AN INTEGRATED PASSIVE AND ACTIVE CONTROL SYSTEM FOR SNORING NOISE CANCELLATION

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Snoring noise usually affects sleeping of the other persons in one room. In the paper, to reduce snoring noise, the rigid baffle with the finite height and width is placed between the two persons. The bed and bedhead are modelled as the rigid semi-infinite plates separately and vertically each other. By simulation, noise reduction producing by placing the baffle is calculated. And noise cancellation change is discussed by adjusting the height and the width of the baffle. Due to the limited size of the baffle, a part of noise wave is diffracted and goes around to the off side of the baffle. To cancel the residual noise due to sound diffraction two loudspeakers as secondary sources are arranged in the barrier. Finally the total reduction of the integrated passive and active system is given.

1. Introduction

Intensive snoring noise will disturb the roommate’s sleep and do harm to working or living the next day. Active headsets used in aviation, military and industry should give maximum protection from high noise levels\(^1\). But for a sleeper wearing a headset, he lies flat in a whole night and lying on his side is uncomfortable. So for a sleeper, both noise reduction and easy sleeping posture are necessary.

Kuo and his groups presented the active headboard design to reduce low frequency snoring noise\(^2,3\). By the tests, for snoring noise at 100-3000 Hz, noise reduction is 15-20 dB when the error sensors are located at both ears. But noise reductions are 2-5 dB and 5-7 dB at left ear and right ear when the error points are located at the headboard.
Spectral range of snoring noise is wide and not limited to low frequency. Usually barrier between the source and the receiver will stop sound propagation and reduce the sound pressure level at the receiver. At middle and high frequencies, the barrier noise reduction is higher due to barrier size comparable to or longer than wave length. In order to reduce wide band snoring noise, the passive and active controls are combined.

In the paper, by simulation barrier insertion loss and active noise reduction are investigated.

2. Model and simulation

The bed plate and the bedhead are modelled by semi-infinite baffle. There are two persons on the bed. One person’s snoring noise is considered as a point source. To reduce snoring noise at the other one’s ears, a rigid barrier with height H and length L is located between the two persons. Noise is furthermore reduced by adding secondary source in the barrier. In the model the two heads are the rigid spheres. The model is shown in Fig. 1.

The origin is located at the intersection center of bed plate and the bedside surfaces. The snoring source is at (0.1, -0.45, 0.2) m, the left ear and right ear of the receiver are at (0.1, 0.55, 0.1) m and (0.1, 0.35, 0.1) m. $l$, $h$ and $t$ are length, height and thick of the barrier.

![Figure 1. Model of an integrated passive and active control of snoring noise](image)

Using COMSOL Multiphysics of the finite element method software, the model geometries are built and the sound field solutions are solved. The whole sound field is modelled by a quarter of a sphere, and the two orthogonal faces represent the bed plate and the bedhead. To get a quarter free field, the field is surrounded by a ball ring PMLs (Perfectly Matched Layers) with 1/2 wavelength thickness. The domain can absorb spherical wave along the radius radiating outside the spherical face and little sound reflects into the sound field. The maximum element size is 1/5 wave length.

2.1 Insertion loss of the barrier

In simulation, point source strength is $1e-4$ m$^3$/s at 500 Hz. Insertion losses of different length barrier with the infinite height and 0.01 m thick at both ears are shown in Fig. 2 (a), and insertion loss (IL) of different height barrier with the infinite length and 0.01 m thick is shown in Fig. 2 (b). IL is defined by Eq. (1).

$$ IL = L_{p0} - L_p $$  \hspace{1cm} (1)

$L_{p0}$ and $L_p$ are sound pressure levels at the receiver without and with the barrier.
Figure 2. The barrier $IL$ with 0.01m thick at both ears of receiver (L-left ear, R-right ear)

Figure 3. The finite size barrier $IL$

Figure 2 (a) and (b) show that insertion loss increases by the barrier length and height increasing. So we can reasonably infer that $IL$ of the infinite length and height barrier is the sound pressure...
level with no barrier at both ears. Considering the barrier size and its insertion loss, the suitable barrier length and height selected are 0.5 m and 0.3 m.

For the applicable barrier, the 0.01 m thick is too thin to steadily stand between the persons. So the thick should be adjusted to satisfy IL and appropriate stability. Figure 3 (a) gives the barrier thick effect on IL. The thick is set at 0.15 m. The barrier IL with 0.3 m height, 0.5 m length and 0.15 m thick at both ears are above 20 dB.

In Fig. 3 (b), ILs at both ears are wavy and tending towards a constant value by the barrier length increasing. The length differences corresponding to adjacent peaks are 0.3 m and 0.4 m approach to 1/2 wavelength of 500 Hz. Due to the finite barrier height, diffraction sound from edges on the barrier top parallel to x axis and edges on the right side parallel to y axis interfere. With the length increase, the latter effect decreases and tends to be ignored. Figure 3 (c) shows the similar appearance.

For Snoring noise, Fig. 3 (d) gives the IL frequency response below 1000 Hz. In calculation, at different frequencies the source strengths are 1e-4 m³/s and actual snoring noise is not used as sources. There are peaks in the curve. It is not similar to the usual infinite length barrier IL in figure 2 which is increasing by the frequency increase. For the finite barrier length, which is 0.68 ~ 13.6 wavelength, diffractions of a few edges make interference wave. IL is over 5 dB above 300 frequencies at both ears. There is omitted IL below 300 Hz and negative at left ear at 150 and 200 Hz. So noise reduction for the lower frequencies is used by active control.

2.2 Noise reduction of active control

According to the local active noise control, there is the quiet zone of 1/10 wavelength around the cancellation point in near field of the secondary field. The two secondary point sources are located at (0.1, 0.075, 0.1) m and (0.3, 0.075, 0.1) m in the barrier. Primary field, sound field with control and noise reduction at z = 0.1 m surface are given in Fig. 4. The bed width is 1.8 m and the length is 2 m.

In simulation, primary point source strength is 10⁻⁴ m³/s, the two secondary sources strengths q are calculated by the Eq. (2).

\[
q = \left[ \begin{array}{c}
q_1 \\
q_2
\end{array} \right] = \left[ \begin{array}{c}
z_{11} & z_{21} \\
z_{12} & z_{22}
\end{array} \right]^{-1} p
\]

\[\text{(2)}\]

\[q = [q_1, q_2]\], the transfer impedance from the ith secondary source to jth cancellation point is \(z_{ij}\), the primary pressure is \(p = [p_1, p_2]\). Left ear is the first cancellation point; the right ear is the second cancellation point.

![Sound pressure level (dB)](a) Primary sound field  
(b) Sound field with active control
Figure 4. sound field with or without active control and active control noise reduction with the barrier at z = 0.1 m surface

(c) Noise reduction of active control  (d) Noise reduction frequency spectral of active control

Figure 4 (a) - (c) show primary field secondary field and noise reduction at 300 Hz. In primary field sound pressure level at both ears are 68 dB and 70 dB. With active control there are 34 dB and 37 dB, and noise reductions are 34 dB and 33 dB. 10 dB quiet zone near left ear is more than quiet zone near right ear. At both ears of the snorer noise is slightly increasing with 0.7 dB and 1.0 dB. In figure 4 (d) noise reductions of cancellation points are above 25 dB, but in actual application, cancellation points cannot be located at both ears for reducing effect on the head activity. So noise reduction at both ears in the application will be less than above-mentioned reduction.

Figure 5. Total noise reduction frequency spectral with the barrier and active control

With active control, noise reduction at lower frequency increased. Below 1000 Hz noise reductions at both ears of the receiver are above 5 dB. As a whole noise reduction fluctuates by the
frequency increasing. The reason is that the barrier size is finite. Diffraction sound wave interference each other and this produces the appearance.

3. Conclusions

According to the FEM model, the effect of the barrier length, height and thick subsections on the barrier insertion loss are investigated. These findings are that IL is wavy by the barrier length or height for finite size barrier. Above 300 Hz IL is over 5 dB at both ears. At lower frequencies, IL is less than 5 dB. Using active noise control improves low frequency noise reduction, noise reduction at cancellation points (both ears) are over 25 dB and at both ears of the snorer noise increment is not beyond 1 dB. Integrated passive and active noise reduction are above 5 dB at both ears.

In this paper, noise reduction effect of cancellation points at both ears is investigated. Noise reduction at more actual cancellation points locations are further studied, and control effect of integrated system in tests will be given.

REFERENCES