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A Study on Evaluation of Strut Type Suspension Noise Caused by Rubber Degradation

Gugyong Kim, Sugnsu Kang, Yongjun Lee, Sooncheol Park, and Wonwook Jung

***Abstract*—**When cars are released from the factory, strut noises are very small and therefore it is difficult to perceive them. As the use time and travel distance increase, however, strut noises get larger so as to cause users much uneasiness. The noises generated at the field include engine noises and flow noises and therefore it is difficult to clearly discern the noises generated from struts. This study developed a test method which can reproduce field strut noises in the lab. Using the newly developed noise evaluation test, this study analyzed the effects that insulator performance degradation and failure can have on car noises. The study also confirmed that the insulator durability test by the simple back-and-forth motion cannot completely reflect the state of the parts failure in the field. Based on this, the study also confirmed that field noises can be reproduced through a durability test that considers heat aging.

***Keywords*—** Insulator, noise, performance degradation, strut

I. Introduction

As passenger car users demand improved quietness, the design focus has been put on improved comfort and reduced noises and it is needed to reduce noises and vibrations generated during driving. Recently, as car weights decrease and their outputs increase, engine exciting forces increase and car bodies become vulnerable to vibrations, requiring enhanced NVH performances [1]. The noises and vibrations of the suspension system are the major sources of noises which undermine comfort and cause anxiety from drivers [2]. Typical independent suspensions include double wishbone and Macpherson strut types. Many automakers have recently adopted the Macpherson strut type as its structure is simple with the suspension system in the front wheel part and its maintenance is easy owing to the one-body type [3]. Struts absorb shocks generated from road surfaces and alleviate the noises and vibrations which are generated at this time and delivered to the car body. Prior to this study, an analysis was made on the customer complaint data collected by the automobile repair industry for the past four years in relation to Macpherson strut malfunctions (3,420 cars; January 2005-March 2009). The analysis results show that 69 percent of the complaints were about noises, 25 percent were about oil leakage and 6 percent were about other problems, indicating that much more problems were related to noises. In most cases, strut noises are extremely small at the time of releasing cars and therefore it is difficult to detect such noises. With the increase in the travel time and distance, however, the noises become bigger to the extent that users feel anxiety. Existing studies on struts and dampers mostly concentrate on initial dynamic characteristics of struts and dampers and noise delivery characteristics during driving [4]-[6]. These studies in particular focus on initial characteristics and thus fail to approach the durability quality with which users are mainly dissatisfied.

G. K. Author is with the Department of Mechanical and Precision Engineering, Pusan National University, Busan, South Korea (e-mail: beaverx@empal.com).

S. K. and Y. L. Authors are with the Department of Mechanical and Precision Engineering, Pusan National University, Busan, South Korea (e-mail: kangss@pusan.ac.kr).

S. P. and W. J. Authors are with the Hyundai Motor Company, Gyeonggi-Do, South Korea (e-mail: testdrv@hanmail.net).

Most suspension system noises do not come from a single part but they are caused by the coupling action between related parts, making it difficult to clearly identify the exact causes. In particular, it is difficult for car and part manufacturers to identify the part noises about which users complained in the field. This is because it is difficult to separate the suspension system noises as the signals measured through driving tests include both engine and flow noises. To resolve the durability noise problem of the suspension system, it is necessary to develop a new test method which can clearly confirm the noise causes. It is also needed to improve the product quality in the right direction based on the results obtained by the newly developed test method. This study developed a new test method which can confirm the field noises in a strut module state or at part makers. Then the study identified the strut noise causes and reproduced the noises through a comparative evaluation test. This comparative test was conducted on the parts which went through a durability test and the strut parts which generated noises in the field as their service time increased.

II. Field Noise and Road Surface Measurement

A. Noise Measurement

Suspension system noises occur when cars are running on a specific road surface. Noises seldom occur when cars are running on normal road surfaces with good pavement conditions. To reproduce the noises consumers' experience, the first thing to do is to examine the road surface on which cars made noises. The maintenance records of automobile repair shops were checked to find out the characteristics of the road surfaces which made noises. The results show that noises were often made on the road surfaces which have relatively narrow grooves (width: 8 cm; depth: 3 cm) after suffering partial settlements following pavage as shown in Fig. 1. To convert the noises consumers experience into data, the noises were measured using a microphone and acceleration sensors. As for the sensor positions, acceleration sensors 1 and 2 were installed in the insulator and damper of the passenger seat strut which makes noises and acceleration sensor 3 was placed in the damper of the driver seat strut. A microphone was installed in the passenger seat to measure the noises occurring within the car (Fig. 2). To check that noises are made on the actual road surface concerned, driving with a used part which received claims was conducted on the surface in question and noise occurrence was confirmed.

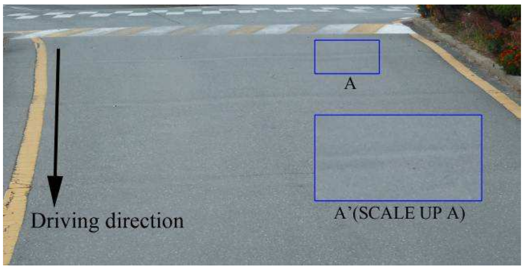

Fig. 1 Road surface generating strut noises

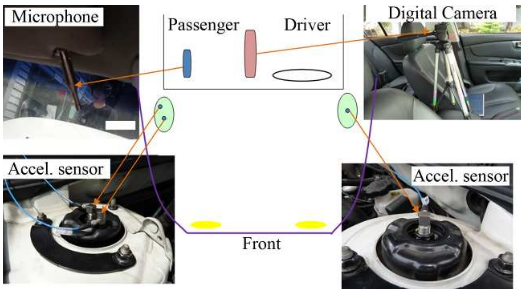

Fig. 2 Sensor installation position

B. Measuring the Road Surface Generating Noises

The road surface exciting noises measured within a car represent noises caused by the road surface exciting force delivered through the wheels. Ultimately, they represent structural noises below the low-frequency band (generally 400Hz) formed by the chassis vibration [7].


Fig. 3 Installation of the strain gauge-attached strut module on the car

Experiments should be conducted under the same conditions in order to evaluate noises quantitatively. In comparatively evaluating various parts of a car, however, the data values vary depending on the car speed and tire positions even on the same road surface. To reduce such variances, it is needed to measure the actual strut movements and it is difficult to discern the noises generated by the road surface exciting as the signals measured through a driving test include both engine noises and flow noises at the same time. Strain gauges were attached to strut parts to observe the strut state during driving on the noise-making road surface. Fixed jigs were made for calibration of sensor-attached parts. Each part was fixed to material testing system (MTS) which read load, displacement and data.

Parts which went through calibration were assembled into a strut module and this module was installed on the car (Fig. 3) to measure the profiles of the noise-generating road surface (Fig. 4). Sensor-attached springs were installed on the car before conducting the experiment. Fig. 4 indicates the strut movement profiles measured on the noise-generating road surface.

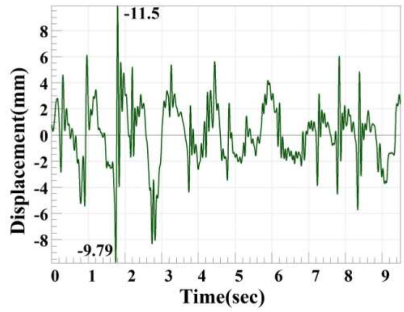

Fig. 4 Profiles of the noise-generating road surface

The data measured here represent spring displacements (Fig. 5; Ds). The spring displacements are divided into the damper displacement (Fig. 5; Dd) and the insulator displacement (Fig. 5; Di). The relation can be summarized in (1).

$$Ds = Dd + Di \tag{1}$$

Here, Ds is spring displacement, Dd is damper displacement, and Di is insulator displacement.

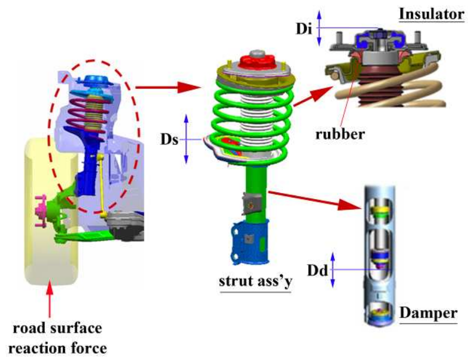

Fig. 5 Diagram of the relation among spring displacement, insulator displacement and damper displacement

III. Lab-Based Noise Reproduction Experiment In A Strut Module State

The following experiment was performed to reproduce the field noises in a strut module state. The experiment was conducted in an anechoic room. The motion of the MTS tester was given using the profiles measured on the noise-generating road surface (Fig 4). To compare the noise degrees, acceleration sensors were attached to the upper ends of the damper rod and insulator in the same way as the positions of the actual car test (Fig. 6).

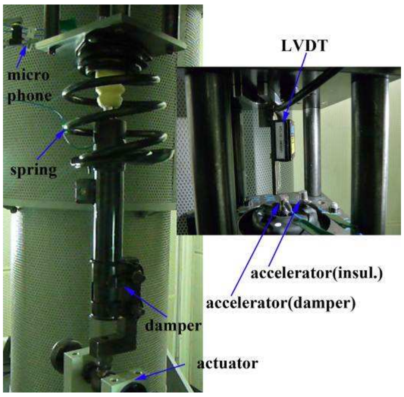

Fig. 6 Composition of spring displacement control experiment devices in a strut module state

Fig. 7 shows the data measured by the accelerometer attached to the upper end of the insulator. It represents the size of acceleration measured on-site and in a lab-based experiment. It can be seen that the lab-based experiment properly reproduces the acceleration size measured on-site.

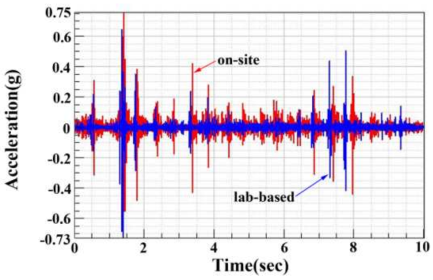

Fig. 7 Comparison of acceleration data measured on-site and in a lab-based experiment

To reproduce the noises with an insulator, it is needed to divide the spring displacements into the damper displacement and the insulator displacement. To this end, a spring displacement control experiment was performed in a single strut module state. The displacement measuring device LVDT (Linear Variable Differential Transformer) was installed on the end of the damper rod to measure the insulator displacement. The measured displacement data are shown in Fig. 8.

In Fig. 8, (a) represents the experiment with the combination of a new damper and a new insulator and (b) indicates the experiment with the combination of a new damper and a used insulator (82,000 km; 4 years). It can be seen that the new product displacement (2.266 mm) is greater than the used product displacement (1.108 mm). Natural rubber (NR) is mostly used for the rubber material of the insulator. To find out the difference between the initial-state (new) insulator and the used insulator, the strut insulators were disassembled and the rubber shapes were compared. The rubber thickness of the initial-state insulator was 37.8 mm and that of the used insulator was 30.9 mm, showing a difference of 6.9 mm (Fig. 9).

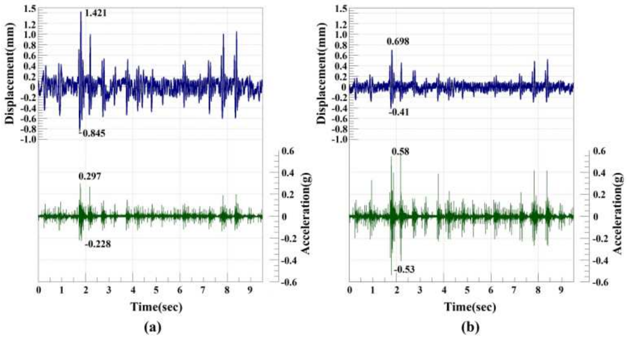

Fig. 8 Comparison of displacement and acceleration data for the insulator noise section: (a) new insulator; (b) used insulator generating noises

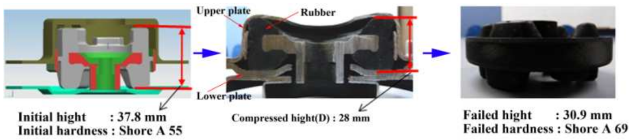

Fig. 9 Insulator rubber thickness and hardness change order

As shown in Fig. 11, the insulator rubber is compressed by the upper and lower metal sheets to prevent vibrations and noises from reaching the car body. The compression amount can be expressed as in (2).

$$C_h = t_2 - t_1 \tag{2}$$

Here, C_h : rubber compression height (mm), t_1 : rubber thickness 30 minutes after insulator disassembling (mm), t_2 : rubber thickness compressed by metal sheets (mm)

It can be confirmed that the rubber compression height, which represents the height difference between the disassembled rubber and the compressed rubber, changed from 9.8 mm (the new product) to 2.9 mm (the used product).

To compare the rubber hardness, the hardness was measured using the durometer (KS M 6518 Shore A type). The hardness value of the initial-state insulator is Shore A 55 and that of the used insulator is Shore A 69, indicating a difference of +14. The insulator degradation was caused by the heat (of the engine and the air) and the repeated loads [8-10]. An experiment was conducted to measure the insulator's temperature changes during driving and stopping. The experiment's conditions included 30 °C in the summer and downtown driving and stopping (Fig. 10). It can be confirmed that the insulator temperature rises up to 50 °C during driving and up to 63 °C during stopping as there is no air circulation and the car iron plate temperature increases due to the engine temperature and the solar heat.

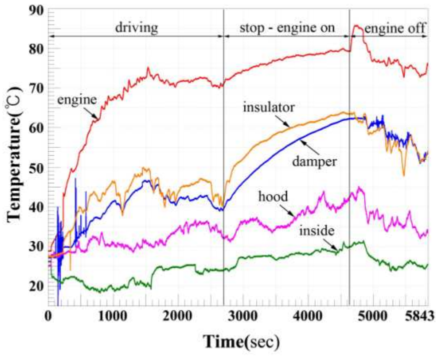

Fig. 10 Insulator during driving in summer (30 °C) and damper temperature data

IV. Insulator Noise Confirmation Test

In general, the insulator movement is affected by acceleration and the load coming from the road surface. Therefore, the stroke measured in Fig. 8 should be converted into a load to conduct an insulator reproduction experiment. The conversion of the stroke into a load was performed by recording the load change depending on the stroke from the load cell after installing the new insulator (which was used when measuring Fig. 10(a)) on the subcomponent tester. Fig. 11 shows the experiment device composition. To ensure exact noise measurement, the reactions which occur during the insulator operation were measured by repeating the noise-generating section 1.5-3.0 seconds (Fig.8) 10 times.

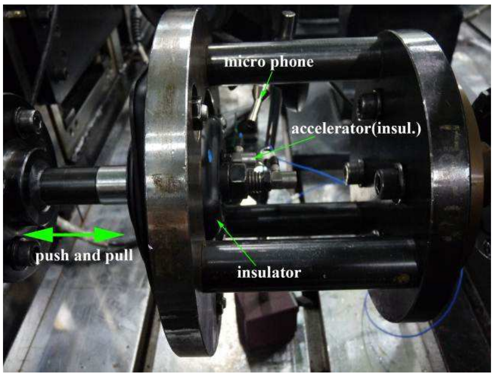

Fig. 11 Composition of insulator noise confirmation experiment devices

With the newly developed noise confirmation test, the acceleration data of the new insulator and the used insulator generating noises were compared (Fig. 12). The insulator noise confirmation test was conducted in a general lab, not in an anechoic room. Accordingly, both the new insulator and the used insulator generated additional ±0.15 g of noises due to the noise occurring during the hydraulic operation. In the case of the used insulator, the noises were generated at positions with greater operation loads and frequencies. As a result, the new test method developed in this study could reproduce the noises generated by the used insulator in the field.

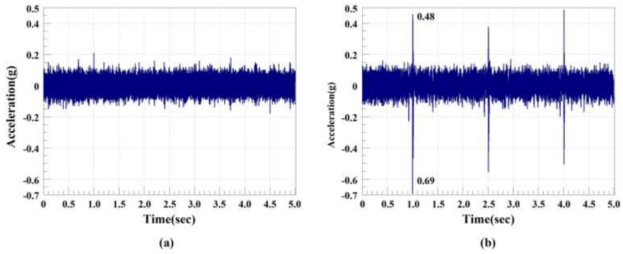

Fig. 12 Comparison of insulator noise generation degrees: (a) new insulator; (b) used insulator generating noises

V. Discussion

A. Effects of Insulator Performance Degradation on Noises

An insulator is a core part which prevents the road surface vibrations and noises from reaching the car body [11], [12]. The noise evaluation test method developed in this study quantitatively confirmed the effects of the insulator performance degradation on noises.

TABLE I
THE CHANGES IN THE RUBBER HARDNESS AND COMPRESSION SET

No.	Mileage (km)	Production date	Hardness change	Compression set(C)	Acceleration(g)
A-1	25,678	2008, 10	14	78.9%	1.24
A-2	25,758	2008, 09	8	56.7%	0.55
A-3	66,898	2005,12	17	78.9%	1.79
A-4	80,010	2005,10	17	68.9%	1.41
A-5	82,353	2006,02	17	72.2%	1.07
A-6	114,922	2007,12	9	48.9%	0.49
B-1	39,315	2007,07	9	57.5%	1.55
B-2	59,615	2007,01	13	55.0%	1.73
B-3	66,507	2006,11	7	45.0%	1.40
B-4	85,773	2006,07	13	70.0%	2.15
B-5	97,070	2006,05	14	77.5%	2.77
B-6	123,612	2006,12	10	65.0%	1.60

Strut modules for each travel distance were collected for two types of cars (Type A and Type B). The module-state lab-based noise evaluation test suggested in this study was performed to confirm the insulator noise characteristics. After the test, the insulator was disassembled to measure the hardness (Shore A) and the compression set (Table I). The compression set calculation method is shown in the following (3).

$$C = \frac{t_0 - t_1}{t_0 - t_2} \times 100 \qquad (3)$$

Here, C : compression set (%), t_0 : initial insulator rubber thickness (mm), t_1 : rubber thickness 30 minutes after insulator disassembling (mm), t_2 : compressed rubber thickness (mm)

The insulator temperature measurement data (Fig. 10) indicate that the temperature during stopping is higher than that during driving. This means that, even when the traveling time is the same, the severity of a car with a long period of stopping time (such as a commuter car which drives on a downtown road with a traffic jam) is greater than that of a car with little stopping time (such as a car continuously running on an express way). The changes in the rubber hardness and compression set summarized in Table I confirm that the insulator rubber degradation is affected by the driving environment more than the simple travel distance or the time of car use.

Fig. 13 shows the results of comparison between the rubber hardness change and the acceleration change depending on the compression set. The experiment results indicate that the acceleration, that is, the noise increases as the rubber hardness changes and the compression set increases.

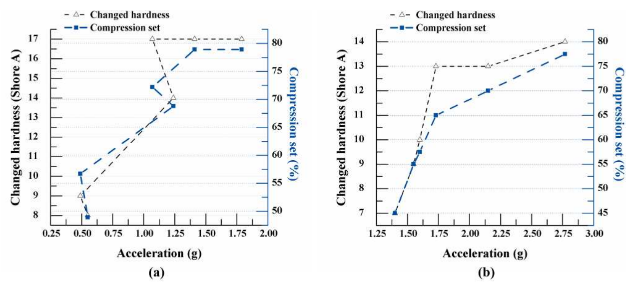

Fig. 13 Comparison of hardness and compression set: (a) Type A; (b) Type B

B. Effects of Damper and Insulator on Noises Delivered

To see how the state of the damper and insulator which constitute a strut affects noises, an experiment was conducted with use of a used part of Type A. A module-state lab-based noise evaluation test was performed using new strut parts except the damper and insulator so that the effects of the parts other than the damper and insulator can be excluded. In the experiment using a used damper and a used insulator, five out of eight samples showed 1 g or greater vibrations which were delivered to the car body through the insulator (Fig. 14(a)). In an experiment using the same damper and a new insulator, even when the damper generated vibrations with great deviations between 5 g and 18 g, only vibrations between 0.35 g and 0.6 g were delivered to the car body through the insulator (Fig. 14(b)). The experiment results show that the insulator performance has greater effects on the vibrations and noises conveyed to the car body than the damper performance.

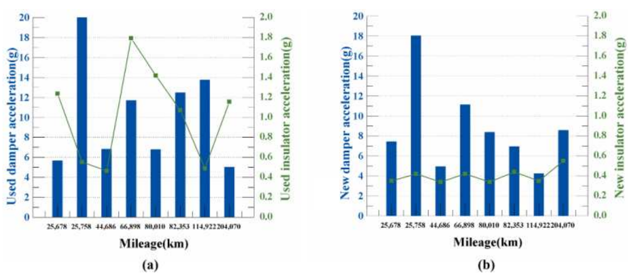

Fig. 14 Effects of insulator performance on noises: (a) used insulator; (b) new insulator

C. Improvement of Insulator Durability Test Method

Existing insulator durability tests are carried out by applying certain repeated compression and tension loads to the insulator at room temperature. In this case, rubber softening takes place due to the repeated loads, failing to reproduce rubber hardening which occurs in the field. In addition, noises are not confirmed even with the insulator noise confirmation test (Fig. 15(a)). To resolve these problems, a cyclic reproduction test was developed by considering the insulator's use environment condition, that is, the temperature condition. The data obtained through the newly developed reproduction test can confirm the noise reproduction as shown in Fig. 15(b).

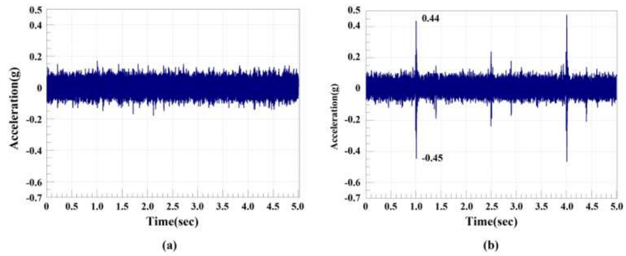

Fig. 15 1Comparison of insulator noise generation degree: (a) existing durability test; (b) cyclic durability test

VI. Conclusion

This study developed a test method which can evaluate noises in a module state of the suspension strut parts and it confirmed the effects of the insulator performances on noises. The results showed that the structural noises delivered to the car body were greatly affected by the insulator.

According to the analysis results of the noise-generating insulator parts, the structural noise delivered to the car body increased as the performance degradation of the rubber part, that is, the hardness change and compression set increased.

The insulator durability test based on the application of simple and mechanical repeated loads fails to completely reproduce the rubber hardening phenomenon occurring in the field. The cyclic test considering the temperature condition could reproduce this phenomenon almost completely and the noise evaluation test could confirm the noise reproduction.

The noise evaluation test developed in this study is expected to be effectively used as a method that can resolve field claims and identify problems occurring in the initial period of strut part development.

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Gugyong Kim received his M.S. degree from Graduate School of Pusan National University, Busan, South Korea in 2008. He is currently in the doctoral course of Graduate school of Pusan National University. He research interests is polymer properties and processing.