Topological Lightweight Optimization Simulation on EMU Luggage Rack Bracket

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Abstract. Basing on unite simulation method with INSPIRE and HYPERMESH, topological lightweight optimization on coach luggage rack bracket structure of China Standard EMU train had been executed. By comparing the simulation results with the test data, accuracy of the computational models had been verified. It was proved that the modified luggage rack bracket structure would have better mechanical performance and reach the goal of lightweight at the same time.

1. Introduction
With the development of high speed railway vehicle technique, demands for component structure lightweight to reach the goal of energy conservation and economy have been increased all along. The coach luggage rack, which had simple structure and was only used for luggage storage in the past, has been upgraded to integrated equipment which contains lamp belt and loudspeaker etc. Among those component parts, luggage rack bracket is the key part which has the important function of supporting the whole luggage rack and loads.

From the point of view on material, magnesium alloy although has lighter weight and better mechanical performance, but it will bring much higher requirements on surface treatment technology. So, it will be more economic and doable to engage the lightweight design of luggage rack bracket from the point of structure optimization [1][2].

2. Original bracket structure analysis

2.1. Original bracket structure

![Figure 1. Original bracket structure](image-url)
In Figure 1, which presents the original luggage rack bracket structure, it has been shown that the mounting base hook would connect with the mounting base and then fix to the carbody sidewall. Baffle is used for covering the gaps between side roof panels behind the luggage rack. As the main load-bearing structure, upper and lower arms could guarantee the stiffness of the bracket. Positioning hole and restriction block are used for assembling section bars. As for support platform, it could support the PC plate which bears the luggage. Sink square is the initial design for weight reduction.

2.2. Analytical process and parameter setup
According to UIC 566-1990 standard requirements, the most serious load case would be: 1000 N/m vertical surface load on PC load-bearing section and 850 N concentrated loads (alternative) on the middle of front section bar at the same time, as is shown in Figure 2.

Making equivalent computation from luggage rack bearing load to bracket bearing load, and then it can be derived that pressure load on Area 1 would be 0.2865 MPa and pressure load on Area 2 would be 0.0158 MPa, as is shown in Figure 3.

2.3. Simulation result analysis on original model
In order to ensure the simulation accuracy, luggage rack complete model was firstly established to engage structure static strength simulation according to UIC 566-1990 standard. As is shown in Figure 4, the maximum vertical deflection was 31.59 mm from simulation and happened in the middle of front section bar. Meanwhile, actual luggage rack strength test was also carried out, as is shown in Figure 5. The test data of deflection was 35.11 mm and the location was the same as simulation result. Deviation between simulation and test would be 10.02% and it could be proved that the computational model we used in this paper was accurate enough.

Furthermore, bracket computational stress and stiffness results were extracted and presented in Figure 6 and Figure 7. It shows that maximum Von Mises stress of bracket structure under the most serious load case was 32.879 MPa and maximum vertical deflection was 0.231 mm, which happened in the front edge of the bracket.
From the contours in Figure 6 and Figure 7, it could be found that sink square area has the lowest and evenly distributed stress, all around 6 MPa and less. Meanwhile, the material of the bracket is cast aluminium, which has 276 MPa yield stress limitation. So the safety margin of this area is relatively high and could be considered to use total material removal technique.

To the area between upper and lower arms, the stress is also in a low level generously and could be considered to use partial material removal technique. In front and back section bar assembling area, the magnitudes of stress are relatively high and has obvious changing gradient. Besides, it must be considered that interface relationship should not be changed in order to guarantee the component interchangeability. So, the red zone presented in Figure 1 would not be in the topological optimization scope in this paper.

3. Topological lightweight optimization

3.1. Retrograde design of bracket structure
In order to find the best design of lightweight structure, we should firstly execute retrograde process on the original model, which is engaging material filling technique on sink square area and between upper and lower arms. Then as is shown in Figure 8, except the red zones (mounting base hook, section bar restriction blocks etc.) marked in Figure 1, all other area of the bracket have been defined as optimization design space. This step could be executed in SolidThinking Inspire.

3.2. First round of topological optimization

Figure 6. Stress contour of original model Figure 7. Deflection contour of original model

Figure 8. Optimization design space  Figure 9. Computational model for first optimization

Figure 10. Best force delivering path Figure 11. Optimization design result
When finishing the retrograding, the raw model would be inputted to Solid Thinking Inspire and execute the first round of topological optimization. Computational model is presented in Figure 9. Three factors of topological optimization should be defined as follows.

(a) Design space: all brown area in Figure 9.
(b) Goal function: minimum structure mass.
(c) Design constraint condition: safety coefficient less than 4.6.

At the meantime, lock the minimum/maximum block size control function and add mould release and symmetry constraint.

After computation, the best force delivering path result is shown in Figure 10. Basing on this, we should merge and simplify complex truss type of the inner structure and then the optimization design result of first round topology is presented in Figure 11.

Output model of first round optimization is the maximum weight reduction model. The reduction ratio is above 45%. However, couple of problems are contained in this model and need to be solved.

(1) Although safety coefficient constraint has been added before topology, problems of over high stress level still inevitably happened in optimized model basing on the best force delivering path, especially in the area of connecting surface with front and back section bars. As is shown in Figure 12, maximum stress value has been over 52 MPa and in the down part of the bracket, there are several high-value stress zones.

(2) If the block size control function has been locked, it is inevitable to generate complex truss structure inside the bracket in order to maintain the mechanical performance. But in actual production, this kind of design cannot be realized due to the difficult moulding technique, not to mention the artistic requirement. So in the following optimization, block size control function must be unlocked.

3.3. Second round of topological optimization
To fix the problem of less strength in bracket bottom, we firstly cancelled all the complex truss structure inside the bracket and magnified the thickness of the bracket bottom from front section bar assembling surface to the back one. Although the inner supporting and stiffness performance has some loss, the bottom area strength performance has been obviously enhanced. Under the same load case, the mechanical simulation has been executed. From the results, it can be found that maximum stress value has been decreased to 22.30 MPa and maximum deflection is 0.6119 mm, which is more than the original model value 0.2314 mm.

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Basing on the computational results above, second round of topological optimization has been executed in Inspire shown in Figure 13. Three factors of topological optimization should be defined as follows.

(a) Design space: all brown area in Figure 13.
(b) Goal function: maximum structure mass.
(c) Design constraint condition: total mass of reserved truss less than 180 g.

At the meantime, add mould release and symmetry constraint. Specially, it should be prescribed that total amount of truss should not be more than two. By several test computations, it has been found that 35 mm is the best choice of minimum block size and can meet the artistic requirement. After second optimization, the best force delivering path has been solved out as in Figure 14 and the total mass of bracket is 1.6965 kg.

Detailed modifications have also executed basing on the second optimization model. The specific content is as follows.

(1) Move the left truss in Figure 14 to the left direction for 17 mm to make it connect with the baffle part and make the shape uniform and smooth.
(2) Make the right truss in Figure 14 uniform and smooth by the biggest width of the result shape. Meanwhile, keep the slope same as the left truss.
(3) Because some more material has been added in the above two steps and it will bring benefit to structure strength and stiffness. So, the most right brown zone in Figure 14 could be removed and make the whole bracket narrower for 2 mm.

The final version of the optimized design solution has been presented in Figure 15.

Figure 15. Final version of the optimized bracket

3.4. Verification for the final version of the optimized design

Figure 16. Stress contour for final model

Figure 17. Deflection contour for final model

Figure 18. Luggage rack vertical deflection contour (optimized bracket used)
As is shown in Figure 16 and Figure 17, structure mechanical performance verification has been executed in HYPERMESH. Compared with the original model under the same load case, the final version of optimized bracket has the maximum Von Mises stress as 22.737 MPa and location keeps the same. Maximum deflection is approximately 0.293 mm and also happens in the foremost part of bracket.

Furthermore, optimized bracket has been assembled into the original luggage rack computation model and another complete structure performance simulation is executed. The maximum vertical deflection was 34.681 mm, which also happened in the front edge of the bracket and slightly larger than the original model data 31.59 mm. So it is proved that the stiffness loss due to the bracket structure change is still in allowed scope.

4. Conclusion

By comparing the original and optimized model simulation results, which have been shown in Table 1, it can be concluded as follows.

| Item                     | Original model | Optimized model | Deviation |
|--------------------------|----------------|-----------------|-----------|
| Mass (kg)                | 1.907          | 1.572           | -17.6%    |
| Maximum Von Mises stress (MPa) | 0.231          | 0.293           | +26.8%    |
| Maximum deflection (mm)  | 32.879          | 22.737          | -30.8%    |

(1) To original model: total mass is 1.907 kg, maximum Von Mises stress is 32.879 MPa and maximum deflection is 0.231 mm under the most serious load case which is defined in UIC 566-1990.

(2) To optimized model in the same load case: total mass is 1.572 kg, 17.6% lower magnitude than the original model, maximum Von Mises stress has decreased to 22.737 MPa, 30.8% lower magnitude than the original model, maximum deflection is 0.293 mm, 26.8% higher magnitude than the original model.

(3) The optimized model can guarantee the features of more lightweight and better mechanical strength performance. This solution of bracket design can provide valued reference to further structure development.

References

[1] Wang, X. M, Song X. W, Liu D. G and Li Z. G. (2013) Topological optimization on luggage rack mounting base of EMU. Rolling Stock, 51: 11.

[2] Qin, S. (2015) Design optimization and simulation analysis on EMU luggage rack. Technological Development of Enterprise, 7: 94-95.

[3] Wen, D. L, Jin X. (2016) Design and modelling of non-uniform honeycomb structures based on topology optimization. Manufacturing automation, 38: 130-133.

[4] Hao, L. G, Ma, B. (2011) Application of topological optimization and casting simulation in light-weight design of forklift driving axle. Special casting & nonferrous alloys, 31: 943-945.

[5] Lan, Q, Du, Y. F and Li, H. (2007) Simulation of transmitting force way of raft foundation using topology optimization. Computer simulation, 24: 163-165.

[6] Zheng, S. P, Lv, C, Liu H. G and Wang, S. L. (2013) Topology optimization on engine supporting structure. Construction machinery and equipment, 44: 39-43.