Research on the Method of Identifying the Indicator Diagram of the Sucker Rod Pumping Unit

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Abstract

In the production process of oil well,using indicator diagram can accurately diagnose out of the working conditions of sucker rod pump in the underground several kilometers, extracting the feature values of indicator diagrams accurately is the key link in the process of identification of indicator diagrams. This paper firstly uses Gibbs wave equation to transform the ground indicator diagram into underground pump indicator diagrams, then combined with geometric features values extraction method and grid feature values extraction method to extract the feature values of indicator diagrams, finally, using Bp network and Euclidean distance classification to recognize indicator diagrams. the result shows that compared with the single geometric feature extraction method and the grid feature extraction method,for the similar indicator diagrams,the method has higher correct recognition rate and the effect is more stable, it provides an effective way to realize the fault diagnosis of sucker rod pumping well and the construction of digital oil field.

Keywords

Indicator diagram, identification, feature extraction.

1. Introduction

In the field of oil production in China, the sucker rod pump is the most widely used method, which accounts for more than 90% of the total number of artificial lift-wells [1]. Because the oil-well pump is located in thousands of meters deep underground, and affected by the wax, gas and water, it is more prone to failure and very difficult to obtain its working condition directly to work in this very complex situations, the current common method to get its working condition is through the analysis of indicator diagram of pumping unit which is drawn with the displacement of sucker rod as abscissa and its load as ordinate, as shown in Figure1.

At present, most oil fields still adopt the way of artificial periodic inspection to check its working condition, From the fault occurrence to find fault, and then identify the fault, this process extends the stop time, which reduces the pumping efficiency. With the progress of science and technology, this way of fault diagnosis seriously hinders the development of oil fields to digital and intelligent, How to use computer to recognize automatically instead of artificial recognition is one of the main research contents of petroleum engineering scholars at home and abroad at present.

In the identification process of indicator diagrams, whether the extracted feature values can accurately represent the main features of the power diagram, plays a decisive role for the accurate identification of indicator diagrams. At present, for the extracting of the feature values of indicator diagrams, geometrical extracting method and grid feature extracting method are widely used. Such as the literature [3], It uses all the data points of the indicator diagram as feature values, and compares them with benchmark, this method contains includes comprehensive information. However, due to every indicator diagram contains hundreds of data points, the calculation will be very large to use this method. In literature [4], geometrical feature values, such as area, perimeter, Maximum load, Minimum load, are used as the feature values of indicator diagrams, although this method can reduce the amount of calculation, but it can only be used to diagnose indicator diagrams that have obvious features. In literature [5], the indicator diagram is is broken down into a number of grids that have the same shape and size, and assign value to every grid based on its location, then calculate its gray average, gray variance, gray deflection, gray keenness, gray energy and gray entropy, these gray values are used as the features of the indicator diagram, but it also can only be used to diagnose indicator diagrams that have obvious features. To this end, this paper presents the combination of the geometrical extracting method and grid feature extracting method, it can not only reduce the dimension of feature vectors, but also accurately reflect the details of the indicator diagram.

2. The establishment of wave equation

The underground pump indicator diagram can directly reflect the working condition of the pump, but it is difficult to obtain directly due to the pump is located in the underground thousands of meters, therefore, it is need to establish the sucker rod wave equation. In 1966, the American shell company of Gibbs and S.G firstly established the sucker rod wave equation, it is the famous Gibbs wave equation [6], the equation is as follows:

$$\frac{\partial^2 u(x,t)}{\partial t^2} = a^2 \frac{\partial^2 u(x,t)}{\partial x^2} - c\frac{\partial u(x,t)}{\partial t} \tag{1}$$

In (1), $u(x,t)$ - the displacement of the cross section of x meters depth of sucker rod at the time of t, a - the propagation velocity of stress on the sucker rod string, c - damping coefficient.

The Fourier series representation of the upper and lower boundary conditions and the initial conditions are as follows:

$$\begin{cases} f(x,t)|_{x=L} = D(t) = \dfrac{\sigma_0}{2} + \sum\limits_{n=1}^{n}(\sigma_n \cos n\omega t + \tau_n \sin n\omega t) \\ u(x,t)|_{x=0} = U(t) = \dfrac{v_0}{2} + \sum\limits_{n=1}^{n}(v_n \cos n\omega t + \delta_n \sin n\omega t) \\ u(x,t)|_{t=0} = 0 \\ \dfrac{\partial u(x,t)}{\partial t}|_{t=0} = 0 \end{cases} \tag{2}$$

In (2), $f(x,t)$ - the load of the plunger at displacement x and at time t, $D(t)$ - the displacement of suspension point at time t, $U(t)$ - the displacement of polish rod at time t, σ_n, τ_n, v_n, δ_n - Fourier coefficients.

By means of separation of variables and Fourier transforms can calculate $u(x,t)$:

$$u(x,t) = \frac{\sigma_0}{2EA_r}x + \frac{v_0}{2} + \sum_{n=1}^{N}(O_n(x)\cos nwt + pn(x)\sin nwt) \tag{3}$$

According to Hooke's law, can obtain $f(x,t)$:

$$f(x,t) = EA_r\frac{\partial u(x,t)}{\partial x} = \frac{\delta_0}{2} + EA_r\sum_{n=1}^{N}(O'(x)\cos nwt + P'(x)\sin nwt) \tag{4}$$

In (4),

$$O_n(x) = (k_n ch\beta_n x + \delta_n sh\beta_n x)\sin\alpha_n x + (u_n ch\beta_n x + v_n sh\beta_n x)\cos\alpha_n x \tag{5}$$

$$P_n(x) = (k_n ch\beta_n x + \delta_n ch\beta_n x)\cos\alpha_n x + (\mu_n ch\beta_n x + v_n sh\beta_n x)\sin\alpha_n x \tag{6}$$

$$O'(x) = [\frac{\tau_n}{EA_r} sh\beta_n x + (\delta_n\beta_n - v_n\alpha_n) ch\beta_n x]\sin\alpha_n x + [\frac{\tau_n}{EA_r} ch\beta_n x + (v_n\beta_n - \delta_n\alpha_n) sh\beta_n x]\cos\alpha_n x \tag{7}$$

$$P'(x) = [\frac{\tau_n}{EA_r} ch\beta_n x + (\delta_n\beta_n - v_n\alpha_n) sh\beta_n x]\cos\alpha_n x + [\frac{\tau_n}{EA_r} sh\beta_n x + (v_n\beta_n - \delta_n\alpha_n) ch\beta_n x]\sin\alpha_n x \tag{8}$$

$$k_n = \frac{\delta_n\alpha_n + \tau_n\beta_n}{EA_r(\alpha_n^2 + \beta_n^2)} \tag{9}$$

$$\mu_n = \frac{\delta_n\beta_n - \tau_n\alpha_n}{EA_r(\alpha_n^2 + \beta n^2)} \tag{10}$$

According to the solution of the wave equation and its boundary conditions, the ground indicator diagram can be converted to the underground pump indicator diagram.

3. Feature value extraction

As the indicator diagram changes varied, the diagram is different greatly in spite of the same faults, in order to make the extracted characteristic value can represent the true shape of the figure, and we take geometric method and grid method to extract the feature value.

3.1 Feature extraction of geometric method

The feature extraction of the geometric method is to obtain the characteristic value directly or do some simple geometric operations to obtain, this method is easy to operate and the calculation amount is small. Here, we extract the following 11 characteristic values.

Table 1 geometric characteristic value

Standing point of upstroke (A)	End point of stroke deformation (B)	End point of upstroke (C)	End point of down stroke deformation (D)
Left upper part area (A1)	Right upper part area (A2)	Left lower part area (A3)	Right lower part area (A4)
Maximum load (Fmax)	Minimum load (Fmin)	Centroid (G)	

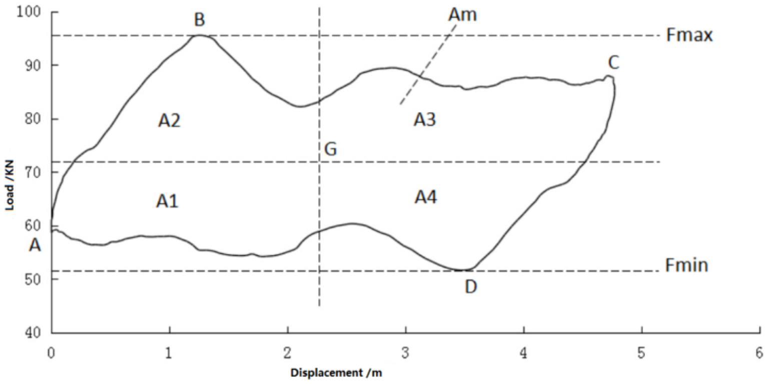

Fig. 1 geometry characteristic values

3.2 Feature extraction of grid method

Grid method of feature extraction is to divide the indicator diagram into some grids[7], as shown in the figure below, assign 1 for the grids which are crossed by the indicator diagram's outline, take these grids as the benchmark, if the grids are outside the indicator diagram's outline, theirs values minus 1 each away from a grid, if the grids are inside the indicator diagram's outline, theirs values plus 1 each away from a grid, then calculate its gray average, gray variance, gray deflection, gray keenness, gray energy and gray entropy, and take them as the feature values.

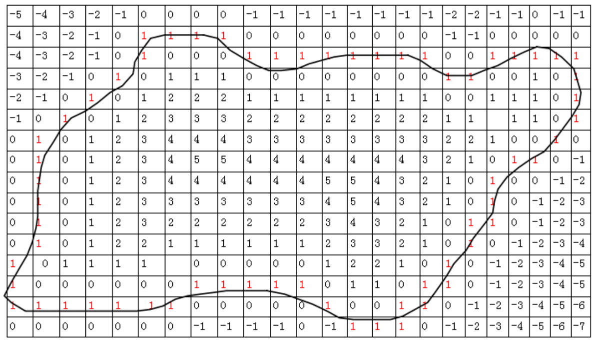

Fig. 2 grid characteristic values

Specific characteristic values are calculated as follows:

Gray average: $$f_1 = \bar{g} = \sum_{r=1}^{R} r \cdot p(r) \tag{11}$$

Gray variance: $$f_2 = \sigma^2 = \sum_{r=1}^{R} (r-\bar{g})^2 \cdot p(r) \tag{12}$$

Gray deflection: $$f_3 = S = \frac{1}{\sigma^3} \sum_{r=1}^{R} (r-g)^3 \cdot p(r) \tag{13}$$

Gray keenness: $$f_4 = P = \frac{1}{\sigma^4} \sum_{r=1}^{R} (r-\bar{g})^4 \cdot p(r) \tag{14}$$

Gray energy: $$f_5 = E = \sum_{r=1}^{R} [p(r)]^2 \tag{15}$$

Gray entropy: $$f_6 = T = -\sum_{r=1}^{R} [1-p(r)] \cdot \lg[1-p(r)] \tag{16}$$

4. BP neural network identification

Artificial neural network is established according to the neural network, and it is a mathematical model of information processing which is similar to the structure of the synaptic connection of the brain. The most representative is the BP neural network model developed in recent years, it is through the error back propagation to change the interconnected relationship between nodes to make minimum the error sum of squares which is also called the steepest descent method, because of its simple, easy operation, small amount of calculation, making it become the most mature training method currently.

The fault diagnosis is realized by three layer network, and the input layer of the network is 17 characteristic values, Implicit layer selects the function of Sigmoid for internal learning and processing, The number of output nodes is set to 4. In the experiment, we selected 500 figures of a field map data as the training data, the training results as shown in figure 3.

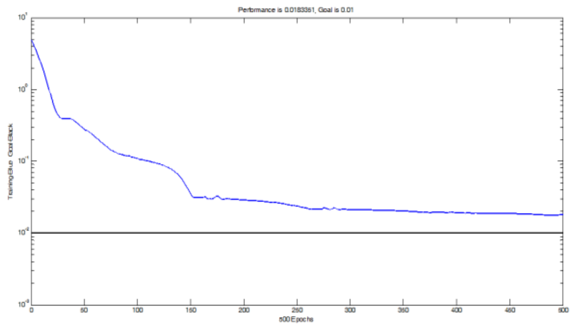

Fig. 3 training results

After the network training, select some data to test, and compare with the geometric feature extraction method and the grid value method, the results are shown in table 2.

Table 2 Diagnostic results

Method	Output result				Diagnostic results	Correct result
geometric method	0.698 3	0.743 4	0.296 2	0.891 4	normal	normal
grid method	0.251 2	0.643 3	0.421 7	0.902 8	normal	normal
Combining method	0.256 7	0.223 6	0.326 7	0.913 3	normal	normal
Geometric method	0.420 3	0.332 0	0.457 2	0.735 0	normal	Touch the pump
grid method	0.525 1	0.717 2	0.348 3	0.881 4	normal	Touch the pump
Combining method	0.424 3	0.355 5	0.710 7	0.510 1	Touch the pump	Touch the pump
geometric method	0.565 3	0.881 9	0.890 1	0.212 0	Insufficient supply of liquid	Insufficient supply of liquid
grid method	0.898 7	0.624 8	0.102 9	0.610 2	Gas effect	Insufficient supply of liquid
Combining method	0.151 0	0.941 2	0.512 0	0.121 9	Insufficient supply of liquid	Insufficient supply of liquid
geometric method	0.156 6	0.854 1	0.828 5	0.798 7	Insufficient supply of liquid	Gas effect
grid method	0.612 3	0.819 8	0.745 6	0.216 9	Insufficient supply of liquid	Gas effect
Combining method	0.944 4	0.212 0	0.151 4	0.331 0	Gas effect	Gas effect

As can be seen from the table 2 that the improved feature extraction method is more accurate than the geometric method and the grid method, at the same time, the output of the improved feature extraction method is more close to the ideal output.

5. Concluding remarks

This paper proposes the feature extraction method of the combination of geometric method and grid method, the practical tests show that it can reduces the dimension of feature vectors, and improves the accuracy of the identification of the indicator diagram. Using computer technology to apply it to oil field production can realize the real-time monitoring and real-time diagnosis of the oil well production condition.

Reference

[1] Li Jingyuan, Chen Guochun, Li Zifeng. Filtering Technology in the Diagnosis of Sucker Rod Pump Pumping System [J]. Acta Petrolei Sinica, 2010, 31(1):144-147.

[2] Li Zhaomin, Lin Riyi. The Rod Pumping System Efficiency Analysis and Optimal Design of Swabbing Parameter [J]. Acta Petrolei Sinica, 2005, 26(5):102-106.

[3] Gao Yonglinag, Tan Chaodong, Zhao Haitao. The Research and Application of Neural Network Identification Method of Pumping Well Dynamometer [J]. Petrochemical Engineering, 2008, (8):51-53.

[4] Liang Hua, Li Mingchuan. Accurate extraction of valve opening and closing points based on the physical meaning of surface dynamometer card [J]. Petroleum Exploration and Development, 2011, 38(1):109-115.

[5] Zeng Jing, Li Mingchuan. Optimization of Diagnosis Based on Neural Network [J]. Control Engineering of China, 2009, 16(2):111-113.

[6] S.G.Gibbs ,A. B.Neely. Computer Diagnosis of Down-hole Conditions in Sucker Rod Pumping Wells [J].Journal of petroleum technology, 1966(1):91-98.

[7] H Chang,Y Zhang, L Chen.An Applied Thermodynamic Method for Correction of TDC in the Indicator Diagram and Its Experimenta1 Confirmation [J]. App1ied Therma1 Engineering, 2004, 25 (5):759-768.