8.6 Exhaust Gas Measurement for Motor Vehicles

8.6.1 Introduction

Concomitant with the introduction of weight regulation for motor vehicle exhaust gasses in 1973, a 10 mode exhaust gas measurement was established and, moreover, in 1994, regulations on the particulate matter (PM) from automobiles was added to this, and methods of measuring hazardous substances from automobiles were formalized.

8.6.2 Measuring equipment overview

Equipment essential for measuring motor vehicle exhaust gasses are equipment that recreates motor vehicle road running conditions (power absorption and control), exhaust gas sampling system, gas analyzers, and data processor.

(1) Power absorption and control equipment

Having set the conditions for the test vehicle or engine, it is driven, and the equipment that absorbs the motive power generated in called a dynamometer. The dynamometer is a system comprising a combination of various control equipment and peripherals. The power absorption system under actual vehicle conditions is called a chassis dynamometer, and a power absorption system for the engine alone is called an engine dynamometer.

With the chassis dynamometer, a roller that rotates in place of the road is taken to be an infinite level road, and a motor wheel is set on the roller, enabling motive experiments to be conducted. An example of a typical system is shown in Fig.8.6.1. In this case, running resistance when actually driving on the road is added to the roller axle from the dynamometer, and the inertial resistance is added by flywheels, closely resembling actual driving conditions on the road. Normal running resistance is added to the fixed level road running resistance. Running resistance at low speed is fixed regardless of the speed, but is magnified at high speeds. Air resistance increases proportionately with the speed of the vehicle. Power generated by the test vehicle on the chassis dynamometer is for the most part absorbed by the dynamometer, but during both acceleration and deceleration, is also absorbed by the flywheel, or else partly as mechaloss (mechanical loss.)

The engine dynamometer also absorbs power from the engine, and as a control mechanism is functionally the same as the chassis dynamometer. The basic concept of the engine dynamometer is an engine mounted on a test-bench, and to transmit to the dynamometer for absorption either directly or via a propeller shaft the power generated when the engine is running, by driving the actuator through commands from the operators console and the control board. Depending on the measurement objectives, various devices can be added, but for transient operation such as in urban test drive mode, flywheel and brake apparatuses are attached, on-the-road driving conditions are recreated in the same way as the chassis dynamometer, with road resistance being provided by the dynamometer, and inertial resistance during both acceleration and deceleration being provided by the flywheel. With the engine dynamometer, because the output from the engine is transmitted directly to the dynamometer, compared with the chassis dynamometer, there is no mechanical loss or tire slippage, and as a means of measuring engine out put, highly accurate results can be expected. Further, because the settings conditions allow for high mechanical accuracy, recreation is also good, and continuous running for long periods of time is also possible, therefore being optimum for examination of the measuring methods, endurance tests for exhaust gas reduction systems, and so forth. The engine dynamometer does not even need to be in the test room with the vehicle, enabling a compact system to be designed, and making effective experiments possible.

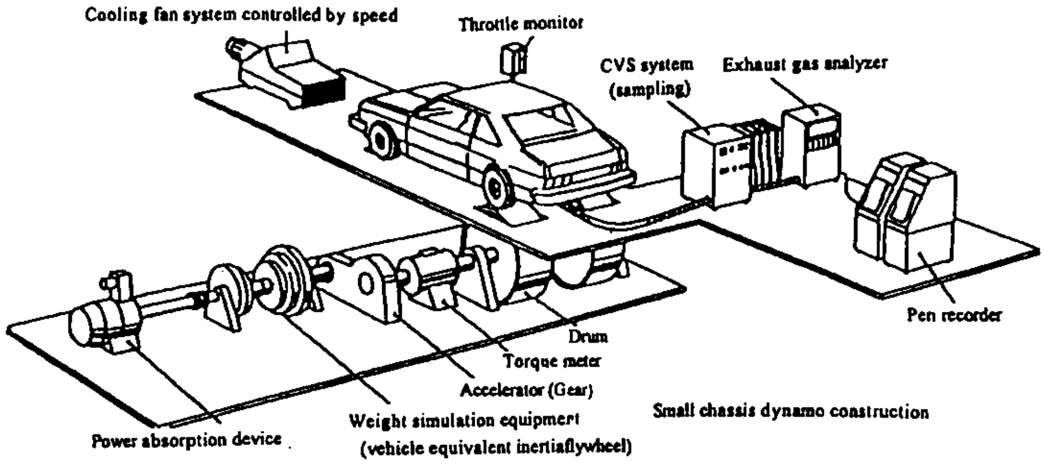

Fig.8.6.1 Gas emission measuring equipment

(2) Exhaust gas sampling equipment.

A. Direct gas sampling

Problems with the direct sampling of automobile exhaust gasses are that pollution of the sampling process route by oil and black smoke, control of the water content included in large quantities of thermal exhaust gasses, and the dissolving of water which is either condensed or adhering to the tube walls of the hazardous substances content tube. Oil and so forth, which cause the pollution of the sampling process route are caught by an oil catcher, and the black smoke is extracted by a heated filter, after which the gasses are introduced into the analyzing system. As for the water content in the exhaust gasses, because there is a danger of measurement of the hazardous substances being sabotaged, measures are taken to condense and extract the water using an electron cooler. For the measurement of adhesive pollutants, flow pipe must be heated. The HC heated induction tube is heated to 190℃, and NOx heated induction tube is heated to 60℃. In addition, as a problem specific to direct gas sampling, there is the issue of "hangup" (the phenomenon whereby HC in the exhaust gas is first adsorbed by the measuring path, and then later becomes unstuck.) In order to prevent this kind of phenomenon, the tube is made from non-adhesive Teflon, and in addition to selecting a sampling system in which the part that comes into direct contact with the gas has a small surface area, backflush (air is flushed from the secondary filter backwards to the exhaust gas inlet) is also carried out, with the intention of dislodging any HC which has been adsorbed.

B. Dilute gas sampling

As a method of solving the problems of direct sampling and accurately obtaining the concentration and quantity of hazardous substances in driving, where the transient operation are subject to violent change, the CVS (Constant

Volume Sampling) method, which is a method of dilute gas sampling, has been created. It has been used in America since 1972 as the official method for regulating motor vehicle exhaust gasses, and Japan has also adopted the 10-mode regulation as the official method since 1973. In 1983, the European Community (EC) reviewed its total back method, which has been used up till then, in favor of the CVS method.

The CVS method collects all the exhaust gasses and dilutes the clean air (the dust are extracted by micro-glass fiber, and the HC by charcoal filter) (10 to 10^2 times), by means of which, the total quantity of exhaust gas and diluted air is sucked by a blower as though it were always the same fixed amount. There are two blower sucking type, PDP (Positive Displacement Pump) and CFV (Critical Flow Venturi). With the PDP method, by operating a Roots Blower at fixed rotations, a combined quantity of constantly fixed exhaust gas and dilution air is sucked. The CFV method uses a principle whereby a fixed flow is achieved when the gas is pushed to the speed of sound, by which means, it is possible to control the flow by selecting and setting the Venturi to correspond the flow required.

In this way, in the CVS method, the total flow of the exhaust gas and the dilution air becomes constantly fixed, and the concentration of hazardous substances within that total flow is proportionate to the weight of the exhaust. Consequently, the gas to be measured is collected in a sample bag as a fixed proportion of the flow from the diluted exhaust gasses, and after the driving mode has been completed, when it is measured in an analyzer, the quantity of hazardous substance emissions from the weight base of the test vehicle can easily be determined. However, because there are many times when pollution of the dilution air becomes a real problem, the dilution air also needs to be collected for analysis in a separate sampling bag, and then subtracted as the background value.

The substance of the bags used in this method is TEDLAR (fluoride vinyl resin PUF50 μ), with a capacity of 150 to 200 ℓ, and a sampling quantity of 5 to 10 ℓ/min. The CVS method dilutes the exhaust gasses with air immediately after they emerge from the muffler, and this system instantly heats the gasses to room temperature, so that because there is no need to install a low temperature trap to eliminate water content in the collection system, there are the advantages that the loss of water-soluble gasses can be avoided, there is little change in the composition due to mutual reaction with highly active chemical substances because of the dilution, and no HC hang-up need be considered either. However, when measuring HC in diesel exhaust gasses, because there is a risk of adsorption by the HC bag, the diluted exhaust gasses are continuously introduced to, and measured by, the analyzer as they are, without being replenished in the bag, and the concentration quantified, by which means the amount of HC exhaust in the test mode can be determined.

C. Dilution tunnel

The construction of a dilution tunnel used in sampling particulate matter in motor vehicle exhaust gasses is shown in Fig.8.6.2. As the figure shows, the dilution tunnel system can be largely divided into four: the main dilution tunnel, the second tunnel, the PM sampling equipment, and the CVS equipment.

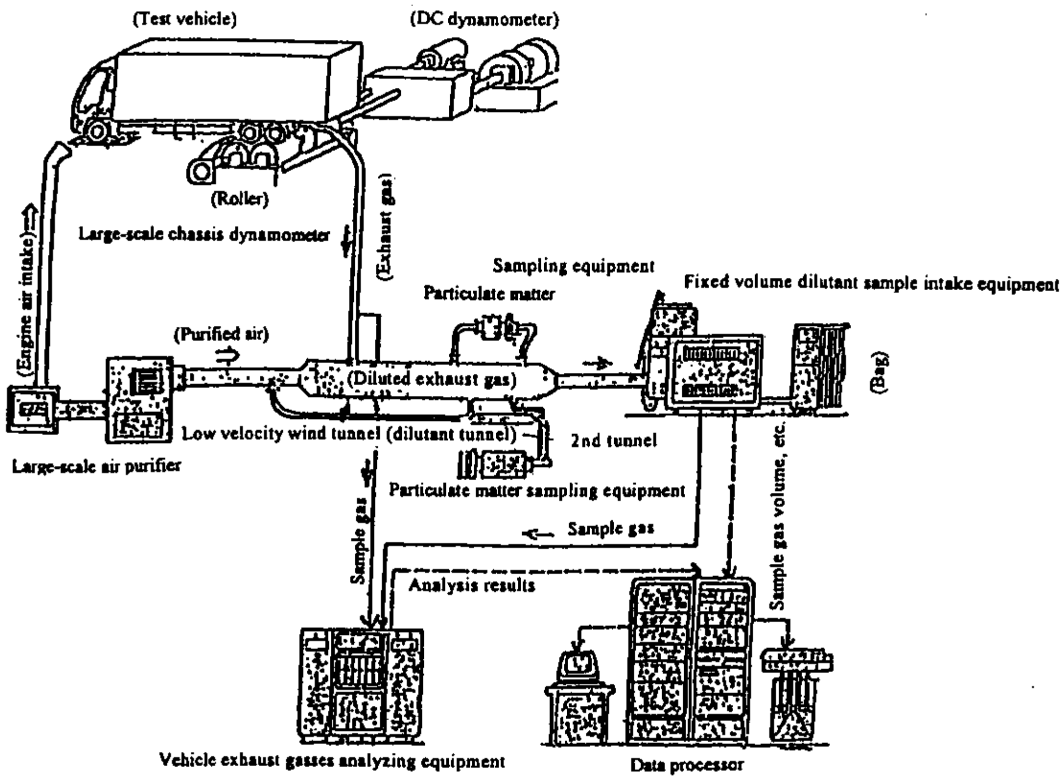

Fig.8.6.2 Dilution tunnel construction

(3) Exhaust gas analyzer

When black smoke and PM are separated from the motor vehicle exhaust gas components, the composition of the gas that is targeted for analysis are NOx, HC, CO, which are the targets of regulation in many countries, and O_2, CO_2, and so forth, which are necessary the fuel burning condition and the fuel consumption of an engine. When the component gasses of motor vehicle exhaust are analyzed in this way, the basic functions to be determined are sensitivity, linearity, the response time, interference effects, and stability (drift), and depending on the measurement objectives for each, the method of analysis has to be selected. Table 8.6.1 shows at a glance the measurement principles for each measurement item as determined by Japanese law [2)3)4)5)].

Depending on the motor vehicle exhaust gas measurement targets (inspection, certification, research, etc.), and the target vehicle (separated by gasoline and diesel), the analyzer measuring items that ought to be used, the measuring principles, the sampling methods, and so forth, are selected, between two and ten analyzers are assembled, and a continuous motor vehicle exhaust gasses measuring device is thereby built. Table 8.6.2 shows the measuring range, accuracy, response time, etc., at a glance for each measurement item. In this device, there is a temperature display for each point on both the heated and maintained temperature paths, and a warning circuit operates whenever there is a cooling unit malfunction, water circulation malfunction, heated line temperature malfunction, or a hydrogen flame ignition or drain level malfunction.

On the other hand, the exhaust gas measuring equipment used in spot checks for automobile repairs, which check that the exhaust standards in the vehicle processes are being adhered to during use, require different specifications for the continuous analyzer. At times, such conditions as lightweight compactness, cheap running costs, and simple operation with short heater time are required for use in on-road inspections. The CO/HC meter, which uses the NDIR method, is a device that fulfills these conditions.

There are also emission standards for the concentrations of black smoke from diesel vehicles, but the laws on measuring black smoke concentrations in Japan use reflective smoke meters. In this method, part of the exhaust gasses from the exhaust pipe are sampled using a suction pump, and those gasses are then passed through a filter paper and a fixed beam of light trained on one black smoke spot generated on the filter paper, and the light reflected back is collected by a photoelectric element and, as the filter paper that determines the smoke concentration uses a tape system, when one measurement is completed, it is transferred automatically.

Table 8.6.1 Measuring principles determined by Japanese law

Type of vehicle		Mode name	NOx	CO, CO_2	HC
Vehicles under GVW 2.5 t	Gasoline vehicles	10·15 Mode	CLD	NDIR	FID
	Diesel vehicles	10·15 Mode	CLD	NDIR	HFID
Vehicles GVW 2.5 t or over	Gasoline vehicles	Gasoline 13 mode	CLD, NDIR	NDIR	FID
	Diesel vehicles	Diesel 13 mode	HCLD, CLD, NDIR	NDIR	HFID

Note: CLD: Chemiluminescence detector, NDIR: Non-dispersive infra-red detector, FID: Hydrogen flame ionization detector, HCLD: Heated Chemiluminescence detector, HFID: Heated hydrogen flame ionization detector.

Table 8.6.2 Specifications for each analyzer

Item	CO (Hi)	CO (Low)	CO_2	HC	NO	THC	NOx	O_2
Measuring principles	NDIR	⇦	⇦	⇦	⇦	FID	CLD	Magnetic
Measuring range	5,000 ppm ⇩ 10%	10 ppm ⇩ 3,000	1% ⇩ 20%	100 ppm ⇩ 1,000	500 ppm ⇩ 6,000	10 ppm ⇩ 5,000	10 ppm ⇩ 5,000	5% ⇩ 25%
Range no.	4	4	4	4	4	9	9	3
Reproducibility	Within ±1% of full scale							
Zero drift	Within ±1% of full scale/8 hours (at temperature range ±5℃)							
Span drift	As above (as above)							
Linearity	Within ±1% of full scale							
90% responses	1.5 to 3.0 sec.					1.5 sec.	1.5 sec.	2. 0sec.

(4) Data processor

This is a computer that calculates the measurement results and controls the analytical and measuring equipment. Depending on the test conditions, it can instruct the analyzer and the CVS equipment according to its preprogramming, and in addition to controlling the measuring system as a whole and operational management of the overall measurement system, it can record measurement data for the emitted gas concentrations and engine operation state, and convert units and calculate concentrations and weight and, as need arises, output its recordings either on paper or on a CRT screen.

8.6.3 Procedure for testing motor vehicle exhaust gas

(1) Preparations for exhaust gas testing

A. Selecting a vehicle: Selected by considering measures against exhaust gas taken, market share, distance traveled, etc.

B. Collecting on-road running resistance data: Implements on-road running resistance data measurements in order to set running resistance loads in the chassis dynamometer. Typical measurement methods include methods for determining a standard test vehicle (measuring air intake pressure corresponding to the speed of the test vehicle), and methods for determining a standard chassis dynamometer (measuring coasting data during on-road driving.)

C. Fixing the test vehicle: Affixing a motor wheel to the center of the roller, and fixing the vertical wheel with a Y-shaped clamp, a wire, etc. By connecting the test vehicle muffler to the CVS gas emissions collecting tube, all the measurement devices (boost meter, fuel consumption meter, air intake flow meter, engine tacho meter) can be attached.

D. Adjusting the measuring equipment: Set the load and chassis dynamometer warmed up, set the analyzer and CVS equipment warmed up, and calibrate the analyzer.

(2) Setting the start conditions

Features of the exhaust gas of vehicles considerably vary at the onset of driving and compared with the driving state after ward. Consequently, exhaust gas tests also yield differences in the measurement results between the hot start method, in which the experiment is begun after the engine has been sufficiently heated, and the cold start method, in which the experiment begins immediately after the engine is started. In the case of the cold start, because the quenching zone widens due to the effects of the cold on the cylinder wall, when compared with the hot start method, the emissions of HC and CO are far greater. In order to bring the catalytic converter and its functions into play requires engine warm up time, and no matter what, immediately after beginning, the reduced effects of hazardous substances is weakened. However, in hot start experiments, it is possible to achieve a stable test condition in a short space of time (speed 60 km/h in 15 mins.), but in the cold start experiments, a long time is required to achieve a stable condition in all parts such as the test vehicle's cooling water, lubricating oil, transmission, and differential gear, if left at room temperature. The cold start experiment soak time is prescribed as being a minimum of 12 hours in America, and six hours in Japan.

(3) Test vehicle operation

A. Unsteady driving

If the test driver is driving under unsteady conditions, the vehicle can be operates as if following the test drive chart that is displayed in real time on the driver's aid CRT screen. However, the allow able error of time and speed in this case is determined as being speed ± 2 km/h, time within ± 1 second, and therefore, retesting is necessary for measurements that are repeated many times outside of the tolerance ranges. Public laws that determine driving modes in small vehicles such as gasoline-fueled passenger cars, use unsteady mode experiments in many countries. The urban driving pattern that is used as basic data for setting the emission factor for calculating total emissions of hazardous substances in the region also use unsteady driving factors.

B. Steady driving

Standard test mode of gross vehicle weight of 2.5 t or higher combine the load and the engine revolutions speed to measure exhaust gas at each point. In this case, because engine control using the chassis dynamometer is technically difficult, generally, tests are conducted using an engine dynamometer. Engine control under steady conditions can either be manual (by dial settings) or commands can be entered from the control board. In either case, the vehicle driving mode is step shape, and exhaust gas measurements are taken in line with this mode. In the case of steady driving, Japan continues to use the hot start, but America uses the cold start. 13 Mode, which is suitable for heavy vehicles of GVW 2.5 t or more is also considered in Japan to be steady driving.

(4) Exhaust gas measurements

Exhaust gas measurements are either diluted gas measurements or direct gas measurements. In unsteady test conditions, generally, the diluted gas method is used. Part of the exhaust gas are diluted using CVS equipment, and used to fill a bag, then through a mixing process in the bag, the test modes are averaged out, and the concentration of harmful substances in the bag, and the emissions of hazardous substances from the quantity of diluted gas absorbed by the CVS equipment are calculated. The sampling quantity in the bag is set at 5 to 10 ℓ/min., but in urban driving pattern, the sampling quantity must be adjusted depending on the length of the measurement time. The chain of measuring operations such as the filling, analyzing, exhaust, and purging of diluted gas emissions is automatically controlled by computer. If exhaust gas measurements under steady conditions are carried out using the direct gas method, fuel consumption and air intake must also be measured at the same time. When PM is collected with an exhaust gas temperature within the main dilution tunnel at 51.7℃ or more, the operators switch to using the second tunnel, but in addition to the condition of exhaust gas temperature, in exhaust gas tests for vehicles in which the concentration of PM within the exhaust gas is high, the requirements may exceed the suction pump's capabilities, and there may be no choice but to use the second tunnel. Filters that have finished collecting PM are measured on a pair of scales after soaking within the range of 1 to 80 hours, and the PM emissions determined.

(5) Black smoke measurements

Black smoke standards for new vehicles in Japan target the black smoke concentrations at revolutions speed of 40%, 60%, 100% at maximum output under full load conditions. Consequently, when conducting tests, either a chassis dynamometer or an engine dynamometer must be used. Black smoke measurements when the vehicle is being used are adapted to suit the loadless rapid acceleration mode.

8.6.4 Indicated problems

Motor vehicle exhaust gas emission measurements require major equipment, and it is not the case that just any organization can carry them out. When the fact that measurement data is as yet insufficient is considered, it is hoped that measurement facilities will be quickly built and completed. In particular, there is an urgent need to establish methods for measuring and understanding hazardous chemical species from motor vehicle.

(8.1) References

1) Japanese Standards Association; JIS Handbook 10, Environmental Technology, JIS (1996)

2) Environmental Agency, Planning and Co-ordination Bureau, Research and Co-ordination Division supervised; Notes on Environmental Measuring and Analytical Methods, Japan Environmental Measuring and Analysis Society (1984)

3) Japan Society of Air Pollution ed.; Air Pollution Handbook (1) Measurement Collection, Corona Ltd. (1975)

4) Himi, Yasuji; Practical Dust and Soot Measurements, Japan Thermal Energy Technology Association (1974)

5) JISB8330

6) JISB8222

(8.2) References

1) Japan Standard Association; JIS Handbook 10, Environmental Technology, JIS (1996)

2) Japan Society of Air Pollution; Air Pollution Handbook (4) Combustion, Corona Ltd. (1979)

(8.3) References

1) Japan Standard Association; JIS Handbook 10 Environmental Technology, JIS (1996)

2) Standard Association.; Air Pollution Handbook (1) Thermal Fuel edition, Corona Ltd. (1975)

(8.4) References

1) Japan Standard Association; JIS Handbook 10, Environmental Technology, JIS (1996)

2) Japan Standard Association; JIS Handbook 12, Petroleum, JIS (1983)

3) Japan Society of Air Pollution; Air Pollution Handbook (4) Combustion edition, Corona Ltd. (1979)

(8.5) Literature cited

1) Himi, Yasuji; Practical Dust and Soot Measurements, Japan Thermal Energy Technology Association (1974)

2) JISB99909

3) JISB9910

4) JISZ8808

(8.6) Literature cited

1) Air Quality Bureau, Environment Agency; Motor vehicle Environmental Pollution Control in Japan, Sep. 1996.

2) Horiba CO,. LTD Zero Emission (Challenge to the Zero Emission), 1993

3) Road Transport Bureau, Ministry of Transport; Technical Standard for 13 Mode Exhaust Emission Measurement for Diesel Powered Motor Vehicles, Nov. 1993.

4) Road Transport Bureau, Ministry of Transport; Technical Standard for 10-15 Mode Exhaust Emission Measurement for Gasoline Fueled Motor Vehicles, July 1991.

5) Road Transport Bureau, Ministry of Transport; Technical Standard for 10-15 Mode Exhaust Emission

Measurement for Diesel Powered Motor Vehicles, July 1991.

6) Road Transport Bureau, Ministry of Transport; Technical Standard for 13Mode Exhaust Emission Measurement for Gasoline Fueled Motor Vehicles, Sept. 1992.