System for measurement and control of drill string vibration

K A Bashmur[1]**, E A Petrovsky**[1]**, V V Bogachev**[1]**, V V Kukartsev**[1,2] **and V S Tynchenko**[1,2]

[1]Siberian Federal University, 79, Svobodny Av., Krasnoyarsk, 660041, Russia
[2]Reshetnev Siberian State University of Science and Technology, 31 Krasnoyarsky Rabochy Av., Krasnoyarsk, 660037, Russia

E-mail: haros.dem@gmail.com, bashmur@bk.ru

Abstract. The article discusses issues of ensuring effective and reliable measurement and control of drill string vibration. A system for active measurement and control of drill string vibration is presented. The system combines both wellhead equipment elements and downhole equipment. At that, there is a specially designed hydromechanical extensional vibration sensor used in wells. The wellhead equipment includes elements of record and analysis of obtained data about drill string vibration. Moreover, the system includes wellhead equipment for stopping vibration. The article analyses optimal parameters for the shape of the hydromechanical vibration sensor. Its optimal shape is established.

1. Introduction

Current approaches to drilling are closely connected with the use of modern technologies that are of high reliability [1]. That is the reason why it is necessary to design new high-tech equipment that allows to work with minimal downtime caused by maintenance and repair. Along with it, bottom-hole conditions need to be continuously monitored in order to precisely regulate the technological process. Measurement precision in these parameters significantly effects operator's judgement as well as the one of the control systems. Consequently, equipment for measurement of borehole parameters, as well as complexes based on them, need to transmit precise date and be of high reliability.

At the present moment, leading companies in deep-hole drilling for oil and gas more and more often implement sophisticated soft- and hardware complexes in order to automate the technological process of well construction [2]. However, effect of external factors certainly limits the use of any given system or complex [3]. To such factors, slurry abrasive wear, temperature differences, as well as high dynamic stress may be attributed [4].

What deserves individual attention is vibrational load when a drill bit couples with rock in place, which negatively effects a drill string and its equipment. Vibration wears and significantly reduces the operating life of downhole equipment.

There is a range of methods for controlling drill string vibration. They are passive, semi-active and active [5]. The passive methods imply that a system does not require external power sources.

Active control methods imply application of force that is equal and opposite to external vibrations. Active drill string vibration control may be divided into control of a well collar and a well bottom-hole, and along the whole length of a drill string. Active control systems may set optimum drilling parameters to stop vibration. At the same time systems need to include precise measurement systems for ensuring precise control. At present, measurement is performed using various electronic sensors, which reduces system reliability in general [6]. Semi-active systems combine advantages of passive and active control. To adapt to an optimal structure state, semi-active control systems use passive control equipment which requires less power to change parameters and to maintain operational state of a passive system [7].

Consequently, the issue of design of precise and reliable control systems for maintaining operational reliability and sustainability of drill strings in conditions of vibrational loads is one of the most relevant objectives for the well drilling sphere.

2. Designed system for active control and measurement of vibration in a well

The authors have designed a system for active control of drill string vibration (Patent No. RU 2705852) that is based on continuous control and measurement of drill parameters using a boring pump.

In pictures 1 and 2, there is a functional diagram of the system for downhole equipment (figure 1) and wellhead equipment (figure 2) respectively.

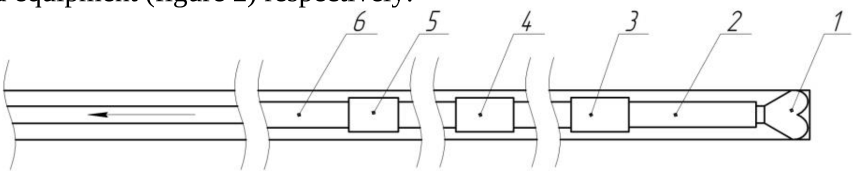


Figure 1. System for control of drill string vibration (downhole equipment): 1 – bit; 2 – downhole motor; 3 – downhole flow meter; 4 – tachometer; 5 – hydromechanical vibration sensor; 6 – drill string.

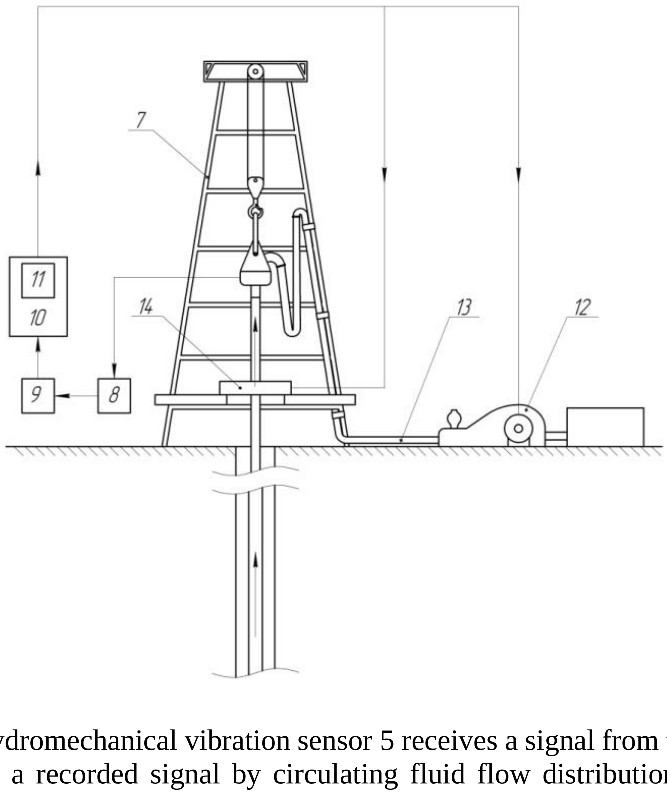


Figure 2. System for control of drill string vibration (wellhead equipment): 7 – boring rig; 8 – recording device; 9 – transducer; 10 – control module; 11 – feedback controller; 12 – boring pump; 13 – pump line; 14 – drill string spinner.

Hydromechanical vibration sensor 5 receives a signal from the vibrating bit 1 and/or drill string 6. It forms a recorded signal by circulating fluid flow distribution in the cavity of the hydromechanical sensor.

Recorded signal is transmitted either to tachometer 4, which records a change in the number of downhole motor 2 rotations or to downhole flow meter 3, which records a change in consumption of circulating fluid through the drill string cavity.

After that the signal is transmitted using a communication line, for example, acoustic [8] or hydraulic [9] to the wellhead and it is received by recording device 8. Then the signal is transmitted to the transducer 9. The converted signal is analyzed by the control module 10 using feedback controller 11, so a control signal is formed, which is transmitted either to the drill string spinner 14 in order to change the number of rotations or to the boring pump 12 in order to change the supply of circulating fluid in the drill string.

By changing these drilling parameters, a drill string and a bit stop vibrating. This system improves reliability of obtained data about vibration emergence and its measurement [10].

3. Designed sensor for measuring drill string vibration

To implement the reviewed system hydromechanical vibration sensor is required (figure 3).

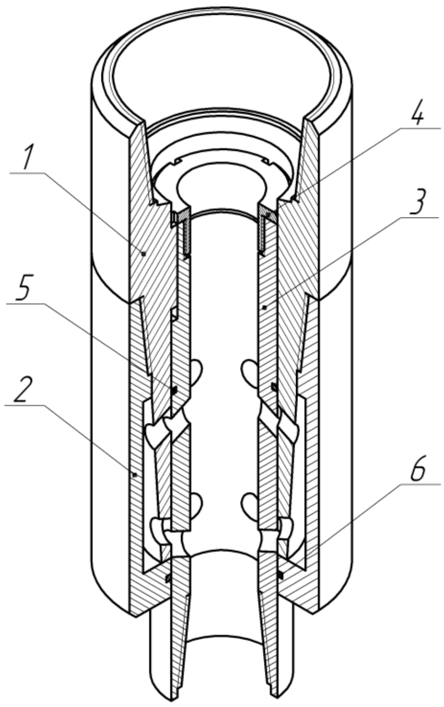


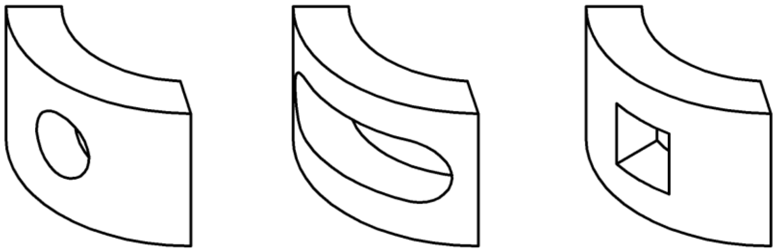
Figure 3. Hydromechanical vibration sensor: 1 – body; 2 – cage; 3 – core; 4 – control sleeve; 5, 6 – seal rings.

The hydromechanical vibration sensor is made of two hollow cylinders that form the body 1 and the core 3 which are connected together by a spline joint, and of the cage 2 that forms the cavity between the body and its internal wall. In the sensor body and core, there is at least one couple of holes that distributes some boring fluid flow to the sensor cavity.

The sensor method is based on receiving vibration load and changing the core's position into an operational one. In this position, holes in the body and the core get connected, and some circulating fluid flow gets distributed from the main cavity of the drill string to the sensor cavity. Consequently, instantaneous value of circulating fluid consumption by the downhole motor changes. It is measured by the downhole flow meter and the tachometer.

4. Analysis of the operating shape of the holes in the vibration sensor

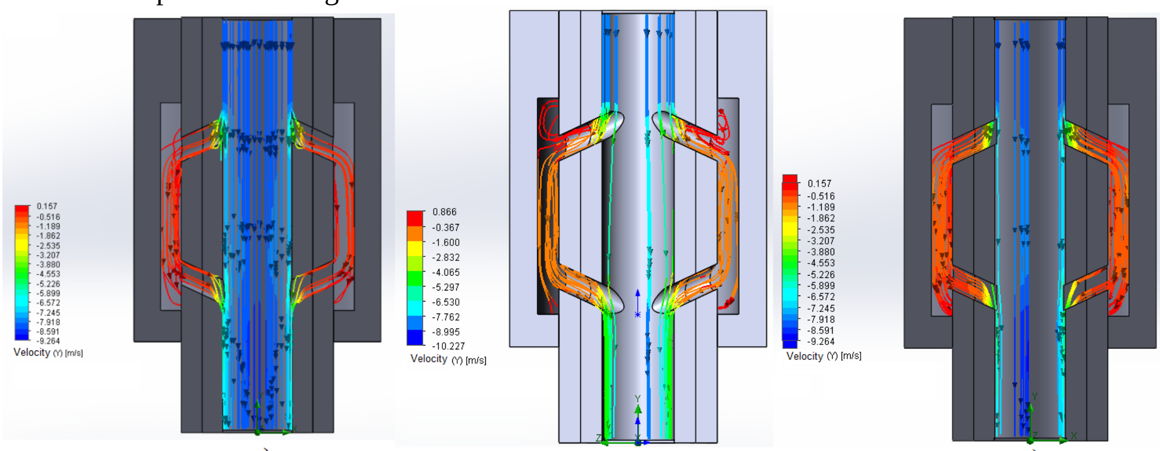
In order to establish the optimal shape and direction of the holes in the hydromechanical sensor, various possible situations were analyzed. The hole shapes are depicted in figure 4.



a) b) c)

Figure 4. Shapes of the holes in the hydromechanical vibration sensor: a) round; b) segmental; c) square.

Circulating fluid flow in the cavity of the hydromechanical vibration sensor in the operational position with various hole shapes (figure 4) was modelled. The results obtained using SolidWorks Flow Simulation are presented in figure 5.



a) b) c)

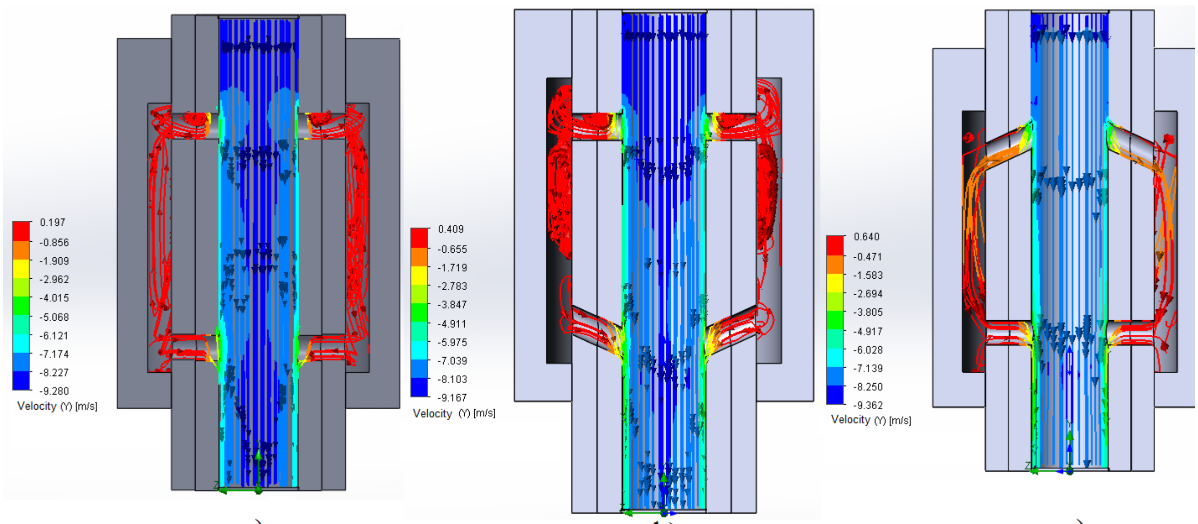
Figure 5. Flow velocity distribution in the operational position of hydromechanical vibration sensor in various hole shapes: a) round; b) segmental; c) square.

After analyzing the distribution data, it may be concluded that a preferred hole shape (figure 5 a) is the round hole shape, because it gives low velocity in the sensor operational cavity, which contributes to holding some of the flow in it. At the same time, the suggested method is better implemented. The square hole shape (figure 5 c) is also functional, because the flow distribution is almost identical to the one with the round shape holes (figure 5 a). However, it is hard to manufacture equipment with such hole shapes.

The segmental (oval) hole shape (figure 5 b) is less preferred, because when using it velocity in the cage cavity is significantly higher than when using the round or square shapes. It is explained by significant narrowing of the circulating fluid flow stream. At that hydraulic resistance caused by this hole shape significantly affects fluid flow velocity, which is inadmissible for making measurements.

Additionally, we analyzed possible directions of the holes when the round shape holes are used. The results are presented in figure 6.

Obtained flow distributions show that when input and output holes are horizontal (figure 6 a), there are whirls, backlash in the hole section. It reduces the sensor effectiveness. When the input hole is horizontal and the bottom hole is tilted (figure 6 b), the situation is similar, which is also rather ineffective. When the input hole is tilted and the upper hole is horizontal (figure 6 c), it is more preferable in comparison with the previous variants.



a) b) c)

Figure 6. Distribution of flow velocity in the operating position of the hydromechanical vibration sensor when the round shape holes are variously directed.

However, the bottom hole creates additional hydraulic resistance, which reduces the velocity of the main flow and which is not observed when the input and the output holes are tilted (figure 5 a). Therefore, the variant shown in figure 5 is the most effective in terms of hole positioning.

5. Conclusion

The article describes the system for active control of drill string vibration by changing boring pump rate when drilling using a downhole motor. It is shown that the design and use of hydraulic mechanical and electric elements in active drill string vibration control and measurement systems are relevant. A hydromechanical vibration sensor is offered as a part of the system. Various hole shapes and directions were analyzed to establish the optimal sensor shape. For this reason, hydromechanical modelling of circulation fluid flow in various possible situations was performed. As the result, a round shape of a tilted hole was established to be the optimal variant.

References

[1] Butler B *et al* 2017 *SPE Drilling & Completion* **32(1)** 175437
[2] Navarro J *et al* 2018 *Tunn. Undergr. Space Technol.* **72** 294–304
[3] Xue Q *et al* 2014 *Shock Vib.* **2014** 429164
[4] Iyasara A C and Ovri J E O 2015 *Int. Journal of Scientific Research Engineering & Technology (IJSRET)* **4** 917–23
[5] Petrovskii E A, Bashmur K A and Nashivanov I S 2019 *Chem. Petrol. Eng.* **54** 711–6
[6] Dong G and Chen P 2016 *Shock Vib.* **2016** 7418635
[7] Wassell M E 2008 *World Oil* **229(9)** 109–11
[8] Zhigang Li 2019 *J. Phys.: Conf. Ser.* **1176** 042062
[9] Shlyk Yu K and Mavlyutov M R 1998 *Higher Educational Institutions News. Neft' i Gas* **1** 45–8
[10] Bashmur K A *et al* 2019 *J. Phys.: Conf. Ser.* **1384** 012005