Applying the Accelerometer Signal for Precise Determination of SRP Polished Rod Position

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In the sphere of oil production the design of surface pumping units remains unchanged for many years while the controllers have been continuously improved. Sustainable maintenance of the controller is closely tied to reliability of data acquired from pumping unit. The method of signal reception and processing will be described in this article.

From the 1930es to present electric motors or internal combustion engines have been used as a prime mover for beam-balanced pumping units, both for vertical and inclined wells. An alternative to this type of actuator is a hydraulically driven long stroke drive or chain drive.

Controllers for drives of sucker rod pumps perform a wide range of tasks associated with telemetry, remote control, optimization with the aim to increase productivity, accident prevention, measurement of flow rate, obtaining information on the status of the downhole equipment, the reservoir pressure data and the flow of oil.

The usage of modern controllers, such as the "WellSim controller", allows the operator to reduce energy consumption by 67%, increase production by 2–4% and determine amount of oil production with accuracy ±2%.

Measuring Instruments

Modern types of controllers work with a wide range of sensors such as thermometers, pressure gauges, flow meters, sonars, Hall-effect sensors and others. It can also run in sensor-less mode, but the primary and the most preferred mode for the controller is to work with the load sensors and the position of the polished rod.

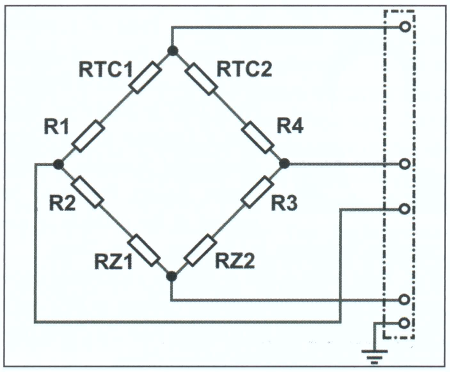

Fig. 1 **Strain gauge bridge; R1 ... R4 – strain gauges, RTC1, RTC2 – temperature compensation, RZ1, RZ2 – zero adjustment**

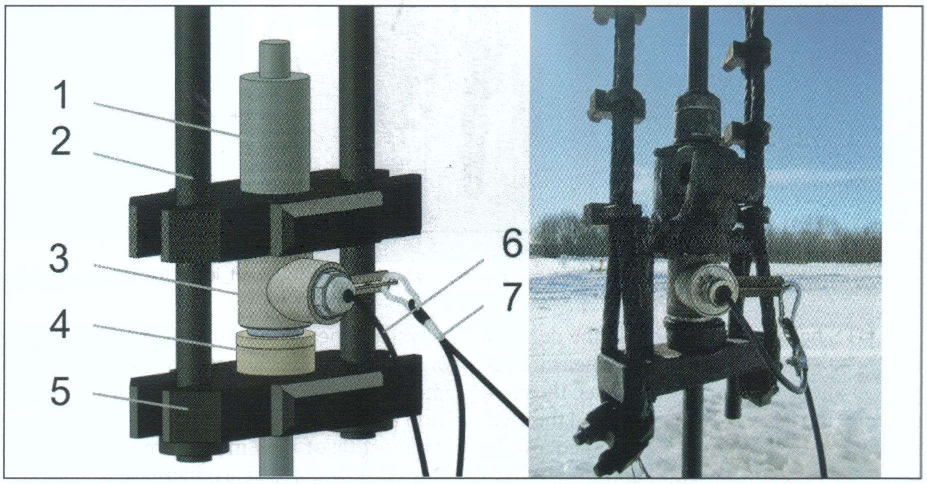

Fig. 2 **Sensor on polished rod; 1 – collet, 2 – wireline, 3 – sensor, 4 – spherical washers, 5 – carrier bar, 6 – cable, 7 – cable fasteners**

A typical scheme of strain gauge bridge with temperature compensation shows Figure 1.

The sensor (Fig. 2) is situated on the suspension of the polished rod so it can constantly measure its weight while moving with it all the time during upstroke and downstroke. To avoid misalignment the sensor is placed on the spherical washers, allowing the sensor to incline with the polished rod and thus equally spread measured weight on the sensor. Helical cable adjusts to the current situation according to the movement of the polished rod in order to minimize damage of the cable.

Load sensors are often manufactured in similar designs, which are determined by operating conditions and presence of aggressive and explosive chemicals presented at the well site. That dictates the choice of durable stainless steel casing, which provides pressurization and protection of sensitive electronic stuffing.

WellSim controllers use combined load and position sensors EMS 122, produced by Naftamatika, that consist of an accelerometer and a strain gauge bridge both incorporated in a stainless steel housing. After processing the controller produces a filtered signal of load and the graph of the position of the rod obtained by double integration of the accelerometer signal. Signal processing provides several technical problems.

The first of them is the signal noise in the channel of the accelerometer.

The sensor has a direct connection to the strain gauge and the signal loses quality by passing through a long cable to the controller. The other problem is that the signal of the strain gauge is in the millivolt range and depends on temperature, humidity, quality of connectors and other signals in the circuit – all these factors accumulate to an error. A natural solution for these problems is to use a voltage regulator, which will ensure the stable operation of the sensor, and to increase noise protection by using pre-amplification of the load sensor signal.

Due to the integrated gain, the sensor EMS 122 has a sensitivity 0.184V/1000 kg (approximately 1000 times wider amplitude than normal) which significantly increases noise protection of the output signal and improves its metrological characteristics.

Dynagraph Cards Analysis

Good metrological characteristics of the EMS 122 allow realization of many interesting features: precise calculation of oil production, determination of pump intake pressure, dynamic liquid level and pump fillage. Precise measurement is crucial for automatic control but filtering of input signal requires high computing capability.

As a result of data acquisition the dynagraph card has appeared, which can be analysed by the controller to determine working characteristics of SRP and possible malfunctions. The dynagraph card is a powerful tool for technologists, but in practice the problem is that malfunctions and rod oscillation make it hard for the operator to read it (Fig. 3).

Under optimal conditions (Fig. 4a), the graph is close to a tetragon (blue line) and is

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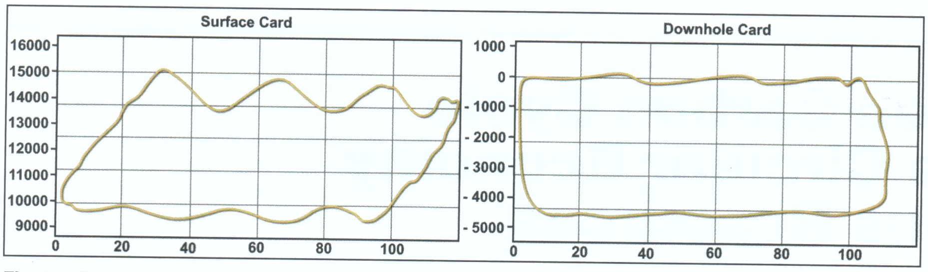

Fig. 3 Surface and downhole cards

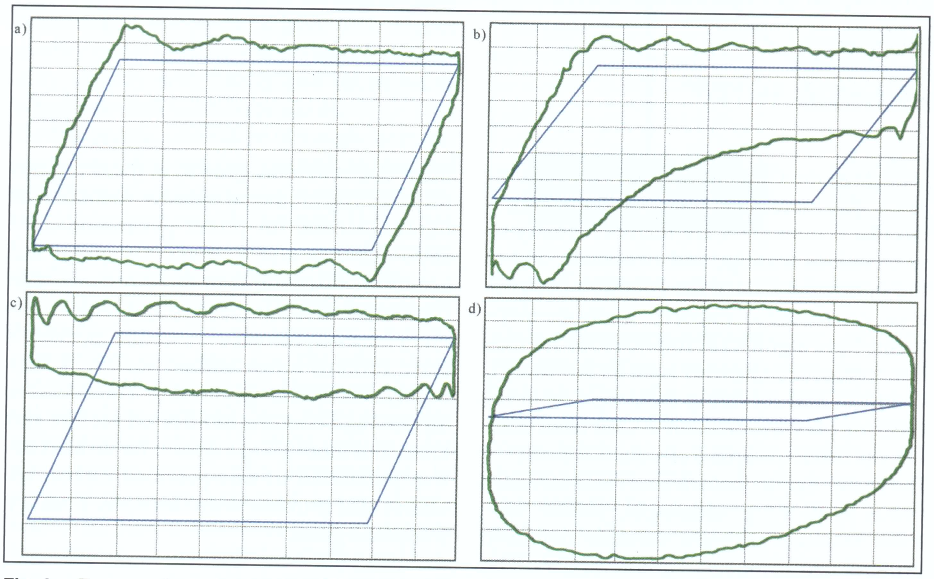

Fig. 4 Dynagraph cards showing different downhole conditions

called "Ideal Theoretical Graph". It is desirable that the real graph is as close as possible to the theoretical one. In normal operation, SRP shows the best efficiency.

With insufficient pump intake pressure, the graph takes the form of a pistol. In this mode (Fig. 4b), there are plunger strikes on the fluid, increased equipment wear and reduced efficiency.

Other two border cases of deviation from the theoretical graph are rod breakage (Fig. 4c), when SRP works completely without avail, and wax in the well (Fig. 4d), which dramatically reduces efficiency due to frictional losses.

Modern well controllers are able to precisely determine SRP working conditions and possible malfunctions even whilst suffering interference on the dynagraph card, by virtue of significant computing power and advanced algorithms.

Raw Signal Processing

The dynagraph card data passes filtering with a frequency of 6 MHz and then is scanned for crossing the x-axis. The controller ignores the intersection, which occurs earlier than 3.75 s after the last one to avoid false positives. Then the data is transmitted to the calculation module of the controller.

The accelerometer signal usage is associated with the problem of zero-setting and absence of equability of the characteristics of individual modules. To solve this, the controller automatically calibrates the accelerometer after connection: the controller begins to collect the signals of the accelerometer for 5 min after turning on. During this process the pumping unit is stopped and the accelerometer is motionless. The controller accumulates the acceleration values array for 5 min and then calculates the average value of the zero signal which becomes basic and is called the DC component of the accelerometer signal. After calibration the controller starts the pumping unit and begins to build a dynagraph card in the normal working mode.

The accelerometer data is processed using Fourier transform, which decomposes a function of a real variable into the frequencies that make it up.

Those frequencies describe the coefficients ("amplitudes") during the decomposition of the original function into elementary components – harmonic oscillations with different frequencies. The aim of the transformation is the constant determination of the interference presented in the signal from the accelerometer.

Raw signal of acceleration (Fig. 5a) passing through series of Fourier functions. The whole array of the accelerometer signals for one whole cycle passes through Fourier series. Processing requires considerable computing resources and allows determination of zero coefficient of decomposition (DC component) and Fourier coefficients for sine and cosine. Visually the graph of acceleration becomes smoother after processing due to exclusion of high-frequency noise (Fig. 5b).

The raw position signal (Fig. 6) is calculated through the double integral of filtered acceleration signal. To draw a graph, Fourier function needs to be double integrated considering the fact that the zero coefficient is the constant.

Conclusion

The application of this filtering mechanism can help to achieve significant reliability of the results and at the same time opens a lot of possibilities of expanding diagnostic methods. Thus the controller using the accelerometer can detect shocks and vibrations that indicate a malfunction of the gearbox and other ground equipment without the participation of the strain gauge. Additional diagnostics can detect these problems at early stages and create the preconditions to prevent more serious damage to equipment.

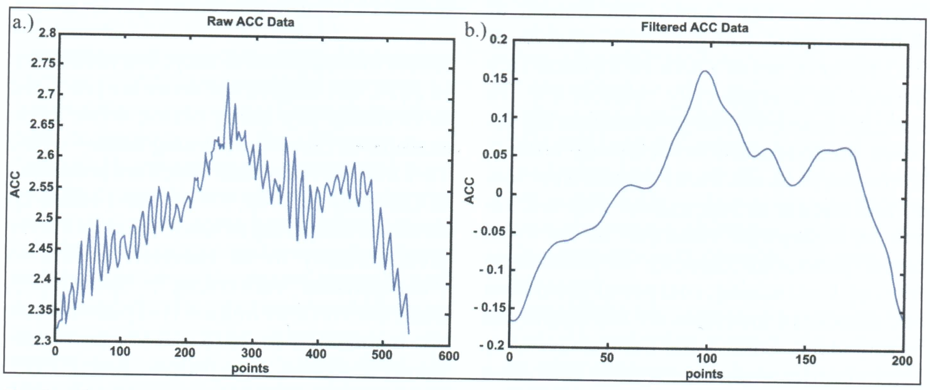

Fig. 5 Raw (a) and filtered (b) ACC signal

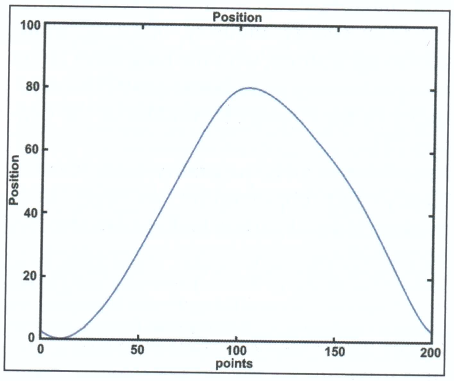

Fig. 6 Position signal