

Development of a 1.7 L CNG Engine for the 2001 Civic GX

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ABSTRACT

Honda has upgraded the Civic GX, which has been in production since 1998, with a newly developed CNG engine for the 2001 model. Based on the gasoline engine in the 2001 model Civic, this CNG engine was given larger displacement and an improved air intake system for better torque at low to medium speeds. A layout that integrates the air intake system and the CNG regulator was adopted to make the power plant more compact. The new Civic GX is the world's first vehicle to be qualified as an AT P-ZEV by the CARB. In order to satisfy the AT P-ZEV requirements, the vehicle was given the capability for quick light-off of the catalyst from a cold start, high-precision air-fuel ratio control, and reduced exhaust emissions. It has certified for Japan ULEV status. This model also achieved a 7% improvement in city driving fuel economy over the 1998 model by changing the transmission that is paired with the CNG engine from a 4AT to a CVT.

1. Introduction

As deterioration of air quality due to exhaust emission from automobiles is recognized as a global issue, development work is being carried out on power plants that use alternative fuels other than gasoline in order to reduce the pollutants in exhaust emissions. Among alternative fuels, compressed natural gas (CNG) with CH₄ (methane) as its main component is a fuel that has little impact on air quality, and is viewed as having excellent prospects due to the possibility of easy supply with vast amounts of reserves of natural gas using city gas networks as infrastructure.

Honda has mass produced the Civic GX since 1998. The Civic GX uses a dedicated CNG engine, and features an output performance equivalent to that of a gasoline vehicle while at the same time achieving the lowest exhaust emission performance in the world. With the full model change to the Civic series in 2001, further efforts were made to reduce exhaust emissions in order to comply with newly enacted exhaust emission regulations. In addition, a power plant for

CNG was developed with the aim of longer driving distances. This paper introduces the details of these developments.

2. Development Aims

The following target performances were set in order to realize the highest level of environmental countermeasures in the world while at the same time achieving an ease of use equivalent to gasoline vehicles as a mass production passenger vehicle fueled by CNG.

(1) The lowest exhaust emissions performance in the world

US: Complying with the California State AT P-ZEV (Advanced Technology Partial-Zero Emission Vehicle) category, which is considered to be the most severe in the world.

Japan: Complying with the "Ultra-Low Emission Vehicle" certification standards which are a 75% reduction from the 2000 standard level, and complying with the exhaust emission technology guidelines for compressed natural gas vehicles.

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(2) Longer driving distance

Improving fuel economy by 5% or more focusing on city driving in order to lengthen the driving distance without changing the tank capacity.

3. Outline and Specifications

3.1. Engine

The engine is based on the gasoline engine of the 2001 model Civic with CNG support added. The main engine unit features valve recession countermeasures⁽¹⁾ (changed intake and exhaust valve and valve seat materials) like the 1998 model and an increased compression ratio.

The intake system up to the air cleaner and resonator is mounted to the power plant, and the fuel system described hereafter is also integrated to reduce the power plant size and facilitate engine mounting during factory production.

The displacement was increased and the intake system was also changed to increase the torque at medium to low speeds. Combined with a continuously variable transmission (CVT), driveability in urban areas was improved, which mainly use the medium to low engine speed range.

The main specifications of the CNG engine are shown in Table 1, the output characteristics in Fig. 1, and the engine appearance in Fig. 2.

3.2. Fuel Supply System

Fig. 3 shows the CNG cylinder and fuel supply system layout in the vehicle body.

The CNG cylinder is based on the 100 L capacity (20 Nm³ when filled at 20 Mpa) all-composite tank developed for the 1998 model. The cylinder was mounted between the rear seat and the trunk. A new rear suspension layout allowed the cylinder to be mounted in a forward and lower position. The front-to-back space in the trunk, which presents a concern for CNG vehicles, is therefore larger by 82.5 mm than in the 1998 model.

Table 1 Engine specifications

Engine code	D17A	
Cylinder configuration	In-line 4-cylinder	
Bore x stroke (mm)	75.0 x 94.4	
Displacement (cm ³)	1 668	
Compression ratio	12.5 : 1	
Valve train	SOHC	
Number of valves	4 per cylinder	
Valve diameter (mm)	In.	30
	Ex.	26
Fuel supply system	Multi-point injection	
Ignition system	Programmed ignition (Plug hole coil)	
Max. power (kW/rpm)	74 / 6 100	
Max. torque (N·m/rpm)	132 / 4 000	

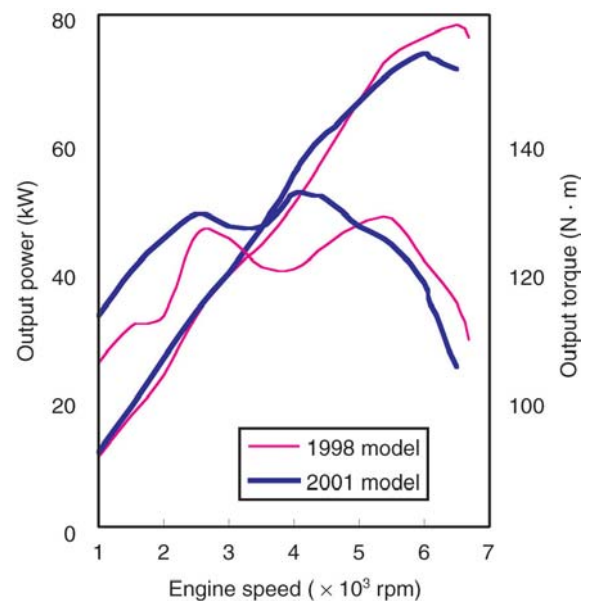


Fig. 1 Engine performance

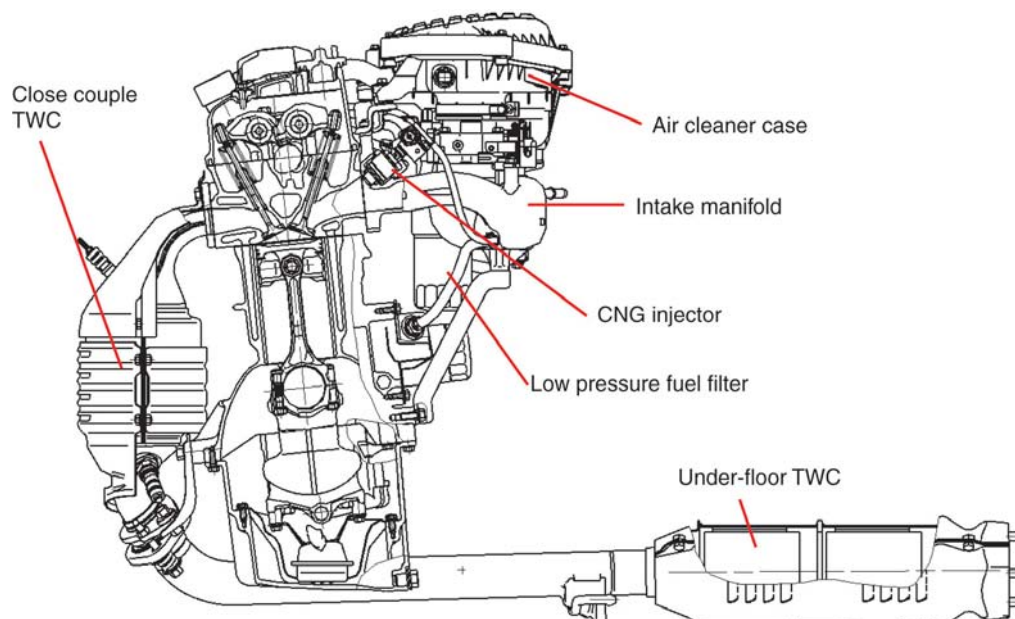


Fig. 2 2001 model CNG engine

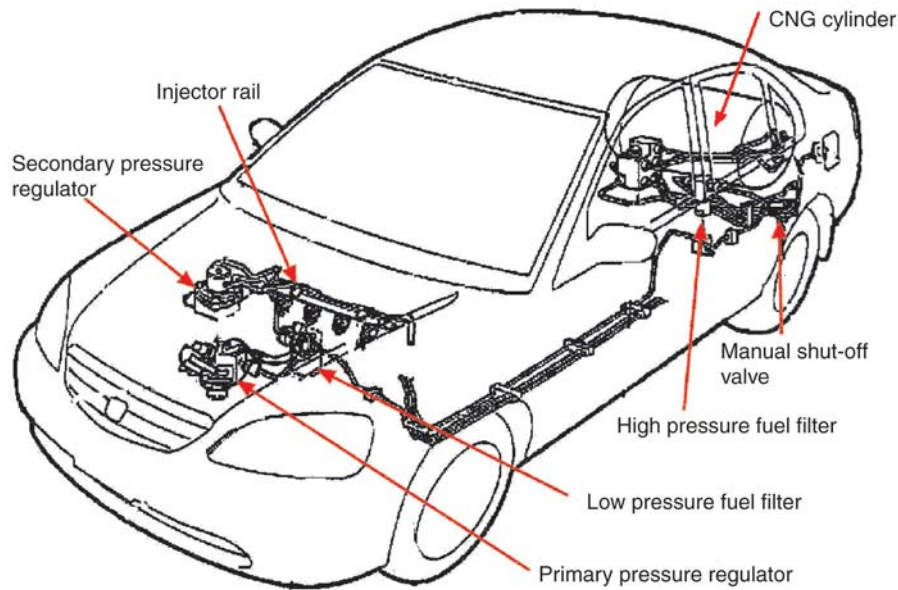


Fig. 3 Overview of Civic GX CNG fuel supply system

The regulator for adjusting the fuel pressure performs pressure reduction in two stages in order to provide stable fuel pressure. The 1998 model combined the primary and secondary stages in an integrated regulator structure, but the regulator in the 2001 model has a split structure. A low pressure fuel filter is located between the primary and secondary regulator. This filter removes any oil and water contained in the fuel. The primary stage regulator is located at the chassis side below engine room toe board, and the secondary stage regulator and the low pressure fuel filter are mounted on the engine. The layout flexibility of the engine compartment was increased by splitting the regulator, which has a large volume.

Fuel is supplied to the engine using the multi-point injection (MPI) method, which positions a special injector⁽²⁾ at each cylinder and sprays fuel into the intake ports. In this layout, the injector and injector rail are mounted on the intake manifold. The intake manifold was designed specially for a CNG engine, making it different from the intake manifold for the base gasoline engine.

4. Low Emission Technology

The emission system was designed in order to comply with the US California State P-ZEV category, which is considered to be the most severe exhaust emission regulation in the world.

As a result, the 2001 model Civic GX was qualified as the world's first AT P-ZEV by the California Air Resources Board (CARB).

4.1. AT P-ZEV

The P-ZEV category is required to have the exhaust emission levels (tail pipe emissions) of a Super Ultra Low

Emission Vehicle (SULEV), the evaporative emission (fuel vapor emissions) of the zero evaporative emission category, and a durability guaranteed distance of 240,000 km (150,000 miles).

Non-methane organic gas (NMOG) in the hydrocarbons (HC) are subject to P-ZEV regulations. CH₄ has little impact on air quality (extremely low photochemical reactivity), so other types of HC are subject to regulation, while CH₄ is excluded. In addition, approximately 80% of hydrocarbons emitted in a non-combusted state from engines using CNG as fuel are CH₄. CNG engines have an advantage compared to gasoline engines when reducing NMOG to the P-ZEV level.

Therefore, reducing NO_x is the main issue for achieving P-ZEV level exhaust emission performance using CNG as a fuel. In addition, the NO_x emissions level of 1/10 ULEV (80,000 km equivalent) achieved by the 1998 model must be guaranteed over an even longer driving range (240,000 km) (Fig. 4).

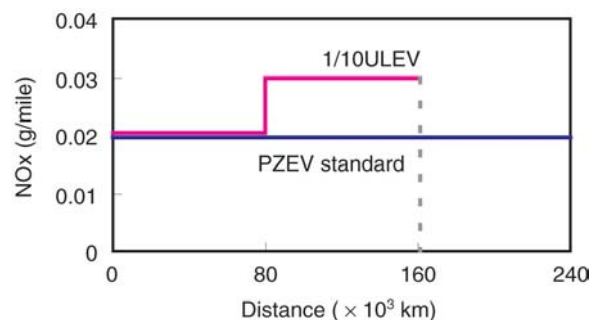


Fig. 4 P-ZEV emission standard and 1998 model Civic GX emission target (1/10 ULEV)

Evaporative emissions do not apply because the fuel system is sealed using a pressure vessel and the main fuel component is CH₄. Furthermore, CNG fuel can minimize its influence on air quality throughout the fuel manufacturing and distribution cycle. For these reasons, the AT P-ZEV (Advanced Technology P-ZEV) category is applied to P-ZEV using CNG as fuel.

The 240,000 km durability guarantee was subjected to similar verification testing as other Honda vehicles, by extending the concentrated durability method from the equivalent of 160,000 km (100 k miles) to the equivalent of 240,000 km (150 k miles). As a result, the emission system was verified to have maintained P-ZEV exhaust emission performance even after running for 240,000 km.

Among the emission system technologies that make it possible to achieve AT P-ZEV, the following low emissions technologies are described below. (1) Exhaust system and catalytic converter which have a large influence on quick light-off of the catalyst after engine start, (2) O₂ sensors which are the key to air fuel ratio feedback, and (3) air fuel ratio control for reducing NO_x after catalyst light-off.

4.2. Exhaust System and Catalytic Converter

The exhaust system uses the same close coupled and under-floor catalytic converter layout as in the 1998 model (Fig. 5). The close coupled converter has superior temperature rise characteristics, so the time until catalyst light-off can be shortened, which is effective for reducing exhaust emissions after engine start. The under-floor converter aims to reduce exhaust emissions after warming-up.

The exhaust manifold was changed from the conventional cast iron type to pressed and welded stainless steel materials, and was welded together with the close coupled converter. The under-floor converter and exhaust pipe, which had been connected with a flange, were welded together to form an integrated unit and thus reduce their weight. The close coupled converter outlet and the exhaust pipe were connected using a spherical flexible joint. These enhancements were intended to reduce the thermal capacity by reducing the weight of the exhaust system from the engine outlet to the under-floor converter by 1.5 kg over previous models.

The 2001 model sought to improve fuel economy by adopting a continuously variable speed transmission (CVT) and controlling engine speed to keep lower than the 1998 model (Fig. 6). This is disadvantageous for heating the catalyst after starting the engine. However, the reduction in the thermal capacity of the exhaust system provided compensation in the temperature rise characteristics, which achieved levels on a par with the 1998 model (Fig. 7).

4.3. O₂ Sensors

Air fuel ratio control uses two O₂ sensors. A primary O₂ sensor is located at the exhaust manifold, and a secondary O₂ sensor is located at the close coupled converter outlet (Fig. 5). These O₂ sensors were developed specially for CNG⁽³⁾. CNG engine exhaust emissions contain a large amount of hydrogen (H₂). As a result, when the air-fuel ratio is close to the theoretical optimum, the primary O₂ sensor controlled air-fuel ratio (λ point) shifts to the lean side so that the NO_x emissions level increases. This is countered by adding a catalytic coating to the element surface of the sensor and eliminating the influence of H₂ to increase the λ point detection accuracy. On the other hand the CH₄ in the exhaust emission following the catalyst undergoes oxidation on the

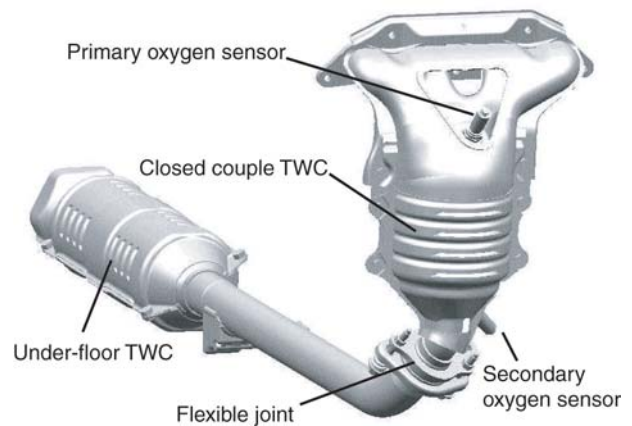


Fig. 5 Exhaust and catalytic converter system

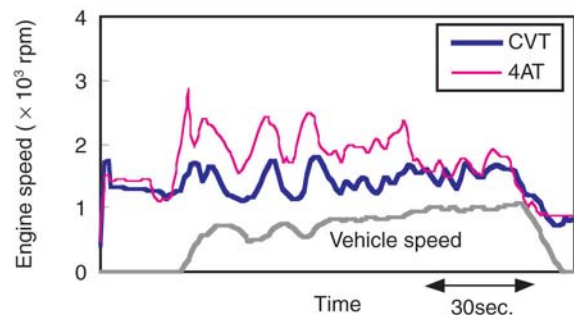


Fig. 6 Engine speed comparison between CVT and 4AT

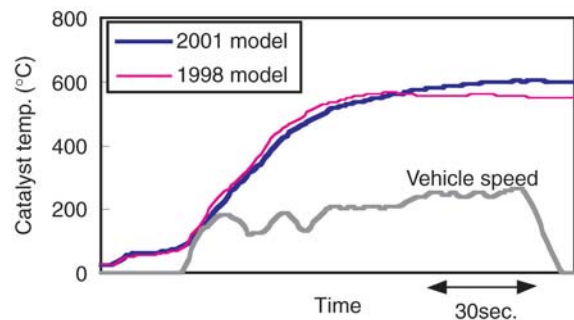


Fig. 7 Catalyst temperature after engine start

sensor element, causing the sensor output to invert between the rich and lean sides quickly. This was suppressed by adding silver (Ag) to the secondary O₂ sensor element located after the close coupled converter.

4.4. Air Fuel Ratio Control

Air fuel ratio control is performed using two O₂ sensors in order to reduce NO_x after catalyst light-off. Here, air fuel ratio compensation according to the secondary O₂ sensor output is added to the $\lambda = 1.0$ feedback using the primary O₂ sensor. This enables control that maintains constantly low NMOG and NO_x emissions levels for any engine operating state.

Control is performed at $\lambda = 1.0$ when cruising normally and accelerating to suppress CO and NMOG. On the other hand, when excess oxygen is present inside the catalyst, there is insufficient capacity for reducing NO_x. Therefore, when excess oxygen passing through the catalyst causes the secondary O₂ sensor output to indicate the lean side (0 V side), the O₂ feedback center (the control air fuel ratio) is shifted to the rich side ($\lambda < 1.0$). (Fig. 8) The catalyst interior is adjusted to a state suited for NO_x reduction by shifting the control air fuel ratio to the rich side to consume the excess oxygen. When there is excess oxygen inside the catalyst such as after fuel cut operation during deceleration for reducing fuel consumption, momentary rich control is performed to reduce NO_x emissions by consuming oxygen in a short time (Fig. 9). These control modes make it possible to reduce NO_x after catalyst light-off and balance it with NMOG at low values (Fig. 10).

Unlike gasoline engines, CNG engines do not need to increase the amount of fuel immediately after starting the engine at normal temperatures. However, the air fuel ratio prior to starting O₂ feedback is controlled to a level richer than $\lambda = 1.0$ in order to shift the inside of the catalyst to the rich side beforehand and reduce NO_x emissions.

4.5. Achieved Exhaust Emission Values — US/Japan

P-ZEV category exhaust emission levels were achieved as a result of reducing NO_x by enhancement of the exhaust system and air fuel ratio control. Table 2 shows the P-ZEV standard values and the achieved values, and Fig. 11 compares NO_x emission values in each LA-4 mode phase with those of the previous model.

The 2001 model satisfied the Japanese exhaust emission technology guidelines for compressed natural gas vehicles, and also acquired “Ultra-Low Emission Vehicle” certification, which is a 75% reduction from 2000 standard values. Table 3 shows the 10-15 mode emissions values, and Table 4 shows the 11 mode emissions values.

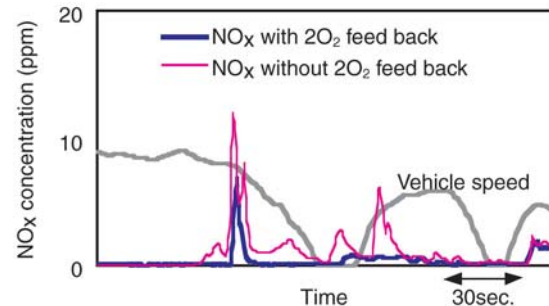


Fig. 10 NO_x reduction from use of 2O₂ feed back system

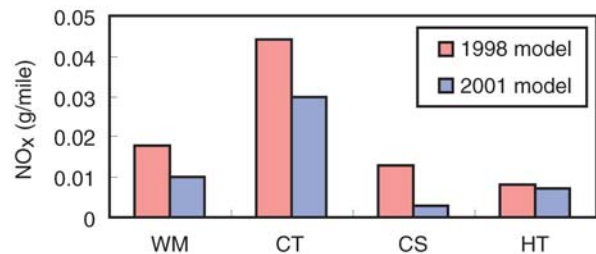


Fig. 11 NO_x emission comparison between 2001 and 1998 model

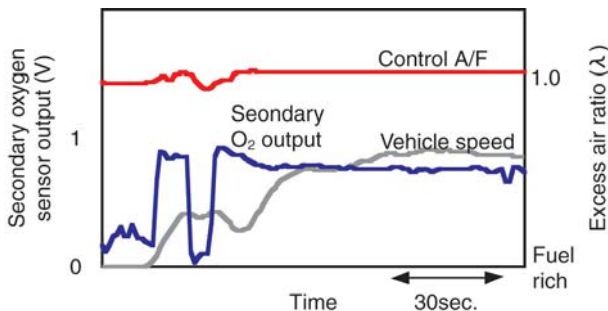


Fig. 8 A/F feed back control with secondary oxygen sensor

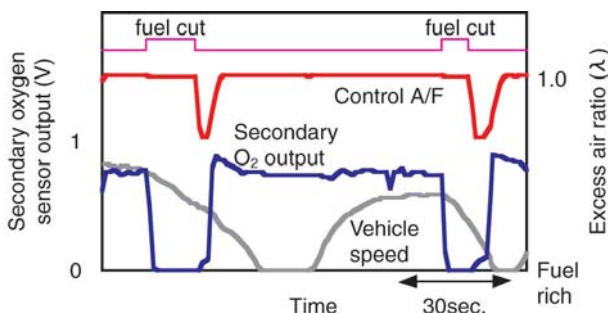


Fig. 9 A/F control after fuel cut

Table 2 USA emission values (in-house test result)

	CO	NMOG	NO _x	Highway NO _x
P-ZEV standard	1.0	0.01	0.02	0.03
Achieved Value	0.088	0.001	0.008	0.011

(g/mile)

Table 3 Japan 10-15 mode emission values

	CO	THC	NMHC	NO _x
2001 Civic GX	0.06	0.01	0.01	0.01
J-ULEV standard	0.67	0.02	—	0.02
CNG standard	0.67	0.04	0.03	0.04

(g/km)

Table 4 Japan 11-mode emission values

	CO	THC	NMHC	NO _x
2001 Civic GX	0.3	0.4	0.1	0.1
J-ULEV standard	19.0	0.55	—	0.35
CNG standard	19.0	1.10	0.88	0.70

(g/test)

5. Low Fuel Consumption Technologies

5.1. Reduced Engine Friction

In order to reduce the friction of the engine, MD (Micro Dimple) treatment⁽⁴⁾ was applied to the surface of the piston skirt portions, a lower-viscosity engine oil was used, the pin metal width of the crank shaft was reduced, and the valve spring load was reduced. As a result, in spite of increase in the displacement, the same engine friction was achieved as the 1998 model (1.6 L).

5.2. CVT

The CVT changes the pulley ratio in a step-less manner, making it possible to continuously use the engine in the low fuel consumption ratio range. As shown in Fig. 12, the 4-speed automatic transmission accelerates while shifting up, resulting in use at high revolutions and low load. In contrast to this, the CVT is capable of accelerating at continuously low revolutions and high load, therefore reducing engine friction and pumping loss. As a result, the CVT makes it possible to reduce fuel consumption during city driving which has frequent acceleration and deceleration. CVT internal control uses hydraulic pressure. The hydraulic control solenoid valve and hydraulic circuit were improved with the aim of improving the pulley ratio and starting clutch control accuracy. In addition, the transfer efficiency was improved by reducing the metal belt side pressure.

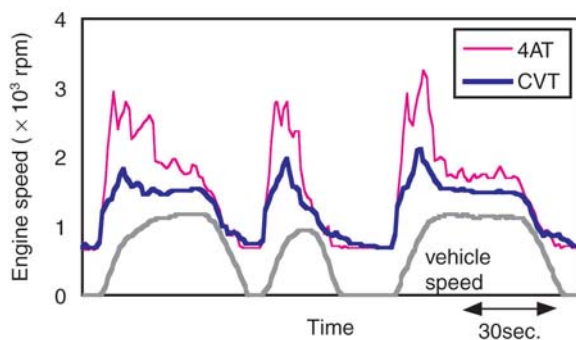


Fig. 12 Engine speed comparison between CVT and 4AT

Table 5 USA fuel economy (Label FE)

	City	Highway
2001 model	30	34
1998 model	28	34

(mile/GGE)

Table 6 Japan 10-15 mode fuel economy

	10-15 mode
2001 model	18.8
1998 model	17.0

(km/Nm³)

5.3. Achieved Fuel Economy

These low fuel consumption technologies focused on adoption of a CVT, reduced fuel consumption by 7% in the US City (LA-4) mode compared to the 1998 model (Table 5). In addition, in the Japanese 10-15 mode, a 10% reduction in fuel consumption resulted in the achievement of a driving range of 380 km (Table 6).

In the United States, the labeled amount of CNG fuel consumed is shown converted to the gasoline gallon equivalent (GGE). On the other hand, the Japanese figures show the amount of CNG using volume (Nm³) in the standard condition.

6. Deterioration of the CNG Emission System in the Market

Exhaust emission measurement tests were conducted on vehicles that were actually driven for long distances in the market. This was done to investigate the deterioration of the emission system in the 1998 model Civic GX which is the first CNG vehicle mass produced and sold by Honda. The test vehicles were five taxis used in the State of Connecticut, US. All vehicles had been driven the durability guaranteed distance of 160,000 km (100 k miles) or more, with the longest driving distance reaching 222,000 km (138 k miles).

Fig. 13 shows the result of the measurement. These results confirmed that all vehicles satisfied the development targets for exhaust emission levels, with NMOG and NO_x levels 1/10 of the ULEV values (with respect to standard levels when driving 160,000 km). It was also found that no change took place in the rate of degradation of exhaust emission levels even after driving 160,000 km.

These results showed that there was no difference between the emission system deterioration verified in-house by actual driving and the concentrated durability method and that occurring in the course of actual use. They also verified that the same deterioration was maintained at 160,000 km and beyond.

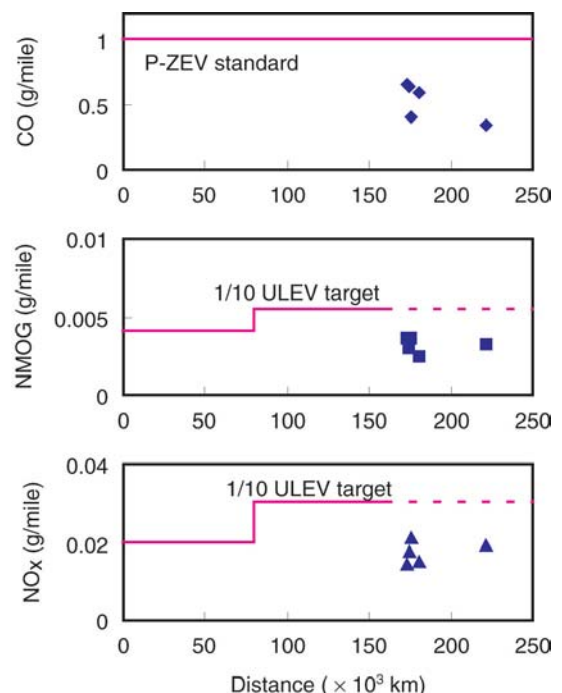


Fig. 13 Emission test results for 1998 Civic GX obtained on market

7. Conclusion

The 2001 model Civic GX achieved the lowest exhaust emission performance in the world by improving temperature rise characteristics of the exhaust system and air fuel ratio control. As a result, the 2001 model Civic GX received the world's first AT P-ZEV qualification in the State of California, U.S.A. And in Japan, it received "Ultra-Low Emission Vehicle" certification.

In addition, fuel economy during city driving was improved by 7% using low fuel consumption technologies centering on adoption of a CVT.

On the other hand, the exhaust emission of 1998 models actually driven in the market was measured, and these results confirmed that the exhaust emission performance of 1/10 ULEV, which was the development target, is maintained even in vehicles that had been driven in excess of 160,000 km.

8. Afterword

CNG is a gaseous fuel, so when used in an internal combustion automobile engine, stable combustion is possible even in low temperatures or immediately after starting. In addition, CNG has little influence on durability and deterioration of the emissions system. Therefore, low exhaust emission performance can be maintained throughout the total course of vehicle usage. Furthermore, the effects of CNG fuel on air quality can be kept to a minimum including in the manufacturing and distribution processes. For these reasons, CNG vehicles hold promise as alternative fuel and low pollution vehicles. Urban air quality can be improved by increasing the ratio of CNG vehicles. For CNG vehicles to achieve widespread adoption, it is necessary to create the proper environment such as increasing the number of CNG filling stations (constructing infrastructure) so that CNG vehicles can be used without worrying about driving range, etc. In addition, CNG fuel price settings and preferential tax systems for CNG vehicles must also be investigated.

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