Feature Article

50th Anniversary Product

The OBS-1000 Series
On-board Engine Emission Measurement System

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While recognition of the importance of environmental problems is increasing, environmental impact caused particularly by engine emissions is attracting public attention. Emission regulations themselves are getting tighter than ever, but not only that, the global trend is to demand even further advances beyond merely meeting regulation requirements.

Surveying of vehicle emissions in a ‘real world’ condition is discussed here as an example. At HORIBA, the on-board emission measurement system OBS-1000 series was released for this purpose. The OBS-1000 series consists of gas analyzers, flow meter, various sensors, and data logger. Measuring and recording of the concentration of CO, CO_2, HC, and NOx in real world conditions, air-fuel ratio, calculation of mass emission of each component and fuel consumption, etc., are possible. In this paper, the outline of this system is described.

Introduction

At present it is common to perform engine emission measurement in a laboratory with an exclusive system. In certification test for new vehicles, which requires consistent conditions, such a test system is indispensable. On the other hand, it is very difficult to reproduce real world conditions faithfully in a laboratory. Therefore, sufficient information has not been provided for practical evaluations of on-road emissions, such as partial contamination of NOx seen around the main roads. Recently, to overcome such a situation, emission surveys of vehicles under real world conditions have attracted public attention [1]-[5]. The OBS-1000 series, which is one of the 50th anniversary products of HORIBA, is an on-board type emission measurement system aiming at emission evaluation whilst on the road [6]-[10].

In this paper, system configuration and an actual road test examination will be discussed.

System Outline

System Configuration and Acquired Data

The system configuration of OBS-1000 series is shown in Figure 1 and Figure 2. One of the main component of the system is the gas concentration analyzer. It uses a MEXA-1170HNDIR non-dispersive infrared (NDIR) analyzer for the CO, CO_2, and HC measurement. The zirconia (ZrO_2) analyzer; MEXA-720NOx is also used for NOx and air-fuel ratio (A/F) measurement [11]-[13]. The OBS-1100 (CO, CO_2, and HC measurement), OBS-1200 (NOx and A/F measurement), and OBS-1300 (all component measurement) can be chosen as variations by combining with the appropriate analyzer. Each type has an exhaust flow meter using Pitot tube method. These items will be mentioned later.

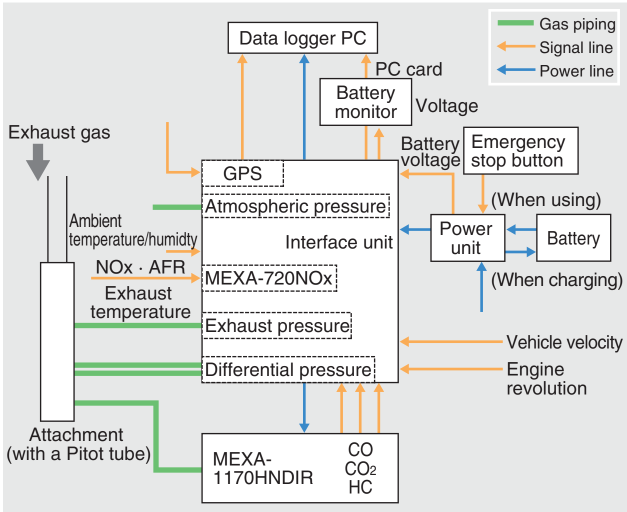

Figure 1 Configuration Concept of the OBS-1000 Series

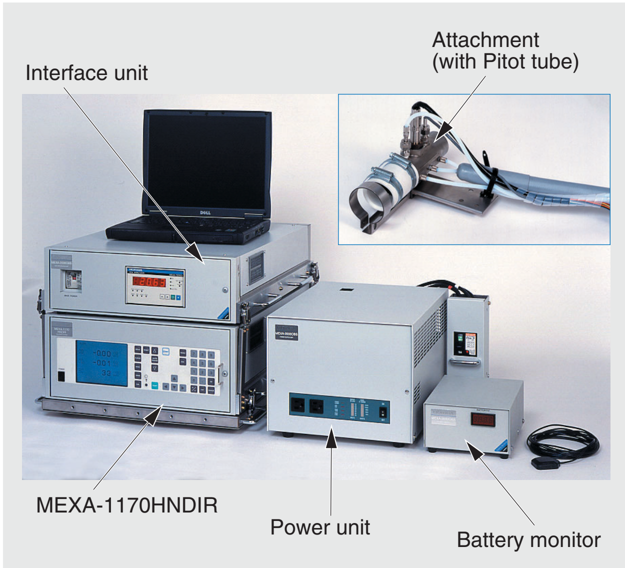

Figure 2 Appearance of Main Components of the System

The sampling port for the MEXA-1170HNDIR, the ZrO_2 sensor of the MEXA-720NOx, and a Pitot tube for measuring exhaust gas flow are integrated into an exclusive attachment, which can be affixed to the exhaust pipe of the test vehicles. The ports for exhaust pressure measurement and the exhaust thermometer are also provided with this attachment.

In addition, an atmospheric pressure sensor and an ambient temperature and humidity sensor for environmental monitoring are contained in the system. Furthermore, it also has a GPS receiving antenna, so that the location of the test vehicle (latitude, longitude, etc.) can be acquired. The time trend data from these analyzers and sensors are first input into an interface unit, and are transmitted to a notebook-type personal computer from there. The data logger software for the OBS-1000 series is installed in this personal computer, and the input data are displayed and recorded. The vehicle speed and the engine revolution signals are input into the interface unit as external inputs, and are read in addition to other items by the personal computer.

The system power is supplied from a dedicated car battery. For ease of use, it also has a battery monitor and recharging capability from a commercial power supply.

Gas Analyzer

The MEXA-1170HNDIR used for the series is a heated type analyzer, and newly developed specially for on-board measurement. The vibration-resistant pyro-electric infrared sensor is used for detecting each target component (CO, CO_2, HC). The sample for the MEXA-1170HNDIR is acquired from the exclusive port of the attachment, and it is directly fed to the analyzer through the heated tube without passing through the dehumidification equipment. Therefore, a detector for H_2O, which is not a measurement component, is also included in the analyzer, and the interference from H_2O in the sample is compensated. The sensor of the MEXA-720NOx, which is the direct-insertion type, is installed on the exhaust pipe directly, and the amplifier unit is contained in the interface unit. This sensor measures NOx and A/F simultaneously.

Pitot Tube Type Flow Meter

A diagram of the flow meter using a Pitot tube is shown in Figure 3. The Pitot tube is usually used as an anemometer, which reveals the gas flow velocity from the differential pressure between the total pressure measured from the hole oriented toward the flow direction and the static pressure measured from the hole oriented in the perpendicular direction. In this system, the gas flows inside the attachment that has a known diameter, therefore, the gas velocity measured by the Pitot tube method can be converted into the gas flow rate.

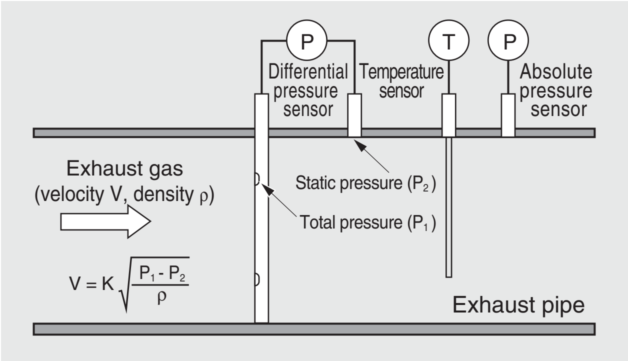

Figure 3 Configuration of Pitot Tube Type Flow Meter

The calculation of the flow rate from the differential pressure of the Pitot tube is shown in equation (1).

$$Q_{exh}(t) = K \times \sqrt{\frac{P_{exh}(t)}{101.3} \times \frac{293.15}{T_{exh}(t)} \times \frac{\Delta h(t)}{\gamma_{exh}}} \quad \text{..........(1)}$$

$Q_{exh}(t)$: Exhaust gas flow rate (at standard condition) [m^3/min]

K : Coefficient

$P_{exh}(t)$: Exhaust pressure [kPa]

$T_{exh}(t)$: Exhaust temperature [K]

$\Delta h(t)$: Differential pressure of Pitot tube [kPa]

γ_{exh} : Exhaust density at the standard condition [g/m^3]

The proportional coefficient K is different for every attachment, and is determined in advance by comparison with a SAO (Smooth Approach Orifice) flow meter. The calculation of equation (1) is performed in the data logger PC, and it is displayed and recorded as the exhaust flow rate.

Calculation Functions of the OBS-1000 Series

In the OBS-1000 series, the following calculation using the saved data can be performed in addition to the real-time display of the input data.

Calculation of Mass Emission

The concentration output (CO, CO_2, HC, and NOx) of each analyzer can be converted into mass emission using the gas flow rate obtained by the Pitot tube. The mass emission per unit time is shown in equation (2), and the calculation of the mass emission per mileage is shown in equation (3). Since this system does not dehumidify the sample, compensation calculation for concentration change by water condensation is not performed.

$$M_x(t) = C_x(t) \times 10^{-6} \times \frac{Q_{exh}(t)}{60} \times \gamma_x \quad \cdots\cdots (2)$$

$$M_{x\_total} = \Sigma M_x(t) \times \frac{1}{L} \quad \cdots\cdots (3)$$

$M_x(t)$: Mass emission per unit time of component x [g/s]
$C_x(t)$: Concentration of component x [ppm]
$Q_{exh}(t)$: Exhaust flow rate (standard condition) [m^3/min]
γ_x : Density of component x at the standard condition [g/m^3]
M_{x_total} : Mass emission per mileage of component x [g/km]
L : Running distance [km]

In the OBS-1000 series, since HC is measured by the NDIR method, the concentration is output at that for n-hexane (hexane equivalent concentration, ppmC6 unit). On the other hand, total hydrocarbon (THC, ppmC unit) concentration by the flame ionization (FID) method is used for laboratory devices in many cases. The coefficient, which can be set arbitrarily, is provided in this system, and it enables the HC outputs by the NDIR to be converted into the outputs of the THC equivalent.

Calculation of Fuel Consumption

The calculation of the fuel consumption and fuel economy are possible using A/F measured by the MEXA-720NOx or A/F calculated by the carbon balance method. The calculation are shown in equation (4) and equation (5).

$$Fc(t) = \frac{Q_{exh}(t)}{60} \times \gamma_{exh} \times \frac{1}{(A/F)+1} \quad \cdots\cdots (4)$$

$$Fe = \frac{1}{\Sigma Fc(t)} \times \rho \times L \quad \cdots\cdots (5)$$

$Fc(t)$: Fuel consumption [g/s]
$Q_{exh}(t)$: Exhaust flow rate (standard condition) [m^3/min]
γ_{exh} : Exhaust gas density at the standard condition [g/m^3]
A/F : Air-fuel ratio
Fe : Fuel economy [km/L]
ρ : Fuel density [g/L]
L : Running distance [km]

Real World Test

Next, is an example in which a real world test was performed using the on-board measurement system.

Eco-drive EKIDEN

HORIBA performed "Eco-drive EKIDEN" using the OBS-1000 series from January to September of 2003. It was a trial which commemorated the 50th anniversary of foundation, in which continuous real world test data over a long distance was acquired by mounting the same system on test vehicles in Japan, the U.S., and Europe while changing drivers (Figure 4).

The test route is shown in Figure 5.

Figure 4 The Eco-drive EKIDEN Final Goal (in September 29, 2003 Kyoto head office)

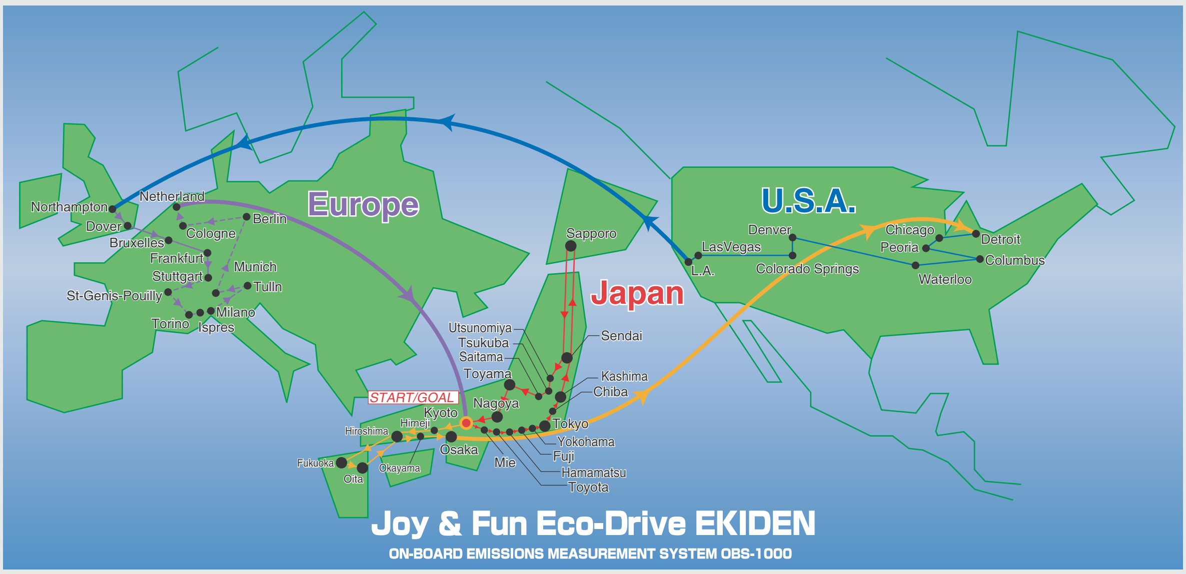

Figure 5 Eco-drive EKIDEN Road Test Route

The test route, after acquiring the on-road test data of western Japan including Kyushu and Shikoku with the Kyoto head office as the starting point, was; crossing between Detroit and California in the U.S., and additionally turning around seven nations in Europe from Northampton in Britain. Then, running the whole length of east Japan and Hokkaido again from Kyoto, and finally returning to Kyoto. The test vehicles used in each region are shown in Figure 6.

Figure 6 Test Vehicles in Each Region

Example of Eco-drive EKIDEN Test Results

An example of the test run results (velocity, fuel economy, and CO_2 mass emission) obtained by the Eco-drive EKIDEN is shown in Figure 7.

The data was acquired between the ferry bus stop of the Ehime Sada cape peninsula and Matsuyama street. The road conditions were as follows:

- A Section was a mountain path with little traffic
- B Section was a flat route along the seashore with little traffic
- C Section was a city area with much traffic and signals
- D Section was a mountain path of a Prefectural road with much traffic
- E Section was an abrupt mountain path.

In Figure 7, the average value (sum value for CO_2 emissions) for every 30 seconds is plotted for velocity, fuel economy, and CO_2 mass emission in accordance with the road test route. Comparing each chart together with the road conditions, first, in B Section, it turns out that velocity, fuel economy, and CO_2 mass emission were very stable. This shows that this section is flat with not so much opportunity for stopping and it was able to run nearly in the steady state. Then, the average velocity decreased in C Section because there were many signal stops and much traffic. The fuel economy was very good and CO_2 mass emission were very low. This shows that the electric drive was used frequently in these driving conditions. Furthermore, it revealed that data varied greatly in the mountain paths such as on the A, D & E Sections, and the degree of the slope of the road influenced the road running state and CO_2 mass emission.

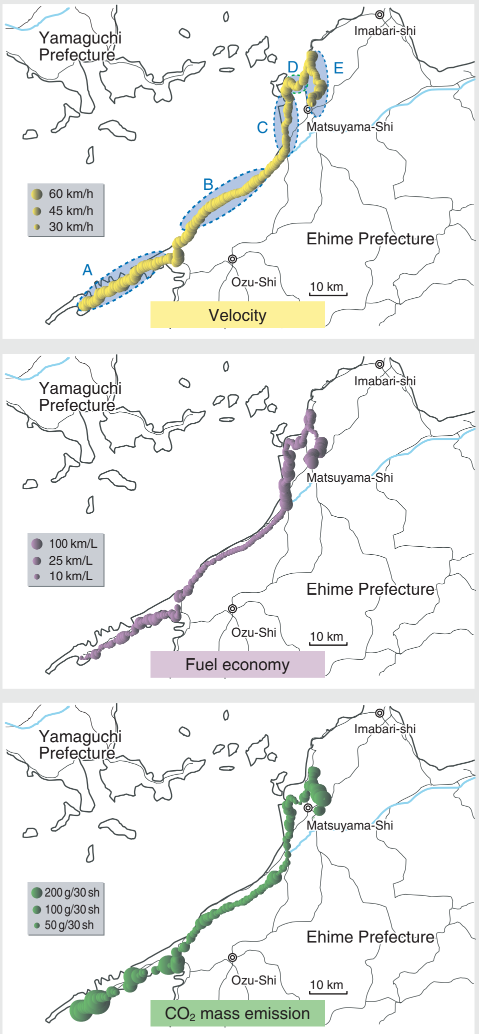

Figure 7 Road Test Data in Eco-drive EKIDEN

Conclusion

In this paper, it can be seen that with the OBS-1000 Series, real world emission measurement on the road is possible. We expect that this system will be utilized in many fields such as evaluating the environmental impact of multipurpose and off-road power plants as well as road emission tests of passenger cars, trucks, etc., and that it will provide useful information for engine development and environmental preservation.

Moreover, this product has served as a trigger, for further work on on-board emission measurement around the world, and other needs such as practical research-and-development and regulation compliance testing have been increasing.

We would like to be engaged in the development of subsequent products suitably embracing the 50th anniversary from now on.

Gratitude is expressed to the team members engaged in development of this product, and the members of HAD (United States) and the members of HE (Europe) who were supporting, and especially to Mr. Hans Srix and Hiroshi Nakamura who were principal personnel.

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