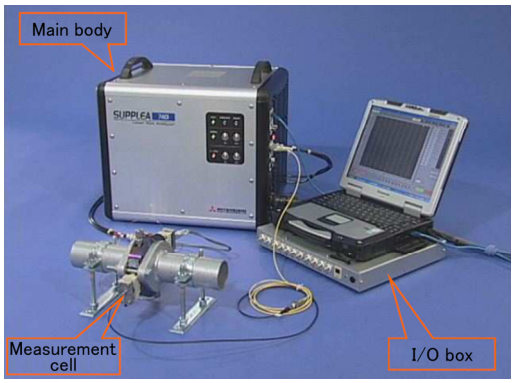
Direct High-speed Exhaust Gas Measurement System Using Semiconductor Laser

- A Useful Tool for Developing Energy-efficient Engines and Urea SCR Catalysts -



Transportation Systems & Advanced Technology Division
Advanced Mechanical Systems Department

Although the development of electric vehicles is being promoted to achieve a low-carbon society, the mainstream of motive power for the near future will be internal combustion engines. A system capable of making measurements within 1 ms is required to capture the phenomena that occur during the engine combustion cycle, so that the transient combustion in internal combustion engines can be analyzed in depth to further improve fuel efficiency and reduce emissions. While emission regulations are becoming increasingly stringent, EURO VI, the next-generation standard in Europe, requires a high-accuracy measurement system to measure ammonia (NH_3), which will be subject to control.

1. Features of SUPPLEA and TDLAS

1.1 Super-prompt Laser Exhaust Gas Analyzer (SUPPLEA)

The super-prompt laser exhaust gas analyzer (SUPPLEA) can measure exhaust gas temperatures and multicomponent (H_2O, CO, CO_2 and CH_4) gas concentrations with an ultrafast response in 1 ms. The following are some possible applications.

(1) Because of its 1-ms ultrahigh-speed response direct measurement, SUPPLEA can visualize transient phenomena during an engine combustion cycle and identify phenomena never before captured, such as fuel-rich/lean combustion, misfire detection and variation between cylinders. Therefore, the system can be applied to engine development, including hardware and software.

(2) With the combination of a fast response flowmeter and a total hydrocarbon (THC) analyzer, an ultrafast response fuelometer (on ms order) is expected to be put into operation.

(3) SUPPLEA is a portable system that can be mounted on an actual vehicle for on-vehicle measurement. Using the same measuring device in test bench experiments and field tests, it is possible to eliminate instrument error between the devices used at different testing stages and considerably shorten the engine development period.

(4) Gas temperature measurement unaffected by the radiation heat from the piping is possible because the temperature is measured by thermal analysis based on the H_2O absorption spectrum.

1.2 Tunable Diode Laser Absorption Spectroscopy (TDLAS)

Tunable diode laser absorption spectroscopy (TDLAS) is capable of high-speed response measurement (≤100 ms) of NH_3 on the order of ppm. The following are some sample applications.

(1) TDLAS can accurately measure NH_3, which will be controlled under the EURO VI regulations (regulated value: 10 ppm).

(2) The system can measure the NH_3 distribution in a catalyst system based on simultaneous measurements at two points. This shortens the development period of NOx reduction after-treatment systems (urea SCR catalyst) and enables development aiming at reducing the amount of catalyst (cost reduction).

(3) Being capable of a fast response (100 ms), the system enables the visualization of momentary ammonia slip, which has been difficult with the conventional measurement system, Fourier transform infrared spectroscopy (FTIR).

2. Specifications of SUPPLEA and TDLAS

The specifications of the systems are summarized in **Table 1**.

Table 1 System specifications

	SUPPLEA	TDLAS	
		Direct measurement	Sampling-type measurement
Measurement principles	Semiconductor laser absorption spectroscopy	Semiconductor laser absorption spectroscopy	
Type of gas measured, etc.	H_2O, CO, CO_2, CH_4; Temperature	NH_3	
Measurement range	Temperature: 30 - 800 (°C)	NH_3: 0 - 1,000 (ppm)	
	H_2O, CO_2: 0 - 20 (vol%)		
	CO: 0 - 10 (vol%)		
	CH_4: 0 - 1,000 (ppm)		
Response time	1 ms	100 ms	200 ms or less (at a sampling flow rate = 12 L/min)
Dimensions (W × H × D) (mm)	435 W × 385 H × 365 D (mountable on a vehicle)	540 W × 1,200 H × 800 D	540 W × 1,200 H × 800 D (measurement panel)
			750 W × 877 H × 300 D (sampling rack)
Weight	35 kg	85 kg	120 kg (measurement panel)
			80 kg (sampling rack)
Detection limit (2σ)	CO, CO_2, CH_4: ±2 (%/FS) @ 25°C & 0.1 MPa abs.	5 ppm @ 300°C & 0.1 MPa abs.	2 ppm @ 300°C & 0.1 MPa abs.
	H_2O: ±2 (%/FS) @ 150°C & 0.1 MPa abs.		
	Temperature: ±10 (°C) @ 150°C & 0.1 MPa abs.		

3. Examples of measurements

3.1 SUPPLEA

3.1.1 Visualization of Transient Phenomena

With the conventional sampling-type measurements, it is difficult to increase speed due to the time required for pre-treatment and supplying the sampling gas to the analyzer. As a result, sampling-type measurements could not have precisely captured the transient phenomena occurring when the concentration changes. Examples of transient phenomena visualized using SUPPLEA are as follows:

(1) Engine start

As shown in **Figure 1**, the system precisely captured the appearance of unburnt carbon (CH_4) and CO momentarily because of incomplete combustion during cold startup.

(2) Fuel cut

As shown in **Figure 2**, the system precisely captured the appearance of CO and CH_4 transiently during fuel cut. This contributes to optimizing control by the electronic control unit (ECU).

3.1.2 Applications in Misfire Detection

Misfire detection requires responsiveness that can meet the speed of the engine combustion cycle. When a four-cylinder engine is operated at 6,000 rpm, the required cycle to monitor each cylinder is the following equation.

6,000 rpm × (1 combustion stroke/2 rotations) × 4 cylinders ÷ 60 sec = 200 Hz (5 ms)

Therefore, SUPPLEA can be applied to misfire detection because it has a responsiveness of 1 ms, which enables five-point sampling during one combustion cycle. The graph on the left of **Figure 3** shows the SUPPLEA measurement waveform that was obtained when a single-cylinder engine was operated at 3,600 rpm. The results of fast Fourier transform (FFT) analysis of engine revolution and the gas temperature shown on the right side of Figure 3 both coincide at 30 Hz, indicating that the system precisely visualized the variation in gas temperature during the engine combustion cycle.

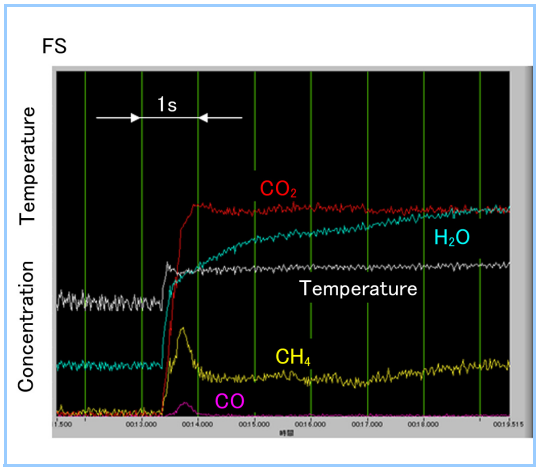


Figure 1 Transient phenomena during engine start

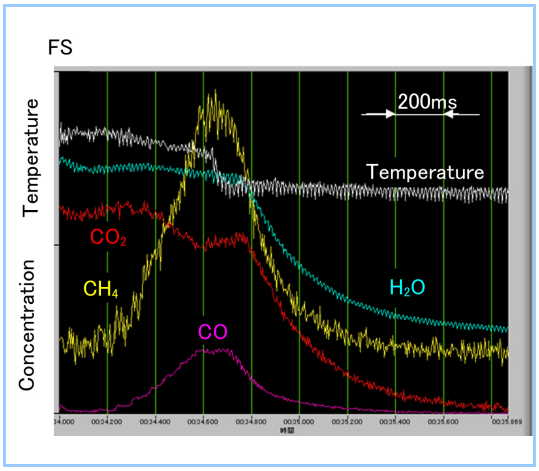


Figure 2 Transient phenomena during fuel cut

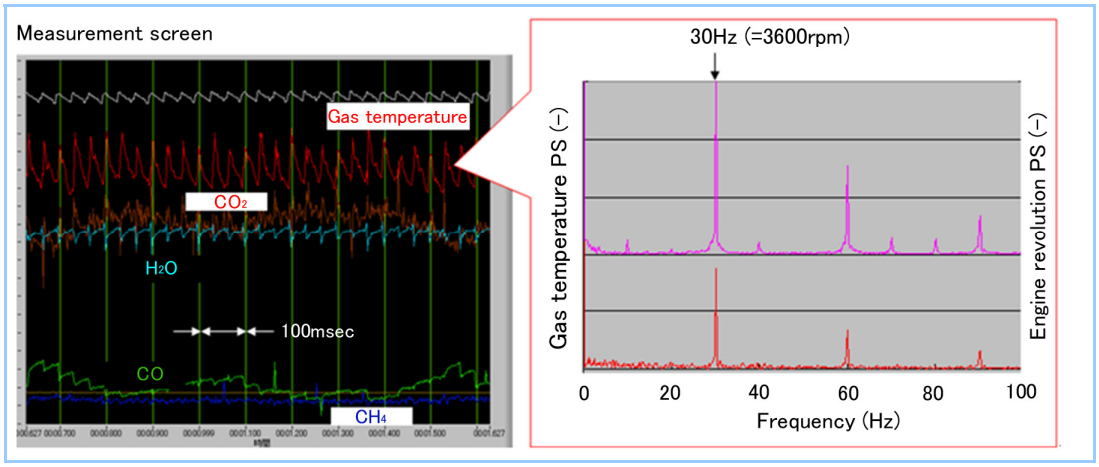


Figure 3 Gas temperature measurement and FFT results

3.2 TDLAS

The NH_3 concentration was measured by TDLAS (sampling-type and direct measurements), while the amount of NH_3 supplied was increased in a stepwise manner at 2-sec intervals. The maximum amount of NH_3 supplied was approximately 500 ppm.

As shown in **Figure 4**, the response of the sampling-type measurement was approximately 200 ms, while that of the direct measurement was about 100 ms. These results matched the amount of NH_3 supplied.

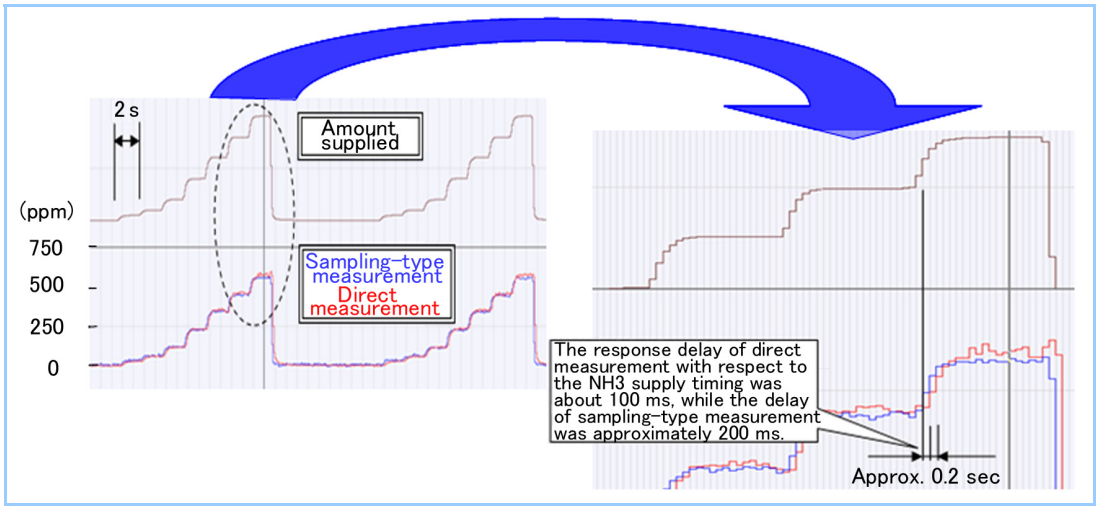


Figure 4 Measurement results