

Research into New Emission Control Techniques for Motorcycles to Achieve EURO-3 Emission Regulation

Shunji AKAMATSU*
Hiroaki MIYATA*

Tomoya KONO*
Ryutaro YAMAZAKI*

Mamoru URAKI*

ABSTRACT

The EURO-3 emission regulation will be enforced in Europe in the year 2006. To meet the regulation, emission reduction technologies were developed using a motorcycle with a liquid-cooled, four-cylinder, 1 100 cm³ engine. In order to reduce HC during the cold-start cycle the catalyst was activated early by means of combining an Idle Air Control Valve System (IACV) with ignition retard and atomization of fuel spray. In order to reduce NO_x during the extra-urban driving cycle, the number of cells and capacity of the three-way catalyst were optimized. However, the increase of catalyst capacity caused increase of exhaust resistance, and reduced engine power. In order to solve this problem, location of the catalyst was optimized. By these measures, the EURO-3 regulation value was sufficiently attained without detriment to the engine power and drivability.

1. Introduction

In recent years, as concern for environmental issues grows, demands for reduction in emissions from motorcycles have increased. New emissions regulations are being implemented in various countries throughout the world. For example, in Europe, which is a main market for large motorcycles, the Euro-3 emission regulation is scheduled for implementation in 2006. In addition, cold-start mode and high-speed mode are added in the measurement modes of the regulation. Hence it is difficult to meet the regulation for motorcycles.

For exhaust emission reduction on large motorcycles combinations of three-way catalysts, O₂ feedback and secondary air induction systems are commonly used. However, demand for favorable drivability is also a

requirement of the engines for high-speed high-output motorcycles, therefore having a strong demand of both high-output and low emissions. This paper describes research of the emissions reduction system that satisfies the Euro-3 regulation based on the CBR1100XX.

2. Euro-3 Regulations and Issues

Regulations of motorcycle emissions are being strengthened especially in Europe and Asia. It is in these areas that their percentage of contribution to atmospheric pollution cannot be ignored. Included in the Euro-3 regulation are several items where the regulation has been strengthened with new policies for reduction of motorcycle emissions. Figure 1 shows the measurement mode for the Euro-3 regulation while Table 1 compares the regulation

* Asaka R&D Center

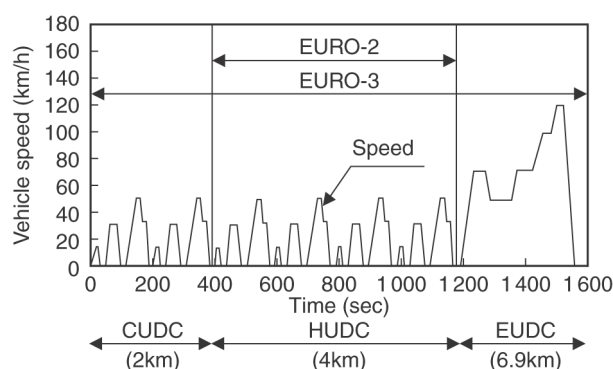


Fig. 1 Federal test procedure

Table 1 EURO-3 emission standards

(Displacement $\geq 150\text{cm}^3$)			
Standards	CO (g/km)	THC (g/km)	NOx (g/km)
EURO-2	5.5	1.0	0.3
EURO-3	2.0	0.3	0.15

values with those of Euro-2. In comparison with the Euro-2 regulation, the changes and requested performance for the Euro-3 regulation is given below.

- (1) Due to cold start and sampling requirements, in addition to improvements in the purification rate of the catalyst, early activation for CO and HC cleanup are required.
- (2) Due to the addition of the high-speed mode (EUDC), which causes an increase in NOx emissions, an improvement in the catalyst purification rate for NOx is required.
- (3) Due to the addition of 30 000 km durability requirements, long-term stability of the entire emissions reduction system is required.

3. Technical Method for Reducing Emissions

In conjunction with the research of technology needed to meet Euro-3, the exhaust emissions performance of a mass production motorcycle that meets Euro-2 was retested. Figure 2 shows the exhaust measurement results when Euro-3 were divided into 3 intervals⁽¹⁾. The first-interval is the first 2 cycles after startup and called Cold-Urban-Driving-Cycle (CUDC). The second-interval is 4 cycles and

called the Hot-Urban-Driving-Cycle (HUDC), as same as the current ECE40-01. The third-interval is the additional high-speed mode called the Extra-Urban-Driving-Cycle (EUDC). The amount of exhaust shown in the first-interval (CUDC) shows a condition where the catalyst is not sufficiently active and therefore it is not providing an adequate purification rate. In order to rectify this issue, technology for reducing engine out emissions and to provide early activation of the catalyst need to be worked on. The second-interval (HUDC) shows a condition where the catalyst is sufficiently active but as the regulation is more stringent, further reduction in emissions is required. The third-interval (EUDC) is a new, high-speed mode and NOx emissions have greatly increased during the acceleration to 120 km/h.

As a result, in order to meet Euro-3 regulation, development focused on the issues of reducing HC emissions during cold start and NOx emissions during high-speed mode.

4. Test Vehicle

A mass production liquid-cooled in-line 4-cylinder motorcycle with a displacement of 1 100 cm^3 was used for testing. The main specifications are shown in Table 2. An electronically controlled fuel injection system is used for fuel supply and O₂ sensors are used for feedback control. The system is shown in Fig. 3. A pintle type injector is used for fuel injection.

A metal substrate three-way catalyst and secondary air induction system are used for the exhaust cleanup system. Due to not having enough space, the catalyst cannot be mounted beneath the exhaust manifold. Therefore, it is mounted on the rear of the exhaust pipe as shown in Fig. 4.

Table 2 Specifications of test engine

Items	Specifications
Cooling system	Liquid-cooled
Cylinder configuration	In-line 4-cylinder
Bore $\times$ Stroke (mm)	79 $\times$ 58
Displacement (cm^3)	1 137
Compression ratio	11.0 : 1
Valve train	DOHC

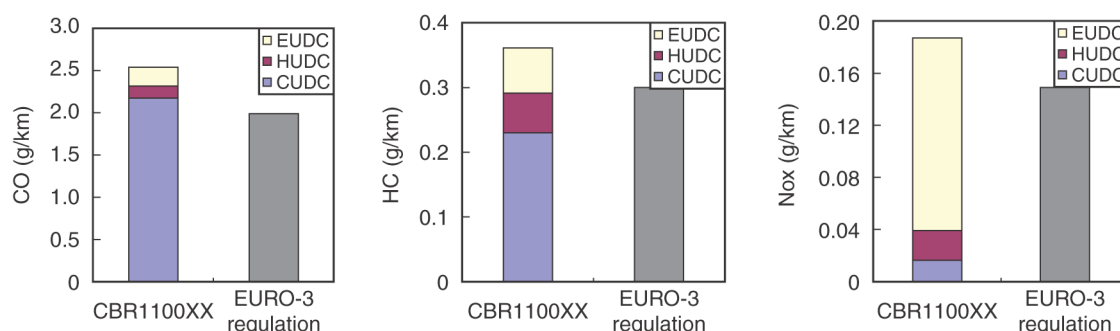


Fig. 2 CBR1100XX emissions by EURO-3 mode

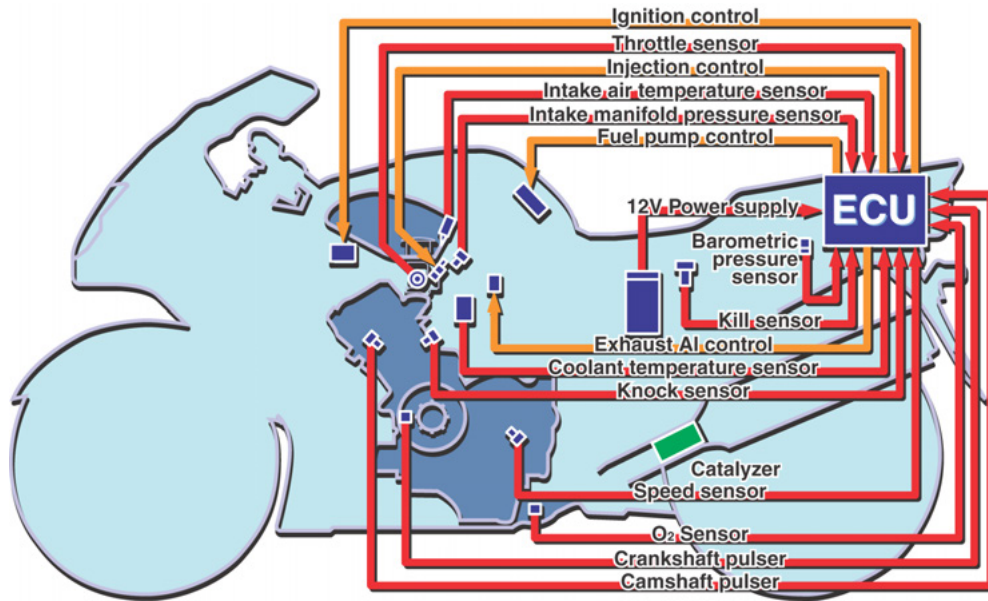


Fig. 3 Diagram of PGM-FI system

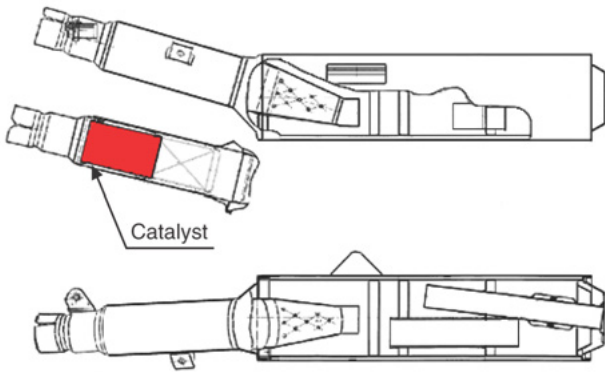


Fig. 4 Catalyst location

5. Emission Reduction Technology

Various emissions reduction technologies have been developed for automobiles; however, the technologies that can be adapted to large motorcycles with high-speed, high-output engines are extremely limited. For example, in order to activate the catalyst early, catalysts are placed beneath the exhaust manifold in many automobile applications⁽²⁾; however, due to difficulties of layout and the effect on their output characteristics, it is difficult to apply this to motorcycles. Therefore, this research focused on technology that can be applied to motorcycles.

5.1. Reduction of HC Emissions at Cold Start

There are several approaches to reduce the HC emissions at cold start. This report will describe the method of reducing HC emissions using improved atomization of fuel spray by the injector, and the method of obtaining early activation of catalyst by increasing intake air volume using an Idle Air Control Valve (IACV) and by increasing exhaust temperature by retarding ignition timing.

5.1.1. Atomizing injector

Improved atomization of the injected fuel spray and its effect for reduction of engine out HC emissions were

investigated. The specifications of the injector used for the test are shown in Table 3.

The 12-hole tapered nozzle injector used for this test provided much better atomization as compared to the pintle type. Through utilizing this atomizing injector, a reduction in HC emissions prior to catalyst early activation as well as during deceleration has been realized. A 20% reduction in HC emissions compared to conventional levels has been obtained. The results are shown in Fig. 5.

Table 3 Specifications of test injectors

	Developed injector	Base injector
Nozzle	Taper nozzle	Pintle nozzle
Number of nozzle	12	1
Static injection quantity	252mm ³ /st	258mm ³ /st
SMD	80μm	120μm

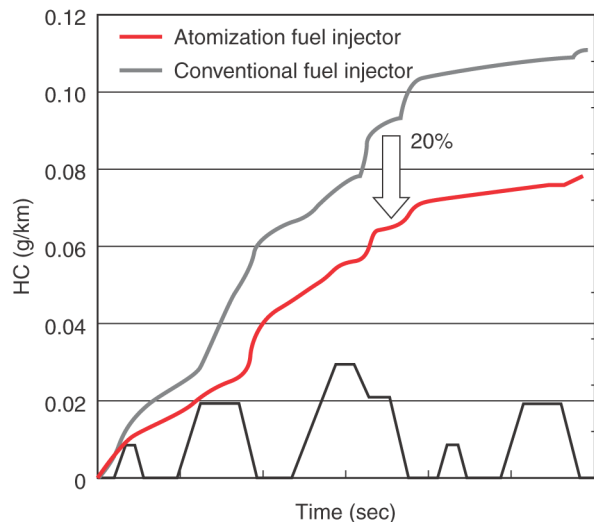


Fig. 5 HC reduction by atomized injector

5.1.2. Early activation of the catalyst

In order to reduce HC emissions during CUDC mode, a prompt increase in the temperature of the catalyst leading to early activation is effective. However, it is difficult to both simply move the catalyst closer to the exhaust valve and maintain output. For this test, the ignition timing was retarded in order to increase the temperature of the exhaust. However, when ignition timing is retarded, intake air volume becomes insufficient and idle engine speed decreases. Therefore, the IACV controlled by the ECU to provide optimum airflow was used to correct for the amount of air.

Figure 6 shows the results of ignition timing, catalyst temperature, and reduction in HC emissions in this test. By retarding the ignition timing, the time the catalyst takes to reach activation temperature (300 °C) was reduced by 70 seconds. HC emissions were reduced by 30% at 300 seconds.

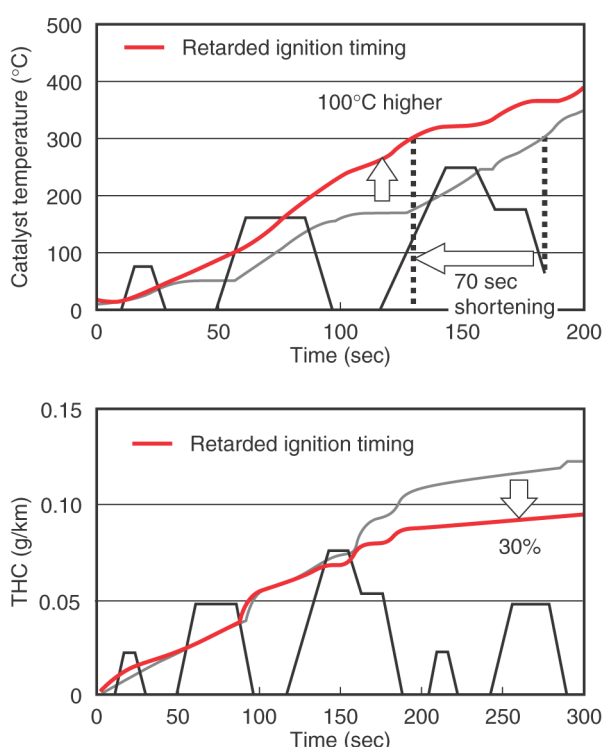


Fig. 6 Effect of quick warm-up system

5.2. NOx Reduction for High-speed Mode

The EUDC mode drive cycle is within the O₂ feedback area for this test motorcycle and the air-fuel ratio is set to a stoichiometric air-fuel ratio that enables the three-way catalyst to provide efficient exhaust cleanup performance. For this test, optimization of the number of cells and the volume of the catalyst and optimal tuning of the air-fuel ratio were performed for NOx reduction for the EUDC mode.

5.2.1. Selection of catalyst

In general, large volume catalysts have the ability to reduce emissions. However, due to limited space on motorcycles, the size of catalysts and places they can be mounted are limited. The number of cells and amount of precious metals were used as parameters to confirm reduction of the three components CO, HC and NOx in this test and the specification for the catalyst was defined. Figure 7 shows the

Table 4 Specifications of test catalyst

Items	Specifications
Cell density	300 cpsi
Catalyst layer thickness	50μm
Diameter of carrier	80 mm
Length of carrier	90 mm
Precious metal	Platinum, Rhodium

test results for increasing the number of cells in the catalyst while holding its volume constant. When using more cells than were used in the base catalyst, each of the three components was found to be reduced. However, if more than 600 cpsi were used, conditions actually got worse. The back pressure in the muffler was considered along with these results and it was decided to use 300 cpsi. The measurement results for the amount of emissions when using the same catalyst volume while increasing the amount of precious metals are shown in Fig. 8. Increasing the amount of precious metal reduces CO and HC emissions. However, it causes NOx emissions to increase. Increase in the amount of precious metals increases cost. However, due to the purification rate requirements, the amount used has been doubled compared with the base catalyst. The final specification for the catalyst is shown in Table 4.

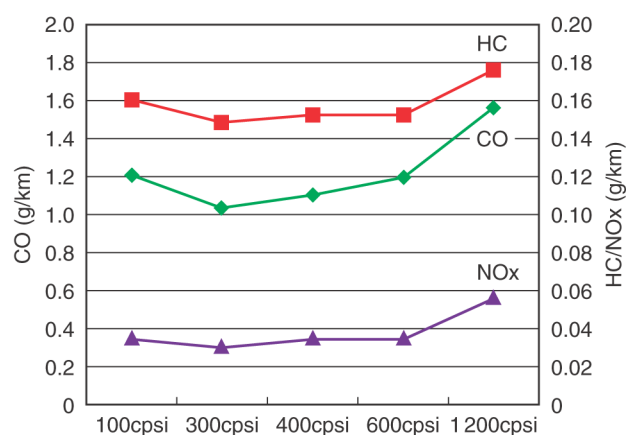


Fig. 7 Emission results from different number of cells

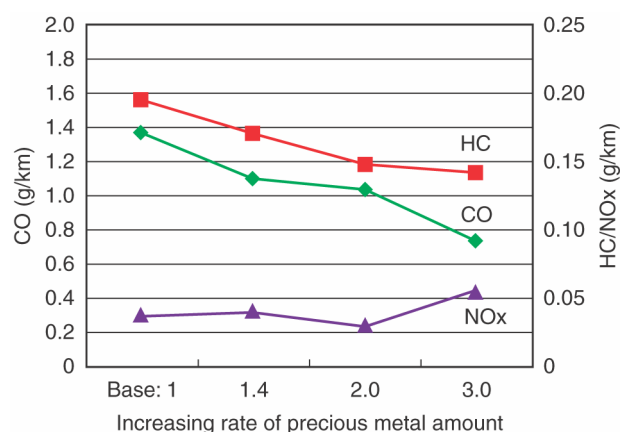


Fig. 8 Emission results from different amount of precious metal

5.2.2 precise control of the air-fuel ratio

It is said that the purification rate of all three components using a three-way catalyst is best when using a stoichiometric air-fuel ratio. For this test, in place of the O_2 sensor, a UEGO sensor was used and the air fuel ratio providing minimum emissions density at all loads was determined during the emissions drive cycle tests. The purification rate based on air-fuel ratio was compared for the current emissions drive cycle with a maximum speed of 50 km/h and for the new EUDC mode with a maximum speed of 120 km/h.

The results are shown in Fig. 9. The air-fuel ratio that provides the minimum emissions density has moved into the rich area as the drive cycle changed to high load. It follows that through adjusting the air-fuel ratio, it was possible to reduce emissions.

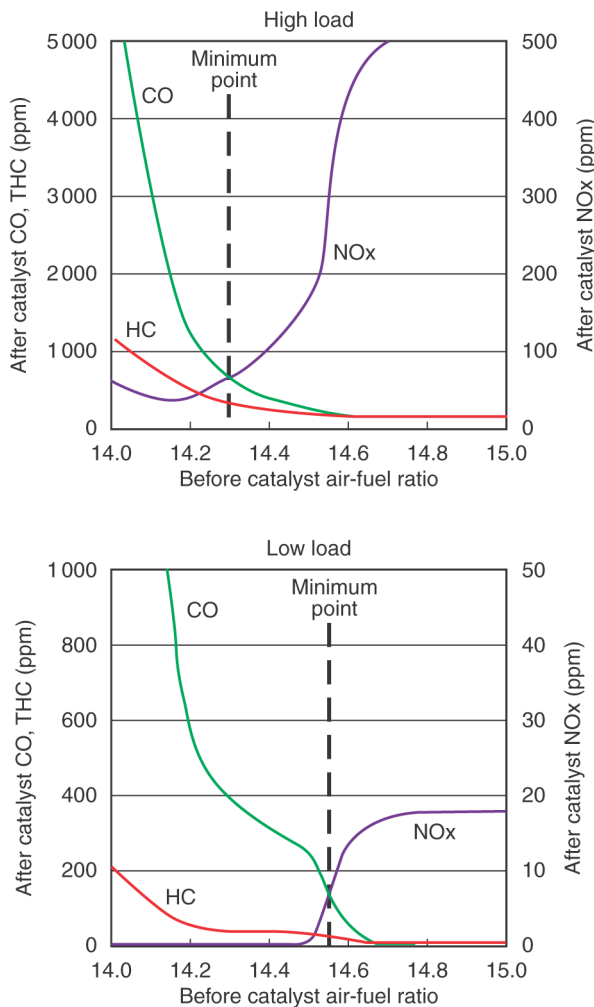


Fig. 9 Reforming gas ratio by different air-fuel ratio

5.3. Effect on Power

Concerning the reduction in output associated with the increase in catalyst volume, Fig. 10 shows the results of confirmation based on peak power, back pressure and number of cells. When the number of cells in the catalyst is increased, the back pressure also increases leading to a reduction in power. Taking into the consideration the requirements of maintaining high power for a super sports type motorcycle, the specifications as shown in Table 4 were chosen.

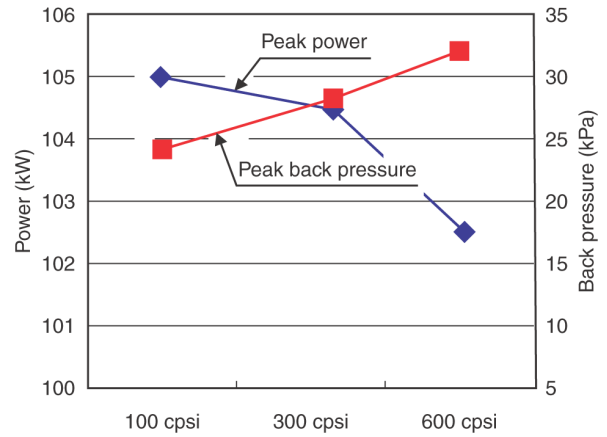


Fig. 10 Back pressure of catalyst

6. Test Results

6.1. Emissions

The measurement results for Euro-3 emissions taken on the test motorcycle are shown separately for CUDC, HUDC, and EUDC in Fig. 11.

- (1) In the CUDC mode, HC emissions were reduced by 73% compared to the base.
- (2) In the EUDC mode, NOx emissions during high speed driving were reduced by 97% compared to the base.

These results enabled the system to pass the Euro-3 emissions regulation.

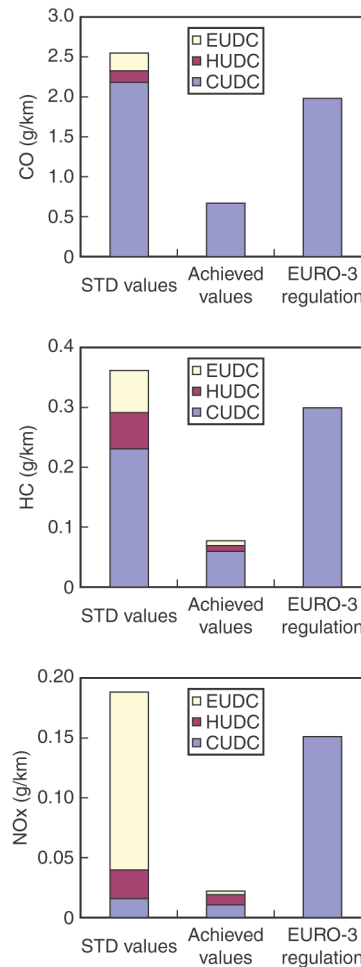


Fig. 11 Exhaust mass emission

6.2. Power Output

Though the number of cells in the catalyst was increased, the power output performance remained the same as the base model. Figure 12 shows the power output performance curve.

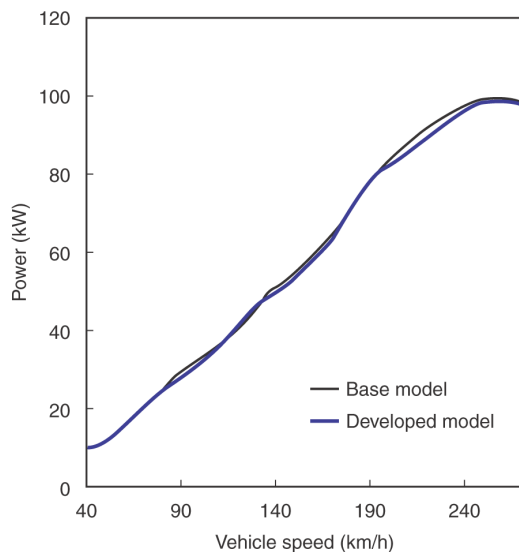


Fig. 12 Power output

6.3. Durability

The 30 000 km durability test, established in the regulation, was performed. Figure 13 shows the change in emission values and it can be seen that even after the durability test, the regulations are met without difficulty.

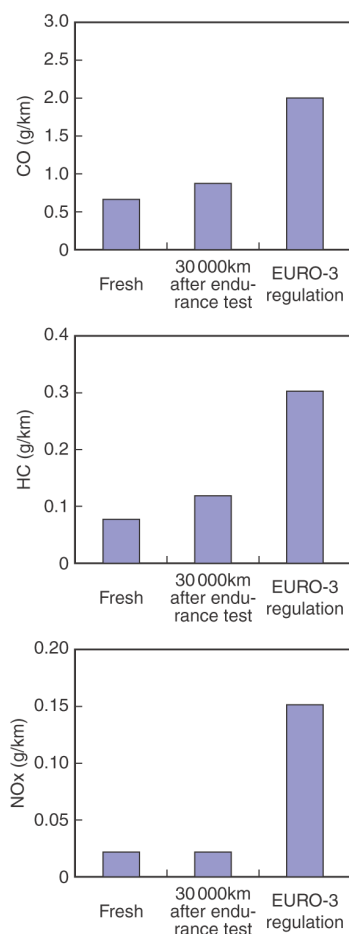


Fig. 13 Durability performance of emission reduction system

7. Conclusion

Increasing the performance of the after treatment system for the exhaust gas has enabled the same engine specifications to meet the Euro-3 regulations, while maintaining the same power output and drivability.

- (1) Increase in exhaust temperature by retarding ignition timing was effective for reducing HC emissions at cold start.
- (2) The purification capability of the catalyst was used to its fullest by controlling the target air-fuel ratio during feedback control to meet driving requirements for reduction of NOx during high-speed mode.
- (3) Increase of the number of catalyst cells has enabled the purification rate of the catalyst to increase, while maintaining power output.

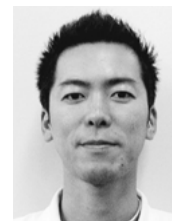
References

- (1) Kitagawa, H., Mibe, T., Okamatsu, K., Yasui, Y.: Super Ultra Low Emission System for ACCORD SULEV, HONDA R&D Technical Review, Vol. 12, No. 2, p. 37-44
- (2) Matsuki, M., Ohura, H., Watanabe, K., Kinoshita, Y.: Development of a 1.5L Lean-burn Engine for the 2001 Civic, HONDA R&D Technical Review, Vol. 12, No. 2, p. 29-36

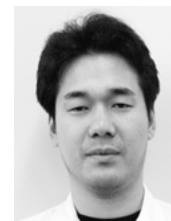
■ Authors ■



Shunji AKAMATSU



Tomoya KONO



Mamoru URAKI



Hiroaki MIYATA



Ryutaro YAMAZAKI