Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

Hydromechanical method of control of drillstring torsional vibrations

To cite this article: K A Bashmur *et al* 2020 *J. Phys.: Conf. Ser.* **1582** 012010

Hydromechanical method of control of drillstring torsional vibrations

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Abstract. The article discusses issues related to the vibrations of drillstring (DS). The relevance of the fight against torsional fluctuations DS and the reasons for their occurrence are analyzed. The hydromechanical method of control of torsional oscillations DS and device for its implementation is proposed. This method is characterized by its versatility and practically does not depend on the conditions of well drilling. Characteristics of the developed control method are determined by means of the hydraulic model of drilling mud behavior. The model illustrates the operability of the method and can assist in the selection of parameters for regulator design.

1. Introduction

Due to exhaustion of readily available hydrocarbon resources there is an invariable trend of growth of "difficult" wells, including deep, deep-water, inclined directed and horizontal wells. Drilling cost considerably increases in view of direct dependence between deterioration in conditions of drilling capacity and emergence of vibrations [1]. Then the vibrations of drillstring (DS) become increasingly negative as a factor in the likely substantial increase in the economic costs of drilling. According to statistics, the unproductive time caused by the DS vibrations is 25% of the total unproductive drilling time [2].

At the same time vibrations of the system "drive - drillstring - bit" are inevitable, because drilling is a dynamic process of destruction of the processed rock by its abrasion, shearing and/or crushing.

The vibrations and impacts of the DS can affect many characteristics of the drilling process, such as the optimal trajectory and design of the wellbore, the life of the drilling equipment and tool, the mechanical speed of the drilling and the "intelligency" of the drilling in terms of the effects of the vibrations of the DS on the downhole telemetry sensors and their performance in particular [3].

2. Tortional vibrations of drillstring

Torsional vibrations of DS develop in environments representing hard rocks or salt interlayers [4]. They are also intensified by increased friction of the pipe string against rock, which is characteristic of inclined and deep wells, especially when drilling with aggressive bits (PDC) [5], the imbalance of which also refers to the causes of this form of vibrations.

Consequences of this type of vibrations can be various damages and emergency situations with DS and its connecting elements, for example, shuffling or diverting DS elements, initiation of other types of DS vibrations, as well as significant increase of non-productive drilling time [6].

One of the most energy-intensive types of DS torsional vibrations is the "stick-slip motion" of aggressive bits of frequency less than 1 Hz, also referred to as "stick/slip" vibrations caused by non-uniform rotation of DS along the length, in particular due to friction of the bottom arrangement of the drill string against the well walls [7]. This type of DS vibrations is diagnosed by fluctuations of wellhead and bottomhole sensors of moments or revolutions, and at best - accelerometers as part of telemetry equipment. At the same time torques of drive and bit do not coincide, which leads to bit wedge due to lack of energy for rock destruction and further spiral-like twisting of pipe string in growth of driving force, and then sharp free rolling DS at high speed without interaction of bit with rock (slip) [8].

A similar mechanism of torsional vibrations caused by a scab-like face with a frequency ~ 1 Hz and amplitude up to 2 kN·m, formed during drilling with multiball bits [3]. Here, additional energy is needed to overcome the bump formed by the rolling cutters when they fail into it again and again. The consequences are the same as the previous kind of torsional fluctuations.

Thus, the development of methods and means to combat torsional vibration DS is a pressing task of the oil and gas industry. In particular, the fight with torsional vibrations DS by means of adaptive regulators still remains one of the most effective measures of control of vibration state DS [9].

3. Developed method and device for control of torsional vibrations of drillstring

Figure 1 shows the developed DS torsional vibration control device [10].

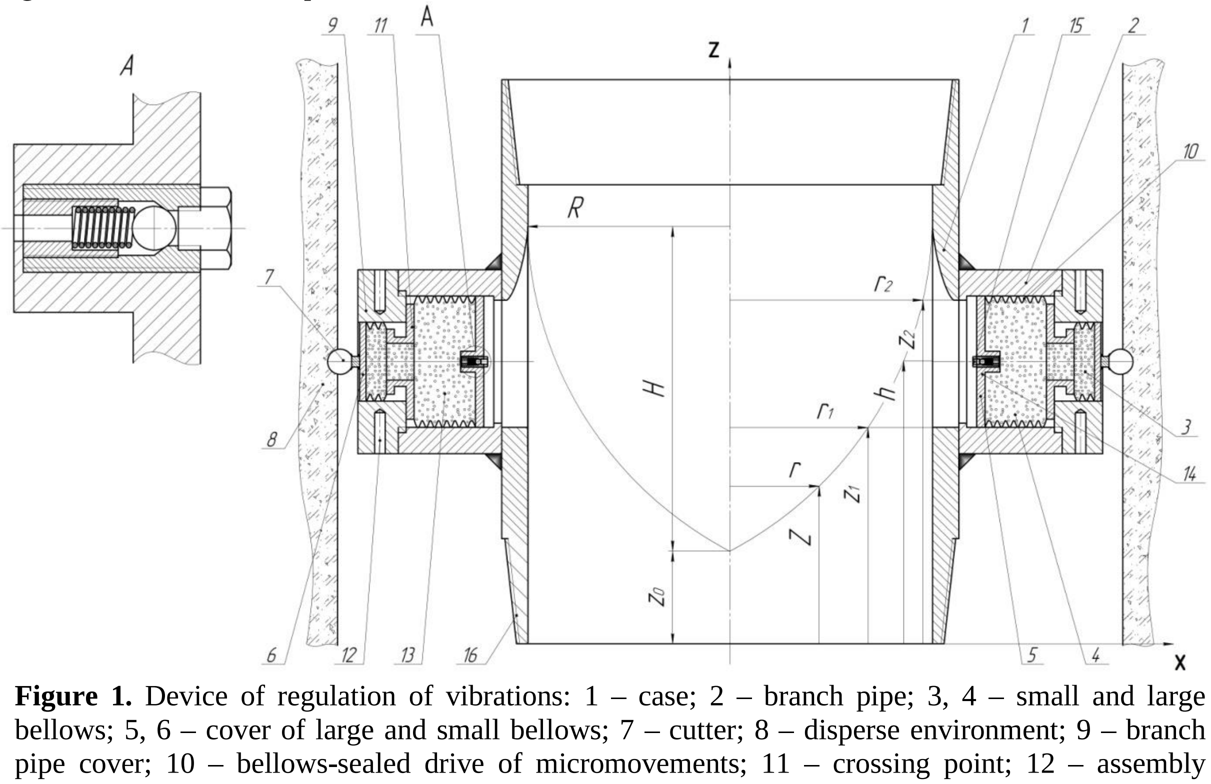

Figure 1. Device of regulation of vibrations: 1 – case; 2 – branch pipe; 3, 4 – small and large bellows; 5, 6 – cover of large and small bellows; 7 – cutter; 8 – disperse environment; 9 – branch pipe cover; 10 – bellows-sealed drive of micromovements; 11 – crossing point; 12 – assembly openings; 13 – gas; 14 – lengthening in a cover; 15 – valve; 16 – conic carving; R – cylinder radius; H – rotation paraboloid height; z_0 – vertex of the paraboloid of rotation from the origin; Z – projection of the distance to the particle on the z-axis; r – radius from the axis of rotation to the particle (on the liquid level on the surface of the paraboloid).

Installation of the DS torsional vibration regulator is carried out at the theoretically calculated surface level of the hydrostatic column of the drilling mud in DS.

Drilling fluid is supplied via DS. Obtained force effect of drilling fluid pressure is transmitted to regulator depending on DS rotation speed by converting drilling fluid pressure force by means of bellows drive of micro-displacements 10 for insertion of cutter 7 into dispersed medium 8. The force of resistance to DS rotation changes as the pressure on the micro-displacement drive 10 of the cutter 7 changes by its interaction with the dispersed medium 8 (rock of the well wall). Volume of drilling fluid can be formed by ring installed in case 1 above drive 10. Filter may be arranged at branch pipe inlet. As the DS rotation speed increases, the pressure on the micro-displacement actuator 10 increases. At this time, the drive 10 is moved to the periphery of the cylindrical working to a depth dependent on the pressure on the drive 6 and therefore on the number of revolutions DS, and the cutter 7 is introduced into the medium 8. This increases the torque of resistance to DS rotation. As the DS rotation speed decreases, the pressure on the micro-displacement drive 10 decreases, and it moves toward the DS center, thereby reducing the recess of the cutter 7 in the medium 8 and reducing the torque of resistance to DS rotation.

In this way, the medium insertion tool forms and changes the resistance forces that affect the DS rotation moment. Thus vibration loads - amplitude and frequency of forced torsional oscillations transmitted to DS elements are regulated. The method is also applicable for systems of rotating pipelines, hollow shafts with supply of, for example, lubricant or cooling agent and other systems.

The universality of this method is also visible, in particular due to: damping of any types of torsional oscillations at independence of the system from the source of oscillations and autonomy at absence of additional measuring equipment, as well as improvement of operating qualities and reliability of the regulator due to small number of mechanical connections in the device, small weight and size indices in conditions of the well environment, its effective control when using accurate drive of micro-displacements in the regulator.

4. Definition of characteristics of developed method of control of torsional vibration of DS

It will be appreciated that it is of most interest to determine the dependence of the pressure force of the drilling fluid on the micro displacement actuator on the DS rotational speed. This is the goal we put in the task of defining characteristics for the developed method.

The model for determining the characteristics of the developed method is shown in Figure 1. At the same time inertia forces acting on drilling fluid at DS rotation with frequency ω create paraboloid of rotation with height H and vertex z_0. Obviously, the level surfaces are also paraboloids of rotation, and the piezometric surface coincides with the free surface of the liquid at atmospheric pressure. Then the free surface equation is:

$$z = z_0 + H \tag{1}$$

where: z_0 – the rotation paraboloid top; H – the height of the point on the level surface of the paraboloid of rotation.

Expressing the height of the paraboloid of rotation, we get from (1):

$$z = z_0 + \frac{\omega^2 r^2}{2g} \tag{2}$$

where: ω – DS speed; r – the radius of the particle from the axis of DS rotation to the surface of the level of the paraboloid of rotation.

In order to simplify the calculations, it is assumed that the volume of liquid in the system in question does not change. Then, the mud level before the start of the DS rotation can be expressed as:

$$h = \frac{1}{2}[2z_0 + \frac{\omega^2}{2g}(r_1^2 + r_2^2)] \tag{3}$$

where: r_1, r_2 – radii-distances to particles from the axis of DS rotation on the surface of the level of the paraboloid of rotation.

We express the rotation coordinate of the paraboloid of (3):

$$z_0 = h - \frac{\omega^2}{4g}(r_1^2 + r_2^2)\,. \tag{4}$$

Overpressure at any point of the liquid is, taking into account (2) and (4):

$$p = \rho g h + \frac{\rho}{2}\omega^2 r^2 - \frac{\rho}{4}\omega^2 r_1^2 - \frac{\rho}{4}\omega^2 r_2^2\,. \tag{5}$$

Then the pressure force on the whole cover of the micro-displacement drive is:

$$dF = p \cdot 2\pi r dr\,. \tag{6}$$

Taking integral as per R for (6), we get dependence of pressure force on the cover of micro displacement drive on rotation speed DS n:

$$F(n) = \rho g h \pi R^2 + \rho \pi R^2 (R^2 - r_1^2 - r_2^2)\pi^2 n^2\,. \tag{7}$$

To estimate the numerical data, we create a dependency (7) (Figure 2). Table 1 shows the parameters required to construct the dependency (7) and close to the actual drilling conditions of oil and gas wells.

Table 1. Parameters to graph the dependency of the pressure force of the drilling fluid F on the n DS rotation speed

Parameter	ρ, kg/m^3	h, mm	R, mm	r_1, mm	r_2, mm
Value	1450	135	116	62	92

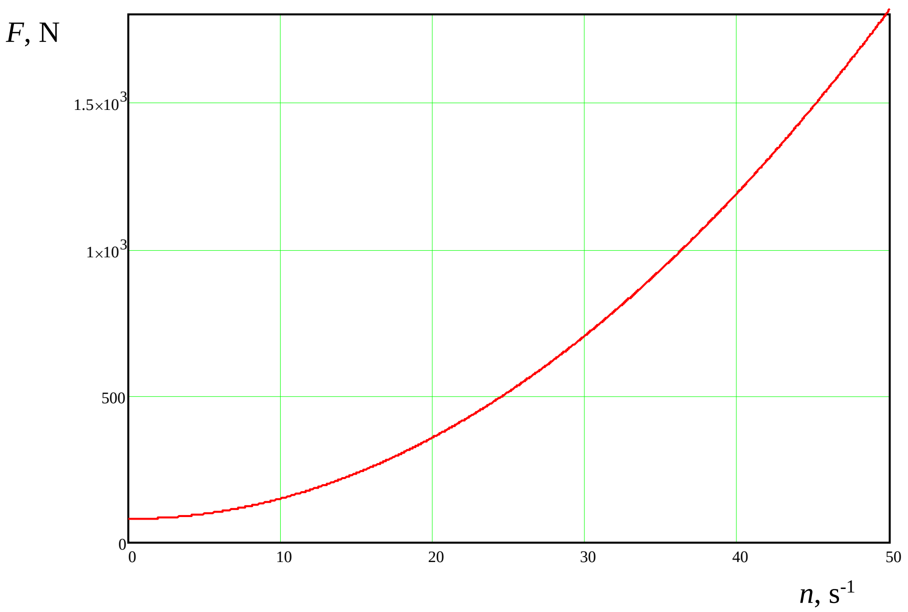

Figure 2. The dependency of the pressure force of the drilling fluid from the DS rotation speed.

The dependence is a parabola with a center (n = 0) equal to the hydrostatic pressure force on the cover (first compound in expression (7)), and a parabola branch dependent on the DS rotation speed (second compound in expression (7)). It is obvious that inertia forces prevail considerably over hydrostatic pressure, which indicates the operability of the developed DS method of torsional vibration damping. As a result of the evaluation of these parameters, it is possible to select characteristics of the micro-displacement drive. In particular, selection of pressure for filling the drive cavity with gas and rigidity of bellows corrugations.

5. Conclusion

The relevance of DS torsional vibration damping, as well as the development of effective methods and means of their regulation, has been revealed. In particular, it has been found that DS stick/slip oscillations are particularly dangerous. The method of controlling torsional oscillations based on creating a torque of resistance to DS rotation by hydromechanical means when using energy of drilling fluid is disclosed. The parameters of the method have been evaluated, its operability has been shown. A design based on this DS vibration control method has been created.

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