HEAVY-DUTY GASOLINE ENGINE WHDC VALIDATION STUDY

Transmitted by CATARC

1. Purpose

In order to verify the feasibility to take WHDC cycles as the emission test cycle of gasoline engine, in the request of Prof. Stein from WHDC working group, some validation studies of WHDC cycles with gasoline engine were carried out. As a comparison, some emission tests of gasoline engine with CHN III cycle were also done.

2. Engine tested / fuel and Equipment

2.1 Engine tested:

Engine type – L4, four stroke, positive ignition, 2.237L capacity;
Fuel feed- EFI; multiply point injection with ECU and oxygen sensor (close-loop);
After-treatment system – 3-way catalytic converter.

2.2 Equipment

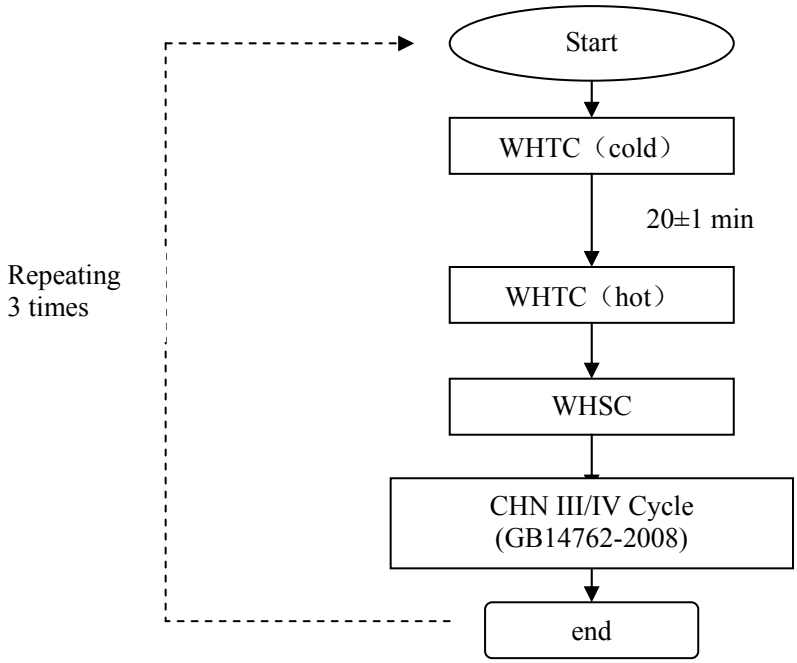
Engine dynamometer: APA404/8EU(Austria AVL)
Exhaust gas analyzer: CEBII(Austria AVL-Germany Pierburg)
CVS: CVS4000(Austria AVL -Germany Pierburg)

2.3 fuel

93 gasoline for motor vehicle (DB11/238-2007);
RON: 94.2;
(RON+MON)/2: 89.0;
Density: 742.7 kg/m^3;
Pb content: 0.0025 g/L
Mn content: 0.0014 g/L;
Sulphur content：0.003 %（m/m）;
Benzene content:0.64%(v/v);
Alkene content:19.2(v/v)；
Alkene+Aromatic HC:46.0%(v/v).

3. Test sequence

The test sequence of emisssion test cycles for heavy-duty gasoline engine could be seen in Fig.1. The test sequence commenced at the start of the engine then the WHTC（cold） was performed. Immediately upon completion of the cold start WHTC test, we take 20±1min as a hot soak period for the hot start test. As a comparison, a CHN III/IV test cycle had been done after WHSC. After CHN III/IV test, the engine tested was cooled down naturally to ambient temperature for next WHTC (cold). The tests of WHTC (hot), WHTC (cold), WHSC and CHN III/IV Cycle have been repeated three times.



4. Test results

4.1 Pollutants emissions of CO, THC and NOx

4.1.1. The test results of exhaust emissions for four emission cycles from the engine tested is shown in Table 1.

Table 1. The test results of exhaust emissions for four emission cycles

Emissions (g/kWh)	WHTC (cold)			WHTC(hot)			WHSC			CHN III		
	Test1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
CO	6.71	5.39	5.72	5.18	5.43	5.82	11.68	11.04	11.52	2.68	2.01	1.95
NOx	0.27	0.25	0.26	0.36	0.25	0.38	0.00	0.00	0.03	0.03	0.08	0.00
THC	0.41	0.38	0.41	0.32	0.26	0.18	0.64	0.54	0.56	0.23	0.26	0.19

4.1.2. The column diagrams of the pollutants CO, THC and NOx relative emissions for four emission cycles (Test 1#, test 2# and test 3#)from the engine tested are shown in Fig.2, Fig.3 and Fig.4 individually.

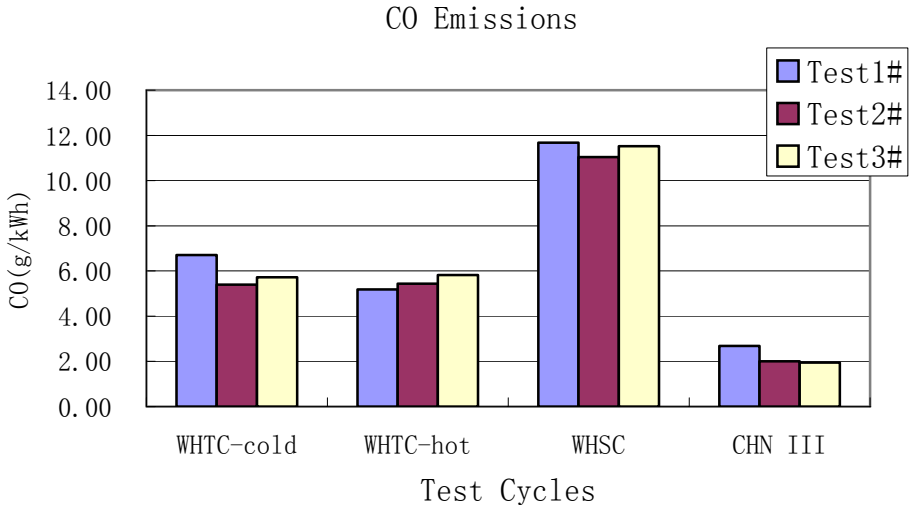


Fig.2 CO relative emissions

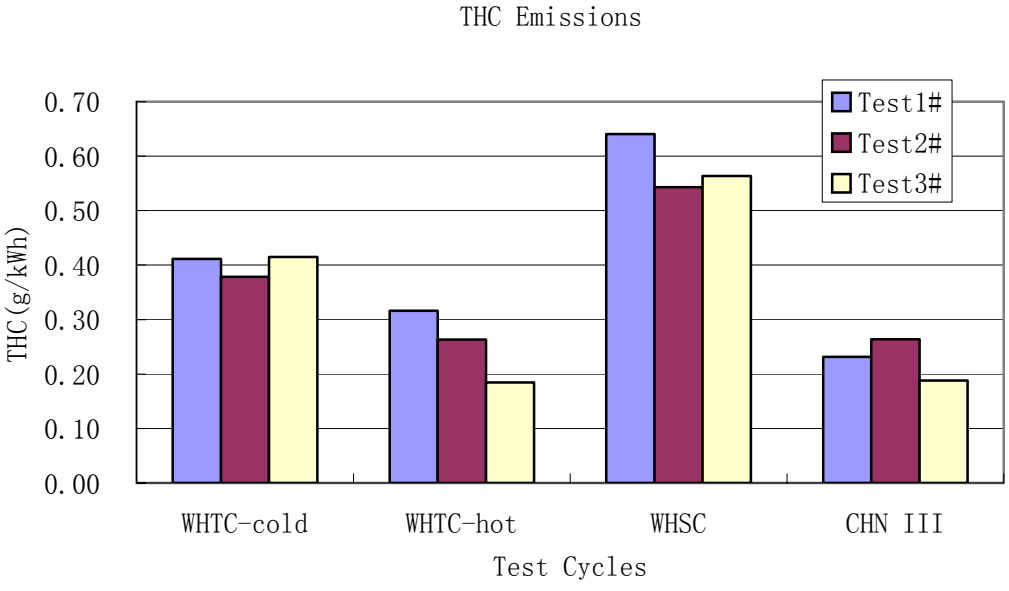


Fig.3 THC relative emissions

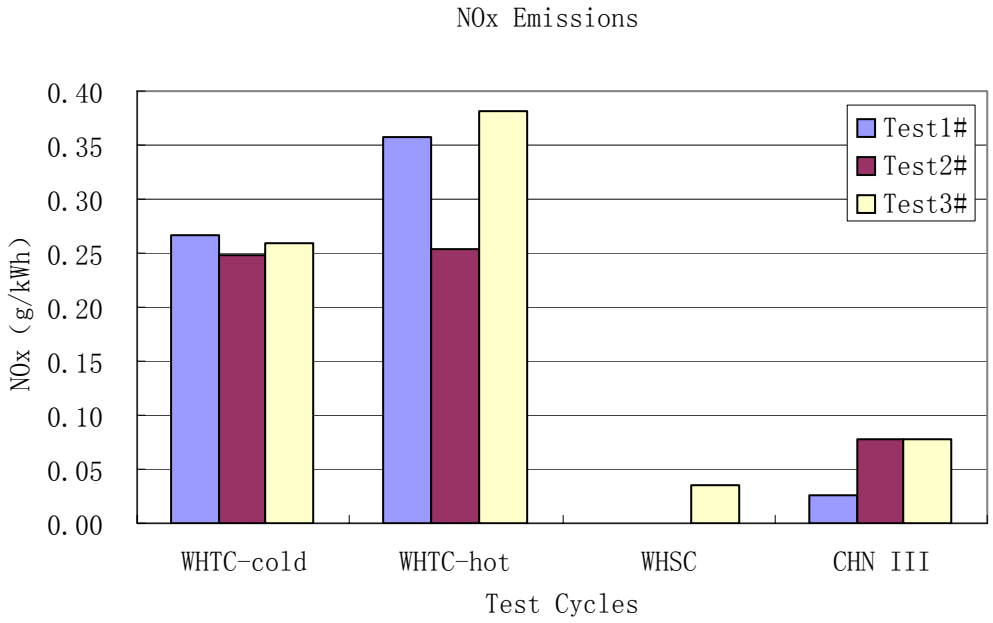


Fig.4 NOx relative emissions

4.1.3. The average emissions of the pollutants CO, THC and NOx of three tests (Test 1#, test 2# and test 3#) is shown in table 2.

Table 2. The average emissions of the pollutants CO, THC and NOx of three tests

Average Emissions (g/kWh)	CO	NOx	THC
WHTC-cold	5.94	0.26	0.40
WHTC-hot	5.48	0.33	0.25
WHSC	11.41	0.01	0.58
CHN III	2.21	0.06	0.23

4.1.4. The column diagram of average emissions of the pollutants CO, THC and NOx for four emission cycles is shown in Fig. 5.

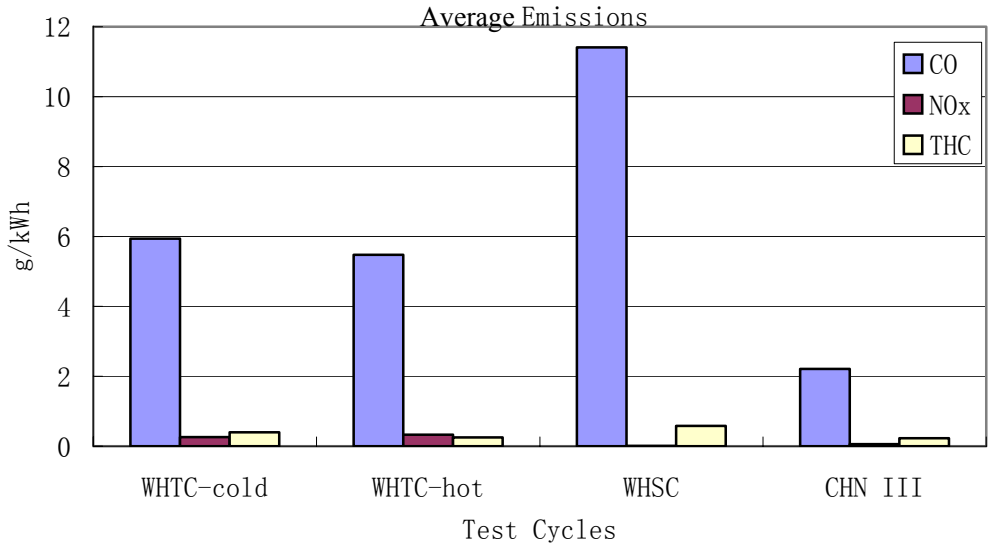
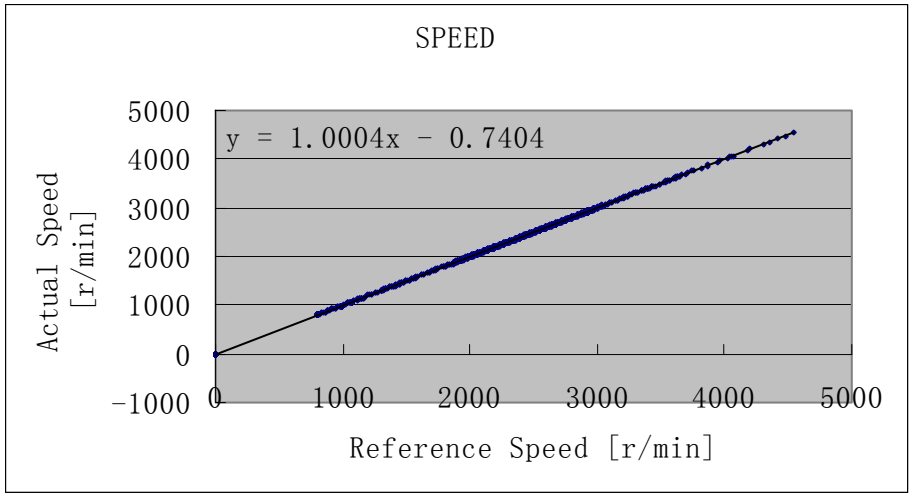
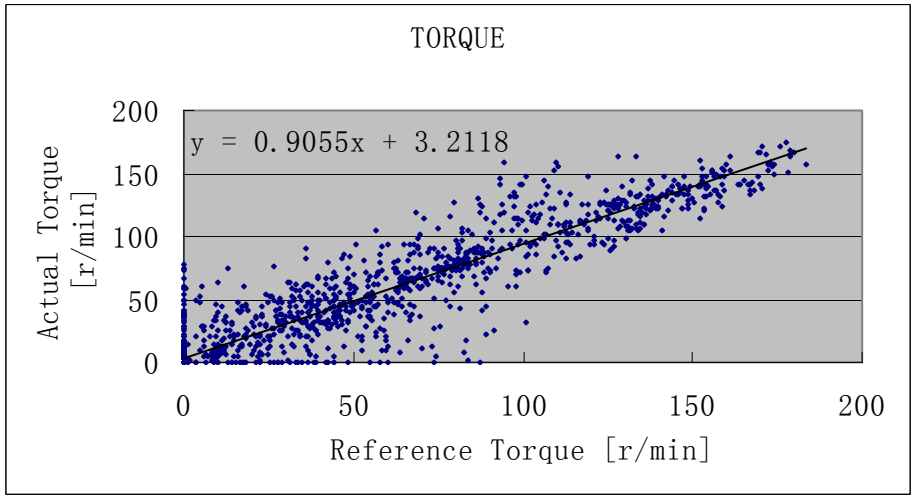


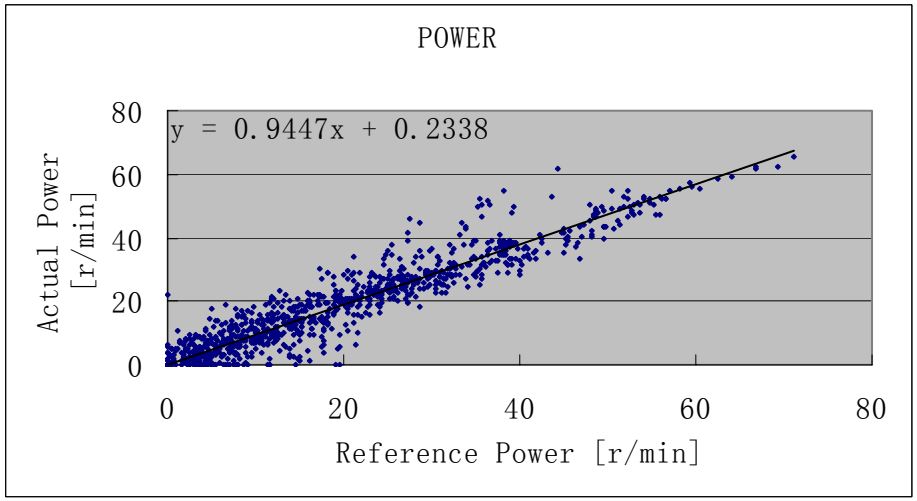
Fig.5 CO, THC and NOx average emissions

4.2. Validation statistics of the test cycles

4.2.1. WHTC (cold)

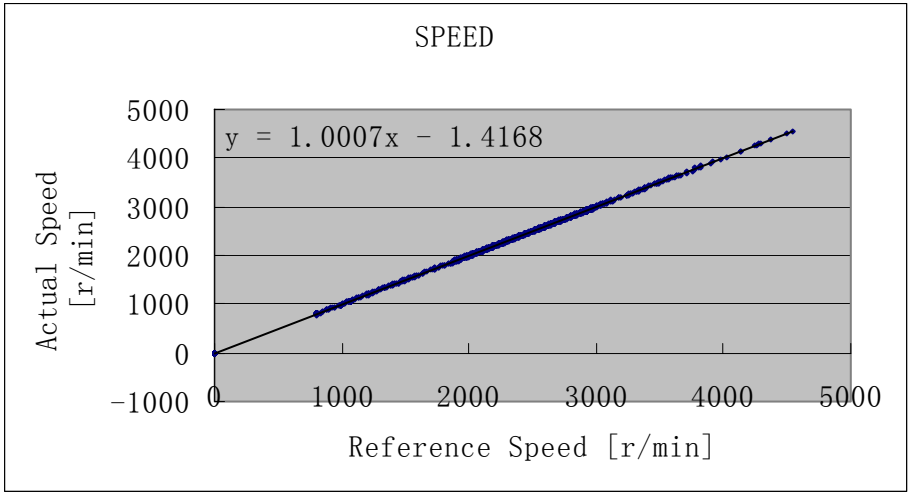


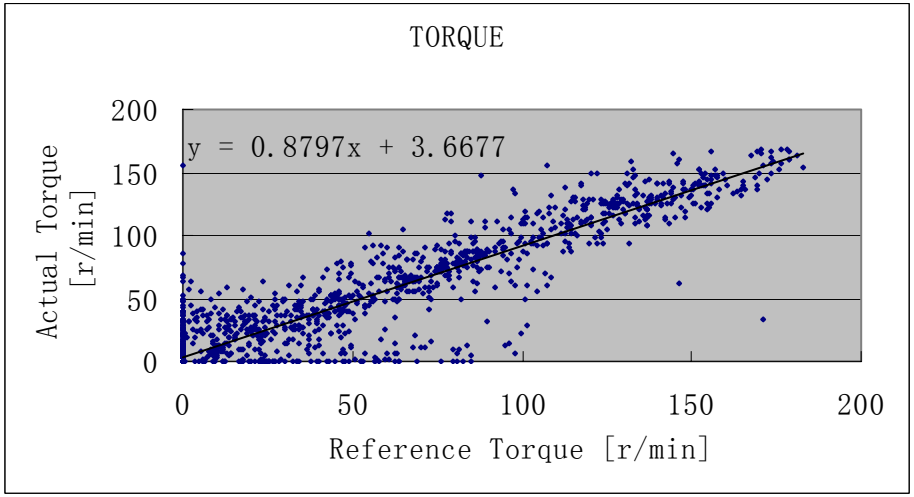


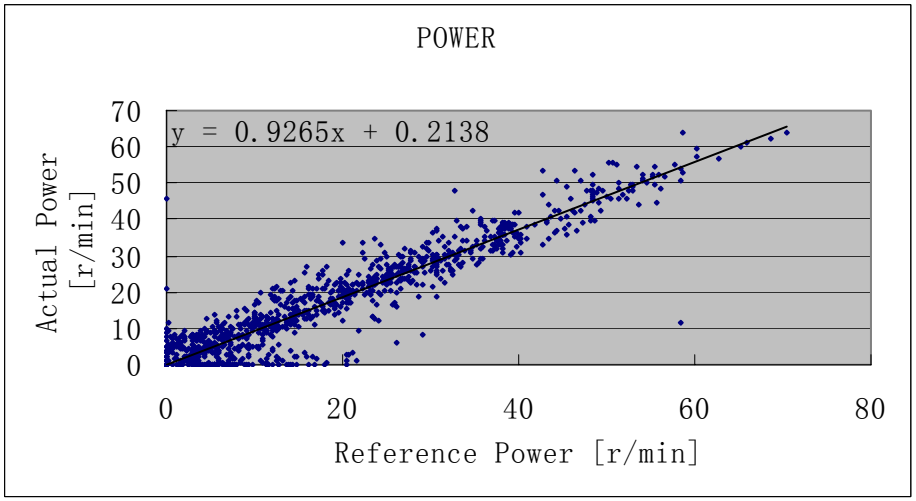


	Speed		Torque		Power	
Standard error of estimate (SEE) of y on x	2.466	OK	15.590	OK	3.581	OK
※limit	max. 100 r/min.		22.62.		5.228.	
Slope of the regression line, m	1.000	OK	0.906	OK	0.945	OK
※limit	0.95~1.03.		0.83~1.03.		0.89~1.03.	
Coefficient of determination, r^2	1.000	OK	0.895	OK	0.938	OK
※limit	min. 0.970.		min. 0.850.		Min. 0.910.	
y intercept of the regression line, b	-0.740	OK	3.212	OK	0.234	OK
※limit	± 50 r/min.		±20Nm .		±4kW .	

4.2.2. WHTC (hot)

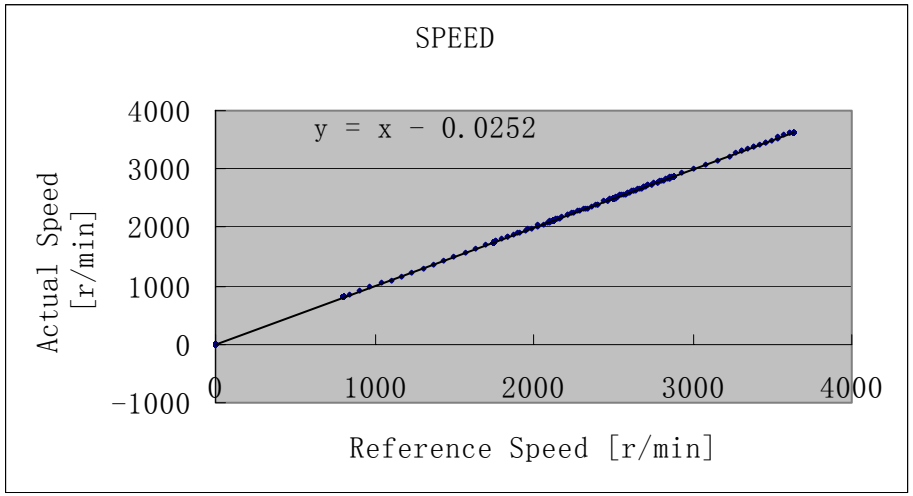


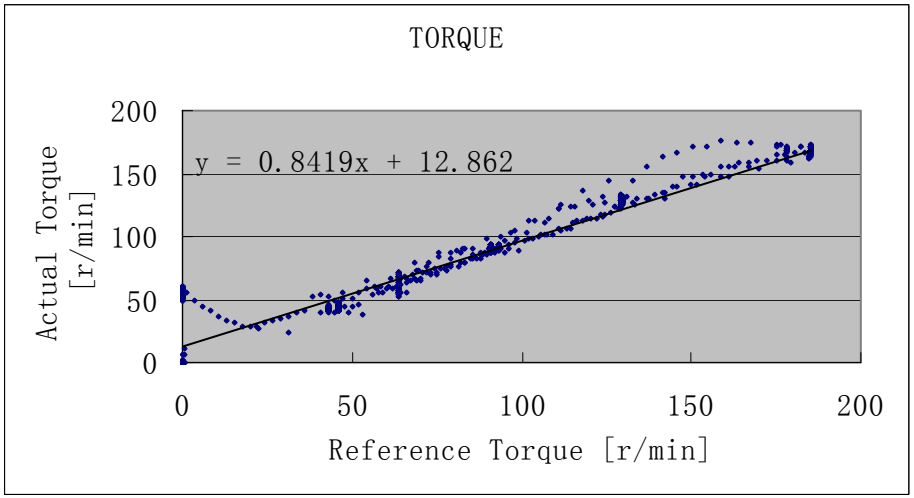


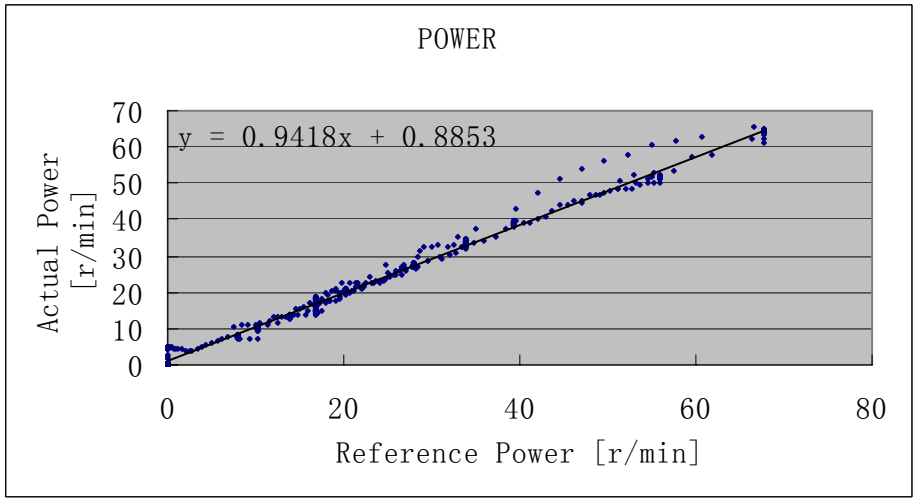


	Speed		Torque		Power	
Standard error of estimate (SEE) of y on x	4.114	OK	17.029	OK	3.813	OK
※limit	max. 100 r/min.		21.97.		5.13.	
Slope of the regression line, m	1.001	OK	0.880	OK	0.926	OK
※limit	0.95~1.03.		0.83~1.03.		0.89~1.03.	
Coefficient of determination, r^2	1.000	OK	0.872	OK	0.928	OK
※limit	min. 0.970.		min. 0.850.		Min. 0.910.	
y intercept of the regression line, b	-1.417	OK	3.668	OK	0.214	OK
※limit	± 50 r/min.		±20Nm .		±4kW .	

4.2.3. WHSC

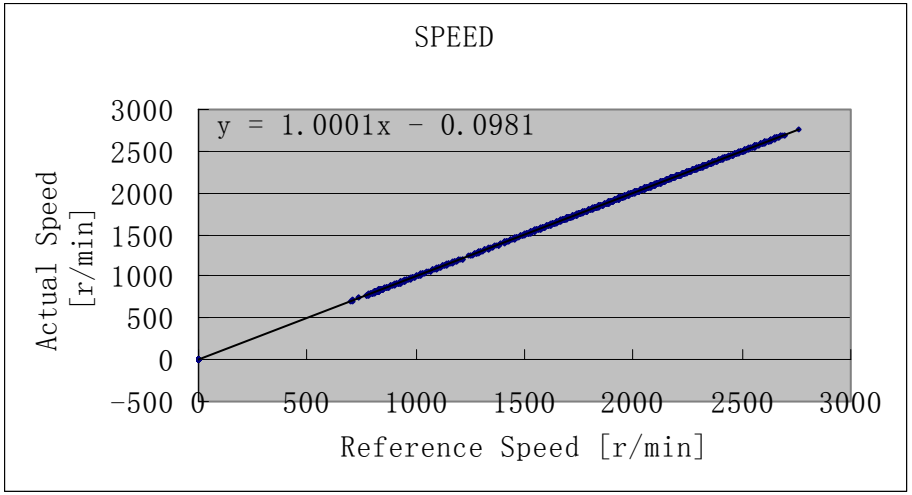


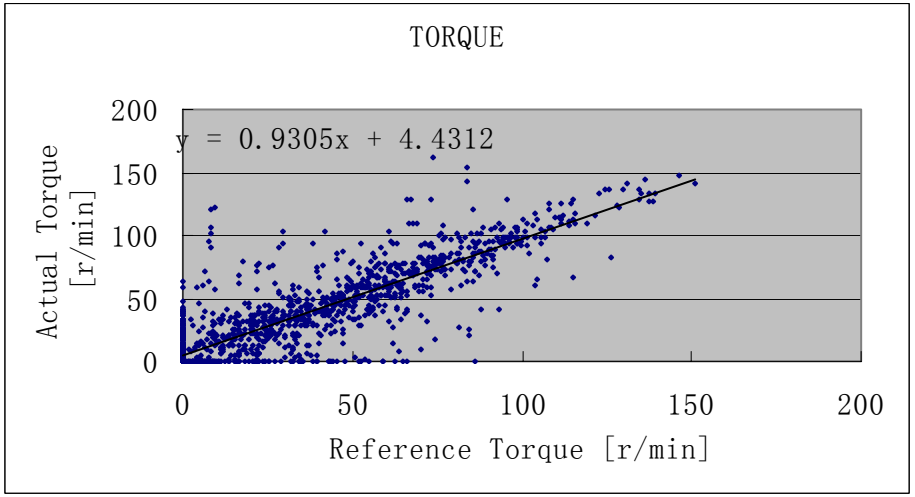


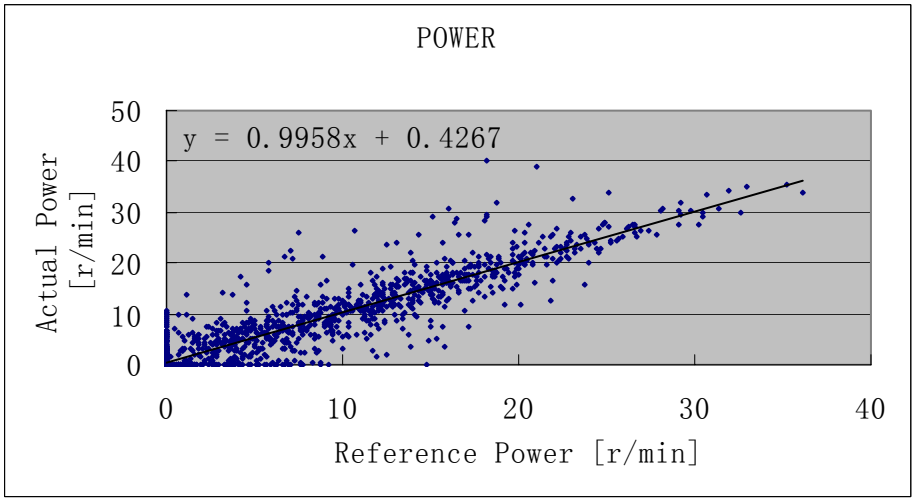


	Speed		Torque		Power	
Standard error of estimate (SEE) of y on x	0.312	OK	15.526	OK	1.534	OK
※limit	max. 100 r/min.		22.88.		5.23.	
Slope of the regression line, m	1.000	OK	0.842	OK	0.942	OK
※limit	0.95~1.03.		0.83~1.03.		0.89~1.03.	
Coefficient of determination, r^2	1.000	OK	0.880	OK	0.988	OK
※limit	min. 0.970.		min. 0.850.		Min. 0.910.	
y intercept of the regression line, b	-0.025	OK	12.862	OK	0.885	OK
※limit	± 50 r/min.		±20Nm .		±4kW .	

4.2.4. CHN III/IV Cycle







	Speed		Torque		Power	
Standard error of estimate (SEE) of y on x	0.718	OK	15.652	OK	2.918	OK
※limit	max. 100 r/min.		24.30.		6.03.	
Slope of the regression line, m	1.000	OK	0.930	OK	0.996	OK
※limit	0.95~1.03.		0.83~1.03.		0.83~1.03.	
Coefficient of determination, r^2	1.000	OK	0.791	OK	0.864	OK
※limit	min. 0.950.		min. 0.750.		Min. 0.750.	
y intercept of the regression line, b	-0.098	OK	4.431	OK	0.427	OK
※limit	± 50 r/min.		±20Nm .		±4kW .	

5. Conclusions

According to the test results of pollutants CO, THC and NOx emissions (4.1.) and validation statistics of the test cycles (4.2.), we summarize as follows:

(1) The engine tested could meet the validation criteria of the GTR completely both WHTC and WHSC cycles.

(2) The emissions of pollutants CO, THC and NOx from WHTC are reasonable.

(3) The emissions of pollutant CO from WHSC is about 2 times as that of WHTC, and is over 5 times as that of CHN III/IV Cycle. The contribution to CO emissions of WHSC mainly come from the 2, 5 and 10 modes of WHSC which run at the conditions of 100% load with $\alpha < 1$ excess air ratio.

(4) WHTC is applicable for the emissions test cycle of gasoline engine, but WHSC is not applicable for that of gasoline engine for its too high CO emissions.