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RESEARCH ON ULTRA LOW EMISSION TECHNOLOGY FOR LARGE DISPLACEMENT MOTORCYCLES

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ABSTRACT–With the aim of achieving half the regulated value of EURO-3 Emission Regulations, an ultra low emission motorcycle has been developed based on a motorcycle with an 1800 cm^3, horizontal opposed 6-cylinder engine. For the fuel supply system, an electronically controlled fuel injection system was applied. For the emission purification system, three-way catalysts, a feedback control system with a LAF (Linear Air-Fuel ratio) sensor, and a secondary air induction system were applied. To reduce CO and HC emissions during cold starting, an early catalyst activation method combining RACV (Rotary Air Control Valve) and retarded ignition timing was applied. After the catalyst activation, air-fuel ratio was controlled to maximize the purification ratio of the catalyst according to vehicle speed. For the air-fuel ratio control system, the LAF sensor was used. Furthermore, fine adjustment by the LAF feedback control reduced torque fluctuation due to the air-fuel ratio change. As a result, smooth ride feeling was maintained. Owing to these technologies, half the regulated value of EURO-3 has been achieved without any negative impact to the large-scaled motorcycles' drivability. This paper presents the developed ultra low emission technologies including the control method using an LAF sensor.

KEY WORDS : Ultra low emission, Motorcycles, Linear air-fuel ratio feedback

1. INTRODUCTION

Recently, amid growing concern for the global environment, the demand for lower exhaust gas emissions is rising and new emission regulations are being introduced in many countries around the world.

For example in Europe, a major market for large-scaled motorcycles, EURO-3 Emission Regulations will be enforced. This regulation is tightened by adding new measurement modes for cold start and high-speed.

In the case of large-scaled motorcycles, a combination of three-way catalysts, O_2 feedback control and secondary air induction are commonly applied. But for motorcycles that feature lightweight and prioritize drivability, simultaneous pursuit of drivability and reduced emissions is generally difficult.

In this research, emission reduction technology aiming to achieve half the regulated value of EURO-3 was developed based on a maximum displacement level motorcycle, the GLX1800. As a result, the targeted values have been achieved without any negative impact on drivability. This paper presents the developed emissions reduction technology.

2. TARGET AND ISSUES

Emission regulations for motorcycles are tightened mainly in Europe and Asia where its contribution to air pollution is said to be significant. Among them, EURO-3 Emission Regulations, which will be enforced in early 2006, require new countermeasures against emissions. Table 1 shows the emission regulation values and the targets of this development. Figure 1 shows the measurement mode of EURO-3. The first 2 km from engine start is called CUDC. The next 4 km is called HUDC, the same as the conventional EURO-2. The last 6.9 km is the newly added high-speed mode and is called EUDC.

The accumulated value of each exhaust gas component

Table 1. Emission regulations.

(Displacement ≥150 cm^3)

Year	Regulations	CO (g/km)	HC (g/km)	NOx (g/km)
1999	EURO-1	13.0	3.0	0.30
2003	EURO-2	5.5	1.0	0.30
2006	EURO-3	2.0	0.3	0.15
	Targets	1.0	0.15	0.075

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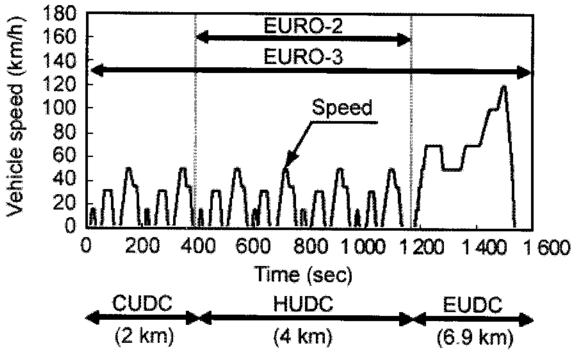

Figure 1. Emission test procedure.

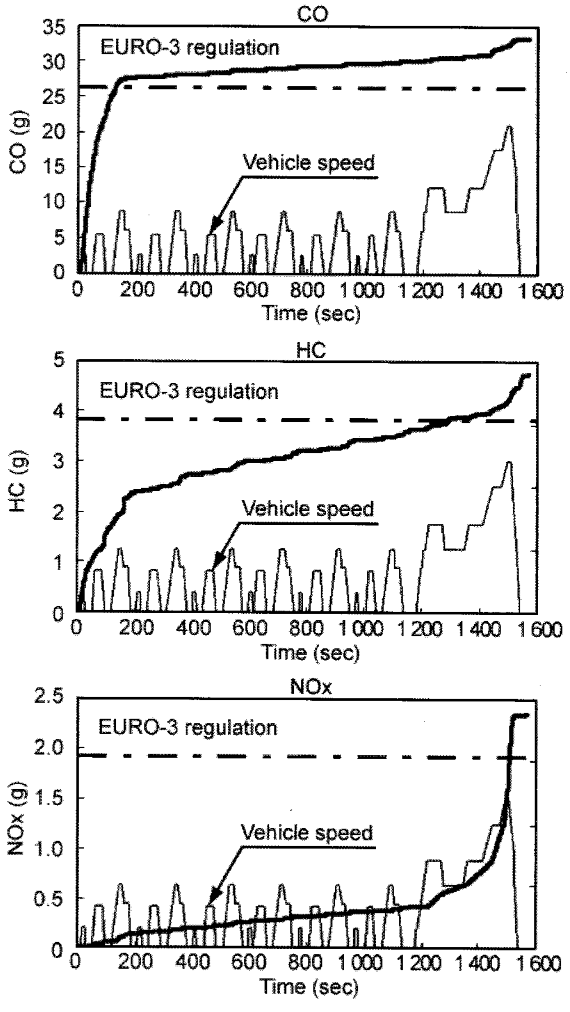

Figure 2. Accumulated emissions by EURO-3 mode.

Table 2. Specifications of test engine.

Items	Specifications
Cooling system	Liquid-cooled
Cylinder configuration	horizontally opposed 6-cylinder
Bore×Stroke	74 mm×71 mm
Displacement	1,832 cm^3
Compression ratio	9.8:1
Valve train	SOHC

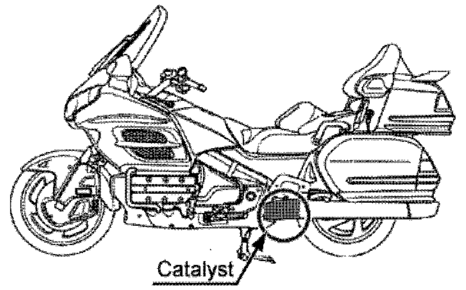

Figure 3. Catalyst location.

with respect to elapsed time is shown in Figure 2. Examination of accumulated emissions of each component revealed the following two issues.

(1) CO and HC were increased during the cold start mode and the sampling mode (CUDC). Therefore, the catalyst is required to activate earlier as well as improve purification to further reduce CO and HC.
(2) NOx was increased during the high-speed mode (EUDC). Therefore, the catalyst is required to further purify and lower NOx emission.

3. TEST VEHICLE

A commercially produced motorcycle with an 1800 cm^3, horizontal opposed 6-cylinder engine was used for testing. The specifications are shown in the Table 2.

For fuel supply, an electronically controlled fuel injection system was applied. An O_2 sensor was used for feedback control.

Multiple-hole type injectors were used for fuel injection. The emission purification system was composed of metal substrate three-way catalysts and a secondary air induction system. The catalysts were located at the lower rear area of the vehicle due to space restriction. The layout is shown in Figure 3.

4. EMISSION REDUCING TECHNOLOGY

4.1. HC Reducing during Cold Start

To reduce HC emission during cold starting, an early catalyst activation method was applied. The early catalyst activation was realized by two countermeasures (Akamatsu, 2004). One is to increase intake air volume with RACV, and the other is to increase exhaust gas temperature by ignition retard. To reduce HC emission during CUDC mode, it was effective to activate the catalyst at an early stage by increasing the catalyst temperature. But a design to put the catalyst close to the exhaust valve had difficulties in maintaining power and establishing an acceptable layout of the completed vehicle. In this research, the exhaust gas temperature was increased by ignition retard. But simple retarding the ignition timing would cause lowered idling revolution or poor drivability due to lowered output power. Therefore, the ignition timing was adjusted to satisfy both of the drivability and the early activation of the catalyst. Furthermore, the intake air volume was optimally compensated using the RACV controlled by ECU. Figure 4 shows the test results including ignition timing, catalyst temperature and HC emission during CUDC mode. Time-to-catalyst activation starting temperature (300 deg C) was shortened by 50 seconds. As a result, HC emission after 300 seconds was reduced by 20%.

4.2. NOx Reducing during High-speed Mode

Generally, as catalysts have already been activated during high-speed mode, air-fuel ratio is adjusted to stoichiometric, at which the three-way catalyst shows good purification efficiency (Kitagawa, 2000; Matsuki, 2000). Therefore, catalyst performance improvement is essential for emission reduction. The common methods include increasing catalyst size or precious metal optimization. But by tuning the air-fuel ratio to optimum value, this research attempted to reduce NOx emission without changing the catalyst size.

4.2.1. Optimum tuning of air-fuel ratio control

Though three-way catalysts were said to show the maximum purification ratio for the three components when setting at stoichiometric air-fuel ratio, this research verified the optimum air-fuel ratio to minimize exhaust gas concentration according to the load condition of each emission mode. The relationship between the exhaust gas concentration at the catalyst delivery side and the changed air-fuel ratio at the catalyst entry side are shown in Figure 5, representing a light load at 50 km/h and a heavy load at 120 km/h. The air-fuel ratio to minimize exhaust gas concentration at the catalyst delivery side

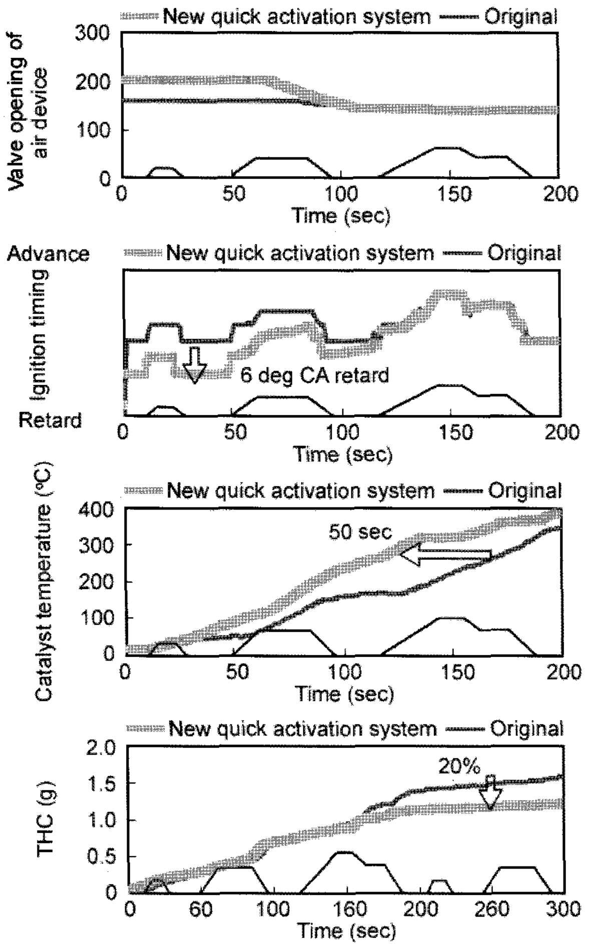

Figure 4. Effect of quick warm-up system.

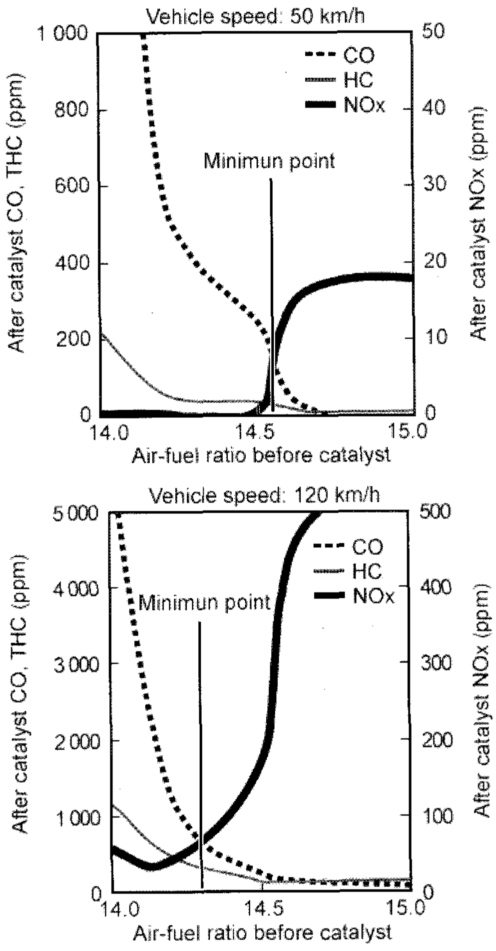

Figure 5. Reforming gas ratio by different air-fuel ratio.

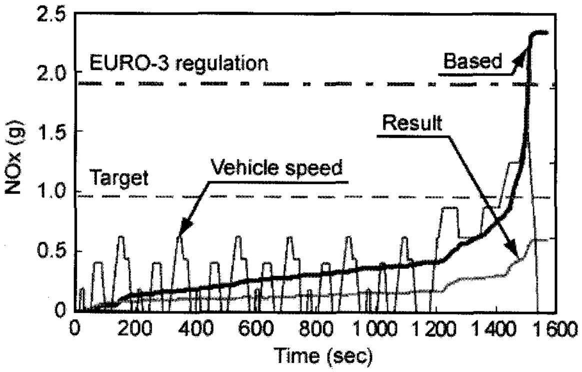

Figure 6. Test results of NOx emission.

was shifted to the rich side in the heavy load area. Therefore, optimum control of air-fuel ratio would contribute to reducing emissions. The test results of NOx emission during the EUDC mode in this research are shown in Figure 6. The NOx emission in the heavy load area was reduced by 75% compared to the previous control method.

4.2.2. LAF feedback control

A LAF sensor was used for the air-fuel ratio control. The LAF sensor is capable of linearly measuring the air-fuel ratio in the exhaust gas. The structure is shown in Figure 7. The basic structure is the same as O_2 sensor. The exhaust gas is reached to gas detection chamber from element rear side via deposit trap layer and diffusion-limited layer. The function principle of the sensor is shown in Figure 8. To make equal to residual oxygen concentration of an oxygen criteria electrode and the gas detection chamber, an electric current is applied to the pump cell. The current value indicates the residual oxygen in the exhaust *gas.*

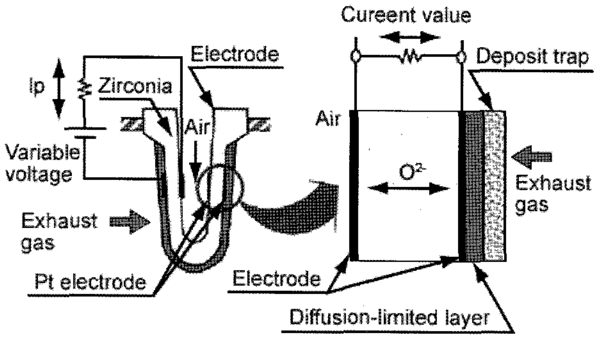

Figure 7. Structure of LAF sensor.

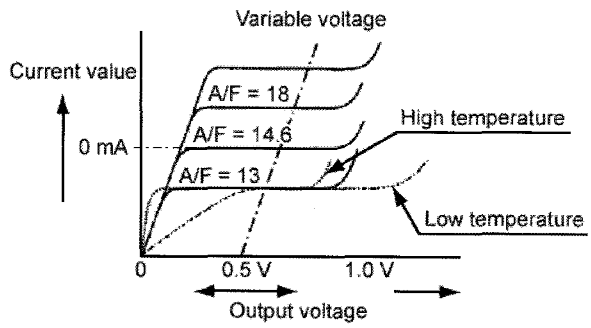

Figure 8. Function principle of sensor.

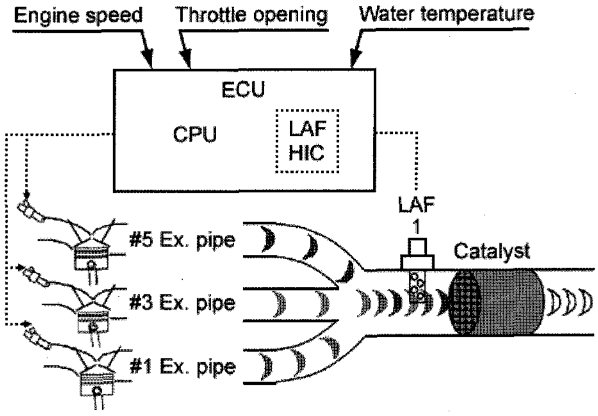

Figure 9. Outline of control procedure.

The outline of the control procedure is shown in Figure 9. The control flow is as follows.

(1) Determine the supplied air-fuel ratio from the electric current value obtained by the LAF sensor.
(2) Determine the starting timing for control from engine speed, throttle opening, water temperature, etc..
(3) Determine the targeted air-fuel ratio according to engine load, derived from engine speed and throttle opening.
(4) Control the injector's open duration to correspond with the targeted air-fuel ratio.

As shown in the layout of Figure 9, catalysts are provided for the both groups of three cylinders composing horizontal opposed 6-cylinder engine. LAF sensors are attached at the connecting points to measure the air-fuel ratio of exhaust gas. Using the LAF sensor, the air-fuel ratio was controlled.

5. CATALYST SPECIFICATIONS

The specifications of the catalyst used in this research are shown in Table 3. To maintain an effective size, the catalyst was designed to be an oval type and to be attached at lower position of the vehicle body. The number of cells was determined to be 300 cpsi in consideration of maintaining output power and purification performance. The amount of precious metal was increased to twice the base specification in consideration of cost and performance. The emissions result after increasing the precious metal amount is shown in Figure 10.

Table 3. Specifications of test catalysts.

Items	Specifications
Material	20 Cr 5 Al
Cell density	300 cpsi
Wall thickness	50 μm
Oval substrate, WxHxRadius	144 mmx68 mmx34 mm
Length of substrate	70 mm
Precious metal	Platinum, Rhodium

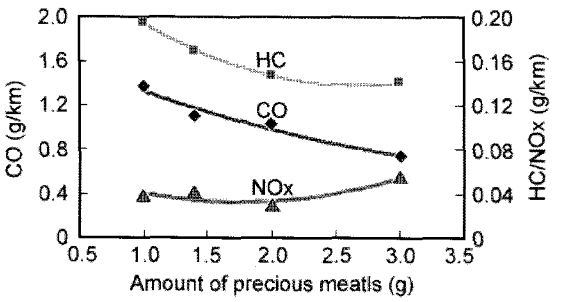

Figure 10. Emission results from different amount of precious metal.

6. DRIVABILITY MAINTAINING

As motorcycles are lighter than automobiles, combustion fluctuation brings drivers more discomfort due to vehicle vibration. One of combustion fluctuation factors is fluctuation of the air-fuel ratio. To stabilize the air-fuel ratio, the air-fuel ratio control with the LAF sensor was utilized. Since the previous control with O_2 sensor could only judge whether the air-fuel ratio was lean or rich, the air-fuel ratio fluctuated widely. The LAF sensor improv-

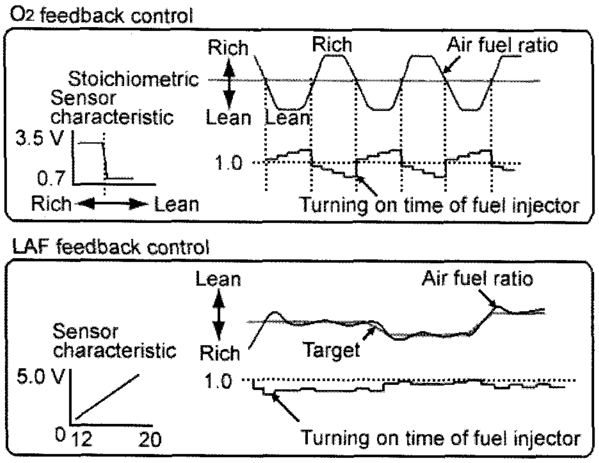

Figure 11. Comparison of air fuel ratio control.

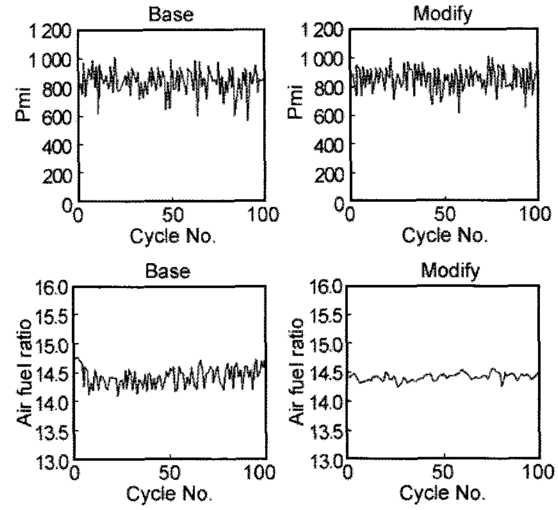

Figure 12. Fluctuation width of air-fuel ratio and change of combustion pressure.

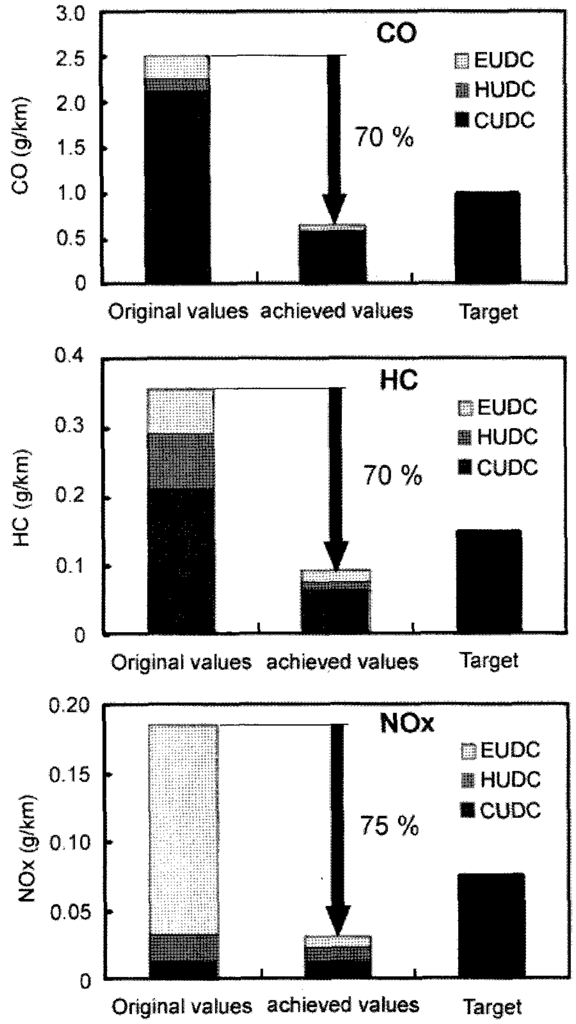

Figure 13. Emission results by EURO-3 mode.

ed convergence of the air-fuel ratio to the targeted value and decreased the fluctuation. The comparison of the air fuel ratio control is shown in Figure 11. The fluctuation width of air-fuel ratio and change of combustion pressure are shown in Figure 12. Owing to that the decreased air-fuel ratio fluctuation moderated the combustion pressure fluctuation, drivability performance was maintained.

7. TEST RESULTS

The measuring results based on EURO-3 Emission Regulations are shown in Figure 13.

(1) For CO and HC, the emission was decreased by 70% compared to the base model in the CUDC mode, one of the issues.

(2) For NOx, the emission was decreased by 75% compared to the base model in the EUDC mode, the other of the issues.

As a result, half the regulated value of EURO-3 has been achieved.

8. CONCLUSIONS

(1) To reduce HC during cold start, early catalyst activation by increased exhaust gas temperature has been effective. The early activation was realized by increased amount of intake air and retarded ignition timing.

(2) To reduce NOx, maximizing of catalyst purification rate has been effective. The purification rate was constantly optimized according to load level by tuning air-fuel ratio.

(3) To maintain drivability, precise control of air-fuel ratio has been effective. The air-fuel ratio was adjusted by LAF feedback control technique.

Applying these methods, half the regulated value of EURO-3 Emission Regulations has been achieved for the existing engine specifications without negative impact on output power or drivability.

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