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Research Article

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Lightweight Design of Passenger Vehicle front Seat Based on Topology Optimization

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Abstract In this paper, the lightweight design of a passenger car seat is carried out. DP590 duplex steel is used as the integral material of the frame, and the allowable stress of the steel under bending condition is 211.5MPa. This lightweight design uses HyperWorks for pretreatment and post-processing. Based on the Chinese national standard GB15083-2019 automobile seat test method, the finite element analysis of the seat frame model is carried out. The topological optimization of the seat frame is carried out by using the topology module in HyperMesh. The optimized seat frame structure is subject to the static analysis in HyperMesh. Finally, the overall quality of the seat frame is reduced under the condition of meeting the strength and rigidity of the seat structure and no failure of all parts. The lightweight seat bone mass is reduced by 1.8kg and 11.4% compared with the original skeleton mass, realizing the lightweight effect of the seat.

Keywords Seats, Lightweight, HyperWorks

Introduction

The lightweight technology of automobile mainly refers to the design optimization of automobile parts without changing the original overall performance of automobile. The realization of automobile lightweight is of great significance not only in environmental protection but also in improving the overall safety of automobile. The relevant research data shows that: the fuel efficiency can be increased by 6% - 8% by reducing automobile mass by 10%. At the same time, the reduction of the overall mass of the vehicle can also alleviate the injury of passengers in the collision process to a certain extent. The vehicle seat accounts for 8% of the vehicle mass, ranking the fourth in all auto parts systems. Therefore, research on lightweight of automobile seats is very important for reducing the vehicle mass. Several auto parts enterprises have carried out lightweight development for seats of different brands [1-4]. The seat is an important component of the automobile cab and also the main safety component [5]. As the interior trimming part directly contacting with human body, the vehicle seat plays an important role in the comfort and safety of passengers. However, the traditional seat design, while fully considering the safety of the seat, ignores the optimization of the overall quality of the seat, so that the seat is heavier. In order to improve the overall performance of the vehicle, it is also very important to reduce the weight of the seat while ensuring the structural strength and rigidity of the seat [6].

In 1988, Bendproposed the homogenization method, which takes the geometric parameters of the microstructure as the design variables and converts the topology optimization into scale optimization [7]. Topology optimization has become one of the effective techniques in structural optimization design by adjusting material layout and force transmission path. At the same time, a lot of technical difficulties are found in the application of topology optimization method in industry and engineering, which further promote the progress of topology optimization theory [8-12]. In order to leave enough safety space for the vehicle in collision, Ye Chang analyzes the impact resistance of the seat. By adjusting the backrest angle of the seat, adjusting the seat slide rail and conducting topology optimization on the angle adjuster, the impact resistance of the seat is finally strengthened and the lightweight requirements are also met [13-14]. The topology optimization method can improve the strength of the overall structure while optimizing the structure, and reduce the weight on the premise of ensuring that the overall performance meets the actual use requirements without changing the original layout [15-19].

Static Analysis of Seat Frame

The seat frame is the basis of the entire seat, and must have sufficient strength, appropriate stiffness and as light as possible to ensure that the seat has good safety and comfort under various complex driving conditions, avoid excessive deformation and ensure a certain life. Therefore, this section carries out static analysis on the seat frame under the relevant national regulations to obtain stress nephogram and displacement nephogram, and analyzes the postprocessing results to check whether the strength, rigidity and other performances meet the requirements, so as to provide reference for further optimization and improvement.

Hyperworks Software Introduction

HyperWorks is an efficient finite element front and rear processor, designed and developed by Altair Company in the United States. At present, it is applied by most automobile design companies at home and abroad. It can establish various complex finite element and finite element difference models, and has good interfaces with various CAD and CAE software and has efficient grid division function. This paper uses the HyperWorks' pre - and postprocessing to mesh the seat frame, adds boundary conditions, establishes a finite element model, and carries out finite element analysis to verify whether the stiffness and strength of the seat frame meet the design requirements, so as to provide a theoretical reference for the design.

Establishment of Static Model of Seat Frame

The vehicle seat is generally composed of hundreds of parts. Some parts such as cushion frame, backrest frame, sliding rail and support leg play a critical role in safety as bearing parts. Some parts such as spring, foam and angle regulator are only used to ensure the comfort of passengers and adjust the sitting posture of passengers. Therefore, on the premise of not affecting the accuracy of the analysis results, reasonably simplifying and ignoring some non-bearing parts can not only save a lot of time and costs, avoid the computer crash and other uncertainties in the calculation process, but also ensure the accuracy of the calculation results. Import the original seat frame model into HyperMesh Open, remove redundant components and connections, extract midplane, mesh, remove fillets and small connection holes, define properties, apply constraints and loads, etc.

Finite Element Model Meshing

Because most of the seat frame is composed of sheet metal parts and pipe fittings, the shell element is used for simulation analysis. The suspension spring and cushion spring are simulated by beam element, and the headrest rod is simulated by solid element. Combined with the overall size of the seat, the average 5mm grid element is adopted, with the minimum element no less than 2mm and the maximum element no more than 10mm. Finally, 59834 finite element model elements of the seat and 42852 nodes are obtained. The seat geometry model is shown in Figure 1

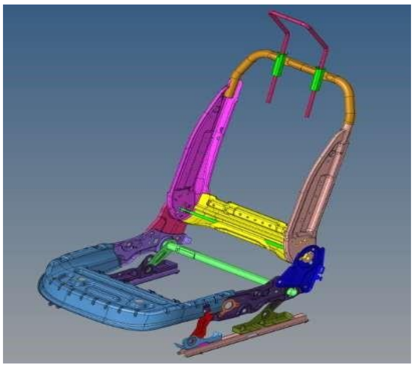


Figure 1: Geometric model of seat

Definition of material properties

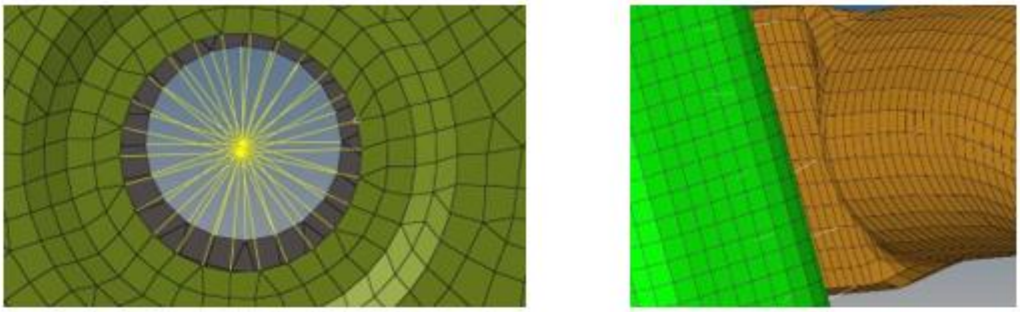
The seat frame is made of steel and DP590 duplex steel. The safety factor is 2 and the allowable stress is 211.5MPa. The specific material properties are shown in Table 1.

Table 1: DP590 Material Properties

Name of material	Modulus of elasticity (MPa)	Poisson's ratio	Density ton/mm^3	Yield strength (MPa)
DP590	215000	0.28	7.85E-09	423

Connection mode and addition of constraint

Parts on the seat are generally connected by welding and bolting. Rigid of spotweld is adopted for rigid connection in welding, connection of bolt is adopted for connection, and parts such as height-adjusting pump and angle regulator with little impact on overall rigidity of seat frame are simplified. The finite element model of seat frame is shown in Fig. 2. The floor connecting plate and the rear end hole of the lower sliding rail are connected to the body with full constraint simulation seat, as shown in Figure 3.



Bolted connection

Weld

Figure 2: Connection mode

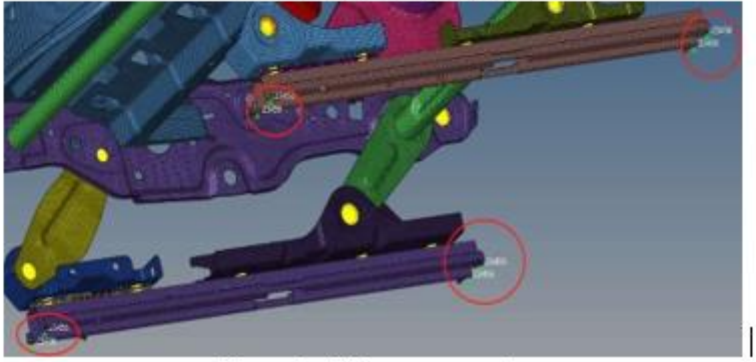


Figure 3: Adding a constraint

Simulation

When analyzing the strength of seat back according to GB15083-2019 automobile seat test method, apply a load of 530Nm to the seat back relative to the R point of the seat. The seat and the seat fixing point can bear the load, and the fixing device, adjusting device and locking mechanism cannot be opened [20]. As shown in Figure 4.

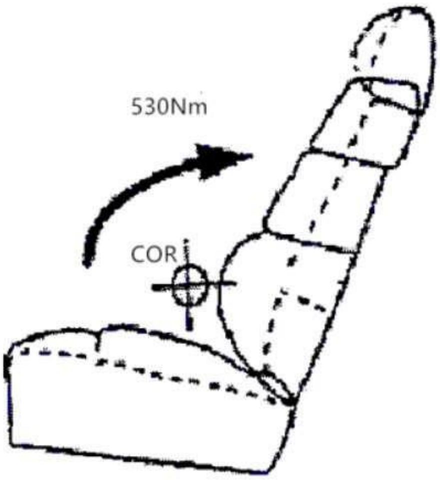
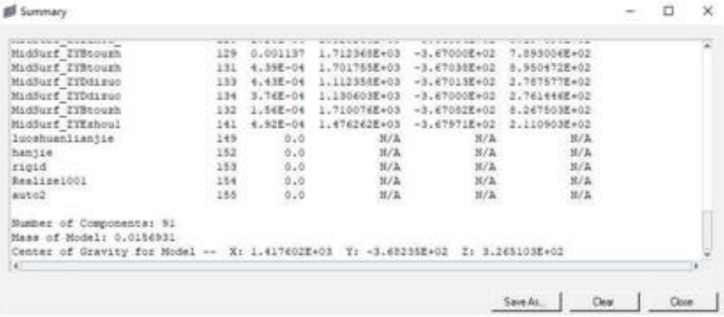


Figure 4: Loading diagram of seat back static strength regulation

In the static strength analysis of the seat back, it is statically simulated by direct loading, and 530N · m moment is applied at the backrest with the seat "R" point as the reference point. In general, actual tests in the laboratory shall be carried out with the load directly applied to the backrest, with appropriate simplification in the finite element analysis as appropriate. Find the centre of mass of the seat (X: 1.417602E+03, Y: -3.68235E+02, Z: 3.265103E+02), As shown in Figure 5. Under the static strength condition of the seat back, it can be simplified as that the load force is applied to the concentrated point P of the U-tube of the backrest, the distance between the point P and the point R is 575.09mm, and the included angle between the straight line formed by the point P and the point R and the vertical direction is 30.635 °. The load loading conditions and positions of the points P and R are shown in Figure 6. Therefore, a load of 530Nm relative to the seat R point is applied to the seat back, which is equivalent to a horizontal force of 1071.9N in the X direction applied to the point P.



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MidSurf_ZYBtouzh              129  0.001137  1.712368E+03  -3.67000E+02  7.893006E+02
MidSurf_ZYBtouzh              131  4.39E-04  1.701755E+03  -3.67038E+02  8.950472E+02
MidSurf_ZYDdizuo              133  4.43E-04  1.112358E+03  -3.67013E+02  2.787577E+02
MidSurf_ZYDdizuo              134  3.76E-04  1.130603E+03  -3.67000E+02  2.761446E+02
MidSurf_ZYBtouzh              132  1.56E-04  1.710076E+03  -3.67082E+02  8.267503E+02
MidSurf_ZYEzhoul              141  4.92E-04  1.476262E+03  -3.67971E+02  2.110903E+02
luoshuanlianjie               149       0.0           N/A           N/A           N/A
hanjie                        152       0.0           N/A           N/A           N/A
rigid                         153       0.0           N/A           N/A           N/A
Realize1001                   154       0.0           N/A           N/A           N/A
auto2                         155       0.0           N/A           N/A           N/A

Number of Components: 91
Mass of Model: 0.0156931
Center of Gravity for Model --  X: 1.417602E+03  Y: -3.68235E+02  Z: 3.265103E+02
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Figure 5: Seat center of mass

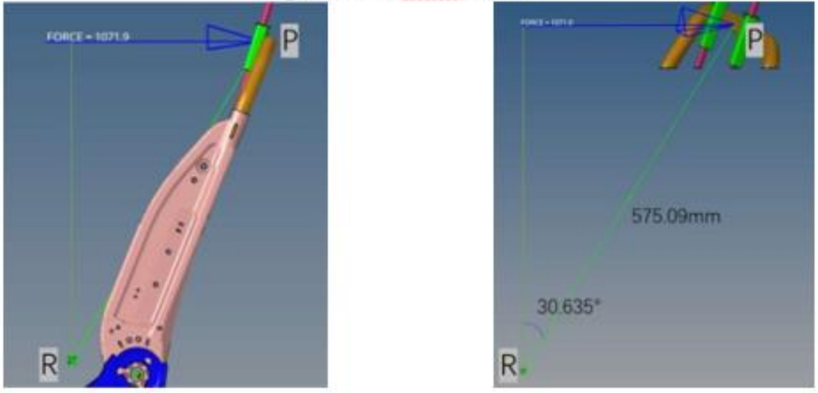

Figure 6: Load loading of simulation model

Simulation Result

The displacement and stress nephograms of the overall deformation of the seat frame under the equivalent 530Nm load are obtained by solving the finite element model after the constraint and load are applied.

Figure 7 shows the stress nephogram of the seat back after 1071.9N is applied. It can be seen from the figure that the overall stress distribution of the seat frame is relatively uniform, without many stress mutation and stress concentration. The part mainly bearing the load is distributed under the seat. As the seat is of symmetric structure, most of the stress is evenly distributed on both sides. The stress value concentrated on the left side of the seat is relatively high and that on the right side is relatively low. The maximum stress occurs at the bolted joint of seat base, i.e. 57.68MPa, which is far less than the allowable stress of DP590 duplex steel, with large lightweight space.

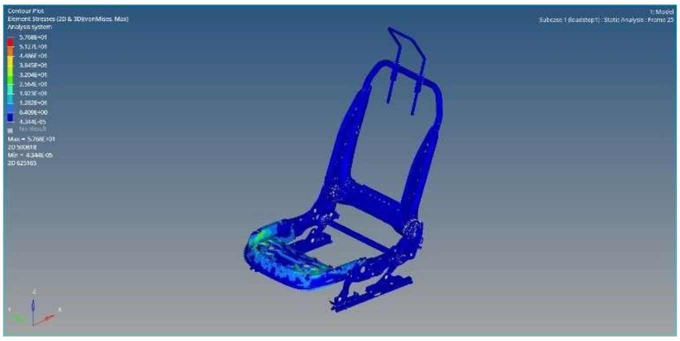

Figure 7: Stress nephogram under equivalent 530Nm load

Figure 8 shows the displacement nephogram of the seat back after 1071.9N is applied. It can be seen from the figure that the overall deformation of the seat frame is smooth without sudden change. The overall displacement of the seat is uniform without torsion in the Z direction. The maximum deformation value is 3.630mm, located at the upper headrest skeleton, less than 20mm specified in the national standard.

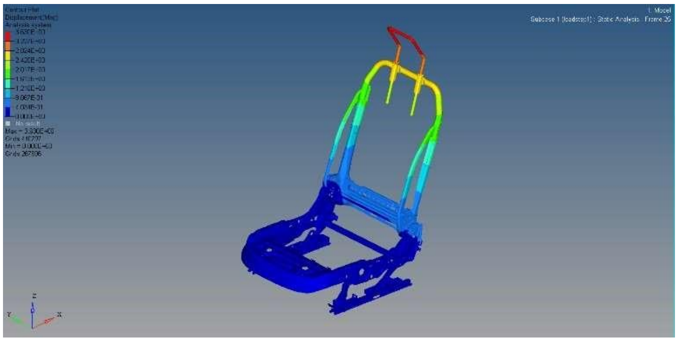

Figure 8: Displacement nephogram under equivalent 530Nm load

Lightweight Design of Seat Frame

The significance of automobile lightweight is not only to reduce automobile curb weight as much as possible under the premise of guaranteeing automobile strength and safety, but also to change automobile structure, material, process and other aspects under the premise of guaranteeing automobile quality unchanged or without significant increase, so as to enhance automobile safety, usability, economy and other performances.

Ways of lightweight

Generally, there are three ways to realize automobile lightweight: structure optimization, application of lightweight materials and advanced manufacturing process. Structural optimization and lightweight materials are widely used in the lightweight design of seats. The structure optimization is divided into topological optimization, dimension optimization and shape optimization. The topological optimization has the most obvious effect on the weight reduction of the seat. It mainly calculates and analyzes the static strength through finite element analysis and optimization algorithm. Under the condition of meeting the strength and performance of the seat mechanism, it can remove the redundant materials as far as possible and rationalize the force transmission path of the seat under various working conditions. High-strength steel is the main lightweight material used. Its tensile strength is 2~3 times of ordinary low-carbon steel. It has good ductility and can be rolled into very thin steel plate. It is an important lightweight material. The other is lightweight materials, mainly including magnesium, aluminum alloy, carbon fiber and other composite materials.

Topological optimization of main components of seat frame

The simulation results show that the stress value of most parts of the seat is far less than the yield strength, so the parts with smaller stress and larger mass and area are selected as the main objects of topology optimization. The side plates and bottom plates on both sides of the backrest are selected as the topological optimization design space, the minimum displacement of the seat headrest frame is taken as the optimization target, and the volume fraction of 0.25 is taken as the constraint condition. The seat frame is optimised using the topology module in HyperMesh.

The main scope of the topology optimization is on the backrest side panel and the seat bottom fender shield. The optimization effect is generated in the flat area in the middle of the backrest side panel and the large range of the bottom fender shield. It shows that under the current working condition, the stress of this part is small and does not belong to the main force transmission path of the backrest. As shown in Figure 9.

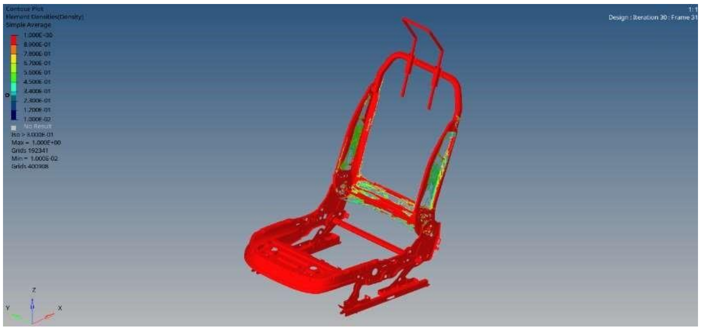

Figure 9: Simulation results of topology optimization

Based on the solution obtained by topology optimization, materials with density below 0.6 are removed as much as possible, and lightweight treatment is carried out on the original model to obtain a lightweight seat frame model, as shown in Figure 10.

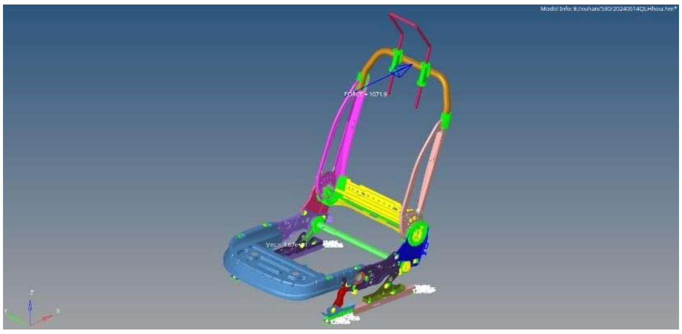

Figure 10: Lightweight seat frame model

Lightweight result analysis

In order to ensure that the optimized seat frame can meet the requirements of strength and stiffness, the key parts cannot fail and have no protruding sharp points, it is necessary to verify the optimized seat frame again, apply the same load and constraint conditions as before to check and calculate the above model after lightweight, and obtain the stress nephogram and displacement nephogram of the overall deformation of the seat frame under the equivalent 530Nm load after lightweight.

Observe the overall stress nephogram of the lightweight rear seat frame. As shown in Figure 11, the stress value of the seat frame before and after lightweight changes greatly, with the maximum value of 194.5MPa, but it does not exceed the allowable stress of DP590 duplex steel 211.5MPa, which meets the national standard requirements of the seat frame under the load of equivalent 530Nm.

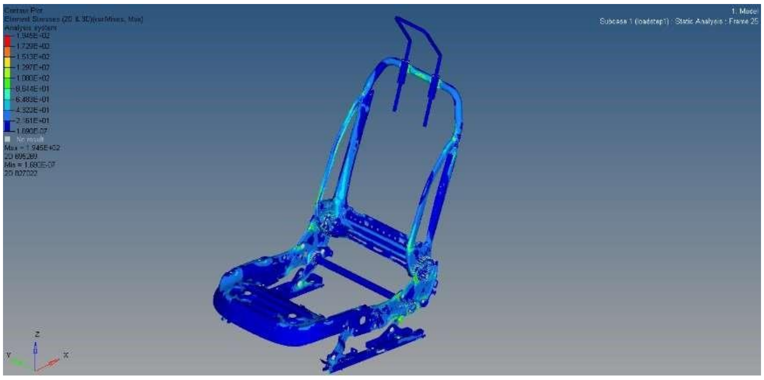

Figure 11: Stress nephogram under equivalent 530Nm load after lightweight

Observe the overall displacement nephogram of the seat frame after lightweight. As shown in Fig. 12, compared with the deformation before lightweight, the deformation of the frame has no obvious change, and the displacement change transition is gentle. The displacement of most of the stressed parts is less than 5mm, which conforms to the national standard requirements of the seat frame under the equivalent 530Nm load, and the risk of part failure is small.

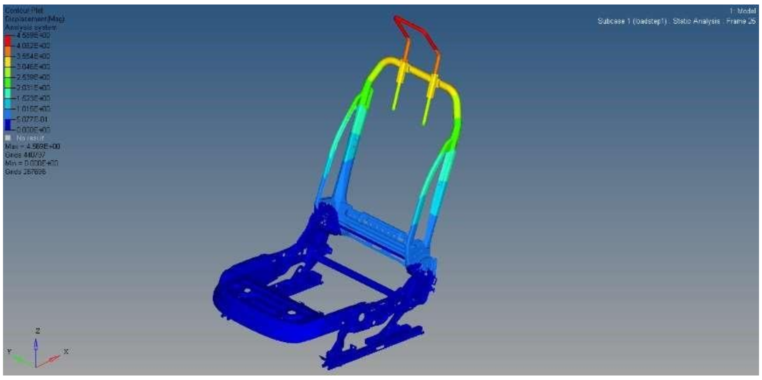

Figure 12: Displacement nephogram under equivalent 530Nm load after lightweight

Therefore, it can be seen from the simulation results that the overall displacement of the seat frame does not change significantly after lightweight treatment, which is less than 20mm specified in the national standard and meets the use conditions. The stress of most structures is below 194.5MPa, less than the allowable stress of DP590 duplex steel of 221.5MPa, meeting the service conditions under the load of equivalent 530Nm, and the lightweight scheme is qualified.

Based on the finite element model after lightweight, the mass of the model before and after lightweight is calculated in HyperMesh. See Figure 13 and Figure 14.

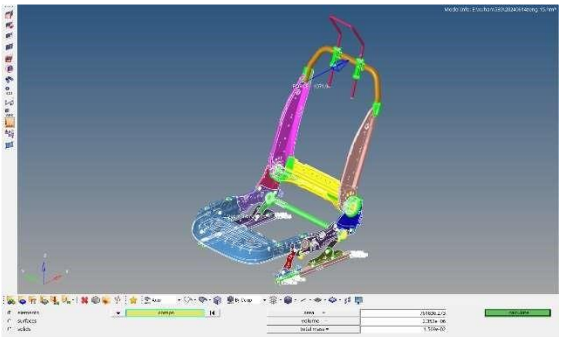

Figure 13: Weight of seat frame before optimization

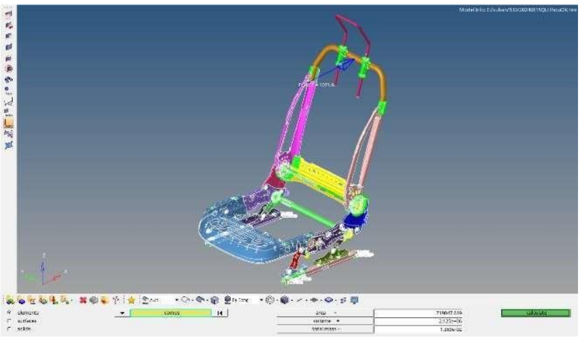

Figure 14: Optimized weight of seat frame

The weight of seat frame before topology optimization is 15.69kg, and the weight of seat frame after topology optimization is 13.89kg. The weight of seat frame is reduced by 11.4%, finally realizing the lightweight effect of seat frame. As shown in Table 2.

Table 2: Comparison of lightweight results of seat frame

	Maximum displacement (mm)	**Maximum stress (MPa)**	**Maximum seat frame mass (kg)**
Lightweight front	3.630	57.68	15.69
Lightweight rear	4.569	194.5	13.89
Contrast	1.445	136.82	1.8

Conclusion

In this paper, the front seats of an automobile are modeled and the finite element model is established. The finite element model is analyzed according to the national standard GB15083-2019 automobile seat test method. According to the regulatory requirements, the constraint, contact and load conditions of the model are set to determine the seat parts that have a greater impact on the quality of the seat frame. The variable density method is used to optimize the seat frame topology based on the topology module in HyperMesh, with the minimum displacement of the seat headrest frame as the optimization objective and the volume fraction 0.25 as the constraint condition. Finally, under the condition of meeting the structural strength and rigidity of the seat and no failure of all parts, the weight of the seat frame is reduced by 1.8kg, which is 11.4% less than the original seat frame, and the lightweight effect of the seat is obtained.

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