MOVEMENT REGIMES OF THE LIFTING GEAR OF A DRILLING RIG.

Malko B.D. Ivasiv V.M.
Ivano-Frankivsk National Technical University of Oil and Gas

One of the most loaded mechanisms of the drilling rig is a lifting gear. Its perfection and reliability decrease time of the trip and in such a way increase the effectiveness of drilling rig operation. Insufficient calculation of movement and burden characteristics of the lifting gear brings to violation of power drive energy resources and law of resistance, laid in mechanism component, or to the overload and falling out of main components and parts and as a result there may be a decrease of the work effectiveness of the whole drilling rig.

Analytical model of the lifting gear of the drilling rig is shown on pict.1. There is depicted the following: I_1 – brought out to the drawworks drum shaft inertia moment of the movable parts of the drive, I_2 – brought out inertia moment of the drawworks drum and movable parts of the block-and-tackle system, I_3 – brought out inertia moment which includes mass of string of pipes and floating block, M_M – the moment of the tyre-pneumatic socket (coupling), c_{23} – brought out rope rigidity of block-and-tackle system and string of pipes, M_T - braking torque.

Taking into consideration the fact that the engine works, the mass I_1 rotates with the angular speed ω_{10}. By turning on the tyre-pneumatic socket (coupling) we move drawworks shaft and block-and-tackle system. The working time of the coupling we divide into two periods (pict. 2) where $t_{бн}$ is the time of towing under immovable conducted coupling half, $t_{бр}$ is the time of towing under the difference between the speeds of the drive ω_1 and conducted ω_2 coupling halves.

The results of the theoretical and experimental investigations show [1, 2], that the time of the full bond of coupling halves comes to $t_{34}= t_{бн} + t_{бр}= 2…5c$. After the full bond, the period of acceleration of drum hoist and floating block is still going on. This period of time comprises t_{p1}. So the full time of acceleration is equal to:

$$t_p = t_{бн} + t_{бр} + t_{p1} \quad (1)$$

The duration of the time $t_{бн}$ is determined by the characteristics of the coupling q_M [3], and by the moment on the belt brake M_T. The moment of the coupling increases according to the law:

$$M_M = q_M t (\alpha - \beta t), \quad (2)$$

where α ,β - are coefficients which determine the character of moment changes,

$q_M = \frac{M_{MK}}{t_{MK}}$, M_{MK} – maximum moment which can be transmitted by the coupling, t_{MK} – the time of moment increase to the maximum magnitude.

The movement of the second coupling half and mass I_2 begins, when the moment in the coupling M_M becomes equal to the moment of brake M_T, that is

$$M_M = M_T$$

Including (2) there can be determined the time $t_{бн}$

$$t_{бн} = \frac{\alpha}{2\beta} + \sqrt{\frac{\alpha^2}{4\beta^2} - \frac{M_T}{\beta q_M}} \quad (3)$$

During the period of time $t_{бн}$, the selection of an interval between the hook and the elevator link is taken place and the deformation of the hook's spring and cable standoff are accomplished.

The calculations show that during the time of deformation selection the draw works drum shaft rotates to the angle $\varphi_{бр} \leq 360°…370°$. Taking into consideration the fact that resistance force depends on travel, the movement equation of the conducted coupling half is the following:

$$I_2 \ddot{\varphi}_2 = M_M - c_{23}\varphi_2 \quad (4)$$

We substitute the value M_M in (4) and we solve it having zero at initial conditions:

$$\varphi_2 = q_M \left[\frac{2I_2\beta}{c_{23}^2}(1-\cos pt) + \frac{\alpha}{c_{23}}\left(t - \frac{1}{p}\sin pt\right) - \frac{\beta t^2}{c_{23}} \right] \quad (5)$$

The speed of coupling half

$$\omega_2 = q_M \left[\frac{2I_2 \beta P}{c_{23}^2} \sin pt + \frac{\alpha}{c_{23}} (1 - \cos pt) - \frac{2\beta t}{c_{23}} \right] \quad (6)$$

The movement rate remains up to the deformation of the drilling line, when the efforts in it $F_k = c_{23}\varphi_2$ reaches the mass of floating block and string of pipes Q_k.

From this condition we can find:

$$\varphi_{2H} = \frac{M(Q)}{c_{23}}$$

So, the duration of the first and second periods is determined by the coupling characteristics q_M and moment magnitude M_T.

We substitute the value φ_{2H} to the equation (5) and find the duration $t_{бр}$ of the first acceleration period of the second coupling half and drawworks shaft. The solution is possible only by numeral method. Beginning with this period of time the string of pipes is moving.

The most efficient regime of turning on the coupling is considered the regime, when full bond of coupling halves is carried out directly before "picking up" the string of pipes [4]. In this case such equality is taken place $\omega_1 = \omega_2$, where ω_1 – is the speed of the drive coupling half.

We can find its value according to the formula:

$$\omega_1 = \omega_{10} - \frac{q_M t^2}{I_1} \left(\frac{\alpha}{2} - \frac{\beta}{3} t \right) \quad (7)$$

where ω_{10} is the initial speed of the drive coupling half

We equate the right parts of equations (6), (7) and determine the bond time of coupling halves $t_{зм}$. It must be slightly different from the time $t_{бр}$ or be equal to it.

There begins the acceleration of string of pipes. The movement equation is the following:

$$I_{зв}\ddot{\varphi}_3 = M_\partial - M_o \quad (8)$$

Here $I_{зв} = I_1 + I_2 + I_3$

$M_\partial = M_{\partial k} - \lambda\dot{\varphi}_3$ - brought out engine moment,

$M_{\partial к}$ - boundary moment,

λ - steepness coefficient of engine mechanical characteristics

M_o – moment from the weight force of the string of pipes and resistance to their movement in the well.

The solution of the equation (8) with regard to speed is the following:

$$\omega_3 = \omega_{3M} e^{-\frac{\lambda}{I_{3B}}t} + \frac{M_{\partial k} - M_o}{\lambda}\left(1 - e^{-\frac{\lambda}{I_{3B}}t}\right) \qquad (9)$$

Here ω_{3M} - is the speed of junction of coupling halves (pict. 2)

The speed of the drawworks drum asymptotically approaches to the established value where

$$t \to \infty: \qquad \omega_y = \frac{M_{\partial K} - M_o}{\lambda}.$$

The process of acceleration may be considered as completed if the speed of the drum reaches the value $\omega=0,95\omega_y$. Now we can find the duration of the acceleration period:

$$t_{p1} = \frac{I_{3B}}{\lambda}\ln\frac{\omega_y - \omega_{3M}}{0,05\omega_y} \qquad (10)$$

So, the increase of steepness λ leads to the decrease of time for acceleration t_{p1}. But under such conditions increases the acceleration and inertia forces.

The angle of drum turning in the period of pipe acceleration is equal to:

$$\varphi_3 = \omega_y\left[t + \frac{I_{3B}}{\lambda}\left(e^{-\frac{\lambda}{I_{3B}}t} - 1\right)\right] - \frac{I_{3B}\omega_{3M}}{\lambda}\left(1 - e^{-\frac{\lambda}{I_{3B}}t}\right) \qquad (11)$$

At the end of the floating block lifting process it is necessary to stop it. Movement brake may be fulfilled by constrained method – turning on the brake of drawworks drum or by unconstrained method – the movement of floating block upward is stopped under the influence of the floating block mass itself and the mass of pipes. In both cases the process of braking begins from the turning off the tyre-pneumatic socket (coupling).

Let's consider that the coupling discharge and turning on the belt brake begin simultaneously.

The equation of masses' movement I_2, I_3 to the full release of coupling halves is the following:

$$\left.\begin{aligned} I_2\ddot{\varphi}_2 &= M_M - M_\Gamma - c_{23}(\varphi_2 - \varphi_3) \\ I_3\ddot{\varphi}_3 &= c_{23}(\varphi_2 - \varphi_3) - M_o \end{aligned}\right\} \qquad (12)$$

The coupling moment in the period of discharge changes according to the law [1]:

$$M_M = M_{MK}\left(1 - \frac{t}{t_p}\right)$$

where M_{MK} – maximum moment which can be transmitted by the coupling,

t_p – time of full coupling discharge.

The moment of belt brake increases according to the linear law [4]:

$$M_{\Gamma} = M_{\Gamma K} \frac{t}{t_{\Gamma K}}.$$

The solution of the equation system for relative motion of masses I_2, I_3 is the following:

$$\varphi_2 - \varphi_3 = A\sin(pt+\beta) + Dt + E \qquad (13)$$

where $A = \sqrt{E^2 + \frac{D^2}{p^2}}$, $p^2 = \frac{c_{23}(I_2+I_3)}{I_2 I_3}$, $D = -\left(\frac{M_{MK}}{t_P} + \frac{M_{M\Gamma}}{t_{\Gamma K}}\right)\frac{I_2}{c_{23}(I_2+I_3)}$,

$$E = \frac{(M_{MK}I_3 + M_O I_2)I_2 I_3}{c_{23}(I_2+I_3)}, \quad \beta = \mathrm{arctg}\frac{EP}{D}.$$

Let substitute (13) in (12) and after integration, find the movement laws φ_2, φ_3:

$$\omega_2 = \omega_y + \frac{M_{MK}t}{I_2}\left(1 - \frac{t}{2t_p}\right) - \frac{M_{\Gamma K}}{2I_2 t_{\Gamma K}}t^2 + \frac{c_{23}}{I_2}\left[\frac{H}{p}\cos(pt+\beta) - \frac{D}{2}t^2 - Et\right], \qquad (14)$$

$$\varphi_2 = \omega_y t + \frac{M_{MK}t^2}{2I_2}\left(1 - \frac{t}{3t_p}\right) - \frac{M_{\Gamma K}}{6I_2 t_{\Gamma K}}t^3 + \frac{c_{23}}{I_2}\left[\frac{H}{p^2}\sin(pt+\beta) - \frac{D}{6}t^3 - \frac{E}{2}t^2\right], \qquad (15)$$

$$\omega_3 = \omega_y - \frac{c_{23}}{I_3}\left[\frac{H}{p}\cos(pt+\beta) - \frac{D}{2}t^2 - Et\right] - M_O t, \qquad (16)$$

$$\varphi_3 = \omega_y t - \frac{c_{23}}{I_3}\left[\frac{H}{p^2}\sin(pt+\beta) - \frac{D}{6}t^3 - \frac{E}{2}t^2\right] - \frac{M_O}{2}t^2. \qquad (17)$$

From the equation (16), using the condition ω_3=0, we find the time $t_{3\Gamma}$ to the movement stop of brought out mass I_3 (of floating block and string of pipes). We substitute the received value of t_{3K} to the equation (17) and determine the way of floating block to the full stop:

$$S_{\Gamma} = \varphi_3 \frac{r}{U} \qquad (18)$$

where r – medium radius of cable spinning to the drum,

U - multiplicity of cable systems

The equation (13) permits to determine the condition of cable tightness (looping):

$$\varphi_2 - \varphi_3 \geq 0.$$

This condition may be broken during the first half-minute of vibration, when

$$\sin(pt_H + \beta) = -1,$$

or

$$Dt_H + E \geq A.$$

From here, after some non-complicated changes we receive characteristic magnitude of the increase of braking moment:

$$q_\Gamma = \frac{M_{\Gamma K}}{t_{\Gamma K}} \leq \frac{2(M_{MK} I_3 + M_O I_2)}{t_H^2 - \frac{1}{p^2}} - \frac{M_{MK}}{t_p} \qquad (19)$$

By unconstrained method of movement stop of the floating block, the moment is on the brake $M_\Gamma=0$. Equation system (12) will be simplified. The solutions of (13)…(17) are not changed.

Travel of the established movement of the floating block is equal to:

$$S_y = H - S_p - S_\Gamma \qquad (20)$$

Here H – is a necessary travel of the floating block when lifting one stalk.

The time of established movement comprises:

$$t_y = \frac{S_y U}{r\omega_y} \qquad (21)$$

In such a way there have been determined the travel and time on the separate movement stages of the floating block in the process of lifting.

REFERENCES

1. Antonov A.A. Pneumatic Friction Couplings in Oil Industry. – M.; 1973. – 160p.
2. Arkhangelsky V.L. The Characteristic Influence of Pneumatic Operating Coupling on the Dynamic Loads in Lifting System of Drilling Rigs. – Machine and Oil Equipment, 1970, №9. – P. 7-13
3. Malko B.D. Analysis of Turning on Regimes of Friction Couplings. Prospecting and Development of Oil and Gas fields. IFSTUOG, 1996, №3. P. 140-145.
4. Vynytsky M.M. Efficient Management of Round-Trip. – M.: Nedra, 1978. – 252p.