# Adaptive vibration absorbing method of torsional vibrations for processing equipment

**K A Bashmur[1], E A Petrovsky[1], I A Mazurov[1], V V Bukhtoyarov[1], S V Tynchenko[1] and A A Gorodov[1]**

[1]Siberian Federal University, 79, Svobodny Avenue, Krasnoyarsk, 660041, Russia

E-mail: bashmur@bk.ru

**Abstract.** This article describes issues relating to monitoring vibrations affecting the processing equipment. Especially, the problem of negative influence from the increased vibration background in well drilling, where the issue is the most acute, is being described. The urgency of creating methods to monitor vibration condition, due to which it becomes possible to design reliable and efficient structures with the required characteristics and purpose, is shown. Particular attention is paid to passive methods for monitoring torsional vibrations of pipe columns. In this case, the developed method for monitoring the vibration condition of torsional vibrations is presented, and its effectiveness is shown. In addition, a new device for monitoring torsional vibrations to the developed method, which is distinguished by its simplicity as well as high potential of reliability and efficiency, is shown.

## 1. Introduction

The vibrations of machinery and equipment of the oil and gas complex are one of the main negative factors leading to decrease in fault-free time and increase in repair and operating costs. The problem is particularly acute in drilling, since vibrations of the drive unit – drill string – drilling bit system (hereinafter referred to as DS vibrations) are inevitable, since the drilling is a dynamic process of destruction of the rock that being worked [1].

DS vibrations are one of the factors limiting drilling performance. In addition, vibrations and impacts of DS can affect many characteristics of the drilling process, mainly: optimal trajectory and wellbore construction, equipment and tool life, as well as the intelligence of drilling in terms of the impact of DS vibrations on the telemetry downhole instrumentation and their indicators in particular [2].

In the last decade, well drilling has come to widespread use of complex and expensive technologies, therefore, the vibration effect on equipment arising during the drilling process leads to even greater economic losses. Therefore, the development of effective methods for monitoring vibration condition is an urgent task [3].

## 2. The relevance of the development of vibration condition monitoring method

One of the ways to reduce the cost of drilling operations is to increase the penetration of a well, which can be achieved by changing the operating parameters: the DS rotary speed or the axial stress on the bit. However, a change in these parameters may lead to intense vibrations of DS. Variable stress may cause serious damage to drilling equipment.

DS vibrations, which can occur during the rotary drilling, may be divided into three main types: axial, torsional, lateral. The main problems related to various types of DS vibrations are summarized in Table 1.

**Table 1.** Negative influence of the vibrations on the drilling process

| Type of vibration | Negative influence |
|---|---|
| Axial | 1. Increased wear and / or breakdown of the DS and tool;<br>2. damage and / or fatigue breakdown of the the bit blades;<br>3. abnormality of the downhole equipment. |
| Torsional | 1. Slowing down, well-drilling shutdown;<br>2. damage and / or fatigue breakdown of the the bit blades;<br>3. elution, ring-off, and tight pull of the thread connections;<br>4. touching the bottom-hole assembly (BHA) with the wellbore wall; additional mechanical friction losses. |
| Lateral | 1. Premature and uneven tool wear;<br>2. unplanned well reaming;<br>3. DS buckling, the narrowing of its flow area. |

When drilling with PDC bits, problems are often caused by torsional stick / slip vibrations. They are uneven rotation of the DS along its length, caused by the cutting resistance of the rock characteristic of this type of bit [4].

To reduce the vibration level, there are various methods and monitoring systems. Nowadays, active methods of monitoring the DS vibration have a high potential [5]. For example, a widely known, proposed by Jansen and Van den Steen [6], method of monitoring stick / slip vibrations with the help of active control of a wellhead hydraulic motor. However, active monitoring methods have number of drawbacks, which are almost impossible to eliminate. In particular, it is low reliability of recording arrangements and their vibration measurement parameters, as well as high response time. Most methods of active monitoring are not beyond the scope of laboratory research.

There are methods of active and semi-active vibration monitoring, based on the action of the electromagnetic field [7]. However, they require the provision of electricity and are significantly dependent on heavy down-hole conditions.

Another method to monitor vibrations is to protect equipment with the help of vibration dampers built into the DS. The use of vibration dampers, balancing the dynamic DS system, is one of the most popular and effective methods of passive vibration monitoring [8]. Usually, the vibration dampers of torsional vibrations consist of elastic elements, which are mechanical or hydraulic springs, which provide for the reduction of vibration stress. The advantage of using passive monitoring with vibration dampers is its reliability, efficiency and wide functionality. Thus, the methods of passive vibration monitoring still contain a high potential for engineering creativity and it is invariably only that they are massively being realized and put into practice.

## 3. New method of vibration condition monitoring

The authors developed a method to monitor torsional vibrations, which can be used to neutralize torsional vibrations of technological equipment, in particular, stick / slip vibrations of DS. The essence of the method is as follows. A cutter is being installed on the rotating part, which has contact with a substance close in composition to the rock through some external stress. In this way, the cutter forms and changes the resistance forces that influence the rotation torque. Thus, they control the vibration stress, that is, the amplitude and frequency of the forced torsional vibrations transmitted to the DS elements.

Consider a principle of the method of monitoring the vibration condition (Figure 1).

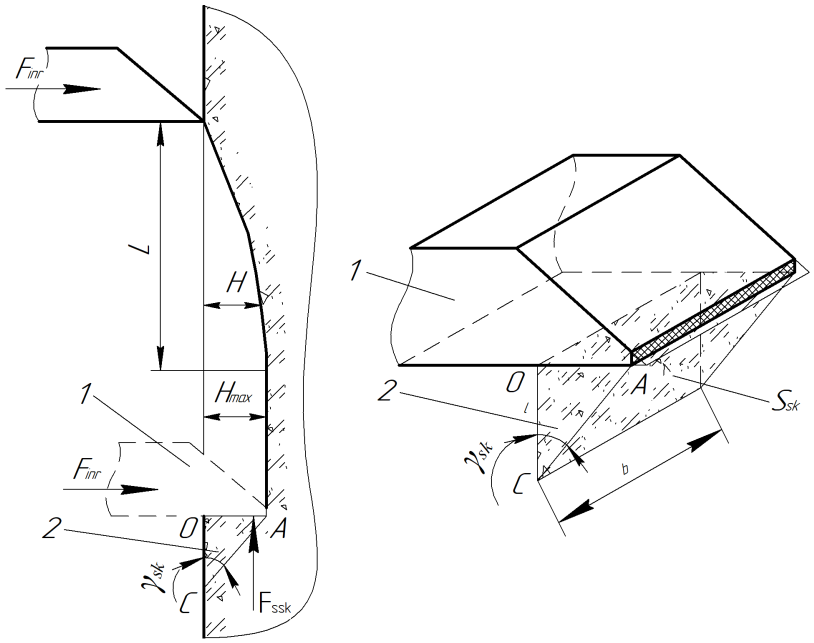


**Figure 1.** Scheme of the method: 1 – cutter; 2 – elements of the cut rock

For some time along the cutting plane $L$, the depth of $H$ penetration into rock 2 increases to the maximum value $H_{max}$. This period of the cutter 1 operation is taken as established, under the condition of equality of all forces acting on the cutter. The penetration of cutters at a certain depth $H$ occurs under the action of an external force $F_{inr}$, acting axially on the cutter. In this case, the moment of resistance to the DS rotation $M_{svr}$ increases if the force $F_{ssk}$ the related to its increases.

Determine the moment of resistance to the DS rotation $M_{svr}$:

$$M_{svr} = F_{ssk} d \tag{1}$$

where $F_{ssk}$ – is the force of the rock resistance to spalling, $d$ – is the arm of force of the spalling action.

Thus, the analysis of the effectiveness of the monitoring method comes to the determination of the force of rock resistance to spalling $F_{ssk}$ when penetrating the cutter. The method proposed by Zvorykin [9] was chosen as the basis for the calculation.

We can determine the magnitude of the resistance force to rock spalling $F_{ssk}$ as:

$$F_{ssk} = S_{sk} \sigma_{sk} \tag{2}$$

when $S_{sk}$ – is the area of spalling of the rock, $\sigma_{sk}$ – is the pressure at the resistance of the rock to spalling.

Following Figure 1, the value of $S_{sk}$ is determined by the product of the rectangle sides $b$ and $l$, and $l$ is expressed by the product of the side AC and $\cos\gamma_{sk}$ of a right-angled triangle AOC, respectively, the side AC is expressed by dividing the side $AO$ by $\sin\gamma_{sk}$. Considering also that AO = $H_{max}$:

$$l = \frac{H_{\max}}{\sin \gamma_{sk}} \cos \gamma_{sk} = H_{\max} \cot \gamma_{sk} \tag{3}$$

$$S_{sk} = b H_{\max} \cot \gamma_{sk} \tag{4}$$

Substituting the derived expression for $S_{sk}$ into equation (2), the authors obtain the magnitude of the force $F_{ssk}$:

$$F_{ssk} = \sigma_{sk} b H_{\max} \cot \gamma_{sk} \tag{5}$$

Substituting the expression $F_{ssk}$ into equation (1), the authors obtain the magnitude of the moment of resistance to the DS rotation $M_{svr}$:

$$M_{svr} = \sigma_{sk} b H_{\max} d \cot \gamma_{sk} \tag{6}$$

According to the formula (6) and according to the data from table 2, taken for a real well, the authoirs graph a dependency of the moment of resistance to rotation on the deepening of the cutter (Figure 2).

**Table 2.** Parameters to graph the dependency of the moment of resistance to the DS rotation $M_{svr}$ on the depth of the cutter penetration $H_{max}$

| Parameter | *d, mm* | $\gamma_{sk}$, ° | $\sigma_{sk}$, *MPa* | *b, mm* |
|---|---|---|---|---|
| Value | 140 | 10 | 37 | 20 |

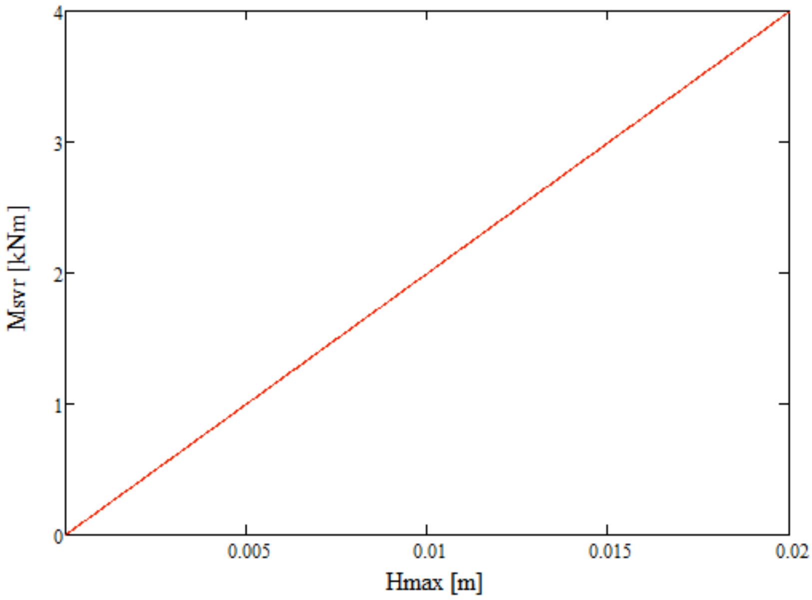


**Figure 2.** Dependency of the moment of resistance to DS rotation on the depth of the cutter penetration

The graph shows that the moment of resistance to the DS rotation $M_{svr}$ is a linear dependency when considering this cutting model. When $H_{max}$ = 2 cm is reached, the moment of resistance to the DS rotation of $M_{svr}$ reaches 4 kNm. The calculations are given for interaction of one cutter, and when adding other cutters, the moment of resistance to DS rotation will increase by multiple. For example, if you add the 2nd symmetrical cutter and when each of 2 cm is deepened, the moment of resistance to DS rotation $M_{svr}$ will be 8 kNm.

Some types of powerful modern top drive systems, which are characterized by these types of stick / slip vibrations of the DS when drilling by them, reaching a maximum rotation torque of 58 kNm and more. It is known that stick / slip vibrations in this case can reach 20 % of the maximum rotation torque of the drive, that is, 11.6 kNm [10]. Thus, it is seen that with nominal drilling modes and vibrations, this vibration monitoring method can effectively neutralize the stick / slip DS vibrations.

## 4. Developed vibration-monitoring device

Based on the presented method for monitoring the cutter and the magnitude of its stroke, the authors developed a vibration-monitoring device (Figure 3) [11].

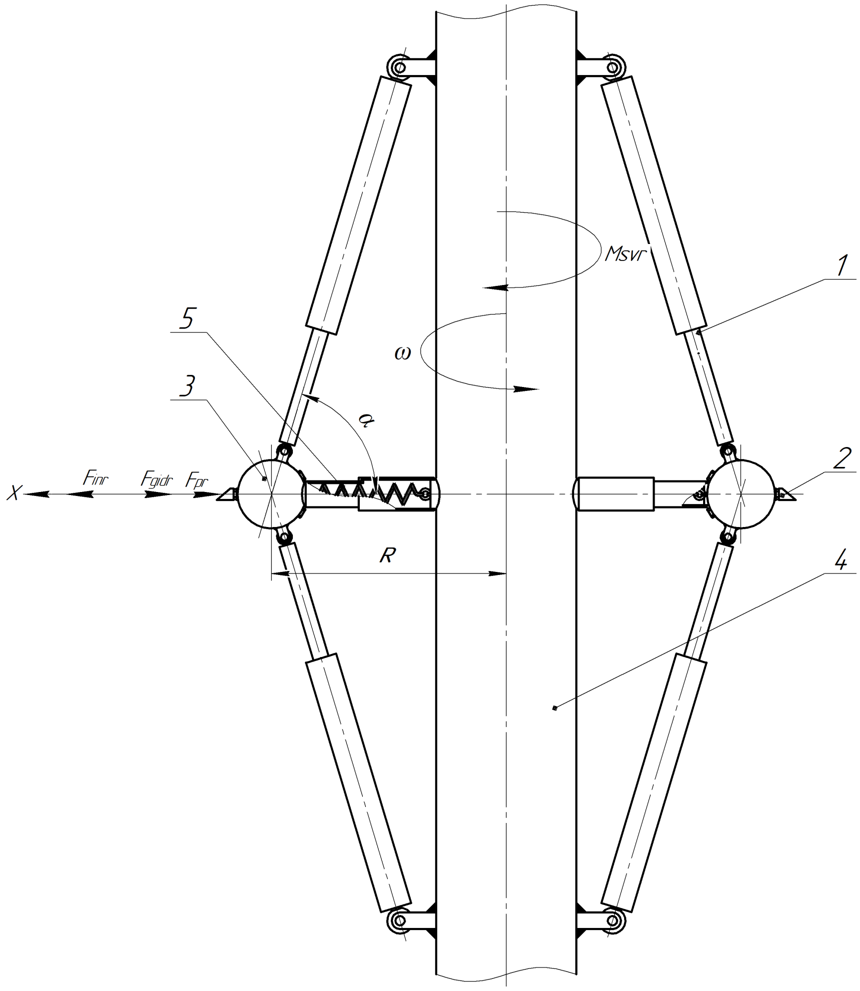


**Figure 3.** Vibration-monitoring device: 1 – shock absorber, 2 – cutter, 3 – pivot, 4 – DS (or shaft), 5 – recoil spring

The operation of the device is based on the formation of force actions transmitted to object. The change in the vibration condition of an object when a monitoring device is connected can be carried out both by the vibrational energy redistribution of the device to the object, and by using the device's interaction with the rock (with wellbore walls). The first method is implemented by changing the inertia force of the monitoring system. Under the action of vibration stress of a wider frequency range, the second method is more preferable which is based on penetration of cutters into the rock.

The device works as follows. When increasing the DS rotary speed $\omega$, the shock absorbers arm 1 $R$ increase, respectively, the pivots` mass 3 move to periphery and the cutters 2 are penetrating to the depth $H_{max}$ under the influence of the force $F_{inr}$. When decreasing the DS rotary speed $\omega$, the shock absorbers arm 1 $R$ decrease, respectively, the pivots` mass 3 move to the side of DS 4 thereby reducing the deepening of the cutters into the rock, and the position of the shock absorbers is also stabilized due to the springs force 5 and hydraulic shock absorbers 1.

When changing the DS rotary speed $\omega$, parameters of piston pressure $P$ in the shock absorbers, spring force $k$, as well as angle $\alpha$ between the shock absorber and axis X change:

$$2(2F_{gidr} + F_{pr}) = 2F_{inr} \tag{7}$$

where $F_{gidr}$ – is the pressure force in a tube of the shock absorber, $F_{pr}$ – is the elastic force of recoil spring, $F_{inr}$ is external stress on the cutter (inertia force of rotate DS).

Expressing the forces in the formula (7), the authors obtain the final version of the vibration damper working condition:

$$2PS\cos\alpha + kx = m\omega^2 R \quad (8)$$

where $P$ – is the pressure in the shock absorber tube, $S$ is the piston area, $k$ is the spring force, $x$ – is the spring elongation (cutter depending $H_{max}$), $\alpha$ – is the angle between the shock absorber and the axis X, $m$ – is the pivot mass, $\omega$ – is the DS rotation frequency, $R = R_0 + | x |$ – shock absorber arm, $R_0$ – the initial value of the shock absorber arm.

The operation of the vibration damper for a given the cutters deepening in the rock can be constructively regulated by the parameters $P$, $S$, $k$, $R$ of expression (8).

## 5. Conclusion

The relevance of the development of effective methods for monitoring the vibrations of technological equipment, in particular stick / slip DS torsional vibrations, is revealed. The method of monitoring stick / slip torsional vibrations, based on the resistance to DS rotation moment creation, is proposed. The assessment of the method, which showed its high efficiency, is carried out. The construction design based on this method of control is created. The ways of regulating the construction design parameters, which significantly affect the torsional vibrations monitoring, are reflected.

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