Particle Swarm Optimization and Its Application Cases

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Abstract. How to achieve the best performance, best cost, and other engineering requirements quickly and accurately under numerous constraints is the most important problem to be solved in current structural optimization. At the same time, the structure is diversified, and the structures such as the gantry and the rigid frame are common structural forms. Because the gantry structure mainly bears the axial force and the stress is simple, most of the current structural optimization is based on the truss structure as the research model. In reality, this type of structural frame is more common than the analysis frame. However, due to its complex force, the structural optimization based on the rigid frame structure is less studied, and the global optimal solution is sought.

1. Introduction
This thesis uses high-level programming language to compile the rigid frame finite element analysis module, and in the preparation of the particle swarm optimization algorithm to calculate the module, and finally use the interface program to combine the two to achieve the rigid frame structure finite element analysis and optimization. The procedure of the procedure is as follows: the initial value of each design variable is determined by the given or random value (without the given initial value, it is a random value) [1]; the finite element program reads the initial value of each design variable; the finite element program calculates the objective function value, the maximum stress and maximum displacement optimization program tests the constraints such as maximum stress and maximum displacement, and at the same time determines the new design point bogie frame side beam according to certain optimization rules.

2. Basic principles and methods of particle swarm optimization
In recent years, people have made great achievements in the exploration of biological behavior in nature. Based on this, they have completed modeling of their basic concepts in computers and created so-called artificial intelligence methods. Artificial intelligence is also divided into the study of biological individual human nerves and group behaviors such as ant colony, school of fish, bird population, etc [2]. The simulation of group behavior is also called group intelligence. Particle swarm algorithm is a very superior algorithm in the field of group intelligence. Its essence is derived from the research on the group behavior of bird foraging. It models the bird's space in reality as the feasible area of the particle, and the birds. The position in reality is modeled as the position of the particle, and
the mutual cooperation and information sharing during the foraging process is modeled as the search process [3].

3. The advantages of particle swarm optimization
The performance improvement of the algorithm mainly focuses on improving the accuracy of the optimal solution. Although the PSO algorithm has shown its strong superiority compared with the traditional algorithm, it has to admit that it still has many deficiencies. At present, there are mainly three aspects for the study of its performance: the standard particle swarm algorithm uses a linear inertia weight, which can make the algorithm early to facilitate global search, and later favors local search. At present, the most advanced method for inertia weight is the method of automatically adjusting the inertia weight through the convergence rate and evolution rate. This method will be described in detail in Chapter 4 of this paper. This method compares linearly to the inertial weights, and is in terms of convergence efficiency [4]. There is a clear improvement. At the same time, there has been a particle swarm algorithm with a convergence factor, but this method has a greater degree of dependence on the choice of parameter values, and essentially the same as the control inertia weight. Enhancing the diversity of populations refers to the shortcomings of the standard particle swarm algorithm, which is mainly due to the dispersion of populations in the search space to enhance diversity, thereby improving the overall ability and the ability of the algorithm to search for the best. At present, more ideas are applied to increase the diversity of the population as a means. As we all know, intelligent algorithms not only include the particle swarm algorithm, but also include simulated annealing, genetic algorithms, etc. These algorithms have different ideas, different technical means, and have advantages and disadvantages in dealing with optimization problems [5]. If you can mix different methods and use the advantages of each other, you will be able to achieve better results. For example, the widely used generalized particle swarm optimization algorithm is a combination of genetic algorithm and particle swarm optimization algorithm. This method has proved to have a good effect on traveling salesman problems.

4. Application of particle swarm optimization in steel structure welding engineering

4.1. Study of the steering architecture beam
The bogie frame is an important welding part of the rail car. The quality of the bogie frame has an important influence on the speed and safety of the rail car. Therefore, this section discusses the welding process for the bogie frame of rail passenger cars. The purpose is to propose a process plan that enables the bogie frame to have better welding quality through optimized design. The finite element modeling of the side frame of the bogie frame is adopted [6]. The bogie frame of the high-speed railcar is generally composed of two pairs of side beams and cross beams. The side beams are welded by the upper cover plate, the lower cover plate, the left and right upright plates, and the spacer plate. On the axle box spring, it is a large, complex welded structure.

The side beams of the frame have four main welds. According to the basic process requirements, each weld must be completed by two welding operations. That is, each weld can be composed of two layers of welds, inner and outer. Since the heat input of the welding seam of the spacers in the side beams of the bogie side beams is small and the deformation is small, the spacer plates can be simplified.

4.2. Stress calculation of steering frame beam
To a large extent, the welding residual deformation and residual stress will have opposite trends, and this is a difficult problem encountered when studying the reduction of welding residual deformation and stress [7]. When the amendment is fixed by the fixture, the amendment will have higher residual stress and lower residual deformation; conversely, an amendment, if there is no constraint in the welding process, will have lower residual stress after welding and higher residual deformation. It is
difficult to design a process scheme that has both optimal welding residual deformation and stress. That is, take $W$ as the weighted form of residual deformation and residual stress:

$$W = \omega_1 \cdot \delta / \delta_{\text{max}} + \omega_2 \cdot \sigma / \sigma_{\text{max}}$$

4.3. Mathematical Modeling Using Particle Swarm Optimization

The proposal of the standard particle swarm optimization algorithm provides a fast and efficient choice for solving the optimization problem to a great extent. However, the standard particle swarm optimization algorithm cannot solve the problem when the parameters of the optimization problem are not continuous. Therefore, the finite element model of this structure was established. Because the welds and the areas closer to the welds generally have larger changes in temperature, stress and strain, while in the areas far from the welds [8], the temperature gradient is smaller, and the residual deformation and stress are correspondingly smaller. According to the distribution of forces, temperature and other parameters, we can adopt the treatment method of dividing the weld and the area closer to the weld than the dense grid far from the weld. This can effectively reduce the number of grids while ensuring accuracy, thereby improving computational power. In order to obtain a better instantaneous temperature field distribution, the finite element model of the structure is divided into three areas: welding area, thermal reaction area, and away from the weld area (or parameter insensitive areas such as temperature).

| Temperature (K) | Heat conductivity (W/(mm·K)) | Specific heat capacity (KJ/(Kg·K)) | Density (g/mm³) | Expansion coefficient (l/K) | Elastic modulus (MPa) | Yield stress (MPa) |
|----------------|-------------------------------|-----------------------------------|-----------------|-----------------------------|----------------------|-------------------|
| 293            | 5.119e-2                      | 472.66                            | 7.8198e-6       | 1.135e-5                    | 2.160e5              | 360.0             |
| 373            | 1.991e-2                      | 485.99                            | 7.7923e-6       | 1.173e-5                    | 2.104e5              | 345.6             |
| 573            | 4.459e-2                      | 518.77                            | 7.7291e-6       | 1.189e-5                    | 1.995e5              | 301.0             |
| 773            | 3.678e-2                      | 569.90                            | 7.6565e-6       | 1.190e-5                    | 1.842e5              | 227.5             |
| 1073           | 2.398e-2                      | 693.66                            | 7.5903e-6       | 1.223e-5                    | 1.422e5              | 51.3              |
| 1373           | 2.811e-2                      | 686.21                            | 7.4448e-6       | 1.453e-5                    | 0.852e5              | 15.0              |

Figure 1. Temperature-dependent properties.

4.4. Using Particle Swarm Optimization for Modeling and Analysis

The stress field analysis model of the frame side beam is the same as the one used in the thermal field. The boundary conditions of the stress field simulation analysis are: According to the actual welding process of the side beam of the bogie, the two ends of the side beam of the bogie frame are restrained, one end is fully constrained, and the other end constrains the direction. In the simulation of the stress field of the side beam of the bogie frame, the element method is also introduced into the calculation process in order to simulate the metal filling process of the welding. The unit changes the unit by changing the unit's property value. In this, the operation is performed by changing the cell stiffness properties. The stiffness matrix of the element does not become a zero matrix, but it becomes a very small value from the original value. Generally reduce the above material properties to. Therefore, the stiffness matrix of the material is always present. When the element is born, the stiffness, mass, specific heat, and other parameters of the material are restored to the original values. In order to adapt to the node's current position, all cells must exist before the calculation, and when the cell is reactivated, their shape will change (lengthen or shorten) accordingly.
4.5. *Particle swarm Optimization Test Verification*

In order to verify and verify the simulation analysis results and test results of the side frame of the bogie frame, the welding parameters, welding sequence and welding direction of the simulation analysis are all set according to the actual method adopted in the actual project, and other welding residual stress and deformation are not considered. The way. The results of actual engineering welding in this paper were extracted using a coordinate measuring instrument and a ray diffraction system. The model of the test model and the finite element simulation analysis use the same materials, dimensions, and welding settings. According to the company's requirements, the welding interface of the side frame of the bogie frame is a single-side interface, using carbon dioxide arc welding, welding wire diameter 1.2mm, welding current 300A, welding voltage 30V, welding speed 7mm/s, welding efficiency coefficient 0.8. Based on the above settings, the thermostatically coupled welding simulation analysis of the side frames of the bogie frames was calculated in ANSYS.

![Figure 2. Temperate-dependent thermal properties.](image)

![Figure 3. Simulation result of stress field.](image)

In order to compare the accuracy of the results of the simulations and experiments, the deformation of the weld seams of the bogie frame side beam top cover and the right side upright plate was extracted as a comparison standard for welding deformation. The welds at the joints of the axle box springs in the vertical side beam welds should be extracted as a comparison standard for welding stress.
The residual deformation and stress obtained by the experiment are in good agreement with the results obtained from the simulation analysis in this paper. The maximum residual deformation occurs in the middle of the weld, the simulation result is -5.74cm, the test result is -6.14mm, and the relative error is 7.2%. The direction of residual deformation is along the negative direction of the Y axis. The maximum welding residual stress obtained from the simulation analysis was 344.36MPa, and the test result was 348MPa with a relative error of 1.0%. Stress, visible in the distribution trend of residual stress, is the same. The residual deformation of the welding simulation analysis is less than the measurement result because the spot welding of the company before the formal welding will produce smaller welding residual deformation and stress. However, the distribution trends of simulated values and experimental side beams are consistent, and there are small differences between the values. In short, the way of setting up the welding simulation analysis and its results can fully reflect the actual welding situation. Based on this, it is further proved that the welding simulation model built in this paper, the input of moving heat source in temperature field, the deformation process of stress field and the stress simulation process are correct and effective.

![Figure 4](image.png)

**Figure 4.** The convergence graph of the best result of three mathematical models.

### 4.6. Convergence Analysis

Finally, the application of discrete particle swarm optimization algorithm to the optimal solution of the bogie frame welding requires the convergence analysis. The discrete particle swarm algorithm has the characteristics of simple parameter setting and strong search ability. The algorithm has a simple optimization mode and global search performance, easy to use in conjunction with other algorithms. Because the actual problem does not fall into the local optimum, this paper uses this algorithm to optimize the proxy model. By implementing the discrete particle swarm optimization algorithm, the mathematical model obtained the best results after multiple optimizations, the optimal convergence trend of the specific optimization iteration. For the sake of comparison, different optimization objectives have been unified at the order of magnitude. According to the mathematical optimization model, the minimum value was reached after iteration. The mathematical model with the residual stress as the optimization goal has the fastest convergence speed. And all mathematical models also basically converge in the fiftieth iteration.

Optimal welding residual deformation and stress analysis results after optimizing the residual deformation and stress as the goal, the best residual deformation is -3.92mm and the maximum residual stress is 212.56MPa. The optimization results corresponding to the above two results are reduced to different degrees respectively. The maximum welding residual deformation and stress in the optimal weighted form are -5.12mm and 247.39MP, respectively. The above two results are not the minimum welding residual deformation and stress values, but their weighted results are optimal.
According to the order and direction of welding applied by the project, it is generally known that the inner layer sequence is III (2143), the outer layer sequence is III (7658), and the welding direction is I (11). Corresponding welding residual deformation and stress are -5.74mm and 344.36MPa, respectively, taking into account the combined effect of residual deformation and stress. The welding order and direction of the optimal weighting scheme are II (4123), V (7658), III (10), respectively. Obviously, the residual deformation and stress of the optimal weighting result are not the lowest results, but the residual deformation and stress results of the welding sequence and direction are about 11% and 38% lower than the results of the corporate plan, respectively. When comprehensively considering the impact, this scheme is the best.

5. Analysis and Prospect

It can be seen that the arrangement of welding sequence and direction can be optimized by the finite element method using the discrete particle swarm algorithm. The research results of this paper can be provided for the welding arrangement scheme of the side frame or many large welding parts of the bogie frame or many welding parts in actual production guide. In production practice, the welding deformation and stress of the side beams generally exceed the range of different technical requirements of the product. Therefore, it is very necessary to provide effective methods to control welding deformation and stress. Through the comparison of experimental and simulation results, the authenticity and correctness of the welding values of the side beams are verified. Therefore, the best welding sequence and direction chosen is reasonable.

On this basis, the particle swarm algorithm is discretion and partially improved, which makes the particle swarm algorithm more applicable to the discrete variable problem. Finally, the particle swarm optimization algorithm is used to optimize the rigid frame structure. So the outlook for the future work is as follows:

The particle swarm optimization algorithm was used to realize the optimization design of the planar rigid frame structure and the combined structure. At the same time, the traditional algorithm was used to optimize the design, and various optimization results were compared. On the one hand, it was verified that the particle swarm algorithm can be solved better. The size optimization problem of plane rigid frame and plane combined structure, on the other hand, also verified that PSO algorithm has better global convergence and stability than traditional optimization algorithm and can more effectively avoid local convergence. The inertial weight and update mode of discrete particle swarm optimization algorithm are improved to some extent, which makes the algorithm have better globality and convergence, which greatly improves the precision and efficiency of the operation. At the same time, it aims at the discrete particle swarm with constant step change. For the problem of discrete variables and discrete variables of given values, this paper uses the method of mapping on the basis of the standard particle swarm algorithm to discretize the variables. At the same time, it uses the improvement measures of the particle swarm algorithm to successfully solve the optimization of the rigid frame structure problem. A systematic description of the constraints that the structure needs to meet in the rigid frame design is made, and the shortcomings of ambiguous constraints in the previous rigid frame design papers are reinforced. At the same time, the discrete particle swarm optimization algorithm is applied. Under the premise of satisfying the structural constraints, the optimization design of the rigid frame is completed. In addition, the optimization results are compared with the design method, the full stress design method and the genetic algorithm, and it is verified that the particle swarm algorithm has certain advantages in accuracy. At the same time, by comparing the optimization results of different numbers of design variables, it is verified that adding design variables in discrete particle swarm optimization can effectively improve the accuracy without significantly reducing the computational efficiency.

6. Conclusion

According to the review, by studying the influence of welding sequence and direction on the welding residual stresses and deformations of the side frames of high-speed railway passenger car bogie frames,
the welding simulation of the side frames of the bogie frames was performed in the software using a Thermos-mechanical coupling method. Using the particle swarm algorithm's mobile positioning mode, different welding sequences and direction combinations were designed. In order to improve the optimization efficiency, an optimized agent model based on the experimental design method was established to minimize the combination of welding deformation and stress. The discrete particle swarm algorithm proposed in this paper achieves the optimization of the welding sequence and direction. The best solution obtained gives the optimal welding process plan. The verification results show that the application of this scheme greatly reduces the computational cost required in the welding process and significantly reduces the loss of calculation accuracy. The application shows that the optimized solution of this paper effectively reduces the welding deformation and stress in the welding process. It has a guiding role in improving the welding process of high-speed railway passenger rail longitudinal beam steel structures, and improving the manufacturing quality and service performance.

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