VARIATION OF BRAKING TORQUE DURING LOWERING OF THE DRILL GASKET

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Abstract:
This paper analyzes the braking torques necessary to control the descent of the drill bit in the well. Separately, it analyzes the cases of using only the belt brake (movement stop brake) and the belt brake with to the hydraulic brake (the motion control brake). The use of both brakes will increase service life and the braking system.
Keywords: *braking, gasket, belt brake, hydraulic brake, borehole*

1. Introduction

The lowering of the gasket is done, as in the case of lifting, drill pipe stand by drill pipe stand. In contrast to lifting, when the energy provided by the motors was required for the upward movement of the load, the descent is due to the gravitational effect. Upon introduction, the drum is disconnected from the drive system, the downward movement of the gasket being made due to its own weight and the problem of controlling the lowering of the gasket arises. The control of this movement is performed with the help of brakes which have the role of adjusting the lowering process and locking the gasket in the desired position. There are several types of brakes capable of performing these functions: locking brake with bands and hydraulic or electromagnetic brakes. The auxiliary operations where the power of the motors is required when descending a step of the drilling gasket are detailed in figure 1 [1].

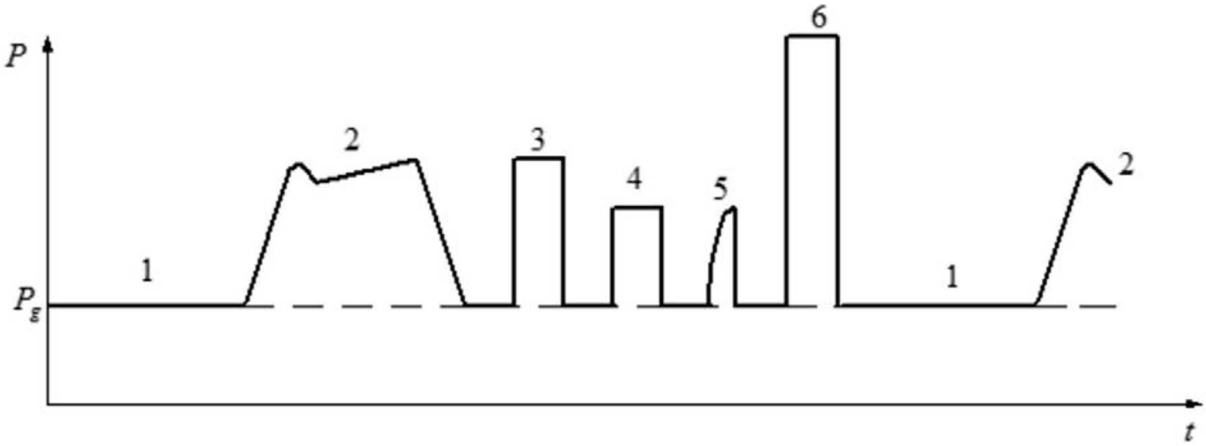

Fig. 1. *Auxiliary operations where the power of the motors is required when descending a drill pipe stand*
1. Drill pipe stand down; 2. Lifting the empty travelling block; 3. Raise of the drill pipe stand from stack; 4. Screwing; 5. Tightening; 6. Pick up the drill gasket from the slips

During the lowering process, the energy of the engines is required only for performing auxiliary operations, namely:

- raising the empty travelling block;
- skipping the drill pipe stand from stack;
- screwing the drill pipe stand and tightening the threaded joints;
- skipping the gasket of the slips.

The brake will be used only during the lowering of the load (duration , figure 2) and in the static cases of keeping the load suspended in the hook.

The variation of the speed of the hook over a complete cycle is shown in figure 2 and is done as follows:

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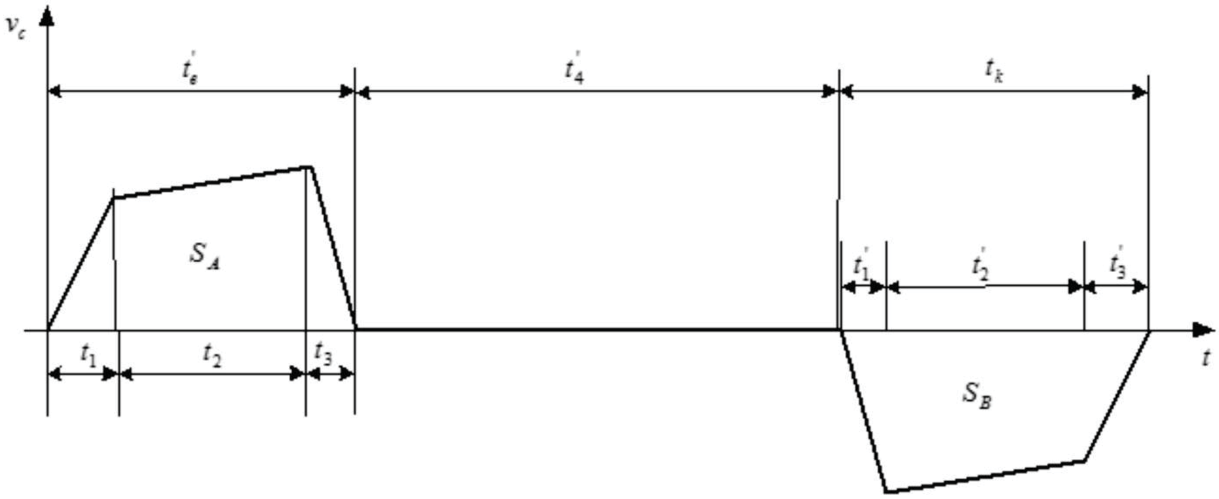

Fig. 2. *Hook speed over a complete cycle*

where: $t_4^{'}$ is the auxiliary time;

$t_e^{'}$ is the lifting (raising) time of the empty travelling block:

$$t_e^{'} = t_1 + t_2 + t_3 \quad (1)$$

t_k the time during which the load (force) is lowered:

$$t_k = t_1^{'} + t_2^{'} + t_3^{'} \quad (2)$$

Because the descending (duration $t_e^{'}$) and ascending (duration t_k) movements are equal to each other (equal to the joint of drill pipe length) the areas under the velocity curves (tachograms) in figure 2 are equal:

$$S_A = S_B = k\, l_p \quad (3)$$

with k scale coefficient and l_p the length of the drill pipe stand.

It is forbidden to apply the brake before the end of the period t_3. During this period the gasket still has upward (decelerated) movement, which the brake cannot stop (the drilling cables do not take compression effort). If the brake is applied to $t_3^{'} < t_3$, the gasket will gain the ascent speed v_a (g – the gravitational acceleration).

$$v_a = g\left(t_3 - t_3^{'}\right) \quad (4)$$

In this case, the following processes occur:

- the drum stops when the brake is applied;
- the gasket continues the upward movement, over a distance Δh, a time interval Δt :

$$\Delta h = \frac{g\left(t_3 - t_3^{'}\right)^2}{2} \quad (5)$$

- potential energy is accumulated:

$$E_p = G\,\Delta h \quad (6)$$

- the cable can jump off the rollers, but even if it does not jump, the gasket falls at the beginning of the period t_4 from height Δh, developing the kinetic energy, which is taken by the cable through shock.

$$E_c = \frac{1}{2} m\, g^2 \left(t_3 - t_3^{'}\right)^2 \quad (7)$$

where, m is the cumulative mass of the load (forces) and the mobile equipment (travelling block-hook).

2. Determination of braking torques in case the hydraulic brake is not used (adjusting brake) [2]

Braking torques of static force (at rest of the gasket) (the deadweight of the hoisting equipment is considered included) at the beginning of the descent M_{fs1} and the end of the descent M_{fs2} of a drill pipe stand are:

$$M_{fs1} = F_s \frac{D_z}{2} \quad (8)$$

$$M_{fs2} = F_s \frac{D_1}{2} \quad (9)$$

where: F_s - the force from the fast line to the hoisting drum

$$F_s = \frac{F_c}{2m} \quad (10)$$

F_c – maximum force from the drilling hook of the drilling rig;

m – number of sheaves of the travelling block;

D_z – the diameter of the drilling line winding on the last drill line string (in the case of the drilling rig with a hook force of 3200 kN, usually, the maximum number of drill line string of the hoisting drum is 5);

D_1 – the diameter of the cable winding on the first string of drill line.

Let's consider the case of a quasi -vertical borehole [3]. But, during the lowering period of the drill bit, the load at the hook decreases due to the local friction and resistance, this being:

$$F_{sc} = F_s^{'} - \left(F_f + F_p + F_r\right) \qquad (11)$$

$F_s^{'}$ – static force at the hook-block;

$$F_s^{'} = G_{sa}^{'}\left(1 - \frac{\rho_n}{\rho_o}\right) \qquad (12)$$

$G_{sa}^{'}$ – weight of gasket in air;

ρ_n – the density of the drilling mud;

ρ_o – density of steel.

F_f – the friction force of the drill string in the drilling mud, on the inner and outer walls;

$$F_f = \lambda\,\rho_n \frac{v_c^2}{2}\pi\left[\left(D_{epf} + D_{ipf}\right)L_{pf} + \left(D_{epg} + D_{ipg}\right)L_{pg}\right] \qquad (13)$$

λ – global coefficient that takes into account friction phenomena;

v_c – the lowering speed of the drilling gasket;

D_{epf}, D_{ipf}, L_{pf} – the outer, inner diameters and length of the drill pipe;

D_{epg}, D_{ipg}, L_{pg} – the outer, inner diameters and length of heavy pipe (drill collars).

F_p – the friction force of the gasket on the deflected hole walls,

$$F_p = k_p\,F_s^{'} \qquad (14)$$

k_p – coefficient that takes into account the friction of the gasket on the borehole walls.

F_r – the resistance force coming from the edges of the joints of the gasket in move.

$$F_r = c_r\,F_s^{'} \qquad (15)$$

c_r – coefficient that takes into account the influence of the existence of the gasket joints being in motion.

The force at the active drill line of the hoisting drum is:

$$F_{2m+1} = F_{sc}\,\frac{\beta - 1}{\beta\left(\beta^{2m} - 1\right)} \qquad (16)$$

β – coefficient that depends on the efficiency of the travelling-block sheaves, which, for sheaves mounted on bearings, has values within the range $\beta = (1{,}02...1{,}04)$.[4]

The moments of braking of this force, at the beginning and at the end of the descent of a drill pipe stand, are:

$$M_{f1} = F_{2m+1}\frac{D_z}{2} \qquad (17)$$

$$M_{f2} = F_{2m+1}\frac{D_1}{2} \qquad (18)$$

During the period t_1 the load descent begins when, under the action of the gravitational force, the moving masses are accelerated: the load (useful) at the hook, the sheaves of the travelling-block and crown-block, the drilling line and all the solid masses with the hoisting drum and the draw works shaft. The torque increases from the value 0, at the torque of starting, until the torque M_{f1} when the speed in descent reaches the speed of regime. At this time the brake belts are applied. Now the condition is that the braking torque does not exceed the torque of static forces M_{fs1}. At the end of the period t_1, when the acceleration is a_1, the braking torque is:

$$M_{fs1} = F_{2m+1}\frac{D_z}{2} + \frac{F_{2m+1}}{g}\frac{D_z}{2}a_1 + \left(\beta^{2m}J_{red} + J_a\right)\frac{2}{D_z}a_1 \qquad (19)$$

Note: In order not to hasten the brakes and the drilling rig, the braking must be done with a torque M_{fs1} between (M_{f1}, M_{f2}).

J_{red} – the reduced moment of inertia of the moving masses: the sheaves of travelling-block and crown-block and drill line;

J_a – the moment of inertia of the solid pieces of the hoisting drum shaft.

From the relation (19) the acceleration from the end of the period t_1 is established:

$$a_1 = \frac{M_{fs1} - F_{2m+1}\dfrac{D_z}{2}}{\dfrac{F_{2m+1}}{g}\dfrac{D_z}{2} + \left(\beta^{2m}J_{red} + J_a\right)\dfrac{2}{D_z}} \qquad (20)$$

With this acceleration a_1, the duration will be realized to descent the drill pipe stand length l_{p1}.

$$t_1 = \frac{0 + v_1}{2}\frac{1}{a_1} \qquad (21)$$

$$l_{p1} = \frac{v_1}{2 \cdot 2m}t_1 \qquad (22)$$

v_1 – the speed of the active drill line at the end of the period t_1, is considered equal to the speed from the end of the period of hoisting the maximum load (force) at the hook:

$$v_1 = \frac{\pi\,n_1}{60}D_z \qquad (23)$$

n_1 – drum speed (rpm) in first gear.

After finishing the drill pipe stand length l_{p1} descent, begins the periods t_2 and t_3. At the beginning of the period t_2, braking is performed at the braking torque M_{f2} and until the end of the descent (complete introduction of the drill pipe stand, when all static and inertia forces must be braked). The braking torque must not exceed the braking torque of static forces.

$$M_{fs2} = F_{2m+1}\frac{D_1}{2} + \frac{F_{2m+1}}{g}\frac{D_1}{2}a_3 + \left(\beta^{2m}J_{red} + J_a\right)\frac{2}{D_1}a_3 \quad (24)$$

The acceleration a_3 in this period is:

$$a_3 = \frac{M_{fs2} - F_{2m+1}\frac{D_1}{2}}{\frac{F_{2m+1}}{g}\frac{D_1}{2} + \left(\beta^{2m}J_{red} + J_a\right)\frac{2}{D_1}} \quad (25)$$

With this acceleration a_3, the braking time until stopping t_3 will be realize lowering the drill pipe stand length l_{p3}.

$$t_3 = \frac{0 + v_3}{2}\frac{1}{a_3} \quad (26)$$

$$l_{p3} = \frac{v_3}{2 \cdot 2m}t_3 \quad (27)$$

v_3 – the speed of the fast drill line at the end of the period t_3 is considered equal to:

$$v_3 = \frac{\pi n_1}{60}D_1 \quad (28)$$

During the period t_2 are applied the brake belts so that:
a. the lowering speed remains constant or
b. drum speed remains constant.

a. The descent speed remains constant - in this case, due to the variation of the diameter with the drill line winding, the drum speed (angular velocity) increases. The influence of the drum speed variation is negligible. Resistant torques resulting from the inertia of the drum with the drill line wrapped appear. [4]

The length of the drill pipe stand lowered during this period is l_{p2}:

$$l_{p2} = l_p - (l_{p1} + l_{p3}) \quad (29)$$

The descent duration of this drill pipe stand length is t_2:

$$t_2 = \frac{l_{p2}}{\frac{v_1}{2m}} \quad (30)$$

The angular speeds and accelerations at the drill drum will be:

$$\omega_1 = \frac{2v_1}{D_1};\quad \omega_1^{'} = \frac{2v_1}{D_z} \quad (31)$$

$$\varepsilon = \frac{\omega_1 - \omega_1^{'}}{t_2} \quad (32)$$

The braking acceleration is established on the assumption that the angular acceleration is constant, at the average of the winding diameters D_1 and D_z

$$a_2^{'} = \frac{\varepsilon\left(\frac{D_1 + D_z}{2}\right)}{2} \quad (33)$$

The braking torque at the end of the period t_2 will be:

$$M_{f2}^{'} = F_{2m+1}\frac{D_1}{2} + \left(\beta^{2m}J_{red}\right)\frac{2}{D_1}a_2^{'} \quad (34)$$

b. the drum speed remains constant - in this case, the lowering speed decreases and occurring resistant torques resulting from the inertia of the crown block-travelling block-drill line system.

The speed variation is:

$$n_1 = \frac{60v_1}{\pi D_1} = \frac{60v_1^{'}}{\pi D_z} \Rightarrow v_1^{'} = v_1\frac{D_z}{D_1} \quad (35)$$

The acceleration is:

$$a_2^{''} = \frac{v_1^{'} - v_1}{t_2} \quad (36)$$

The braking torque will be:

$$M_{f2}^{'} = F_{2m+1}\frac{D_1}{2} + \frac{F_{2m+1}}{g}\frac{D_1}{2}a_2^{''} + \beta^{2m}J_{red}\frac{2}{D_1}a_2^{''} \quad (37)$$

The variation of the braking torque is shown in figure 3.

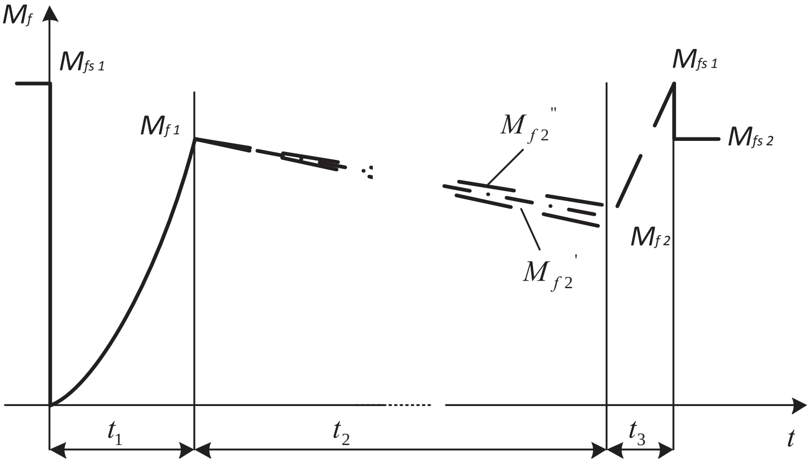

Fig. 3. *The variation of the braking torque through the the brake belts*

The total descent time is:

$$t_c = t_1 + t_2 + t_3 \tag{38}$$

3. Determination of braking torque when the hydraulic brake is also used (adjusting brake) [5]

The torque developed by the hydraulic brake is influenced by the geometric dimensional elements of the hydraulic brake:

$$M = \frac{z\,k\,a}{0{,}45}\left(R_2^5 - R_1^5\right)n^2 \tag{39}$$

z – the number of blades on one side of the brake stator;
k – coefficient of resistance of the descending blades;
a – coefficient that takes into account the proportional increase of the width of the blade;
R_2 – the outer radius of the blades part;
R_1 – the inner radius of the blades part..

During the period t_1 the hydraulic brake speed increases and, at the end of the period, the braking torque M_{fs1} appears. If this torque is only taken over by the hydraulic brake, the brake speed, respectively of the shaft of draw works is:

$$\left.\begin{aligned} M_{fs1} &= M'_{r1} \\ M_{fs1} &= M \end{aligned}\right\} \Rightarrow n = \sqrt{\frac{M'_{r1}}{\frac{z\,k\,a}{0{,}45}\left(R_2^5 - R_1^5\right)}} \tag{40}$$

If the speed n is lower than the speed allowed for the hydraulic brake type n_r, then can be used only this brake type (adjustable). If $n > n_r$, also apply the belt brake before the end of the period t_1. From the braking torque M_{f1} will be reduced the hydraulic brake torque developed at maximum speed n_r (Figure 4).

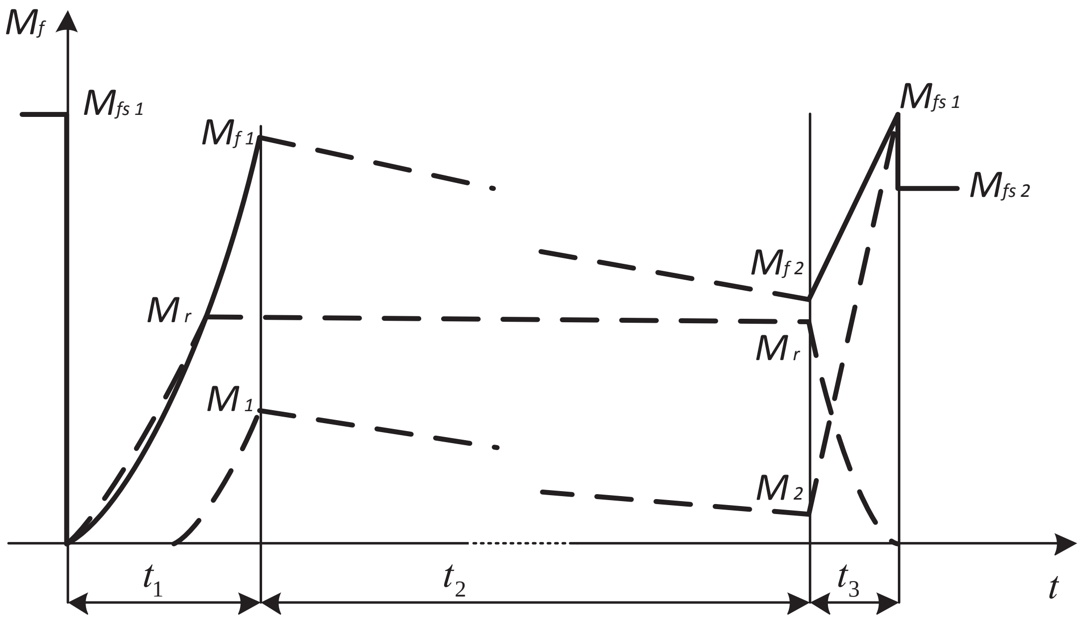

Fig. 4. *The variation of the braking torque through the brake belts and hydraulic brake*

In this case, the torque developed by the brake belts will be:

$$M_1 = M_{f1} - M_r \tag{41}$$

$$M_r = K\,n_r^2 \tag{42}$$

With $K = \frac{z\,k\,a}{0{,}45}\left(R_2^5 - R_1^5\right)$.

At the beginning of the period t_3, the torque taken by the brake belts is M_2, and at the end of this period, the torque becomes equal to M_{fs1}, because the torque of the hydraulic brake $M_r = 0$ (speed $n = 0$).

3. Conclusions

a. At the end of the period t_1 and during the period t_2, the hydraulic brake is capable of taking over all the braking torque. During the period t_3, the drum speed must be reduced to zero. The hydraulic brake torque drops (with n^2) and the brake belts must take over the entire braking torque.

b. The belt brake shall be applied shortly before the end of the period t_1 and at the beginning of the period t_3. The accelerations are high, the application of the brakes must be done gradually, in which case the friction torque increases progressively.

c. The area of the surfaces under the curves represents the energy developed by the load lowering and taken over by brakes. From the comparison of the diagrams in Figures 3 and 4, it can be seen that in case of hydraulic brake coupling, the brake belts take on less energy (the brake belts and the winch drums will be used more slowly). The hydraulic brake is important in ensuring the high reliability of the brake drums, the belt brake and the braking system.

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