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Study on Vibration Characteristics through Torsion Spring Constants within Automobile Muffler

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Abstract

In the present study, torsion springs with different spring tensions were designed and produced, and a study was conducted concerning what effects vibration occurring in an exhaust variable valve has on engine performance and back pressure. Therefore, it will be affirmed by designing and producing torsion springs with different spring tensions in the present study what effects vibration produced in the exhaust variable valve has on engine performance and back pressure. According to the results of conducting back pressure experiments with respect to mass flux supply for 4 types of K1, K2, K3 and K4 having different torsion spring constants of an exhaust variable valve, a conclusion was obtained showing a parabolic trend in the order of K1 < K2 < K3 < K4 and it could be seen from burst of speed section and certain section of K1, K2, K3 and K4 that vibration due to opening and closing of the valve occurred in the exhaust variable valve with different torsion spring constants in the order of K1 (0.6 (g)) < K2 (0.8 (g)) < K3 (1.3 (g)) < K4 (1.8 (g)). Therefore, when a pulsation phenomenon occurring in a combustion chamber of automobile engines is minimized, it is considered that more improved performance can be obtained from stabilized engine combustion.

Keywords: Automobile Muffler, Back Pressure, Exhaust Variable Valve, Exhaust Conducting Copy Device, Vibration

1. Introduction

Recently, as the environment problems caused by automobiles are changing with continuing adverse conditions, requirements for optimum fuel efficiency, BSR (Buzz, Squeak, Rattle) or power performance improvement including minimal noise are increasing.[1, 2]. As a result, research and development of mufflers to meet these requirements is being conducted.[3,4]. An automotive exhaust system should be able to improve engine performance to an optimum, while the exhaust generated in a combustion chamber of the engine should produce a minimum back pressure[5,6].

Therefore, studies on an exhaust variable valve that enables improvement of engine performance as well as a light weight design of the exhaust system are being actively pursued[7,8]. An exhaust variable valve is employed based on the principle that the valve is opened by back pressures produced inside a muffler and closed by spring tension, and improvement or degradation in performance of an engine will be influenced by how the spring tension is designed[9,10].

Results of the studies cited thus far fail to clarify specific effects that vibration characteristics occurring as a function of spring constants of an exhaust variable valve can have on performance and back pressure of the engine. In general, an exhaust variable valve employs 4 typical types of springs as shown in Figure 1, among which the torsion spring is used as the most commercialized product.

Therefore, in the present study, by designing and producing torsion springs with different spring tensions, it will be affirmed what effects the vibration produced in the exhaust variable valve has on engine performance and back pressure.

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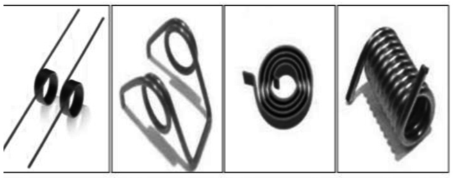

Figure 1. Type of springs used in exhaust variable valve.

2. Experimental Method

The exhaust variable valve used in the present study, having a diameter of D = 43 mm and a thickness of t = 1 mm, was designed by utilizing CATIA V5 as in Figure 2 (a) and installed inside a muffler.

The torsion springs installed in the exhaust variable valves were designed according to the magnitudes of tension by referring to KS (Korean Industrial Standard) specifications. Also, an exhaust behavior simulation device was produced by designing behaving positions of the exhaust variable valve as shown in Figures 2 (b), (c) to simulate the inside of the exhaust system.

Figure 3 is a schematic diagram of the exhaust conducting copy device made by copying a vehicle exhaust system. In consideration of the maximum flux transferred from the engine combustion chambers, two blower fans were used as the source.

An orifice type flow meter was installed to measure differential pressure, and, as for the form and internal structure of the muffler, a 1,400cc class gasoline engine muffler equipped with an exhaust variable valve was copied and made with an acrylic structure. Testing was performed on 4 exhaust variable valve specimens (K1, K2, K3 and K4) with varying torsion spring constants. The opening angle of the valves was captured and recorded using a non-contact method camera at each experimental condition.

The order of operation is as follows: ① A certain amount of air is collected and stored in the air tank. ② Assuming a variable blower, flux and pressure representing that of the gas emissions from engine combustion are

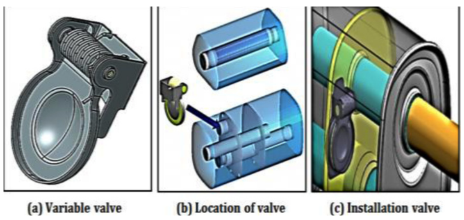

Figure 2. Modeling of exhaust variable valve inside a muffler.

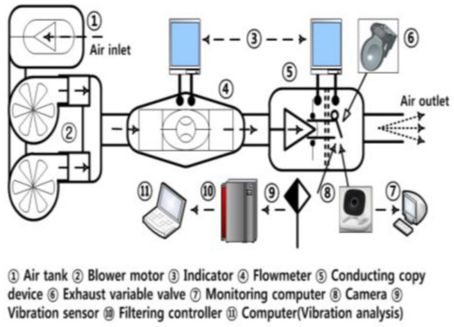

Figure 3. Schematic of the exhaust conducting copy

created. ③ The differential pressure measured is monitored in real time through the indicators, and is converted from pressure units (kPa) to flow Q (g/s). ④ The flux is measured using the differential pressure. ⑤ Flux and pressure are caused within the exhaust conducting copy device, which was made to copy the structure of a muffler. ⑥ The exhaust variable valve here is opened in a semi-active manner due to the pressure generated. ⑦ & ⑧ Monitoring is performed using non-contact method cameras to measure the angle of the exhaust variable valve. ⑨ The sensors are used to detect the vibration generated when the exhaust variable valve is opened. ⑩~⑪ The detected noise signals are filtered and analyzed in real-time using a computer.

The experiment was repeated 10 times in this order, and the results were averaged. The specifications of the schematic of the exhaust conducting copy device are as shown in Table 1.

3. Results and Discussions

Figure 4 shows the result of performing the behavior experiment for 4 different torsion spring constants being K1, K2, K3, K4 respectively of an exhaust variable valve by

Table 1. Specifications of the exhaust conducting copy device

Item	Specification
Blower-motor	16,000 rpm/ 4.5m^3/min
Flow meter	DP (pressure)/ Process
Indicator	RT: 0.1%/Response time: 16 ms
Camera	Process connection: USB type
Acceleration sensor	Sensitivity: 15 %, Frequency: 1.0 to 10,000 Hz

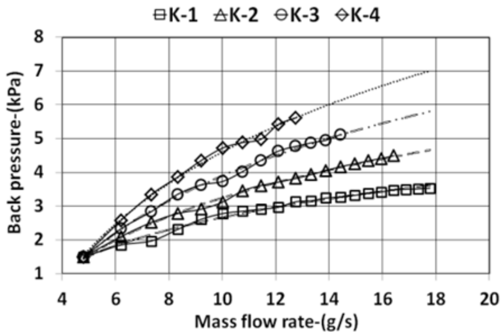

Figure 4. Mass flux of back pressure for different spring constants.

using the exhaust variable simulation device. The lateral axis of the graph shows a mass flux, while the longitudinal axis shows a back pressure where a pressure drop caused by mass flux occurred within the muffler simulation device.

According to the back pressure experiments with respect to mass flux, a change with parabolic trend of increasing in the order of K1 < K2 < K3 < K4 was observed. This signifies that as the mass flux is increased, the torsion spring tension of an exhaust variable valve causes back pressures inside the muffler simulation device to vary differently from each other.

Figure 5 illustrates the vibration result of the valve detected as a function of torsion spring constants of the exhaust variable valve when a flux of 6.2(g/s) was supplied from the blower to the exhaust variable valve. The lateral axis of the graph shows vibration detection time, while the longitudinal axis shows vibration magnitude of the valve. Also, the left side of the graph shows Burst of speed section (BOSS), while the right side shows Certain section (CS).

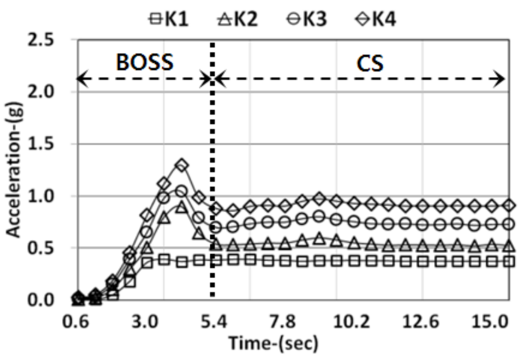

Figure 5. Vibration levels for different spring constants at flux 6.2 (g/s).

A flux of 6.2(g/s) supplied from the blower corresponds to the engine speed ranging from about 450rpm to 500rpm as an initial starting condition of the engine, and the graph was subjected to a trend analysis by utilizing actually measured data.

According to the experiments, BOSS of K1 showed a trend for occurrence of the most minute vibration near 3 seconds, while BOSS of K2, K3, K4showed a trend for instantaneous vibration between 0.6 seconds and 5.4 seconds. This was explained that the vibration was produced from accumulated pressure drop of the flux supplied by the blower since the gap between the valve and the pipe was minor.

CS of K1 was stabilized after about 3 seconds, while CS of K2, K3 and K4 had vibration produced in the valve after 5.4 seconds. Such trend was suggested to be a cause for maintenance of opening and closing angles of the valve also in a stable trend as time elapsed.

Figure 6 displays the vibration result of the valve detected as a function of torsion spring constants of the exhaust variable valve when a flux of 7.3(g/s) was supplied from the blower of the exhaust variable valve. According to the result of analyzing a flux of 7.3(g/s) supplied from the blower, it is shown to correspond to an engine speed of around 900rpm to 1,000rpm.

According to the experimental results, BOSS of K1, K2 showed a somewhat varying trend of vibration between 0.6 seconds and 3.6 seconds, while BOSSS of K3, K4 displayed an expanded trend of vibration up to near 6.2 seconds. This was considered to be an early pulsation phenomenon where the exhaust variable valve began to be opened and closed due to an increase in the flux supplied form the blower.

CS of K1, K2 was stabilized after 3.6 seconds, while CS of K3, K4 obtained stabilized vibration after 6.2 seconds. Such trend signifies that opening and closing angles of the valve continued to be maintained in a stable trend as time elapsed.

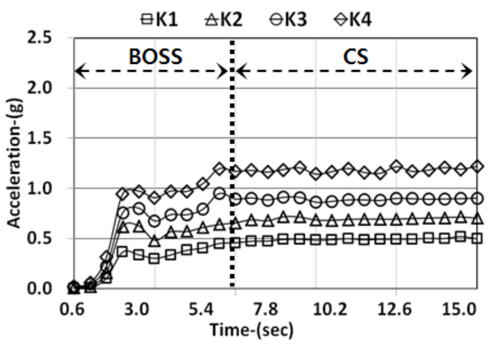

Figure 6. Vibration levels for different spring constants at flux 7.3 (g/s).

Figure 7 shows the vibration result of the valve detected as a function of torsion spring constants of the exhaust variable valve when a flux of 8.3(g/s) was supplied from the blower of the exhaust variable valve. Also, according to the result of analyzing a flux of 8.3(g/s) supplied from the blower, it is shown to correspond to an engine speed of around 1,500rpm to 1,600rpm.

According to the experimental results, vibration was gradually increased in BOSS of K1since the vibration trend of small magnitude occurred between 0.6 seconds and 3.2 seconds, which increased to a magnitude of 0.7(g) near 6 seconds, while the second vibration of 1.3(g) occurred near 9.8 seconds in BOSS of K2, K3 and K4. This was seen as a point of time where back pressures were actively decreased as a pressure drop occurred inside the muffler simulation device.

CS of K1, K2 was stabilized after 3.6 seconds, while CS of K3, K4 maintained a stabilized vibration trend after 6.2 seconds. This could be explained as vibration of the valve was expanded in BOSS to have an effect on the blower impeller (blade), and unstable changes in back pressure are presumed to affect the combustion chamber of the engine if the blower is assumed to be a combustion chamber of the engine.

Figure 8 shows the vibration result of the valve detected as a function of torsion spring constants of the exhaust variable valve when a flux of 9.2 (g/s) was supplied from the blower of the exhaust variable valve. Also, according to the result of analyzing a flux of 9.2 (g/s) supplied from the blower, it is shown to correspond to an engine speed around 2,300 rpm to 2,700 rpm.

According to the experimental results, BOSS of K1 showed a result expanded in the magnitude of vibration to 0.7 (g) at a point of 5.4 seconds after vibration with an extremely small magnitude of 0.25 (g) between 0.6 seconds and 3.0 seconds, while BOSS of K2, K3, K4 showed a similar vibration trend near 3.8 seconds in the order of vibration magnitude of K2 (1.2 (g)) < K3 (1.5 (g)) < K4 (2.0 (g)). According to the results of analyzing this, it was analyzed to be a cause for transmission of a weak shock to the valve due to an increase in the standard flux and an instantaneous pressure drop supplied at a rapid rate.

CS of K1 was stabilized after 5.4 seconds, while CS of K2, K3 and K4 maintained a stabilized vibration trend after 5.2 seconds which was identical with that for K1. This was analyzed to be a cause for reaching a limit of torsion spring tension of the exhaust variable valve by the flux transmitted to many distributions.

Figure 9 shows the vibration result of the valve detected as a function of torsion spring constants of the exhaust variable valve when a flux of 10.0 (g/s) was supplied from the blower of the exhaust variable valve. Also, according to the result of analyzing a flux of 10.0 (g/s) supplied from the blower, it is shown to correspond to an engine speed around 3,000 rpm to 3,500 rpm.

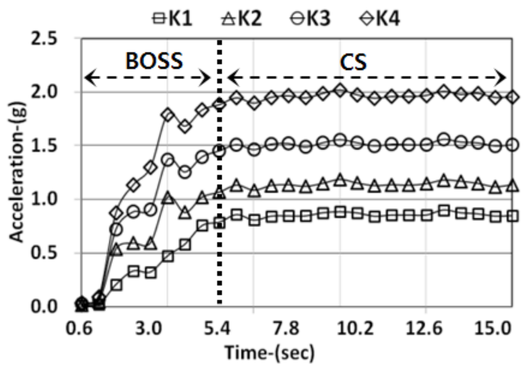

Figure 8. Vibration levels for different spring constants at flux 9.2 (g/s).

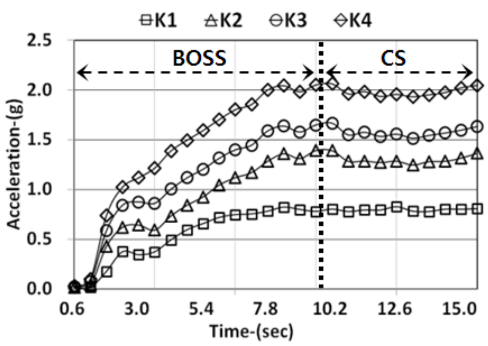

Figure 7. Vibration levels for different spring constants at flux 8.3 (g/s).

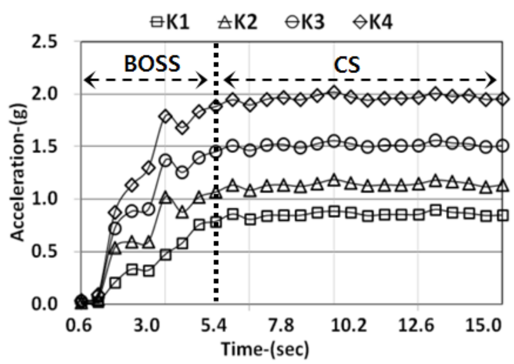

Figure 9. Vibration levels for different spring constants at flux 10.0 (g/s).

The experimental results suggest that BOSS of K1, K2, K3 and K4 experienced vibration due to valve opening and closing in the exhaust variable valve with different torsion spring constants between 0.6 seconds and 4.8 seconds in the order of K1 (0.6 (g)) < K2 (0.8 (g)) < K3 (1.3 (g)) < K4 (1.8 (g)). This could be seen to indicate that all opening and closing angles of the exhaust variable valves behaved and to be a cause for the change in opening and closing angles of the valve in the order of K1 (6 °) < K2 (5 °) < K3 (3.8 °) K4 (2 °). Therefore, this could be analyzed to be a vibration opened and closed as a result of the initial vibration angle of BOSS reacting increasingly faster.

CS of K1, K2, K3 and K4 was stabilized after 4.8 seconds, and the results could be seen from a significant increase in the flux supplied by the blower where opening and closing of the exhaust variable valve were maintained to produce subtle pulsation.

Figure 10 illustrates the vibration result of the valve detected as a function of torsion spring constants of the exhaust variable valve when a flux of 11.4(g/s) was supplied from the blower of the exhaust variable valve. Also, according to the result of analyzing a flux of 11.4(g/s) supplied from the blower, it is shown to correspond to an engine speed of around 3,600rpm to 4,000rpm.

The experimental results indicate that BOSS of K1, K2, K3, K4 experienced vibration due to valve opening and closing in the exhaust variable valve with different torsion spring constants between 0.6 seconds and 7.4 seconds in the order of K1(0.8(g)) < K2(1.2(g)) < K3(1.6(g)) < K4(2.1(g)). This might signify that all opening and closing angles of the exhaust variable valves behaved under a high flux supplied from high-speed revolution of the blower and were be the cause for changes in opening and closing angles of the valve in the order of K1(6.5 °) < K2(5.5 °) < K3(4.4 °) K4(2.8 °). Therefore, the vibration trend of BOSS was analyzed to be a vibration result produced from unstable changes in back pressures inside the muffler simulation device.

CS of K1, K2, K3 and K4 was stabilized after 7.4 seconds, and it could be seen that a strong back pressure inside the muffler simulation device was transmitted to the blower to show certain vibration trend. Therefore, a contradiction could be reaffirmed that a fuel economy could be lowered by increasing a back pressure inside the muffler when engine speeds of an automobile are high.

Figure 11 shows the vibration result of the valve detected as a function of torsion spring constants of the exhaust variable valve when a flux of 12.7(g/s) was supplied from the blower of the exhaust variable valve. Also, according to the result of analyzing a flux of 12.7(g/s) supplied from the blower, it is shown to correspond to an engine speed of around 4,700rpm to 5,000rpm.

According to the experimental results, BOSS of K1, K2 showed a similar vibration trend between 0.6 seconds and 3.8 seconds in the magnitude of K1 (0.5 (g)) < K2 (0.8 (g)), while BOSS of K3, K4 showed a similar vibration trends between 0.6 seconds and 5.8 seconds in the magnitude of K3 (1.4 (g)) < K4 (2.1 (g)). According to the results of analyzing this, it could be analyzed as a cause for the slowdown in response to opening and closing of the valve, since torsion spring constants of the exhaust variable valve of K3, K4 were designed to be somewhat strong.

CS of K1, K2 was stabilized after 3.8 seconds, while CS of K3, K4 was deemed to be the same as the results of K1, K2. Even if a maximum flux of the blower was supplied, there was not any noticeable peculiarity in CS.

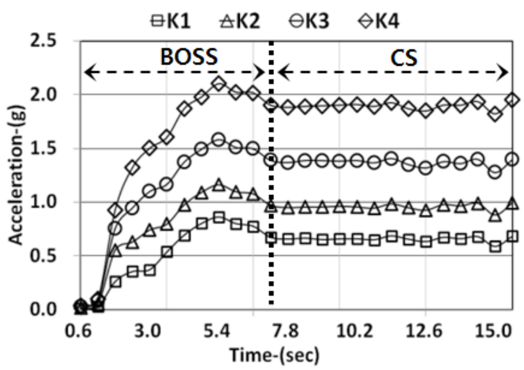

Figure 10. Vibration levels for different spring constants at flux 11.4 (g/s).

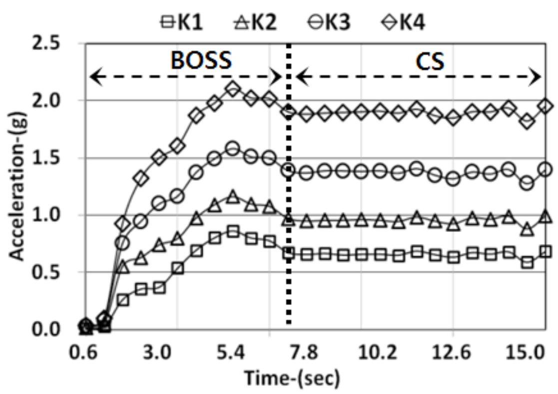

Figure 11. Vibration levels for different spring constants at flux 12.7 (g/s).

4. Conclusions

Based on the results of measuring the opening and closing angles for 4 different torsion spring constants being K1, K2, K3, K4 respectively of an exhaust variable valve, and experimenting with vibration produced in the exhaust variable valve through back pressure experiments employing an exhaust behavior simulation device, the following conclusions could be obtained.

- According to the results of conducting back pressure experiments with respect to mass flux supply for 4 different torsion spring constants being K1, K2, K3, K4 respectively of the exhaust variable valve, a parabolic trend increasing in the order of K1 < K2 < K3 < K4 was observed.
- For combustion pressures produced in the combustion chamber of an engine, back pressure performance could be seen to be improved when back pressures inside a muffler were maintained in a stable manner, in the case of adjusting torsion spring tension of the exhaust variable valve.
- Since the discharge flux produced in the combustion chamber of an automobile varies with driving conditions, it indicates that shock sound due to closing shock of the exhaust variable valve could be produced in case of rapid acceleration of speed.
- When an automobile engine speed reaches acceleration domain, back pressures of a particular domain can be reduced in the exhaust variable valve, and it is considered that a more excellent engine performance can be obtained than in the case of specifically designed torsion spring tension.

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