Evaluation of Diverse Engine Exhaust Particle Emissions Using a New Solid Particle Counting System

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The Particle Measurement Programme (PMP), organized under the Working Party on Pollution and Energy (GRPE) of the United Nations Economic Commission for Europe (UN/ECE), proposed a measurement protocol for particle number emissions from light duty vehicles (LDV) and European Union (EU) has announced limits for particle number emission, scheduled for introducing from 2011. PMP and EU are now working on the measurement protocol and limiting particle number for the emission from the heavy-duty engines (HDE).

For particle emission testing of HDE, HORIBA has developed a second generation of Solid Particle Counting System (SPCS), which is much smaller than the conventional SPCS and suitable for use in engine test cells. Emissions from HDE are generally tested in engine test cell which has less space than chassis test cells used for testing emissions from LDVs. Therefore, the major design concept of new SPCS is downsizing and making it user-friendly without compensating the accuracy and the reliability.

Equivalency of conventional and new SPCS was determined using statistical analysis. Fig. 1 shows measurement result of diesel vehicle without DPF. Both systems show the good reproducibility and new SPCS pass both *t*-test and *F*-test.

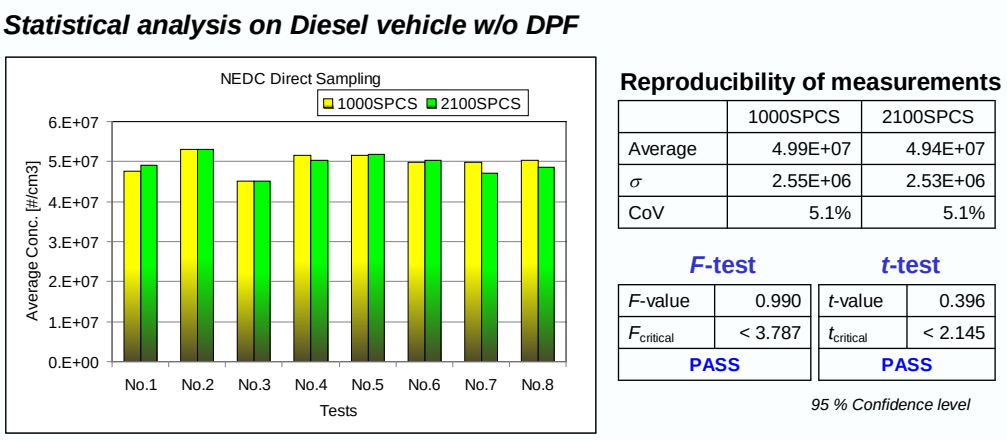

Fig. 1 Determination system equivalency

Correlation between conventional and new SPCS was also evaluated with gasoline direct injection (GDI) vehicle driving FTP and NEDC cycle. The both systems show similar measurement results and show the good correlation.

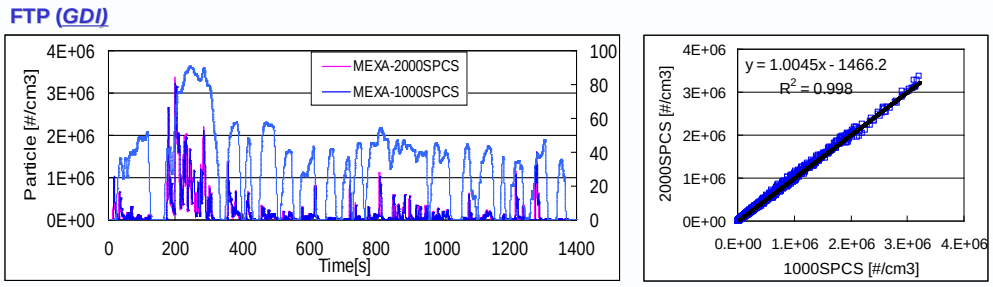

Fig. 2 Correlation between conventional and new SPCS

Using the second generation SPCS, this report discussed particle number emission characteristics from diverse engines and after treatment technologies such as DPF equipped and non-DPF diesel engines, and GDI vehicles under different test cycles.

Fig. 3 shows particle emission levels on FTP and NEDC cycle. Significant number of particles are emitted on FTP phase 1 (Cold transient) then phase 3 (Hot transient). More particles are emitted on FTP than NEDC due to the aggressive acceleration in FTP cycle. These results support that gasoline particle filter (GPF) may not be necessary if the fuel injection is optimized during the cold start condition and the high acceleration mode.

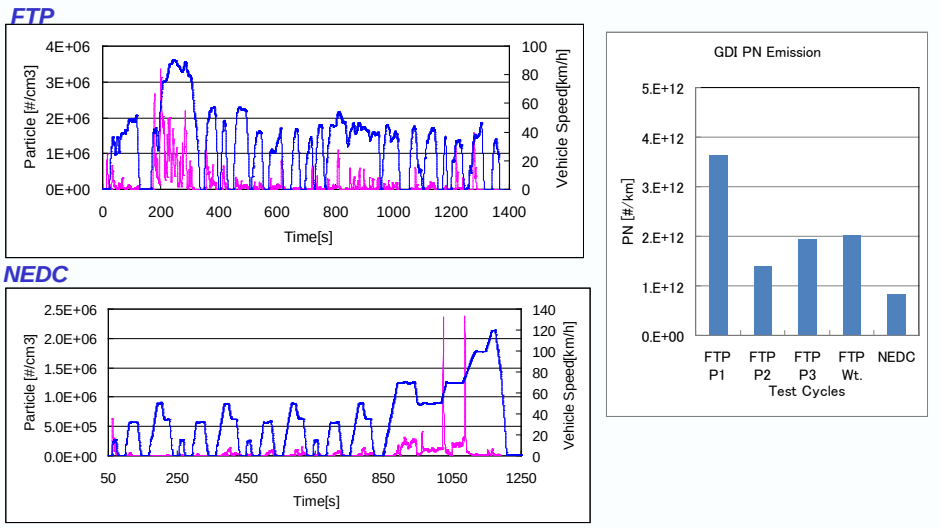

Fig. 3 GDI emission levels on FTP and NEDC

An example of particle emission during the regeneration is shown in Fig. 4. Regeneration occurred at the 10th mode of WHSC, where the engine output 100 % load at 75 % engine speed. Significant numbers of particle were emitted at 10th mode due to the regeneration. At the following 11th mode, considerable particles are emitted because the soot cake on the DPF wall is removed by the regeneration. The regeneration might be caused by high temperature and possibly presence of NO_2.

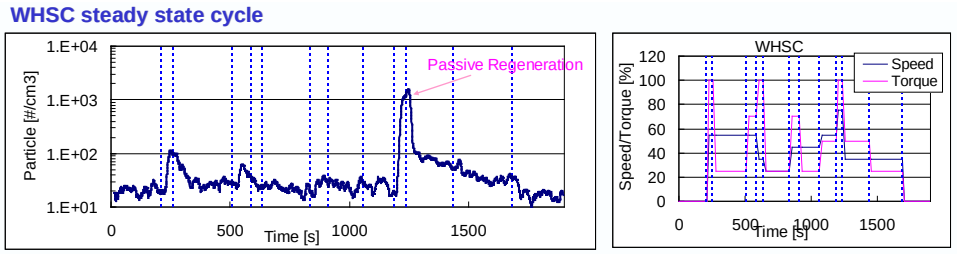

Fig. 4 Example of passive regeneration

We conclude the following from this study.

- Second generation of solid particle counting system has been developed which is compact and transportable so that the system is easily installed in a small engine cell.
- Equivalency of the new model was evaluated by statistical analysis. The new model shows good equivalency against the conventional model. The correlation between the two systems is very good.
- GDI vehicle emits more particles on FTP than NEDC, due to high accelerations in the cycle
- Significant numbers of particle were emitted at the 10th mode of WHSC due to the passive regeneration caused by high temperature and/or presence of NO_2.

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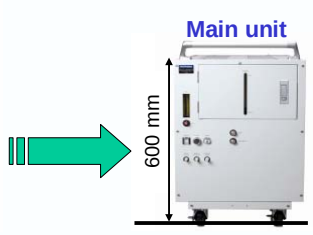
1. The New Solid Particle Counting System

MEXA-1000SPCS

New generation SPCS (MEXA-2000SPCS)

- **Compact main unit**
  - **Easy to install and transport in a laboratory**
  - **Small foot print**
- **High accuracy sampling system**
- **Various optional modules**
  - **Sampling modules to allow wide range of applications**
  - **Calibration module to check the performance as required by ECE regulation**



Main unit

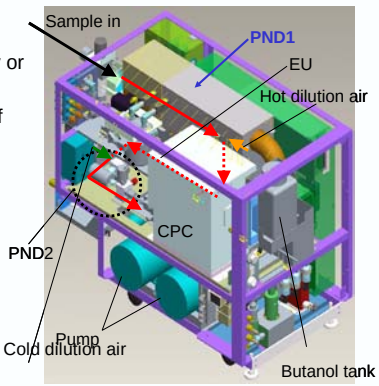
Optional modules

Sample line selector
Dilution factor checker
PCRF check
Volatile particle generator

SCU DFC VGU

2. Key Features of MEXA-2000SPCS

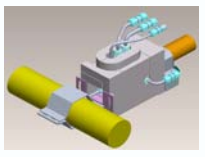
- Fully integrated system for stand-alone operation manually or under host computer control using AK-LAN interface
- Verifiable accuracy and proven reliability due to absence of rotating parts
- Automatic or semi-automatic utility function for:
  - Tracer based dilution factor check
  - PCFR check
  - Volatile remover efficiency check
  - CPC and system linearity check
  - CPC zero, span and system zero checks



3. Key Features of MEXA-2100SPCS

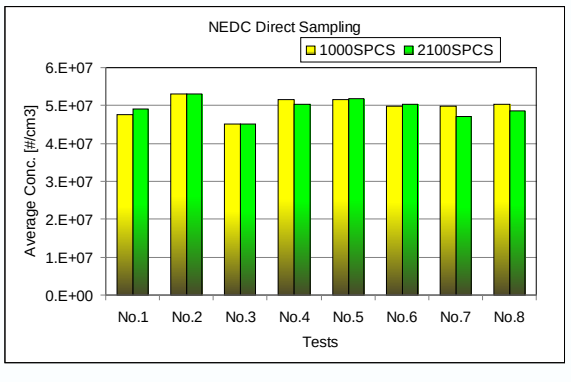
- Direct Sampling Unit (DSU) allows sampling raw exhaust under high pressure and high temperature.
- +100 kPa max. and 350 ºC max.

Direct Sample Unit (DSU)



4. Determination of System Equivalency

Statistical analysis on Diesel vehicle w/o DPF



Reproducibility of measurements

	1000SPCS	2100SPCS
Average	4.99E+07	4.94E+07
σ	2.55E+06	2.53E+06
CoV	5.1%	5.1%

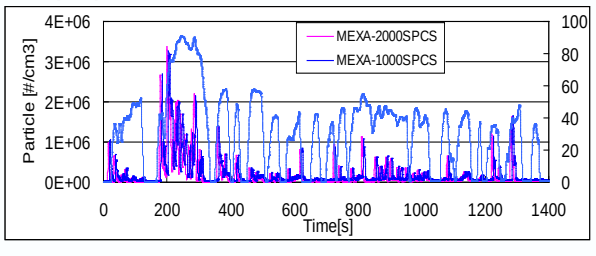
F-test		*t*-test	
F-value	0.990	*t*-value	0.396
$F_{critical}$	< 3.787	$t_{critical}$	< 2.145
PASS		PASS	

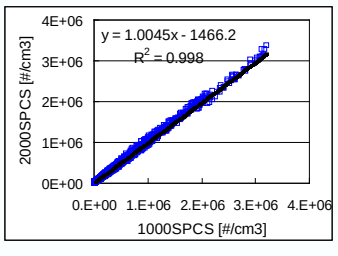
95 % Confidence level

Equivalency of conventional and new models are determined by statistical analysis.
Two SPCSs show good reproducibility on raw exhaust measurements

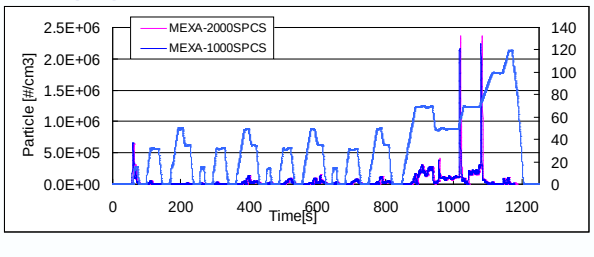
5. Correlation between conventional and new SPCS

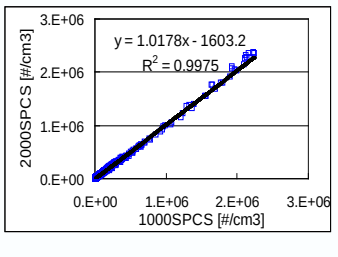
FTP (*GDI*)





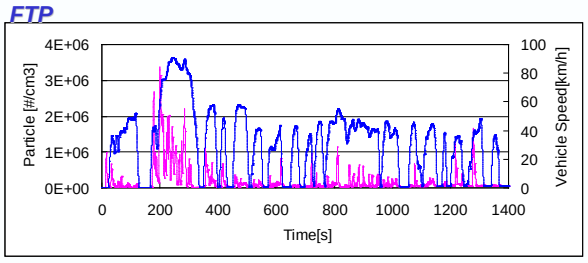
NEDC (*GDI*)

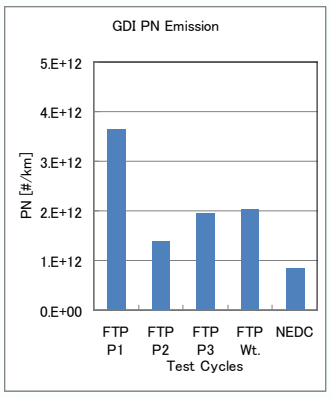




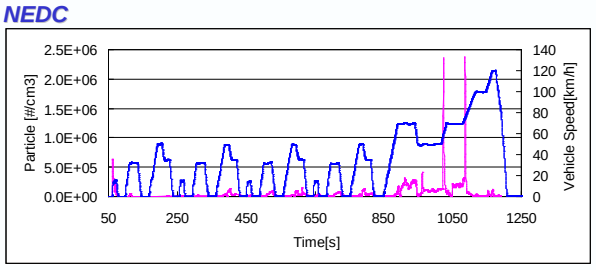
6. GDI Emission Levels on FTP and NEDC

FTP





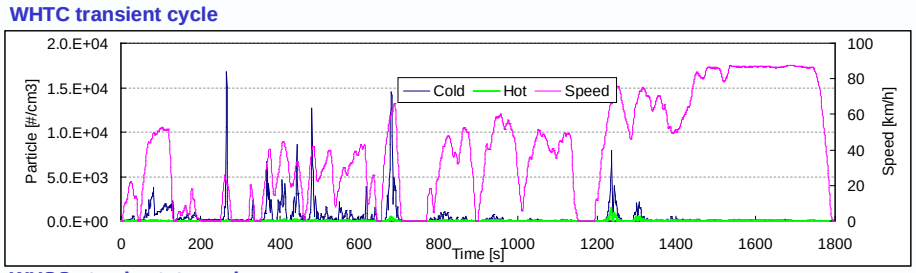
NEDC



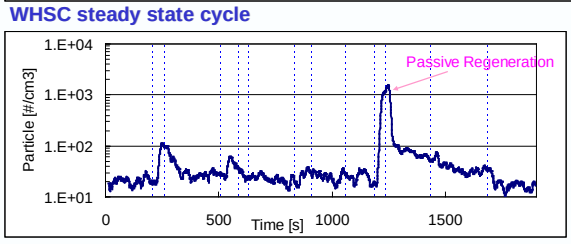
GDI vehicle emits more particles on FTP than NEDC, due to high accelerations in the cycle

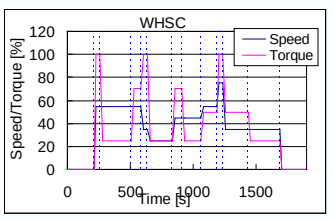
7. WHTC and WHSC Tests of Heavy Duty Diesel with DPF

WHTC transient cycle



WHSC steady state cycle





Significant numbers of particle are emitted at the 10th mode due to the passive regeneration caused by high temperature and/or presence of NO_2.

Conclusions

- Second generation of solid particle counting system has been developed which is compact and transportable so that the system is easily installed in a small engine cell.
- Equivalency of the new model was evaluated by statistical analysis. The new model shows good equivalency against the conventional model.
- The correlation between the measurements by new and conventional systems is very good.
- GDI vehicle emits more particles on FTP than NEDC, due to high accelerations in the cycle
- Significant numbers of particle are emitted at the 10th mode of WHSC due to the passive regeneration caused by high temperature and/or presence of NO_2.