Our Initiatives for Efficient Data Analysis of Worldwide Harmonized Light Vehicles Test Procedures (WLTP) Testing Processes

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Keywords WLTP, Data analysis, Efficiency

Abstract

We developed data analysis software compliant with Worldwide harmonized Light vehicles Test Procedures (WLTP) tests in accordance with the operation process of the Japan Automobile Research Institute (JARI). This software performs time synchronization of measurement data from MEIDACS operation measurement system and various measuring instruments, extracts data for each cycle and phase, and performs calculations in accordance with each test method – compliant with various test methods for Pure Electric Vehicles (PEVs), Hybrid Electric Vehicles (HEVs), Fuel Cell Hybrid Vehicles (FCHVs), and other vehicles. In addition, the final form used to organize data can be output in the customer's specified format.

The analysis process, which was previously performed manually using spreadsheet software, has been automated using script-based software, reducing overall work and processing time. To support scalability and future revision, we have made it possible for customers to perform software maintenance, the process of changing, modifying and updating software, through additions and edits.

1 Preface

The Japan Automobile Research Institute (JARI) is a neutral and public interest organization dedicated to automotive testing and research. JARI also deals with (1) liaison work (making requests for co-operation) with automakers for automotive standardization, (2) making recommendations, and (3) market research. JARI leads the industry in automotive technology. For this reason, JARI conducts tests using a variety of vehicle types and environmental conditions. This article introduces data analysis software that can efficiently perform data analysis and evaluation compliant with various automobile test methods of Worldwide harmonized Light vehicles Test Procedures (WLTP). This software was produced jointly with JARI.

2 WLTP Test

In WLTP, the types of vehicles to be tested are divided into detailed categories, and the testing methods are different. The main category is classified into Internal Combustion Engine (ICE) vehicles, Pure Electric Vehicles (PEVs), Hybrid Vehicles (HEVs), and Fuel Cell Hybrid Vehicles (FCHVs) according to the Vehicle Propulsion System Definitions (VPSD). HEVs and FCHVs are further subdivided into types that can be recharged from external source and those that cannot. For example, within the HEV category: Off-Vehicle Charging Hybrid Electric Vehicles (OVC-HEVs) is a hybrid electric vehicle that can be recharged by plugging into an external source of electricity. This is commonly referred to as a plug-in hybrid vehicle; Not Off-Vehicle Charging Hybrid Electric Vehicles (NOVC-HEVs) is a hybrid electric vehicle that cannot be recharged by an external source of electricity. We will introduce some of the Type 1 tests, including (methods for measuring exhaust gas, fuel consumption, and power consumption) for these vehicles.

2.1 ICE Vehicles

After preconditioning and soaking, ICE vehicle runs one cycle of the Worldwide-harmonized Light Vehicles Test Cycle (WLTC). We measure (1)

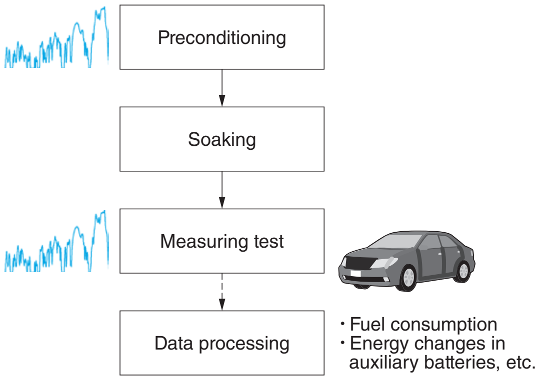


Fig. 1 Test Procedure for ICE Vehicle Emission Testing

This shows the WLTP Type 1 test flow for ICE vehicles.

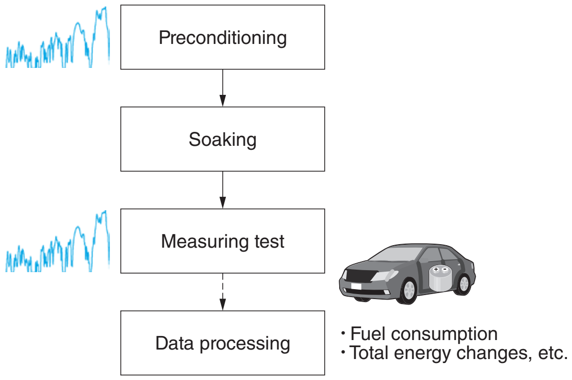


Fig. 2 Test Procedure for NOVC-HEVs

This shows the WLTP Type 1 test flow for NOVC-HEVs that cannot be recharged by an external source of electricity.

exhaust gas concentration, the volume of diluted exhaust gas, etc., (2) calculate gaseous emissions, including: CO_2 emissions, Particulate Matter (PM) emissions, Particulate Number (PN) (if applicable), and (3) the fuel consumption. There is a provision to correct CO_2 emissions based on changes in the electrical energy of the auxiliary battery and the Willans coefficient specific to the combustion type. **Fig. 1** shows the test procedure for a typical ICE vehicle emission test.

2.2 NOVC-HEVs

In NOVC-HEV tests, which cannot be recharged from external source, the WLTC is run for one cycle after preconditioning and soaking. Then the exhaust gas concentration, volume of diluted exhaust gas, changes in electric energy of the propulsion battery and auxiliary battery, etc. are measured. We calculate gas emissions including: CO_2 emissions, PM emissions, PN (if applicable), and the fuel consumption. One difference from ICE vehicles is that CO_2 emissions are corrected based on the amount of change in electrical energy that is the sum of the propulsion battery and auxiliary battery before and after the test, and the slope of the vehicle-specific coefficient. **Fig. 2** shows the NOVC-HEV test procedure.

2.3 OVC-HEVs

The OVC-HEV can be recharged from an external source. It has one side of PEV, one side of NOVC-HEV, and has a complex state, such as a transition state from PEV to HEV. This makes the test and calculation content more complicated. During the soaking after preconditioning, the test brings the propulsion battery to a fully charged state. The test changes from the Charge Depleting (CD) state, in which the vehicle runs using battery energy, to the Charge Sustaining (CS) state, in which the battery's energy state is stable. The test continues until the CS state is reached. During the cycle, the exhaust gas concentration, volume of diluted exhaust gas, changes in the electric energy of the propulsion battery, etc. are measured. The WLTC cycle is repeated until the changes in battery charging or discharging energy are within the specified range. The test procedure calculates the equivalent all-electric range, charge-depleting actual range, electric energy consumption, recharged electric energy, charge-sustaining fuel efficiency, and gaseous emissions, including: CO_2 emissions, PM emissions, and PN (if applicable). In addition, in the CS state, as with NOVC-HEV, there is a provision to correct CO_2 emissions based on the amount of change in electrical energy before and after the WLTC cycle test. **Fig. 3** shows the OVC-HEV test procedure.

2.4 PEVs

For PEVs, it measures changes in the electrical energy of the battery during driving and the amount of externally charged energy after driving, and calculates the pure electric range and the electric energy consumption. There are two test procedures. One test is a consecutive cycle test procedure in which the driving battery is fully charged during the soak after the preconditioning and the cycle of the WLTC is repeated until the driving battery is exhausted. The other test is a shortened test procedure by combining the cycle of the WLTC and the high-speed constant speed driving. The test selection is made depending on the number of

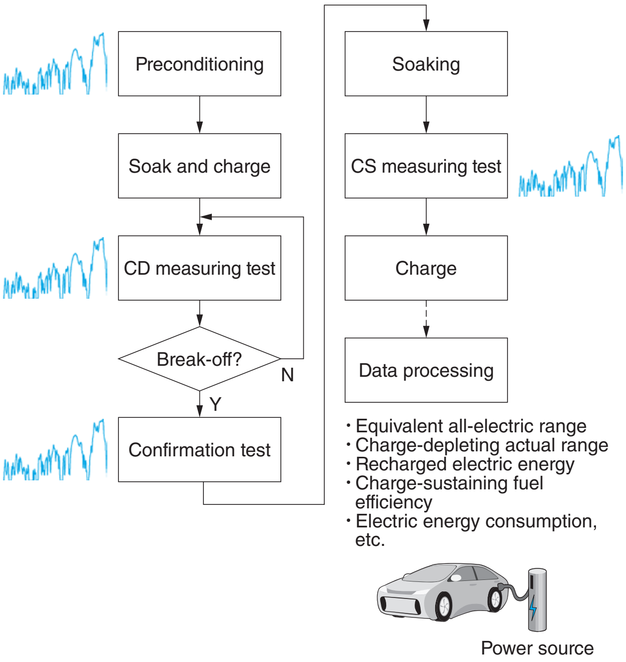


Fig. 3 **Test Procedure for OVC-HEVs**

This shows the WLTP Type 1 test flow of OVC-HEVs that can be recharged by plugging into an external source.

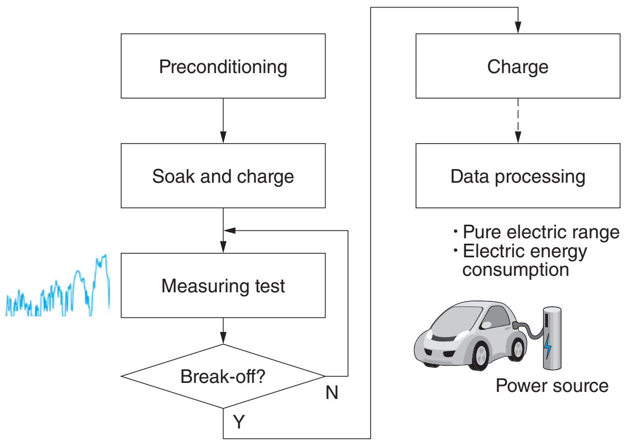


Fig. 4 **Test Procedure for PEVs (Consecutive Cycle Test Procedure)**

This shows the WLTP Type 1 test flow by PEVs consecutive cycle test procedure.

cycles expected to run at WLTC. **Fig. 4** shows the PEV test procedure (consecutive cycle test procedure). **Fig. 5** shows the test procedure (shortened test procedure).

2.5 NOVC-FCHVs

In the case of fuel cell hybrid vehicles that use hydrogen (H_2) as fuel, which cannot be recharged from external source, precise measurement of hydrogen consumption is required. Therefore, during the test, we do not use an on-board hydrogen storage tank, but instead supply fuel from outside the vehicle with a hydrogen cylinder and measure hydrogen consumption based on the difference in cylinder weight before and after the test. Fuel cell vehicle have no emissions or CO_2 emissions, so we calculate the fuel consumption of hydrogen fuel. There is a provision to correct the fuel consumption based on the amount of change in electrical energy in the propulsion battery before and after the test. **Fig. 6** shows the NOVC-FCHV test procedure.

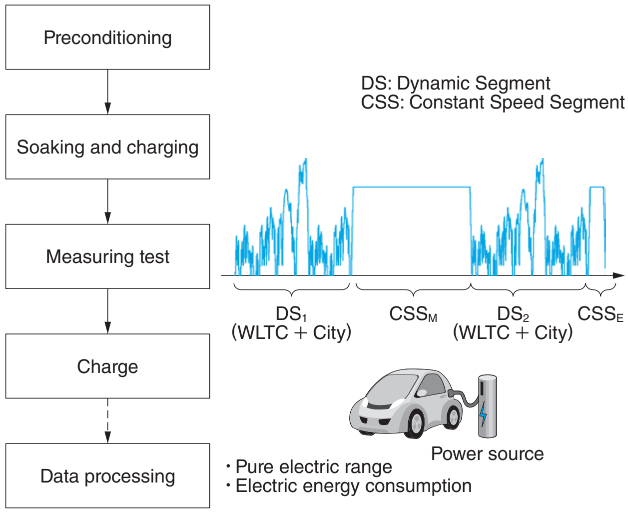


Fig. 5 **Test Procedure for PEVs (Shortened Cycle Test Procedure)**

This shows the WLTP Type 1 test flow by PEVs shortened cycle procedure.

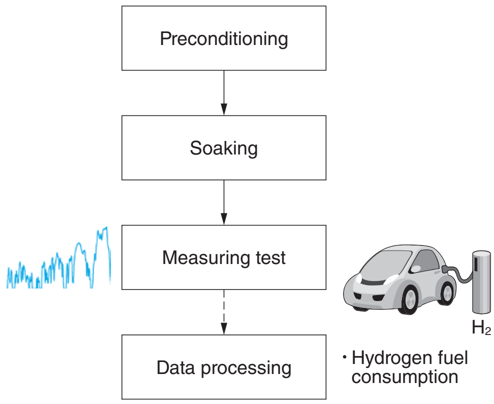


Fig. 6 **Test Procedure for NOVC-FCHVs**

This shows the WLTP Type 1 test flow for NOVC-FCHVs that cannot be recharged by an external source.

3 Data Analysis

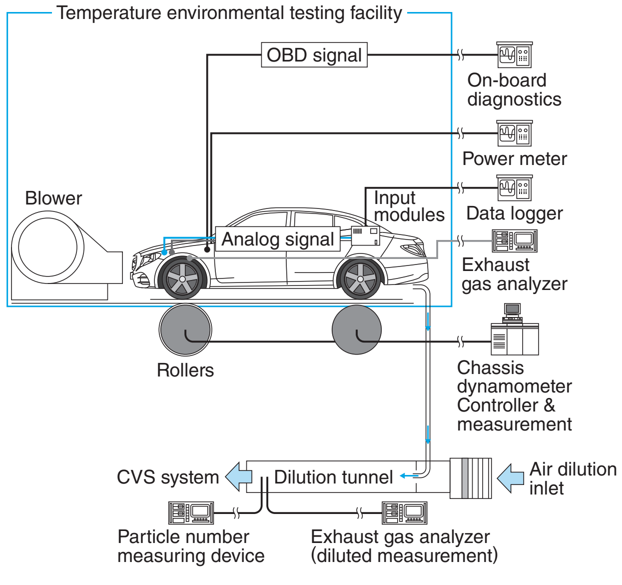
In the WLTP test method, data analysis is complicated because the test methods and measurement targets differ depending on the test vehicle. In addition, the targets to be calculated, gaseous emissions, fuel consumption, electric energy consumption, range, etc., also differ.

In the case of pure ICE vehicles, the main measuring instruments include an exhaust gas analyzer to measure exhaust gas concentration and an exhaust gas measurement system (CVS) device to measure volume of diluted exhaust gas. In case of testing pure electric vehicles, we do not use exhaust gas analyzers, but a power meter is used as the main instrument to measure changes in battery energy and the amount of external power supplied. In case of testing HEVs equipped with ICE, the test requires measuring instruments such as power meter, in addition to exhaust gas analyzer and CVS device. The actual distance driven in the test is measured using a chassis dynamometer. Data obtained from various measuring devices uses not only data obtained by measuring instantaneous values at a fixed sampling period, but also data obtained by measuring the average concentration by bag sampling according to the measured component in the exhaust gas analyzer and averaging processing of the instantaneous concentrations. Since the data used in the measurement are used, it is necessary to handle the data processing according to the measurement equipment. When handling data collected with different measuring instruments, the measurement start timing, sampling period, and data format often differ. Preprocessing for data analysis requires steps such as data extraction, data integration, and data conversion to ensure the same timing and sampling period. By performing appropriate data preprocessing, the time axis of all data is unified, the data for each cycle or phase can be extracted for each test, and calculations can be performed according to regulations.

3.1 Conventional Operation

JARI conducts tests using equipment appropriate for the test purpose, such as a chassis dynamometer, exhaust gas analyzer, and power meter. Fig. 7 shows an example of how the equipment and measuring equipment used during testing are connected. Until now, when testing ICE vehicles, the dynamometer system controlled the exhaust gas analyzer and CVS equipment. Such system automatically collected data, calculated the metrics, and displayed the forms. Fig. 8 shows an example of a report using a chassis dynamometer system.

For PEVs and HEVs, in addition to the above processes, we are testing with additional equipment such as power meter. For data analysis, spreadsheet software was used to analyze the report results from the dynamometer system and individual measurement files from various measuring instruments. For time-series data, humans assess the vehicle speed signals, and other signals, adjust the data positions so that they are at the same timing, synchronize them, and isolate driving cycles and phases. In addition, for data measured at random sampling times, such as vehicle On Board Diagnostics (OBD) signals, preprocessing such as interpolation processing took time.



Source: Japan Automobile Research Institute (JARI)

Fig. 7 Example of Connection between Test Equipment and Measuring Instruments

An example of connection is shown for dynamometer and various measuring instruments used for the measurement of vehicle exhaust gases, fuel consumption, electric energy consumption, and other values.

3.2 Initiatives to Improve Test Efficiency

We worked together with JARI to solve the problem. This is to improve the efficiency of JARI's data analysis and prevent human errors. As part of this effort, we made data analysis software that is compliant with WLTP. Together, we discussed JARI's test operation methods, issues, and requests, and decided on functions and data analysis methods. In particular, we reviewed the automation of measurement data synchronization, which had previously been done by humans, and introduced a new mechanism. The data handled corresponds to the data formats of the various measuring instruments used, and the data extracted can also be flexibly handled depending on the vehicle and test. These data analysis functions have been implemented using software that runs on scripts. These scripts take into account scalability in the event that regulations are revised or test operation methods need to be changed, and allow customers to handle additions and edits themselves.

3.3 Data Synchronization

If multiple instruments measure and save data independently, the measurement data will be out of sync due to differences in the timing of measurement start times and sampling cycles, which will hinder analysis. In order to synchronize the measured data, it is necessary to unify the sampling period and align the data so that each piece of data has the same time axis. For example, if a vehicle speed signal is input as an analog signal to each measuring device, an error of several sampling times may occur if you try to match the timing by evaluating the absolute value due to offset errors, full scale differences, etc. The data synchronization method we implemented this time extracts characteristic parts from the signals captured by each device and automatically adjusts the timing. Fig. 9 shows an image of data synchronization. In addition, data measured

Fig. 8 Form Examples by Chassis Dynamometer

This shows form examples of the test result in regard to ICE vehicle testing.

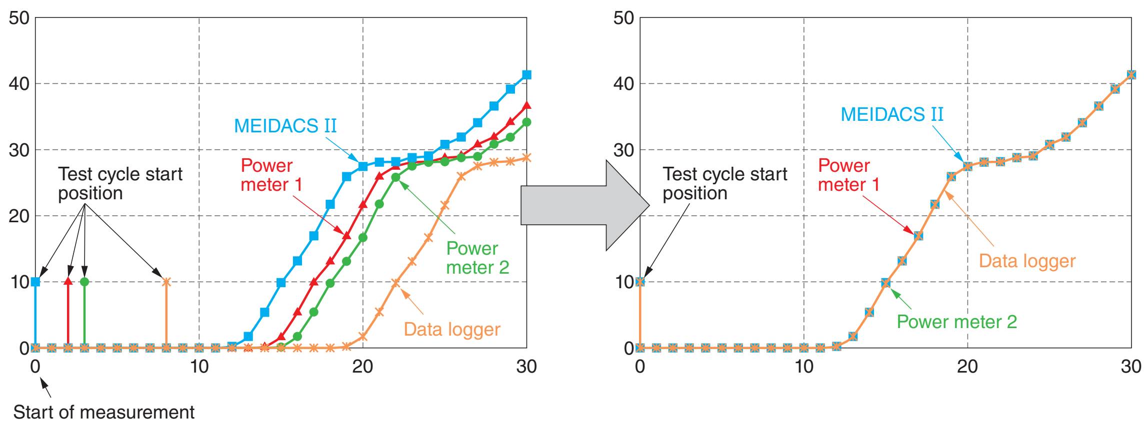


Fig. 9 Data Synchronization Images

The time-serial data before and after the data synchronization is shown where the signal timing is adjusted for the respective measuring instruments.

試験帳票

試験番号	:	
試験担当者	:	

1. 試験自動車概略

1.1. 全般

車台番号	:	
用途	:	
車体の形状	:	
駆動方式	:	

1.1.1 パワートレイン

パワートレイン	:	

1.1.10 電動機

型式		
最高出力		kW/rpm

1.1.11 駆動用バッテリー

型式		
容量		Ah
電圧		V

1.1.12 パワー・エレクトロニクス

製造者		
型式		
出力		kW/rpm

1.1.13 燃料電池スタック

型式		

1.2 車両H

1.2.1 車両重量

車両H　試験自動車重量		kg

1.2.2 走行抵抗パラメータ

f0		N
f1		N/(km/h)
f2		N/(km/h)^2
サイクルエネルギー要求量		MJ
走行抵抗測定結果		

1.2.3 走行サイクル選択パラメータ

走行サイクル		
車両最高速度		km/h

2. 試験結果

2.1 燃料消費率試験結果

シャシダイ負荷設定方法	:	惰行法
ダイナモ制御モード	:	固定走行方式／反復方式
惰行モード有無	:	
追加プリコン	:	

2.1.1 車両H

試験日	:	
試験場所	:	
冷却ファン下端の高さ	:	
車両前部からのファンまでの距離	:	

2.1.1.4 走行距離

2.1.1.4.2 純電気航続距離

純電気航続距離	WLTCモード値
計算値	km
申告値	km

2.1.1.5 電力消費率

2.1.1.5.2 純電気自動車の電力消費率

電電力消費率	WLTCモード値
計算値	Wh/km
申告値	Wh/km

2.2 重量

2.2.1 車両H

試験自動車重量		kg
走行抵抗測定時の平均重量		kg
種別		
重量配分		Front　kg
		Rear　kg

Fig. 10 Example of PEVs Test Result Format Output from Data Analysis Software

An example of PEVs test result format output from the data analysis software is shown.

at random sampling times is processed through interpolation processing to create data that has the same sampling period as other signals before synchronization processing is performed.

3.4 Forms

Data is extracted from data that has undergone timing and time axis synchronization processing, and arithmetic processing is performed in accordance with the WLTP test method, making it possible to output the final results in a form format. Fig. 10 shows an example of the PEVs test report format output from the data analysis software made for this initiative.

4 Postscript

We introduced some of our initiatives on data analysis software development for WLTP. This was carried out jointly with Japan Automobile Research Institute (JARI). We received positive feedback that the introduction of this software has shortened data analysis time and enabled tests to be conducted more efficiently.

Going forward, we will continue to provide products and services that meet the needs of our customers.

In closing, we would like to express our deep gratitude to all related people at the JARI for your cooperation in providing advice and evaluation in carrying out this initiative.