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LIGHTWEIGHT DESIGN OF TRUSS STRUCTURE OF PIPE BELT CONVEYOR BASED ON DOE ANALYSIS

Lidong Zhou*, Yuan Liu, Xuelin Zeng, Huiqiang Yao and Zengfa Wu

School of Mechanical Engineering
Taiyuan University of Science and Technology
No. 66, Waliu Road, Wanbailin District, Taiyuan 030024, P. R. China
{ LuMang_yuan; yao886359; 15034400461 }@163.com; 1063976204@qq.com
*Corresponding author: lidongzhou@tyust.edu.cn

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Abstract. *In order to solve the problem of waste of steel in truss structure design of the pipe belt conveyor, an optimization design method based on Design of Experiments (DoE) was proposed. Firstly, the load combination of the truss of the pipe belt conveyor was analyzed, and then by establishing the finite element model of the truss in 3D3S and analyzing the maximum combined internal force distribution of the tie rod, the dangerous tie rod was found out. Secondly, in order to select control parameters with higher sensitivity, the parameter correlation analysis was carried out on the design size of the rod section. Then, a response surface model through Latin hypercube sampling and nonparametric regression methods was established. Based on the response surface model, the Multi-Objective Genetic Algorithm (MOGA) was employed in the process of optimization simulation calculation. The results show that the overall mass of the optimized truss structure is reduced by 32.8%, which achieved the purpose of the lightweight structure; at the same time, the stress ratio of the members is increased under the strength and stiffness requirements, which utilizes fully the section of the members.*

Keywords: Pipe belt conveyor, Truss, 3D3S, Lightweight design, Multi-objective optimization

1. **Introduction.** With the wide application of the pipe belt conveyors and the demand for efficient and green development, they are developing in the direction of large capacity, long distances, and more complex and flexible line layouts [1,2]. Trusses and outriggers are the main load-bearing structures for tubular belt conveyors, accounting for about one-third of the total cost. Therefore, the trend towards longer distances and larger volumes means a further increase in the number and overall cost of trusses and outriggers. However, for the truss structure of the circular tube belt conveyor, the designers often refer to the existing engineering cases for design, which results in a bulky structure and a serious waste of steel [3]. This is not in line with the requirements of green development. Therefore, it is very necessary to carry out a lightweight design for the truss structure of the pipe belt conveyor.

There has been extensive research on the lightweight design of the truss structure of the pipe belt conveyor. In terms of structural improvement, Horak [4,5] proposed an improved method for the roller shutter of the pipe belt conveyor. After analyzing the arrangement characteristics of traditional trough belt conveyors and pipe belt conveyor idlers, he proposed a window panel with an inverted "U" section. Subsequently, a triangular truss was proposed, which saves more steel than the typical rectangular section truss [6-8]. In terms

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of section optimization of rods, Fan et al. [9,10] used APDL language to realize the parametric analysis of the truss model, and took the structural quality as the optimization goal and the cross-sectional area of the member as the design variable to optimize each member of the truss, based on the full stress optimization criterion. Liu [11] obtained the equivalent stress diagram and axial force diagram of the truss girder structure of the pipe tube belt conveyor using Ansys software analysis. Wu et al. in [12], and Zhou and Meng in [13] analyzed the truss of the pipe belt conveyor by finite element, and used the optimization toolbox to optimize the section of the member. Song et al. [14] conducted the response surface analysis and target-driven optimization analysis of the section of the member with the maximum stress of a truss in the Ansys Workbench simulation platform, which optimized the size of the angle steel's section.

Most of the above studies directly used Ansys Workbench to carry out static finite element analysis on the truss structure of the pipe belt conveyor, and then optimized the section of the rod. On the one hand, as an industrial building structure, the pipe belt conveyor truss has been rarely studied based on the relevant specifications of building structural loads to calculate and combine the loads when it is statically analyzed. On the other hand, when the section size of different types of rods is optimized for design, there are many input and output parameters. Based on the DoE experimental design theory, process and efficiency of the design can be effectively optimized. Therefore, it is necessary to carry out the static analysis research and optimal design of the truss structure of the pipe belt conveyor based on the relevant specifications and principles of building structural loads and the DoE experimental design theory.

Based on the existing research, this paper takes the pipe belt conveyor project of a steel company in Changzhi, Shanxi Province as the background. The pipe diameter is 200 mm and the truss with the longest span which is 30 m is selected as the research object. The organization of this paper is started with static analysis of truss structures, multi-objective optimization analysis of truss structure based on DoE, results and analysis and finally closed by conclusions.

2. Static Analysis of Truss Structures.

In order to obtain the distribution law of the internal force of the truss and find the most dangerous member, it is necessary to carry out a static analysis of the truss to pave the way for the next optimization design.

2.1. Load analysis.

Pipe belt conveyors are often installed outdoors. So the truss structure not only bears the weight of the conveyed materials, but also bears the effects of wind load, snow load and temperature. Often multiple loads act on the structure at the same time, resulting in a variety of load situations. Therefore, the loads must be analyzed and combined prior to the static analysis of the truss.

The pipe belt conveyor truss structure is a typical industrial building structure [15], and the load borne can be calculated and combined by referring to the engineering structure load and reliability design principle [16] or related specifications. Loads of building structures can be divided into three categories: permanent loads, variable loads, and accidental loads. For the truss structure of the pipe belt conveyor, the permanent load includes the weight of the truss, the idler, the conveyor belt and the material; the variable load includes the floor live load, wind load, snow load and temperature effects; accidental loads include seismic effects, etc.

The effect design value of its basic load combination is determined by taking the most unfavorable load combination, which is calculated by the following Equations (1) and (2) [17].

1) The design value of the effect controlled by the variable load shall be calculated as follows:

$$S_d = \sum_{j=1}^{m} \gamma_{G_j} S_{G_j k} + \gamma_{Q_1} \gamma_{L_1} S_{Q_1 k} + \sum_{i=1}^{n} \gamma_{Q_i} \gamma_{L_i} \psi_{c_i} S_{Q_i k} \tag{1}$$

2) The design value of the effect controlled by the permanent load shall be calculated as follows:

$$S_d = \sum_{j=1}^{m} \gamma_{G_j} S_{G_j k} + \sum_{i=1}^{n} \gamma_{Q_i} \gamma_{L_i} \psi_{c_i} S_{Q_i k} \tag{2}$$

where γ_{G_j} is the partial coefficient of the j-th permanent load; γ_{Q_i} is the partial coefficient of the i-th variable load; γ_{L_i} is the i-th adjustment coefficient of variable load considering the design service life, where γ_{L_1} is the adjustment coefficient of the dominant variable load Q_1 considering the design service life; $S_{G_j k}$ is the load effect value calculated according to the standard value of the j-th permanent load $G_j k$; $S_{Q_i k}$ is the load effect value calculated according to the standard value of the i-th variable load $Q_i k$, where $S_{Q_1 k}$ is the one that controls the variable load effects; ψ_{c_i} is the combined value coefficient of the i-th variable load Q_i; m is the number of permanent loads involved in the combination; n is the number of variable loads participating in the combination.

The effect design value S_d of accidental combination of loads can be adopted according to the following provisions.

1) The effect design value used to calculate the limit state of carrying capacity shall be calculated as follows:

$$S_d = \sum_{j=1}^{m} S_{G_j k} + S_{A_d} + \psi_{f_1} S_{Q_1 k} + \sum_{i=2}^{n} \psi_{q_i} S_{Q_i k} \tag{3}$$

where S_{A_d} is the load effect value calculated according to the standard value A_d of accidental load; ψ_{f_1} is the frequency occurrence coefficient of the first variable load; ψ_{q_i} is the quasi-permanent value coefficient of the i-th variable load.

2) For the design value of the overall stability of the damage structure after the occurrence of accidents, the calculation should be performed according to the following formula:

$$S_d = \sum_{j=1}^{m} S_{G_j k} + \psi_{f_1} S_{Q_1 k} + \sum_{i=2}^{n} \psi_{q_i} S_{Q_i k} \tag{4}$$

2.2. **Model establishment and load application.** Due to the fact that load combinations of the truss structure are complex and diverse, the calculation of the internal force of the members is huge and electrical calculation is often used. In this paper, 3D3S software is used to model and analyze the truss structure. 3D3S software is a professional steel structure design software developed by Tongji University. Compared with the general finite element software Ansys, 3D3S can quickly generate load combinations and calculate the internal force of members under different load combinations according to the requirements of the specification. It is more suitable for the analysis of such building steel structures.

For the truss, the span is 30 m, the height is 1.35 m, the spacing between the intermediate sections is 1.5 m, and the section width is 0.65 m. The longitudinal schematic diagram of the truss is shown in Figure 1. Different from ordinary trusses, the section between the trusses of the pipe belt conveyor is the window panel. And the transverse section is shown in Figure 2. The preliminarily selected rod profiles and material properties are shown in Table 1. The thickness of the window panel is 5 mm.

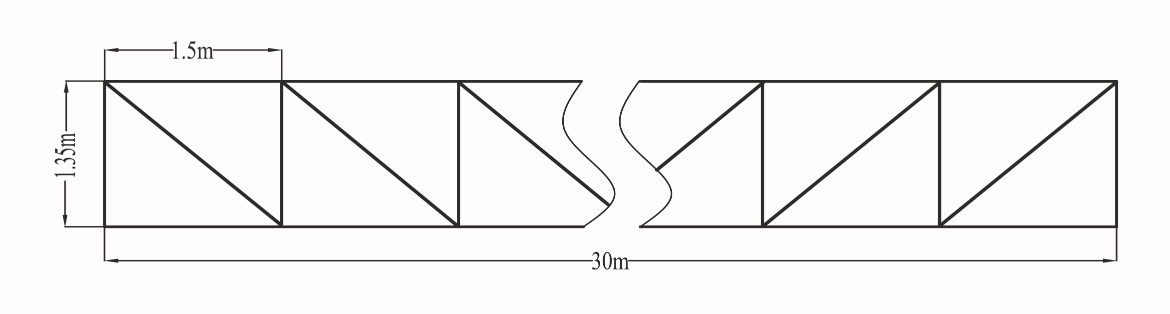


FIGURE 1. Longitudinal diagram of truss structure

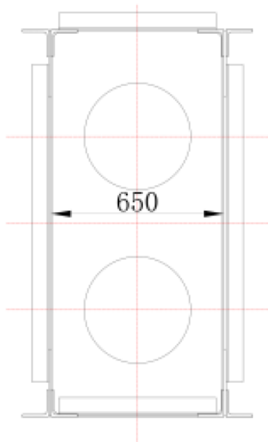


FIGURE 2. Cross section of truss structure

TABLE 1. Member profiles and material properties

Chord	Oblique bar (Oblique transverse abdomen)	Material	Elastic modulus	Poisson's ratio	Density
L100 × 8, B8	L70 × 5	Q235-A	$E = 2.06 \times 10^5$ N/mm^2	$\mu = 0.30$	$\rho = 7850$ kg/m^3

When calculating the internal force of a truss, it is usually assumed that the load action line passes through the nodes of the truss [18]. Therefore, in this paper, various types of loads are applied to the nodes of the truss in the form of nodal loads. The load application conditions are shown in Table 2. In addition, in this paper, one end of the truss is fixed and the other end is hinged. The finite element model of the truss is shown in Figure 3.

2.3. **Analysis results.** Through the internal force analysis of the structure by 3D3S, the maximum combined internal force of each member is obtained, as shown in Figure 4. It can be seen from Figure 4 that the maximum combined internal forces of the truss structure are located at the lower chord in the middle and the inclined rods at both ends. Therefore, these rods are the most dangerous and need to be considered in the optimization design.

In addition, by counting the stress ratios of the chord and oblique rods (oblique transverse abdomens), it is found that the number of rods with a stress ratio less than 0.5

Table 2. Load application conditions

Working condition	Load size
Dead load	2.5 kN/m^2
Live load	2.5 kN/m^2
Wind load	0.4 kN/m^2
Snow load	0.4 kN/m^2
Temperature effect	Maximum temperature rise condition 25°C Maximum temperature drop condition −25°C
Seismic effect	The seismic fortification intensity is 7 degrees (0.10 g)

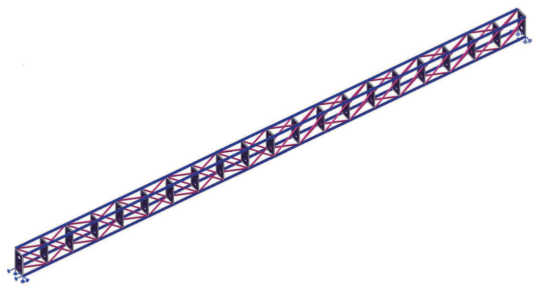


Figure 3. Truss structure 3D3S finite element model

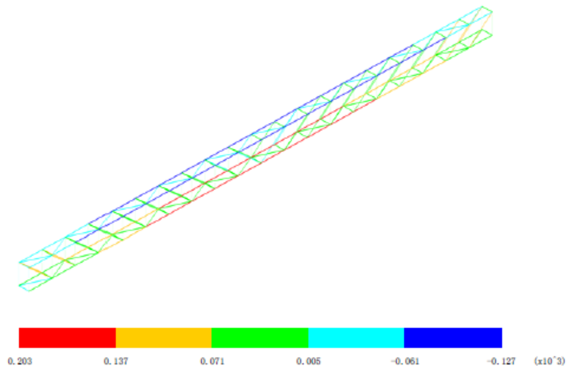


Figure 4. Distribution of maximum combined internal force of truss members

Table 3. The proportion of the number of members with a stress ratio less than 0.5

Stress ratio	Chord	Oblique bar (Oblique transverse abdomen)	Total
The proportion of the number of members with a stress ratio less than 0.5	35%	63.75%	49.375%

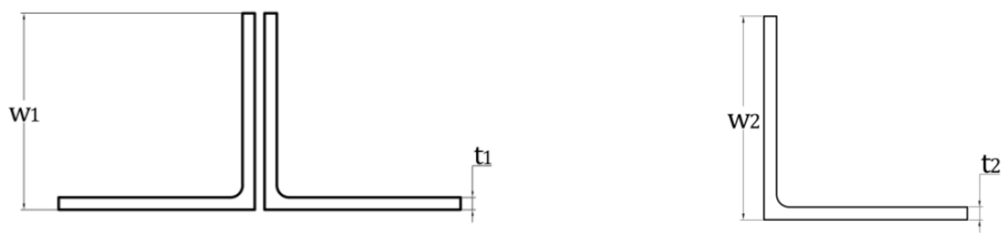
is close to 50% of the total number of rods. At the same time, the maximum mid-span displacement is 13.141 mm, which is less than $L/400$ (L is the truss span) required by the specification [19]. It shows that the section of the truss profile is not fully used and there is room for optimization. Among them, the statistics of stress ratios of various types of members are shown in Table 3.

3. **Multi-Objective Optimization Analysis of Truss Structure Based on DoE.** DoE – Design of Experiments [20] is a theory and method to study the correct design of experimental plan and analysis of experimental data. Its essence is to use mathematical methods to arrange experiment plans scientifically and reasonably, which can greatly reduce the scale and time of experiments while ensuring the reliability of experiments. When the truss structure is in lightweight design, there are many input and output parameters. The cross-sectional dimensions of different types of members are design variables, which is restricted by factors such as strength and stiffness. DoE method is used for data processing and optimization design, which can improve the computational efficiency and optimize the design process [21].

3.1. **Determination of design variables, constraints and objective function.** The width and thickness of the truss chord, the oblique bar (oblique transverse abdomen) and the thickness of the window panel are selected as design variables, as shown in Figure 5. The displacement and the maximum equivalent stress in the middle of the chord are used as constraint conditions. The minimum mass of the truss chord, the oblique bar (oblique transverse abdomen) and the window panel is taken as the objective function. From this, the mathematical model of the lightweight of the truss can be obtained, as shown in Equation (5).

$$\begin{cases} 0.075 \le W_1 \le 0.11 \\ 0.005 \le t_1 \le 0.008 \\ 0.045 \le W_2 \le 0.063 \\ 0.004 \le t_2 \le 0.006 \\ 0.003 \le t_3 \le 0.006 \\ \sigma_{\max} \le \dfrac{[\sigma]}{1.2} = 195.833 \text{ MPa} \\ w_{\max} \le \dfrac{L}{400} = 0.075 \text{ m} \\ \min M_1 \\ \min M_2 \\ \min M_3 \end{cases} \tag{5}$$

where W_1, t_1, M_1 are respectively the width, thickness and mass of the double chord angle steel. W_2, t_2, M_2 are respectively the width, thickness and mass of oblique bar (oblique transverse abdomen) angle steel. t_3, M_3 are respectively thickness and quality of the window panel. $\sigma_{\max}$ is the maximum equivalent stress value. $w_{\max}$ is the maximum



(a) Sectional view of chord angle steel (b) Sectional view of angle steel of inclined rod (oblique transverse abdomen)

FIGURE 5. Design variables of various types of member sections

deformation. Among them, the unit of width and thickness is m, and the unit of mass is kg.

3.2. **Parameter correlation analysis.** By studying the sensitivity of input parameters to output parameters, parameter correlation analysis can screen out the primary and secondary control parameters. That is, screen out that design variables that are more sensitive to the optimization target, which can save experimental costs.

It can be seen from Figure 6 that the width W_1 and thickness t_1 of the chord angle steel section have a greater influence on the maximum deformation and the maximum equivalent stress, and correlation values exceed 0.5 or are close to 0.5. The major influences on the quality of the chord, oblique bar (oblique transverse abdomen) and the window panel are the width and thickness of the section.

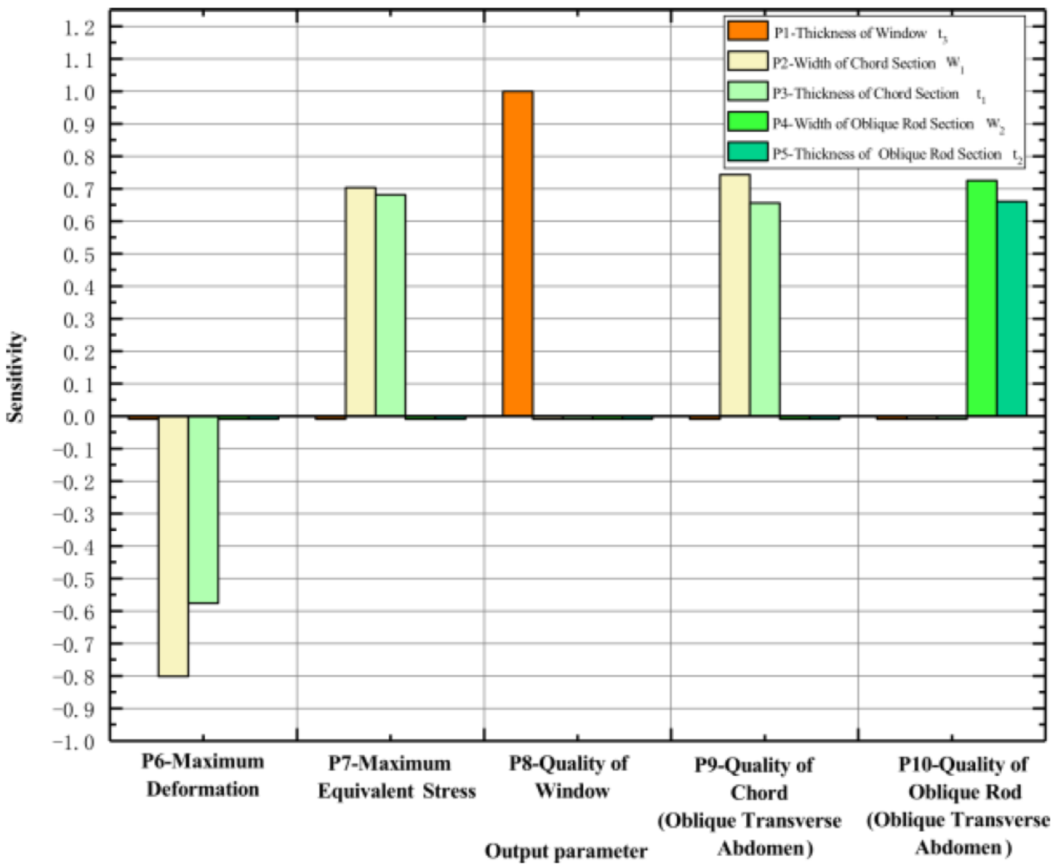


FIGURE 6. Sensitivity of design parameters

3.3. **Construction and analysis of the response surface model.** In order to obtain the best combination of design variables and parameters, the optimization process should traverse the entire area of the sample space, which is difficult to achieve due to the large amount of calculation in the multi-parameter optimization simulation. Therefore, the response surface method in the approximate model is used to simulate and fit a continuous response surface through a small number of characteristic sample points. A suitable response surface model can significantly improve the effectiveness of subsequent optimization calculations, and can also more accurately reflect the relationship between input and output parameters [22,23].

First, based on the analysis results of the input parameters and output parameters obtained from the parameter correlation analysis above, and the accuracy of the response surface model and the efficiency of the optimization calculation, the Latin hypercube sampling method is selected to generate sample design points. The Response Surface Optimization module in Ansys Workbench is used to develop the simulation calculation scheme.

The Latin hypercube sampling method takes a sample point randomly in the set, which can effectively avoid the collapse phenomenon of sample points. Meanwhile, it has strong space filling ability and non-repeatability, and is strong in fitting second-order or high-order nonlinear performance [24].

Latin hypercube sampling can be described as the extraction of Q uniform sample data between 0 and 1 in an n-dimensional vector space. We use N by Q matrices A and B respectively to store the sample coordinates. Five design variables (W_1, t_1, W_2, t_2, t_3) of the truss section are taken as input variables. Accordingly, the maximum deformation $w_{\max}$, maximum equivalent stress $\sigma_{\max}$, chord mass M_1, oblique bar (oblique transverse abdomen) mass M_2 and window panel mass M_3 are taken as the response values. The sample type was set as CCD, and 79 samples were generated. The sample data and corresponding response values were obtained through calculation and solving, as shown in Table 4.

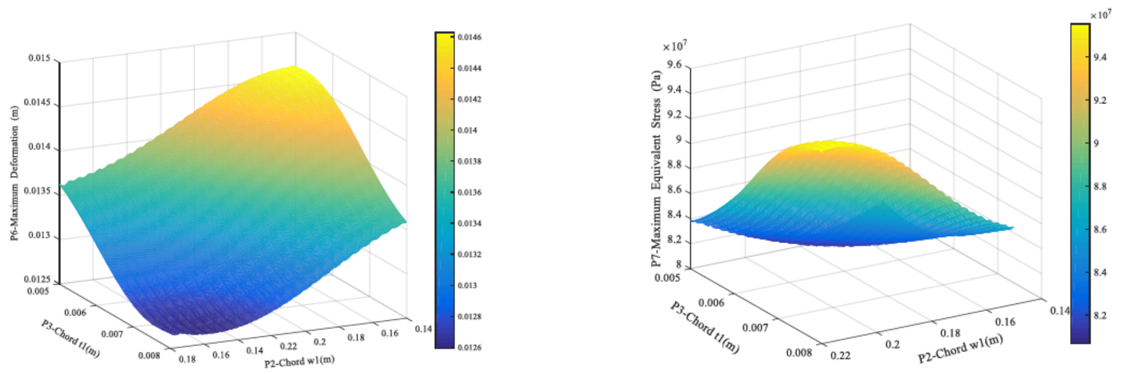
Table 4. Sample design points

Name	W_1/m	t_1/m	W_2/m	t_2/m	t_3/m	$w_{\max}$/m	$\sigma_{\max}$/Pa	M_1/kg	M_2/kg	M_3/kg
1	0.102	0.00707	0.061	0.00454	0.00465	0.0133	1.58E+08	25.703	9.936	29.709
2	0.106	0.00684	0.048	0.00480	0.00508	0.0133	1.55E+08	25.821	9.151	32.461
3	0.103	0.00601	0.046	0.00551	0.00404	0.0135	1.53E+08	23.380	9.499	25.823
4	0.091	0.00532	0.049	0.00495	0.00482	0.0143	1.63E+08	20.347	9.376	30.842
5	0.100	0.00608	0.060	0.00546	0.00411	0.0137	1.61E+08	23.175	10.629	26.309
6	0.104	0.00696	0.046	0.00520	0.00584	0.0132	1.58E+08	25.804	9.268	37.319
7	0.077	0.00760	0.055	0.00561	0.00472	0.0138	1.87E+08	22.566	10.333	30.195
8	0.096	0.00582	0.062	0.00558	0.00581	0.0140	1.62E+08	22.089	10.918	37.157
9	0.087	0.00563	0.063	0.00442	0.00429	0.0144	1.65E+08	20.442	9.953	27.442
...	...	...	...	...	...	...	...	...	...	...
79	0.097	0.00737	0.059	0.00492	0.00485	0.0132	1.62E+08	25.634	10.159	31.004

Then, considering the characteristics of the research problem and the scale of the sample space in this paper, a non-parametric regression method is used to realize the response surface fitting of the output quantity and establish the response surface model, which has the advantages of high robustness, high model accuracy and avoiding noise point interference. In Figure 7, the response of output parameters to the design variable of string bar section is selected, where (a) is the response of the maximum deformation $w_{\max}$ to W_1, t_1; (b) is the response of the maximum equivalent stress $\sigma_{\max}$ to W_1, t_1.

In addition, the sensitivity of the design variables to the output parameters can be obtained through the response surface analysis, so as to obtain the relationship between the output parameters and the design variables. The sensitivity of each design variable to the objective function is shown in Figure 8. It can be seen from the figure that the section width W_1 and thickness t_1 of the chord double angle steel have the greatest influence on the maximum deformation $w_{\max}$ and the maximum equivalent stress $\sigma_{\max}$.

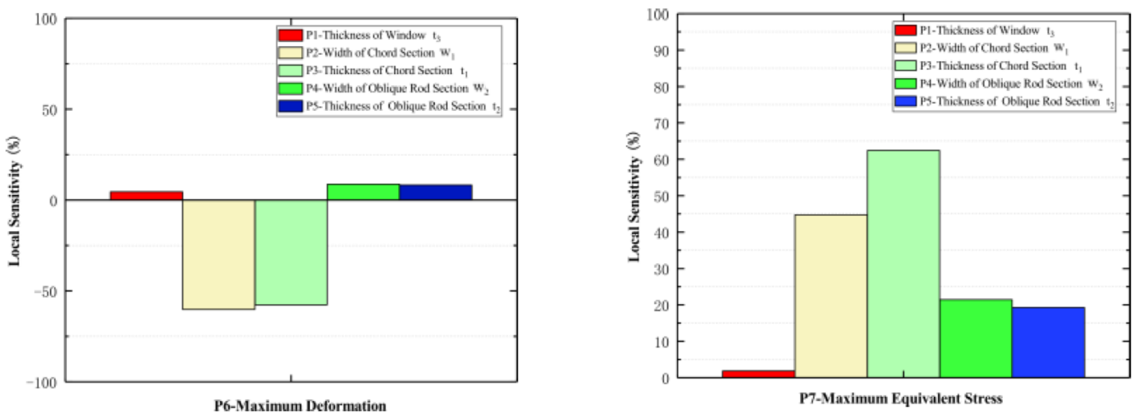
3.4. **Multi-objective optimization.** This paper selects the optimization scheme of Multi-Objective Genetic Algorithm (MOGA), which is a variant of the popular NSGA-II (Non-dominated Sorting Genetic Algorithm II) based on the concept of controlled elite. The scheme supports multiple objectives and constraints, which has a good global search



(a) Response of the maximum deformation $w_{\max}$ to W_1, t_1

(b) Response of the maximum equivalent stress $\sigma_{\max}$ to W_1, t_1

FIGURE 7. Response surface model



(a) Sensitivity of design variables to maximum deformation

(b) Sensitivity of design variables to maximum equivalent stress

FIGURE 8. Sensitivity of design variables to objective function

function and can be solved without complex auxiliary information [25,26]. The MOGA algorithm optimization scheme is generated by the Response Surface Optimization module in Ansys Workbench. The initial number of samples is 4000; the number of samples in each iteration is 800; the maximum allowable Pareto percentage is 70; the maximum number of iterations is 20; and 3 candidate samples are obtained.

Through the finite element calculation of the three groups of candidate points obtained from the optimization, the calculation results are compared with the optimized solution. The obtained error is very small, which can be ignored in engineering applications. So, the optimization results are further verified, as shown in Table 5.

The most suitable one is selected from the three sample candidate points, and the design variables are rounded to correspond to the type of steel. The result is compared with those before optimization, as shown in Table 6.

It can be seen from Table 6 that after the optimization of the truss structure, the overall mass is reduced by 3298.98 kg, which is 32.8% lighter than the existing truss. In addition, although the maximum equivalent stress and maximum deformation have increased, the strength and stiffness are still allowed. At the same time, the proportion of the number of

TABLE 5. Validation of optimized candidate points

	Maximum combined stress/Pa	Maximum displacement/mm	Truss quality/kg
Candidate point 1	1.875E+08	14.651	3241.4
Calculation result 1	1.897E+08	14.921	3241.4
Candidate point 2	1.823E+08	14.611	3212.672
Calculation result 2	1.877E+08	14.862	3212.672
Candidate point 3	1.765E+08	14.554	3198.552
Calculation result 3	1.801E+08	14.755	3198.552

TABLE 6. Comparison of results before and after optimization of truss structure

	Parameter	Before optimization	The optimized	The revised
Chord/mm	W_1	100	77.775	80
	t_1	8	5.47	6
Oblique bar (Oblique transverse abdomen)/mm	W_2	63	51.017	56
	t_2	6	4.73	5
Window panel thickness/mm	t_3	5	4.001	4
Maximum deformation/mm	$w_{\max}$	13.141	14.651	13.558
Maximum combined stress/Pa	$\sigma_{\max}$	1.691E+08	1.875E+08	1.763E+08
Truss quality/kg	M	4910.204 kg	3241.4 kg	3298.98 kg
The proportion of the number of members with a stress ratio less than 0.5		49.375%		33.125%

rods with a stress ratio less than 0.5 decreased by 16.25%, indicating that the cross-section of rods is more fully used than before optimization.

4. **Conclusion.** 1) Based on the relevant specifications of the building structure, the load combination of the truss structure of the pipe belt conveyor was accurately analyzed. The static analysis was carried out in the 3D3S software, and the distribution of the maximum combined internal force of the truss members has been correctly obtained.

2) Based on the DoE experimental method, the optimization research on the sections of various types of truss members has been carried out, and the overall lightweight of the truss structure has been realized. a) The response surface model has been established through Latin hypercube sampling and non-parametric regression method, which can accurately and reasonably describe the relationship between input and output parameters, laying the foundation for optimization calculation; b) The multi-objective genetic algorithm has been used for optimization calculation. After optimization, the overall mass of the truss was reduced by 32.8%; and the stress ratio of each member was improved; and the section of the member was more fully used. However, the actual cross-section dimensions of angle steel are discrete serial values. Therefore, it is necessary to take the section of the main profile of the truss as the discrete variable and use the discrete variable optimization

algorithm to study the lightweight of the truss, so that the optimization results have more application value.

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REFERENCES

[1] W. J. Meng, Development and future of circular tube belt conveyor, *Lifting the Transport Machinery*, no.14, p.5, 2021.
[2] W. G. Song, Research progress and design calculation method of pipe conveyor, *Chinese Journal of Engineering Design*, vol.25, no.1, pp.1-11, 2018.
[3] Top ten events of China's material handling industry (Part 2), *Lifting the Transport Machinery*, no.4, pp.8-14, 2022.
[4] R. M. Horak, Improved idler panel design for pipe conveyor, *Bulk Solids Handling*, vol.17, no.4, pp.521-526, 1997.
[5] R. M. Horak, A new technology for pipe or tube conveyors, *Bulk Solids Handling*, vol.23, no.3, pp.174-180, 2003.
[6] P. Staples, Effects of support structures on belt conveyor systems – A case for the triangular gantry, *Proceedings of the BELTCON 11 International Conference*, Johannes-burg, South Africa, 2001.
[7] S. Ramjee and P. Staples, Pipe conveyors for infrastructure projects: Innovative solution for conveyor systems, *Bulk Solids Handling*, vol.35, no.4, pp.20-27, 2015.
[8] Y. Zhang, Efficient elevated conveyor structure and better maintenance using self-powered trolley, *SME Annual Meeting*, Salt Lake City, pp.23-26, 2014.
[9] T. Fan, Z. Liu, G. Han and P. Cheng, FEA of truss girder of tubular belt conveyor, *Mining & Processing Equipment*, vol.40, no.5, pp.52-56, 2012.
[10] T. Fan, Z. Liu, G. Han and J. Wang, Lightweight design of truss girder based on full stress, *Lifting the Transport Machinery*, no.1, pp.36-38, 2012.
[11] X. Liu, The finite element analysis of truss beam structure based on ANSYS, *Advanced Materials Research*, no.594, pp.2939-2944, 2012.
[12] B. S. Wu, M. W. Hu and Q. P. Chen, Ansys Workbench-based finite element analysis for truss structure of pipe belt conveyor, *Lifting the Transport Machinery*, no.3, pp.6-9, 2013.
[13] M. F. Zhou and W. J. Meng, APDL-based optimal design of truss girder of pipe belt conveyor, *Lifting the Transport Machinery*, no.11, pp.17-20, 2013.
[14] Y. X. Song, M. Yin and W. F. Jiang, Response surface optimization of section of belt conveyor truss structure, *Coal Mining Machinery*, vol.38, no.9, pp.67-70, 2017.
[15] GB 50592-2010, *Code for Design of Colliery Building and Structure of Coal Mine*, China Planning Press, Beijing, 2011.
[16] G. Q. Li, H. W. Huang, X. Wu, S. R. Liu and F. F. Sun, *Design Principles of Engineering Structural Load and Reliability*, China Architecture & Building Press, Beijing, 2016.
[17] GB 50009-2012, *Code for Loading of Building Structures*, China Architecture & Building Press, Beijing, 2012.
[18] Z. Y. Shen, Y. J. Chen and Y. Y. Chen, *The Basic Principle of Steel Structure*, China Architecture & Building Press, Beijing, 2015.
[19] GB 20017-2017, *Design Standards for Steel Structures*, China Architecture & Building Press, Beijing, 2017.
[20] Y. N. Min, *Design of Experiments (DOE) Application Guide*, Machinery Industry Press, Beijing, 2011.
[21] Y. J. Yuan, *Multi-Objective Optimization of Bridge Crane Girder Based on DOE and Wolf Pack Algorithm*, Master Thesis, North University of China, 2019.
[22] J. M. Ni, Y. Liu, X. Y. Shi, X. N. Gao, J. Q. Li and Y. N. Wei, Optimization design method for turbine blades of turbocharger based on DoE analysis, *Transactions of the Chinese Society for Agricultural Machinery*, vol.47, no.47, pp.361-367, 2016.

[23] J. B. Hu, J. S. Zhang, J. Y. Fang, X. L. Meng and P. B. Sun, Lightweight design of body frame of diamond frame saw based on DOE, *Modular Machine Tool & Automatic Manufacturing Technique*, no.6, pp.31-34, 2018.
[24] G. X. Chen, Y. Cao, D. L. Zhang, J. X. Wu and M. M. Chen, Research on static and dynamic characteristics and lightweight of angle steel flange welding robot gantry frame structure, *Modern Manufacturing Engineering*, no.9, pp.62-71, 2022.
[25] H. Suryoatmojo, M. F. Afif, V. Lystianingurum, E. Setijadi and R. Mardiyanto, Optimal sizing of solar powered unmanned aerial vehicle system for continuous flight based on multi objective genetic algorithm, *ICIC Express Letters*, vol.14, no.8, pp.741-749, 2020.
[26] Y. J. Su, *Multi-Objective Optimization of Building Energy Efficiency Based on Genetic Algorithms*, Master Thesis, Shenzhen University, 2017.

Author Biography

Lidong Zhou received the B.Sc. degree in Engineering from Taiyuan University of Technology, China, 2003; the Ph.D. degree in Engineering from Beijing Institute of Technology, China, 2010.

He is currently a full-time professor at the School of Mechanical Engineering, Taiyuan University of Science and Technology, China. His main research interests include design and characteristic analysis of continuous conveying machinery, fatigue fracture reliability and life evaluation method and experimental research of heavy equipment structure.

Yuan Liu received the B.Sc. degree in Engineering from Hubei University of Automotive Technology, China, 2020; he is studying for the M.Sc. degree in Engineering from Taiyuan University of Science and Technology, China.

His research topic in the master stage is about the key issues of steel structure of pipe belt conveyor.

Xuelin Zeng received the B.Sc. degree in Engineering from Taiyuan University of Technology, China, 2019; the M.Sc. degree in Engineering from Taiyuan University of Science and Technology, China, 2022. He is working as a mechanical engineer in a machining company.

His research topic in the master stage is about the optimization design of steel structure of pipe belt conveyor.

Huiqiang Yao received the B.Sc. degree in Engineering from Yuncheng University, China, 2019; he is studying for the M.Sc. degree in Engineering from Taiyuan University of Science and Technology, China.

His research topic in the master stage is about the simulation research on the conveyor belt stiffness of pipe belt conveyor.

Zengfa Wu received the B.Sc. degree in Engineering from Taiyuan University of Technology, China, 2020; he is studying for the M.Sc. degree in Engineering from Taiyuan University of Science and Technology, China.

His research topic in the master stage is about the design and research of intelligent idler replacement device for pipe belt conveyor.