Feature Article

Development and Status of the Worldwide Harmonized Light Duty Vehicle Test Procedure

Les HILL

The globalisation of automotive exhaust emissions testing and measurement procedures has been in progress for a number of years and has already been introduced for vehicles such as motorcycles, on road heavy-duty vehicles (trucks/buses) and Non-Road Mobile Machinery (NRMM). The latest vehicle category for which a Global Technical Regulation (gtr) is to be developed in the Light Duty Vehicles. The paper reviews the history and current status of the Worldwide Harmonized Light Duty Vehicle Test Procedure (WLTP) program and the development of the new regulation for its world wide application. The document will also compare the draft WLTP requirements and procedures with those of the USA who have recently introduced their own draft procedures (CFR 1066) and highlight potential conflicts.

Introduction

In the past few years, there has been a large increase in activity in the development of new legislation, both in the reduction in the allowable mass limits of toxic and photo-chemical emission species and also in the development of new testing procedures, calculations and test system specifications. Coupled to this, there has also been a large increase in the variety and complexity of vehicle powertrain design including individual elements such as the internal combustion engine, potential of electrical/mechanical hybrization, transmissions and the exhaust after-treatment. Such diversity of powertrain design creates challenges to the emissions measurement systems, the test procedures and calculations.

The globalisation of automotive exhaust emissions testing and measurement procedures has been in progress for a number of years and regulations have already been introduced for vehicles such as motorcycles, on road heavy-duty vehicles (trucks/buses) and Non-Road Mobile Machinery (NRMM). The latest vehicle category for which a Global Technical Regulation (gtr) is to be developed is for Light Duty Vehicles (LDVs) for passengers and small commercial applications.

The paper summarises the progress and key elements of the Worldwide Harmonized Light Duty Vehicle Test Procedure (WLTP) program, as well as summarising other legislative developments in the LDV emissions measurement field.

Background

Whilst the amounts of permissible toxic, photo-chemical and Greenhouse Gas (GHG) emissions have been and are always likely to be decided by individual countries, the global harmonisation of emissions and fuel economy measurement methods, test procedures and calculations has been a long standing goal in order to simplify and streamline the certification process, test laboratory equipment and its calibration/verification.

The process for the WLTP was initiated at the UN-ECE WP29 meeting on the 4th June 2008 in Geneva. A target schedule for its development was presented at that meeting (Figure 1).

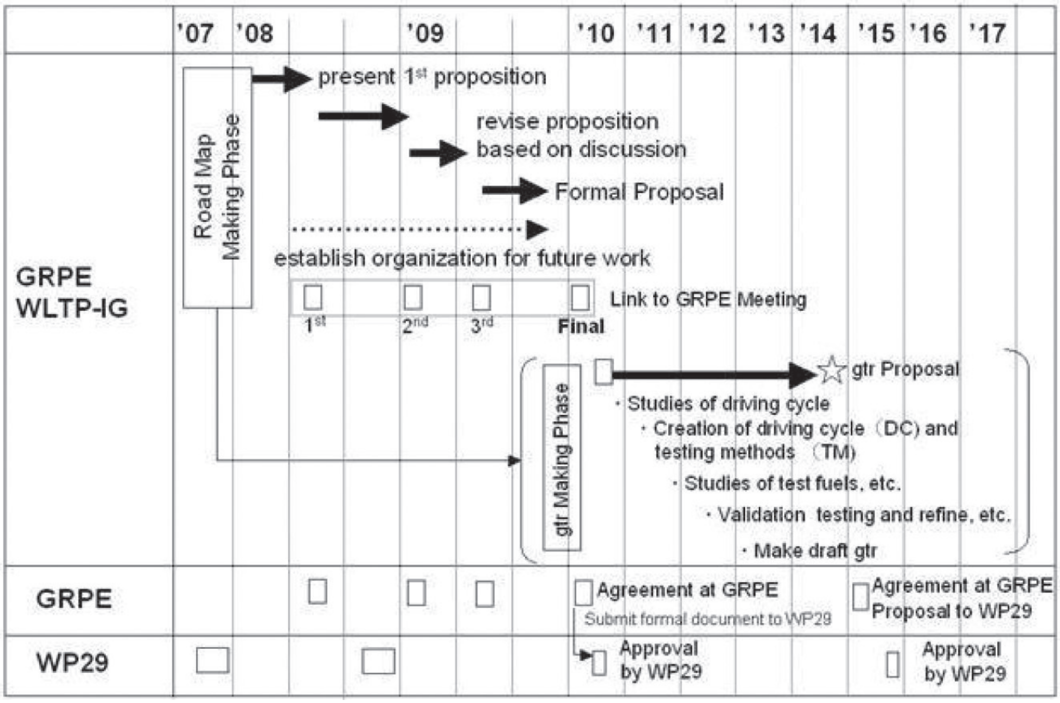

Figure 1 Original WLTP Development Schedule

WLTP Working Organisation and History

The development of the WLTP was passed to the GRPE (Group of Rapporteurs on Pollution and Energy) section of WP29 and organised into a number of Working Groups (WG).

- DHC : generation of the new vehicle speed/time drive cycle
- DTP : definition of the new test procedures, calculations and equipment specifications. The task of the DTP was further subdivided into smaller WGs.
  - PM/PN : procedures, specifications and calculations for the measurement of Particulate Matter (PM) mass and solid Particle Number (PN)
  - AP : new additional pollutants, their measurement procedures, calculations and equipment specifications
  - E-Lab : new test procedures, calculations and equipment specifications for electrified and hybrid electric vehicles
  - Reference Fuels : definition of the test fuels

The members of the various working groups are representative of the wide spectrum of interested parties and included light duty vehicle manufacturers, regional industry organisations, regional Technical Authorities, the USA EPA, the CARB, Environmental Monitoring/Study Groups and Equipment/Test System Suppliers.

These WGs report their status, open issues and future plans to the main WLTP organising committee primarily on a twice yearly basis at the UN-ECE GRPE meeting in Geneva. Individual working group meetings are scheduled as required by the activities either on a face to face basis or using web/phone conference.

Development of the New Drive Cycle (DHC WG)

The development of a new test drive cycle that can be applied globally for all countries and vehicle types has proven to be the big challenge of the WLTP program. This task was given to the DHC Working Group whose primary goals were outlined as:

- Devise a methodology for the development of a worldwide harmonized light-duty driving test cycle
- Develop guidelines for in-use data collection;
- Develop and validate a worldwide Harmonized light duty vehicle driving test cycle (to include validation, confirmation and round robin tests).

Road trip data was supplied by several regions/countries including the USA, Europe, Japan, China, India and Korea. This data was analysed and processed by the DHC WG and consolidated into a new drive cycle. The format of the new drive cycle followed the form of the schedules created for other gtrs where the speed/time trace is basically separated into urban, rural and highway phases. It was a request from the European Commission Directorate General for Enterprise and Industry (EU DG-ENTR) and the regional Technical Authorities that the drive cycle should be realistic of European driving and so an extra high speed phase was added with velocities above 130 km/h. It was recognised that such speeds would not be realistic for some countries or for some vehicle classifications with low power and so the test could be configured to eliminate the higher speed phases.

Version 1 of the Worldwide Harmonized Light Duty Vehicle driving Test Cycle (WLTC) was generated and subjected to evaluation in a Validation Phase by the various interested parties. As a result of the testing of various types of light duty vehicle, a series of modifications were made to improve the driveability and reproducibility of the drive cycle, culminating eventually in the version 5 of the WLTC that has been used in the current validation of the draft WLTP procedures, specifications and calculations (Figure 2).

The actual phases of the drive cycle to be used within the test depend on the power: weight ratio of the vehicle with the higher speed phases being eliminated if the vehicle is unable to meet the maximum speed in the phase. It is expected that further modifications will be made to the drive cycle as a result of the current validation program in progress.

In addition to the speed/time trace, another issue was that of the vehicle speeds at which the manual gear changes

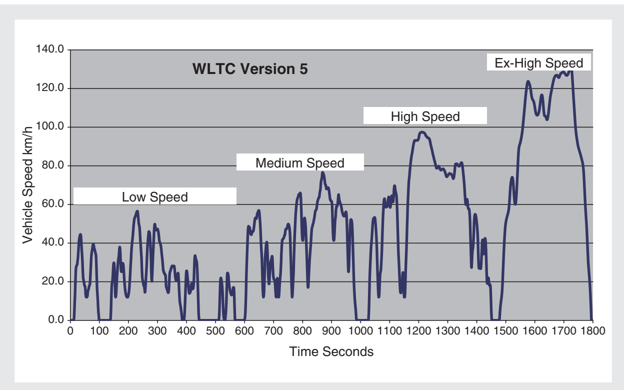

Figure 2 WLTC Version 5

are to be made. Currently, there are three proposed schemes under discussion:

- Fixed speeds
- Vehicle specific shift points: calculated based on the engine power, vehicle weight, number of gears, gear ratios, engine idle speed. This is the default method being used for the current Validation exercise.
- Alternative methods: such as vehicle Gear Shift Indicators (GSI) whose fitment is being made mandatory in Europe for all light duty vehicles fitted with manual transmissions. Their use will require a reliable solution on how these indicators can be made visible on the driver's aid used to display the speed/time trace to the test driver during the emissions test.

Development of the New Test Procedure (DTP)

The DTP Working Group started the draft process by reviewing and amalgamating the test procedures, calculations and specifications from the existing regulations from the USA (CFR 86), UN-ECE (Regulation 83) and JAPAN. A fundamental decision was, for the initial introduction of the new test procedure, to specify the full exhaust flow dilution technique using a constant volume sampler (CVS) as the only prescribed method of gaseous, particulate matter (PM) and solid particle number (PN) measurement. Other methods, such as partial flow dilution (for PM mass and gaseous compounds) and direct exhaust mass measurement (for gaseous compounds) were discussed but not included due to the technical unknowns/uncertainties and the lack of published correlation data on light duty vehicles. However, such alternative techniques could be included in the future once data is available.

The EU DG-ENTR and the Technical Authorities requested that the new test procedures should be more realistic and representative of the "real world" operation of the vehicle, particularly in the area of CO_2 and fuel economy determination. TUV Nord provided a report from their test program[1], comparing the vehicle manufacturers' CO_2 emissions data against data measured in their own laboratory. This outlined the key parameters that have an effect on the CO_2 emissions of the vehicle (Table 1). This resulted in lengthy discussions on a number of key topics such as the test cell/soak area temperature, the procedure and parameters for the vehicle road load determination and the vehicle mass to be used

Table 1 TUV Nord Summary of Factors Influencing CO_2 Emissions on LDVs
Influencing factors in the determination of CO_2 emissions and fuel consumption within the framework of passenger car type approval

Item	Parameter	Current status in Europe	Influence on CO_2 type test value	Recommendations for the WLTP
Test cycle "DHC"	Tolerance range	Use of tolerance to achieve lower CO_2 emissions is possible	- /+	Tolerances should be as narrow as possible; no smoothi ng out of the driving cycle curve and no excessive use of the accelerator pedal; option: driving robots
	Gearchange points	Gearchange points currently laid down for manual gearboxes: in case of optimisation, CO_2 reduction is possible	+++	GSI; alternatively, gear change point table based on vehicle parameters, automatic gearboxes in default mode
Measuring/ Test procedure "DTP"	Selection of test vehicle	Worst case for exhaust gas type test; minimum equipment for determination of CO_2 (overload) is possible	-- /++	Worst case variant wi th regard to vehicle weight and driving resistance
	Coast down test	Vehicle preparati on (tyre p ressure , toe angle), test track and ambient conditions influence the results	--- /+++	Setting of the vehicle (tyre pressures, toe angle) in accordance with the manufacturer's instructions; definition of the environmental conditions in accordance with ECE R83, average results in terms of forces, definition of the road surface
	nertia	Increments of 250 lbs, greatest inertia mass 5000 lbs	- /+	Halving o f the flywheel mass classes to 125 lbs, Adaptation of maximum flywheel mass to vehicle mass
	Test stand load setting	±10% at 20 km/h; ±5 % at 40 up to 120 km/h	- /+	Tolerances as narrow as possible; driving resistance on the road as set point
	Ambient conditions in the exhaust gas laboratory	20 °C to 30 °C	-	Conditioning at 22 °C +3 °C - 2 °C
	Battery charge state	Not defined, generally, battery is full at the start of the test	-	Measurement of the charging balance during the test, correction of emissions and consumption
	Auxiliary equipment	Auxiliary eq uipment is currently not taken into consideration	----	Auxiliary consumers in default mode; additional test for mobi le air condition, information regarding CO_2 and energy consumption o f optional auxiliary equipment
Type approval procedure	Conformity of production (CoP) testing	Random sample checks at the end of the production l ine		End-of-line check of production vehicles with regard to CO_2 and energy consumption
	In-service testing	Random-sample checks of the exhaust gas emissions of vehicles on the road.		In-service monitoring wi th regard to CO_2 and energy consumption

for testing; some of which are still to be finally resolved.

Measurement of PM Mass and PN

Relatively few changes were made to the existing procedures, calculations and specifications for these compounds. Some key modifications were:

- ability to use CVS systems applying double dilution of the vehicle exhaust (harmonizing the EU with the JAPAN/USA regulations) for PM mass measurement
- Changes to the PN equipment specifications to take account of the measurement of PN emissions when the vehicle particle trap is being regenerated (now included in the WLTP having been excluded in the current UN-ECE Regulation 83)

Measurement of Additional Pollutants (AP)

In addition to the current list of regulated or measurement compounds related to toxic, photo-chemical or fuel economy determination, other compounds have been specified for measurement under the WLTP procedures. These include:

- Nitrogen Dioxide (NO_2)
  NO_2 is already measured and controlled as it is a component of NOx (along with nitric oxide - NO). It has been identified as an individual component to be potentially measured as some combinations of vehicle/ exhaust after-treatment have been shown to generate NOx exhaust tailpipe emissions with a high proportion of NO_2 which is the more toxic of the NOx compounds. At this stage, it has not been decided at what basis (mass or percentage of NOx emissions) will be used to set the permissible NO_2 limits.

- Nitrous Oxide (N_2O)
  Identified as a greenhouse gas (GHG)

- Ammonia (NH_3)
  NH_3 is already measured and controlled under EURO VI for heavy duty vehicles that are using active NOx

reduction methods such as Selective Catalytic Reduction (SCR) that have the potential to generate significant excess amounts of NH_3 if incorrectly applied. Unlike the other compounds that are proposed for measurement in the new WLTP, which will be made exclusively from diluted exhaust gas (via CVS), the measurement of ammonia will be made directly from the vehicle exhaust tailpipe and will be compared against an average concentration limit in the same way as heavy duty vehicles.

- Ethanol (C_2H_5OH), Acetaldehyde (ethanal : CH_3CHO), Formaldehyde (methanal : CH_2O)
  These compounds were added specifically for the use of fuels containing ethanol. The current proposal of the working group is that their measurement will be required for 100 % ethanol fuel and for gasoline mixtures containing more than 21% ethanol by volume (> E21), although the option of using a proportional factor based on the content of ethanol and the mass of Non-Methane Hydrocarbons (NMHC) is also being considered.

The candidate methods of measurement and equipment for the above compounds have been summarised by the working group and will be confirmed during actual vehicle testing in the Validation Phases of the WLTP program.

Test Procedures for Electrified Vehicle Testing (E-Lab)

A separate working group was created to consider the test procedures, calculations and specifications for the testing of all types of electrified vehicles including Battery Electric Vehicles (BEV), plug-in type hybrids (known as On Vehicle Charged Hybrid Electric Vehicles - OVC-HEVs) and conventional hybrids that are able to recover the kinetic energy of the vehicle but do not have an externally Rechargeable Energy Storage System (RESS) which are known as Not On Vehicle Charged Hybrid Electric Vehicles (NOVC-HEVs).

The base method for the test procedure was adopted from the existing SAE J1711 June 2010 standard "Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid Electric Vehicles, including Plug-in Hybrid Vehicles".

A large number of open issues remain to be resolved regarding the details of the necessarily complicated test procedure which are likely only to be resolved after actual testing of vehicles during the current validation program.

Future Issues for Light Duty Vehicle Emissions and Fuel Economy Testing

The overall certification of Light Duty Vehicles in Europe is under discussion at the present time. Updated testing procedures are under review for evaporative emissions testing and a new test to determine the CO_2 emissions impact of LDV air conditioning systems is under discussion (MAC - Mobile Air Conditioning). In addition to the WLTP development process, there are a number of other activities related to Light Duty Vehicle emissions and fuel economy measurement that will impact on the future development and testing of light duty vehicles.

The first is the development of emissions legislation in the USA

Having relinquished the co-chairmanship of the DTP Working Group in November 2010 because of the extensive commitments to domestic legislative demands, the US Environmental Protection Agency (EPA) has developed their own new draft test procedure, calculations and specifications for light duty vehicles called CFR 1066. This is based on their existing CFR 1065 regulations that are applied to all applications of internal combustion engines such as heavy duty on-road and off-road, locomotives, marine, recreational and small utility engines etc. It has been proposed that the CFR 1066 will be applied for PM mass measurement for the 2017 model year and to gaseous components for the 2022 model year and so will be used for the introduction on the newly approved California LEV III and EPA Tier III emissions standards. In their current draft forms, the WLTP and CFR 1066 test procedures are not mutually compatible in all aspects which obviously could undermine the objective of global acceptance of the WLTP. Currently automotive industry and other technical groups are working together with the EPA and the California Air Resources Board to resolve the differences and to harmonize the two sets of draft test procedures, calculations and specifications.

The second is a new initiative from Europe known as the Real Driving Emissions for Light Duty Vehicles (RDE-LDV)

The program was created following the measurement of emissions from light duty vehicles when being driven on the road under real world conditions by the EU Joint Research Centre (JRC) using portable emissions measurements systems (PEMS). These systems were originally developed to meet the requirements of heavy duty engine certification procedures for the USA and Europe, which require an on-road verification test of the vehicles into which the engines are installed. The results from the JRC testing was published[2] and identified that the NOx mass emissions from diesel (compression ignition) vehicles were higher than their certified levels, in some cases by a factor of four. In addition, the NO_2 content of these NOx emissions were significantly higher than the gasoline (spark ignition) equivalent vehicles.
As a consequence, the EU DG-ENTR initiated the RDE-LDV working group to evaluate these results and to consider test methods to determine real world emissions from light duty vehicles. It is anticipated that these test methods will be supplementary for European certification when the WLTP test procedure is introduced.

Conclusion

The development of the new Global Technical Regulation for Light Duty Vehicles is in progress and will be introduced for emissions and fuel economy certification during the last half of this decade. Its eventual adoption by all territories and countries should simplify the design and specifications of the test facilities and improve the efficiency of the vehicle certification process. However, further work is likely to be required in order to harmonize the specifications of the equipment, test procedures and calculations to be acceptable to the USA legislative authorities. HORIBA Automotive Test Systems continue to actively monitor and contribute to the development of the new regulations to ensure that our customers are supported with compliant instrumentation and test systems for their light duty vehicle programs in a timely manner.

References

[1] TUV Nord : Analysis of the relevance of influencing factors when determining CO_2 emissions and fuel consumption during type approval of passenger cars on behalf of the BASt

[2] On-road Emissions of Light-duty Vehicles in Europe - *ENVIRONMENTAL SCIENCE & TECHNOLOGY* vol. 45 no. 19 p. 8575-8581

Les HILL

Global Product Planning Group
Automotive Test Systems
HORIBA Limited