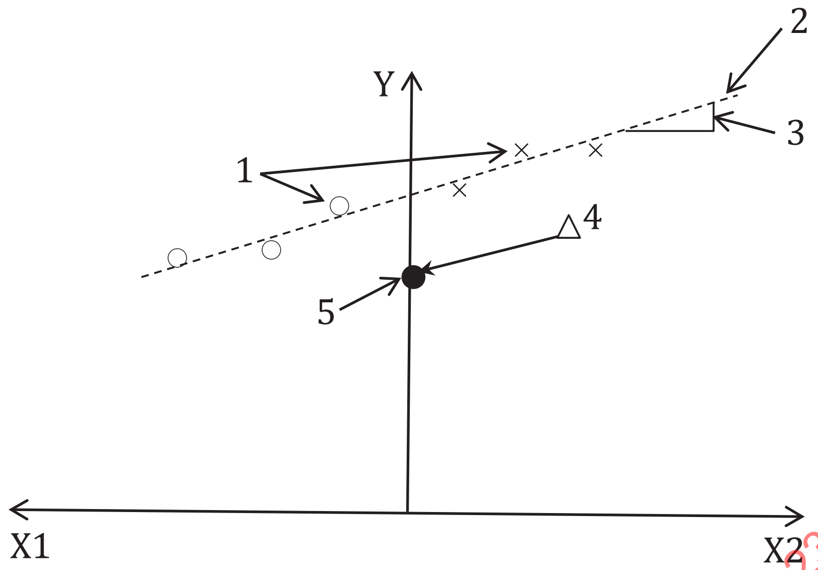
This annex describes the calculation procedure to determine the exhaust emissions and fuel consumption at $\Delta E_{\mathrm{RESS}} = 0$.

A.2 Method for correcting the exhaust emissions and fuel consumption

A.2.1 Data required for correction coefficient

A.2.1.1 General

The exhaust emissions and fuel consumption test shall be repeated several times to determine the correction coefficient defined in A.2.1.2.1. See Figure A.1. The ΔE_{RESS} shall be measured during the test. The SOC and ΔE_{RESS} should be in the normal range specified by the vehicle manufacturer.



Key

X1 energy balance (in Wh), discharge
X2 energy balance (in Wh), charge
Y exhaust emissions M_E (in g) or consumed fuel M_F (in l)
1 data
2 premeasured data for determination of correction coefficient
3 exhaust emission K_{ME} or consumed fuel K_{MF}
exhaust emission
4 measured value (C_s, $M_{E,s}$)
C_s is the energy balance (in Wh)
$M_{E,s}$ is exhaust emission (in g)
5 corrected value ($M_{E,c}$) = $M_{E,s}$ - K_{ME} × C_s
fuel consumption
4 measured value (C_s, $M_{F,s}$)
C_s is the energy balance (in Wh)
$M_{F,s}$ is fuel consumption (in l)
5 corrected value ($M_{F,c}$) = $M_{F,s}$ - K_{MF} × C_s

Figure A.1 — Example of data collected from ADT

A.2.1.2 Corrections

A.2.1.2.1 Exhaust emission and fuel consumption correction coefficient

The exhaust emission correction coefficient, K_{ME}, in g/Wh, for each exhaust emission component in exhaust gas such as CO, HC, NO_X and CO_2 for an ADT shall be calculated.

The correction coefficients shall be calculated using Formula (A.1):

$$K_{ME} = \frac{n \times \sum C_i M_{E,i} - \sum C_i \times \sum M_{E,i}}{n \times \sum C_i^2 - (\sum C_i)^2} \quad \text{(A.1)}$$

where

$M_{E,i}$ is each exhaust gas component, in grams per test, in an ADT;

C_i is the energy balance at the test, in Wh (use the minimum unit);

n is the number of data.

The exhaust emission correction coefficient shall be a four-significant digit figure by rounding the fifth significant digit figure.

The fuel consumption correction coefficient, K_{MF}, in l/Wh, for an ADT shall be calculated.

The correction coefficients shall be calculated using Formula (A.2):

$$K_{MF} = \frac{n \times \sum C_i M_{F,i} - \sum C_i \times \sum M_{F,i}}{n \times \sum C_i^2 - (\sum C_i)^2} \quad (A.2)$$

where

$M_{F,i}$ is each fuel consumption result in an ADT, in litres per test;

C_i is the energy balance at the test, in Wh (use the minimum unit);

n is the number of data.

The fuel consumption correction coefficient shall be a four-significant digit figure by rounding the fifth significant digit figure.

A.2.1.2.2 Exhaust emission and fuel consumption at $\Delta E_{RESS} = 0$, M_{EC}

The value of each exhaust emission, M_{EC}, at $\Delta E_{RESS} = 0$, is derived from Formula (A.3):

$$M_{EC} = M_{E,s} - K_{ME} \times C_S \quad (A.3)$$

where

$M_{E,s}$ is each exhaust emission in grams per test;

K_{ME} is the correction coefficient defined in A.2.1.2.1;

C_s is the energy balance of RESS, in Wh (use the minimum unit).

The value of fuel consumption, M_{FC}, at $\Delta E_{RESS} = 0$, is derived from Formula (A.4):

$$M_{FC} = M_{F,s} - K_{MF} \times C_S \quad (A.4)$$

where

$M_{E,s}$ is fuel consumption in litres per test;

K_{MF} is the correction coefficient defined in A.2.1.2.1;

C_s is the energy balance of RESS, in Wh (use the minimum unit).

Annex B
(informative)

Calculation of allowable range of RESS energy change

B.1 General

The allowable energy change in RESS, expressed by Formula (1) in 5.3.2, may be rewritten as Formula (B.1), using the net heating value (NHV) of fuel:

$$\left|\Delta E_{\mathrm{RESS}}\right| \le 0{,}01 \times J_{\mathrm{NHV}} \times m_{\mathrm{fuel}} / 3\,600 \qquad \text{(B.1)}$$

where

ΔE_{RESS} is the energy change in RESS over the ADT, in Wh;

J_{NHV} is the net heating value (per consumable fuel analysis), in J/kg;

m_{fuel} is the total mass of fuel consumed over the ADT, in kg.

For batteries or capacitors, this allowable energy change can be expressed as shown in Formulae B.2 to and B.5 below.

B.2 Batteries

The energy balance in the battery over the ADT, ΔE_{b}, in Wh, can be calculated from the measured charge balance, ΔQ, and is expressed as follows:

$$\Delta E_{\mathrm{b}} = \Delta Q \times V_{\mathrm{system}} \qquad \text{(B.2)}$$

where

ΔQ is the charge balance of the battery over the ADT, in Ah;

V_{system} is the nominal system voltage of battery system, in V.

NOTE V_{system} means the same as nominal voltage.

For batteries, the formula above may be rewritten as follows:

$$\left|\Delta Q\right| \le 0{,}01 \times \frac{J_{\mathrm{NHV}} \times m_{\mathrm{fuel}} / 3\,600}{V_{\mathrm{system}}} \qquad \text{(B.3)}$$

B.3 Capacitors

The change of energy stored in the capacitor over the ADT, ΔE_{C}, in Wh, is expressed as follows:

$$\Delta E_{\mathrm{C}} = \frac{C}{2} \times \left({V_{\mathrm{final}}}^2 - {V_{\mathrm{initial}}}^2 \right) / 3\,600 \qquad \text{(B.4)}$$

where

C	is the nominal capacitance of the capacitor, in F;
V_{final}	is the terminal voltage of the capacitor at the end of the test, in V;
$V_{initial}$	is the terminal voltage of the capacitor at the beginning of the test, in V.

For capacitors, the formula above may be rewritten as follows:

$$\left|V_{final}^{2} - V_{initial}^{2}\right| \leq 0{,}01 \times \frac{2 \times J_{NHV} \times m_{fuel}}{C} \quad \text{(B.5)}$$

Annex C
(informative)

Theory for the linear regression method

This annex shows how the linear regression method can theoretically be applied to the correction method for determining the fuel consumption of HEVs.

The consumed energy of HEVs is composed of the fuel energy consumed by the ICE power train system and the electric energy consumed by electric power train system. It is necessary to estimate the consumed fuel during the test in zero charge balance condition ($\Delta E_{RESS} = 0$) in other words that the battery SOC after the test is equal to the SOC before the test. Assuming that the average efficiency of the ICE power train system during the test period is equal to that in the estimated zero charge balance condition, then Formula (C.1) applies.

$$\alpha \times E_0 = (\alpha \times E_f) + (\beta \times \kappa \times E_e) \quad \text{(C.1)}$$

where

- α is the average efficiency of ICE power train system during the test period;
- β is the average efficiency of electric power train system during the test period;
- κ is the average efficiency of battery system during the test period;
- E_f is the consumed energy of fuel during the test period;
- E_e is the consumed/regenerated energy of electricity during the test period;
- E_0 is the estimated consumed energy of fuel during the test period, in zero charge balance condition.

By applying the additional values listed below, Formula (C.1) can be rewritten to Formula (C.2):

$$\alpha \times \gamma \times U_0 = (\alpha \times \gamma \times U_m) + (\beta \times \kappa \times E_e) \quad \text{(C.2)}$$

where

- γ is the volume energy density of fuel;
- U_0 is the estimated consumed fuel during the test period, in zero charge balance condition;
- U_m is the consumed fuel during the test period.

By dividing the consumed values from Formula (C.2) by the distance travelled, L, and introducing the corresponding consumption values listed below, Formula (C.2) can be rewritten as Formula (C.3):

$$\alpha \times \gamma \times FC_0 = (\alpha \times \gamma \times FC_m) + (\beta \times \kappa \times EC_m) \quad \text{(C.3)}$$

where

FC_0 is the estimated fuel consumption rate in the test period, in zero charge balance condition;

FC_m is the fuel consumption rate during the test period;

EC_m is the electric energy consumption rate during the test period;

m signifies "measured".

Therefore, the measured fuel consumption rate, in certain charge balance condition, FC_m, can be expressed as follows:

$$FC_m = FC_0 - \left[\frac{\beta \times \kappa}{\alpha \times \gamma} EC_m \right] \quad (C.4)$$

Electric energy consumption rate, EC_m, can be expressed as follows:

$$EC_m \cong V \times \frac{\Delta Q}{L} \quad (C.5)$$

where

V is the system voltage, in V;

ΔQ is the charge balance of the battery during the test period, in Ah;

L is the distance covered in the test period, in km.

Formula (C.4) and Formula (C.5) lead to following Formula (C.6):

$$FC_m = FC_0 - \frac{V}{\gamma} \times \frac{\beta \times \kappa}{\alpha} \times \frac{\Delta Q}{L} \quad (C.6)$$

Formula (C.6) shows that FC_m is the function of charge balance per distance ($\Delta Q/L$). Refer to D.3.2 for further information.

Formula (C.6) also shows that the gradient of this formula is in proportion to β/α, namely to the ratio of electric and ICE traction system efficiency. It also shows that the y-axis-crossing value indicates resultant fuel consumption rate in zero charge balance condition.

In this annex, the polarity of ΔQ is set plus when battery energy is increased (charging) in accordance with battery manners.

Annex D
(informative)

Guidelines for charge balance measurement

D.1 General

On the fuel consumption test of HEVs, it is essential to measure the charge balance in the rechargeable energy storage system (RESS) during the test period to compensate for the effect of energy change in RESS on fuel consumption. This document, which defines a basic fuel consumption test method for non-externally chargeable HEVs, does not define required accuracy on a current measurement system but defines required accuracy on charge balance as required accuracy for the total current measurement system. So, the accuracy of current sensor or current measuring system for each test should be individually managed.

Investigating the required accuracy on a current measuring system is a complicated task, due to the fact that the effect of current measurement error on fuel consumption test accuracy depends on both vehicle characteristics and the test cycle. As the charge balance is normally obtained by integrating battery current (remainder of "accumulated value of charging current" minus "accumulated value of discharged current") and as the battery current is composed of intermittent high charging current, intermittent high discharging current and low current with long duration time, it is necessary to pay special attention to managing the DC stability in the current measurement system to keep required accuracy.

In consideration of these backgrounds, this annex provides detailed guidelines for the charge balance measurement method (including requirement for current measuring systems) to fulfil the required total accuracy prescribed in this document.

This annex describes procedures on charge balance measurement to ensure necessary and sufficient accuracy of fuel consumption test on HEVs with batteries, which is conducted based on this document.

D.2 Outline of error in HEV fuel consumption test

As shown in Figure D.1, the relationship of fuel consumption and charge balance is estimated by linear regression method using test results in scheduled driving test, to obtain resultant fuel consumption. The regression line will be scattered by errors caused by various factors. Factors that affect the fuel consumption test have been classified according to the following three types:

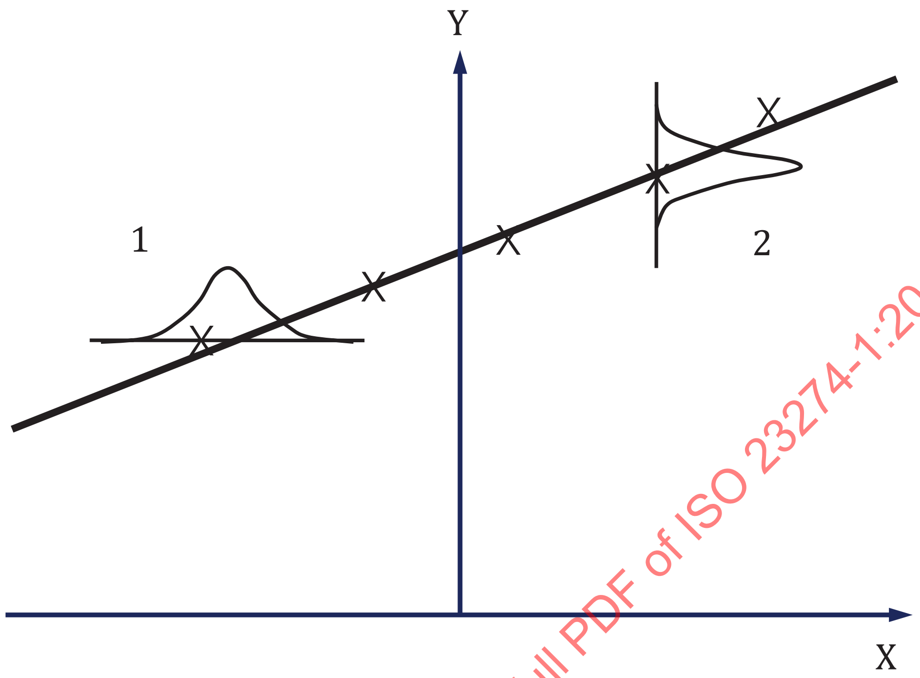
a) errors in the fuel consumption measurement;

b) errors caused by the load simulation on the chassis dynamometer;

c) errors in the charge balance measurement.

Whereas the first two types of errors scatter the regression line vertically, the third type of error scatters the line horizontally as shown in Figure D.1. Thus, the third error indirectly affects resultant fuel consumption, while the first two errors directly affect fuel consumption.

As mentioned above, when the fuel consumption of HEVs is expressed as a linear formula in the charge balance of battery (ΔQ), the gradient of the regression line will be a function of the distance covered and the average ratio of the electric power train efficiency to the ICE power train efficiency during the test period. Consequently, the effect of the third type of error on the resultant fuel consumption will strongly depend on the test vehicle and the test cycle. Thus, the required accuracy for charge balance measurement will be strongly dependent on the test cycle and the characteristics of test vehicle. So, it is important to ascertain the required accuracy for the charge balance measurement that will ensure the resultant fuel consumption test for a specific test cycle and vehicle meets the required accuracy. In addition, it is important to define the procedures for measuring current and data processing to ensure that the final result meets the required accuracy.



Key

X charge balance of battery per distance (in Ah/km) [or energy balance of battery per distance (in Wh/km)]

Y fuel consumption rate (in l/km)

1 electricity measurement error

2 fuel measurement error + load simulation error

Figure D.1 — Relationship of three error factors on tests

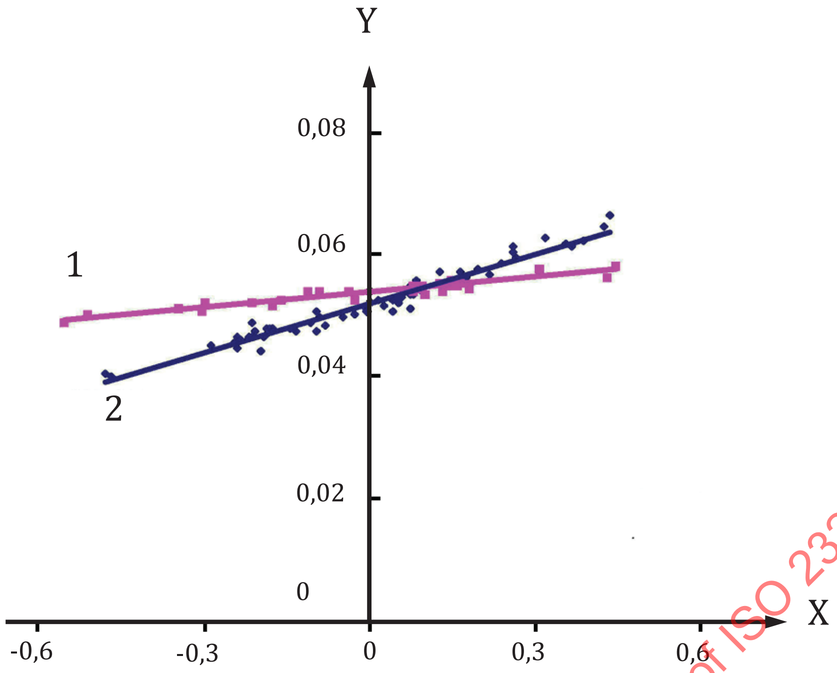
D.3 Guideline for measurement

D.3.1 General

Investigations on required accuracy for charge balance measurement systems and procedures to keep the required accuracy are described in the following sub clauses.

D.3.2 Normalization to reduce the effect of test cycle

Figure D.2 shows the fuel consumption vs. ΔQ characteristics of a HEV on the market during the Japanese 10-15 mode and the U.S. urban dynamometer driving schedule (UDDS). The two resultant regression lines exhibit remarkable differences in their gradients (i.e. the first-order coefficients of the linear regression lines). This fact makes it difficult to compare test results for the same vehicle in different test cycles or to check whether the regression line of a new result is reasonable by comparing it with a standard regression line for another test cycle.



Key

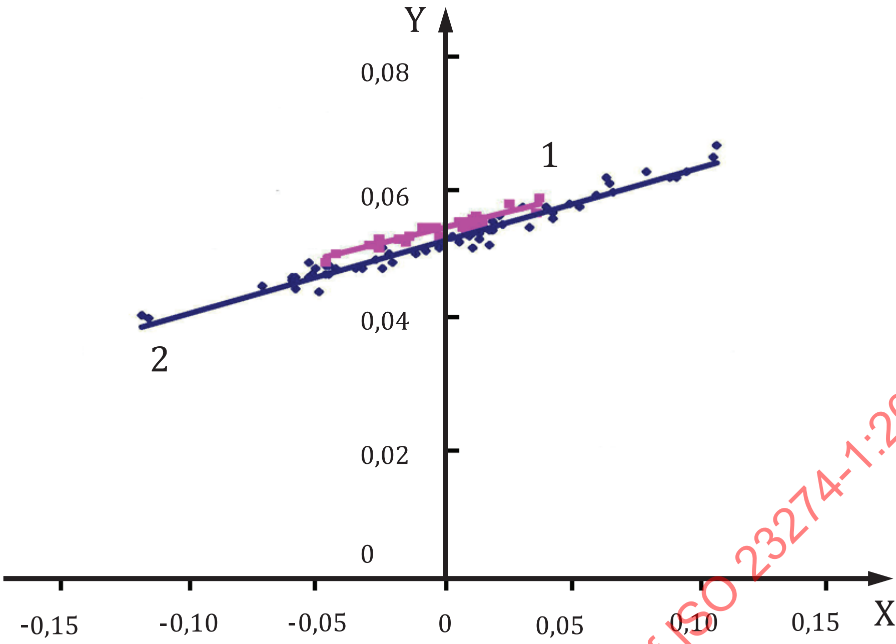
X charge balance of battery (in Ah)

Y fuel consumption rate (in l/km)

1 the urban dynamometer driving schedule (UDDS)

2 the Japanese 10-15 mode

Figure D.2 — Fuel consumption rate — Δ*Q* characteristics in two test modes



Key

X charge balance of battery per distance (in Ah/km)

Y fuel consumption rate (in l/km)

1 the urban dynamometer driving schedule (UDDS)

2 the Japanese 10-15 mode

Figure D.3 — Fuel consumption rate — Charge balance per distance characteristics in two mode tests

Figure D.3 shows the fuel consumption versus charge balance per distance characteristics of the HEV shown in Figure D.2. The two regression lines show no remarkable differences in their gradients, so that it is possible to estimate the validity of a newly obtained result by comparing it to the standard regression line of another test cycle for the HEV.

In order to discuss the accuracy of the charge balance measurement by referring to the accuracy of the fuel consumption test, the linear regression method should be applied to the fuel consumption as a function of charge balance per distance ($\Delta Q/L$) rather than as a function of the charge balance (ΔQ).

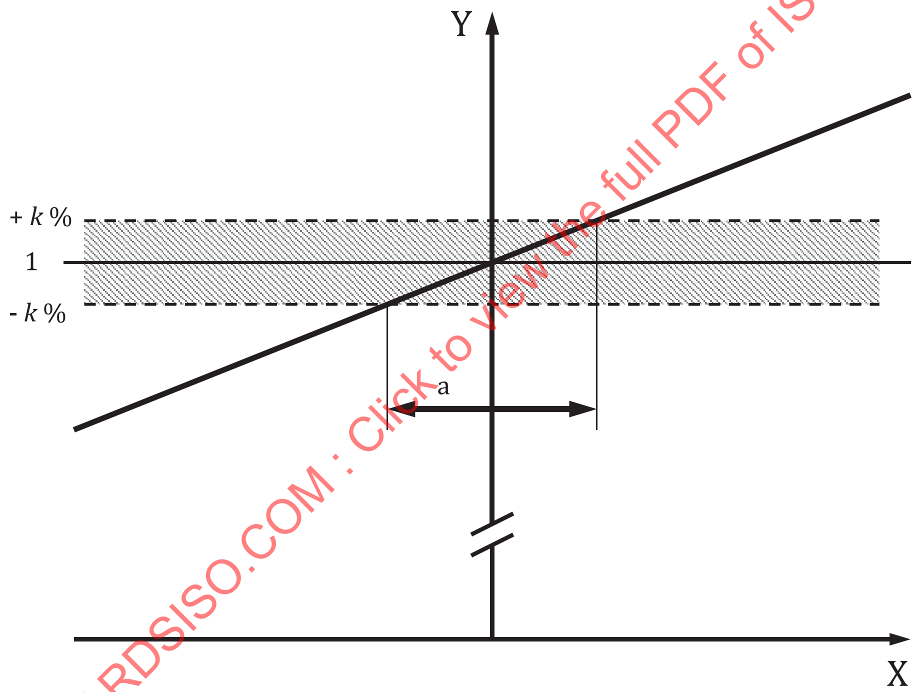
Physically, it indicates that the fuel consumption is not a function of the charge balance per distance [i.e. charge balance in battery (in Ah) / distance travelled (in km)] but rather that it is a function of the energy balance per distance [energy change in battery (Wh) / distance travelled (in km)]. But the energy efficiency of the battery (the Wh efficiency) depends on loads and it varies dynamically corresponding to the charging/discharging current and battery conditions. So, it is difficult to apply integration of the power as a scale for clarifying the energy level in the battery [i.e. the state of charge of the battery (SOC)]. On the contrary, the coulomb efficiency of a battery is usually close to unity, making the charge balance (integrated value of current) a suitable parameter for clarifying the energy level of a battery.

As the purpose of using the linear regression method is to estimate the fuel consumption under the conditions of no energy change, it is not essential to apply the energy balance or energy as a scale to confirm no energy change. However, when it comes to the quantity of energy change in the battery during the test, the charging/discharging energy should be measured by taking into account the charging/discharging efficiency, or an approximate energy should be calculated as a product of the "charge balance" and the nominal voltage of battery.

D.3.3 Guideline to define the accuracy of the current measuring system required by corresponding test cycle

As mentioned above, the effect of charge balance per distance (i.e. the coefficient of the first-order term of the linear regression line) on the fuel consumption depends on the characteristics of the HEV, and is approximately the same level for different test cycles on the same HEV. So, the influence of the charge balance measurement error on fuel consumption is also dependent on the HEV to be tested. That is, the allowable error for the charge balance measurement or the required accuracy of the current measurement system has to be discussed by taking into account the HEV characteristics.

Figure D.4 shows relationship between energy balance of battery (ΔE_b) and measured fuel consumption [expressed ratio of measured fuel consumption (FC_{meas}) to true fuel consumption (FC_0)]. As shown in Figure D.4, the allowable energy change in the battery (ΔE_b) for a fuel consumption error of less than *k* % of the fuel consumption can be calculated using the relationship between the electric energy and the consumable fuel energy. But such an energy-based discussion will be problematic, since it requires use of an approximation to calculate the energy change in the battery and of a conversion to evaluate the two energy sources (electric energy and fuel energy) on the same table. So, a discussion based on energy is not suitable for an actual test, because of its complicated operation and the uncertainty in the operation process.



Key

X energy balance of battery, ΔE_b (in Wh)

Y FC_{meas} / FC_0

a allowable ΔE_b (in Wh)

k allowable fuel consumption rate error (in %)

Figure D.4 — Allowable error in energy balance of battery, ΔE_b

In the meantime, the allowable error in the charge balance per distance, in Ah/km, can be estimated directly using the information in Figure D.5. Figure D.5 shows the estimated fuel consumption, in l/km, for different charge balance per distance, in Ah/km, obtained using the linear regression method. The linear regression line shows the relationship between fuel consumption and charge balance per distance directly, that is, the effect of the thermal/electric system efficiency and the energy conversion ratio are already taken into account. Thus, it is possible to define the allowable error in the charge balance per distance for achieving a fuel consumption rate error of less than *k* %. It should be noted

