
**Hybrid-electric road vehicles —
Guidelines for charge balance
measurement**

*Véhicules routiers électriques hybrides — Lignes directrices pour le
mesurage de la balance de charge*

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Introduction

On the fuel consumption test of non-externally chargeable *hybrid-electric vehicles* (HEV), it is essential to measure the charge balance in a rechargeable energy storage system (RESS) during a test period in order to compensate the effect of energy change in a RESS on fuel consumption. ISO 23274, 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 required accuracy of current sensor or current measuring system for each test should be individually managed.

To investigate 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 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 huge charging current, intermittent huge discharging current and small current with long duration time, it is necessary to pay special attention to managing the d.c. stability in the current measurement system to keep the required accuracy.

In consideration of these backgrounds, this Technocal Report describes detailed guidelines for charge balance measurement methods (including requirements for current measuring systems) to fulfil the required total accuracy prescribed in ISO 23274.

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Hybrid-electric road vehicles — Guidelines for charge balance measurement

1 Scope

This Technical Report describes procedures of charge balance measurement to ensure necessary and sufficient accuracy of a fuel consumption test on *hybrid-electric vehicles* (HEV) with batteries, which is conducted based on ISO 23274 (see Bibliography).

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1

charge balance

⟨of a battery⟩ change of charge in a battery during test period

NOTE Normally expressed in ampere-hours.

2.2

energy balance

⟨of a battery⟩ change of energy in a battery during test period

NOTE 1 Normally expressed in Watt-hours.

NOTE 2 For practical use, following approximate definition is made: “charge balance of battery multiplied by the nominal voltage, normally expressed in Wh (ISO 23274)”.

2.3

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

2.4

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

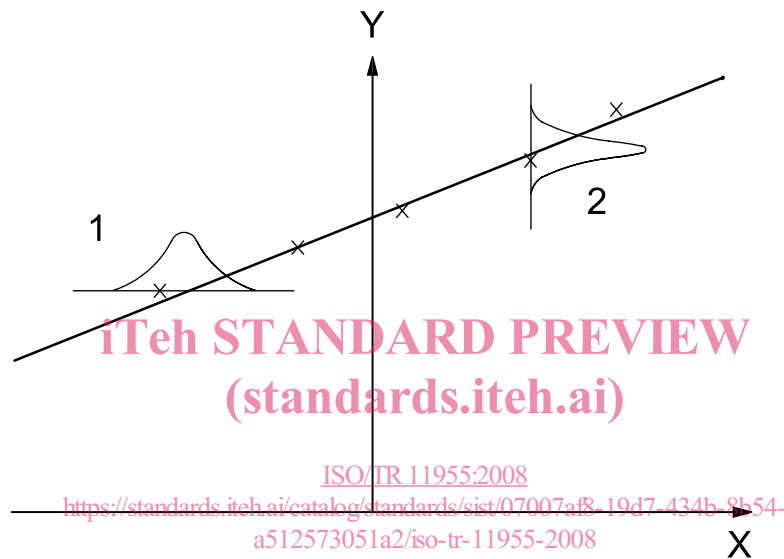
3 Outline of error in HEV fuel consumption test

As shown in Figure 1, the relationship of fuel consumption and charge balance is estimated by the linear regression method, using test results in a scheduled driving test, to obtain resultant fuel consumption. The regression line is 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 error scatter the regression line vertically, the third type of error scatters the line horizontally as shown in Figure 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 equation in the charge balance of the 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 the test vehicle. So, it is important to ascertain the required accuracy for the charge balance measurement that will ensure that 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 per distance of battery in Watt-hours per kilometre or ampere-hours per kilometre
- Y fuel consumption in litres per kilometre
- 1 electricity measurement error
- 2 fuel measurement error + load simulation error

Figure 1 — Relationship of the three error factors on tests

4 Guideline for measurement

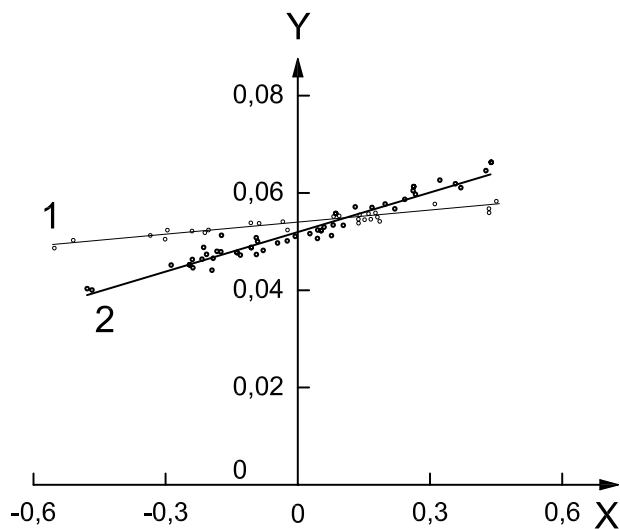
4.1 General

Investigations into the required accuracy for charge balance measurement systems and procedures for retaining the required accuracy are described in 4.2 to 4.4.

4.2 Normalization to reduce the effect of the test cycle

Figure 2 shows fuel consumption vs. ΔQ characteristics of an HEV on the market during the Japanese 10-15 mode and the U.S. urban dynamometer driving schedule (U.D.D.S.). The two resultant regression lines exhibit remarkable differences in their gradients (i.e. the first-order coefficients of the linear regression lines).

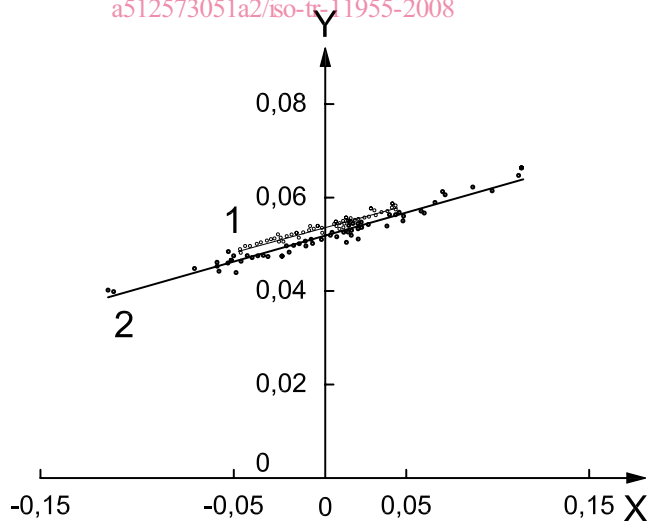
This fact makes it difficult to compare test results for the same vehicle in different test cycles or to check whether the regression line of a new result is reasonable by comparing it with a standard regression line for another test cycle.



Key

- X charge balance, ΔQ in ampere-hours
- Y fuel consumption in litres per kilometre
- 1 U.D.D.S.
- 2 10-15 mode

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 Figure 2 — Fuel consumption — ΔQ characteristics in two test modes
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Key

- X charge balance per distance in ampere-hours per kilometre
- Y fuel consumption in litres per kilometre
- 1 U.D.D.S.
- 2 10-15 mode

Figure 3 — Fuel consumption — Charge balance per distance characteristics in two test modes

Figure 3 shows fuel consumption vs. charge balance per distance characteristics of the HEV shown in Figure 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 divided by distance travelled (Ah/km)] but rather that it is a function of the energy balance per distance [energy change in battery divided by distance travelled (Wh/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, if we discuss 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.

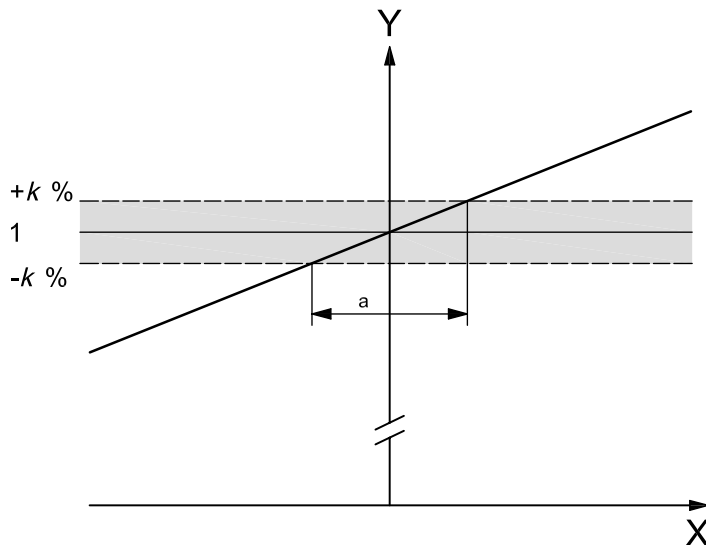
4.3 Guideline to define the accuracy of the current measuring system required by the corresponding test cycle

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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 4 shows relationship between energy balance of battery, ΔEb , and measured fuel consumption [expressed as a ratio of measured fuel consumption (FC_{meas}) to true fuel consumption (FC_0)]. As shown in Figure 4, the allowable energy change in the battery, ΔEb , 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.

In the meantime, the allowable error in the charge balance per distance (Ah/km) can be estimated directly using the information in Figure 5. Figure 5 shows the estimated fuel consumption (l/km) for different charge balance per distance values (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, we can define the allowable error in the charge balance per distance for achieving a fuel consumption error of less than k %. It should be noted that we can define the allowable error only for the charge balance per distance and that it is not possible to define the allowable error in the current measurement system at this stage.



Key

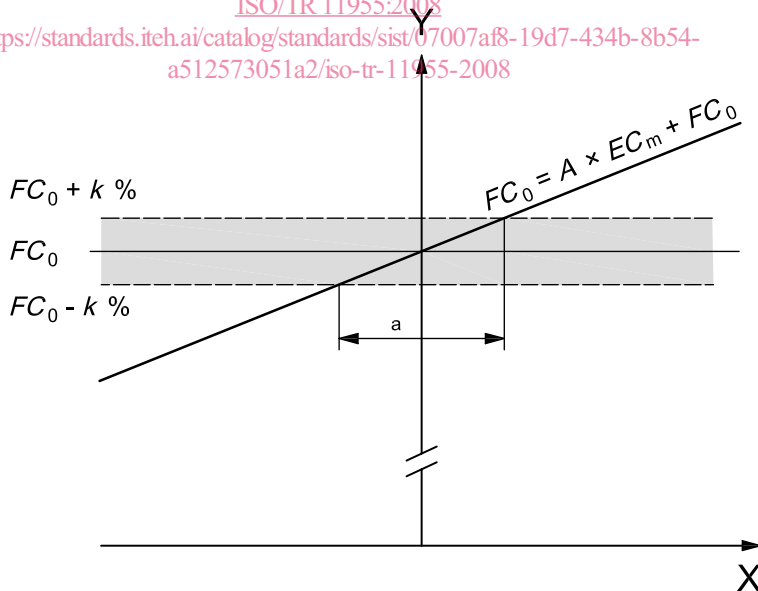
- X energy balance of battery, ΔEb
- Y FC_{meas}/FC_0
- a Allowable ΔEb

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Figure 4 — Allowable error in energy balance of battery, ΔEb

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Key

- X charge balance per distance, EC_m in ampere-hours per kilometre
- Y FC_{meas} in litres per kilometre
- a Allowable EC_m .

Figure 5 — Allowable error in charge balance per distance