A STUDY OF OPTIMUM DESIGN AND ANALYSIS WITH D.O.E FOR AUTOMOTIVE SEAT FRAME

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In modern times, development trend of automobiles is the tendency to prefer the high fuel efficiency of automobile. Also, the structure of seat that takes 4% of automobile's weight is the target to be secured the stability enough and attain the lightweight. To meet this, the characteristics of load to be applied to seat structure must be analyzed from the initial time, and it must be considered and designed material, thickness, distance to be assembled with recliner and condition of section through the calculation of numerical value. This study performed to reduce stress and moments to be occurred to seat frame through keep the optimum condition with D.O.E for cushion frame of seat due to passenger inertia weight at the rear Collision of automobile. This study looked for optimum values with Minitab and analyzed the cushion frame of seat with LS-DYNA, FEA tool, according to those Factor.

Keywords: Automobile Seat; Finite Element Analysis; D.O.E; Seat Cushion Frame; Back angle of seat.

1. Introduction

Modern automotives makers have concentrated their efforts on developing the high fuel ratio of automobile with new energy to provide the high cost and the exhaustion for oil due to the failure in supply of fossil fuel. And, automotive users have wanted to the high fuel ratio of automotives due to high oil cost. According to this tendency, the seat structure, about 4% of the weight of automobile, needs to secure the safety and realize the light weight for increasing the competitiveness of automobiles. To secure the safety and

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the light weight for automotive seat structure must need to analyze the characteristics of load be supplied to seat structure at the initial structure design step. And through the calculation of numerical values, it must be selected suitable materials and designed suitable section condition for load condition. After finishing the initial structure design step, this structure has been carried out through FEA for the Strength and the legislation tests requested from automotive makers. It is possible to analyze the stress for each part of structure. If the stress is very high or if parts have over strength against specification, it must validate through re-analysis after the establishment of improvement device and repeat the analysis until obtaining the requested level. And then this structure is verified through the vehicle test with the optimum results. When verified, structure is designed the detail. So, it is realized the optimum safety and the light weight for structure. But, that method is very hard and need to the time for validation. Especially, it has the problem not to be considered the error between design and the vehicle test. And, so sometimes it is no optimum selection for the size and material of parts.

This study analyzed the factors effect at the seat structure with Design Of Experiments for the designed structure to be obtained the requested items of automobiles makers and legislation. And, this structure re-verified and re-designed through FEA. So, this study realized to keep the optimum level for the deformation of seat cushion frame when rear collision and reduce the weight, the cost and the period of development.

2. Design of Experiments for the Analyses of Seat Cushion Structure

2.1. Design of Experiments ^[1]

This study is used to 1/2 fractional design not full factorial design with Design Of Experiments. So, the result of 1/2 Fractional design can be the same with Taguchi's method. And, Taguchi's method is used to the orthogonal array to carry out more efficient design in the discrete design space and can obtain similar the results of full factorial design with 1/2 fractional design and minimum analyzed times. So, this study carried out the design for improving the deformation of seat cushion frame at rear collision of vehicles with the orthogonal array in the discrete design space. According to the condition of the seat cushion frame, the factors are material, thickness, section of shape and hole distance of recliner. And, there are 2-levels for 4-factor. The combined table of the levels for each factor is shown in Table 1.

Table 1. Factor and Level

Item	Level 1	Level 2
Material	SPFH590	SPFC780
Thickness	2.0	1.4
Section	A	B
Hole Distance	100mm	111mm

The orthogonal array was used to $L8$, and the value of level was selected to based to the initial design value of many design values. The optimum values were solved through Analysis Of Variance (ANOVA), and then the excellent value after comparing with the results of each law of matrix experiments became the optimum value. To select the optimum level, it was analyzed that the design factors give the design value the effects with the ratio of Signal-Noise (S/N ratio). The ratio of Signal-Noise was derived from quality loss function made with a quadratic equation. The ratio of Signal-Noise is the standard considered average and dispersion at the same time. This study was used to “smaller-then-better type” because the stress impacted at cushion frame of seat, the back angle of seat and moment of frame profit more low. Used the ratio of Signal-Noise is shown in the follows.

$$S / N = -10 \cdot \log_{10} \left(\frac{1}{n} \cdot \sum_{i=0}^n y_i^2 \right) \quad (1)$$

Here, n is the repeat measured time in combination of the same factors and levels, y_i is the analyzed result at that time. So, it looks for the condition of factor that the stress of seat cushion frame is the objective function and the average is minimized. For significance factors and no significance factors, significance factors were selected in the confidence interval of 95% through ANOVA. To validate the optimum condition, the estimated value with optimum was validated with FEA, and judged the reappearance for the ratio of Signal-noise. Finally, the optimized model was decided the response optimizer combined 3 kinds of the response like Stress, Moment and Back angle of seat.

2.2. Test Method for the rear collision

The evaluation of safety at the rear collision of vehicle judge an injured value of dummy at the collision of vehicle. But, it is impossible to test before finishing the development vehicle. So, to test with the similar vehicle condition, special test bench was made like Fig.1. Seat was installed at the sled like the same vehicle condition, and after AM50%(75Kg) of dummy was took a seat, according to of the rule of vehicle’s safety standard , at the collision, Safety of seat must be validated for impacted force at rear collision of moving wall with 35~38Km/h of velocity described at the vehicle structure standard. The validated standard of safety of seat is the angle variation of the back of seat and disjuncting or breakdown of various locking parts.

Fig. 1. Rear Collision Strength Test

Cushion frame's parts of the above validating items is to effect for the angle variation of the back of seat after rear collision, and the side structure of cushion connected the back of seat and cushion. At the rear collision, as it is affected the pressure at the back of seat due to inertia force of dummy, Moment was occurred at control part of the back of seat. And assembling parts jointed the side structure of cushion and control part of the back of seat were affected the forces to the direction of F1 and F2. At the collision, free body diagram is shown in Fig.2.

Fig. 2. Free Body Diagram of Seat

At the rear collision of vehicle, the back of seat effected to the inertia force of dummy due to the collision was occurred the maximum variation of angle, and then it was stopped in constant deformed position. At that time, the angle of the back of seat was occurred to large deformation, but, according to the specification, permanent deformed angle is very important at the stable. At that time, the angle of the back is called “Back angle”.

3. Optimum Model ^[2]

As Fig.2, assembling part affected firstly due to inertia force of passenger in the cushion structure at rear collision is the side structure of cushion. The factors affected in the strength of the side structure of cushion have many things. But, if total factors were considered, the times of experiments are increased and it can not be changed the design at limited layout condition. Therefore, in the factors affected in the side structure of cushion, the control factors without changing the layout of structure and can be approached are material, thickness, section of shape and hole distance of recliner. So, those were selected to factors.

3.1. Selection for factor and level

The seat structure must reduce the weight and cost, assure the required strength and be considered the productivity of parts. Therefore, materials are SPFH590 applied at current and SPFC780 improved the strength. The thickness of material are 2.0mm and 1.4mm. Sections of shape are 2 kinds and is shown in Fig.3. the hole distance of recliner are 100mm and 111mm. So, it can make 4 factors and 2 levels.

Fig. 3. Section type and Distance

3.2. Modeling for D.O.E and Finite Element Analysis for Each Model^[3]

8 kinds of samples were made for 4 factors and 2 levels with the orthogonal array of Minitab. Modelings of those samples were analyzed with FEA. The result table of arranged samples with Design Of Experiments is shown in Table 2.

This study was performed the structure analysis for 8 samples made by Design Of Experiments. The boundary condition of structure is, it gave the rigid condition at floor, and the seat made to bolting of beam element in track Floor Mounting bracket and fixed to 6-D.O.F for 4 points installed in floor of vehicle. The point of seat belt is established to take the behavior like floor of vehicle. And, the pulse of velocity applied to Car makers was input in floor of vehicle. Meshes of seat model were composed 2×10^5 for Node and 16×10^4 for element and meshes of the side structure of cushion were composed 4892 for node and 4662 for element. The results of FEA for 8 samples made by Design Of Experiments are shown in Table 2. As the analysis of the bellows table, it is not possible to clear the standard of smaller-then-better type. So, to analyze the exact results, it is needed to response analysis with the results composed stress, moment and Back Angle. The 3 kinds of results are smaller-then-better condition. When composed 3 kinds of results, it can be decided optimum design model.

Table 2. Arrangement of samples with D.O.E and the Results of FEM

No	Material	Thickness (mm)	Section of shape	Hole Distance (mm)	Stress (N/mm ²)	Moment (Nm)	Back Angle
Sample.1	SPFC780	2.0	A	100	1125	2,010	13
Sample.2	SPFC780	2.0	B	111	851	2,133	7
Sample.3	SPFC780	1.4	A	111	1184	1,870	19
Sample.4	SPFC780	1.4	B	100	1052	2,011	11
Sample.5	SPFH590	1.4	A	100	839	1,843	21
Sample.6	SPFH590	1.4	B	111	885	1,953	12
Sample.7	SPFH590	2.0	A	111	902	2,009	13
Sample.8	SPFH590	2.0	B	100	710	2,109	7.5

This study can be looked for the optimum factor for each responses i.e. Stress, Moment, and Back Angle with 4 factors. In the results, This study found the best sample like No.6.

3.3. Optimum model by response optimizer

After rear collision, the Optimum model must be similar to the current model for the permanent deformed angle of seat, not allowed the excessive stress and the using Moment of recliner does not exceed 2000Nm of the maximum limited moment. the optimum model can be reduced the weight and satisfy the above requirement. The comparison of Current model and Optimum model by response optimizer is shown in table 34.

Table 4. Comparison of Current and Optimum

Item	Material	Thickness (mm)	Section of shape	Hole Distance (mm)
Current	SPFH590	2.0	A	100
Optimum	SPFH590	1.4	B	103

The result of FEA for Current and Optimum model is shown in Table 4. According to the result of Table 4, it can be found that for optimum model, the stress was 10.2% down and moment was 3% down than current. But, the Back Angle of seat was similar to current. So, it can be found the optimum model with thickness, section of shape and hole distance of recliner. Hereby it is possible to develop the model has enough strength and reduced cost.

Table 5. Comparison of Stress, Moment and Back Angle

Item	Stress (N/mm ²)	Moment(Nm)	Back Angle
Current	902	2,009	13

Optimum	810	1,950	13

4. Conclusion

This study was used to Design Of Experiments and established optimum test condition. And, the rear collision test was simulated by FEM and than it is possible to optimize the side structure of cushion affected the back angle of seat for the structure of seat at the rear collision. This study can be realized the optimum seat frame condition for each factor and

level with Design Of Experiments. Especially, at response optimizer of Design Of Experiments, specification satisfied smaller-then-better condition for Stress, Moment and Back angle is SPFH590 for material, 1.4mm for thickness, B type for Section of shape, and 103mm for hole distance of recliner. The optimum model can obtain 10.2% down for stress, 3% down for Moment then current but, the similar angle for Back angle with current and can be realized about 30% down than current for weight.

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