Method of measuring vibratory condition of a drill string

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Abstract. The article discusses issues related to the improvement of the operational reliability of downhole measurement systems. The circumstances of insufficient readings accuracy due to severe operating conditions are shown. The inherent negative factors are given, which jointly affect the reliability of the systems and measuring instruments in use. In particular, special attention is paid to vibration loads and the need for their measurement. The urgency of development and research of new reliable systems is demonstrated. A developed method for measuring the vibratory condition of a drill stem and a developed device for the implementation of this method are presented, and operation of the latter is analyzed.

1. Introduction

The improvement and development of technical and economic indicators for drilling oil and gas wells is directly related to the need for measuring and monitoring the drilling operations profile. Along with the increase in the number of monitored parameters, more and more requirements are imposed on the reliability of measurement results. This is due to the increase in drilling speed, depth of directional wells, high cost of the equipment and magnitude of the responsibility for management decisions in the technological process [1]. Therefore, development of reliable and efficient devices and methods for measuring and monitoring well parameters is one of the most important tasks for the oil and gas industry.

2. Urgency of development and investigation of reliable methods for measuring performance parameters

Modern borehole measurement tools and systems, such as MWD (Measurement While Drilling) and LWD (Logging While Drilling), are usually implemented using electronic systems [2]. The well deepening process is inevitably related to the occurrence of various kinds of dynamic loads. These are, first of all, vibration loads and temperature stresses increasing with the depth of the well, which have an adverse effect on measuring systems as a whole and their electronic components in particular [3, 4]. Abrasive and physico-chemical wear also affects the drill string (DS) equipment and, therefore, the measuring systems contained in them [5]. In particular, the geothermal gradient imposes certain restrictions on the use of some measuring devices in a reliable range, for example, devices with permanent magnets at great depths of wells [6].

The above mentioned factors can result in damage to reliability of the measured parameter values, abnormal operation and failure of drilling parameter measuring and control systems [3].

The dynamic loads, which occur when the downhole tool (bit) interacts with the rock, are probably the most detrimental loads that occur during drilling. The influence of vibrations on DS equipment includes loss of stability of the drilling modes, deterioration of the well stem drilling and lower resource of the well equipment [1].

Various control systems are used to control DS vibratory condition, which incorporate sensors measuring amplitude and frequency of the acting oscillations [7, 8]. As it was mentioned before, the sensors contain electronic components that have low operational reliability under high dynamic loads, and often require power sources, which is not always reasonable in a borehole due to increasing general risks for the device performance.

In this regard, development and investigation of reliable means of measuring vibrations, which would depend little on external factors, seems to be an urgent task. In particular, such principles can be implemented on the basis of mechanical devices containing electronic components.

3. New method of measuring vibratory condition of the DS equipment

The authors developed a method for measuring vibrations in downhole conditions, which can be used for a continuous assessment of the vibratory condition without relying on electronic components as the primary analyzing system [9].

The essence of the method is as follows. When longitudinal and/or torsional vibrations occur in the drill string, the bit breaks off from the rock causing a shift of the rigidly bound drill string bottom (DSB) assembly. A hydromechanical vibration sensor, which perceives the vibration load, is installed above drill collars (DC) in the area subject to DS tensile loads (Figure 1).

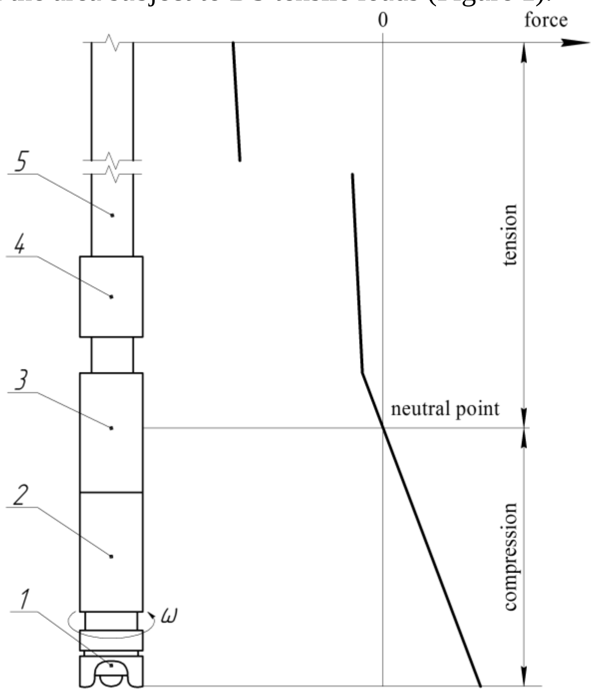

Figure 1. Method for measuring DS vibrations in a well: 1 – a bit; 2 – a mud motor; 3 – MWD; 4 – a hydromechanical vibration sensor; 5 – a drill string.

The sensor redistributes part of the mud flow into the sensor cavity according to the amplitude of the acting vibrations. The resulting change in the flow rate through the DS main stem is either recorded by a downhole flow meter or affects the mud motor speed, which, in turn, is recorded by a tachometer.

4. Development of device for measuring vibratory condition of downhole equipment

For the implementation of the proposed method of measuring vibrations, the authors developed a hydromechanical vibration sensor (Figure 2) [9].

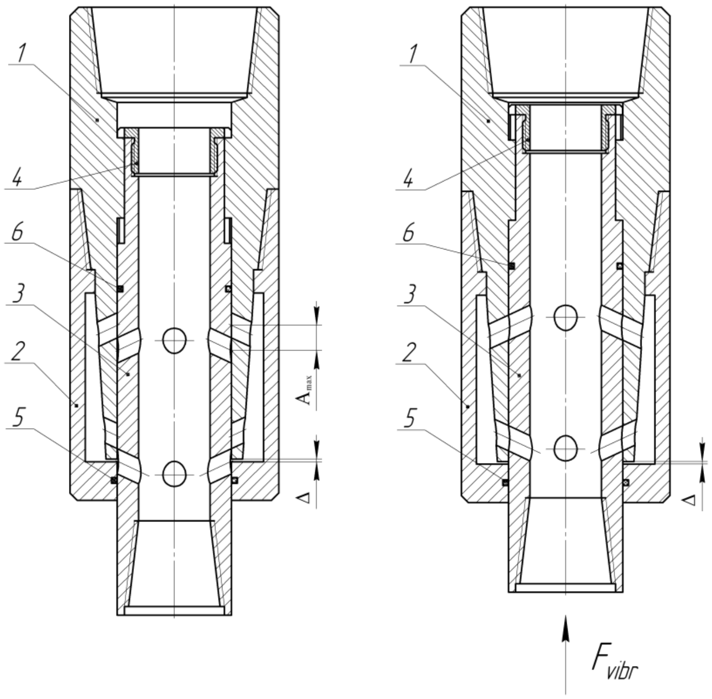

Figure 2. Hydromechanical vibration sensor: 1 – a case; 2 – a cup; 3 – a stem; 4 – an adjusting sleeve; 5, 6 – packing rings.

The hydromechanical vibration sensor is a mechanical device installed in the DS assembly, which perceives the vibration load from the downhole tool and generates a signal on occurrence of vibrations.

The sensor works as follows. When the bit is detached from the bottom, the vibration force F_{vibr} affects the stem 1 of the sensor and moves it along the guide slots in the case 2 to an intermediate or extreme position at maximum amplitude of vibration A_{max}. There is an intersection or coincidence of holes in the sensor, through which part of the mud flow moving within the DS cavity passes into the cavity formed by the case 1 and the cup 2. As a result, the mud flow rate in the DS main stem changes, which is registered by bottom sensors. Thus, the proposed method is implemented.

5. Analysis of the hydromechanical sensor performance

In order to assess performance of the developed sensor, it is necessary to obtain a mud flow rate $Q(A)$ through the hole dependence on the amplitude A of the acting vibrations. In general, the flow through the hole is determined as follows:

$$Q(A) = \mu \cdot S_{\mathrm{h}}(A) \cdot \sqrt{2g \cdot H} \qquad (1)$$

where μ – is flow coefficient; S_h – is opening area of the hole; H – is height of the mud hydrostatic column above the hole.

The $S_h(A)$ dependence is determined by solving a geometric task of finding an area formed by the intersection of two circles (Figure 3).

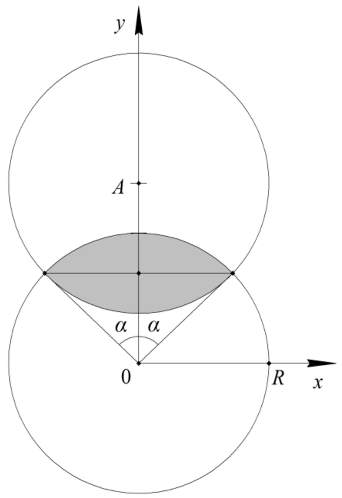

Figure 3. Calculation scheme for determining the area of two intersecting circles.

A system of equations of two circles is put down as follows:

$$\begin{cases} x^2 + y^2 = R^2, \\ x^2 + (y - A)^2 = R^2. \end{cases} \tag{2}$$

Transformation of the system of equations (2) provides an obvious solution $y = \frac{A}{2}$.

The area formed by intersection of two circles will be equal to twice the area of a circle segment:

$$S_{\text{op}} = R^2 \cdot (2\alpha - \sin 2\alpha) \tag{3}$$

Using obvious geometric transformations, the expression for S_{op} is brought to the following form:

$$S_{\text{op}}(A) = 2R^2 \cdot \arccos\left(\frac{A}{2R}\right) - \frac{A}{2} \cdot \sqrt{4R^2 - A^2} \tag{4}$$

Then the S_{h} value can be put down as follows:

$$S_{\text{h}}(A) = \pi R^2 - 2R^2 \cdot \arccos\left(\frac{A}{2R}\right) + \frac{A}{2} \cdot \sqrt{4R^2 - A^2} \tag{5}$$

Substitution of expression (5) into formula (1) gives the $Q(A)$ dependence:

$$Q(A) = \mu \cdot \left(\pi R^2 - 2R^2 \cdot \arccos\left(\frac{A}{2R}\right) + \frac{A}{2} \cdot \sqrt{4R^2 - A^2}\right) \cdot \sqrt{2g \cdot H} \tag{6}$$

The flow coefficient μ is determined from an empirical expression depending on the Reynolds number. When Re >10000 [10]:

$$\mu = 0.592 + \frac{5.5}{\sqrt{\text{Re}}} \tag{7}$$

According to the formula (6) and data close to the actual ones from table 1, a graph can be built up to present the dependence of mud supply through the hydromechanical sensor hole on the amplitude of acting vibration (Figure 4).

Table 1. Parameters for plotting a graph of Q through the hydromechanical sensor hole dependence on the amplitude of the acting vibrations A

Parameter	*R*, mm	Re	μ	*H*, m
Value	8	24519	0.627	60

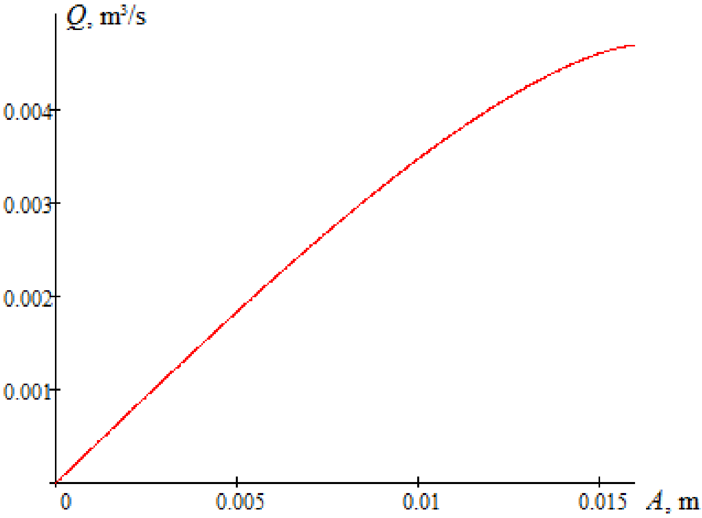

Figure 4. The dependence of the mud flow rate through the hydromechanical sensor hole on the vibration amplitude.

Thus, one of the advantages of the created method is that it is can be quite easily analyses to estimate the vibration parameters and does not require additional downhole analyzing devices.

The simulation was performed in the SolidWorks Flow Simulation software module to determine the distribution of velocities and pressure flows at the hydromechanical sensor working position. The simulation results are shown in Figure 5.

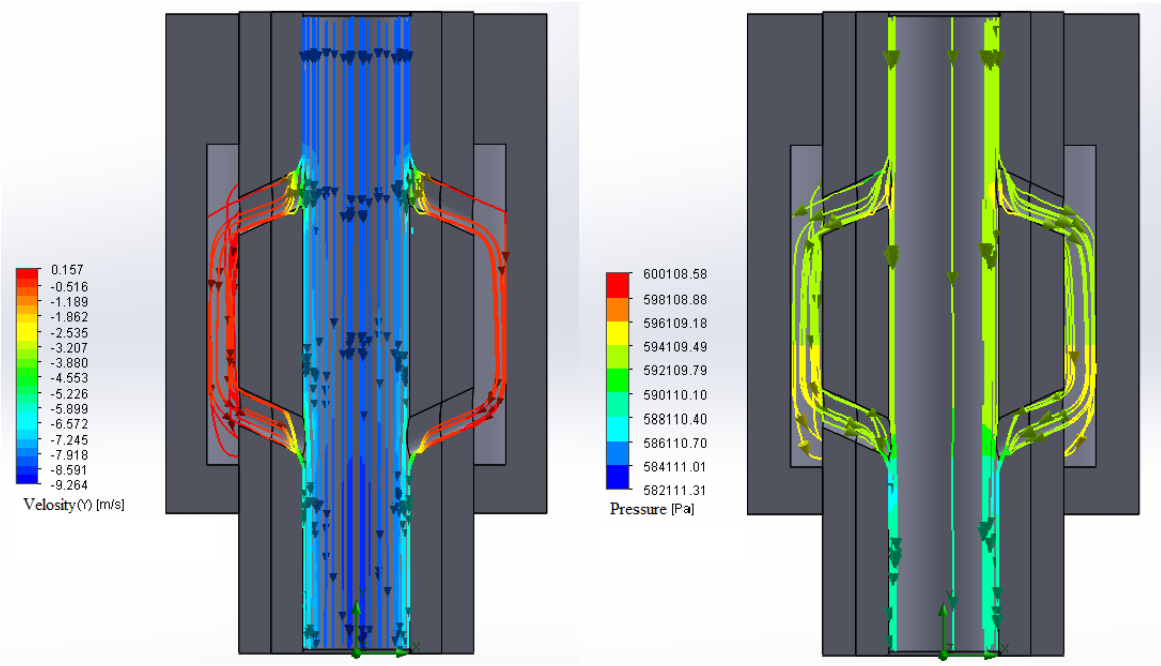

Figure 5. Model of mud flow velocity (left) and pressure (right) distribution in the hydromechanical sensor.

It can be seen from the obtained flow distributions that the return flows are practically absent, and the created hydraulic resistances have little effect on the drilling mud flow. Thus, the proposed method and device for measuring the DS vibratory condition are operable and can be used to assess the vibration parameters.

6. Conclusion

The urgency of development and investigation of reliable methods for measuring DS vibrations in a well has been revealed. A method for measuring vibrations based on the use of a hydromechanical sensor that perceives the vibration load from the bit, which results in a change in drilling mud supply through the DS main stem, is proposed. A design of a hydromechanical sensor is proposed that implements this method of vibration measurement. The analysis of the method performance was carried out, and the flow rate dependence on the acting vibrations amplitude was obtained to prove that the developed method can be easily applied in analysis to estimate the vibration parameters and does not require additional downhole analyzing devices. The obtained models of flow distributions through a hydromechanical sensor show that there are practically no reverse flows therein, and the created hydraulic resistance has little effect on the drilling mud flow.

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