Diagnostics on the Restricted Flow of Exhaust Gas in the Gasoline Engine

Young Soo Lim[1], Kyoung Hoon Kim[2], and Se Woong Kim[3]

***Abstract*—**This work presents an experimental analysis for engine diagnostics by the variation of engine revolution speed and intake pressure as the flow area of exhaust gas is reduced or clogged due to the damaged catalytic converter. The reduced flow area of exhaust pipe is realized through the converter gasket with hole. The Stall test, the cranking test, the intake pressure test and the analysis of waveform were carried out. The heavy restriction of exhaust flow could be predicted by the stall test and the cranking test. The results showed in the waveform of fast acceleration test that the angle of returning line at releasing point and the recovering time to idle speed could be good standards to detect the restricted flow of exhaust gas. And also, it was possible to predict the restricted flow in exhaust pipe by the amplitude of intake pressure.

***Keywords*—**diagnostics, exhaust gas, restricted flow, waveform of intake pressure.

I. Introduction

It is obvious that the automobile is a very useful system for life by the benefit of the technology developed for hundreds of years. But, the negative aspect of automobile is appeared as the exhaust emission has become a social problem. The intensified standards for emissions have forced automotive manufacturers to exert strong efforts in reducing the pollutant emissions and improving the efficiency of engines [1]. As the pretreatments of emissions related with combustion technology can't be satisfied with the strict standards of emissions, after-treatments have to be applied to reduce emissions. The most effective system for reducing engine emissions is the catalytic converter found on most automobiles and other modern engines. In case of gasoline engines, 3-way catalyst is used to reduce CO, HC and NO_x simultaneously.

The most widely used catalyst materials are platinum and rhodium, with other noble metals. Aluminum oxide is used as the base ceramic material for most catalytic converters. The efficiency of a catalytic converter is very dependent on temperature. When a converter in good working order is operating at a fully warmed temperature of 400℃ or above, it will remove 98~99% of CO, 95% of NO_x, and more than 95% of HC from exhaust flow emissions[2]-[3].

Converters lose their efficiency with age due to thermal degradation and poisoning of the active catalyst material. At high temperature, the catalyst material can sinter and migrate together, forming larger active sites that are less efficient. Serious thermal degrading occurs in the temperature over 1000℃. And also the alumina of catalyst carrier can be cracked, damaged or collapsed by the thermal fatigue [4]-[7]. As a results, the flow of exhaust gas may be restricted with wreckage. This causes unstable idling, decrease in power and poor fuel economy as well as inability in purification of exhaust gas. It is not easy to diagnose the damaged catalyst without disassembling the catalyst converter. So, the diagnostics requires indirect methods which indicate the restricted flow by engine operating conditions such as combustion sound, idle speed, engine power, intake pressure and exhaust pressure.

There were many researches on the estimation of exhaust pressure and the engine diagnostics concerning misfire, knocking and abnormal combustion [1], [8]-[11]. But, there is not much research about the restricted flow in exhaust pipe due to the damaged catalytic converter.

This work presents an experimental analysis on engine diagnostics by the variation of engine power and intake pressure when the flow area of exhaust gas is reduced or clogged due to the damaged alumina of base ceramic material. The reduced flow area of exhaust pipe is realized through the converter gasket with hole. Six converter gaskets are applied in experiments. The stall test, the cranking test, the intake pressure test and the analysis of waveform are carried out. The purpose of this work is to find the effective diagnostic methods by several kinds of experimental tests.

II. Experimental Apparatus and Methods

A. Engine and Measuring Apparatus

The experimental engine is a four-stroke cycle, four-cylinder, 1.5 DOHC, spark-ignition engine. Hi-ds workstation collect data from the pressure sensor, the throttle position sensor, and the crankshaft position sensor. Fig. 1 shows the schematic diagram of experimental apparatus. Intake pressure is measured at position A of intake manifold and flow rate of exhaust gas is measured by the air flow sensor of Karmann vortex type at position C in exhaust tail pipe. A gasket is assembled between catalytic converter and exhaust pipe. The original gasket has flow diameter of 56mm and five models of gaskets are made to realize the restricted area of flow. Table 1 shows the gasket models and their diameters of flow sections. Fig. 2 is the photo of gaskets for experiment.

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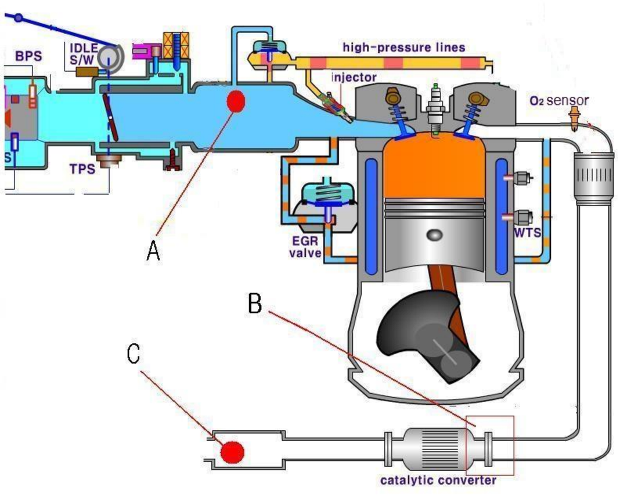

Fig. 1 Schematic diagram of experimental apparatus

Fig. 2 Gaskets for experiment

TABLE I
GASKETS REALIZING THE RESTRICTED AREA OF FLOW

Gasket Model	Flow Diameter(mm)	Ratio of Dia.to Original (%)
A	7.0	12.5
B	14.0	25.0
C	28.0	50.0
D	43.0	76.8
E	51.5	92.0
F	56.0	100

B. Experimental Methods

1) Stall Test

Stall test is to detect troubles of engine and automatic transmission. It measures maximum engine revolution speed that the speed ratio of torque converter is zero when engine is accelerating at "D" or "R" of shifting lever in automatic transmission. This test is useful to check the performances of one way clutch, shifting clutch and brake in torque converter as well as engine performance. As the stalling speed exceed the specified value, rear clutch or one way clutch of transmission is sleeping. On the other hand, as the stalling speed is less than the specified value, lack of engine power will be predicted. It tells abnormal condition of engine due to the misfire, incorrect ignition timing or trouble in fuel system. Stall test can be used to detect the restriction of exhaust flow which causes reducing engine power.

2) Cranking Test

Cranking test measures the intake pressure while the engine is driven by the starting motor without combustion for ten seconds. Engine throttle valve is maintained with wide open throttle during cranking test.

3) Intake Pressure at no load

Intake pressure varies with the charging efficiency of cylinder at given engine revolution speed. As the exhaust gas can't be discharged smoothly, the exhaust pressure in exhaust pipe increases and the residual gas in cylinder increases too. Consequently, it has a bad effect to the charging efficiency of cylinder and the intake pressure. In this test, the intake pressures are measured and compared when the engine rotates at no load with 700 rpm, 1,000 rpm, 2,000 rpm, and 3,000 rpm respectively.

4) Waveform of intake pressure

In this test, the waveform of intake pressures are measured in conditions of idling and fast accelerating. And also, characteristics of their waveforms are compared and analyzed. The amplitude of intake pressure is the main factor on the idle test. The shapes of waves which the engine returns to idle condition after accelerating are important on the fast acceleration test.

III. RESULTS AND DISCUSSION

The restricted flow of exhaust gas can be detected indirectly from variation of engine revolution at stalling. As the stalling speed is less than the specified value, lack of engine power owing to the restricted exhaust flow will be predicted. Fig. 3 shows the stalling revolution speeds of experimental engine as to the flow diameters of exhaust gaskets. Stalling speed did not vary to 25% reduction of diameter, but decreased with reducing flow area above that. Reduction rates of engine revolution speed were 5.2% of model C(dia. 28 mm), 14.8% of model B(dia. 14 mm) and 31.8% of model A(dia. 7 mm). As 1/2 diameter means 1/4 area, it is possible to detect above 75% reduction of flow area by stall test. The heavy restriction of exhaust flow can be predicted by stall test.

Fig. 4 shows the pressures in intake manifold of engine as to the flow diameters of exhaust gaskets during cranking for ten seconds. There were little change in intake pressures of model D and E compared with model F of original engine. But it was observed that intake pressure increased with restriction of flow. The residual gas in cylinder is increased in proportion to the starting pressure of intake stroke as the flow area of exhaust gas is reduced. Consequently, temperature of fresh air in cylinder climbed and the quantity of intake air decreased. So, the pressure in intake manifold increased owing to the low suction from cylinder. The intake pressures of model A, B and C increased 23.7%, 21.8% and 9.7% than that of original engine respectively. The heavy restriction of exhaust flow can be predicted by cranking test.

The vacuum pressure in intake manifold at no load can vary according to the leakage of intake manifold, the reduced compression pressure, EGR and troubles such as piston, piston ring, valve and head gasket. The vacuum pressure in intake manifold will increase with the quantity of air flow to cylinder but will decrease with the angle of throttle opening.

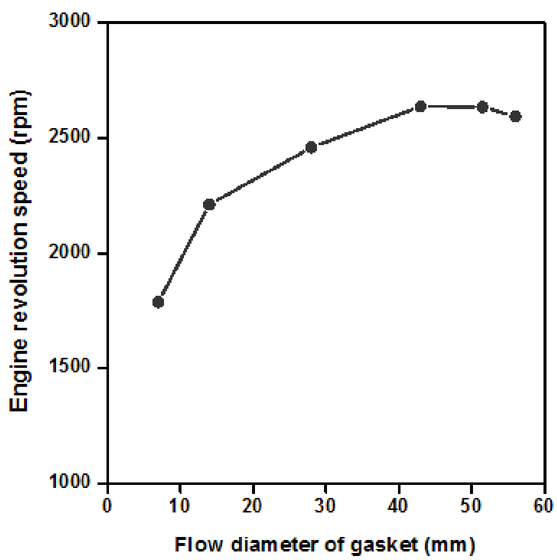

Fig. 3 Stalling speeds of experimental engine as to the flow diameters of exhaust gaskets

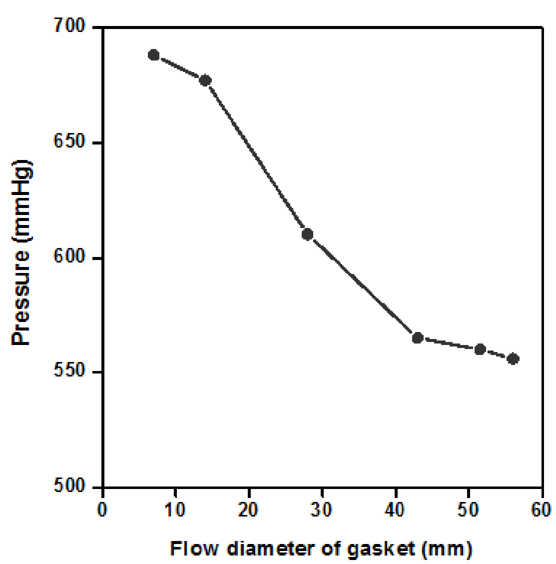

Fig. 4 Pressures in intake manifold as to the flow diameters of exhaust gaskets during cranking test

Fig. 5 shows the vacuum pressures in intake manifold of engine at no load as to the engine revolution speeds and the flow diameters of exhaust gaskets.

As shown in Fig. 5, variations of vacuum pressures in intake manifold were not large enough to distinguish the restricted states at less than 1,000 rpm of engine revolution speed. The vacuum pressure in intake manifold of original engine was increased with increasing engine revolution speed for the reason that quantity of suction air to cylinder and the throttle opening were increased with engine revolution speed but the effect of suction air was larger than that of throttle opening. The vacuum pressure at 3,000 rpm was 41.4% higher than that at idle speed. It was shown that vacuum pressures were decreased in over 2,000 rpm as the flow diameter of gasket was under 28 mm. It was because the flow of exhaust gas was not smooth and the residual gas in cylinder was increased and so the throttle opening was widened more than that of original engine with increasing engine revolution speed. In this case, the quantity of suction air to cylinder and the throttle opening were increased with engine revolution speed but the effect of throttle opening was larger than that of suction air. But, the operating condition of engine was unstable and variations of revolution speeds were large. It is easy to make engine speed at no load higher to 3,000rpm. By this method, the restriction of exhaust flow can be predicted as the vacuum pressure in intake manifold does not increase or decreases at over 2,000 rpm.

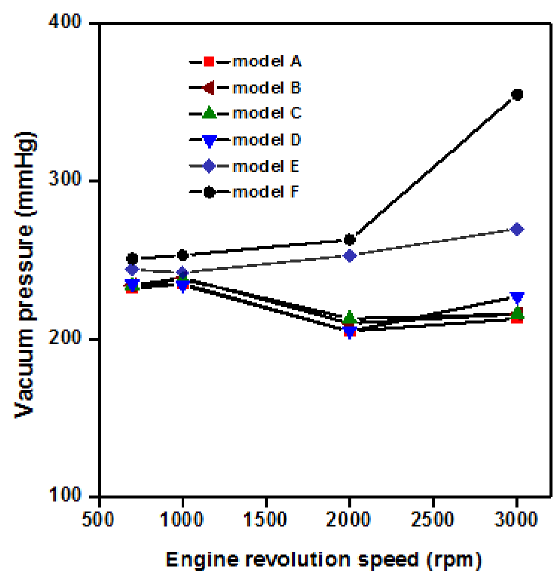

Fig. 5 Vacuum pressures in intake manifold as to the engine revolution speeds and the flow diameters of exhaust gaskets

The pressure in intake manifold continue to fluctuate with time. It has the frequency, the amplitude of wave and the pattern of waveform as well as the mean value of pressure. They can be used to predict or detect an abnormal combustion of operating engine. Especially, the pattern of waveform may become a good criteria. So, the waveform of intake pressure was studied to detect the restriction of exhaust flow.

Fig. 6 shows the waveforms of pressures in intake manifold during fast acceleration of engine. The experimental engine was accelerate rapidly from idle state to wide open throttle and was released to idle state again. The returning time to idle state after released will differ owing to the inertia of intake air and the air suction of cylinder. A quick return will be made if the exhaust gas flows smoothly and the residual gas in cylinder is little. In Fig. 6, C was to the normal engine with flow diameter of 56 mm, B was to the restricted flow engine with flow diameter of 14 mm and A was to the restricted flow engine with flow diameter of 7 mm. As shown in figure, the returning line was steep because the engine returned quickly from accelerated speed to idle speed. But, the restricted flow engines had higher pressures in transient states and took longer time to recover the idle speeds. The angle of returning line at releasing point and the recovering time to idle speed can be good standards to detect the restricted flow of exhaust gas by the damaged catalytic converter.

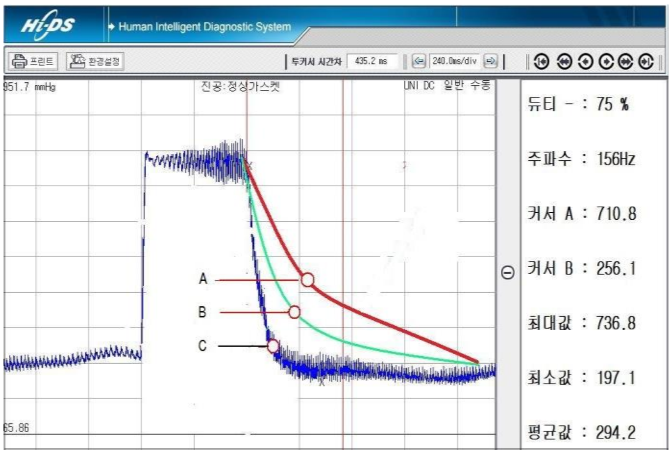

Fig. 6 Waveforms of pressures in intake manifold during fast acceleration of engine

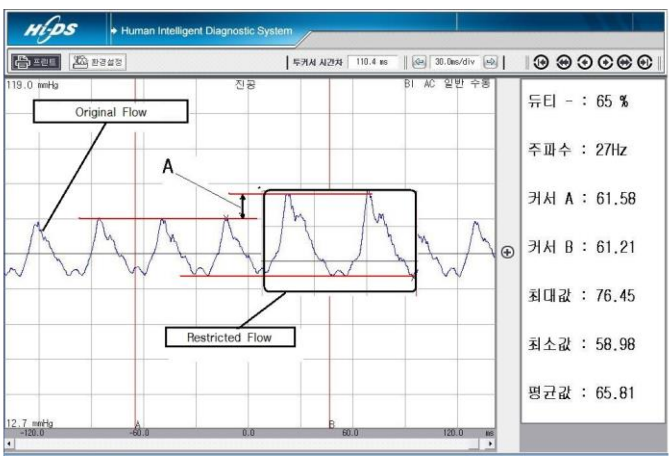

Fig. 7 Waveforms of pressures in intake manifold at idle state of engine

The frequency and amplitude of intake pressure will vary with engine conditions such as the engine revolution speed, the engine load and the combustion situation. In this work, the amplitude of instantaneous pressure in intake manifold was measured and compared for possibility to detect the restricted flow in exhaust pipe. Fig. 7 shows the amplitudes of intake pressures at idle state of operating engine for the normal operating engine and the restricted flow engine with flow diameter of 7 mm. It was shown in Fig. 5 that the mean value of intake pressure of the original engine was lower than that of the restricted flow engine. It was appeared in Fig. 7 that the waveform of intake pressure of original engine had a big amplitude and low frequency than that of the restricted flow engine. Fig. 8 shows the magnitudes of amplitudes of intake pressure as to the flow diameters of exhaust gaskets at idle state of engine. The amplitude of intake pressure was decreased almost linearly as the flow diameter of gasket was increased. The variation of amplitude appeared even at small change of flow diameter. The increasing rates of amplitude of model A with flow diameter of 7 mm showed 56.4%, model B 43.7%, model C 25.8% model D 8.9%. The restricted flow in exhaust pipe can be predicted by comparing the amplitudes of intake pressures.

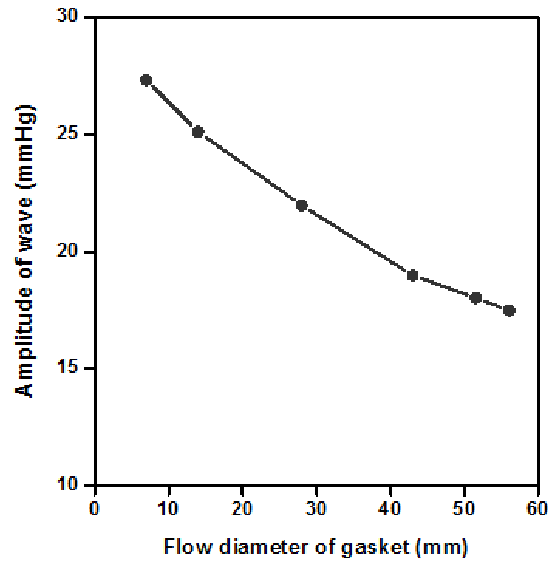

Fig. 8 Amplitudes of pressures in intake manifold as to the flow diameters of exhaust gaskets at idle state of engine

IV. Conclusions

In this paper, experimental studies were performed to find the effective engine diagnostics by the variation of engine power and intake pressure when the flow area of exhaust gas was reduced or clogged due to the damaged catalytic converter. Six types of converter gaskets were applied to realize the reduced flow area of exhaust pipe. The stall test, the cranking test, the intake pressure test and the analysis of the waveforms of intake pressure were carried out. The main results of the experiments are summerized as follows:

1) The heavy restriction of exhaust flow can be predicted by the stall test and the cranking test.

2) By comparing the intake pressure at no load, the restriction of exhaust flow can be predicted as the vacuum pressure in the intake manifold does not increase or decreases at over 2,000 rpm.

3) In the waveform of intake pressure of the fast accelerating test, the angle of returning line at releasing point and the recovering time to idle speed can be good standards to detect the restricted flow of exhaust gas by the damaged catalytic converter.

4) The amplitude of intake pressure was decreased almost linearly as the flow diameter of gasket was increased. The variation of amplitude appeared even at small change of flow diameter. Therefore, it is possible to predict the restricted flow in exhaust pipe by analyzing the amplitude of intake pressure.

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