BP-ANN model to optimize the structural parameter setting of transfer point

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Abstract. In order to optimize the structural parameter setting at the transfer point, the principle of CFD-DEM coupling is used to simulate the production conditions of the material mass flow rate: 150kg/s, height difference: 3m, material density: 1400kg/cm³, and the operation of different structural parameter settings at the transfer point. Based on the pumping volume, equipment wear degree and dust concentration in the exhaust pipe, the weight coefficients of the three indicators given by the comprehensive analytic hierarchy process and the CRITIC method are 0.49, 0.32 and 0.16 respectively, and then the structure parameter settings obtained by the orthogonal test are simulated and optimized by using the BP neural network model. The optimized parameters of orthogonal test are the chute angle of 45 degrees, the number of suction ports of 3, the belt speed of 1.5m/s and bandwidth of 1000mm; the optimized parameters of BP neural network model simulation are chute angle of 45.53 degrees, the number of suction ports of 2.86, the belt speed of 1.48m/s and the bandwidth of 996mm. The results show that the BP-ANN model has the advantages of simplification, high efficiency and time saving, and can provide a new method for enterprises to set the structural parameters at the transfer points reasonably according to their own production conditions.

1. Introduction

In industrial production, some enterprises, such as material processing, power plants, mining and so on, will have bulk material transportation in their production links, and the transfer point in the bulk material transportation process is the key part for enterprises to prevent dust, reduce dust and control dust. Therefore, many scholars have carried out a series of researches on the transfer point: Jia Huiyan[1], et al. have studied the dust emission law of the transfer point by using the methods of field test and numerical simulation; LV Tai[2], et al. have made an optimized study on the vacuuming method of the transfer point; Liu Weili[3], et al. have analyzed the gas-solid two-phase flow of the dust suppression technology at the transfer point. At present, the research on the transfer point is mostly in the aspects of dust reduction and dust suppression technology, while the research on the reasonable selection of the structural parameters of the transfer point under the actual production conditions is less. Production enterprises often choose the structural equipment specifications of transfer points according to experience, so in actual production, there will be problems such as large equipment wear, frequent maintenance work, energy consumption and so on. Therefore, it is necessary to study the reasonable setting of transfer point structural parameters.
The structural parameters at the transfer point include: chute angle, number of suction ports (air outlets), belt speed and bandwidth. Under the actual production conditions, such as: transportation volume (mass flow), falling height of materials, type (density) of materials, the reasonable setting of structural parameters at the transfer point depends on the size of the suction volume, the dust concentration of the suction pipe and the wear degree of the equipment. This study is complex. By consulting some data and literature [4-9], it is found that the study can take the air volume, dust concentration in the exhaust duct and the wear degree of the equipment as the evaluation indexes, analyze the weight coefficients of the three indexes by the combination of subjective evaluation method (AHP) and objective evaluation method (CRITIC), and then use the back propagation artificial neural network (BP-ANN) model to analyze the structural parameters obtained from the orthogonal test. Finally, the optimal structure parameters are determined.

2. Methods and results

2.1. Test scheme
Using FLUENT software and EDEM software, using the method of CFD-DEM two-way coupling [10-12], we select the production conditions with material mass flow of 150kg/s, material falling height of 3m and material density of 1400kg/cm³, establish models under different operating conditions and carry out numerical simulation calculation for four structural parameters of chute angle, number of suction ports, belt speed and bandwidth, as shown in Figure 1. The data of simulation results is imported into CFD-Post software for numerical analysis and determination of three indexes.

![Figure 1. Model at the transfer point](image)

1. Upper conveyor belt, 2. Chute, 3. Lower conveyor belt, 4. Dust cover, 5. Suction pipe, 6. Suction port

2.2. Index determination

2.2.1. Determination of the exhaust volume. The simulated data is processed by CFD-post software, and the velocity $V_{ij}$ of different positions of the air outlet plane is derived. The average velocity $V$ and the area $A$ of the air outlet plane are calculated. The value of exhaust volume $L$ is: $L = 3600VA$.

2.2.2. Determination of dust concentration in exhaust duct. The simulated data is processed by CFD-post software, and the concentration $C_{n-ij}$ of different points in different tangent planes of the exhaust duct is derived. The average value $C_n$ of each tangent plane is calculated, and then the value $C$ is calculated according to the formula $C = C_n / n$, and the value $C$ is the dust concentration of the exhaust duct.

2.2.3. Determination of wear degree of equipment. The simulated data is processed by CFD post software, the pressure values of dust cover wall, dust cover wall, pipe wall and other equipment are derived, and the number, pressure value and area of the point where the maximum pressure occurs and the maximum value point are found out. According to the number, pressure value and area of the maximum pressure point, the equipment wear is defined as 10 grades of 1-10, and then these 10 grades are taken as the criteria of equipment wear degree.
2.3. Weight analysis of each index

AHP method combined with critical method was used to establish the comprehensive weight of three indexes on exhaust volume, dust concentration in exhaust pipe and wear degree of equipment, etc.

2.3.1. Determination of AHP weight coefficient. According to the results and laws of numerical simulation, the influence of suction volume, dust concentration in suction pipe and wear degree of equipment on the structural parameter setting of transfer point is judged. In the light of the influence degree, these three indexes are divided into three levels for quantification, and they are sorted according to the order of suction volume > wear degree of equipment > dust concentration in suction pipe, and the comparative priority matrix of different index combinations are constructed, and the relative scores of each index are calculated. After calculation, the weight coefficients of the AHP method for the exhaust volume, the wear degree of the equipment and the dust concentration in the exhaust pipe are 0.40, 0.34 and 0.26 respectively. The consistency comparison factor CI = 0.07, the consistency ratio CR = 0.0565, all < 0.1, indicating the consistency of the index priority comparison judgment matrix.

2.3.2. Determination of weight coefficient of CRITIC method. Nine groups of data of each index of orthogonal test are processed by linear interpolation [index component = (test value - Test minimum) / (test maximum - Test minimum) × 100], and after unit dimension is eliminated, calculating each index of suction volume, wear degree of equipment, exhaust duct dust concentration: the contrast intensity (Sj), conflict (Rj), comprehensive weight (Cj), weight (Wj). After the CRITIC method, the weight coefficients of exhaust volume, wear degree of equipment and dust concentration in exhaust pipe are 0.42, 0.33 and 0.24 respectively.

2.3.3. AHP-CRITIC mixed weighting method to determine the weight. The AHP method gets the weight coefficient based on subjective information, the CRITIC method gets the objective weight coefficient of the corresponding index, and synthesize the two coefficients to get the comprehensive weight of three index components. The formula of comprehensive weight is $\omega_{ij} = \omega_{AHP-ij} \omega_{CRITIC-ij} / \sum \omega_{AHP-ij} \omega_{CRITIC-ij}$. After calculation, the comprehensive weight of the exhaust volume, equipment wear degree and dust concentration in the exhaust duct are 0.49, 0.32 and 0.16 respectively, that is, the comprehensive score = (maximum exhaust volume / exhaust volume) × 0.49 × 100 + (maximum equipment wear degree / equipment wear degree) × 0.32 × 100 + (maximum dust concentration in the exhaust duct / exhaust duct) × 0.16 × 100.

2.4. Orthogonal test design and results

According to the literature report[8-9] and the pre-simulation results, the design of the transport point structure scheme of L9 (3^4) orthogonal test is used in this study. Taking the suction volume, equipment wear degree and dust concentration of the exhaust pipe as the index, the orthogonal test is carried out for the four factors affecting the transfer point structure parameter setting, including chute angle (A), number of suction ports (B), belt speed (C), bandwidth (D). Test design and results can be found in Table 1.
Table 1. Orthogonal test results of transfer point structure setting

| Test serial numbers | A  | B  | C    | D    | Synthesis scores |
|---------------------|----|----|------|------|------------------|
| 1                   | 45 | 1  | 1    | 500  | 72.56            |
| 2                   | 45 | 2  | 1.5  | 800  | 91.23            |
| 3                   | 45 | 3  | 2    | 1000 | 94.35            |
| 4                   | 55 | 1  | 1.5  | 1000 | 87.46            |
| 5                   | 55 | 2  | 2    | 500  | 89.01            |
| 6                   | 55 | 3  | 1    | 800  | 80.37            |
| 7                   | 60 | 1  | 2    | 800  | 82.30            |
| 8                   | 60 | 2  | 1    | 1000 | 74.86            |
| 9                   | 60 | 3  | 1.5  | 500  | 88.61            |
| mean 1              | 86.04 | 80.77 | 75.93 | 83.39 |
| mean 2              | 85.61 | 85.03 | 89.10 | 84.63 |
| mean 3              | 81.92 | 87.77 | 88.55 | 85.55 |
| range               | 4.12  | 7.00 | 13.17 | 2.16  |

Table 2. Analysis of variance of orthogonal test

| Fators | Deviation sum of squares | DOF | Value F | critical value of F | Significance |
|--------|--------------------------|-----|---------|---------------------|--------------|
| A      | 30.775                   | 2   | 4.365   |                      |              |
| B      | 74.655                   | 2   | 10.591  |                      |              |
| C      | 333.015                  | 2   | 47.377  |                      |              |
| D      | 7.049                    | 2   |         |                      |              |

Note: $F_{0.005 (2,2)} = 19.00$

According to the results of Table 1 Orthogonal test, the factors that affect the structure setting of transfer point from large to small are: C > B > A > D. The results of Table 2 variance analysis show that the belt speed has significant difference at all levels, which is the main factor affecting the structure design of transfer point. The best structure setting combination is $A_1B_3C_2D_3$, that is, the chute angle is 45 degrees, the number of suction ports is 3, the belt speed is 1.5 m/s, and the belt width is 1000 mm.

2.5. Modeling and application of BP neural network

2.5.1. BP-ANN model construction. A 4-N-1 BP neural network model with N as the hidden layer is built by using the mathematical software MATLAB. Taking the data of chute angle, number of suction ports, belt speed and bandwidth as the input layer and the comprehensive score as the output layer, the simulation optimization model of transfer point structure setting is constructed. The neural network diagram is shown in Figure 2.

![Figure 2. Operation model of BP neural network](image-url)
2.5.2. Operation of BP neural network

2.5.2.1. Neural network model test. The 9 groups of data in Table 2 are imported into BP neural network model, in which 7 groups of randomly selected data are used for model training and the remaining 2 groups of data are used for model testing. By training the number of different neurons, we know that when the number of hidden layer nodes is 10, the training function is trainlm, the maximum number of training iterations is 800, the transfer function of the hidden layer neurons is tansig, the transfer function of the output layer neurons is purelin, and other parameters are the default values, the relative error between the output value of the two groups of predicted data and the actual value is less than 1.5%, indicating that the neural network has a good precision of training and prediction and meets the test requirements.

2.5.2.2. Simulation and optimization of optimal structure setting of neural network model. In the orthogonal experiment, 64 different combinations of chute angle, number of suction ports, belt speed and belt width were obtained. Taking these 64 combinations as input values, the simulation optimization is carried out under the neural network model constructed above. Through the selection of the comprehensive evaluation results of the output layer, it is finally determined that under the conditions of material mass flow rate of 150 kg/s, material height difference of 3m and material density of 1400 kg/cm³, the optimal structural parameters of the transfer point are: chute angle of 45.53 degrees, number of suction ports of 2.86, belt speed of 1.48m/s and bandwidth of 996mm.

2.6. Verification test

According to the orthogonal test and BP neural network optimization, the structure setting is verified, parallel 3 times. The average comprehensive score of structure setting is 95.31 by orthogonal test and 95.97 by BP neural network optimization. The comprehensive scores of the two structures are close, but the time of numerical simulation of a group of working conditions in orthogonal test is about one week, while the time of BP neural network modeling is about three hours, which greatly saves the test time. In addition, the numerical simulation software has higher requirements for computer configuration, while the performance of BP neural network using MATLAB software has lower requirements.

3. Conclusion

• In this study, the orthogonal test and BP neural network model are combined. In view of the influence of many levels and factors on the structural parameter setting of transfer point, partial tests are used instead of comprehensive tests to reduce the number of tests and avoid repeated tests. Then, the prediction model is established by using the self-organization and self-learning ability of BP neural network technology, and the BP-ANN model is simulated and optimized, Fast, efficient and accurate optimization of structural parameter settings.

• At present, production enterprises often select the structural parameters of the transfer points based on experience: chute angle, number of suction ports, belt speed and bandwidth, without considering the control of structural parameters on suction volume, equipment wear degree and dust concentration of suction pipe. Although dust removal effect can be achieved, there are problems such as large equipment wear, frequent maintenance work and energy consumption occur after the equipment is put into production. The BP-ANN model in this study can optimize the setting of structural parameters at the transfer point and ensure the economic and efficient operation of the equipment.

• Using AHP method which is inclined to subjective evaluation and critic method which is based on the contrast strength and conflict between evaluation indexes and can reflect the objective weight of each index, the subjective index and objective index are combined to calculate the comprehensive weight, which ensures the accuracy of each index weight and makes the evaluation result more objective and true.
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