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Lightweight design research of solar panel bracket

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Abstract: *In order to improve the overall performance of solar panel brackets, this article designs a solar panel bracket and conducts research on it. This article uses Ansys Workbench software to perform finite element analysis on the bracket, and simplifies the bracket based on the results of the finite element analysis. Based on the simplified bracket model, this article adopts the response surface method to lightweight design the main beam structure of the bracket, and analyzes and compares the bracket models before and after optimization. The optimized main beam adopts a section height of 100mm, a section width of 36mm, and a section thickness of 2mm. Compared to the original bracket, the optimized bracket has reduced weight by 8.459kg, with a weight reduction rate of 14.45%. At the same time, the maximum displacement of the optimized bracket decreased by 0.0375mm compared to the before, and the maximum stress also decreased by 0.10MPa compared to before optimization. This indicates that while reducing the weight of the bracket, the overall performance of the bracket has also been improved.*

Keywords: *Solar panel bracket; Workbench; Finite element analysis; Response surface; Multi-objective optimization*

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I. Introduction

In recent years, solar panels have been widely used in various fields, providing clean and renewable energy for social development. With the advancement of technology and the reduction of costs, the application range of solar panels will continue to expand, and become an important component in promoting sustainable development. The solar panel bracket needs to bear the weight of the solar panel and maintain its stability. If the bracket structure is not strong enough, the solar panel may deform or even break, not only affecting power generation efficiency, but also potentially damaging equipment. Therefore, the study of the structural strength of solar panel bracket is very important for improving the reliability and safety of solar systems.

Liu et al. studied common exhibition hall solar panel structures. And the finite element method was used to analyze the wind load response of the solar panel, and the displacement and stress values of the solar panel under wind load were obtained, providing reference for the subsequent design of solar structures[1]. Yang et al. conducted research on column biaxial solar photovoltaic brackets, studying the structural loads at different solar altitude and azimuth angles. Conduct static analysis and optimization design of the bracket based on the load. This optimization method can shorten the construction period and reduce costs to a certain extent[2]. Mao et al. conducted research on the installation stability of columnar solar panel brackets, using static analysis and linear buckling analysis methods to analyze the load-bearing capacity, structural strength, and stability of the brackets under different conditions[3]. Yin takes a certain buckle type full hall bracket as the research object, and uses the finite element method to analyze the stiffness and strength of various parts of the bracket system. And the wind resistance stability of the support was analyzed, and the calculation results met the requirements[4].

As a clean and renewable energy source, the application range of solar panels is continuously expanding[5-7]. With the continuous development of solar panels, solar panel brackets are also facing increasingly high requirements. The solar panel bracket needs to bear the weight of the solar panel, and its strength structure needs to ensure that the solar panel will not deform or damage[8, 9]. Based on this, this article conducts research on solar panel brackets, and the analysis results can provide reference basis for the design of subsequent solar panel brackets.

II. Brackets model and calculation method

2.1 Brackets model

The new solar panel bracket designed in this article has a length of 4030mm, a width of 992mm, and a height of 1296mm. All parts of the solar panel bracket are welded with rolled edge groove steel. Considering the main factors, the non stressed parts and process holes on the solar panel bracket were simplified, and the simplified three-dimensional model of the solar panel bracket is shown in Fig. 1.

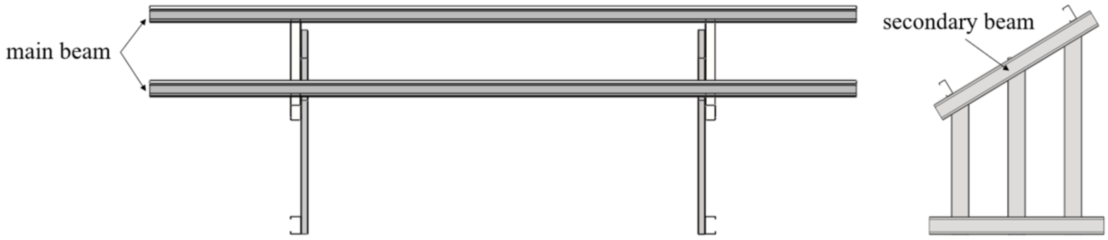


Fig. 1 3D solid model of solar panel bracket

2.2 Boundary conditions

Considering that the solar panel brackets are all welded with slot steel, this article uses quadrilateral elements for grid division in Ansys Workbench. The grid unit size is set to 5mm, and the bracket is divided into a total of 312372 units and 2200190 nodes. The materials of each part of the solar panel bracket are made of Q235 carbon structural steel, with the elastic modulus of 210GPa, the Poisson's ratio of 0.3, and the mass density of 7850kg/m^3. The weight of a single solar panel is 152N, and the width of each solar panel is about 800mm, which means that the bracket designed in this article can install 4 solar panels. Because the solar panels are installed on two main beams, each main beam bears a load of 304N on the solar panels, and fixed constraints are set at the bottom of the bracket. The boundary conditions of the solar panel bracket are shown in Fig. 2.

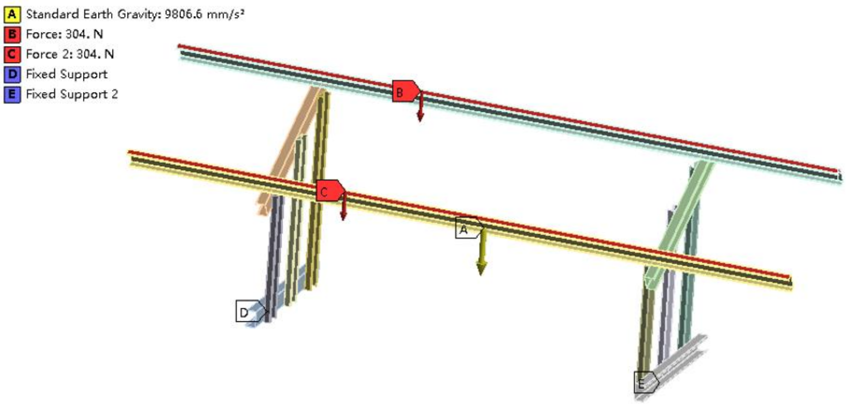


Fig. 2 Boundary conditions of the solar panel bracket

In order to more intuitively reflect the deformation of the main beam of the bracket, this article adds monitoring paths (1: starting point, 2: ending point) on the upper surface of the two main beams. The schematic diagram of the monitoring path is shown in Fig. 3.

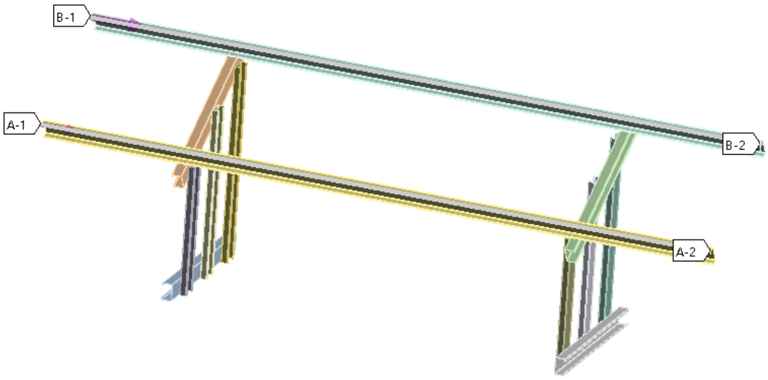


Fig. 3 Monitoring path

2.3 Static analysis results

The displacement calculation results of the solar panel bracket are shown in Fig. 4. The maximum displacement of the bracket occurs in the middle of the two main beams, with a maximum displacement of 2.8999mm. Meanwhile, the displacement change at the middle of the upper main beam is slightly greater than that at the middle of the lower main beam. The maximum displacement on the main beam of the solar panel bracket is less than 3mm, and the overall displacement on other components is less than 1mm, which can meet the strength design requirements of the bracket.

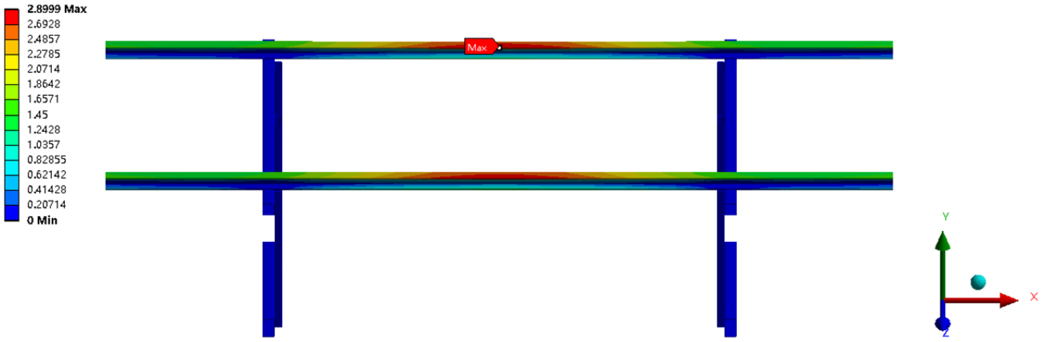


Fig. 4 Overall displacement diagram of the bracket

From Fig. 5, it can be seen that the left end of the upper and lower main beams (A-1 and B-1) is the starting point, and the displacement of the upper and lower main beams decreases from 1.5027mm and 1.5334mm at the left end to 1.4135mm and 1.4317mm at the main beam ratio of 12.43%, respectively. This is because the secondary beam on the left side of the bracket provides a supporting effect on the main beam. Under the action of load and self gravity, the displacement of the upper and lower main beams continues to increase from 12.43% of the main beam proportion to 50.0% in the middle of the main beam. The displacement of the upper and lower main beams in the middle is 2.8926mm and 2.8854mm, respectively. Afterwards, as the proportion of the main beams increases, the displacement of the upper and lower main beams gradually decreases to 1.4135mm and 1.4317mm at 87.57%. The displacement changes and trends on the left and right sides of the main beam show a symmetrical state. Compared to the upper main beam, the displacement on both sides of the lower main beam is slightly greater than the displacement on both sides of the upper main beam, but the displacement in the middle of the lower main beam is slightly smaller than the displacement in the middle of the upper main beam. The displacement of the upper and lower main beams is very small, which can meet the strength requirements of the solar panel bracket.

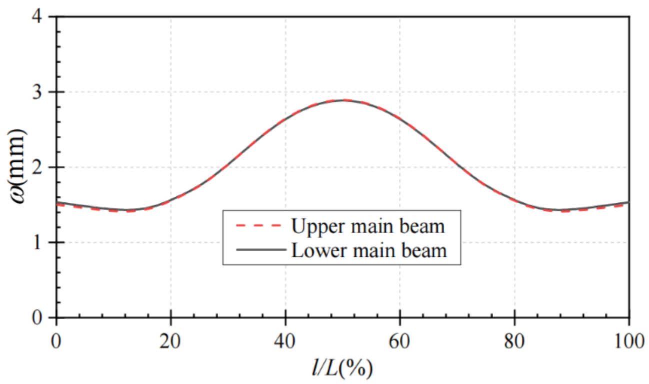


Fig. 5 Displacement curve of the main beam

The stress calculation results of the solar panel bracket are shown in Fig. 6. The high stress of the bracket occurs at the contact point between the main beam and the secondary beam, and the maximum stress of the bracket occurs at the connection between the upper main beam and the left secondary beam, with a maximum stress value of 119.99MPa. The local stress of the bracket is shown in Fig. 7. Meanwhile, based on the mechanical parameters of the bracket material, it can be seen that the stress values of each part of the bracket are far less than the yield strength limit of the bracket material.

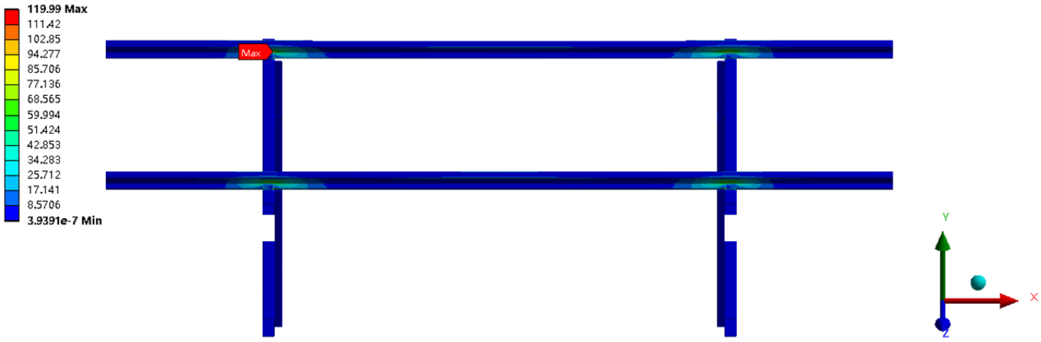


Fig. 6 Overall stress diagram of the bracket

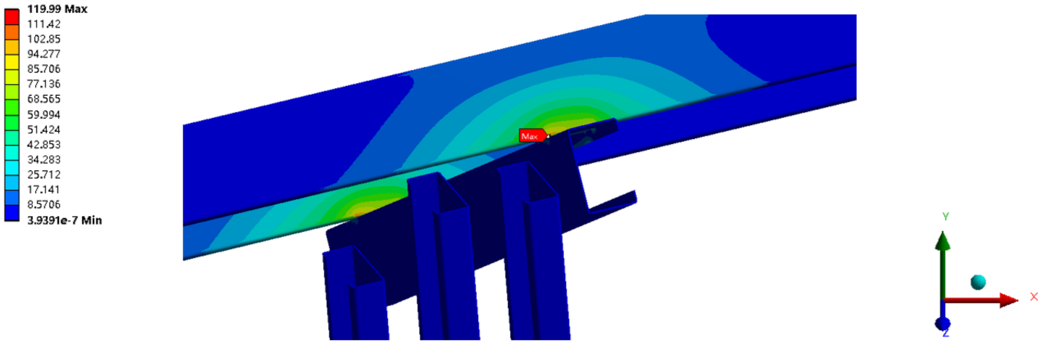


Fig. 7 Local stress diagram of the bracket

From Fig. 8, starting from the left end of the upper and lower main beams (A-1 and B-1), the stress values of the upper and lower main beams gradually increase from 0.7542MPa and 0.7923MPa at the left end to 15.653MPa and 15.641MPa at the main beam ratio of 20.89%, respectively. As the distance increases, the stress values of the upper and lower main beams gradually decrease to 1.9924MPa and 1.9924MPa at 27.86%, and then increase again to 9.7837MPa and 9.8233MPa at 50.0%. The stress changes on the right side of the upper and lower main beams are symmetrical with those on the left side. From this, it can be seen that the stress values of the main beams of the bracket are relatively small, and fatigue failure will not occur, which can meet the strength design requirements of the solar panel bracket.

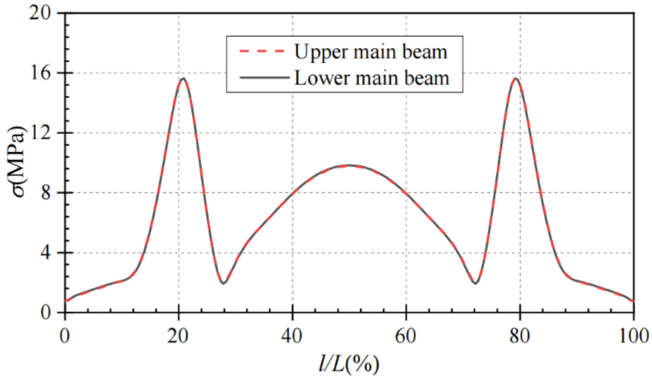


Fig. 8 Stress curve of the main beam

From the static analysis results, it can be seen that the displacement and stress changes of the bracket mainly occur in the main and secondary beams, while there is no significant change at the bottom of the bracket. Based on this, remove the middle support components on the left and right sides of the bottom of the bracket, and the simplified solar panel bracket is shown in Fig. 9. The performance parameters of the solar panel bracket before and after simplification have little variation, and the parameter comparison is shown in Tab. 1.

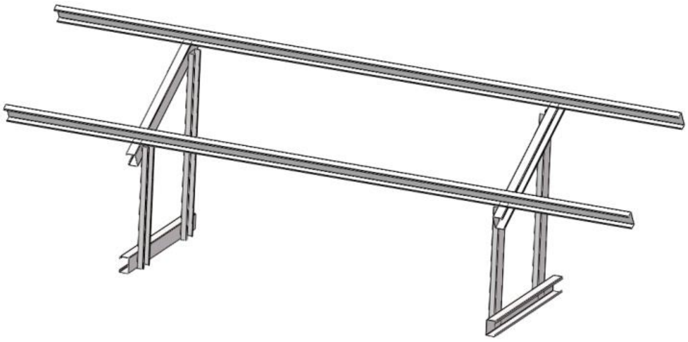


Fig. 9 Simplified solar panel bracket

Tab. 1 Comparison of bracket performance parameters before and after simplification

name	Original bracket	Simplified bracket	Variation
Quality (kg)	58.558	52.377	-6.181
maximum displacement (mm)	2.8999	2.9048	+0.0049
maximum stress (MPa)	119.99	120.0	+0.01

III. Optimization design based on response surface methodology

Considering that the solar panel bracket has a certain strength design margin, this article optimizes the design of the bracket while ensuring its strength design requirements. This article utilizes the Response Surface Optimization in Ansys Workbench software to optimize the design of the main beam structure of the bracket. That is, to optimize its cross-sectional shape while determining the length of the main beam. The optimization design flowchart is shown in Fig. 10.

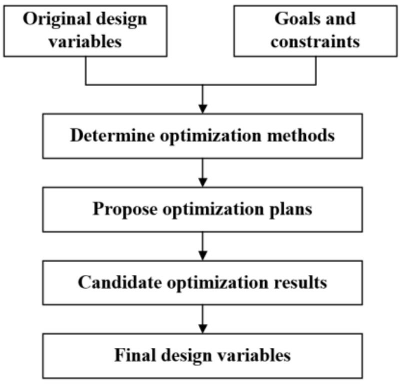


Fig. 10 Optimization design process

3.1 Optimizing mathematical models

In order to ensure the optimal performance of the solar panel bracket while meeting the strength requirements, this article optimizes the cross-sectional shape of the main beam of the solar panel bracket. This optimization aims to optimize the quality, maximum displacement, and maximum stress of the bracket. By optimizing the cross-sectional shape of the bracket, more efficient design can be achieved, improving the performance and reliability of the bracket.

$$\min F(x) = \{F_1(x), F_2(x), F_3(x)\}^T \quad (1)$$

$$\begin{cases} F_1(x) = \min(m_{\max}) \\ F_2(x) = \min(\omega_{\max}) \\ F_3(x) = \min(\sigma_{\max}) \end{cases} \quad (2)$$

Where: $m_{\max}$ is the mass of the bracket, kg; $\omega_{\max}$ is the maximum displacement of the bracket，mm; $\sigma_{\max}$ is the maximum stress of the bracket, MPa.

Using response surface analysis method for multi-objective optimization[10-12], the height *h*, width *b*, and thickness *t* of the main beam were used as design variables. The range of design variables is shown in Tab. 2, and the cross-sectional shape of the longitudinal beam is shown in Fig. 11.

Tab. 2 Value range of design variables

Design variable	Initial value	Value range
Main beam height *h*/mm	110	100~120
Main beam width *b*/mm	40	35~45
Main beam thickness *t*/mm	2	1.5~2.5

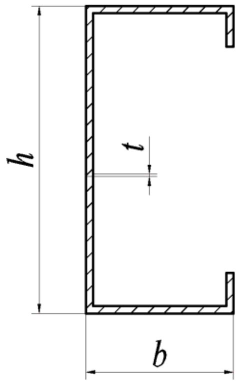


Fig. 11 Cross section shape of the main beam

In summary, the optimization model for establishing the multi-objective optimization problem of the main beam is as follows:

$$\begin{cases} \min F(x) = \{F_1(x), F_2(x), F_3(x)\}^T \\ s.t. \begin{cases} 100 \le h \le 120 \\ 35 \le b \le 45 \\ 1.5 \le t \le 2.5 \end{cases} \\ X = [h, b, t]^T \end{cases} \quad (3)$$

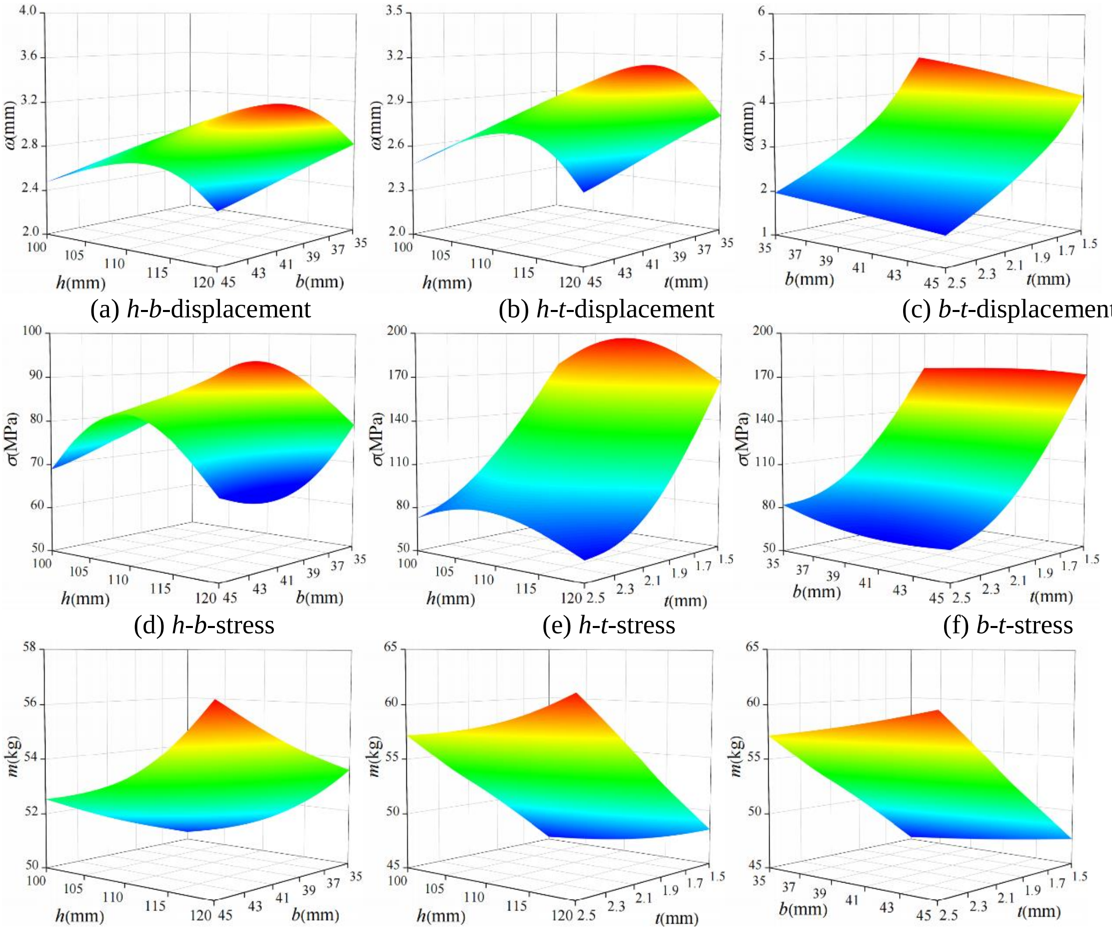
3.2 Optimization

In this optimization, the Central Composite Design was selected and 15 sets of design points were generated based on the optimization method. The calculation was carried out with constraint conditions. The completed data is shown in Tab. 3.

Tab. 3 Calculation results of optimization design points

Order	Main beam height *h*/mm	Main beam width *b*/mm	Main beam thickness *t*/mm	m_{max}/kg	ω_{max}/mm	σ_{max}/MPa
1	2	110	40	52.38	2.9047	120.0047
2	1.5	110	40	46.11	5.0122	198.3634
3	2.5	110	40	58.51	1.9492	84.1859
4	2	100	40	51.11	2.6839	111.650
5	2	120	40	54.91	2.6336	90.1593
6	2	110	35	51.11	3.1581	122.3516
7	2	110	45	53.64	2.7372	119.4245
8	1.59	101.87	35.93	45.88	4.1767	173.08
9	2.41	101.87	35.93	55.12	2.0564	88.0240
10	1.59	118.13	35.93	48.11	4.3268	157.4820
11	2.41	118.13	35.93	58.61	2.1084	80.7624
12	1.59	101.87	44.065	47.52	3.7283	158.730
13	2.41	101.87	44.065	57.60	1.8079	76.190
14	1.59	118.13	44.065	49.75	3.8201	159.7716
15	2.41	118.13	44.065	61.09	1.8223	72.6371

This article uses the Genetic Aggregation algorithm to fit the response surface and uses multi-objective genetic optimization algorithm to solve the optimal parameters of the main beam. In genetic algorithm, this article sets the maximum allowable Pareto percentage to 70%, which means that the iteration will be stopped when at least 70% of the samples are included in the Pareto optimization frontier obtained in this iteration. The initial total number of samples was 3000, and three optimal design points were ultimately selected from the results. Fig. 12 shows the optimized response surface of the bracket main beam, while Tab. 4 lists the parameters of the candidate optimal design points.



(a) *h*-*b*-displacement (b) *h*-*t*-displacement (c) *b*-*t*-displacement

(d) *h*-*b*-stress (e) *h*-*t*-stress (f) *b*-*t*-stress

(g) *h*-*b*-mass (h) *h*-*t*-mass (i) *b*-*t*-mass

Fig. 12 Response surface

Tab. 4 Candidate optimal design points

Order	Main beam height h/mm	Main beam width b/mm	Main beam thickness t/mm	m_{max}/kg	ω_{max}/mm	σ_{max}/MPa
1	100.13	35.348	2.040	50.815	2.7269	111.25
2	100.15	35.916	2.0282	50.791	2.7367	11.93
3	100.13	36.535	2.0218	50.834	68.806	112.0

By comparing the three candidate points mentioned above, the optimized dimensions are rounded. The optimized parameters are: the height h of the main beam is 100mm, the width b of the main beam is 36mm, and the thickness t of the main beam is 2mm. The optimized bracket mass has been reduced by 35.8kg compared to before optimization. The parameter change table is shown in Tab. 5.

Tab. 5 Parameter changes before and after optimization

Name	Main beam height h/mm	Main beam width b/mm	Main beam thickness t/mm	bracket mass m/kg
Original	110	40	2	52.377
Optimized	100	36	2	50.099
Difference value	10	4	0	2.278

3.3 Optimized analysis results

According to the rounded dimensions in Tab. 5, the main beam structure of the solar panel bracket was modified and re simulated in Ansys software. The simulation calculation results of the bracket after size optimization are shown in Fig. 13 and Fig. 14. The optimized size of the solar panel bracket reduces the weight by 8.459kg compared to the original bracket, with a weight reduction rate of 14.45%. Meanwhile, the maximum displacement of the optimized bracket is 2.8624mm, which is 0.0375mm less than the original bracket. The maximum stress of the optimized bracket is 119.89MPa, which is 0.10MPa less than the original bracket. While achieving lightweight of the bracket, it further improves the overall performance of the bracket.

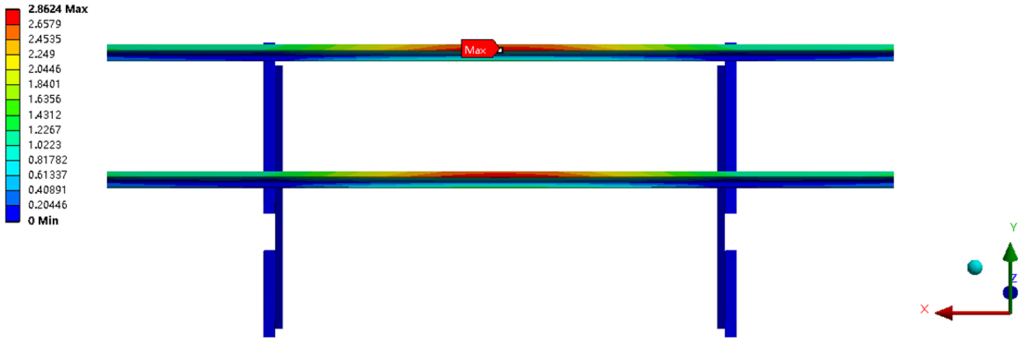


Fig. 13 Overall displacement of the optimized bracket

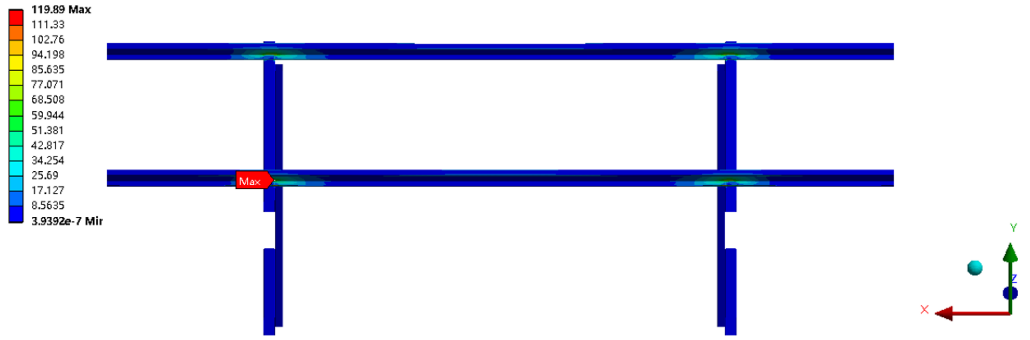


Fig. 14 Overall stress of the optimized bracket

From Fig. 15, it can be seen that the overall displacement of the two optimized main beams is smaller than that before optimization, and the trend of displacement changes of the main beams before and after optimization is roughly the same. The maximum displacement of the upper main beam decreased from 2.8926mm before optimization to 2.8539mm after optimization, with a displacement change of 0.0387mm. The maximum displacement of the lower main beam decreased from 2.8854mm before optimization to 2.8424mm after optimization, with a displacement change of 0.043mm. This means that the maximum displacement of the front and rear crossbeams after optimization decreased by 1.34% and 1.49%, respectively.

From Fig. 16, it can be seen that the overall stress of the two optimized main beams is slightly greater than that before optimization, and the displacement trend of the main beams before and after optimization is roughly the same. The maximum stress of the upper main beam increased from 15.653MPa before optimization to 16.844MPa after optimization, with a stress change of 1.191MPa. The maximum stress of the lower main beam increased from 15.641MPa before optimization to 16.684MPa after optimization, with a displacement change of 1.043MPa.

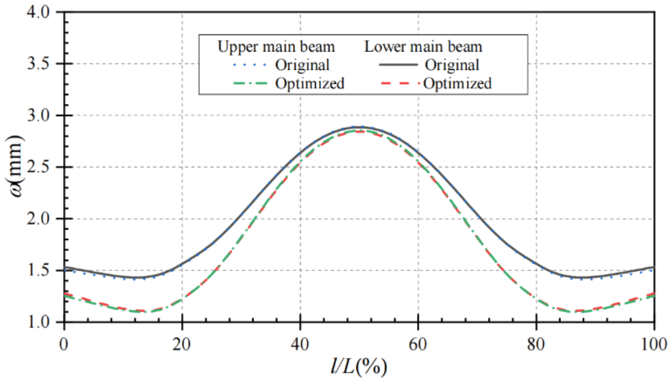


Fig. 15 Displacement comparison curve of the bracket main beam before and after optimization

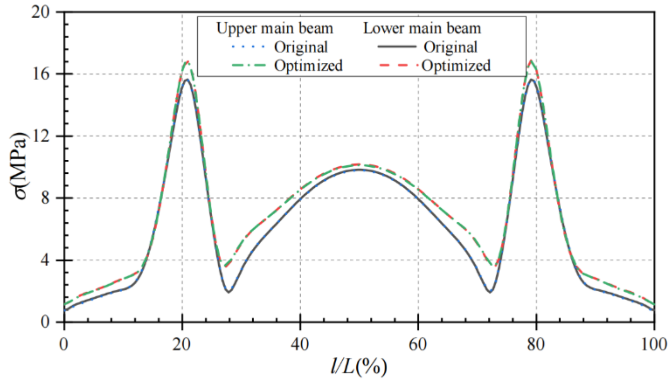


Fig. 16 Stress comparison curve of the bracket main beam before and after optimization

From the above content, it can be concluded that the overall displacement and stress changes of the bracket before and after optimization are very small. It can reduce the weight of the bracket while improving the overall performance of the bracket. The comparison of performance parameters of the bracket before and after optimization is shown in Tab. 6.

Tab. 6 Performance comparison of bracket before and after optimization

Name	Original bracket	Simplified bracket	Optimized bracket
m_{max}/kg	ω_{max}/mm	σ_{max}/MPa	50.099
ω_{max}/mm	2.8999	2.9048	2.8624
σ_{max}/MPa	119.99	120.0	119.89

IV. Conclusion

As a load-bearing component of solar panels, studying the strength of brackets is of great significance for ensuring the safe and stable operation of solar panels. In the established solar panel brackets system, this article conducts numerical simulation on the brackets and optimizes the design of the main beam part of the brackets based on the analysis results. The main conclusions are as follows:

(1) By analyzing the displacement diagram and stress diagram of the brackets, it can be concluded that the maximum displacement of the brackets under stress is less than 3mm, and the maximum stress does not exceed 120MPa. Based on the finite element analysis results, simplify the design of the bracket by removing the middle support components on the left and right sides of the bracket bottom. The performance parameters of the solar panel bracket before and after simplification have very little change. The solar panel bracket can meet the strength design requirements, and there is a certain margin in the strength of the bracket, which can be lightweight designed while ensuring the overall performance and structural strength of the bracket.

(2) Using multi-objective genetic algorithm to further optimize the simplified bracket, the optimized main beam height is 100mm, the main beam thickness is 2mm, and the main beam width is 36mm. After multi-objective optimization, the mass of the bracket was 50.099kg, which decreased by 8.459kg compared to the original bracket, and the weight reduction rate was 14.45%. The maximum displacement of the optimized

bracket decreased by 0.0375mm compared to before optimization, and the maximum stress decreased by 0.10MPa compared to before optimization. While reducing the weight of the bracket, it improves the overall performance of the bracket.

(3) This article monitors the displacement and stress of the two main beams of the bracket, which can clearly reflect the structural performance of the main beam. The analysis results can provide reference for the design of subsequent solar panel brackets.

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