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Determination of the location of the technological equipment on the chassis of the oil field aggregates

Wyznaczenie najlepszego miejsca montażu urządzeń technologicznych na podwoziu pojazdów naprawczych na polach naftowych

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ABSTRACT: Currently, it is impossible to imagine the repair and drilling of any well without the use of modern mobile equipment. With technological progress, not only new development technologies in the branch of field exploitation appear, but also new equipment with which oil and gas wells are repaired and reconstructed. Today, oil production is mainly carried out by the operation of wells without a pumping derrick, which makes it possible to sharply reduce the cost of metal and funds. Operations of downhole equipment lifting and tripping in a well are carried out using self-propelled mobile units representing tracked or wheeled transport vehicles on which a derrick (mast) with a winch, transmission and hoisting system is mounted. Lifting units are equipped with a mechanism for raising the mast to the working position and lowering it to the transport position. Installations with a lifting capacity of up to 32 tons inclusive are designed for lifting operations during routine underground repair of wells, whereas over 32 tons minimal lift capacity are required during major repairs and well development. The mobile unit is subjected to oscillatory movements both during transportation along unpaved, semi - destroyed, muddy and snow-covered roads to the well (for development, repair), and during well drilling. The frequency of the oscillating movement depends on the state of the uneven road. The unevenness of the road is expressed by spectral functions. In this case, both the chassis and the body of the mobile unit, as well as the technological equipment located on it, are subjected to oscillatory movements. As a result, technological equipment, as well as devices and equipment located on it, lose their accuracy, which leads to accidents both during drilling and during operation. Therefore, in order to minimize the influence of oscillatory movements on the operability of technological equipment, a technique was developed for technological equipment positioning on the chassis of a mobile unit at an optimal scheme according to the proposed method.

Key words: oil and gas wells, transport bases, vibration frequency, oscillatory movements, design, optimal location, technological equipment.

STRESZCZENIE: Obecnie nie można sobie wyobrazić naprawy i wiercenia otworów bez nowoczesnego sprzętu. Wraz z postępem technologicznym następuje nie tylko rozwój nowych technologii w zakresie eksploatacji złóż, ale także nowych urządzeń, za pomocą których dokonuje się napraw i rekonstrukcji odwiertów ropnych i gazowych. Obecnie wydobycie ropy naftowej odbywa się głównie poprzez eksploatację otworów bez wieży wydobywczo-obróbczej, co pozwala na znaczne obniżenie kosztów zakupu stali i innych nakładów finansowych. Operacje podnoszenia i zapuszczania wyposażenia wgłębnego w otworze wykonywane są za pomocą samobieżnych jednostek mobilnych, obejmujących gąsienicowe lub kołowe pojazdy transportowe, na których zamontowana jest wieża wiertnicza (maszt) z wciągarką, przekładnią i urządzeniem dźwigowym. Jednostki podnoszące wyposażone są w mechanizm podnoszenia masztu do pozycji roboczej i opuszczania go do pozycji transportowej. Instalacje o udźwigu do 32 ton włącznie przeznaczone są do operacji podnoszenia podczas bieżących napraw odwiertów, a powyżej 32 ton – do poważnych napraw i prac w odwiertach. Jednostka mobilna jest poddawana ruchom oscylacyjnym zarówno podczas transportu po nieutwardzonych, częściowo zniszczonych, błotnistych i zaśnieżonych drogach prowadzących do odwiertu (w celu wykonania prac, napraw), jak i podczas wiercenia otworu. Częstotliwość ruchu oscylacyjnego zależy od wysokości profilu nierówności drogi. Nierówności drogi wyrażają funkcje spektralne. W takim przypadku zarówno podwozie, jak i korpus jednostki mobilnej, a także usytuowane na niej wyposażenie technologiczne poddawane są ruchom oscylacyjnym. Powoduje to, że sprzęt technologiczny, jak również znajdujące się na nim urządzenia i wyposażenie tracą swoją precyzyjność, co prowadzi do wypadków zarówno podczas wiercenia, jak i podczas prac operacyjnych w odwiertach. Dlatego w celu zminimalizowania wpływu ruchów oscylacyjnych na sprawność urządzeń technologicznych opracowano technikę usytuowania urządzeń technologicznych na podwoziu jednostki mobilnej w optymalnym schemacie, zgodnie z proponowaną metodą.

Słowa kluczowe: odwierty ropne i gazowe, bazy transportowe, częstotliwość wibracji, ruchy oscylacyjne, projekt, optymalne usytuowanie, sprzęt technologiczny.

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Introduction

The main way to sustain the levels of oil recovery in developed oil and gas horizons is maintaining active and inactive well installations and drilling new production wells. Work in these areas is carried out using technical complexes of various solutions, among which a special place is given to mobile facilities with appropriate transport and technical base. These mobile complexes are designed for re-positioning during drilling, development, repair and restoration of oil and gas wells in all climatic regions. Purposeful research work was carried out in this direction in the USA, Russia, Ukraine, China, as well as in Kazakhstan and Azerbaijan, as a result of which the newest mobile complexes such as KORO 80/100, ARB-100/125, X 1750, etc. were developed (Figure 1). The main equipment of mobile units with the help of which lifting operations are carried out include lifting winches, derricks, pumping units, etc. mounted on self-propelled transport bases. Tracked tractors T-100, T-130, T-150, T-170 are selected as transport bases, and KAMAZ, KRAZ, MZKT, KZKT, MAZ-537 and others are selected as wheelbases (Rig for repair and exploration of oil and gas wells, 2012; Lifting device AM 14/40.2010.CONFIND).

When transporting to the drilling site (for development, repairing) by dirt roads, mobile installations undergo oscillatory movements, as a result of which the equipment and instruments positioned on the chassis of the unit lose their functional accuracy.

It is known that many roads in oil and gas fields are semi-destroyed or barely maintained. During exploration, drilling and operations on the fields, the required equipment and devices are installed on the chassis of all-terrain machines that are repositioned by movement along these roads. Such roads can be described by different spectral functions of irregularities. When machines move on these, apparatus and devices that are on the chassis make non-stationary oscillatory movements, which can lead to their failure. Therefore, these devices and apparatus must be placed on the chassis of the machines in such a way that the vibration frequency is minimal (Tinajin DFXK Petroleum Machinery Co., Ltd.; Sichuan Kunlun Petroleum Equipment Manufacturing Co., Ltd.; Lifting device AM 14/40.2010.CONFIND).

Solution of the problem

Let there be a machine with three axles, with one axle at the front of the machine and two close axles at the rear of the machine. On the body there are five loads with masses M_1, M_2, M_3, M_4, M_5, the distances from the center of gravity of which are l_1, l_2, l_3, l_4, l_5, respectively. The distance between the front axle and the midpoint between the rear axles is denoted by L. Distances l_1, l_2, l_3, l_4, l_5 are to be determined for optimal distribution of loads on the machine body. Oscillations in the longitudinal plane when driving on a road characterized by a clamped spectral function of irregularities are then to be considered. The design diagram is shown in the Figure 2.

Here: P – is the total weight of the machine; $\overline{P}_1$, $\overline{P}_2$, $\overline{P}_3$, respectively – are the forces of interaction of the suspensions of the front and rear axles with the body; M_1, M_2, M_3, M_4, M_5 – are the weights of masses on the body. Considering the minimal distance between the rear axles and the low magnitude of bending deformations, the reactions of the two rear axles will be replaced by one resultant $\overline{P}_2'$, i.e. $\overline{P}_2' = \overline{P}_3 + \overline{P}_2$. Let us create equations of motion, choosing as coordinates the vertical displacements of the front Y_{10} and rear Y_{20} axles and the points of the body Y_1 and Y located above them. The heights of the irregularities under the front and rear wheels will be designated Z_1 and Z_2, respectively. Let us also denote by m_1 and m_2 the masses of the front and rear axles; M, J – are the mass and moment of inertia of the body relative to the central axis perpendicular to the plane of the drawing; and c_m, c, v – are the stiffness values of tires, suspensions and the coefficient of viscosity of friction in shock absorbers for left and right suspension elements (Dedkov and Yurikov, 2014; Grigoriev et al., 2020).

Figure 1. Truck mounted repair-drilling rig ARB-100

Rysunek 1. Urządzenie naprawczo-wiertnicze ARB-100 zamontowane na ciężarówce

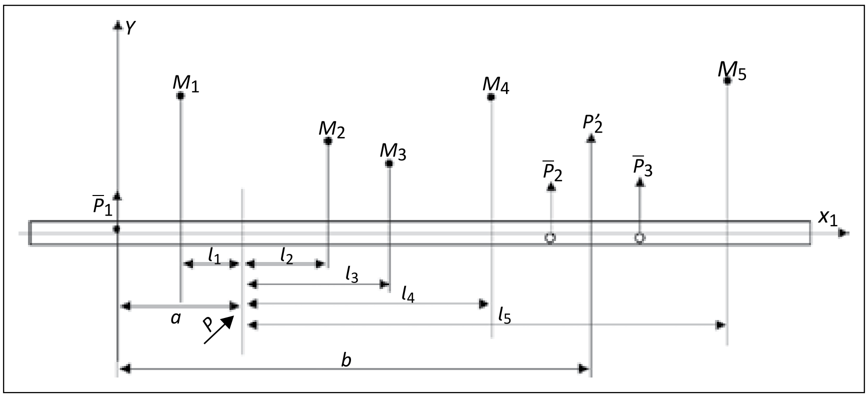

Figure 2. Oscillation pattern in the longitudinal plane when driving on a road characterized by a given spectral function of irregularities

Rysunek 2. Wzór drgań w płaszczyźnie podłużnej podczas jazdy po drodze charakteryzującej się daną spektralną funkcją nierówności

The oscillation equations will be:

$$\left.\begin{aligned} c_{mj}(Z_i - Y_{i0}) - P_i = m_i Y_{i0}'' \\ c_i(Y_i - Y_{i0}) + \gamma(Y_i' - Y_{i0}') = P_i \end{aligned}\right\}, i = 1.2 \tag{1}$$

and the equations of body vibration:

$$\left.\begin{aligned} M\left(Y_1''\frac{b}{L} + Y_2''\frac{a}{L}\right) = \bar{P}_1 + P_2' \\ J\left(\frac{Y_1'' - Y_2''}{L}\right) = P_1 a + P_2' b \end{aligned}\right\} \tag{2}$$

From system (2):

$$\left.\begin{aligned} P_1 = Y_1''\frac{Mb^2 + J}{L^2} + Y_2''\frac{Mab - J}{L^2} \\ P_2' = Y_1''\frac{Mab - J}{L^2} + Y_2''\frac{Ma^2 + J}{L^2} \end{aligned}\right\} \tag{3}$$

Considering that $Mab \approx J$, from (3) (Taha, 2016; Plotnikov et al., 2021) we have:

$$P_1 = \bar{M}_1 Y_1''; P_2 = \bar{M}_2 Y_2''; \bar{M}_1 = \frac{b}{L}M; \bar{M}_2 = \frac{a}{L}M \tag{4}$$

Thus, under condition (4), the oscillations of the front and rear parts are independent. In view of (4) in (1), dropping the indices, we have:

$$\left.\begin{aligned} \bar{M}Y'' + mY_0'' + c_m Y_0 = c_m Z \\ \bar{M}Y'' + cY + \gamma Y' - cY_0 - vY_0' = 0 \end{aligned}\right\} \tag{5}$$

Substitute in (5) $Z = ze^{iwt}$; $Y_0 = y_0 e^{iwt}$; $Y = ye^{iwt}$

$$\left.\begin{aligned} -\bar{M}y\omega^2 e^{iwt} + c_m y_0 e^{iwt} - my_0\omega^2 e^{iwt} = c_m z e^{iwt} \\ -\bar{M}y\omega^2 e^{iwt} + cye^{iwt} + i\omega y e^{iwt} - cy_0 e^{iwt} - vy_0 i\omega e^{iwt} = 0 \end{aligned}\right\}$$

or

$$\left.\begin{aligned} -\bar{M}y\omega^2 + c_m y_0 - my_0\omega^2 = c_m z \\ -\bar{M}y\omega^2 + cy + i\omega y - cy_0 - vy_0 i\omega = 0 \end{aligned}\right\} \tag{6}$$

From the second equation (6):

$$y_0(c + iv\omega) = y(c + iv\omega - \bar{M}\omega^2)$$

and from the first, we have:

$$y[(c_m - m\omega^2)(c + iv - \bar{M}\omega^2) - \\ -\bar{M}\omega^2(c + iv\omega)] = c_m(c + iv\omega)z$$

Thus, the complex frequency response of the vertical movement of the body has the following form (Robotnov, 1988):

$$\Phi_y(i\omega) = \frac{Y}{Z} = \frac{y}{z} = \\ = \frac{c_m(c + iv\omega)}{(c_m - m\omega^2)(c + iv - \bar{M}\omega^2) - \bar{M}\omega^2(c + iv\omega)} \tag{7}$$

Further, knowing the spectral function of road irregularities $S_z(\omega)$, we can calculate the spectral displacement function:

$$S_y(\omega) = |\Phi(i\omega^2)|^2 S_z(\omega)$$

The spectral function of road irregularities is obtained from the experimental correlation function $K_z(x)$. Let the road correlation function be expressed by the formula:

$$K_z(x) = D_z e^{-\gamma|x|}$$

When moving at a speed V, $S_z(\omega)$ has the form:

$$S_z(\omega) = \frac{1}{\gamma}S_0\left(\frac{\omega}{\gamma}\right) = D_z\frac{2\gamma_1}{\gamma_1^2 + \omega^2} \\ \gamma_1 = \gamma V \tag{8}$$

The spectral body acceleration function will be:

$$Sy''(\omega) = S_z(\omega)|\Phi_{y''}(i\omega)|^2 = \omega^4 S_z(\omega)|\Phi(i\omega)|^2 \tag{9}$$

Substituting (8) into (9), we have:

$$Sy''(\omega) = D_z\frac{2\gamma_1}{\gamma_1^2 + \omega^2}\frac{c_m^2}{M^2m^2}\cdot\frac{(c^2 + v^2\omega^2)\omega^4}{|F(\omega)|^2}$$

where:

$$F(\omega) = \omega^4 - \omega^2\left(\frac{c_m}{m} + \frac{c}{m} + \frac{c}{\bar{M}}\right) + \\ + \frac{c_m c}{m\bar{M}} - i\frac{V}{\bar{M}}\left[\omega^3\left(1 + \frac{\bar{M}}{m}\right) - \omega\frac{c_m}{m}\right]$$

Then the acceleration variance is:

$$D_{y''} = \frac{1}{\pi}\int_0^\infty S_{y''}(\omega)d\omega$$

Therefore, the root-mean-square acceleration experienced by a vehicle when driving on an uneven road is:

$$\sigma y'' = \sqrt{D_{y''}} \tag{10}$$

In finding the root-mean-square accelerations for individual masses M_1, M_2, M_3, M_4, M_5 through their displacements U_1, U_2, U_3, U_4, U_5 we obtain:

$$\left.\begin{aligned} U_1 &= \frac{y_1 - y_2}{L}(a - l_1) + y_1 = \frac{a - l_1}{L} y_2 + \frac{b + l_1}{L} y_1 \\ U_2 &= \frac{y_2 - y_1}{L}(a + l_2) + y_1 = \frac{a + l_2}{L} y_2 + \frac{b - l_2}{L} y_1 \\ U_3 &= \frac{y_2 - y_1}{L}(a + l_3) + y_1 = \frac{a + l_3}{L} y_2 + \frac{b - l_3}{L} y_1 \\ U_4 &= \frac{y_2 - y_1}{L}(a + l_4) + y_1 = \frac{a + l_4}{L} y_2 + \frac{b - l_4}{L} y_1 \\ U_5 &= \frac{y_2 - y_1}{L}(a + l_5) + y_1 = \frac{a + l_5}{L} y_2 + \frac{b - l_5}{L} y_1 \end{aligned}\right\} \quad (11)$$

Hence, for the root-mean-square acceleration we get:

$$\begin{cases} \sigma U_1'' = \dfrac{a - l_1}{L}\sqrt{Dy_2''} + \dfrac{b + l_1}{L}\sqrt{Dy_1''}; \\ \sigma U_1'' = \dfrac{a + l_1}{L}\sqrt{Dy_2''} + \dfrac{b - l_1}{L}\sqrt{Dy_1''};\ i = \overline{2.5} \end{cases} \quad (12)$$

we now introduce the notation $l_i = -l_i$; $i = \overline{2.5}$.

Let us define the minimum values $\sigma U_1''$ depending on l_i. As follows from (12):

$$\frac{\delta \sigma U_1''}{\delta l_k} \begin{cases} 0 & i \neq k \\ \dfrac{1}{L}\sqrt{D_{y_2''} - D_{y_1''}} & i \neq k \end{cases} \quad (13)$$

Where: $i, k = \overline{1}, \overline{5}$.

Since $\sqrt{D_{y_2''} - D_{y_1''}} \neq 0$ in general, quantities (13) gain their minima on the boundary l_i. In contrast, $0 \leq l_i \leq +a$, if M_i is in front of the center of gravity and $0 \leq l_i \leq +b$, if M_i is behind the center of gravity. Then, in case $0 \leq l_i \leq +a$:

$$\left.\begin{aligned} \sigma_{U_i''}|_{l_i=0} &= \frac{1}{L}\left(a\sqrt{D_{y_2''}} + b\sqrt{D_{y_1''}}\right) \\ \sigma_{U_i''}|_{l_i=0} &= \sqrt{D_{y_1''}} \end{aligned}\right\} \quad (14)$$

and for the case $0 \leq l_i \leq +b$:

$$\left.\begin{aligned} \sigma_{U_i''}|_{l_i=0} &= \frac{1}{L}\left(a\sqrt{D_{y_2''}} + b\sqrt{D_{y_1''}}\right) \\ \sigma_{U_i''}|_{l_i=0} &= \sqrt{D_{y_2''}} \end{aligned}\right\} \quad (15)$$

1. Consider the case when $0 \leq l_i \leq +a$, let us suppose $\sqrt{D_{y_2''}} > \sqrt{D_{y_1''}}$ and $\sqrt{D_{y_2''}} = \sqrt{D_{y_1''}} + \Delta D_{y_2''}$, then from (15) we have:

$$\sigma_{U_i''}|_{l_i=0} = \sqrt{D_{y_1''}} + \frac{a}{L}\Delta D_2''$$

In this case $\sigma_{U_i''}|_{l_i=0} > \sigma_{U_i''}|_{l_i=-a}$ and:

$$min\sigma_{U_i''} = \sigma_{U_i''}|_{l_i=-a} = \sqrt{D_{y_1''}} \quad (16)$$

If $\sqrt{D_{y_2''}} < \sqrt{D_{y_1''}}$ and $\sqrt{D_{y_2''}} = \sqrt{D_{y_1''}} - \Delta D_{y_2''}$

$$\sigma_{U_i''}|_{l_i=0} = \sqrt{D_{y_1''}} - \frac{a}{L}\Delta D_2''$$

In this case $\sigma_{U_i''}|_{l_i=0} < \sigma_{U_i''}|_{l_i=-a}$ and:

$$min\sigma_{U_i''} = \sigma_{U_i''}|_{l_i=-a} = \sqrt{D_{y_2''}}\frac{a}{L} + \sqrt{D_{y_1''}}\frac{b}{L} \quad (17)$$

2. Consider the case when $0 \leq l_i \leq +b$, let us suppose $\sqrt{D_{y_2''}} > \sqrt{D_{y_1''}}$ and $\sqrt{D_{y_1''}} = \sqrt{D_{y_3''}} + \Delta D_{y_1''}$, then from (16) we have:

$$\sigma_{U_i''}|_{l_i=0} = \sqrt{D_{y_1''}} - \frac{b}{L}\Delta D_1''$$

that is $\sigma_{U_i''}|_{l_i=0} > \sigma_{U_i''}|_{l_i=-a}$, therefore:

$$min\sigma_{U_i''} = \sigma_{U_i''}|_{l_i=-a} = \sqrt{D_{y_2''}} \cdot \frac{a}{L} + \sqrt{D_{y_1''}} \cdot \frac{b}{L} \quad (18)$$

If $\sqrt{D_{y_2''}} < \sqrt{D_{y_1''}}$ and $\sqrt{D_{y_1''}} = \sqrt{D_{y_2''}} - \Delta D_{y_1''}$, then $\sigma_{U_i''}|_{l_i=0} = \sqrt{D_{y_2''}} + \dfrac{b}{L}\Delta D_1''$ and $\sigma_{U_i''}|_{l_i=0} > \sigma_{U_i''}|_{l_i=0}$, hence:

$$min\sigma_{U_i''} = \sigma_{U_i''}|_{l_i=b} = \sqrt{D_{y_2''}} \quad (19)$$

Since the unevenness of the road is the same for both the front and rear axles and $m_2 > m_1$, therefore, $\sqrt{D_{y_2''}} > \sqrt{D_{y_1''}}$, then the main conditions for placing the mass between the front axle and the center of gravity are cases (17) and (19), and in order for $\sigma_{U_i''}$ to be minimal, it should be placed above the front axle. In the case where the mass needs to be placed between the rear axle and the center of gravity, for a minimum $\sigma_{U_i''}$, it should be placed in the center of gravity. In this case, the masses should be arranged so that the condition:

$$\sum_{i=1}^{5} M_i l_i = 0 \quad (20)$$

From (20), it follows that the origin is at the center of gravity, that is, for masses that are to the left of the center of gravity $l_i < 0$, and for masses that are to the right of the center of gravity $l_i > 0$, since (17), (19), (20) are incompatible, then for the minimality of $\sigma_{U_i''}$ one should take $l_i = 0$; $i = \overline{1.5}$. In this case, the minimum condition is satisfied (Robotonov, 1988; Plotnikov et al., 2021).

Now suppose that $M_1 > M_2 > M_3 > M_4 > M_5$, the corresponding sizes of these masses will be denoted by A_i, B_i, $C_i (i = \overline{1.5})$, where A_i is the size in the direction of the x-axis; B_i are the y-axes; C_i – along the z-axis. Thus, we will place system OXYZ so that the origin of coordinates coincides with the center of gravity, the x-axis is directed along the length of the machine, the z-axis is across the machine, and the y-axis is perpendicular to the plane oxz. In addition, the masses M_i must be in:

$$D_1\left\{-\frac{a_1}{2} \leq x \leq \frac{a_1}{2}; -\frac{b_1}{2} \leq y \leq \frac{b_1}{2}; -\frac{c_1}{2} \leq z \leq \frac{c_1}{2}\right\};$$

of course, $a_i > A_i$, $B_i > b_i$, $c_i > C_i$. Under these conditions, for minimal $\sigma_{U_i''}$, the largest mass, that is, M_1 must be in the center of gravity. Moreover, the mass M_i must be at a point that is at a distance $l_2 = A_1/2 + A_2/2$ from the center of gravity. Furthermore, in order for condition (20) to be satisfied, mass M_3 must be at a distance $l_3 = -M_2/M_3 \cdot l_2$ from the center of gravity. Arguing in a similar way, we derive:

$$\begin{aligned} l_4 &= l_3 - \frac{A_4}{2} = -\frac{M_2}{M_3} l_2 - \frac{A_4}{2} = -\left[\frac{M_2}{M_3}\frac{(A_1+A_2)}{2} + \frac{A_4}{2}\right] \\ l_5 &= -\frac{M_4}{M_5} l_4 = \frac{M_4}{M_5}\left[-\frac{M_2}{M_3}\frac{(A_1+A_2)}{2} + \frac{A_4}{2}\right] \end{aligned} \tag{21}$$

Thus, for the optimal distribution of the given masses on the plane *OXY* under the given conditions for the distances from the center of gravity, we obtain:

$$\left.\begin{aligned} l_1 &= 0 \\ l_2 &= \frac{(A_1+A_2)}{2} \\ l_3 &= -\frac{M_2}{M_3}\frac{(A_1+A_2)}{2} \\ l_4 &= -\left[\frac{M_2}{M_3}\frac{(A_1+A_2)}{2} + \frac{A_4}{2}\right] \\ l_5 &= \frac{M_4}{M_5}\left[-\frac{M_2}{M_3}\frac{(A_1+A_2)}{2} + \frac{A_4}{2}\right] \end{aligned}\right\} \tag{22}$$

Conditions (22) mean that the most massive body should be in the center of gravity, the second and fifth bodies should be in the front, and the third and fourth bodies – in the rear part of the body.

The obtained expressions make it possible to determine the optimal structures of the distribution of technological equipment of all kinds of units designed to perform various technological operations on wells.

Discussion

The developed model allows solving the problem of layout of the technological base at the design level. This makes it possible to significantly reduce the possible emergency scenarios when moving the location and operation of mobile oilfield units and thereby significantly reduce the cost of their services.

To solve these problems, we do not bypass access to the technology of the fishing area, as well as the required design challenges and operational characteristics of the developed mobile installations, which makes it difficult to use the developed model to create their technological base.

To reduce the frequency characteristics of vibrations, the technological base when relocating a mobile installation in fishing conditions, the masses of the base elements from the center of mass of the installation are used. The mass of the elements of the base m_i are represented by the coordinates of the location of its center of mass, which are characterized by the distances L_i.

Results

As a result of theoretical research in the article, a method was developed for determining the minimum vibration frequency of individual parts of the vehicle body when they move on minimally developed and badly maintained dirt roads. The obtained analytical expressions make it possible to determine the optimal distance for devices and devices from the center of gravity of machines, depending on their mass, which can significantly reduce the effect of vibrations on units and devices installed on the body of the machine. It has been proven that the most convenient place for more sensitive devices and devices are the points of the hold located on the front axle of the vehicle. The developed methodology can also be applied for optimal placement of equipment on offshore platforms.

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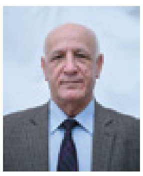

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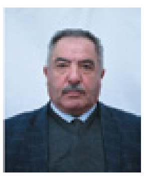

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