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Dash Sound Package Optimization Using Genetic AlgorithmBased On SEA Method

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ABSTRACT

Sound packagehas become an effective method to reduce Sound Pressure Level (SPL) of receiver cavity and has been widely used in automobile and aircraft industries.But, how to design sound package with better insulation and lower weight is always the concerned problem when sound package is used. In the paper,a vehicle dash was selected as the studied object, which is one of the main noise transmission paths from engine cabin to passengers' cabin. Statistical Energy Analysis (SEA) model of the dash was established. Then Transmission Loss (TL) of dash was computed and compared with experimental data to validate the simulation model. Sound package was added into the model and thicknesses of soft layer on each SEA panel are selected as design parameters. The TL of dash at 1000Hz was selected as objective.Finally, Genetic algorithm (GA) was adopt to optimize sound package thickness of different regions and a sound package with better performance was found out. This method could provide some guides for how to determine the optimal sound package and which can maximize the TLunder a fixed weight increasement.

Keywords: Sound package optimization, GA I-INCE Classification of Subjects Number(s): 35.4

1. INTRODUCTION

Reduction of SPL at passengers' cabin is an important part during the vehicle design process. Many measures such as damping, sound package etc. are taken to solve this problem. Sound packages are indispensablepart and have been mounted at many placesof a vehicle. Good performance of sound package for dominant noise transmission path such as dash, floor and roof can be designed quickly and accurately based on SEA method, which has achieved great success for air-borne noise transmission problems [1]. But SEA method is not convenient to determine the thickness distribution of sound package for each local region of analyzed object. In this condition, different thickness of sound packages usually depend on the installation space without taking the weight of sound package into consideration. Actually, the thickness of sound package at dominant transmission path should be larger and the thickness of sound package at non-dominant transmission path should be smaller to achieve the optimal balance between weight and Insertion Loss (IL) of sound package.

In the aspect of sound package optimization,Non Dominating Sorting Genetic Algorithm (NSGAII) had been once adopted to optimize sound package [2], which is effective to seek out global optimal solution. X. Wu etc. [3] increased or reduced thickness of sound package of every local region based on FE-SEA hybrid method to improve TL of a dash. In the present study, thickness of sound package of each SEA panel is selected as design parameters and the objective is TL value at 1000Hz.In order to find out the global optimal solution of thickness of sound package and improve the accuracy of optimized result, no approximation model [4] or experimental design [5] are used but GA [6] calls VA One [7] directly to compute the result of each iteration.Then,the TL of the dash with optimized sound package is compared with that of the dash with initial sound package.

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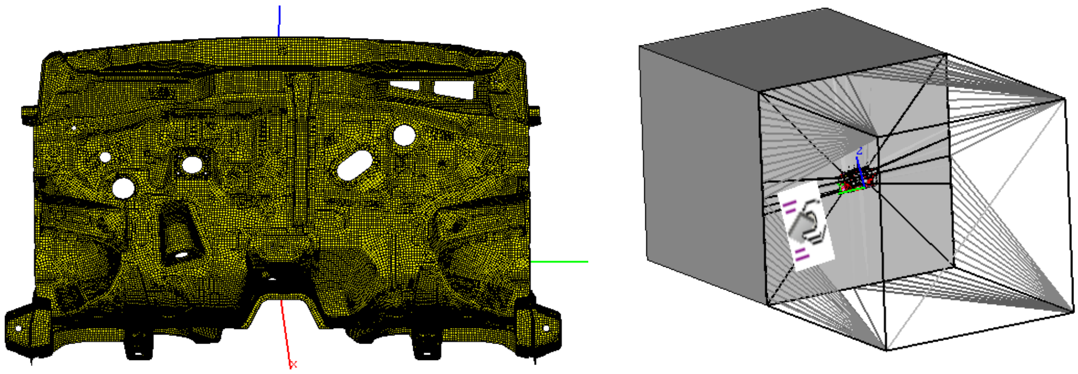
2. SEA MODELESTABLISHING

2.1 SEA model of a vehicle dash

Finite element structure of a vehicle dash as shown in figure 1(a) was imported into VA One and plate or singly curved shells were used to model SEA panel. According to mesh principles of SEA subsystem [8], the mode number N of each subsystem should be higher than 5 in analyzed frequency bandwidth. The source and receiving chambers can be modelled as SEA acoustic cavity subsystems or SEA semi-infinite fluids. If the cavities are large and the receiving chamber is damped, then there is nearly no difference between this two approaches [9]. In the paper, the TL is calculated based on SEA acoustic cavity and Constraint pressure model. A constraint pressurewith 1 Pa isadded on a large acoustic cavity, whose volume is 1000 m^3. This large cavity istaken to represent the source cavityas the reverberant room and another acoustic cavity represents the receiving side as the anechoic room. Face junctions are established between SEA panels and cavities, which are used to storage and transfer energy.Finally, 12 SEA panels are modeled and the dash SEA model was illustrated in figure 1(b).



(a) (b)

Figure 1 –(a) Finite element structure of the dash; (b) SEA model of the vehicle dash

2.2 Sound package establishing

Dash sound package is usually combined by absorbing material and insulation material, and the combination of soft cotton and hard cotton is widely used for sound package design. The thickness of hard cotton is uniform, while the thickness of soft cotton is non-uniform and usually decided by installation space. So, it's necessary to compute the thickness distribution of soft cotton. Firstly, CAD model of dash sound package is imported in Hypermesh and only soft cotton model is kept. Then the upper and lower face of soft cotton are meshed.The lower face of soft cotton is taken as a reference and the nodes of upper face are projected onto the lower face. Finally, the distance between nodes of upper face and projected nodes of lower face are gained, which stand for the thickness of soft cotton [10]. Table 1 shows the statistical value of thickness distribution of soft cotton ofsound package of a dash. The average thickness of 5~20mm have larger coverage, while the average thickness of 25mm and 30mm have much smaller coverage.

Table 1 - Thickness distribution of soft layer of sound package

Average Thickness(mm)	Coverage（%）	Average Thickness(mm)	Coverage（%）
5	19.95	20	25.26
10	25.32	25	6.53
15	16.96	30	5.96

In order to optimize the thickness of sound package of each SEA panel, it's necessary to use average thickness of noise control treatment to instead multi-noise control treatment, otherwise the design parameters are too many. Each average thickness from table 1 multiplies corresponding coverage to get the average thickness of sound package. We get the initial thickness of soft cotton and hard cotton are 14.5mm and 5.5mm, respectively. The material parameters of soft cotton and hard cotton are shown in table 2.The sound package coverage is 95%. The total weight of initial sound package is 7.64kg and the weight of reinforcing plates are also included. The material of the dash is steel with0.8mm thickness.The thickness of soft layer of sound package on each region is chosen as design parameters.Because there are two reinforcing plate in the yellow areaof figure 2, whose converges are 54% and 32%, respectively, the rest 16% are sound package without reinforcing plate. 3 design parameters are defined in this area. The total number of design parameters are 13as illustrated in figure 2.

Table 2 - Material parameters of sound package

Material	Density(kg/m3)	Flow Resistivity(N.s/m4)	porosity	tortuosity	Viscous c.l.(m)	Thermal c.l.(m)
Softcotton	109	132019	0.932	1	1.59e-5	1.59e-5
Hard cotton	152	166333	0.891	1	1.13e-5	1.64e-4

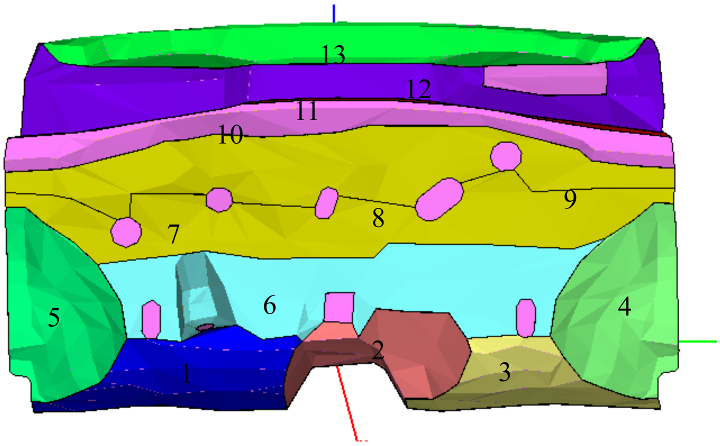
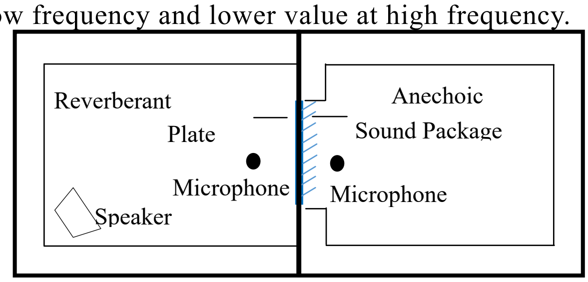


Figure 2 –Design regionsof the dash

3. MODEL VALIDATIONON

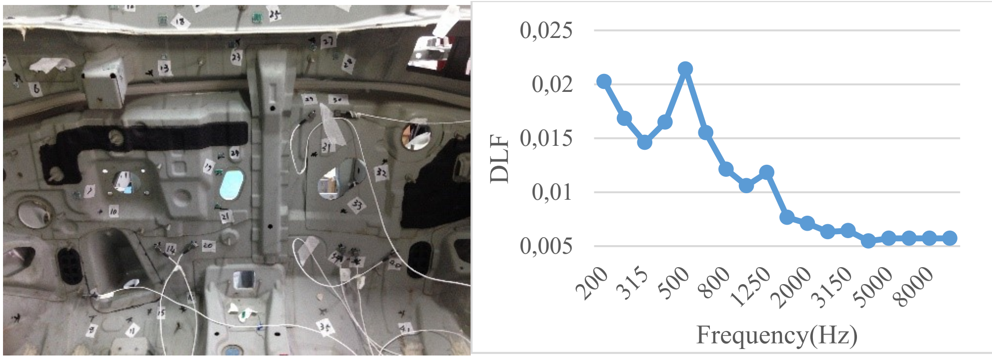
According to the thickness distribution, the thicknesses of all soft cotton added intoSEA model are 14.5mm. Before adding sound package into the model, the accuracy of the model must be validated. So, the TL of steel panel between experimental data and simulation are compared. The engine cabin of the dash is reverberation room and the passenger cabin is anechoic room. The panel is mounted between reverberant room and anechoic room. Several microphones are placed at each side of the panel as shown in figure 3(a). The four sides of dash are enclosure to avoid leak as illustrated in figure 3(b). TLs of all holes such as the steering column and air conditioning vents etc. are also measured and added on the face connections of SEA model to compute the TL of dash accurately.In addition, Damping Loss Factor (DLF) of different areas are measured. Figure 4(a) shows the measured points of sensors and figure 4(b) shows the average DLF of steel panel. DLF of the steel panel has higher value at low frequency and lower value at high frequency.



(a)

(b)

Figure 3 –(a)Test enivorment schematic diagram;(b) Reality installation situation



(a) (b)

Figure 4 –(a) Measured points of sensors; (b) DLF of dash steel panel

Then, the SEA model of steel panel is established and reinforcing plates are also taken into account.When SEA method is used, the TL is calculated as follows:

$$\mathrm{TL} = 10\lg\left(\frac{A_c\omega}{8\pi^2 n_1 \eta_2 c_1^2}\left(\frac{E_1}{E_2} - \frac{n_1}{n_2}\right)\right) \tag{1}$$

Where, $A_c$is the area of dash;n_1,$n_2$are modal density of receiver and source cavity, respectively; η_2 is damping loss factor of receiver cavity; E_1, E_2 are energy of receiver and source cavity, respectively;c_1 is sound speed; The calculated TL of steel panel is compared with experiment result as shown in figure 5.

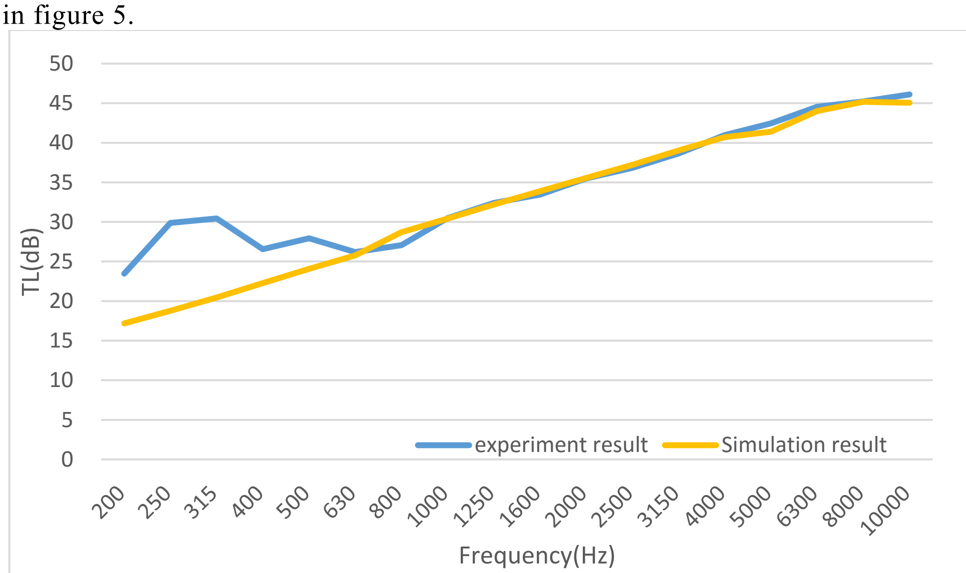


Figure 5 - TL of steel panelcomparisonbetween experiment and simulation

In figure 5, there is a little difference between experiment and simulation result over800Hz, which proves that the simulation model is reliable. But tolerances from 200~630Hz are much larger because SEA method is inaccurate at lower frequency [11].

4. OPTIMIZATIONAND RESULT ANALYSIS

4.1 Optimization

Sound package are added on each SEA panel. The thickness soft cotton ofsound package on each SEA panelis selected as design parameter, whose thickness varies from 5~30mm, while the thickness of hardcotton remains constant. Since TL varies with frequency, TL at a fixed frequency or average TL or overall TL can be choose to define as the objective. In the paper, the objective is TL at 1000Hz of dash. The optimization process can be described as follows:

$$\text{ObjectiveMax TL}$$

$$\text{S.t.}\begin{cases} W \le W_0 \\ a \le T_i \le b, \quad i = 1,2,\cdots n \end{cases} \tag{2}$$

Where, T_i is the thickness of the ith part; a is the lower limit of thickness; b is the upper limit of thickness; n is the number of parts;W_0 is the limit of sound package weight.

This optimization problem is solved by the combination of global GA and Sequential Quadratic Programming (SQP) [12]. Selection, crossover and mutation are three basic genetic operators for GA, which are used to keep diversity of next generation and pass the best gene to next generation. The population size determines the diversity of each generation. Increasing the population size can ensure a more comprehensive search but cost more time. The stopping criteria is either that the maximum number of generation reaches or that the maximum relative change of the objective value between generations is within convergence tolerance.Firstly, Global GA is used to seek the optimal solution to avoid falling into local optimal solution.Then the result achieved by GA was taken as initial value for SQP, which is used to refine the search.

4.2 Result analysis

In this paper, the maximum number of generation is 100, the population size is 50, the convergence tolerance is 1e-6 andthe upper limit of sound package weight is 8kg. Finally the optimize thickness of different regions are gained as shown in table 3 and the optimized TL is compared with TL of initial sound package as illustrated in figure 6.

Table 3 – Optimized thickness of soft cotton of different regions

Region number	Thickness(mm)	Region number	Thickness(mm)
1	18.20	8	9.95
2	19.62	9	21.00
3	17.11	10	20.27
4	19.00	11	20.25
5	17.79	12	22.34
6	6.98	13	19.68
7	8.50		

One can see fromtable 3 that thicknesses of region 6,7,8 are reduced and the thicknesses of other regions are increased. In this condition, the TL of optimized sound package is illustrated as figure 6.The TLof dash with optimized sound package is higher from 630~4000Hz and the maximal TL increment is 2dB. Therefore, the optimized sound package achieved by GA is proved to have better insulation performance.What's more, the weight of total sound package has little increment, which is 0.36kg.

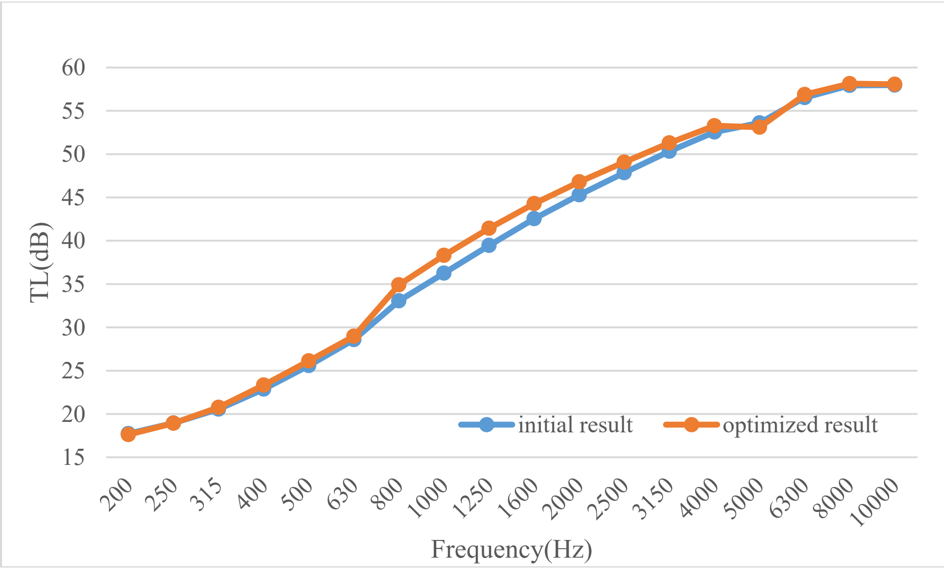


Figure 6 – Comparison between optimized result and initial result for dash TL. Red curve – TL of dash with optimized sound package; Blue curve – TL of dash with initial sound package

5. CONCLUSIONS

In the paper, the sound package of a vehicle dash was optimized, which has better performance under the condition of without increasing the weight of sound package too much. The result was gained by the combination of GA and SQP methods, which are proved to be effective to seek out the global optimal solution.

The method proposed in the paper could be applied to design sound package,which could be also used to optimize sound package of a full vehicle.

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