特集　A Measuring Technology to Analyze the HC Concentration in the Air Intake System*

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In order to comply with the exhaust emission regulations that are becoming more severe every year, more advanced engine control is necessary. Engine engineers are concerned about the Hydrocarbons (HCs) that flow through the air-intake ports and that are difficult to precisely control. The main sources of such HCs are; the canister purge, PCV, and back-flow gas through the intake valves. And the Air/Fuel ratio (A/F) may be aggravated when such HCs flow into the combustion chambers. The influence that HCs have on the A/F may even increase further due to the; increasingly stringent EVAP emission regulations, more effective ventilation in the crankcase, and growth of the VVT-operated angle and timing.

In order to more precisely control the A/F, it is important to estimate the amount of HCs that are difficult to manage, and seek suitable controls over fuel injection, etc. Therefore, the authors have developed a HC concentration measuring technology of the air-intake system using FID (of which the gas sampling performance has been significantly improved). The characteristics of this new system are as follows;

(1) Applicable to each point of the intake system
(2) Applicable to all engine operating conditions including the transition stage
(3) Gas sampling with little influence on the A/F control
(4) Highly accurate: 1%F.S.

This report presents the results gained from several tests carried out on EVAP purging, PCV gas supplying, and VVT system operation, as well as on the process of the development of measuring technology.

Key words : Hydrocarbon (HC) concentration measuring technology, Air / Fuel ratio (A/F)

1. INTRODUCTION

Precise control of A/F is one of the critical factors in reducing the exhaust emission. With the present A/F control system, Fuel supply from injectors is mainly well controlled. On the other hand, difficult to control HCs, which are purged HC from the canister, the PCV gas, and back flow HC through the intake valves as shown in **Fig. 1**, exist in air intake system. In order to reduce the amount of effect these HCs give on the A/F, a feedback control system using the exhaust gas sensor is applied. However, to prevent that large amount of HC flow-in that cannot be completely controlled by the given feedback, the above—mentioned HC flow has to be more gradual.

In order to manage A/F controllability include these HCs, engine engineer must spent on man-hour and efforts for the conformity process of seek suitable injection fuel. And moreover, such burden may possibly grow even bigger, along with the increased amount of HCs. For instance, if the canister purge flow is made twice as much as the current for the increasingly stringent EVAP emission regulations, there is fear that the fluctuation of A/F and unbalanced inter-chamber distribution may double as well.

Then, for aiming at corresponding with the increased amount of HCs, the authors devoted efforts to develop the measurement methods of HC in the intake system. By

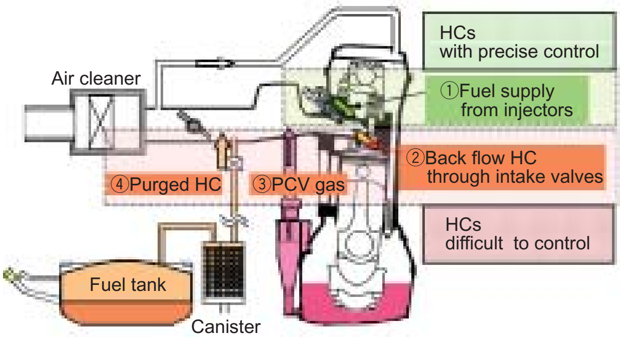

Fig. 1　HCs in air intake system

$$A/F = \frac{\text{Intake air}}{\text{Injection fuel} + \text{Purged HC} + \text{PCV gas} + \text{Back flow HC}} \quad (1)$$

making use of this tool, the authors aimed at improving upon conformity and reducing of man-hour spent on the conformity process.

HC measurement could now be allowed without having to affect the HC concentration at various points in the intake system where the pressure varies. Then, the expected amount of HC, which was under serious consideration, was thus clarified on an experimental base. Furthermore, if injection fuel can be controlled based on the measured HC, then A/F can be proved as being stable even when HC flows in a large volume worth 10 times the amount treated by the current system.

2. DEVELOPMENT OF MEASURING EQUIPMENT

2.1 Sysystem structure

Measuring equipment to analyze HC concentration in air intake system is shown in **Fig. 2**.

For the measurement principle of HC concentration, the FID technique is adopted. Furthermore, in order to carry out analysis by using this FID continuously, this equipment applies a sampling method that can control the sample flow rate according to the intake pressure reading.

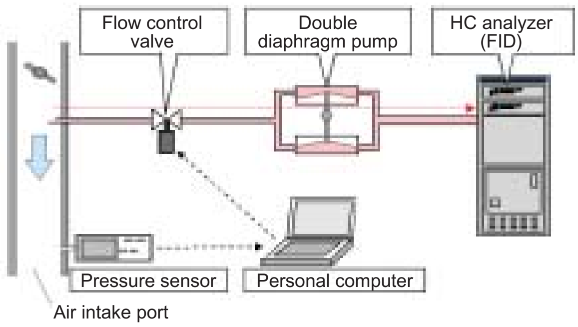

Fig. 2　HC measuring equipment by gas sampling

2.1.1 Means for sampling under negative pressure

In order to sample the gases existing in the intake system under negative pressure, a diaphragm pump is used to assist the sampling process. With this pump, sampling is enabled even down to –60kPa.

2.1.2 Means for stability of sample delay time

A flow control valve is placed between the pump and the measurement point so that sample delay time can always be maintained at target level, even when the intake pressure goes through change. The following will be described how such flow rate coefficient is determined (See **Fig. 3**).

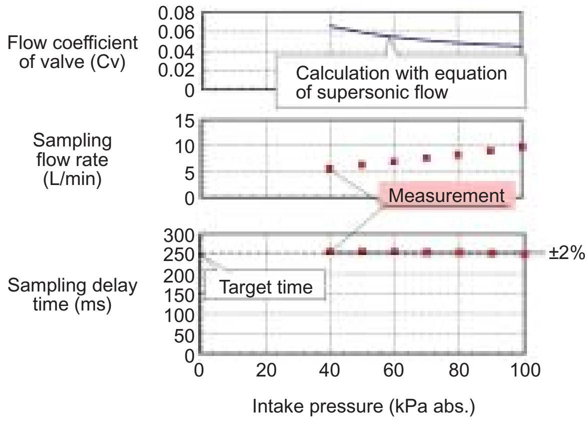

Fig. 3　Stability of sampling delay time per intake pressure

(1) The sample flow rate where sample delay time becomes fixed is calculated by the pressure and volume of the sampling pipe.

(2) On finding the right flow rate, next the valve flow coefficient is calculated by the supersonic flow (EQ. 2). In order to make the valve achieve a supersonic flow, applicable IN and OUT pressures are set for the valve.

$$Cv = \frac{Q}{2.4\ P1}\sqrt{G \times T1} \qquad (@\ P2 / P1 < 0.528) \qquad (2)$$

Cv : Flow coefficient
Q : Sampling flow rate (m^3/h)
G : Specific weight
P1 : Intake pressure (kPa) (IN)
P2 : Pressure between valve and pump (kPa) (OUT)
T1 : Intake temperature (K)

(3) Sample delay time is measured by the calculated flow coefficient of valve.

As a result of this measurement, calculated values matched the actual measurement with 2% accuracy or better. Then consistency of sample delay time was confirmed per every intake pressure. And now, measurement has become possible even in the transitional stages of engine conditions.

2.2 Performance of this equipment

2.2.1 Confirmation of accuracy

To verify accuracy, as pretending that the measurement is 'as if' carried out directly in the air intake system, a confirmation method was established as shown in **Fig. 4**.

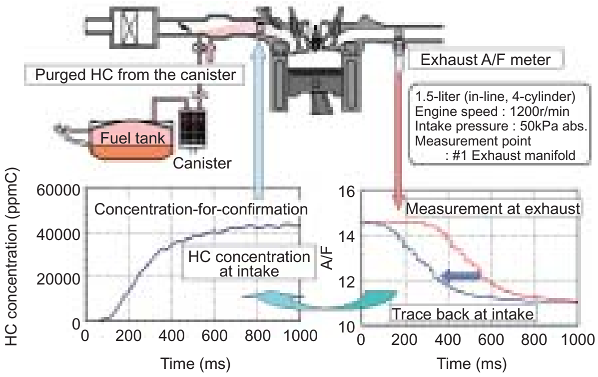

Fig. 4　Confirmation method of accuracy

(1) Change in HC concentration of purging the canister is measured by using the exhaust A/F sensor with response time of 30ms. The change that occurs with the A/F is interpreted as the change in HC concentration.

(2) This A/F measurement traces back the intake system just within that time equivalent to the transportation delay from intake to exhaust.

(3) Change in this A/F is converted into HC concentration in air intake and considered as HC concentration-for-confirmation.

(4) The measurement value and concentration-for-confirmation are compared as in **Fig. 5**. Target measurement accuracy (±3%) is calculated according to the target required for A/F control (±0.5).

(5) If the measurement value is kept in the target measurement accuracy (±3%) for HC concentration-for-confirmation, it is judged that accuracy is satisfactory.

Thus, such target accuracy was achieved and likewise under all engine conditions. (Condition to be confirmed: Engine speed; -6000r/min, Intake pressure; 40-100kPa abs.)

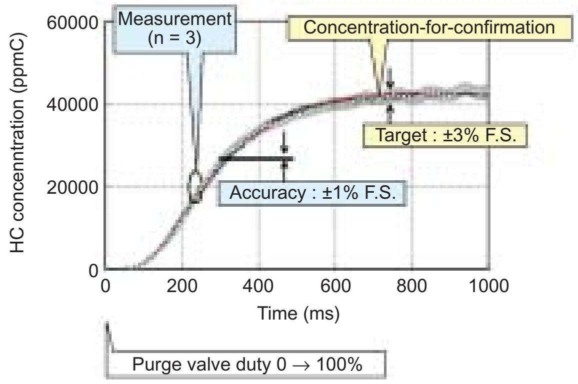

Fig. 5　Confirmation of accuracy

2.2.2 Confirming there is no disturbance caused to the intake condition by gas sampling

Measurement by gas sampling was tried without disturbing the HC concentration in the intake system. Sampling was carried out in small amounts (5-10L/min) to use sample pipes with a smaller diameter (6mm). Whether the flow is disturbed or not by gas sampling from air intake system can be determined by using the exhaust A/F sensor.

The left-side graph of **Fig. 6** shows the ratio of the sample flow to the intake airflow. By minimizing the amount of sample flow, this ratio becomes minimal, and also proves to be just 3%, even under severe conditions of small intake airflow.

The right-side graph of **Fig. 6** is the example comparing the exhaust A/F in the two cases of: with or without sampling. As a result, the influence on A/F 'with sampling' is restrained by 2%, even at the maximum ratio of the sample flow to the intake airflow.

Resultantly, since influence on the intake system was confirmed to be small, this measurement is judged to be satisfactory.

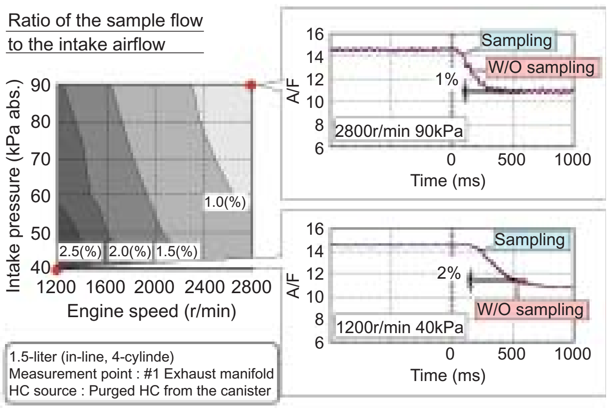

Fig. 6　Influence by gas sampling

2.2.3 Specifications of the equipment

Based on the above observations, it was confirmed that HC measurement inside the intake system could be carried out without having to limit the engine conditions and the measurable positions. This equipment can carry out the following evaluations in the air intake system.

- Distribution of HC concentration
- HC behavior in the transition stage

Table 1 Specifications of HC measuring equipment

Items	Specifications
Measurable gas	Hydrocarbon
Measuring point	Each point at intake system
Applicable engine operating condition	Engine speed : - 6000r/min Intake pressure : 40-100kPa abs.
Accuracy	< 1%F.S.
Measuring range	- 200,000ppmC
Influence of sampling	< 2%

3. MEASUREMENT IN ENGINE

Examples of HC measurement by this equipment in gasoline engine are as follows.

- **Back flow HC through intake valves**

For lower fuel consumption, intake valve must be operated like a larger valve overlap or at delayed close timing. Condition of HC concentration upon every change of valve timing is investigated, as well as the influences caused by the amount of distance away from the intake valves.

- **PCV gas**

For a more effective ventilation of the crankcase, the amount of PCV flow may need to increase. HC influence caused by increasing the PCV flow is investigated by temperatures of the engine oil and by different engine speed.

- **Purged HC from the canister**

Larger amount of purged HC can contribute to lower EVAP emission. The subject of investigation is to follow the difference in HC behaviors by increasing the purged flow.

- **Influence on the A/F by Hydrocarbons**

Each influence that above-mentioned 3 examples of HC respectively has on the A/F is compared in the transition stage of engine operation (acceleration and deceleration).

3.1 Back Flow HC through Intake valves

Test conditions for the back flow HC are shown in **Fig. 7**. The operating angles of intake valves have been set to 5 patterns. The amount of overlap back flow changes by the exhaust valve timing, and the amount of displacement back flow changes as corresponding to BDC. Then, the measurement points are set to 3 distance-points (100, 150, 200mm) from the intake valve. The distance or the area created by back flow HC can be well grasped by this measurement.

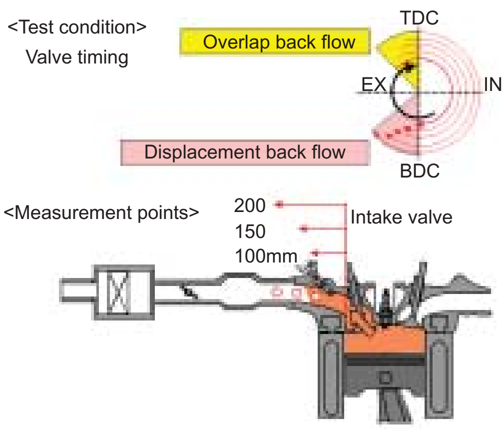

Fig. 7 Test condition and measurement points

Figure 8 shows HC concentration by the difference of the intake valve timing and the distance from that intake valve. It indicates that HC concentration rises along with enlargement of valve overlap. Given this result, it is now clear that overlap back flow is affected more than the displacement back flow. Therefore, it can be said that the unburned gas return to the intake port for raising the rate of internal EGR. And also, though the position of 100mm is located much more upstream the injector, a fairly large amount of HC appears to be present. In this measurement, it turns out to be that fuel injected from the injector must consider this presence of back flow HC.

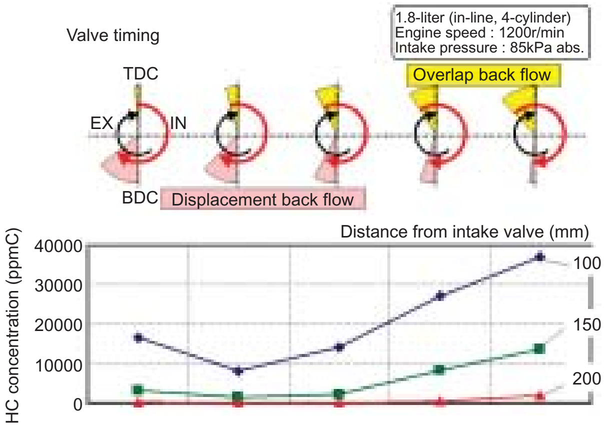

Fig. 8　Influence of back flow HC

3.2　PCV gas

For aiming at efficient ventilation of the crankcase, Change of HC concentration accompanying increase in PCV flow is investigated. In addition, HC concentration according to the difference in engine oil temperatures (30, 55, 80 deg.C) are also investigated.

Figure 9 shows HC concentration according to the difference in PCV flow, oil temperature, and engine speed. It shows a natural tendency of HC concentration rising with the increase in PCV flow and oil temperature. Even at different engine speed, the same tendencies are seen.

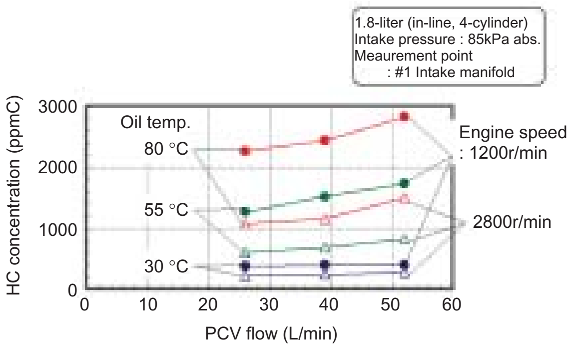

Fig. 9　Influence of PCV gas

3.3　Purged HC from the canister

Investigation was made on some points that drew particular attention when the purged flow from the canister was enlarged. In this experiment, HC behavior was examined as doubling the amount of purged flow. In order to clarify HC transportation in air intake, HC concentration was measured at 3 points in the air intake system as shown in **Fig. 10**.

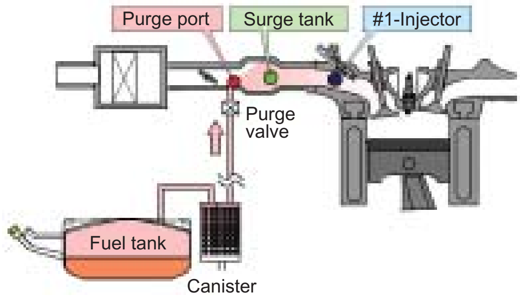

Fig. 10　Measurement points

Purged HC causes rapid change of HC concentration in purge port, and then that HC is mixed and moved to the cylinders by intake air as shown in **Fig. 11**. Since the purge flow is doubled in amount, HC concentration at all measurement points also double. Nevertheless, even with such increase in the purge flow, the transportation delay of purged HC is considered to be always consistent. Therefore, on these results, it is assumed that purge flow rate could be eliminated from the parameter of the conformity test that is carried out upon a large-amount purge.

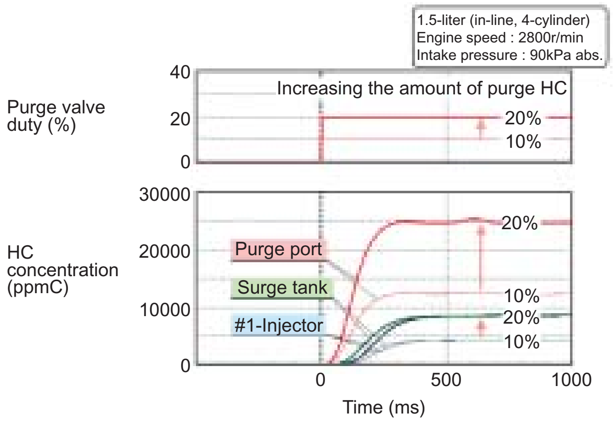

Fig. 11　Behavior of HC purged from the canister

Furthermore, this transportation delay correlates with the volume and volume flow of air intake system. Volume flow of intake system is calculated by totaling the intake air, purge HC and air, and also with the intake pressure and temperature. As referring to this tendency pattern, the number of test engine conditions applied in the conformity process could be reduced overall, and moreover improvement of A/F control can be brought about by the feed-forward control of purged HC. And, HC adsorption of the canister can be better acknowledged by ways of HC concentration sensor or learning control.

3.4　Influence on A/F by Hydrocarbons

Finally, changes in the above-mentioned HC concentration along with varying engine conditions were investigated. This test was carried out with the special focus on cases of acceleration and deceleration in **Fig. 12**. Then, the measurement point is set to 200mm from the intake valve.

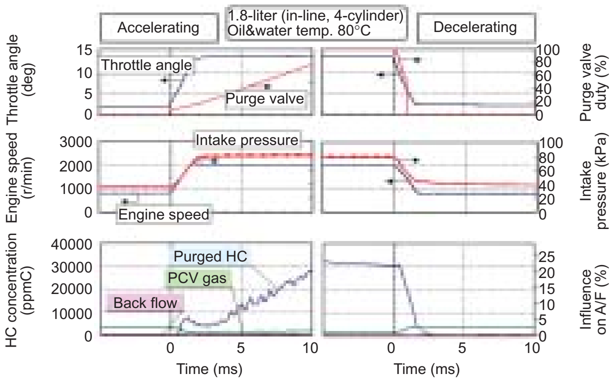

Fig. 12　HC behavior in transitional stage of engine condition

From this result, concentration of three HCs may become large in the order of -- purged HC, PCV gas, and back flow HC. Particularly, the purged HC may continue to become larger depending on duty control of the purge valve and HC adsorption of the canister.

With the present state of control, all HC concentration changes are gradual — slow enough to be treated with feedback control. Also with the canister purge, duty control of the purge valve has been slowed so that feedback can take place. Nevertheless, if the aim is to increase the purge flow rate, then the change in HC concentration inevitably turns rapid.

Therefore, as HC purged from the canister has the most impact on A/F among the difficult-to-control HCs, most attention must be given to the behavior of purged HC.

3.5　Confirmation of A/F control

Figure 13 shows an example that was applied for engine development, that which makes practical use of the measurement results. As this aggressive purge is considered to be about 10 times the amount of flow in the past, attention was drawn to stability of A/F, right upon purge start. Then, in the air intake system, high-concentration HC flows in rapidly as compared with the past performances. In such situation, a large A/F fluctuation is generated by only the feedback control using exhaust gas sensor. But the feed-forward control that actuates reduction of fuel injection, of which amount of reduction is based on the results of this measurement, has helped to belittle the A/F fluctuation.

Based on the above investigation results it can be concluded that, -- by anticipating the purged HC through feed-forward control that is coupled with the conventional feedback control using the exhaust gas sensor, A/F controllability could be maintained even when the purge flow rate is increased.

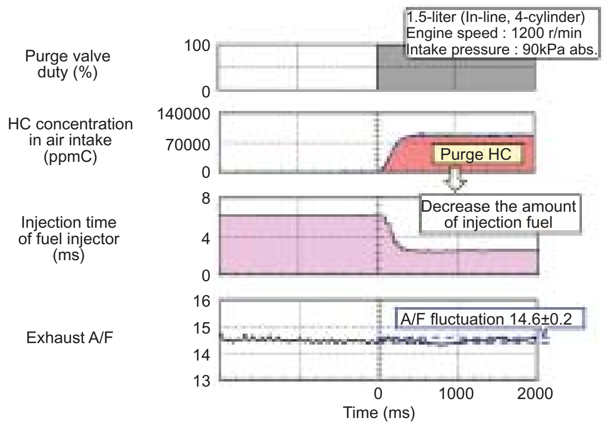

Fig. 13　A/F control in aggressive purging

4．CONCLUSION

The authors have developed on equipment capable of measuring the HC concentration in intake system under various engine test conditions. The equipment that was developed in this study features the following characteristics:

(1) Applicable to each point of the intake system
(2) Applicable to all engine operating conditions including the transition stage
(3) Gas sampling with little influence on the A/F control
(4) Highly accurate: 1%F.S.

In conclusion, the equipment is capable of verifying data relating to the influences brought by the HCs. It has also proven to be a useful tool in developing an effective A/F control.

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