Development and Validation of Emissions and Fuel Economy Test Procedures for Heavy Duty Hybrid Electric Vehicle

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Abstract—**Chassis dynamometer based test procedures were developed to benchmark the emissions and fuel economy performance of heavy duty hybrid electric vehicles (HEVs). And a hybrid electric bus (HEB) was tested according to the presented procedures to make a validation and get a picture of the HEB performance on the fuel economy, cold and hot start running emissions. Results show that the presented procedure is practical for heavy duty HEVs evaluation, and exhibited satisfying reproducibility.**

Keywords-test procedures; chassis dynamometer; fuel economy; emissions; heavy duty; HEV

I. INTRODUCTION

In China, an upsurge of HEV is recurring thanks to government ambitious plan to promote the use of new energy vehicles (NEVs), which also include EVs and FCVs besides the HEVs. To fulfill the national strategy for energy conservation and emissions reduction, China government launched a pilot program for the demonstration of energy conservation and new energy vehicles in 13 cities including Beijing and Shanghai. And now the program is enlarging to 20 cities where the central government will partly fund the purchase of the demonstration vehicles for public transport services by providing some financial subsidy.

This program stimulated greatly the enthusiasm of vehicle manufactures on the NEVs. And since HEVs is technically mature and more accepted by customers than EVs and FCVs, many domestic manufactures increase their devotion on the R&D of HEVs, struggling for their shares of the financial cake, and also the future HEV market.

However, some problems must be solved before the exciting plan can achieve expected success in China. One crucial of them is lack of a complete standard system comprising of a series of test methods to evaluate the key performance of HEVs, especially HEVs. In order to obviate this obstacle, a program to develop and revise relevant standards was started by Ministry of Environment Protection(MEP) and Ministry of Industry and Information Technology(MIIT). For the heavy duty HEVs, there are two standards involved in this program. One is *GB/T 19754 Test methods for energy consumption of heavy duty hybrid electric vehicles* which is in revising; the other is *Measurement methods for emissions from heavy duty hybrid electric vehicles* which is in developing. Work of this paper is also a part of this program.

Considering that the engine bench test methods is inapplicable for heavy duty HEVs, procedures based on chassis dynamometer was formulated. Additionally, a domestic HEB was measured on heavy duty chassis dyno to validate the feasibility and stability of the test procedures.

II. TEST PROCEDURE DEVELOPMENT

The Figure 1 illustrates the chassis dyno test procedure for heavy duty HEVs. This procedure is developed mainly referring to SAE standard document J2711 and Chinese standard GB/T 19754[1, 2].

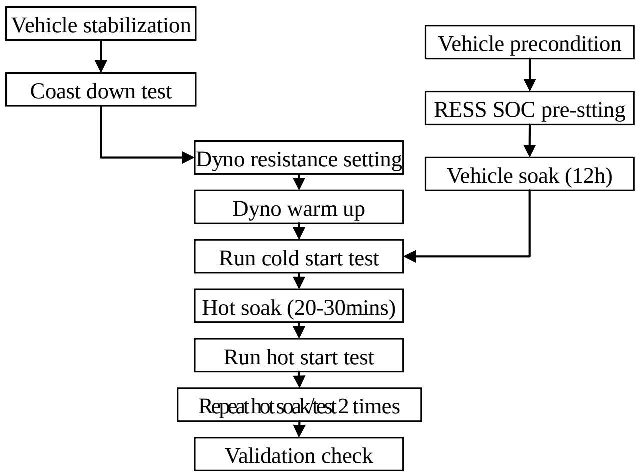

Figure 1. illustration of the test procedure

A. *Method of resistance determination and setting*

When testing vehicle with chassis dyno, it should be firstly determined how much resistance force the dyno need to simulate during test. The basic method is to obtain resistance data of vehicle when running on real road by conducting coast down test. An alternative and simplified method is to calculate according to empirical formulas given by automotive dynamic theory or some test standard documents. Whichever method is

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used, the resistance dyno needs to exert will be determined in form as the following equation.

$$F = A + BV + CV^2$$

Resistance force imposed on the tested vehicle is dependent on vehicle velocity and a set of resistance coefficients, A, B and C. these coefficients are determined by either coast down data or empirical formulas. After that, the dyno will be set with the determined coefficients through an on-dyno coast down test of the tested vehicle.

It should be noted that test vehicle was 65% loaded and its regeneration brake system was disabled when coast down. Then according to the difference of the two set of coefficients which obtained from two types of coast down test, chassis dyno will simulate vehicle resistance.

After the installation of vehicle and the setting of dyno resistance, test vehicle should be pretreated, and then cold and hot tests are carried out on chassis dyno according to test procedure in the regulations.

B. Technical Requirements on Chassis Dynamometer

The application of chassis dyno enables exploration of vehicle's real world performance in lab, without necessity to test on road. Generally chassis dyno can simulate all the vehicle resistances through absorption devices. However, HEV tests present more requirements on chassis dyno than conventional vehicles do. For conventional vehicles, most tests focus on driving ability or performance under driving condition, but rarely concern about braking process. Therefore, what need to be simulated for conventional vehicles is always resistant force they encouter when running on real road, which will lead to dyno operate in absorption mode. Whereas, it is different for HEV. Effects of regenerative braking on performance must be taken into account when evaluating HEV. Therefore, dyno must have capability to completely simulate vehicle's inertia not only when driving, but when braking. Two types of power devices, AC asynchronous motor and mechanical flywheel assembly, can be used to solve the requirement of HEV tests.

C. Test cycle

Test cycle is CCBC (China Typical City Bus Cycle), which was developed on the base of driving data collected from several megacities. It was quoted by the GB19754. The speed profile of CCBC is shown as figure 2.

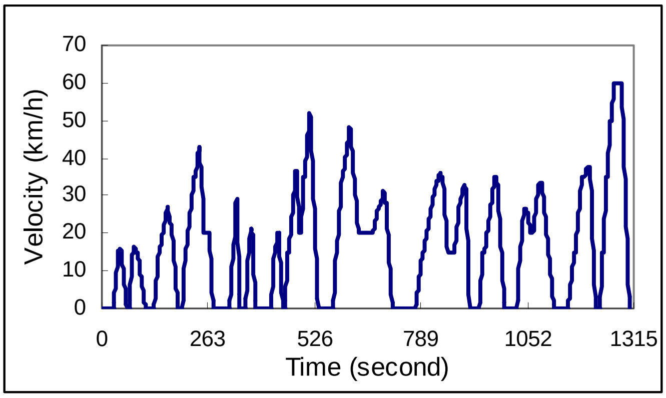

Figure 2. Velocity trace of the CCBC

It is a speed trace of 1314 seconds and 5.8km length. In this study, the researchers double the length of the test cycle, that is, the tested vehicle was required to continuously run the above cycle in figure 2 twice for one track test. Therefore, the characteristic parameters of the complete adopted cycle are shown as Table I.

TABLE I. PARAMETERS OF THE TEST CYCLE

Time	2628s		Distance	11.6km
Average speed	15.9km/h		Maximum acceleration	$0.914 m/s^2$
Top speed	60km/h		Minimum acceleration	$-1.543 m/s^2$
Idle time	762s		Idle occupation	29%

III. TESTED VEHICLE AND MEASUREMENT SYSTEM

A. Main Specification of the Tested Vehicle

Table II gives the main specification of the tested vehicle.

TABLE II. SPECIFICATION OF THE TESTED VEHICLE

Curb weight/GVW	12600/18000kg
Engine	ISBE4+205B 151kW Euro III emission standard
RESS(rechargeable energy storage system)	Ultracapacitor 41.25F BMOD0165 P048
Motor	Three-phase AC induction motor 65kW
Powertrain	Serial-parallel

Figure 3 shows the powertrain structure of the tested HEB.

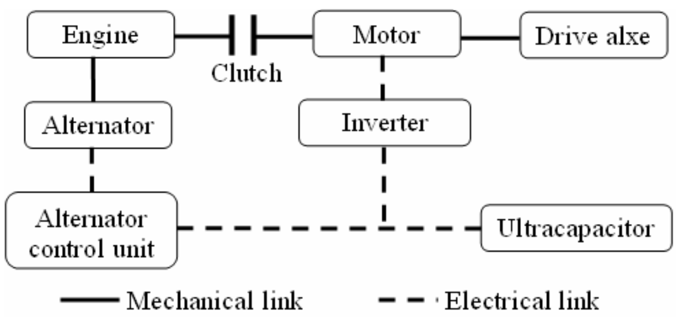

Figure 3. Powertrain structure of the tested HEB

When the driving speed is below 20km/h, motor drives alone and engine keep idling or charge the ultracapacitor through the alternator if necessary. When speed is over 20km/h, the engine and motor jointly drive the HEB.

However, if HEB runs at a steady speed over 20km/h, the engine will drive alone. At the same time, the SOC of ultracapacitor will be detected. The motor will be started in its generator mode if the SOC is lower than the setting value.

When decelerating, the braking energy will be captured and stored into the ultracapacitor pack through the motor.

B. *Measurement System*

The measurement system employed in this program is integrated with an OBS-2200 from HORIBA and an ELPI from DEKATI, which can respectively measure gaseous pollutants (HC, CO, NOx and CO2) and Particulate Matter (PM) second by second on board. Figure 4 shows that test HEB is set up on the measurement system.

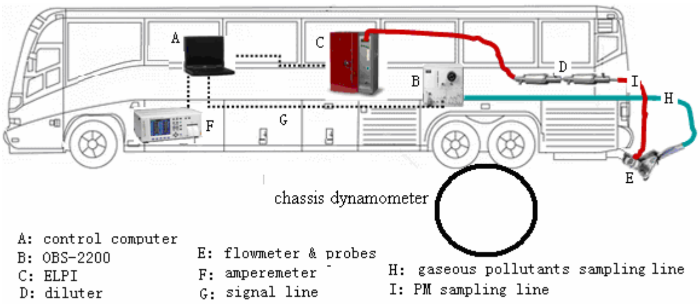

Figure 4. HEB test of lab measurement system

The ELPI is able to measure the transient concentration and size distribution of PM, but unable to obtain the mass emission of PM. By merging the OBS-2200 and the ELPI, the PM measuring capabilities of the measurement system were expanded on the base of ELPI. Measurement system is able to get transient and total mass emission data of PM, as well as concentration and distribution, which is realized by exploiting the function of flowmeter (see E in figure 4). The PM mass emission results can be derived by multiplying the real time PM concentration data and the real time exhaust flowrate data from the flowmeter.

The two instruments were integrated to form an emission system called IPEMS (integrated portable emission measurement system). Repeating comparative tests proved that the IPEMS possesses a sound measurement reproducibility as well as a strong correlativity with regulation class lab test system[3]. In addition, its effectiveness was also validated in corresponding researches[4, 5].

Apart from OBS-2200 and ELPI, there are also other devices included in the measurement system. F is amperemeter to detect and record the changes of RESS with a frequency of 100Hz. The entire system is able to measurement emission, fuel consumption and electric energy consumption of vehicles.

IV. TEST RESULTS

In order to validate the procedure, tests of three days were conducted. The hot tests of each day were conducted with different resistance setting according to different coefficients. On the day 1, dyno was set according to the coefficients resulted from road coast down test. On the day 2, dyno was set by the calculation formula recommended in theory of automotive dynamics[6]. On the day 3, dyno was set by calculation formula of relevant Japanese heavy duty vehicle regulation[7]. The formula is read as

$$F=0.1452V^2+3.9213V+628.013 \quad (1)$$

$$F=0.1501V^2+958.263 \quad (2)$$

One cold test and three hot tests were conducted in each day.

A. *Cold emissions and fuel ecnomy*

Figure 5 shows emission results of the cold test under a resistance setting based on coast down data.

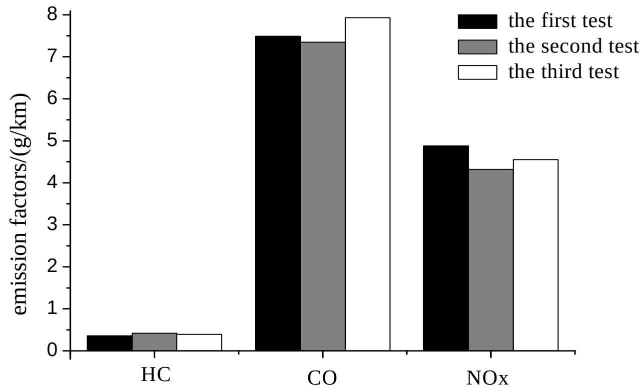

Figure 5. Emissions of cold tests

The cold tests were conducted in early morning of each day after a soak of one whole night on the dyno. Anyway, the emission results show a good reproducibility. The max deviation among the results for HC, CO, and NOx are respectively 7%, 4% and 6%.

Figure 6 shows fuel consumption and electric energy consumption results of the cold test.

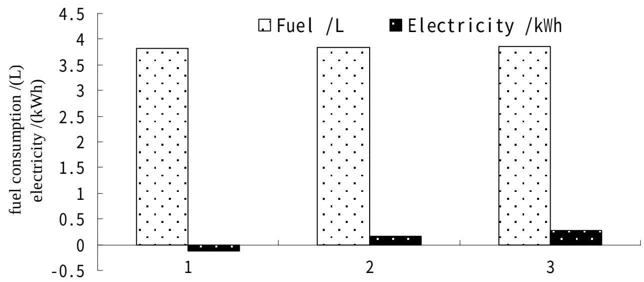

Figure 6. Fuel and electric energy consumption of cold tests

During these three tests, fuel consumption results varied slightly, and net energy changes of RESS are negligible because they are not more than 3% of corresponding fuel consumption if compared on the base of their equivalent heating values.

B. *Hot emissions and fuel ecnomy*

Emissions and fuel consumption under three different resistance setting conditions were investigated in this study. Figure 7 to figure 9 show emission results of regulated pollutants under each condition.

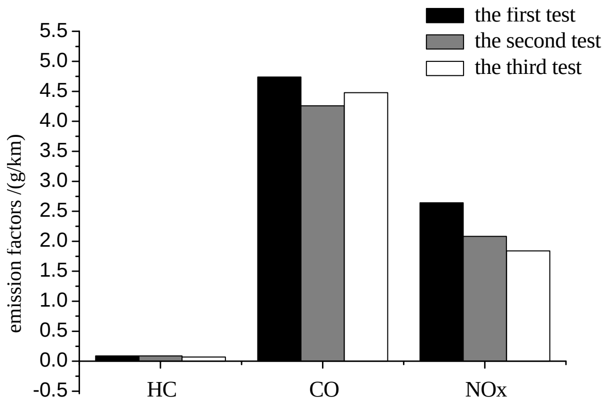

Figure 7. Hot emissions under dyno setting by coast-down

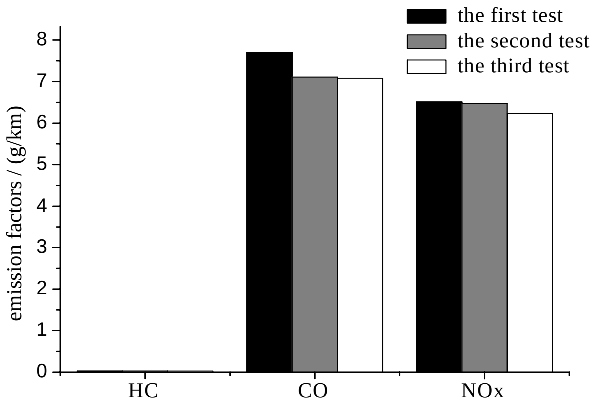

Figure 8. Hot emissions under dyno setting by formula (1)

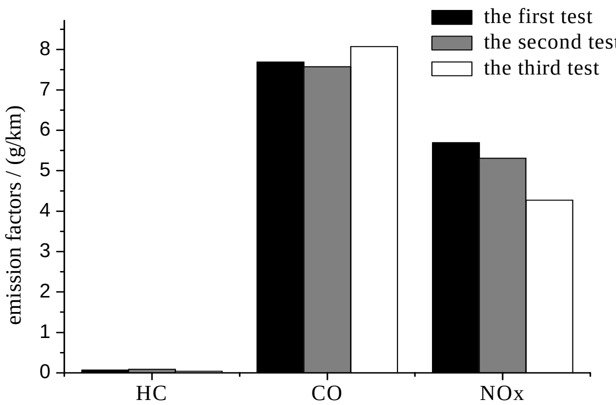

Figure 9. Hot emissions under dyno setting by formula (2)

Results of HC and CO suggest a sound reproducibility. Among tests of each day, deviation of each pollutant is not more than 5%. However, the NOx results show a variation among tests of day 1 and day 3.

Figure 10 shows fuel consumption and energy consumption results under these three different dyno settings.

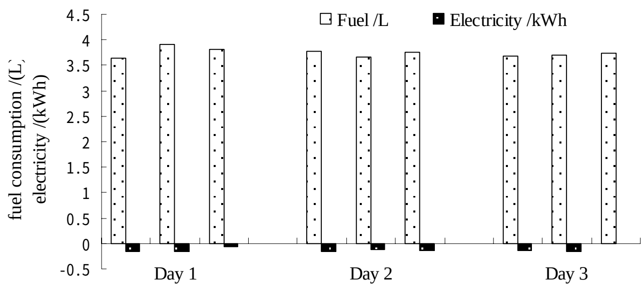

Figure 10. Fuel and electric energy consumption of hot tests

It is similar with results of cold test, the electric energy changes of RESS were negligible compared with fuel consumed. And fuel economy results show good reproducibility.

Figure 11 makes a comparison of emission and fuel economy performance between cold test and hot test. It shows cold running released more emissions, especially HC, than hot running if at the same dyno setting.

The hot running results under different dyno setting were also compared in figure 11. There is a larger variation among the hot emission results of each day because the load of tested vehicle is much different under different methods of resistance setting. However, fuel economy performance exhibited not much difference among three hot tests.

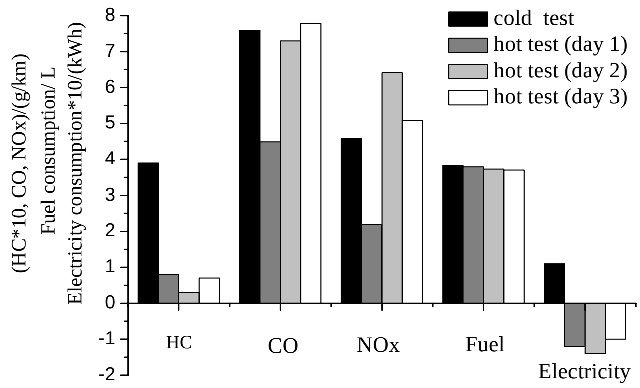

Figure 11. Comparison of average results of all tests

V. CONCLUSION

Chassis dyno based test procedures were developed to evaluate the heavy duty HEVs for their fuel economy and emissions performance.

By HEB validation test on a heavy duty chassis dyno, the accuracy of resistance simulation and target velocity following were verified. And the reproducibility of the presented procedures was proven that measurement results of repeat tests under the same test condition vary within a range not more than 7%.

To further validate the methods to correction emission and fuel consumption results with NEC of RESS, additional tests using battery heavy duty HEV are needed, because more distinct NEC is easier to occur for battery than ultracapacitor which was used by the HEB of this paper.

REFERENCES

[1] GB/T 19754-2005, Test methods for energy consumption of heavy duty hybrid electric vehicles[s]. Published in 2005.

[2] SAE J2711, Recommended Practice for Measuring Fuel Economy and Emissions of Hybrid-Electric and Conventional Heavy-Duty Vehicles. Published in 2002.

[3] Qin Kongjian, Gao Junhua, Gao Jidong, et al. Integration and Validation of An On-board Emission Measurement System for Heavy-duty Vehicles. Automotive Engineering, 2009, 31(11), 1081-1085.

[4] Qin Kongjian, Li Mengliang, Gao Junhua, et al. On-Road Test and Evaluation of Emissions and Fuel Economy of the Hybrid Electric Bus. 2009 SAE International Powertrains, Fuels and Lubricants Meeting.

[5] Li Mengliang, Wang Linghui, Qin Kongjian, et al. Heavy-duty hybrid vehicle emission contrast research under different modes[C]. IEEE Vehicle Power and Propulsion Conference (VPPC), September 3-5, 2008, Harbin, China.

[6] YU Zhi-sheng. Automobile theory[M]. Beijing: Mechanical Industry Press, 2007, 2-15.

[7] Kokujikan. Measurement procedure for JE05-mode exhaust emissions by means of chassis dynamoemter[s]. Automobile type approval handbook for Japanese certification 2008, Attachment 12-2-33.