The Seated Comfort Design of Hybrid Electric Vehicle by Multi-Objective Optimization Method

Guang Yang *, Yong Cao and Haiyan Tao
GAC Automotive Research & Development Centre, Guangzhou, China
*yangguang@gacrnd.com

Abstract. The seated comfort is one of the important parts in vehicle design. The research of the second row’s head comfort and buttocks comfort of a hybrid electric vehicle is conducted by multi-object optimization method in this paper. The surrogate functions of the performances are obtained by design of experiments, and the Pareto optimal front is worked out employing a multi-object optimization algorithm. In the end it proved great improvement in the level of the seated comfort design, and the improved design performed significantly better than the initial one.

Keywords: Multi-objective optimization, Seated comfort, Vehicle design.

1. Introduction
The seated comfort of passenger vehicles is one of the important performances, which represent the competency of products. In the industry, the various indexes are usually set by experience and benchmarking, and there remains much scope for improvement in this mode of operation. Because of the layout of battery pack, the space of the hybrid electric vehicle second row is small. So, the research of the seated comfort is especially valuable in the small room. The seated comfort includes head comfort and buttocks comfort, and both have to do with the vertical dimension. Improving the seated comfort by distributing the space is a multi-objective optimization problem.

With years of experience, the establishing and solving method for multi-objective optimization problems are readily available in the field of academic research. For solving engineering problems, the surrogate model method is employed. Usually, the basic database is established by design of experiments, then the surrogate functions are set by the methods such as the response surface, radial basis function methodology and so on [1]. The calculation method for multi-objective functions include multi-objective genetic algorithm, multi-objective particle swarm optimization algorithm [2], as well as the NWSFA [3-4], which is able to solve constraint multi-objective optimization problems quickly. The response surface methodology and the NWSFA are adopted in this paper.

2. Theoretical basis and material properties
2.1. Theoretical basics.
As we all know, the second row’s passenger comfort is the basic performance for vehicle, the performance includes more than one factor. Define the unconstrained multi-objective optimization problem as,
\[
\min_{x \in R^n} \mathbf{F}(x) = \left[ F_1(x), F_2(x), \ldots, F_m(x) \right] 
\]

Where, the design variable \( x = (x_1, x_2, \ldots, x_n) \in R^n \) is a \( n \) dimensional vector in the optimization problem. \( X \) is the feasible region, so \( x \in X \). \( \mathbf{F}(x) \) is the set of functions composed by \( m \) objective functions, which is denoted by \( F_i(x), i = 1, 2, \ldots, m \). The dimensional vectors have range in practice. So, the mathematical model of the engineering optimization problem with upper and lower limit considered in this paper can be denoted as:

\[
\min \mathbf{F}(x) \\
\text{s.t. } l_i \leq x_i \leq u_i 
\]

2.2. The subjective assessment of seated comfort
The level of head comfort and buttocks comfort is reflected by subjective evaluation. And the subjective evaluation system and method are unified in the industry. Through the evaluation to the samples with different sizes, the head comfort subjective evaluation is finished. The score is from one to ten, and the higher score refers to an upgraded level. According to the weight coefficient of height, weight and gender, the scores of samples are calculated as a certain score to a certain size. Similarly, the buttocks comfort is evaluated by the samples with different thickness of the cushions. And, the evaluation method as well as calculation are the same as head comfort.

3. The model of the passenger comfort problem and solution
The design of second row seated comfort for a SUV with five seats, what the most thing is the vertical dimension allocation. Firstly, the size and gap value of the parts in the dimension chain are compressed as far as possible, such as the thickness of the battery pack, fuel tank, ground clearance and so on. The vertical distance from H point to ceiling and the vertical distance from H point to the lower surface of seat bracket are the design variables that are represented by \( A \) and \( B \). The two variables determine the head space and the thickness of the cushion, which influence the comfort of head and buttocks directly. In addition, backrest angle is also an important influence factor which is represented by \( \alpha \). The three design variables have their scope and relationship, as shown below. \( A \in [835, 865] \text{ mm} \), \( B \in [175, 205] \text{ mm} \), \( \alpha \in [22, 28] \text{°} \), \( A+B = 1040 \text{ mm} \).

Other parts in the vertical dimension chain are constant value, and the seated comfort changes with different allocation of \( A \) and \( B \). The head comfort (toubuSSX) function is defined as \( F_1 \). The buttocks comfort (tunbuSSX) function is defined as \( F_2 \). And the design variables of \( A \) and \( \alpha \) respectively are \( x_1 \) and \( x_2 \). The schematic diagram of the layout dimension chain is shown as figure 1.

![Fig.1 Schematic diagram of layout dimension chain](image)
3.1. Design of experiment
The central composite design is chosen to design the experiment, which is proved to be excellent. The central composite design has the advantages, that are fewer tests, simple design and good predictive. Besides, the higher-order information can be obtained with the expanding of the design space by the method. Thirteen sets of tests are carried out by above method, and the design variables and result of experiments are shown in table 1.

| No. | x1/m | x2/° | Head comfort | Buttocks comfort |
|-----|------|------|--------------|------------------|
| 1   | 0.85 | 28   | 8.8          | 8.1              |
| 2   | 0.85 | 25   | 8.4          | 7.7              |
| 3   | 0.865| 25   | 9.1          | 4.5              |
| ... | ...  | ...  | ...          | ...              |
| 12  | 0.835| 25   | 6            | 9                |
| 13  | 0.84 | 27   | 7.5          | 8.6              |

3.2. The establishing and solving of the functions
The two functions of head comfort and buttocks comfort with A, B and \( \alpha \) are established by response surface method. Because of the relationship of A and B, the functions have two variables. The F1 means the head comfort function and F2 refers to the buttocks comfort function. The figure 2 shows the change rule of the two functions, vertical coordinates toubuSSX and toubuSSX mean F1 and F2.

\[
F1 = -1723.8858 + 6249.18810 \times x1 + \ldots - 395.83333 \times x1 \times x2^2 \\
F2 = 17215.073 - 41158.66789 \times x1 + \ldots + 125.01 \times x1 \times x2^2
\]

In general, if the determination coefficient and adjusting determination coefficient are more close to 1, the response surface function with respect to response variables is more precise. The determination coefficient of head comfort function and buttocks comfort function are 99.86% and 99.64% respectively. The adjusting determination coefficient are 99.67% and 99.14%, respectively. Thus, the response surface functions in the paper can simulate response variables accurately.

Fig. 2 The surface of the two functions
After the calculation by the multi-objective optimization algorithm, the Pareto Optimality Front is demonstrated by the figure 3, as well as the corresponding performances. According to the result obtained, the head comfort increases and the buttocks comfort goes down at the same time. However, we can find that the head comfort declines slowly but the buttocks comfort increases quickly in some scope. This discovery means we can find an excellent decision, with satisfactory head comfort and the buttocks comfort at the same time.

![Fig.3 Pareto optimal front of the functions and performance](image)

By comparing the original design and the pareto optimal front, as illustrated in figure 4, we find that the original design can be improved. Base on the pareto optimal front, shown as table 2, a better design is chosen, with the 8.49 score of head comfort and the 8.45 score of buttocks comfort. The corresponding distance from H point to ceiling is 845 mm, and the backrest angle is 28°.

**Table 2.** The parameters as well as performances of the original and improved designs

|               | x1/m | x2/° | Head comfort | Buttocks comfort |
|---------------|------|------|--------------|------------------|
| Original design | 0.84 | 25   | 6.97         | 8.73             |
| Improved design | 0.845 | 28   | 8.49         | 8.45             |

![Fig.4 Comparison of the original design and POF](image)
4. Conclusion
The original design is checked, with the 6.97 score of head comfort and the 8.73 score of buttocks comfort. According to the result obtained, the design variables can be changed for the satisfying performances in both. By 22.4% increased head comfort and only 3.2% reduction in buttocks comfort, the improved design with the two performances are all in a good level. Then, the result is verified by subjective evaluation, and the performances are balanced well. In addition, the pareto optimal solutions obtained in this paper can be the basis of stylization research.

References
[1] Fliege. J, Drummond, Graña. L. M, Svaiter. B. F. Newton's Method for Multiobjective Optimization[J]. Siam Journal on Optimization, 2014, 20(2):602-626.
[2] Javidrad. F, Nazari. M, A New Hybrid Particle Swarm and Simulated Annealing Stochastic Optimization Method[J]. Applied Soft Computing, 2017, 60(4):634-654.
[3] G. Yang, T. Xu, X. Li. An efficient hybrid algorithm for multi-objective optimization problems with upper and lower bounds in engineering[J]. Mathematical Problems in Engineering 2015,18: 1-13.
[4] G. Yang, The research of NWSA for multi-objective optimization problems and the application in engineering[D], 2015. p. 66(in Chinese).