FEATURE ARTICLE

Opacimeter MEXA-130S

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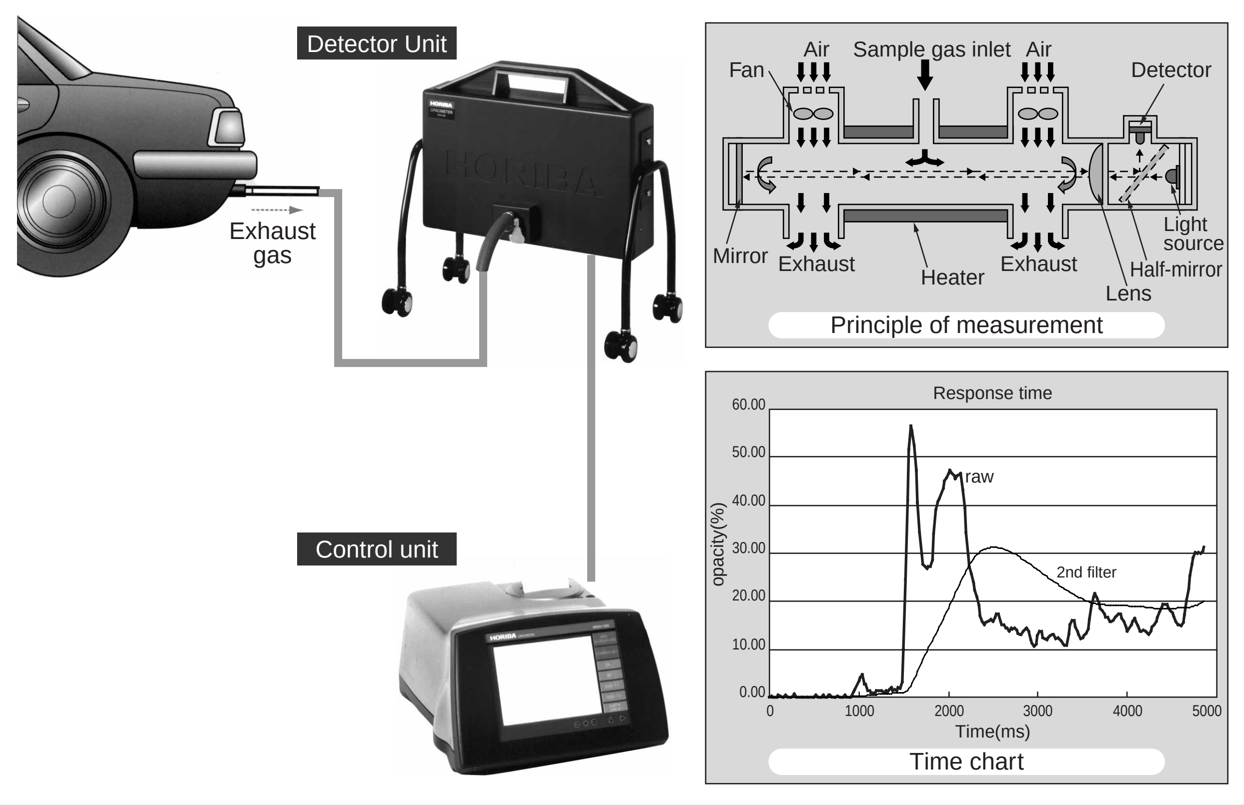
System configuration diagram



Abstract

Reduction of the particulate matter emitted from diesel vehicles is an urgent task. In Japan, aside from the filter weighing method, the main method currently used for PM testing based on regulatory requirements is the reflecting smoke meter method. However, this method does not provide adequate sensitivity and cannot be used for continuous measurement. Horiba has now developed the MEXA-130S Opacimeter, which is capable of continuous and high-sensitivity measurement of all kinds of smoke, blue and white as well as black. The paper describes the measurement principles and features of the MEXA-130S, and reports the results of performance tests. We also performed tests running an engine on a chassis dynamometer to establish the correlation with the filter weighing method, and actually drove a diesel vehicle equipped with a MEXA-130S through an urban area to examine the possibility of onboard measurement of exhaust gas.

1 Introduction

Recent years have seen a growing need to reduce smoke emitted from diesel vehicles. In Japan, a part of “the Safety Regulation for a Road Motor Vehicles” was revised, and the permitted smoke level for new cars on sale from October 1, 1999 was reduced from 40% to 25%.

Until now automobile service shops have measured smoke in exhaust using a smoke meter, whereby the smoke is collected on a filter and the photographic density is measured by means of reflected light (Bosch method).

In general, diesel engines emit mostly black smoke when under a heavy load, and emit more blue and white smoke as the load lightens. This fact has effected the sensitivity of conventional reflecting-type smoke meters according to the engine conditions, leading to inadequate sensitivity and measurement errors.

For this reason, Horiba has developed the Opacimeter MEXA-130S, with high sensitivity and high reproducibility.

2 Overview of MEXA-130S

2.1 Principle of Measurement

Smoke meters that use light can be broadly classified into two types: a light reflecting type that measures smoke concentration based on changes in the reflectivity when light is shown on PM collected on a filter, and a light transmitting type (opacimeter) that measures smoke concentration based on the strength of the absorbed and scattered light when light is shown directly on the exhaust gas. The MEXA-130S uses the light transmission method, which also has a high sensitivity with respect to blue and white smoke.

Fig.1 shows the principle of measurement of the MEXA-130S. The exhaust gas is drawn into the sample cell, and when the gas contains black smoke due to high-temperature fuel combustion and blue and white smoke due to unburned oil, unburned fuel and water, the visible light from the light source is attenuated due to absorption and scattering. The concentration of smoke is calculated from the amount of attenuation using the Lambert-Beer equation (Equation (1)).

The result is expressed as an opacity N (%) given by Equation (2), or a light absorption coefficient k (m^{-1}) given by Equation (3).

$$I = I_o \cdot e^{-kL} = I_o \cdot (1 - N/100) \quad \text{------------} (1)$$

$$N = (1 - I/I_o) \cdot 100 \quad \text{----------------------} (2)$$

$$k = -1/L \cdot \ln(1 - N/100) \quad \text{--------------} (3)$$

I_0 : Light intensity when there is no smoke

I : Light intensity when smoke exists

L : Cell length (m)

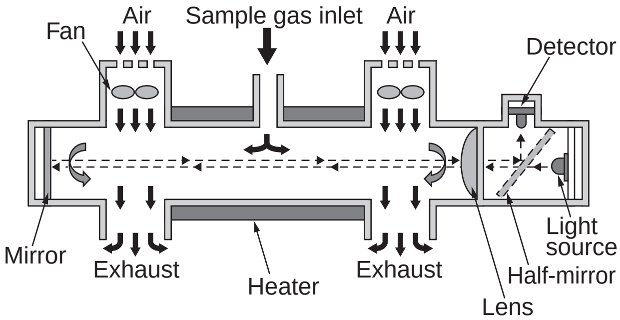


Fig.1 Principle of Measurement of MEXA-130S

2.2 Sampling

The MEXA-130S uses a sampling method that utilizes the exhaust gas pressure. With this method, a special sampling pump is not needed and stable collection of exhaust gas, which is very changeable, is possible.

Fig.2 shows the cycle of the free acceleration method, which is a typical measurement method. A sampling probe is inserted into the tailpipe, and the engine is quickly accelerated with no load to produce smoke. The exhaust pressure causes the smoke to pass through the probe and into the sample cell. the engine is revved a set number of times, the smoke concentration is measured as the peak value of the output signal during acceleration.

An opacimeter and the free acceleration method are used in combination in automobile service shops in Europe[1], and it is anticipated that this will become an effective and convenient smoke measurement method for low-concentration smoke.

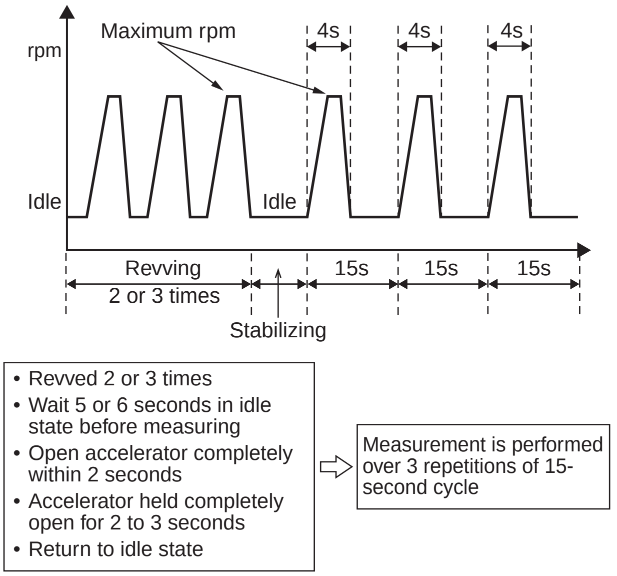


Fig.2 Measurement Cycle of Free Acceleration Method

2.3 Features and Specifications

In addition to the theoretical advantage of measuring smoke concentration in real time, the MEXA-130S is equipped with functions for complete ease-of-operation.

1) The detector unit is separated from the display unit, enabling measurement by a single operator.
2) Supports free acceleration measurement, by displaying guide messages for accelerator operation and by automatic data collection.
3) Simplified maintenance, which can be performed by users.

Fig.3 shows the appearance of the MEXA-130S and Table 1 shows the outline of the specifications.

Fig.3 Opacimeter MEXA-130S

Model	MEXA-130S
Approved standards	ISO-11614 (conformed)
Application	Measurement of smoke in the exhaust gas emitted from diesel engines
Principle	Opacity method Detector : Photo sensor Light source : 560 nm(green LED)
Range	Opacity : 0.00 to 100 % Light absorption coefficient : 0.000 to 10.00 m^{-1}
Sampling method	Partial flow
Connection of sample gas	Dedicated probe (included), 2.5m, I.D. 10mm
Display and resolution	Liquid crystal display Opacity : 0.1 % Light absorption coefficient : 0.001 m^{-1}
Input/output	Digital input/output : RS-232C Analog output : optional
Dimensions	Control unit : 240(W)×357(D)×156(H) mm Detector unit : 380(W)×90(D)×235(H) mm (excluding legs)
Mass	Control unit : Approx. 2 kg Detector unit : Approx. 4.5 kg

Table 1 Specifications of MEXA-130S

3 Performance Evaluation of MEXA-130S

3.1 Evaluation of measurement sensitivity

Fig.4 shows the time chart of the MEXA-130S output signal when an actual vehicle is run using the free acceleration method. A stable signal with sufficiently high S/N was obtained.

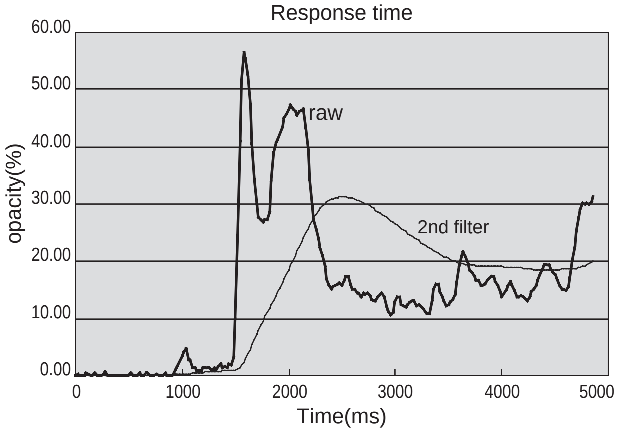


Fig.4 Time Chart of Smoke Measurement Using Free Acceleration Method

3.2 Determination of PM Emission Mass from Smoke Concentration

The sensitivity of an opacimeter is normally calibrated at a light transmittance of 0% and 100% and the linearity verified with the optical filter whose transmittance is known. This means that the readings of an opacimeter are not directly calibrated using PM itself. In order to study the validity of determining the PM emission mass from the readings of an opacimeter, the authors conducted a comparison with the conventional filter method using an engine running test on a chassis dynamometer. The test vehicle was an RV vehicle equipped with a divided combustion chamber diesel engine. The main specifications are shown in Table 2.

Items	Specifications
Engine Type	IDI diesel; with inter-cooler and turbocharger
EGR	With
Gearshift	4 AT
Engine displacement	1.998[L]
Vehicle weight	1500[kg]
Product date	1994[year]
Running history	92,000[km]

Table 2 Main Specifications of Test Vehicle

First we ran the test vehicle on a chassis dynamometer at fixed speeds of 40, 60, 70, and 80 km/h, and measured the PM mass using the filter weighing method. We simultaneously measured the smoke concentration using the MEXA-130S. We may infer that the relation given in Equation (4) holds between the PM mass (M_{PM}) obtained using the filter weighing method and the light absorption coefficient k obtained using the MEXA-130S.

$M_{PM} = \rho_{PM} \cdot k \cdot Qex$ -------------(4)

M_{PM} : PM mass[g/s]

ρ_{PM} : PM density[g/s]

k : Light absorption coefficient[m^{-1}]

C : Conversion coefficient[m]

Qex : Flow rate of exhaust gas[L/s]

Fig.5 shows the test results. A good correlation is evident between the smoke concentration and the PM mass.

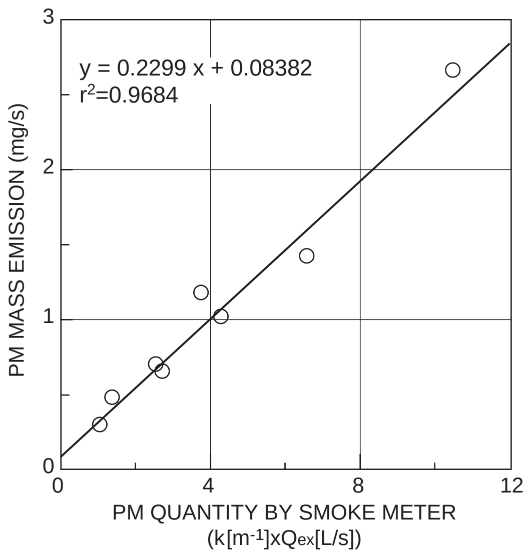


Fig.5 Relation of Smoke Concentration to Emitted PM Mass

3.3 10-15 Mode Running Test

The amount of smoke emitted varies widely depending on the running state. We measured the change in smoke concentration along with other components in exhaust gas in 10-15 mode, a Japanese standard mode for exhaust gas testing.

Fig.6 shows a time chart of vehicle speed and the quantities of HC, CO, and PM emitted. The PM mass was obtained by conversion from the smoke concentration using the approximation line of Fig.5. The emission of PM increases and decreases according to changes in vehicle speed, and the pattern resembles those of other components. The fact that we can observe an emission pattern that is very close to the expected pattern supports the possibility that the MEXA-130S is effective as a real time testing instrument for PM.

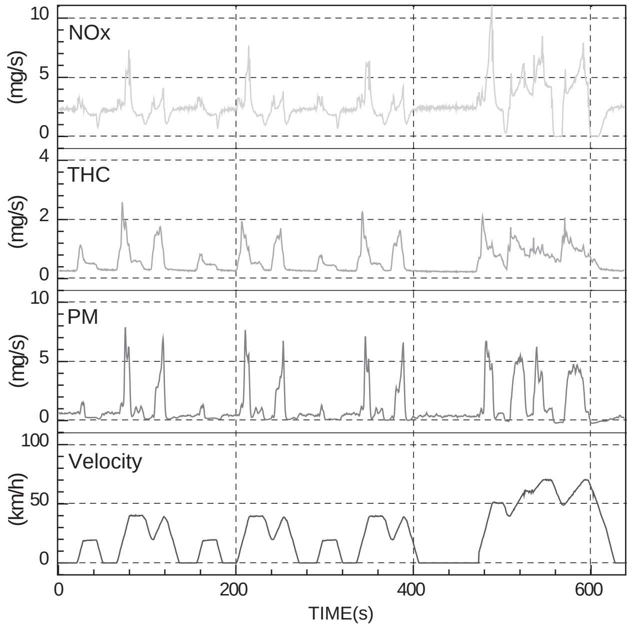


Fig.6 Emission Pattern while Running in 10-15 Modes

3.4 Testing while Driving through an Urban Area

Interest is growing in on-board measurement, whereby a test vehicle is equipped with a small analyzer and the exhaust gas is measured while actually driving through an urban area. Following HC, CO, and NOx testing[2)], the authors studied the possibility of on-board measurement of PM using the MEXA-130S.

We equipped the test vehicle with a MEXA-130S Opacimeter, a Portable-type Total Hydrocarbon Analyzer (MEXA-1170HFID), and a Nitrogen Oxide Analyzer (MEXA-120NOx). We drove the vehicle through the suburbs of Kyoto and measured the exhaust gas. We also simultaneously recorded the output of an excess air ratio sensor and the outputs of various thermometers and humidity sensors.

The results are shown in Fig.7. The emitted mass of PM obtained using the MEXA-130S shows the same pattern of change corresponding to sudden acceleration and deceleration as THC, NOx, the excess air ratio, and fuel consumption. This indicates that the MEXA-130S can be used for PM measurement not only on a chassis dynamo but also in on-board measurement.

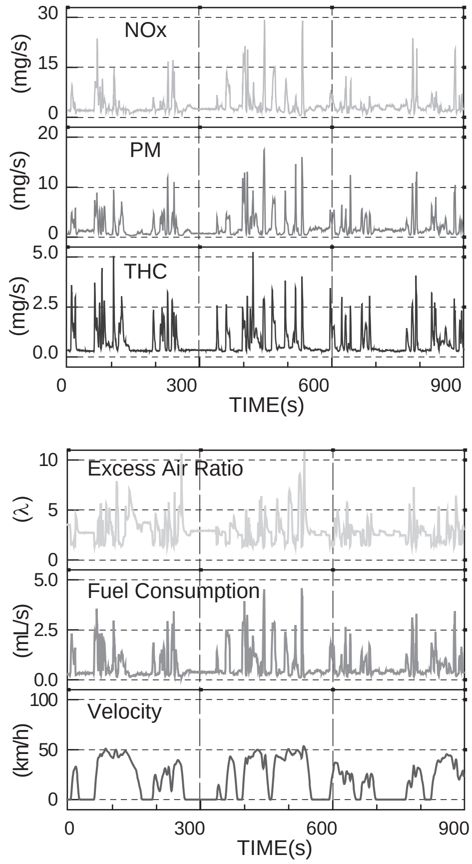


Fig.7 Emission Pattern during Urban-Area On-Board Measurement

4 Conclusion

Development of cleaner and more efficient diesel engines is being constantly pursued. At the same time, it is important to ascertain how much smoke is emitted from vehicles in use and take appropriate measures. We have developed and introduced the MEXA-130S as a high-sensitivity, convenient opacimeter for use in automobile service, research and development, and in the future, automobile inspection. We are confident that this instrument will adequately fulfill this role.

To accurately and stably measure smoke with its complex dynamics, a wider-ranged approach is also important. Horiba has many years of experience in the research and development of measuring instruments for exhaust gas, and with the introduction of this opacimeter, we hope that opportunities for serving our customers will increase even further. For example, the MEXA-130S can serve as a supplement to the conventional filter method, and may possibly even be used for on-board measurement. We hope that this paper serves to deepen exchange with our customers, and will continue our endeavor to develop and introduce new measuring instruments.

References

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