Journal of Petroleum Science and Engineering 160 (2018) 285–301

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

journal homepage: www.elsevier.com/locate/petrol

A novel prediction method for down-hole working conditions of the beam pumping unit based on 8-directions chain codes and online sequential extreme learning machine

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ARTICLE INFO

Keywords:
Beam pumping unit
Working conditions prediction
Time series analysis
8-Directions chain codes
OS-ELM
Grey interval relational degree

ABSTRACT

In the oilfield operation, the beam pumping unit is a very important artificial lift method. As the down-hole parts work at hundred and thousand meters underground, they are hard to be found immediately when failures come out. If we can predict down-hole working conditions and master its continuous operation states in time, great improvement of the oil well production will be developed. In this paper, a novel down-hole working conditions prediction method for the beam pumping unit based on the chaos time series prediction is proposed. First, curve contour of the dynamometer card is redrawn by 8-directions chain codes, and then eight feature vectors are extracted to construct eight feature vector time series; then, the online sequential extreme learning machine (OS-ELM) method is used to build the prediction model, which can realize fast updating with dynamic work condition changes; finally, the grey interval relational degree between the predicted feature vectors and feature vectors of each fault type is calculated to determine the predicted fault type. Actual production data of an oil well are used for example verification, and both online diagnosis and offline diagnosis illustrate the effectiveness of the method.

1. Introduction

The beam pumping unit is a main artificial lift method for oil production in worldwide oilfields; the sucker rod has an up and down movement driven by the motor through mechanical parts, and pulls oil liquids to the ground. A typical structure diagram of the beam pumping unit is shown in Fig. 1.

The beam pumping unit is composed by several parts, such as: motor, belt pulley-gear box, four-bar linkage, sucker rod, pump, oil tube, casing, etc.; in which, the pump is an indispensable part which is working in the oil fluids, composed by pump cylinder, plunger, travelling valve, standing valve, etc. As the sucker rod, pump, oil tube, casing and some other parts are working at hundred and thousand meters underground, some problems of harsh environment, complex working condition, wear, corrosion, mechanical fatigue and function failure make the down-hole part of the system have more hidden faults and stronger uncertainty. At present, there are some typical down-hole fault types at the oilfield production, such as: ”insufficient liquid supply”, ”gas interference”, ”parted rod”, ”oil of high viscidity”, ”leaking of the travelling valve”, ”leaking of the standing valve”, ”pump bumping (upstroke)”, ”pump bumping (downstroke)”, ”sand production”, ”piston goes outside of the cylinder”, etc. Different failure degrees have different influences to the beam pumping unit, which may lead to reduction of production, high energy cost, maintenance of oil well, shut-off of oil well and other production problems.

In actual oilfield production, the dynamometer card is commonly used to analyze down-hole working conditions. It is a two-dimensional curve constituted by ”displacement”-”load” data when the sucker rod's displacement is changing in a complete cycle; the data is collected by some specific data acquisition equipment installed at the suspension point of the ”Horse head”. For analysis of the dynamometer card, the traditional method is as follows: first, the data is collected by operation workers at production site, and then artificial recognition of them is completed by engineers at the management office, and finally production measures are given by the manager according to the artificial recognition results. Now, along with the high-speed development of computer information technology and increasing requirement of advanced technology in oil production, the intelligent analysis method based on the computer has been paid more and more attention to. A self-organize competition neural network based on the unsupervised learning mode

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https://doi.org/10.1016/j.petrol.2017.10.052
Received 24 April 2017; Received in revised form 18 August 2017; Accepted 18 October 2017
Available online 27 October 2017
0920-4105/

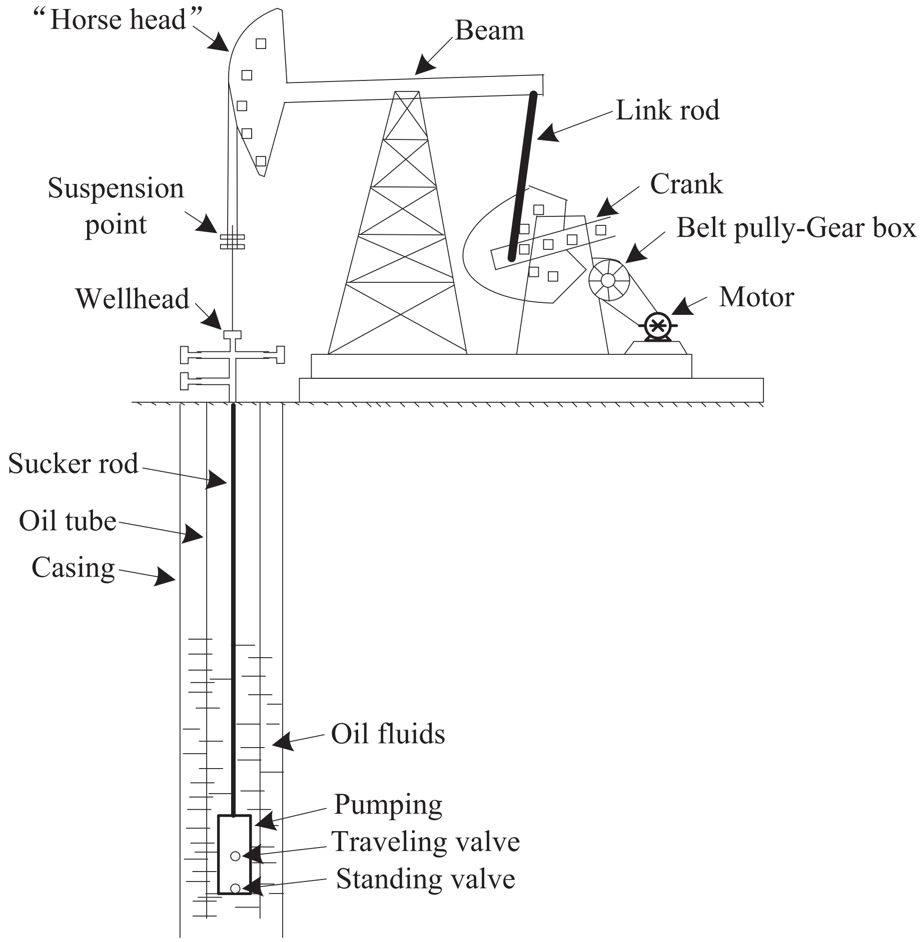

Fig. 1. A typical structure diagram of the beam pumping unit.

was proposed for fault classification of the dynamometer card, which can avoid the generation of local optimal solution at some level (Xu et al., 2007). The artificial neural network was used for pattern recognition of the down-hole dynamometer card of sucker-rod pumping wells (Souza et al., 2009). A fault diagnosis method for sucker-rod pumping wells based on wavelet decomposition and RBF neural network was proposed in (Wu et al., 2011). In (Li et al., 2013a), a fault diagnosis method for sucker-rod pumping wells using the curve moment and the PSO-SVM method was proposed, the invariant moment was extracted as input vector of the diagnosis model and the PSO-SVM model was used to realize classification of the down-hole failure. SVM based method was used to realize computer diagnosis for down-hole working conditions of the submersible reciprocating pumping system (Yu et al., 2013). Multiple fault diagnosis of down-hole conditions of sucker-rod pumping wells was focused on and a multiple fault diagnosis method based on Freeman chain code and designated component analysis was proposed in (Li et al., 2013b). Li et al. (2013c) proposed a dynamic clustering based diagnosis method and built a model using improved fuzzy ISODATA method. Li et al. (2015a) proposed a fault diagnosis method for down-hole conditions of sucker-rod pumping wells based on FBH-SC clustering algorithm, which used an unsupervised learning mode and did not rely on training data. A novel down-hole working conditions diagnosis method for sucker-rod pumping wells was proposed in (Reges et al., 2015), and it analyzed curves between the opening point and the closing point of valve in down-hole pump dynamometer card which were used for classification, and then built a Mamdani fuzzy inference system for 16 down-hole working conditions. In (Gao et al., 2015), automatic identification of down-hole pump dynamometer card was realized, using extreme learning machine (ELM) method.

According to current researches, for down-hole working conditions diagnosis of the beam pumping unit, they mainly aim at state evaluation and positioning when down-hole working conditions have already appeared, but rarely involve prediction of them. In actual production, for some work conditions, if they cannot be known earlier, system production has deviated from normal levels when they are found; although managers can make them back to normal levels by adjusting production measures, this has seriously affected the economic benefits of the production. For some other work conditions, the system has been in a negative or even danger situation when they occur, and managers hardly make the system back to normal levels. So, it is necessary for the beam pumping unit to predict down-hole working conditions. In this paper, we have done some effective researches for prediction method, and mainly resolved two problems: one is how to build a reasonable prediction model, and the other one is how to determine the predicted fault type.

The main structure of this article is as follows: Section 1 simply introduces this paper's research background; Section 2 introduces feature extraction method of the dynamometer card, in which, technical principle that down-hole working conditions can be reflected by graphical shapes of the dynamometer card is given in Section 2.1, and in Section 2.2 a novel dynamometer card feature extraction method based on 8-directions chain codes is proposed; in Section 3, chaotic analysis for time series of the dynamometer card feature vectors is carried out, and then the phase-space reconstruction of them is completed to determine two key parameters of each time series: delay time τ and embedding dimension m; Section 4 builds a prediction model based on OS-ELM method, and X and Y after phase-space reconstruction are used as input and output of the prediction model; in Section 5, an improved grey interval relational degree is proposed to diagnose the fault type of down-