Research on Fault Diagnosis of Oil Pumping Machine based on Wavelet Transform

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Abstract. The fault diagnosis approach of pumping machine based on wavelet transform is proposed. The Mallat algorithm is employed to extract the feature components from the measured electric power figure, the periodic signal of the oil pumping machine as well as the vibration signals of electric machine and the sucker rob can be extracted. Compared these signals with the actual signals, the fault diagnosis information can be obtained, and the fault database can be built. Employing this approach to the running oil pumping machines, the simulation results show that this approach can extract the fault information correctly.

Introduction

In the mechanical oil extraction, the rod pumping is the predominant technique. If there is a way to grasp the working condition of the rod Pumping system promptly and accurately, diagnose problem which the oil well exists, establish the reasonable technical measure, makes the oil well restore the regular production promptly, and enhances the work efficiency and the oil well output.

The application of t indicator diagram is widely used in fault analysis of the pumping unit [1-3]. However, once the down-hole working conditions are too complicated to distinguish, this method is hard to diagnose the faults [4]. In this paper, an approach of extracting the pumping oil machine fault information from the electrical parameters of the oil wells by employing wavelet analysis method is put forward, and a fault database based on the information is built. The simulation results show that the extracted information of the working conditions is identified to the real working conditions.

Concepts of wavelet transform

Wavelet transform includes continuous wavelet transform (CWT), discrete wavelet transform (DWT) and wavelet series transform (WST).

Suppose that t denotes the time, $\psi(t)$ and $\widehat{\psi}(t)$ are the mother wavelet and its dual, respectively, and $\psi(t)$ must satisfy the admission condition, suppose $f(t) \in L^2(R)$, its CWT is defined as

$$W(f,a,b) = \frac{1}{\sqrt{|a|}} \int_{-\infty}^{+\infty} f(t) \psi^*(\frac{t-b}{a}) dt \tag{1}$$

with

$$\psi_{a,b}(t) = \frac{1}{\sqrt{|a|}} \psi(\frac{t-b}{a}) \tag{2}$$

$$\int_{-\infty}^{+\infty} \frac{|\hat{\psi}(\omega)|}{|\omega|} d\omega < \infty \tag{3}$$

Where $\psi_{a,b}$ —Continuous wavelet base, which is a family obtained by extending and parallel shifting the basic wavelet $\psi(t)$

a—Scale or frequency parameter
b—Shifting parameter
ˆ — Fourier transform of a function

Straightforward Mallat algorithm

Mallat algorithm is implemented by the Quadrature Mirror Filter (QMF), which decomposes and reconstructs the processed signal, and makes more and more detail resolution be gained The technology of QMF ensures the complete reconstruction. Its core is multi-resolution analysis, and the decomposition and reconstruction of the signal can be implemented without knowing the structures of the scale function and the wavelet function. It is called a fast algorithm of DWT.The expression of the decomposition of the Mallatalgorithm is:

$$\begin{cases} A_i = \sum_{k=-\infty}^{+\infty} c_{j,k}\varphi_{j,k} \\ D_i = \sum_{k=-\infty}^{+\infty} d_{j,k}\psi_{j,k} \end{cases} \quad (4)$$

As shown in Eq. set (4), for one step DWT to sequence $x[n]$ whose length is N, filtered by two filters with a length of L, the multiplication complexity needed is $2NL$ and the addition complexity is $2N(L-1)$, because there is a downsample of the signal in every step WT.

ψ is wavelet function, φ is the scaling function, at the 2^j factor, $c_{j,k}$ is the low frequency coefficient, $d_{j,k}$ is high frequency coefficient, then A_i, D_i is define as:

$$A_i = A_{i+1} + D_{i+1} \quad (5)$$

Then $f(t)$ can be defined as:

$$f(t) = A_n + D_n + D_{n-1} + \cdots + D_2 + D_1 \quad (6)$$

FFT Algorithm

The discrete Fourier transform (DFT) of a complex sequence $x(n)$ is an N-point complex sequence $X(k)$,defined as

$$Xe^{(j\omega t)} = N^{-1}\sum_{t=0}^{\infty} x(t)e^{i\omega t} \quad (7)$$

The fast Fourier transform (FFT) algorithm, which was firstly proposed by Gauss, and rediscovered by Cooley and Tukey[5], processes the input sequence in $\log_2 N$ stages to compute an N-point DFT, with each stage containing $N/2$ butterflies.

Fault feature extraction algorithm of Beam-Pump Unit electrical parameters based on Mallat algorithm

Motor as the power source of the pumping unit system, the energy changes in the input side of the pumping unit system, including the motor, reducer, the ground mechanical structure, the load, the underground conditions, etc.. Because the energy change of the underground reservoir is slow and the pumping unit is stable in a short time, it can be considered as a stationary signal for the signal of the electrical parameters of the pumping unit for a period of time. But in order to achieve the working information of the pumping unit, usually single stroke electric power of pumping unit is analyzed. Due to the influnce of the pumping unit operating characteristics and the downhole situation, different stages of electrical signals present corresponding signal characteristics. Then, the electric parameter signal is considered as a non stationary signal processing.

Although electric parameter signal is formed by all kinds of mixed signal, all kinds of signals has their time-frequency distribution characteristics. Through analyzing the electrical parameters of the pumping unit, the signals can be extracted as follows:

(1) Motor signal: motor in the operation of the process will produce the electrical signal noise due to belt aging or other reasons, belong to high frequency vibration.

(2) The sucker rod signal: the vibration of the sucker rod with the inertia vibration of the sucker rod and the load mutation caused by the sudden load change of the sucker rod in the upstream stage of the sucker rod, belong to the intermediate frequency signal.

(3) Periodic signal: the trend of the single cycle electric parameter curve, belongs to the low frequency signal.

The algorithm steps are as follows

Step 1: set the wavelet transform order;

Step2 : extract the signals from the pumping electrical power curve using the Mallat algorithm;

Step3 : extract the motor vibration signal;

Step4 : extract the sucker rod vibration signal;

Step5 : transform the sucker rod vibration signal using FFT;

Step6 : classify these signals

Step7 : bulid the database of these Characteristic signal.

Simulation

The simulation oil well is X109X102.The wavelet transform order is 3, the measured power figure of beam pumping unit and the decomposition diagram using Mallat algorithm are showed as figure 1.

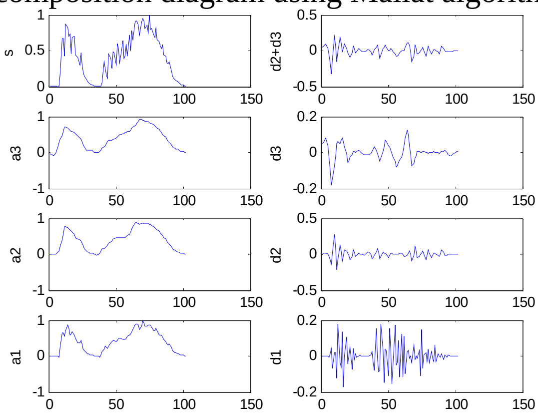

Fig. 1 Measured power figure of beam pumping unit and Mallat waveform figures

The sampling frequency of the electric parameter signal is 4*HZ*. d1 is the high frequency part of the reconstruction of wavelet transform, a1 is the low frequency part of the reconstruction of wavelet transform.From fig. 1, we can see that the moter signal can be extracted at the first order. The second wavelet transform can extract the sucker rod signal, but the low frequency part of the reconstruction of wavelet transform a2 has sucker rob signal. The third wavelet transform can extract the sucker rod signal completely. Then a3 singal represents the period signal. The d2+d3 singal is transformed by FFT, the figure of the energy distribution of each frequency band is showed as fig. 2.

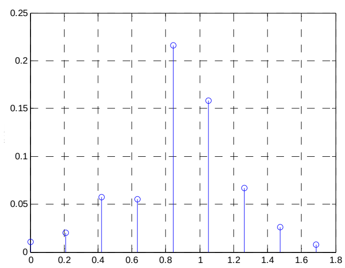

Fig. 2 the energy distribution of each frequency band

Then the signals information can be calculated.

The sucker rod signal: Amplitude $A_r = 0.2706$; Vibration frequency $f_r = 0.8421$; Damping ratio $\xi = 0.1160$.

The moter vibration signal: maximum amplitude $A_m = 0.1756$. The moter vibration is abnormal by analyzing these parameters. These parameters will be input in the database.

the analysis results six pumping wells using the proposed approach is showed in table 1.

Table 1 Analysis database

Number of oil wells	Sucker rod parameters			Moter parameters	symptom
	A_r	f_r	ξ	A_m	
X109X102	0.2706	0.8421	0.1160	0.1756	Moter is abnormal
DXX109_65	0.1627	0.4324	0.0593	0.2104	Moter is abnormal
Y28X4	0.0587	0.8421	0.0252	0.0725	Sucker rod is abnormal
DXX109CX134	0.1087	0.7619	0.0850	0.0725	Normal well
Y1X32	0.4222	0.8000	0.2382	0.2707	Sucker rod and moter are all abnormal
DXY11X107	0.2208	0.5517	0.0460	0.0267	Sucker rod is abnormal

Summary

In this paper, a new method of fault extraction based on wavelet Mallat algorithm is proposed. The method has the following advantages: first of all, the signal of the pumping unit, the motor oscillation signal and the pumping rod oscillation signal can be effectively extracted by wavelet decomposition of the signal. Secondly, the electric parameters which can accurately reflect the pumping unit working condition are actually measured, the extracted signals from the measured electric parameters is consistent with the actual down-hole working conditions. At present, the fault information extraction method based on electrical parameters is still on the primary stage. With the further research, the fault information is extracted, and the accuracy of the fault diagnosis of the pumping unit is effectively improved.

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