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To cite this article: M I Khakimyanov et al 2017 J. Phys.: Conf. Ser. 803 012066

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Monitoring of sucker-rod pump units as a result of the analysis wattmeter cards

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Abstract. The problems of automation of oil wells operated by sucker-rod pumps are considered. The authors have developed a method of mathematical processing of wattmeter cards for diagnosis of downhole pumping equipment. Analysis of wattmeter cards allows controlling the condition of the ground equipment of the pumping unit. Using wattmeter cards, the balance and efficiency of the pumping unit can be calculated. Wattmeter cards spectrum analysis allows determining the vibration and impact loads, which makes it possible to diagnose defects of the reducer and bearings.

1. Introduction
When automating sucker-rod pump facilities (SRPF), two methods are mainly used: dynamometry and wattmetering. The first method allows controlling the operation of the downhole equipment, and the second – that of the ground equipment. Ground equipment of SRPF includes an electric motor, a V-belt drive, a reducer and a pumping unit with balancing weights.

The advantages of wattmetering include the ease of measurements and the ability to keep a record of consumption of the electric power drive [1].

Wattmeter cards analysis allows determining the degree of balance and efficiency of SRPF, diagnosing breakage of belts and rods, detecting blows in the kinematic scheme of the pumping unit.

Historically, the wattmetering method began to be used before dynamometry in the analysis of wells operating modes, since for measuring the force on the polished rod complex, sensors were required. In his works [2, 3], Krichke V.O. developed electronic devices that implement wattmeter cards algorithms. However, the use of wattmetry until now was restrained by computing abilities of controllers [4, 5].

2. Diagnosis of SRPF according to the wattmeter cards
The method of mathematical processing of SRPF wattmeter cards specifically targeted for use in the controller of control station was developed by the authors [6].

The initial data for the analysis are the instantaneous values of the active power in one period of SRPF oscillation. It should be noted that from the arrays of instantaneous current and voltage values, the following parameters can be obtained: active, reactive and full power, power factor, effective values of voltage and current in each phase.
Wattmeter card processing begins with the construction of the smoothed graph (Figure 1). At the next stage, the average value, variance and standard deviation are calculated for the evaluation of shock and vibration components.

3. **Mathematical processing of wattmeter cards**
The mean power value of the oscillation cycle is the average arithmetic meaning of the wattmeter card array:

$$W_{\text{mean}} = \frac{\sum W_i}{n}$$

Here, \(n\) is the number of array points.

The variance can be found from formula

$$S^2 = \frac{\sum (W_i - W_{\text{SM},i})^2}{n}.$$  

Where \(W_{\text{SM},i}\) — the array point of the wattmeter card after filtration.

The mean square deviation is found from the variance.

For the vibration component, the mean square deviation is accepted. For shock component, the instantaneous value of the maximum deviation of the original and smoothed wattmeter cards is taken.

Next, the construction of the spectrum wattmeter card is made. To construct a spectrum constant, the component is removed from the array by passing through a highpass filter. The constructed wattmeter card spectrum is shown in Figure 2. In the analysis, a maximum frequency of the spectrum, frequency of the spectrum’s maximum, the presence and number of peaks are of importance. Defects of gear reducers, bearings, pumping unit elements, the low oil level can be diagnosed by the spectrum.

4. **The construction of the wattmeter card spectrum**
In Figure 3, the original, smoothed graphs and their differences are built. The power line of the noise component of the signal is drawn. By the nature of the noise component of the signal, the dynamics of impacts in SRPF drive elements can be detected.

To calculate the balance of SRPF, let us compare the energy emitted during the course of the up and down movement of the rod. The energy equals the area under the power changing curve. The balance factor is the ratio of these energies with the ideal balance ratio equal to one.

For the calculation of the facility’s efficiency the following energies are found: consumption of the network is going to overcome the friction forces in the ground equipment and transfer them to polished rod. The energy consumption of the network is the area of the figure under the wattmeter card curve for the oscillation cycle. The energy expended to overcome friction forces is equal to a constant power for the oscillation cycle [7-10]. The energy expended to lift the rod string and fluid, as well as to lift the counterweight is defined as the area of the "bulges" of the wattmeter card or as the energy difference between the consumed energy from the network and the expended energy to overcome friction.

Efficiency of the facility is the ratio of the energy transferred on the polished rod to the energy consumed from the network.
Figure 1. The source and smoothed graphics of the wattmeter card.
Figure 2. The construction of the wattmeter card spectrum.
The difference between the source and the smoothed graphs of the wattmeter card.

5. **The difference between the original and the smoothed graphics of the wattmeter card**

A three-dimensional graph of the spectrum can be built to enhance the visibility (Figure 4).

A three-dimensional image of the wattmeter card spectrum allows evaluating the vibration and impact loads fluctuations. At present, in the wattmeter card, there is a blow at the end of the period of oscillation. On the spectrum, it is clearly seen that at the end of the period there are oscillations with a frequency of 2-5 Hz.

![Figure 3](image1.png)

**Figure 3.** The difference between the source and the smoothed graphs of the wattmeter card.

![Figure 4](image2.png)

**Figure 4.** The graph of the three-dimensional spectrum of the wattmeter card.
6. Conclusion

Thus, the following conclusions can be made based on the results of the conducted research:

- Control station should provide measurements of dynamometer and wattmeter cards to implement integrated monitoring of the condition and the mode of operation of SRPF;
- Wattmetering is an effective way to control the condition of the ground equipment of SRPF;
- Wattmetering allows a high degree of accuracy to evaluate balance and calculate the efficiency of SRPF;
- Wattmeter cards spectrum analysis allows determining the vibration and shock loads, which makes it possible to diagnose bearing and gear defects.

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