Cutting Constant Power Speed-adjusting Control System of Electrical Haulage Shearer Based on Rbf Neural Network Pid Control

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Abstract. According to the characteristics of electrical haulage shearer in the process of coal mining and the basic principle of cutting constant power speed-adjusting of electrical haulage shearer, taking the traction motor as the controlled object, and cutting constant power speed-adjusting control method of electrical haulage shearer based on RBF neural network PID control is proposed. Adaptive control method to achieve the electrical haulage shearer constant power speed-adjusting and high precision control. At the same time, improve the efficiency of coal mining, to ensure the safety of the shearer. The modeling and simulation analysis of the cutting constant power speed-adjusting control system of electrical haulage Shearer are carried out by Matlab/Simulink, and the system through the field experiment and the comparative analysis with traditional fuzzy PID control. The results show that the system based on RBF neural network PID control has stronger anti-interference ability, higher control precision, faster response time, stronger practicability and stability.

Introduction

The underground coal seam with the characteristics of anisotropy is inhomogeneous, its physical property is unstable and the changes of hardness is large. Working in such complex and adverse circumstances under the mine, the cutting load of electrical haulage shearer is a random variable, which leads to the instability of its working performance and has an influence on the service life and the efficiency of coal mining [1-3].

The realization of the constant power speed-adjusting of electrical haulage shearer is a practical and feasible method to reduce the influence above caused by the characteristics of coal rocks. The traction speed of haulage shearer determines the load and cutting power of roller, so it is possible to realize the approximate constant power operation of the cutting motor by adjusting the traction speed [4-5]. Based on RBF neural network PID control, to achieve the constant power adjustment of electric haulage shearer, the system has good approximating, global optimization abilities, robustness and quick convergence [6]. By using Matlab/Simulink software, the simulation results show that, comparing with the traditional constant power of haulage shearer control system, it has stronger anti-interference ability, higher control precision, faster response speed. This method ensures that the haulage shearer can make a quick response and speed adjustment towards the random disturbance and the cutting load changes, and realizes the approximate constant power coal mining.

The Basic Principles of Haulage Shearer’s Constant Power Speed Adjustment

The hardness changes of underground coal seam, the dirt band and the changes of traction speed are main factors that lead to time-varying property of haulage shearer cutting loads. The electrical haulage shearer cutting motor load power and traction force is proportional to geological condition coefficient of coal seam and traction speed. The approximate function relationship [7]:

\[ P = K_1 + B \cdot V \]  
\[ T = K_2 + C \cdot V \]
Where: P is the power of haulage shearer; T is traction force; V is traction speed; \( K_1, K_2 \) are coefficients of haulage shearer and other external factors; B, C are geological condition coefficients of coal seam (mainly determined by cutting impedance).

From formula (1) and (2), we can know, although the output power of haulage shearer is certain, the cutting electrical motors often work under overload and underload conditions because of the poor working environment and complex characteristics of coal rocks. The traction speed can be adjusted to adapt to the changes of cutting impedance, so as to improve the working state of the motor, and make the shearer work at rated power as much as possible and make full use of its production capacity. Considering the continuous change of the working surface environment and the factors of the shearer, if the shearer cutting motor is approximately constant power, it can be realized by real-time adjustment of traction speed.

According to formula:

\[
P = \eta \cdot \sqrt{3} \cdot U \cdot I \cdot \cos \Phi
\]

Where: \( U \) is rated voltage of motor; \( I \) is motor current, \( \cos \Phi \) is motor power factor; \( \eta \) is motor efficiency.

In the normal working process, the motor power factor of the motor, the motor efficiency and the voltage of the motor are almost constant, which can be regarded as the fixed value. At this time, the power is directly proportional to the current. Therefore, the constant power speed regulation of the shearer can be achieved by comparing the given current with the actual motor current, and its control schematic diagram is shown in figure 1 [8].

**Design of Speed Control System**

The conventional PID controller has the characteristics of simple algorithm, good stability, high reliability, easy design and wide adaptation, is a kind of basic controller widely used in process control. It can obtain satisfactory control effect when control all kinds of linear invariant system, especially suitable for the controlled system where the parameters of controlled object are fixed and nonlinear [9]. However, the load of the controlled object is variable and the interference factors are complex in the industrial production process. To achieve satisfactory control effect, we need to adjust the parameters of PID online. Sometimes, because of the variability of these parameters, there are often no fixed mathematical models and rules that can be followed by [10]. The PID control system based on RBF neural network in this paper does not rely on the mathematical model determined by the shearer, and has good ability of self-learning and self-adjusting. At the same time, compared with the traditional fuzzy PID control system, the system has the advantages of small overshoot, higher control accuracy, faster response speed, stronger adaptability and robustness [11]. Its control block diagram is shown in figure 2.
Improvement of RBF Neural Network

RBF neural network is a kind of forward network with good performance. It has the characteristic of good approximating, global optimization abilities, simple structure and high training speed [12]. A RBF network structure with 3 hidden layers, as shown in figure 3.

![Figure 3. The structure diagram of RBF neural network](image)

In RBF networks, \( x = [x_j]^T \) is input of the network, the hidden layer output of the network is \( h = [h_j]^T \), \( h_j \) is the output of the neuron \( j \)th of the hidden layer,

\[
h_j = \exp \left( -\frac{\|x - c_j\|^2}{2 \cdot b_j^2} \right)
\]  

(4)

\[c = [c_{ij}] = \begin{bmatrix} c_{i1} & \cdots & c_{im} \\ \vdots & \ddots & \vdots \\ c_{ni} & \cdots & c_{nm} \end{bmatrix}\] is the \( j \)th neuron coordinate vector of the central point of the Gauss basis function of hidden layer, \( i = 1, 2, \cdots, m; \) \( b = [b_1, \cdots, b_m]^T \), \( b_j \) is width of Gauss basis function of \( j \)th neuron of hidden layer. RBF network weight value is \( w = [\omega_1, \cdots, \omega_m]^T \), network output is:

\[
y(t) = w^T \cdot h = \omega_1 \cdot h_1 + \omega_2 \cdot h_2 + \cdots + \omega_m \cdot h_m
\]  

(5)

The expression of Gauss function shows that the approximate error is not only related to the coordinates \( c_j \) and widths of the central points of the Gauss function \( c_j \) but also to the number of neurons in the hidden layer. The conventional RBF neural network has a certain number of hidden layer nodes and fixed network structure, the model uncertainties and time-varying parameters, it is difficult to achieve the identification of the global sense because of the uncertainties and time-varying parameters [13]. This paper uses an improved RBF neural network to realize adaptive...
adjustment of the number of hidden layer nodes, to make sure that RBF neural network is optimal \cite{14-16}. The algorithm flowchart is shown in figure 4.

![Algorithm Flowchart](image)

**Figure 4. The flow chart of improved k-means clustering algorithm**

In RBF network design, we should pay attention to the design of the sum value $c_j, b$ in the effective mapping range of network input. Otherwise, Gauss function cannot guarantee effective mapping, resulting in the failure of RBF network. In the RBF network approximation, the gradient descent method is an effective method to adjust the parameters. The error index of network approximation is:

$$E(k) = \frac{1}{2} \left( y(k) - y_m(k) \right)^2$$

(6)

Adjusting parameters as the following mode:

$$\Delta \omega_j(k) = \eta \left( y(k) - y_m(k) \right) j$$

$$\omega_j(k) = \omega_j(k-1) + \Delta \omega_j(k) + \alpha \Delta \omega_j(k-1)$$

$$\Delta b_j = \eta \left( y(k) - y_m(k) \right) \omega_j \frac{\| x - c_j \|^2}{b_j^2}$$

$$b_j(k) = b_j(k-1) + \Delta b_j + \alpha \Delta b_j(k-1)$$

$$\Delta c_{ji} = \eta \left( y(k) - y_m(k) \right) \omega_i \frac{\| x - c_{ji} \|^2}{b_j^2}$$

$$c_{ji}(k) = c_{ji}(k-1) + \Delta c_{ji} + \alpha \Delta c_{ji}(k-1)$$

Where: $\eta \in (0, 1)$ is learning rate, $\alpha \in (0, 1)$ is momentum factor.
PID Controller Parameters

In this paper, an incremental PID controller is used to make the output layer of the RBF neural network corresponding to the three adjustable parameters of the proportion, differential and integral of the PID controller. The optimal value of PID controller and the optimal control under current state can be achieved by adaptive adjustment of RBF neural network \[17\]. The control error of the system is \( e(k) = r(k) - y(k) \).

The input component of the PID controller is:

\[
\begin{align*}
  x(1) &= e(k) - e(k - 1) \\
  x(2) &= e(k) \\
  x(3) &= e(k) - 2e(k - 1) + e(k - 2)
\end{align*}
\]

The PID control algorithm is:

\[
\begin{align*}
  u(k) &= u(k - 1) + k_p(e(k) - e(k - 1)) + \\
  &+ k_i e(k) + k_d(e(k) - 2e(k - 1) + e(k - 2))
\end{align*}
\]

The quadratic performance index function:

\[
E(k) = \frac{1}{2} \left[ r(k) - y(k) \right]^2
\]

The online adjustment of the three parameters of the PID controller is carried out by the gradient descent method:

\[
\begin{align*}
  \Delta p &= -\eta \frac{\partial E}{\partial k_p} = -\eta \frac{\partial E}{\partial y} \frac{\partial y}{\partial u} \frac{\partial u}{\partial k_p} = \eta e(k) \frac{\partial y}{\partial u} x(1) \\
  \Delta i &= -\eta \frac{\partial E}{\partial k_i} = -\eta \frac{\partial E}{\partial y} \frac{\partial y}{\partial u} \frac{\partial u}{\partial k_i} = \eta e(k) \frac{\partial y}{\partial u} x(2) \\
  \Delta d &= -\eta \frac{\partial E}{\partial k_d} = -\eta \frac{\partial E}{\partial y} \frac{\partial y}{\partial u} \frac{\partial u}{\partial k_d} = \eta e(k) \frac{\partial y}{\partial u} x(3)
\end{align*}
\]

Where:

\[
\frac{\partial m}{\partial d} = \frac{\sum_{j=1}^{N} c_j x_j}{\sum_{j=1}^{N} c_j} \frac{\partial y}{\partial u} \frac{\partial u}{\partial k_p} (k) = \frac{\partial y(k)}{\partial u(k)}
\]

can be identified by neural network.

The Establishment of the Simulink Simulation Model of the Shearer

MATLAB language is powerful in numerical computation. Its Simulink is a software package for modeling, simulation and analysis of all kinds of dynamic systems. The whole simulation process is very simple, convenient and intuitive \[18\]. In order to test the control effect of the constant power speed regulation system of the electric traction shearer based on RBF neural network PID control, taking the domestic MG-750/1915-WD electric haulage shearer as the control object, the transfer function of the shearer traction mechanism is the model parameter is:

\[
G(s) = \frac{0.51s + 1}{(0.00156s^2 + 0.12)s},
\]

the model parameter are shown in table 1 \[19\]. According to the theoretical knowledge of RBF neural network PID control system and the constant power speed control system of shearer, the simulation model shown in figure 5 is established by Matlab/Simulink software. In order to show the superiority of this method, the traditional fuzzy control method is introduced in the model to make a comparison \[20\].
Table 1. Transfer function and model parameters

<table>
<thead>
<tr>
<th>Model parameters</th>
<th>The value of model parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>The transmission ratio of traction institutions</td>
<td>$K_1 = 0.008$</td>
</tr>
<tr>
<td>The power conversion coefficient of drum</td>
<td>$K_2 = 40 - 200$</td>
</tr>
<tr>
<td>The feedback coefficient of current transformer</td>
<td>$K_3 = 0.32 - 1.95V/A$</td>
</tr>
<tr>
<td>The scaling factor of sensor</td>
<td>$K_4 = 0.0028$</td>
</tr>
<tr>
<td>The model parameters of transfer function</td>
<td>$T_1 = 0.15s$, $T_2 = 0.00156s$</td>
</tr>
<tr>
<td>The inertia of motor</td>
<td>$T_i = 0.0135kgm^2$</td>
</tr>
<tr>
<td>The time constant of sensor</td>
<td>$T_e = 0.00215s$</td>
</tr>
</tbody>
</table>

**Figure 5. Simulation model**

**Simulation Results and Analysis**

The simulation experiment on the constant power control of the shearer based on the RBF neural network PID control and the traditional fuzzy control system is carried out by using Matlab/Simulink. After stable operation of the system for 1 s, the dynamic response curves of shearer traction speed (overload state and under load state) and cutting power with the change of coal and rock characteristics were obtained. The speed response curve and the power response curve are shown in figure 6.

(a) The response curves of speed in the state of overload
From the speed response curve, we can see that due to the increase of coal cutting impedance, the speed of the coal mining machine's decreasing because of overloading operation. When the coal cutting impedance is reduced, the cutting load of the shearer decreases, the speed increase because of under-load operation. So as to achieve the approximate cutting and constant power operation of the shearer. When haulage shearer is in the condition overload and under-load, RBF neural network control system has better performance than the traditional fuzzy, the faster response speed to the changes of coal cutting impedance, shorter adjustment time, small speed overshoot. The comparison of two kinds of control system is shown in Table 2.

<table>
<thead>
<tr>
<th>Overload condition</th>
<th>Performance index</th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overshoot time/s</td>
<td>Overshoot /(m/s)</td>
<td>Adjusting time/s</td>
</tr>
<tr>
<td>The traditional fuzzy control</td>
<td>1.52</td>
<td>0.49</td>
<td>2.9</td>
</tr>
<tr>
<td>RBF neural network control</td>
<td>1.25</td>
<td>0.3</td>
<td>2.2</td>
</tr>
</tbody>
</table>

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<tr>
<th>Under-load condition</th>
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<tbody>
<tr>
<td></td>
<td>Overshoot time/s</td>
<td>Overshoot /(m/s)</td>
<td>Adjusting time/s</td>
</tr>
<tr>
<td>The traditional fuzzy control</td>
<td>1.62</td>
<td>0.44</td>
<td>3.1</td>
</tr>
<tr>
<td>RBF neural network control</td>
<td>1.41</td>
<td>0.25</td>
<td>2.4</td>
</tr>
</tbody>
</table>

From figure 6-(c), we can know, in two different control methods of speed adjustment, the shearer motor always runs between two states: overload, under-load, but the constant power control system has better control effect based on RBF neural network PID control. This system has the advantages of smaller amplitude, short power overshoot time, smaller overshoot, faster response speed of to the properties of coal rock, which make it more reliable. The comparison results of the power regulation of the two control systems are shown in Table 3.
Table 3. Performances comparison of power regulation of two control systems

<table>
<thead>
<tr>
<th>Performances comparison of power regulation</th>
<th>Performance index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First overshoot time/s</td>
</tr>
<tr>
<td>The traditional fuzzy control</td>
<td>1.20</td>
</tr>
<tr>
<td>RBF neural network control</td>
<td>1.51</td>
</tr>
</tbody>
</table>

**Conclusion**

The performance of the electric haulage shearer's constant power speed control system based on the RBF neural network PID control is superior to the traditional fuzzy control system. By using the improved K-Means clustering algorithm, the control system realizes the adaptive adjustment of the number of hidden nodes in the RBF neural network, and ensures that the RBF neural network is the optimal. To make sure the control system is global optimal through the online tuning of the three coefficients of the PID controller. The control system has stronger adaptive ability, outstanding anti-interference ability and higher robustness, and is more sensitive to the changes of the characteristics of coal rock, which ensures higher accuracy control of shearer constant power speed control system and improves the efficiency of coal mining. By using the Simulink simulation analysis of two different control systems, the results show that the control system proposed in this paper is a more practical and stable adaptive control system for electric traction shearsers with constant power and speed regulation.

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**References**


