EFFICIENCY OF VENTILATION IN AUTOMOTIVE SEAT CUSHION

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Abstract- The air flow rate of ventilated automotive seat was estimated. The air flow rate out of ventilation holes in pad foam was measured and then was compared with the analysis results. Because pad foam is made of a porous material, about 21.13% of air flow was lost when it passed through pad foam. The air flow which passed through pad foam then would pass through filter foam and seat cover. The air flow rate on the outer surface of seat cover was estimated using performance curve of fan and an airflow cone. Significant amount of air flow was lost on the way. A dummy which represents Hybrid III 50th percentile male by NHTSA (National Highway Traffic Safety Administration) was used to simulate a real driving condition. Only 6.11% of air flow which was generated at fan finally reached a driver.

Keywords- Pad Foam, Seat Cover, Seat Cushion, Ventilated Seat, Ventilation Hole

I. INTRODUCTION

Providing comfortable environment for drivers and passengers becomes an important goal. Ventilated seats may directly affect their comfort and are more preferred by customers. Wolfe et al. combined experimental and computational data to describe the effect of seat cooling on occupant comfort [1]. They developed an accurate model to predict the complex human sense of thermal comfort. Rutkowski developed a model which explains the local conduction, convection, and evaporative cooling between human body and seat surface [2]. The model was verified using a predefined 50th percentile American Male (AM50). Karimi et al. developed a model of the dynamic interaction between an automobile passenger, the cabin environment, and a ventilated seat [3].

Their model accounted for the effect of heating and ventilation through the seat. Hall and Kolich evaluated the optimal seat surface temperature range to optimize human thermal comfort for an automotive seating system application for heated and ventilated seat [4].

There have been intensive efforts to estimate air flow rates in ventilated seats. Because it is not easy to measure and calculate the air flow rate with a driver or a passenger on seat, the estimation has been usually performed without a driver or a passenger. In this paper, air flow which passed through pad foam was measured and analyzed in order to find how much air flow was lost and how uniform the air flow distribution is.

The air flow rate in ventilated automotive seat was estimated with a dummy which simulated a male human body. The Hybrid III 50th percentile American Male was used as a dummy [5]. The airflow cone was attached on the surface of seat cover. Then air flow rate at the outlet of airflow cone was measured. With the aid of performance curve of fan, the air flow rate on the surface of seat cover was estimated.

II. ESTIMATION OF AIR FLOW RATE AT THE VENTILATION HOLES

2.1. Automotive Seat Cushion

The schematic diagram of seat cushion is shown in Fig. 1. The air from a fan is provided to ventilation mat through duct. Then it flows through pad foam, which has five ventilation holes at each of left and right hand sides. After pad foam, it passes through filter foam, which is made of a sponge-like material with low density. It passes through seat cover which is usually made of leather and then finally reaches the driver or the passenger.

The top view of pad foam is shown in Fig. 2 with ten ventilation holes, which are arranged symmetric with respect to an axis along the driving direction (VHi means the i-th ventilation hole). At the left and right sides of seat cushion, bolsters are attached. Bolsters are designed to be geometrically higher in order to prevent lateral motion of driver or passenger. Bolsters and the remaining portion of seat cushion are made of the same foam material though the density of bolsters is higher.

A driver seat of a compact SUV was used in this study to estimate the air flow rate on the seat cover.

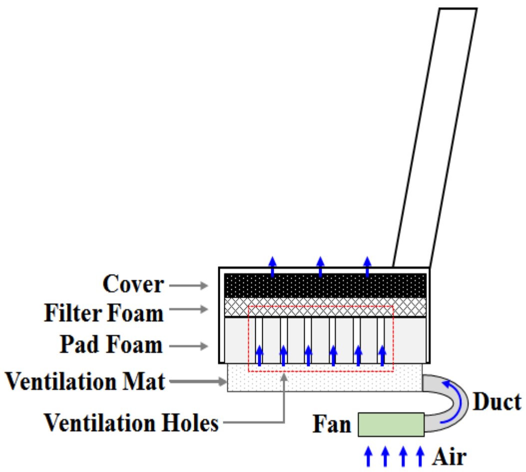


Fig. 1. Automotive Seat Cushion

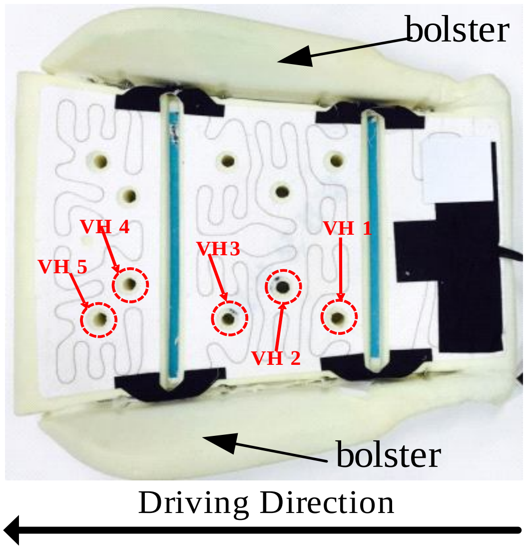


Fig. 2. Ventilation Holes and Bolsters in Automotive Seat Cushion

2.2. Measurement of Air Flow Rate at the Outlets of Ventilation Holes

A thermo-anemo-manometer MP210 by KIMO Insturments was used in the measurement [6]. A pressure module MPR 500 and a vane probe MP210 whose diameter is 14mm were used to measure pressure and velocity, respectively. In Table 1, their specifications are summarized.

Table 1. Specifications of Pressure Module and Vane Probe

	Pressure module	Vane probe
Measuring range	From 0 to ±500Pa	From 0 to 3m/s
Accuracy	±2% of reading ±0.8Pa	±3% of reading ±0.1m/s
Resolution	0.1Pa	0.1m/s

The velocity of air flow was measured, which was multiplied by the area of outlet to calculate the air flow rate. The fan can be adjusted to have 3 different speeds. In this paper, only the highest speed was considered. The air flow rate at the outlet of fan was measured to be 12.117 (CFM).

In order to measure air flow rate at the outlets of ventilation holes, seat cover and filter foam were removed. Then, the air flow rate was measured at the outlet of each ventilation hole. The results are summarized in Table 2.

Table 2. Air Flow Rates at the Outlets of Ventilation Holes (CFM)

	Left-hand Side	Right-hand Side
VH1	1.076	1.305
VH2	0.620	1.076
VH3	0.913	0.913
VH4	0.946	0.946
VH5	0.881	0.881
Total	9.557	

The air flow rates are not symmetrically distributed with respect to a symmetry axis along driving direction even though five ventilation holes at one side are geometrically symmetrical with the other five ventilation holes at the other side. The asymmetry is due to unsymmetrical location and orientation of the fan.

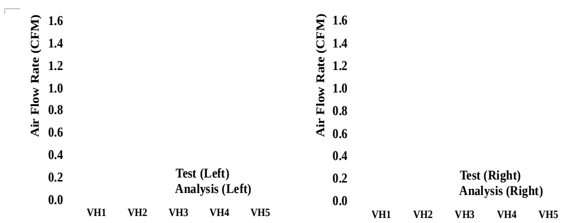
The total air flow rate at the outlets of ventilation holes is only 9.557 (CFM). The air flow rate at the outlet of the fan is 12.117 (CFM). About 21.13% of air flow was lost when it passed through ten ventilation holes in pad foam. The loss is due the fact that pad foam is made of a porous material.

2.3. Analysis of Air Flow Rate at the Outlets of Ventilation Holes

ANSYS/Fluent version 14 was used to calculate air flow rates at the outlets of ventilation holes [7]. The analysis results are shown in Fig. 3 and Table 3 with the test results.

The air flow rate from analysis is larger than that from test at every ventilation hole because no loss is assumed in the analysis. Thus the total air flow rate from analysis is equal to the flow rate at the outlet of the fan.

The air flow rate was the lowest at the second ventilation hole (VH2) at the left hand side in the analysis and in the test. Effort has to be given to increase the air flow rate at this hole for uniform distribution of air flow rate in the future design change.



(a) (b)

Fig. 3. Analysis and Test Results of Air Flow Rates at the Outlets of Ventilation Holes (a) left-hand side (b) right-hand side

Table 3. Air Flow Rate at Each Ventilation Hole (CFM)

	Test Results		Analysis Results	
	Left	Right	Left	Right
VH1	1.08	1.30	1.28	1.49
VH2	0.62	1.08	1.03	1.23
VH3	0.91	0.91	1.16	1.21
VH4	0.95	0.95	1.17	1.22
VH5	0.88	0.88	1.14	1.19
Total-5 Holes	4.44	5.12	5.78	6.34
Total-10 Holes	9.56		12.12	

III. ESTIMATION OF AIR FLOW RATE AT OUTER SURFACE OF SEAT COVER

The air flow which passed through ventilation holes in pad foam had to pass through filter foam and seat cover to reach a driver or a passenger. After passing through seat cover, the air flow was widely spread and its intensity was too small to be measured directly using a vane probe. The performance curve of fan and airflow cone were used to estimate air flow rate at the outer surface of seat cover.

The performance curve of fan was obtained from six measurements of pressure and flow rate by adjusting the size of the opening of rectangular cross section. Then a quadratic regression was used to find the performance curve of the fan as in Fig. 4.

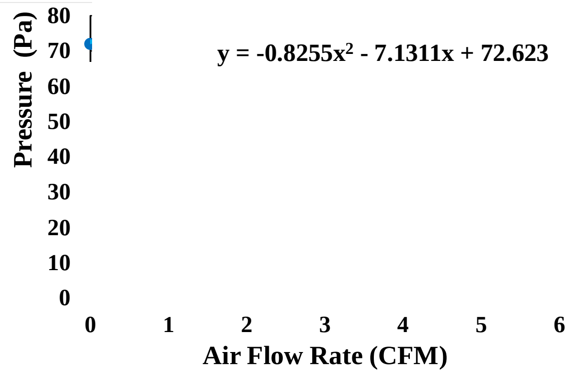


Fig. 4. Performance Curve of Fan

An airflow cone was attached at the outer surface of seat cover in a way to minimize the loss of airflow through a gap between airflow cone and seat cushion. Then air flow rate was measured using a vane probe at the outlet of airflow cone, Q_2 as in Fig. 5.

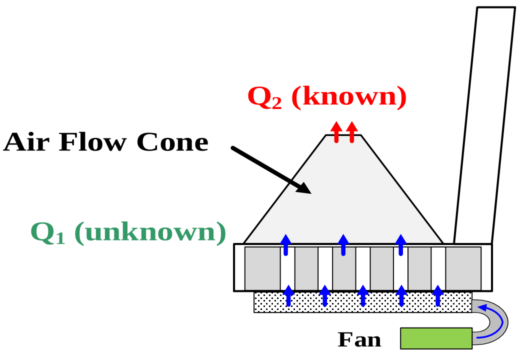


Fig. 5. Use of Airflow Cone to Estimate Air Flow Rate at the Outer Surface of Seat Cover

The speed of air flow at the inlet of airflow cone was found assuming continuity. ANSYS/Fluent was used to calculate the pressure difference between the inlet and outlet of airflow cone. With the calculated pressure difference and the measured air flow rate at the outlet of airflow cone, Q_2, air flow rate at the inlet of airflow cone, Q_1, can be found from Fig. 4. What a driver or a passenger feels is the air flow rate, Q_1.

Using the procedure in the above, the air flow rate at the outer surface of seat cover was estimated without and with dummy. To estimate air flow rate with a dummy, a part of dummy which represents only buttocks and thighs was used. The dummy is Hybrid III 50th percentile male which is specified by NHTSA (National Highway Traffic Safety Administration) and its weight is 75kgf.

The air flow rate was measured at the outlet of airflow cone without and with the dummy. The test set-up to measure the air flow rate at the outlet of airflow cone is shown in Fig. 6.

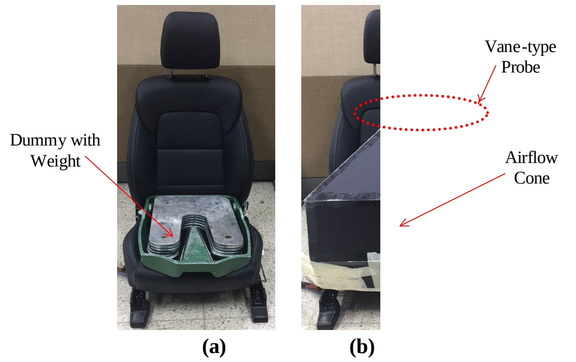


Fig. 6. Test Set-up to Measure Air Flow Rate with Dummy at the Outlet of Airflow Cone (a) before airflow cone was installed (b) after airflow cone was installed

Without dummy, the air flow rate and the pressure at the outlet of airflow cone was measured to be 1.60 (CFM) and 58.21 (Pa), respectively. The pressure difference was calculated to be 3.28 (Pa) using ANSYS/Fluent. Thus the pressure at the inlet of airflow cone was 54.93 (Pa). Finally, from the performance curve of fan (Fig. 7), the air flow rate at the outer surface of seat cover was found to be 2.01 (CFM).

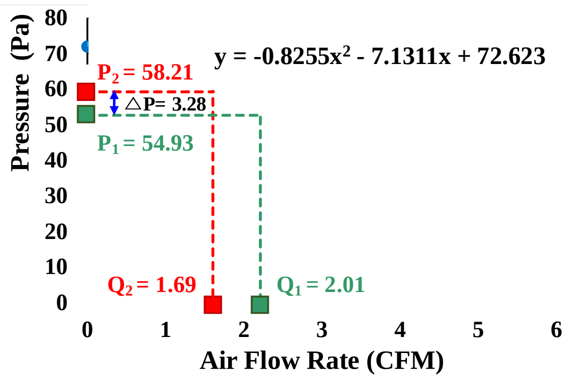


Fig. 7. Performance Curve of Fan and Its Use to Find Air Flow Rate at the Outer Surface of Seat Cover

The same procedure was repeated to estimate the air flow rate with dummy at the outer surface of seat cover. The results are summarized in Table 4.

Table 4. Estimation of Air Flow Rate without and with Dummy at the Outer Surface of Seat Cover

	Without Dummy	With Dummy
Q_2 (CFM, measured)	1.60	0.68
P_2 (Pa, measured)	58.21	67.40
ΔP (Pa, calculated)	3.28	0.55
P_1 (Pa, calculated)	54.93	66.86
Q_1 (CFM, estimated)	2.01	0.74

The air flow rate at the outlet of fan was measured to be 12.117 (CFM). When there was no dummy, which was equivalent to a ventilated seat without a driver, the air flow rate was estimated to be 2.01 (CFM) on the outer surface of seat cover. Only 16.59% of the air flow from the fan reached the outer surface of seat cover. When there was a dummy, the air flow rate was estimated to be 0.74 (CFM) on the outer surface of seat cover. Only 6.11% of the air flow from the fan reached the driver.

IV. RESULTS AND DISCUSSION

Air flow from a fan passes through pad foam, filter foam, and seat cover in ventilated automotive seat cushion. Significant amount of air flow was found to be lost on the way. In order to find how much air flow was lost on the way, a compact SUV driver seat was considered. When air flow passed through a pad foam which is usually made of a porous material, about 21.13% of air flow was lost.

The air flow which finally reached an outer surface of seat cushion was estimated. An airflow cone and performance curve of a fan were used for this purpose. Without a dummy, only 16.59% of the fan-generated air flow reached the outer surface of seat cover. With a dummy, the loss was larger. Only 6.11% of the air flow reached the outer surface of seat cover. In the estimation of air flow at the outer surface of seat cover, an airflow cone was used. Careful attention was given in order to provide a perfect seal between airflow cone and seat cushion. However, some amount of air flow must be lost at the gap between airflow cone and seat cushion. Thus, the efficiency which was estimated in this study may be slightly underestimated.

CONCLUSIONS

The efficiency of ventilation in automotive seat cushion was estimated. The air flow rate was also analyzed using a commercial software ANSYS/Fluent. The following are main conclusions;

1. The amount of loss from the fan-generated air flow can be estimated in ventilated automotive seat with and without a dummy which simulates a real driver.
2. The air flow rate at each ventilation hole can be obtained from the analysis, which can be used to achieve more uniform distribution of air flow rate by changing the size and position of ventilation holes.
3. The air flow rate with a dummy can be significantly lower than without a dummy. The efficiency of ventilation in seat cushion should be estimated with a dummy. Otherwise, the comfort of a driver in a real automotive seat will be significantly overestimated.

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