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AN EMPIRICAL MATHEMATIC MODEL OF DRUMS CUTTING TORQUE

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ABSTRACT

The cutting experiments with different drums (seven types of drums) and picks (eight types of picks) were done, which to acquire the empirical mathematic model of the cutting torque of the shearer drum. According to the existed research results, the structure of the empirical mathematic model of the cutting torque was formed, and regression analysis of the test date was performed to get the suitable date for empirical mathematic model solution by using BP neural network. Based on this, the unknown coefficients of the model were solved, and the empirical mathematic model was acquired, too. To verify the reliability of the empirical mathematic model, the five different experiments were done. The research results indicated that the error of the built empirical mathematic model was smaller than 10%, which satisfied the needs of engineer design.

Keywords: *Shearer Drum, Cutting Torque, BP Neural Network, Empirical Mathematic Model Building*

1. INTRODUCTION

Cutting torque is considered as the most important index for evaluating the performance of shearer drum, and it is influenced by not only coal hardness but also drum's structure and motion. The work of predict different drum's cutting torque is very important, which can provide support and reference for shearer's dynamics characteristic research, reliability analysis research and structure design and modification. For this reason, the vast majority of research works have been done by the scholars.

The neural network model among rock breaking effect and pick distance, cutting thickness were built by researching the influence of the drum structure parameters on the rock breaking effect [1]. The relationship between drum's cutting torque and cutting thickness was obtained with the model test method, which indicated that the performance of vibration cutting with sine wave form was better than the triangular wave [2].The influence of the drum vane wrap angle on the drum cutting performance was studied, which indicated that the cutting force and the cutting performance would be decreased if the wrap angle was increased[3].The influence of pick arrangement of drum on the cutting performance was researched, which indicated that there was no difference on the cutting force when the pick circumference was arranged with equal angle or varied angle[4]. The cutting experiments with different-structure rocks were done, which indicated the cutting performance of the pick was affected mainly by the rock compressive strength, and explained basic rules governing the relationships between specific energy and chip sizes [5−7]. With the help of cutting test bed, the effects of drum's structure parameters and kinematic parameters on drum's cutting torque were studied systematically, and the cutting performance of different drums in specific conditions were obtained [8−13]. The computer simulation technique was used to research the difference of four type drums cutting torque in specific conditions, which indicated that aberrance 1 drum and punnett square drum have more advantages to enhance lump coal rate, aberrance 2 drum was suitable for reducing impact force[14].

From the above, we can see that a lot of research work had been carried out by scholars, including drum's cutting parameter research, kinematic parameters research, and structure parameters research, but evaluate expressions of drum's cutting torque were not given explicitly by any scholar. It's a hard work to build the model by theoretical analysis. The reason for this is because that: dozens of picks were installed in drum, every pick's load couldn't be figure out by existing theoretical formula just for each pick getting different force which is due to pick's arrangement and the affection of adjacent picks; beyond that, the calculation formula's missing of coal-loading torque makes theoretical mathematic model's building more difficult. For those reason, the work of building empirical mathematic model was carried out in this article.

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2. DATE OBTAIN AND DETERMINATION OF MODEL FORM

According to the former scholars researches, drum's cutting torque (T)was influenced by coal compressive strength (σ), alloy head diameter(d), angle between picks(θ), pick taper(β), impact angle(δ), cutting web(B), cutting line spacing(t), rotating speed of drum(n), hauling speed(v), cutting depth(h) and blade helical angle(α). Cutting depth(h), rotating speed of drum(n) and hauling speed(v) satisfy $h = 1000v / nz$, z is blade number, so rotating speed of drum(n) and hauling speed(v)can be expressed by h. Therefore, cutting experiments of seven type sequence model drums and eight type model picks were studied on σ, d, θ, β, δ, B, t , h, α in this paper, and tests results were shown in Table 1. Tests drums and picks were shown in Fig 1 and Fig 2.

Table 1 : Test Results

Order	σ(MPa)	d(mm)	θ(°)	β(°)	δ(°)	B(m)	t(mm)	h(mm)	α(rad)	T(N.m)
1	1.43	8	75	20	50	0.21	30	2.97	0.436	684.4
2	1.97	8	75	20	50	0.21	30	2.58	0.436	846.1
3	2.48	8	75	20	50	0.21	30	2.3	0.436	1014.8
4	1.43	12	75	20	50	0.21	30	2.82	0.436	849.9
5	1.43	10	75	20	50	0.21	30	2.96	0.436	826.7
6	1.43	8	75	20	50	0.21	30	2.97	0.436	684.4
7	1.43	12	75	20	50	0.21	30	2.82	0.436	849.9
8	1.43	12	80	20	50	0.21	30	2.79	0.436	865.1
9	1.43	12	90	20	50	0.21	30	2.61	0.436	921.5
10	1.43	8	75	20	50	0.21	30	3.03	0.436	738.5
11	1.43	8	75	25	50	0.21	30	2.92	0.436	757.9
12	1.43	8	75	30	50	0.21	30	2.87	0.436	837.5
13	1.97	8	75	20	50	0.21	30	2.58	0.436	846.1
14	1.97	8	75	20	45	0.21	30	2.44	0.436	933.2
15	1.97	8	75	20	45	0.21	30	2.34	0.436	1092.8
16	1.97	8	75	20	50	0.21	30	2.58	0.436	846.1
17	1.97	8	75	20	50	0.27	30	2.35	0.436	950.9
18	1.97	8	75	20	50	0.315	30	2.02	0.436	1133
19	1.97	8	75	20	45	0.21	20	2.78	0.349	827.2
20	1.97	8	75	20	45	0.21	30	2.45	0.349	920.2
21	1.97	8	75	20	45	0.21	40	2.34	0.349	974.0
22	1.97	8	75	20	45	0.21	30	2.51	0.262	758.5
23	1.97	8	75	20	45	0.21	30	2.45	0.349	920.2
24	1.97	8	75	20	45	0.21	30	2.56	0.436	835.8
25	1.97	8	75	20	50	0.21	30	5.36	0.436	940.5
26	1.97	8	75	20	50	0.21	30	4.67	0.436	924.5
27	1.97	8	75	20	50	0.21	30	3.77	0.436	833.2

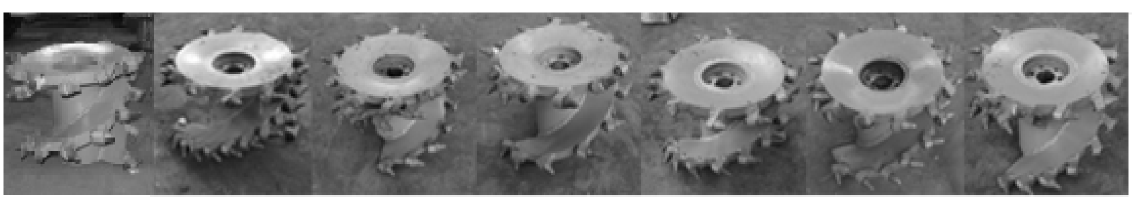

Figure 1: Test Drums

Figure 2: Test Picks

According to the previous research, we could get that: the relationship between drum's cutting torque and coal compressive strength is linear, and the torque increases with the increasing of coal compressive strength; the relationship of drum's cutting torque with alloy head diameter, angle between picks, pick taper, impact angle, cutting web, cutting line spacing and cutting depth is e

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exponential form, and cutting torque is positive index correlation with angle between picks, pick taper and cutting web, negative index correlation with the other structure parameters; cutting torque would grow in power function along with the increase of helical angle[8~13]. According to above research results, the relationship of T with σ, d, θ, β, δ, B, t, h and α could be confirmed, and its mathematical expression could be expressed as Eq(1) form.

$$T = K\begin{pmatrix} K_\sigma \sigma + a_1 e^{b_1 d} + a_2 e^{b_2 \theta} + a_3 e^{b_3 \beta} + a_4 e^{b_4 \delta} + \\ a_5 e^{b_5 B} + a_6 e^{b_6 t} + a_7 e^{b_7 h} + a_8 \alpha^2 + a_9 \alpha + a_{10} \end{pmatrix} \quad (1)$$

Where, K means proportional coefficient which is determined by modeling similarity ratio; the rest of unknown parameters are unknown coefficient.

3. MODEL SOLUTION

According to Eq(1): the relationship of drum's cutting torque and its influential parameters is multivariate nonlinear, the test result would be influenced by some uncontrollable factors, so , great errors would be taken to solving result if using the test date directly. For this reason, a new solution method becomes particularly important. Taking sampling data of metal elements content in a mine point as the example, Xin analyzed and pointed out the advantage of BP neural network in multivariate nonlinear regression analysis than traditional regression method[15]. BP neural network prediction of cutting force when cutting on rocks were studied, which achieved ideal results[16-18]. As one kind of MLP network structure based on error back propagation algorithm, BP neural network can approximate any continuous functions with arbitrary precision, so it can be widely used in nonlinear model building, functional approximation, pattern recognition and classification, etc. Its main idea is that: input learning samples, and use back propagation algorithm to train the network weights and bias repeatedly until actual output vector as close as possible to the expected output vector; The training would be finished until the network output layer's sum of square error is less than the specified error; And then, network weights and bias would be saved. Therefore, in this paper, test date parameters would be optimized by using automatic adjustment training function of BP neural network weights and bias. In other words, the torque value which was forecasted by BP neural network and its corresponding input parameter value were taken to Eq(1) solving unknown coefficient.

The each test conditions were chosen as the input, and the test torque value were chosen as the output in the BP neural network regression analysis. In order to guarantee the prediction accuracy and prediction speed, a 3 layers neural network that contain 13 nodal points in the hidden layer was used in this paper which referenced to previous work. In Eq(1), there are 18 unknown factors except proportional coefficient K, so 18 times training are needed by using BP neural network. The input parameter value and the forecast value as shown in Table 2.

The drum torque empirical mathematical model could be obtained by substituting the value of Table 2 into Eq(1), and it was shown in Eq(2) .

$$\begin{aligned} T &= K\begin{pmatrix} K_\sigma \sigma + a_1 e^{b_1 d} + a_2 e^{b_2 \theta} + a_3 e^{b_3 \beta} + a_4 e^{b_4 \delta} + \\ a_5 e^{b_5 B} + a_6 e^{b_6 t} + a_7 e^{b_7 h} + a_8 \alpha^2 + a_9 \alpha + a_{10} \end{pmatrix} \\ &= K\begin{pmatrix} 0.35\sigma_{ym} - 312.46 e^{-2.56 d_{jh}} + 0.0065\alpha_{jj} + 0.00032 e^{0.22\alpha_{zj}} + \\ 10.44 e^{-1.26\alpha_{cj}} + 0.00035 e^{0.008B} + 0.0015 e^{0.064 S_j} - \\ 0.00038\alpha^2 + 0.008\alpha + 4.15 e^{-1.4h} - 0.43 \end{pmatrix} \end{aligned} \quad (2)$$

Table 2 : Predicted Result Of BP Neural Network

Order	σ(MPa)	d(mm)	θ(°)	β(°)	δ(°)	B(m)	t(mm)	h(mm)	α(rad)	T(N.m)
1	1.97	8	80	25	50	0.315	20	4	0.436	1456.7
2	2.48	10	75	20	45	0.21	30	5	0.436	1140.2
3	1.43	8	60	35	50	0.315	20	4	0.436	1282
4	1.97	12	75	25	40	0.21	30	5	0.349	964.7
5	1.43	10	75	20	50	0.27	40	3	0.523	982.6
6	1.43	8	75	20	50	0.27	30	3.5	0.262	972.1
7	1.97	16	75	25	40	0.21	20	4	0.436	911.7
8	1.97	12	80	20	40	0.315	30	2.5	0.349	1482.6
9	1.97	12	90	20	40	0.27	30	2.5	0.436	1148.0
10	1.43	8	75	20	50	0.21	40	5	0.262	785.5
11	1.43	10	75	25	50	0.21	30	3	0.436	768.2
12	1.43	8	80	30	45	0.27	30	3	0.523	974.8
13	1.97	16	75	20	50	0.21	30	4	0.436	962.3
14	1.97	8	75	30	45	0.315	20	4	0.523	1459.3
15	2.48	8	75	20	45	0.21	30	4	0.436	1137.0
16	2.48	16	90	20	50	0.21	30	2	0.262	1049.4
17	1.97	8	75	30	45	0.27	20	3	0.436	1108.3
18	1.97	10	75	20	50	0.315	30	5	0.349	1508.6

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4. VALIDATION OF MODEL CORRECTNESS

To validate the correctness of the cutting torque empirical mathematical model, five new combined tests of picks and drums were carried out in cutting test bed. The test results and the calculation results were shown in Table 3.

Table 3: Comparison Of Test Results And Calculation Results

Order	σ (MPa)	d (mm)	θ (°)	β (°)	δ (°)	B (m)	t (mm)	h (mm)	α (rad)	Test (N.m)	Calculation (N.m)	Error (%)
1	1.97	12	90	20	45	0.315	30	2.34	0.262	1367.2	1477	8.03
2	1.97	12	90	20	45	0.25	30	3.16	0.262	1132.6	1081.5	-4.51
3	1.97	12	90	20	45	0.315	20	3.01	0.349	1486.3	1460	-1.77
4	1.97	10	75	20	45	0.315	40	4.22	0.349	1421.5	1521.9	7.06
5	1.97	10	75	20	45	0.315	20	3.79	0.349	1405.7	1455.2	3.52

Form Table 3, we can see that: certain error was exist between the forecast value and test results which is not more than ±10%, and the relationship between cutting torque and other parameters was basically correctly reflected by the empirical mathematical model. The correctness of the empirical model was proved from above research.

5. CONCLUSION

(1)The experiments of seven type sequence model drums with eight type picks were carried out in cutting test-bed, and the mean of cutting torques were obtained, which can provide reference for the future researches.

(2)Regression analysis of cutting torque was performed to optimize the date, which would be used in drum's empirical mathematical solution, by using BP neural network; The accuracy of the drum's empirical mathematical model was verified by this work; This solving method bring a new way for complicated data processing and formula solution.

(3)Empirical mathematical model of the sequence drum's cutting torque was obtained, which will provide some theoretical guidance in drum structure design and working parameter optimization.

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