한국기계가공학회지, 제20권, 제7호, pp. 25～32(2021.07) ISSN 1598-6721(Print)
Journal of the Korean Society of Manufacturing Process Engineers, Vol. 20, No. 7, pp. 25~32(2021.07) ISSN 2288-0771(Online)

https://doi.org/10.14775/ksmpe.2021.20.07.025

A Study on the Improvement of Smoke Probe Performance in Diesel Vehicles Using Korean 147 Test Method

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한국형 147검사 방법을 이용한 디젤자동차의 매연프로브 성능 향상 연구

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(Received 05 March 2021; received in revised form 12 April 2021; accepted 19 May 2021)

ABSTRACT

In the previous study, a study was conducted to improve the exhaust gas intake efficiency by improving the existing soot measurement probe in the shape and angle of the exhaust port. As a result, it can be seen that the smoke measurement performance according to the shape and angle is improved. In previous studies, the performance of the soot probe was not confirmed for the Korean KD 147 mode, which has a low suction flow rate and a long inspection time. So, we would like to confirm the improvement of the smoke probe performance of the Korean KD 147 mode, which is close to the actual driving conditions. The probe used in this study is another type of probe, and has a circular ring shape instead of a rib and variable center position unit, so the probe center hole is located close to the center of the exhaust pipe.

Key Words : KD-147 Mode(한국형 검사 모드), Exhaust Efficiency(배기효율), Circular Ring Probe(원형 링 프로브)

1. Introduction

The automotive industry worldwide is transitioning rapidly from the traditional internal combustion engine systems to eco-friendly vehicles. The transport industry's efforts to reduce the damage from the extreme climate change caused by the increasing greenhouse gas emissions constitute a key factor that is driving this transformation.

This trend of eco-friendly vehicles is transforming the market from hybrid systems to electric vehicles and hydrogen fuel cell vehicles. This, in turn, is likely to rapidly decrease the number of small and medium-sized

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cars with internal combustion engines from approximately 2035. In particular, because internal combustion engines using diesel are acknowledged as the primary sources of greenhouse gases and particulate matters, the sale of new cars are likely to be prohibited and to decline in the European Union, China, Japan, and Korea after 2035. The use of vehicle emission inspection inspection systems (a method of greenhouse gas reduction for diesel vehicles) is also likely to decrease steadily from approximately 2035. However, even after this year, exhaust gas inspection would be performed on vehicles with internal combustion engines sold or registered prior to this year and used as a method of reducing the greenhouse gas emissions of vehicles. Furthermore, the proportion of the exhaust system diagnosis method is forecasted to increase[1~9]. Currently, among the diesel vehicle inspection methods, smoke measurement techniques are being implemented. These include the no-load rapid acceleration technique (a no-load test), and the Lug-down 3 mode and KD 147 mode inspection techniques (load tests)[10~12]. It is necessary to enhance the automobile inspection system considering that exhaust gas soot measurements may differ depending on the shape of the exhaust port and insertion angle under certain conditions. Therefore, research has been conducted for improving the exhaust gas or soot intake efficiency by improving the existing soot measurement probe. Consequently, the smoke measurement performance of diesel vehicles was improved according to the shape and insertion angle conditions [13,14]. The performance of the improved soot probe was also demonstrated for the light transmission-type no-load rapid acceleration inspection technology (no-load inspection method) applied to the measurement of soot concentration in diesel vehicles. For this technology, the exhaust gas cannot be measured by a load test using a chassis dynamometer [15].

The objectives of this study are to apply an improved soot probe to the Korean KD 147 mode inspection technology and to verify the improved performance. This inspection technology approximates actual driving conditions because it is characterized by a low suction flow rate and long inspection time. This study is also aimed at improving the effectiveness of the inspection system through the performance verification.

2. Soot Probe

Soot probe is a soot measuring tool used in vehicle exhaust gas inspection. Its inlet needs to maintain a certain distance from the exhaust pipe wall. It requires high durability to prevent damage by the impact and high exhaust heat that occur at this time. To address this requirement, a previous study developed two soot probes and examined their performances. A support was added to the rib of Soot probe (b) used in this study and a hole added to its side. These were incorporated to improve the intake performance according to the variation in angle (see Fig. 2) and thereby, reduce the damage caused by impact (see Fig. 1) and improve its durability.


(a) (b)

Fig. 1 Shape of damaged smoke measurement probe

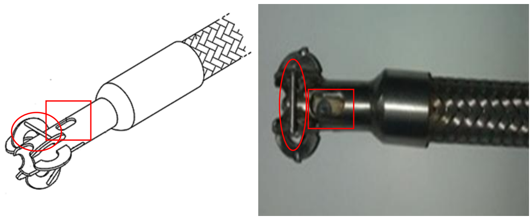
(a) (b)

Fig. 2 Schematic of improved measuring probe(b)

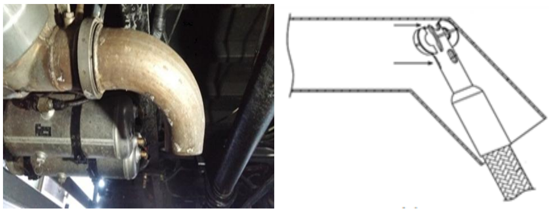
(a) (b)

Fig. 3 Various shapes of automobile exhaust pipe


(a) (b)

Fig. 4 Schematic of improved measuring probe(c)

In addition, if the exhaust pipe has an angle or is larger than the outer diameter of the soot probe, the probe's center can be positioned at the center of the exhaust pipe rather than the existing soot probe (see Fig. 3). As displayed in Fig. 4 (a) and (b), the structure was enhanced to a variable center position unit or circular ring shape. Thereby, the soot probe center could be positioned closer to the center of the exhaust pipe. Furthermore, Probes (a), (b), and (c) have size identical to that of the intake part.

3. Soot Measurement Technology

3.1 Korean Diesel 147 (KD-147 mode) technology

The Korean Diesel 147 mode is an inspection technique performed under standard condition in accordance with the "Regulations on the Enforcement Guidelines for Detailed Inspection of Exhaust Gases from Vehicle" based on Articles 61–69 of the Clean Air Conservation Act. Here, standard condition implies the condition of air at the intake temperature of 298 K and pressure of 100 kPa. With regard to the mode setup, the road load horsepower is measured while a diesel vehicle of standard weight is driven for 147 s according to the predefined driving cycle in Chassis Dynamo. Herein, the soot concentration (%) is measured at constant speed, acceleration, and deceleration for 147 s from an idle state to the maximum speed of 83.5 km/h according to the driving graph. Furthermore, the road load horsepower is set according to the standard vehicle weight in Chassis Dynamo. At this time, the soot concentration is measured under standard conditions using a light transmission-type soot meter with a partial flow sampling method.

The soot concentration is measured in standard conditions with a light transmission type soot meter using a partial flow sampling method. For vehicle inspection, foreign substances such as dust, water, and soil are removed from the wheels of the vehicle, the manual transmission is set to neutral and auto transmission to (N) or (P), and the non-drive wheels are fixed using parking brakes or chocks. The electrical devices and accessories of the vehicle that may affect the emission measurement unduly are not operated. Furthermore, a sampling pipe is inserted to a depth of at least 10 cm and placed at a distance of at least 5 mm from the exhaust pipe's wall. In addition, an engine cooling blower is installed and operated.

3.2 Inspection mode setting

In the warm-up mode, the engine is preheated for 40 s by driving at a speed of 50 ± 6.2 km/h at a load of 40% of the rated engine power in Chassis Dynamo.

In the driving mode, immediately after the warm-up mode ends and the Chassis Dynamo roller stops (see the driving graph in Fig. 5), the vehicle is driven at constant speed, acceleration, and deceleration for 147 s from an idle state to the maximum speed of 83.5 km/h according to the predefined driving data. For the tolerance during driving, the upper and lower limit speeds need to be maintained as displayed in Figs. 6 and 7, respectively.

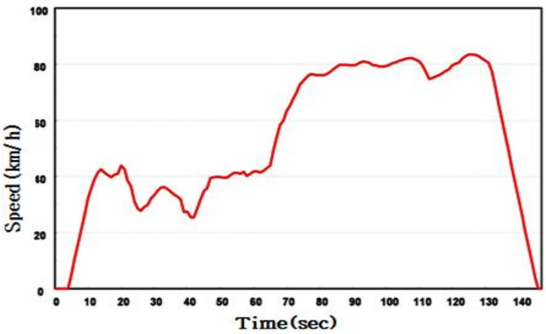

Fig. 5 KD 147 mode running graph

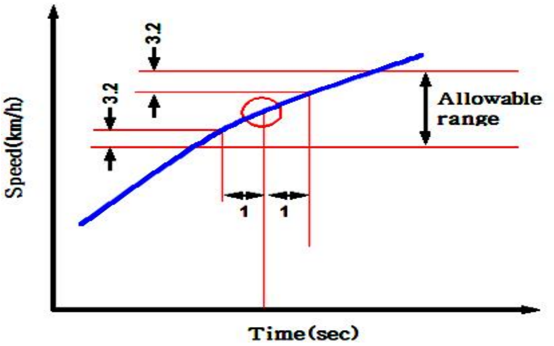

Fig. 6 Maximum speed operation tolerance

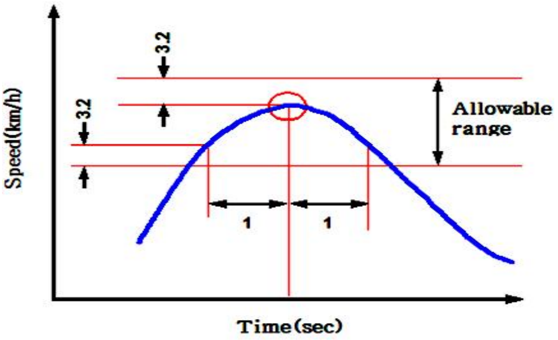

Fig. 7 Lower limit speed operation tolerance

Table 1 Manual transmission driving cycle and gear shift point

Time(sec)	4	8	12	26	52	70	74	141
Gear stage	1	2	3	2	3	4	5	N

With regard to gear shift for manual transmission vehicle, the driving cycle needs to be displayed together with the gear shift time on the driver's monitor screen. The gear shift appropriate to the driving cycle needs to be selected. The gear shift stages over time are implemented as presented in Table 1.

3.3 Assessment of test results

For the assessment of the soot measurement as specified in the close inspection method and the standard in the Enforcement Rule of the Clean Air Conservation Act, the arithmetic mean (A) of five measurements for 1 s at 0.25 s before and after the highest measured value is used as the measured value of the smoke meter. However, if this arithmetic mean exceeds the soot tolerance standard and the soot tolerance standard is 30% or higher, the arithmetic mean (B) for 7 s at 3 s before and after the highest measured value is determined. If this arithmetic mean exceeds the soot tolerance standard by over 20%, the arithmetic mean (A) for 1 s is applied as the measured value. Alternatively, if it exceeds the soot tolerance standard by 20% or less, the arithmetic mean (B) is applied as the measured value. If the soot tolerance standard is 25% or less, the arithmetic mean (B) for 7 s at 3 s before and after the highest measured value is determined. If this arithmetic mean exceeds the soot tolerance standard by at least 10%, the arithmetic mean (A) for 1 s is applied as the measured value. If it exceeds the soot tolerance standard by less than 10%, the arithmetic mean value (B) for 7 s is applied as the measured value. The arithmetic mean (A, B) is assessed as acceptable if it does not exceed the soot tolerance standard and as unacceptable if it exceeds the standard.

4. Test Setup

Fig. 8 displays the components of the automotive load inspection equipment and an actual test vehicle of the comprehensive inspection site of a designated maintenance service provider that satisfies the facility standards of the Clean Air Conservation Act. As displayed in this figure, the components include (from the top left) soot probe, soot suction hose, soot meter, and Chassis Dynamo. A round ring-shaped probe (c) is installed at the bottom. The operation program is displayed at the upper right, and the exhaust pipe tip installed in the test vehicle for soot measurement is displayed at the bottom. The test conditions approximated the standard conditions as presented in Table 2. Tables 3 and 4 present the specifications of Diesel vehicles A and B tested in this study.

5. Test Method and Discussion

5.1 Test method

For the soot measurement test, Probes (a), (b), and (c) were inserted into the exhaust pipe at angles of 70 and 90° to it (see Figs. 9 and 10). The separation of the center of the soot probe from that of the exhaust pipe is also displayed. The test was conducted using the Korean KD 147 mode inspection technique at 90°, wherein the distance between the soot probe and the center of the exhaust pipe is maximum.

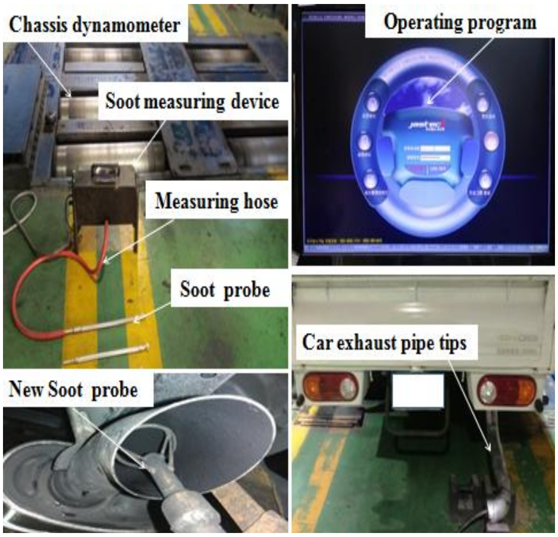

Fig. 8 Configuration of equipment

Table 2 Measuring conditions

Item	Measuring conditions
How to measure	KD-147 mode
Ambient temperature (℃)	10~35
Atmospheric humidity(%)	45~75
Atmospheric pressure(kpa)	101.3

Table 3 Specifications of experimental vehicle A

Item	150,000 km engine
Model	A
Displacement (cc)	2,497
Number of cylinder	4
Maximum output (ps)	126
Rated speed (rpm)	3800
Fuel	Diesel
First registration date	2012
Vehicle weight (kg)	1,870

Table 4 Specifications of experimental vehicle B

Item	260,000 km engine
Model	B
Displacement (cc)	2,607
Number of cylinder	4
Maximum output (ps)	83
Rated speed (rpm)	3800
Fuel	Diesel
First registration date	2001
Vehicle weight (kg)	1,620


(a) (b) (c)

Fig. 9 (a), (b), (c) probes position at 70 degrees

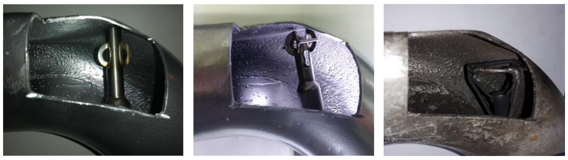
(a) (b) (c)

Fig. 10 (a), (b), (c) probes position at 90 degrees

In addition, residual soot can accumulate in diesel vehicles depending on usage time and mileage. These may cause deviations in the amount of measured soot. Hence, to remove the residual soot in the exhaust system, the soot intake was measured after testing three times in the KD 147 mode.

5.2 Results

Figs. 11–13 display the results of soot intake for the existing soot probe (a) and improved soot probes (b) and (c) for Vehicle A. These are considered as the reference for performance improvement in the rapid acceleration sections (0 km/h to 40 km/h and 40 km/h to 80 km/h) and deceleration section (80 km/h to 0 km/h) according to the driving cycle of the driving graph in Fig. 5. Furthermore, these are obtained using the Korean KD 147 mode inspection technique after inserting the probe into the 90° exhaust pipe. Figs. 14–16 display similar results for Vehicle B.

First, for Vehicle A, almost no soot intake of Soot probe (a) was measured in the rapid acceleration section from 0 km/h to 40 km/h (see Fig. 11). Average soot intakes of 1.0% and 5.0% were measured for Soot probes (b) and (c), respectively. In Fig. 12, which is the rapid acceleration section from 40 km/h to 80 km/h, the average soot intakes of Probes (a), (b), and (c) were 0.5%., 1.0%, and 3.0%, respectively. In Fig. 13, which is the rapid deceleration section from 80 km/h to 0 km/h, almost no soot was measured for Soot probes (a) and (b). Meanwhile, an average soot intake of 2.0% was measured for Soot probe (c).

Furthermore, for Vehicle B, the average soot intakes measured for Soot probes (a), (b), and (c) in the rapid acceleration section 0 km/h–40 km/h (Fig. 14) were 3.65%, 8.3%, and 11.0%, respectively, and those in the section 40 km/h–80 km/h (Fig. 15) were 8.5%, 13.5%, and 16.5%, respectively. In the rapid deceleration section (Fig. 16), almost no soot intake was measured for Soot probe (a), whereas an average soot intake of 1.5% was measured for Soot probes (b) and (c).

For Vehicle A, almost no soot intake was measured for Probes (a) and (b) in the rapid acceleration and rapid deceleration sections. However, the soot intake measurements of 5%, 3%, and 3% for Soot probe (c) in these sections, respectively, verified the improvement in its performance.

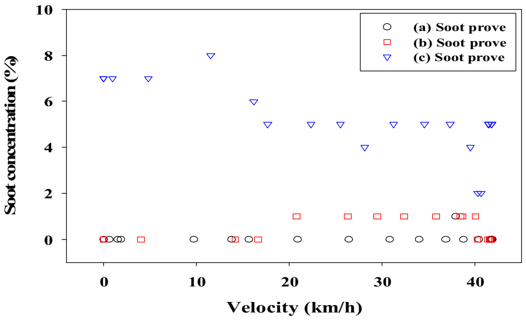

Fig. 11 Rapid acceleration section from 0km/h to 40km/h

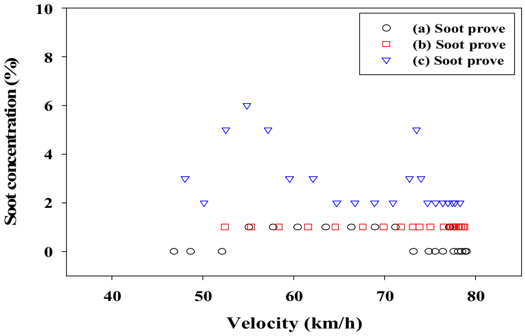

Fig. 12 Rapid acceleration section from 40km/h to 80km/h

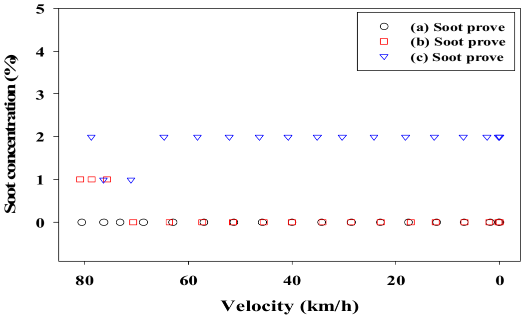

Fig. 13 Section where there is a rapid deceleration from 80km/h to 0km/h

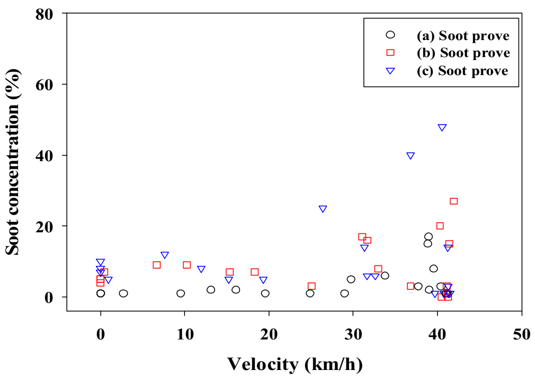

Fig. 14 Rapid acceleration section from 0km/h to 40km/h

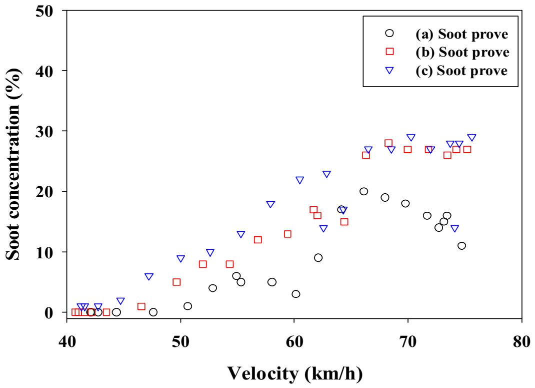

Fig. 15 Rapid acceleration section from 40km/h to 80km/h

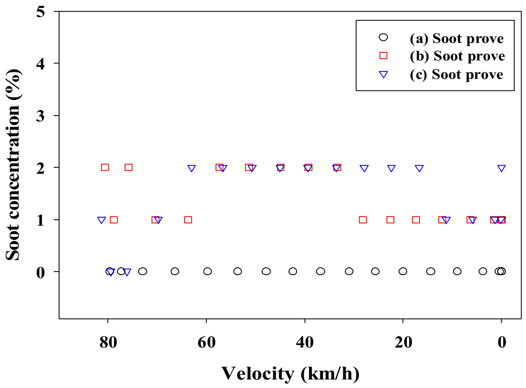

Fig. 16 Section where there is a rapid deceleration from 80km/h to 0km/h

For Vehicle B, in the rapid acceleration sections 0 km/h–40 km/h and 40 km/h–80 km/h, the soot intakes of Probes (b) and (c) were higher by 127% and 200% and by 59% and 94%, respectively, on an average.

For Soot probe (a), the distance between the probe inlet and exhaust pipe wall was not maintained. For Soot probe (b), the probe inlet was positioned on the exhaust pipe wall. However, a certain portion of the inlet was secured by the improved rib position and perforation. For Soot probe (c), the probe inlet was separated completely from the exhaust pipe wall and positioned at the center of the exhaust pipe, whereby the inlet was secured.

6. Conclusion

The following conclusions were obtained from the results of this study on the performance of the soot probe for diesel vehicles using the Korean KD 147 mode inspection method.

1. The Korean KD 147 mode inspection method with the condition of 90° revealed the higher intake efficiency and performance of the improved soot probes (b) and (c).
2. The soot probe exhibited a higher intake efficiency in the rapid acceleration section than in the rapid deceleration section.
3. The improved soot probe (c) exhibited improved intake efficiency and performance because the probe hole was positioned at the center of the exhaust pipe even in the condition of 90° exhaust vent, where the inlet cannot be secured in the rapid acceleration and rapid deceleration sections.

Acknowledgement

This study was supported by the Korea Institute for Advancement of Technology under the funding by the government (Ministry of Trade, Industry and Energy) in 2021 (P0002092, Human Resources Development Support for Industrial Innovation Project 2021).

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