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Self-organization comprehensive real-time state evaluation model for oil pump unit on the basis of operating condition classification and recognition

Wei Liang [a,*], Xuchao Yu [a,b], Laibin Zhang [a], Wenqing Lu [c,1]

[a] College of Mechanical and Transportation Engineering, China University of Petroleum-Beijing, 102249 Beijing, China
[b] Faculty of Technology, Policy and Management, Safety and Security Science Group (S3G), TU Delft, 2628 BX Delft, The Netherlands
[c] Institute of SINOPEC Oilfield Equipment Corporation, SINOPEC Key Laboratory of Petroleum Equipment, 430223, Wuhan, China

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A B S T R A C T

In oil transmission station, the operating condition (OC) of an oil pump unit sometimes switches accordingly, which will lead to changes in operating parameters. If not taking the switching of OCs into consideration while performing a state evaluation on the pump unit, the accuracy of evaluation would be largely influenced. Hence, in this paper, a self-organization Comprehensive Real-Time State Evaluation Model (self-organization CRTSEM) is proposed based on OC classification and recognition. However, the underlying model CRTSEM is built through incorporating the advantages of Gaussian Mixture Model (GMM) and Fuzzy Comprehensive Evaluation Model (FCEM) first. That is to say, independent state models are established for every state characteristic parameter according to their distribution types (i.e. the Gaussian distribution and logistic regression distribution). Meanwhile, Analytic Hierarchy Process (AHP) is utilized to calculate the weights of state characteristic parameters. Then, the OC classification is determined by the types of oil delivery tasks, and CRTSEMs of different standard OCs are built to constitute the CRTSEM matrix. On the other side, the OC recognition is realized by a self-organization model that is established on the basis of Back Propagation (BP) model. After the self-organization CRTSEM is derived through integration, real-time monitoring data can be inputted for OC recognition. At the end, the current state of the pump unit can be evaluated by using the right CRTSEM. The case study manifests that the proposed self-organization CRTSEM can provide reasonable and accurate state evaluation results for the pump unit. Besides, the assumption that the switching of OCs will influence the results of state evaluation is also verified.

1. Introduction

As the dynamic kernel of oil transmission pipeline infrastructure, oil pump unit and its status of health hold a crucial impact on the regular operation of the pipeline system. Once a failure or fault occurs in the pump unit, it may result in

* Corresponding author at: College of Mechanical and Transportation Engineering, China University of Petroleum, No. 18 Fuxue Road, Changping District, Beijing, China.

E-mail addresses: tongxun_1978@126.com (W. Liang), leslie_netherlands@hotmail.com, X.Yu-4@tudelft.nl (X. Yu), Zhanglb@cup.edu.cn (L. Zhang), luwenqing7891@163.com (W. Lu).

[1] Co-corresponding author at: Institute of SINOPEC Oilfield Equipment Corporation, 11th Floor, A2, Financial harbor, #77 Optics Valley Ave, East lake high-tech Area, Wuhan, Hubei, China.

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an unplanned shutdown, economic losses, and even safety accidents. In order to find out the failure or fault and prevent accidents as early as possible, regular maintenance must be implemented. However, if the issue of cost-effect is taken into consideration, condition based maintenance (CBM) is no doubt the best choice. Therefore, it is of great significance to perform a real-time state evaluation on the pump unit. The real-time state itself can manifest the risk of failure or fault in the pump unit. According to the risk information delivered, a further decision about maintenance strategy can be made to ultimately guarantee the stability and efficiency of oil delivery.

Nowadays, several methods are commonly used to evaluate the state of equipment, including Gaussian Mixture Model (GMM) [1–4], Fuzzy Comprehensive Evaluation Model (FCEM) [5–8], Grey Relational Analysis (GRA) [9–11], Hidden Markov Model (HMM) [12–15], Neural Network (NN) [6,16], and so on.

GMM is an extension of single Gaussian probability density function. It is a statistical model to decompose the variable distribution into multiple Gaussian probability density functions. It can fulfill the demand for real-time state evaluation. Nevertheless, the model itself is relatively complicated, and the Gaussian components in the model have no practical physical meanings while all the parameters are required to obey the Gaussian distribution [1,2]. These limitations restrain the application of GMM to a certain extent.

FCEM is a method based on fuzzy mathematics and can transform qualitative evaluation into quantitative evaluation according to the membership theory of fuzzy mathematics [5]. It can take full advantage of expert experience and historical data. But it is limited by the high professional requirements of experts and analysts because the subjectivity from them would greatly influence the accuracy of evaluation results. Moreover, the state evaluation cannot be realized in real-time by using FCEM.

As one of the most widely used models in grey system theory, GRA is to figure out the correlation degree of factors through determining the similarity between the reference data column and several comparative data columns. GRA is particularly useful in processing uncertain information. But at the same time, it requires the target system must be a grey system, satisfying that the information is not complete and non-unique [9].

HMM is a statistical Markov model in which the system being modeled is assumed to be a Markov process with unobserved (hidden) states [15]. It possesses good performance in applications of process state prediction but is limited by its overly simplified assumption, that is, a state depends only on the previous state, and this dependency is independent of time.

NN is a nonlinear statistical data modeling tool that can adaptively change the internal structure according to the external information. It is widely applied in intelligent identification and classification of equipment states. But it requires huge training sample data and higher calculation cost.

Among these methods, Lin et al. combined FCEM with Analytic Hierarchy Process (AHP) to perform a state evaluation on oil pump unit. But, the evaluation is not realized in real-time [8]. On the contrary, it is difficult to evaluate the state of equipment by using GMM alone, since not all the characteristic parameters for state evaluation obey the Gaussian distribution. Nevertheless, the advantages of GMM and FCEM are worthy to be combined as a novel method for the real-time state evaluation of the pump unit.

Besides, Dong et al. proposed a methodology based on segmental Hidden Semi-Markov Models (HSMMs) for equipment diagnosis and prognosis and applied the method in health monitoring of hydraulic pumps [13]. Furthermore, Dong, M. extended his method to an auto-regressive HSMM for more effective diagnostics and prognostics and also applied the method to health management of hydraulic pumps [14].

NN, especially the Back Propagation (BP) model of NN, is extremely useful in intelligent state identification or health prediction. For example, Wu et al. utilized NN to perform health condition predictions for pump bearings and applied the method in the CBM optimization [16].

However, through literature review [11,17,18], it is found that the influence of OCs is hardly taken into consideration when performing a state evaluation on equipment. Actually, in the operation process of industrial equipment, due to the complexity of system or process, the diversity of production plans, external interference and so on, there exist a variety of OCs [19]. Furthermore, in terms of the effects of OCs on the operating parameters, several studies have proceeded. Zimroz et al. studied the effects of non-stationary OCs on the characteristics of vibration signals of wind turbine bearings [20] and planetary gearboxes [21]. Vicuña, C. studied the effects of OCs on the acoustic emissions from planetary gearboxes [22].

In a word, the switching of OCs will be manifested in the operating parameters which are essential for the state evaluation of equipment [23, 24]. Therefore, it is critical to constitute the state evaluation method on the basis of OC classification and recognition. Also, in terms of OC classification and recognition, a lot of work has been done. For example, Wang et al. achieved the OC classification of rod pumping unit by using Least Squares Support Vector Machines (LS-SVM) [25]. Liu et al. achieved the OC recognition of wind turbine by using SVM [26].

In this paper, a methodology to pursue the real-time state evaluation of the pump unit is proposed on the basis of OC classification and recognition. The OC classification is determined by the types of oil delivery tasks at site and the OC recognition is achieved by a self-organization model that is built on the basis of BP model. However, the underlying real-time state evaluation model, which is named as Comprehensive Real-Time State Evaluation Model (CRTSEM), is derived by incorporating GMM and FCEM since both Gaussian distribution and logistic regression distribution simultaneously exist in the state characteristic parameters. Hereafter, by taking the OC classification into consideration, a CRTSEM matrix, in which every individual CRTSEM corresponds to one of the known standard OCs, is constructed. At last, the self-organization CRTSEM