Sound Transmision Characteristics Of Elastomeric Sealing Systems

Junhong Park, Luc G. Mongeau and Thomas Siegmund
School of Mechanical Engineering, 1077 Herrick Laboratories, Purdue University, West Lafayette, IN47907-1077

1. Introduction

Sound transmission through door and window sealing systems is one important contributor to interior aerodynamic noise in road vehicles [1]. Two primary noise generation mechanisms involve the aspiration through small leaks and structural sound transmission due to flow-induced mechanical vibrations of the seals. Aspiration noise when leaks are present is the most significant noise source. It is therefore critical to ensure the air-tightness of the sealing system at the design stage of new vehicles. A good understanding of the dynamic behavior of sealing systems excited by unsteady surface pressures caused by turbulent flow over the vehicle is also essential for the design of sealing systems that are quite. Experiments in actual vehicles on the road or in wind tunnels are costly, time consuming and complicated by the presence of multiple sources and flanking paths. Recent efforts have been towards the prediction of the sound transmission characteristics of the seals using detailed finite element model [2]. Experimental study to evaluate the acoustic barrier properties of different rubber seals and their effectiveness to prevent aspiration were measured in controlled laboratory conditions (Mongeau, [3]). In the present study, simple sound transmission model of the sealing system is presented. Both finite element method and transfer function matrix method is used as an analytical model. These results are compared with experimental data obtained from reverberation room test.

2. Sound Transmission Loss Calculation

Fig. 1 shows the simplified model of the bulb seal for sound transmission calculation. Each seal wall is modeled as an unbounded mass. Here $\hat{P}_{11}$ is incident pressure field to the seal. $\hat{P}_5$ is the transmitted sound wave. For this system, transmission loss is defined as (In an assumption of plate traveling wave on both sides.)

$$R = 10\log(1/\tau), \quad \tau = \left|\hat{P}_5\right|^2 / \left|\hat{P}_{11}\right|^2 \tag{1}$$

where, R is transmission loss and τ is the transmission coefficient.
Finite Element method(ABAQUS) is used to analyze this system. Structural and acoustic coupling elements are used for the interaction between air and seal boundary.

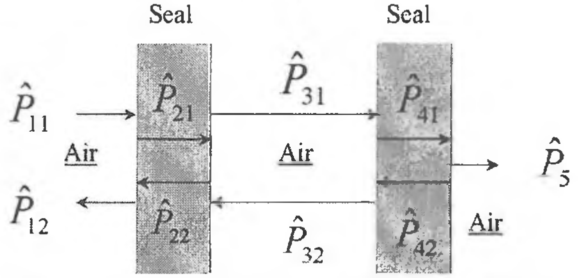

Fig. 1 Simplified model of vehicle door bulb seal

Boundary condition for the left and right ends of the model is non-reflecting to prevent the standing wave resonance at both sides. Boundary condition for top and bottom of the model is rigid wall boundary condition. Incident load can be applied at left side of the wall (acoustic loads) or directly to the left sides of the seal (distributed load to seal face). The loads from turbulent wall pressure fluctuation are more similar to direct loads on the seal surface. Boundary condition for seal edges can be free or fixed. Here, free boundary condition is used for comparison with transfer function matrix method.

Transfer function matrix method was developed and compared with finite element methods. In transfer matrix methods, continuity of the pressure and the velocity of traveling wave field were used. Then relationship between incident pressure and transmitted pressure fields is acquired. It has the form of 8×8 matrix.

$$\begin{bmatrix} -1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ \frac{r2}{r1} & 1 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & e^{-jk_2d_1} & e^{jk_2d_1} & -1 & -1 & 0 & 0 & 0 \\ 0 & \frac{r3}{r2}e^{-jk_2d_1} & -\frac{r3}{r2}e^{jk_2d_1} & -1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & e^{-jk_3L} & e^{jk_3L} & -1 & -1 & 0 & 0 \\ 0 & 0 & 0 & \frac{r4}{r3}e^{-jk_3L} & -\frac{r4}{r3}e^{jk_3L} & -1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & e^{-jk_4d_2} & e^{jk_4d_2} & -1 \\ 0 & 0 & 0 & 0 & 0 & \frac{r5}{r4}e^{-jk_4d_2} & -\frac{r5}{r4}e^{jk_4d_2} & -1 \end{bmatrix} \begin{bmatrix} \hat{P}_{12} \\ \hat{P}_{21} \\ \hat{P}_{22} \\ \hat{P}_{31} \\ \hat{P}_{32} \\ \hat{P}_{41} \\ \hat{P}_{42} \\ \hat{P}_5 \end{bmatrix} = \begin{bmatrix} 1 \\ \frac{r2}{r1} \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \hat{P}_{11}$$

This matrix is solved to get transmission loss as defined in Eq. (1). Here, r_1, r_2, r_3, r_4, r_5 are the acoustic impedances and k_2, k_3, k_4 are the wave numbers in the medium. d_1 and d_2 are seal thickness and L is the separation distance between seal walls.

3. Results and Discussions.

Dynamic mechanical properties of seal material (foamed rubber) were measured (TA Instruments 2970), and used as inputs to the material property for the simulation. The simulation was done for two bulb seals that have different density. One bulb seal has the density of 670kg/m^3 and the other has the density of 370kg/m^3. Measured elastic modulus were 8.0MPa and 2.0MPa respectively. This elastic modulus was measured at 20Hz, room temperature. These measured data were used as an input for simulation. d_1 and d_2 were measured as 2mm and L was 12mm for both seal. Fig. 2 shows the simulation results. Obviously there exist dip in the transmission loss due to mass-air-mass resonance frequency for two different seals. High density seal shows lower resonance frequency as expected. Another possible resonance is the half-wave length resonance inside the seal wall. The longitudinal wave speed in the seal is 126m/sec and 86m/sec respectively. So half-

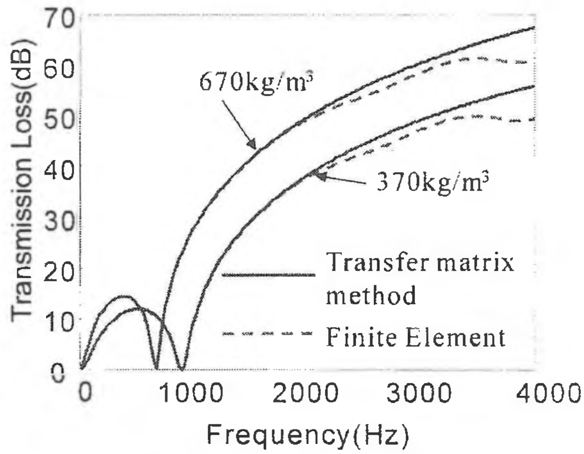

Fig. 2 Simulation results

Fig. 3 is the experimental setup for the measurement of the sound transmission loss of the seal. The fixture can host 25.4cm long samples. The effects of seal compression and material property of the bulb seal can be investigated. Efforts were given to minimize any sound transmission into the receiver side through franking paths by eliminating all leaks. For the generation of reverberant sound fields, two speakers were used as a sound source. At the other sides of the seal, intensity prove (B&K sound intensity probe) was used to measure the transmitted sound intensity. It is located inside the jig cavity. All sides of the cavity walls are treated with sound absorbing material to prevent the acoustic resonance inside cavity. The seal vibration at the receiver side was also measured using the laser vibrometer. The frequency range of interest is from 500Hz to 5kHz.

The bulb seals that were used in the experiment include 670kg/m^3, 370kg/m^3 and 430kg/m^3 density seals. 430kg/m^3 density seal is made from thermoplastic elastomer. The others are made from thermoset rubber compound. The transmission loss measurement results from experiments are shown in Fig. 4. For the calculation of the transmitted sound intensity, the plane wave propagation from the seal and small cavity resonance phenomena was assumed. The incident and transmitted intensity to seal was calculated from (3), (4). (In the assumption that the reverberation room is truly diffuse sound fields.)

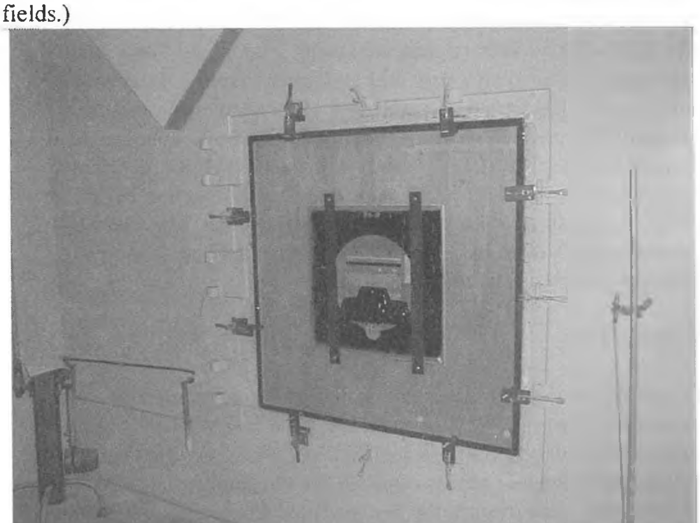

Fig. 3 Experimental setup for transmission loss measurements of bulb seal

$$I_i = \langle p^2 \rangle / (4\rho c) \tag{3}$$

$$I_t = \langle V^2 \rangle \cdot (\rho c) \tag{4}$$

where I_i is the effective intensity inside the reverberation room and p is the average sound pressure inside reverberation room. V is the velocity of the seal wall measured from laser vibrometer. I_t is transmitted intensity.

The comparison between simulation and experimental results does not show much similarity. The measured dip in transmission loss is located at much higher frequency than simulation results. Such phenomena are severe for high density sealing systems. Currently the analytical model for sound transmission calculation is too simple to account for actual seal shapes. Actual seal has round shape. Two walls of the seal are not separated. So, further investigations for the effects of actual seal shape and non-linear visco-elastic properties of the elastomer are necessary.

ACKNOWLEDGMENTS

Thanks are expressed to Ford Motor Company for financial support and their guidance. Also, the contribution of the Herrick Laboratories Technical staff is also gratefully acknowledged.

REFERENCES

[1] George, A.R., and Callister, J.R., 1991, "Aerodynamic Noise of Ground Vehicles." SAE Paper No. 911027.

[2] Gur, Y., and Morman, K.N., 1999, "Sound Transmission Analysis of Vehicle Door Sealing System." Proceedings of the 1999 SAE Noise & Vibration Conference, Paper No. 1999-01-1804, pp1187-1196.

[3] Mongeau, L., and Danforth, R.J., 1997, "Sound Transmission through Primary Bulb Rubber Sealing Systems." 1997 SAE Transactions, Journal of Passenger Cars, Vol. 106, Sec. 6., pp2668-2674.

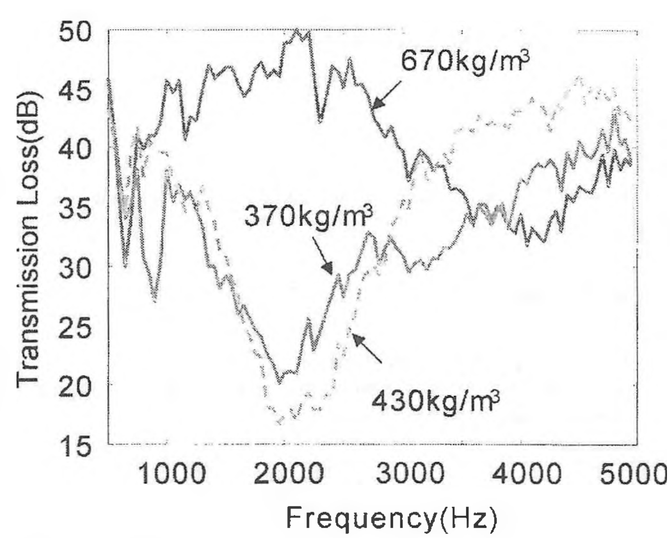

Fig. 4 Experimental results for sound transmission loss calculation from laser vibrometer velocity measurement.