Robust technology and system for management of sucker rod pumping units in oil wells

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We propose a technology for calculating the robust, normalized correlation functions of the signal from the force sensor on the rod string attached to the hanger of the sucker rod pumping unit. The robust normalized correlation functions are used to form sets of informative attribute combinations, each of which corresponds to a technical condition of the sucker rod pumping unit. We demonstrate how these sets can be used to solve identification and management problems in the oil production process in real time using inexpensive controllers. The results obtained from using the system on real objects are also presented in this paper. It was determined that the energy saved and prolonged overhaul period substantially increased the cost-effectiveness.

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1. Introduction

Sucker rod pumping units (SRPUs) are well-known as the primary method to lift oil. Currently, sucker rod pumping is a common practice in oil production worldwide, covering over 85% of the total active well stocks in the USA [1]. The SRPU method is popular because of its simplicity, reliability and applicability to a wide range of operating conditions.

However, in the face of decreasing oil reserves, increased reservoir flooding and well shutdowns caused by delayed equipment diagnostics, the cost-effectiveness of oil production using SRPUs has decreased considerably. Therefore, the ability to identify SRPU technical conditions is a key issue for oilfield profitability over long-term operations and needs to be improved. If this problem is solved, it will become possible to manage SRPUs in real time, which would ensure the necessary stabilization of oil productions. To increase the overhaul period and create the most favorable conditions for efficient oil production management, various methods and tools for technical control and management of SRPUs have been developed over the last several decades [2–8]. These studies demonstrate that the information concerning the force on the rod hanger center contains the least distorted and comprehensive data regarding the condition of the underground pumping equipment. Therefore, dynamometry (i.e., the reading and analysis of the force curve \( U_p(t) \), received from the force sensor in the rod hanger center, \( P(S) \)) is considered the customary means of controlling the technical condition of SRPUs.

The authors of [2] demonstrated the possibility to recognize the force curves \( U_p(t) \), using infra-low frequency spectrum analyzers. The ability to obtain the amplitude spectrum of the dynamometer card is considered an advantage of this method. For instance, it was revealed that the dynamometer cards of normally operating pumps have no even harmonics, while the

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dynamometer cards of leaky pumps have even harmonics with amplitudes that are heavily dependent on the scale of the leakage. However, only four types of technical conditions could be identified using this method [2]. A statistical method was also used to identify technical conditions using dynamometer cards. Due to the limited computation power and memory required, this method compares favorably with other dynamometer card classification methods. In [2,4–6] the authors provide detailed descriptions of the results of numerous studies that have been conducted in this field over many years. A scientific foundation has been formed based on these studies, and various systems for SRPU control and management have been designed using dynamometer cards obtained at the well head.

Based on the performance results of these systems, dynamometer card-based diagnostic methods have been categorized as follows [2]:

1. Diagnostics based directly on the characteristics of the ground dynamometer card.
2. Diagnostics based on the secondary characteristics of the dynamometer card (spectral characteristics, such as the variance, correlation and regression of the force sensor signal, and coefficients of the Fourier series expansion for the dynamometer card).
3. Diagnostics based on the typical characteristics of the shape of the ground dynamometer card.
4. Diagnostics based on comparing the shape of the dynamometer card under consideration to the reference card recorded immediately after well repair and stored in the device memory;
5. Identification based on the characteristics of the plunger dynamometer card calculated from the data of the ground dynamometer card and well design.
6. Identification based on the typical characteristics of the shape of the plunger dynamometer card.

The shortcoming of these methods is that they do not allow for automatic identification of a dynamometer card in real time with sufficient accuracy. For this reason, the identification of dynamometer cards in real life is mostly performed via semi-automatic interpretations, which eventually comes down to a visual analysis of the dynamometer information by a technologist who makes the final decision concerning the technical condition of the SRPU. The results of the diagnostics depend on the qualifications of the technologist, and running diagnostics on all wells, i.e., identifying their technical condition, takes some time. Furthermore, even a highly qualified specialist sometimes has a hard time determining the exact technical condition of the pump visually from the dynamometer cards, particularly for deep wells. Therefore, new technologies for real-time analysis and identification of dynamometer cards with the use of modern controllers must be developed to increase the cost-effectiveness of oil wells. It is reasonable to monitor the changes in the technical conditions of SRPUs by identifying the signal of the rod string force on the hanger per pumping cycle. Our research has demonstrated that one of the most efficient ways to solve this problem is to use a technology to identify the force sensor signal with correlation analysis methods [5–7].

In the known SRPU control systems, the dynamometer card information comes from the force and stroke sensors as electric signal of the force, \( U_p(t) \), and stroke, \( U_s(t) \), via a communication channel. Using combinations of these two variables, \( U_p(t) \) and \( U_s(t) \), the dynamometer card \( U_p(t) = f(U_s) \), whose shape is described by a parallelogram (Fig. 1), is formed. A skilled technologist can identify more than 20 types of SRPU technical conditions through a visual inspections of the distortions in the different sections of the card shape [2]. Performing this operation for a hundred wells, however, is a complicated task.

It should be noted that if an object’s condition is identified by means of hardware, there is no need to use \( U_s(t) \), as this problem can be solved by analyzing the stress curve \( U_p(t) \) only. The main challenge in this problem is that currently no technology can ensure adequate identification of the force signal \( U_p(t) \) in real time. For instance, when correlation analysis technology is used for this purpose, the system is not robust because the error in the correlation function estimates caused by the noise, \( e_1(t) \), accompanying the useful force signal, \( U_p(t) \), changes across a notably wide range under operation. This property is related to the fact that the control object, (i.e., the SRPU) operates in the field environment, which is subject to such factors as temperature and humidity extremes. Additionally, during pump operation, various faults can also cause the formation of a

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**Fig. 1.** Typical dynamometer card of a normally operating SRPU.
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