Research on Grading Method of Energy Efficiency Rating of Portal Crane

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Abstract. This paper combines the hoisting mechanism of the gantry crane, the oscillating mechanism and the luffing mechanism’s own operating characteristics and the physical model of its energy consumption. Through the multiple regression analysis method and the neural network model, the influencing factors of each energy consumption can be determined for each mechanism of the portal crane. The extent of the impact. Finally, the data set is obtained by the regression model and the neural network model simulation output, and the distribution of energy consumption values is obtained through the box line diagram to determine the energy efficiency level and range.

Introduction

At present, household appliances such as refrigerators, washing machines, and air conditioners have enforced energy consumption labels[1]. Compared with household appliances, due to the particularity of the crane's own operation, the friction loss is not easy to measure and many other technical problems, resulting in the long-term lack of energy efficiency detection classification methods and classification. This also sets new requirements for the study of its detection technology, classification methods and related standards. In the field of special equipment, the German VDI-4707 method, which has been put into use, evaluates the energy efficiency of the traction elevators in buildings, and provides corresponding theoretical basis for testing and certification[2]. Ke Yuhui's research first establishes energy efficiency indicators and establishes energy efficiency test methods from load, load ratio, running direction and distance, and summarizes and analyzes the data[3]. Wang Pengcheng et al.'s research discusses the specific application process and electrical connection method of power quality analyzer in elevator energy efficiency test[4]. Wang Shiqin's research introduced the concept of “standard elevator” model, and proposed the elevator energy efficiency coefficient and elevator standby power as energy efficiency evaluation parameters, and gave the mathematical model of elevator comprehensive energy efficiency coefficient[5]. However, for domestic high-energy equipment (such as cranes), there are few studies on energy efficiency levels, and relevant research is still in its infancy. Most of the research is considered from the perspectives of structural optimization, operational state optimization, and energy recovery[6][7][8]. In terms of energy consumption assessment, most of the research is mainly based on analytic hierarchy process and fuzzy comprehensive evaluation[9][10].

In summary, from the research field, the standardization research of crane energy consumption is in the initial stage, and there is a great research space. From the application field, the research on crane energy consumption is extremely necessary and practical, and it has a great economy benefits and social effects.
Energy Consumption Analysis of Hoisting Mechanism and Slewing Mechanism of Portal Crane

Physical Model of the Hoisting Mechanism

The lifting process of the crane is a shifting process, which can be divided into the starting phase, the uniform rising phase and the braking phase before reaching the set height. The hoisting mechanism realizes the lifting and lowering of the cargo by winding or releasing the wire rope in the winding. The brakes are used to realize that the cargo is stationary in the air when the hoisting mechanism stops working, and the forward and reverse rotation of the motor to achieve the ascent and descent of the cargo.

The movement diagram of the hoisting mechanism of the portal crane is shown in Figure 1.

\[
\begin{align*}
E &= \frac{1}{2} MV_t^2 + Mgh + E' \\
V_t^2 &= 2\bar{a}h
\end{align*}
\]

The consumed electric energy \( E \) is mainly converted into energy \( E' \) of kinetic energy and gravitational potential energy and friction loss. \( M \) is the total mass of the crane lifting, including the total mass of the supporting structure, the hook and the weight to be hoisted; \( V_t \) is the speed at which the weight is running smoothly, \( h \) is the lifting height of the weight; \( \bar{a} \) is the average acceleration of the variable acceleration process.

In order not to account for the calculation of the friction coefficient, the value of each variable is changed by one unit of physical quantity each time the value of the other variable remains unchanged. Among them, there is a clear relationship between mass and height and energy consumption. Therefore, we introduce a model of multiple regression analysis.

Establish Multiple Regression Equations

\[
E = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_3^2 + \epsilon
\]

Where \( \epsilon \) is a random error term, obeying \( \epsilon \sim N(0, \delta^2) \), that is, the random error obeys a normal distribution with a mean of 0 and a variance of \( \delta^2 \). \( \beta_0 \) is the regression constant term of the model correction, which has no practical significance. \( \beta_1, \beta_2, \beta_3 \) and \( \beta_4 \) are partial regression coefficients, respectively, indicating the value of the increase in energy consumption for each additional unit quantity when other physical quantities are constant.

Solving the above equation is to obtain the unknown parameter by reducing the difference between the response variable and the predicted value, specifically to minimize the sum of the squares of the residuals. This method is the least square method.

\[
E = -1.153 + 0.105x_1 + 0.175x_2 - 0.756x_3 - 0.375x_3^2
\]
Multiple Regression Test

After applying regression analysis to a model, further metrics are needed to verify whether it meets the assumptions of the regression model. The main reason is to test the credibility of the regression model. The overall test needs to be completed by F test.

### Table 1. F test.

<table>
<thead>
<tr>
<th></th>
<th>Square sum of dispersion</th>
<th>Degree of freedom</th>
<th>Mean square error</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>return</td>
<td>94,966</td>
<td>3</td>
<td>31.655</td>
<td>509.496</td>
</tr>
<tr>
<td>Residual</td>
<td>1.056</td>
<td>16</td>
<td>0.62</td>
<td></td>
</tr>
<tr>
<td>Sum</td>
<td>96.023</td>
<td>20</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It is known that the variable contributes significantly to the model.

The value range of $R^2$ is [0,1]. The larger the value of $R^2$, the better the goodness of fit of the model. The results of the goodness of fit test are shown in Table 2.

### Table 2. Goodness of Fit.

<table>
<thead>
<tr>
<th>Serial number</th>
<th>R</th>
<th>$R^2$</th>
<th>Adjustment$R^2$</th>
<th>Standard estimated error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.972</td>
<td>0.945</td>
<td>0.946</td>
<td>0.2492</td>
</tr>
</tbody>
</table>

Regression Model of the Slewing Mechanism

The regression equation of the gyroscopic mechanism is the same as the hoisting mechanism, and the regression model of the regression mechanism is obtained:

$$E = -4.266 + 0.074x_1 + 0.132x_2 - 0.965x_3 - 0.635x_3^2$$  \(4\)

As with the hoisting mechanism, the F test and the goodness of fit test are also performed.

### Energy Consumption Analysis of Portal Crane Luffing Mechanism

The variables involved in the operation of the luffing mechanism are: load mass, running speed and running distance. In order to obtain the contribution of the physical variable per unit to the total energy consumption during the operation of the luffing mechanism, the same multiple regression analysis method is used here to explore the significance of the partial regression coefficient. However, the actual operation found that the effect of the fitting is not very satisfactory, and the residual value of the residual is large, and the cause should be further analyzed.

After analysis, the main reason is that during the movement of the luffing mechanism, the center of gravity of the boom system has a vertical displacement, and in the actual measurement process, it is difficult to accurately measure the displacement of the center of gravity.

### Energy Consumption Analysis of Luffing Mechanism Based on BP Neural Network

In order to more fully reflect the energy consumption characteristics of the crane luffing mechanism during operation, select the characteristic flow during the operation of the luffing mechanism: weight, distance and speed as the input of the model, in the process of the luffing mechanism The total energy generated is taken as the output. Since the total operating energy consumption is determined by multiple variables, it may not form a specific functional relationship with one of the variables. Therefore, by means of the neural network method, the nonlinear correspondence between them is found through sample learning. The contribution rate of each characteristic variable to the energy consumption of the luffing mechanism reflects the energy consumption characteristics of its operation.

### Introduction of Data Interpolation Method

Due to the accuracy of the sensing and the limitations of the experimental conditions, a large amount of data cannot be measured in practice, in order to make the training results effective and
reliable. A method of data interpolation is introduced here to supplement or approximate the vacant portion of the discrete acquired data.

This paper introduces the cubic spline interpolation method. The basic idea is to use a smooth curve to fit the main points. The cubic spline interpolation constructs a piecewise function according to the given function table, and the constructed function is required to pass. Given a point and with continuous first-order, second-order derivatives. This makes it possible to extend the data set of the neural network.

Use the interp2 function in Matlab to do cubic spline interpolation. The data set can be expanded after interpolation, as shown in the following table. The experimental points that were originally interrupted now have multiple sets of values. The value after data interpolation is not necessarily true measured data, but it makes the original sparse, discrete points become more dense, and it is inevitable that some noise may be added, which improves the generalization and is not easy to lead to sparse Oscillating back and forth in space. After the interpolation is completed, the original 30 sets of measured data are expanded to 90 sets.

<table>
<thead>
<tr>
<th>Serial number</th>
<th>weight (t)</th>
<th>distance (m)</th>
<th>speed (m/s)</th>
<th>Total energy consumption (wh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.7</td>
<td>80.4</td>
<td>2.5</td>
<td>0.7564</td>
</tr>
<tr>
<td>2</td>
<td>12.7</td>
<td>85.7</td>
<td>2.5</td>
<td>0.8343</td>
</tr>
<tr>
<td>3</td>
<td>14.7</td>
<td>91.8</td>
<td>2.5</td>
<td>0.9237</td>
</tr>
<tr>
<td>4</td>
<td>16.5</td>
<td>97.1</td>
<td>2.5</td>
<td>1.0064</td>
</tr>
<tr>
<td>5</td>
<td>18.9</td>
<td>79.9</td>
<td>1.41</td>
<td>0.7602</td>
</tr>
<tr>
<td>6</td>
<td>18.7</td>
<td>80</td>
<td>0.94</td>
<td>0.6885</td>
</tr>
</tbody>
</table>

**Neural Network Operation Result**

According to the foregoing, the load weight, the running distance, and the variable speed are used as the input of the neural network model, and the total energy consumption generated by the luffing mechanism operation process is taken as the output. The value of the BP three-layer neural network is obtained, and finally the contribution of a single physical quantity to the total energy consumption is obtained.

In the case of fewer data samples, the network is not very predictable. When the neural network is interpolated by data, the generalization and prediction accuracy are improved. Figure 2 shows the model convergence.

![Figure 2. Error graph.](image)

**Gante Crane Energy Consumption Rating**

Through the discussion in the above chapters, the corresponding energy consumption caused by the change of the physical quantity of each operating mechanism of the gantry crane during operation is obtained. Our ultimate goal is to obtain the same type of load state and the classification of the different cranes.

In order to obtain the energy distribution of the gantry crane currently put into production, the paper simulates the output data through the obtained regression model and neural network model.
The definition domain of the function is determined by the actual working conditions. Through MATLAB output 90 sets of hoisting mechanism energy consumption, 90 sets of luffing mechanism energy consumption, 90 sets of slewing mechanism energy consumption, and then draw on the principle of box plot, through the number of points to reflect the overall energy distribution.

<table>
<thead>
<tr>
<th></th>
<th>Lifting energy consumption</th>
<th>Variable amplitude energy consumption</th>
<th>Variable amplitude energy consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper quartile</td>
<td>88.35</td>
<td>6.84</td>
<td>8.04</td>
</tr>
<tr>
<td>median</td>
<td>82.65</td>
<td>6</td>
<td>7.23</td>
</tr>
<tr>
<td>Lower quartile</td>
<td>75.95</td>
<td>5.01</td>
<td>6.48</td>
</tr>
</tbody>
</table>

From this, we can get the following conclusions: the unit energy consumption is greater than the upper quantile is four levels; the unit energy consumption is between the upper quantile and the median is three levels; the unit energy consumption is in the median and the lower four points The number of digits is two; the unit energy consumption is less than the lower quartile.

After obtaining the energy consumption grading and scope of different organizations, the energy consumption rating of the whole machine is determined according to the energy consumption classification of each institution. Because in the actual production and use process, the energy consumed by different organizations is different, and the energy consumption of each organization is independent of each other, we can get the proportion of energy consumption of different institutions, as shown in Table 4.

<table>
<thead>
<tr>
<th>project</th>
<th>Lifting mechanism</th>
<th>Luffing mechanism</th>
<th>Slewing mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy consumption ratio</td>
<td>0.8285</td>
<td>0.1323</td>
<td>0.0392</td>
</tr>
</tbody>
</table>

According to the national regulations on energy efficiency, the crane energy efficiency rating is divided into five levels:

(1) Energy efficiency level indicates that the energy efficiency of the product has reached the international advanced level and the energy consumption is the lowest;

(2) Energy efficiency level 2 indicates that the product has lower energy efficiency and is more energy efficient;

(3) Energy efficiency level 3 indicates that the product energy efficiency is the average level of the Chinese market;

(4) Energy efficiency level 4 indicates that the energy efficiency of the product is lower than the market average;

(5) Energy efficiency level 5 is the product market access indicator, and products below this level are not allowed to be produced and sold.

This article refers to the "General Rules for the Preparation of Energy Efficiency Indicators for Energy-Efficient Products" and "Energy Efficiency Ratings and Assessment Methods for Transportation Products". The energy efficiency level is 5% of the energy efficiency of the domestic market products, and the energy efficiency level is 5% to 30% of the energy efficiency of the domestic market products. The energy efficiency level is 30%~55% of the energy efficiency of the domestic market products, the energy efficiency level 4 is 55%~80% of the domestic market products, and the energy efficiency level 5 is 80%~100% of the energy efficiency of the domestic market products, which is lower than the access limit. Cranes are not allowed to enter the market.

Therefore, the article scores 4 points at the institutional level, 3 points for the organization's second level, 2 points for the organization's third level, and 1 point for the organization's fourth level. Combined with the energy consumption ratio of each institution, the score of the energy consumption of the whole machine can be obtained. The range of energy efficiency ratings is shown in Table 5.
Table 5. Energy efficiency interval.

<table>
<thead>
<tr>
<th>Serial number</th>
<th>Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(3.49,4]</td>
</tr>
<tr>
<td>2</td>
<td>(2.66,3.49]</td>
</tr>
<tr>
<td>3</td>
<td>(1.83,2.66]</td>
</tr>
<tr>
<td>4</td>
<td>(1.54,1.83]</td>
</tr>
<tr>
<td>5</td>
<td>[1,1.54]</td>
</tr>
</tbody>
</table>

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References


