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INVESTIGATION OF A FULL-SIZE DAMPER FOR AN ELECTRICALLY DRIVEN CENTRIFUGAL PUMP FOR OIL PRODUCTION

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Abstract

The article describes a way to combat fatigue effects in the details of connecting modules of an electric driven centrifugal pump unit for oil production. A constructive solution for implementing the method in relation to complex downhole conditions in the form of a multifunctional damper using a differential piston to transfer it from the transport position when lowering into the well into the working one is shown. For a full-size damper, experimental studies of its vibration- isolating characteristics have been carried out when used in the form of substrates for supporting arms of elastomers of various densities and compositions. The preferred characteristics of elastomers and their ranking for various frequencies of forced vibrations are determined.

Keywords:

Module, connection parts;
Electrically driven centrifugal pump unit;
Electrocentrifugal pumping unit;
Differential piston;
Damper;
Substrate;
Vibration velocity.

A significant part of the deposits of the Russian Federation entered the late or final stage of exploitation. Therefore, to ensure profitability, increase production rates, etc., reservoir pressure maintenance and hydraulic fracturing are widely used. This is accompanied by a rapid watering of the product, an increase in the amount of mechanical impurities in it, which significantly affects the durability and performance of production units as a whole and their main component, the pumping unit. To obtain an acceptable oil productivity when pumping a gas-liquid fluid with a high water cut, in the capacity of which in Russia, in the overwhelming majority of cases, electric centrifugal pumping units (ECPU) are used, consisting of a pumping unit with a multistage centrifugal pump and an electric submersible motor (ESM) with a hydraulic protection system, connected with each other using studs, tubing, wellhead equipment, etc.

The high rotor speed of the centrifugal pump, the presence of free gas in the pumped-out fluid, salts, imbalance lead to high-frequency vibrations of the entire pumping unit. The transition to a modular design of centrifugal pumping units, which gave significant technical and technological advantages, simultaneously caused the emergence of a new problem: during operation, cases of separation of the pump unit from the tubing, on which they are suspended, and the destruction of the pins connecting the modules with each other became more frequent.

It has been established that the main reason for the detachment of the unit as a whole and (or) its component parts is the fatigue of the metal of the studs or the thread flap due to vibration. Measures to increase the strength of the studs have been implemented as much as possible, but the problem of increasing the durability has been solved only partially. Therefore, the search for a solution to minimize vibration and its negative impact on the durability and performance of centrifugal pumping units remains relevant. This problem is typical for both downhole pumps and surface pumps, especially multiple ones, but for downhole electrically driven centrifugal pumps, the problems are much more significant, since their suspension on tubing is, in fact, free, practically not limiting the amplitude of oscillations. As a result, the pumping unit collides with the casing pipes, transmitting shock loads to the connecting elements. In this case, the collision does not occur along the entire length of the pump unit, but in separate sections, therefore, the unit modules also experience bending moments, which also affect the connection parts. Due to the described physical picture of the pumping unit in the well, in order to increase its durability and performance, taking the quality of its component parts for granted, it was decided to create a device that would limit the amplitude of oscillations and at the same time soften the shocks. Considering the aggressiveness of borehole fluids, the range of their

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possible temperatures, multicycle nature of the high-frequency oscillations, rubbers were chosen from the whole variety of elastomers as a damping element, showing stable characteristics in the composition of other functional devices during long-term operation under such conditions.

When developing the damper, the problem of trouble-free simple transfer of the pump from the transport state when lowering it to a technologically defined suspension depth, into the operating state, and vice versa, was also solved. At the same time, in the transport state, its diameter should not exceed the diameter of the pump unit, and in the operating state it should correspond to the inner diameter of the casing at the installation site, preferably with the creation of an elastic pressing force for damping and axial vibrations.

As a result of the analysis of the developed draft designs, a design was chosen that most fully meets all the requirements (fig. 1), which can be mounted between any modules of the pumping unit, as well as in the place where the unit is fixed on the tubing string [1].

In this construction, the axial force created by the differential piston under the action of the pressure difference inside the tubing and in the annular space is used as an active force to transfer the damper from the transport state to the operating state:

$$F = (P_{in} - P_{out}) \times \left(A_1 - A_2\right), \tag{1}$$

where P_{in} - pressure in the tubing at the level of the damper installation;

P_{out} – outside tubing pressure at damper installation level;

A_1 and A_2 - areas of the ends of the larger and smaller pistons of the differential piston, respectively.

Since the pumped-out liquid must pass through the differential piston, it is made with a through axial bore of the largest possible diameter.

The second idea implemented in the design is that when transferring from the transport to the operating position, the differential piston does not compress the elastomer, but pushes the support levers with slips onto the tapered surface of the rubber sleeve, which is used as a damping substrate for the levers. Thanks to this solution, the creation of a pre-stressed state is excluded, and, therefore, the full potential of the damping properties of rubber is retained.

The transfer of the vibration damper from the transport position to the operating position is carried out automatically after the pump is switched on, as a result of which the pumping-out liquid starts filling the tubing pipes with a simultaneous certain decrease in the level in the annulus. The pressure drop created in this case, and, consequently, the axial force on the differential piston moves it and the levers with slips kinematically connected to it relative to the body and the rubber substrate. The vibration damper will operate at any, upper or lower, position of the piston with a larger diameter relative to a smaller one. But the lower location is preferable, since in this case the function of the anti-flight device will be additionally realized.

The reverse process, i.e., the transfer of the damper from the working position to the transport position also occurs automatically: after the pump is turned off and the liquid levels in the tubing and the annulus are equalized, the axial force disappears and the damper body with the rubber backing fixed in it is pulled out from under the levers when lifting tubing.

If the unit is disconnected for any reason above the vibration damper, the unit's gravity will tend to push it down. Levers with slips in contact with the casing will remain stationary due to the frictional force created by the expanding action of the rubber substrate, since the direction of relative movement of the substrate with the body to the levers will remain.

Experimental studies of the vibration-isolating characteristics of the damper were carried out on

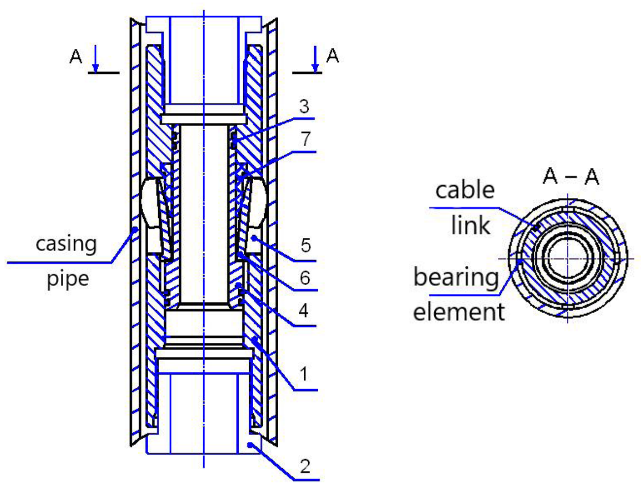

Fig. 1. Schematic model of the proposed damper
1 - Body; 2 - ECPU module; 3 - Boring; 4 - Differential hollow piston; 5 - Longitudinal slot; 6 - Support arm; 7 - Substrate

a specially created vibration stand, the design of which is described in the work [2]. The vibration velocity was chosen as a parameter characterizing the vibration-isolating properties of the damper, for the registration of which the vibration analyzer Korsar++ was used. In order to obtain reliable information corresponding to a wide range of possible vibration values of the pumping unit, the experiments were carried out with a full-size damper with varying imbalance and frequency of forced vibrations. Different values of imbalance on the stand were achieved by changing the distance (shoulder) between the weight fixed on the driven multi-grooved pulley and the pulley shaft. A feed nut assembly was used to create an axial force that simulates the hydraulic force generated in the borehole by means of a differential piston.

To assess the performance and achievement of the set goal using the developed damper, at the initial stage, the planning of experiments [3] and experimental studies of the damper [4] with a rubber substrate P-12 with unbalances of 1500, 2720 and 3940 g×mm were carried out, the results of which are presented in figure 2.

The graphs of this figure show the nature of the change in vibration V_c (rms velocities RMS) measured on a rigidly fixed damper housing as a function of imbalance «δ» and frequency «ν» for rubber P-12 with a density of ρ = 2200 kg/m^3.

These experiments have shown: an increase in vibration with an increase in imbalance and vibration frequency; qualitative coincidence of the nature of vibration change for different values of the imbalance «δ»; non-linear dependence of vibration change on imbalance $V_c = f(\delta)$ for the entire frequency range; not proportional to the increment of ΔV_c to the increment of $\Delta\delta$ at any frequencies.

Qualitatively similar dependences were obtained for rubber grades DX-23 and G-9304 with densities of 1230 kg/m^3 and 1150 kg/m^3, respectively. Graphical visualization of the qualitative effect of the same imbalance on the vibration of the case when using substrates of the indicated three brands of rubbers in the damper with exactly the same shapes and sizes at the same axial force from the feed nut assembly are shown in figures 3-5.

Analysis of the combined patterns of changes in vibrations from frequency with the same imbalances showed that for the studied brands of rubbers it is the same, the difference is only in numerical values. At the same time, it was found that with an increase in the imbalance, the vibration of the damper body increases, and, consequently, its relative efficiency decreases; for the damper under study, for any brand of rubber, the resonance mode occurs in the region of 34.6 Hz; in the frequency range from 13.5 to 23.5 Hz, the damping properties improve with an increase in the density of the rubber, i.e., sequentially from G-9304, DX-23, P-12. At frequencies of 23.5 to 50 Hz, the picture is the opposite, i.e., the damping capacity increases with decreasing density.

It should be noted that the test bench, like any research rig, does not fully recreate the operating

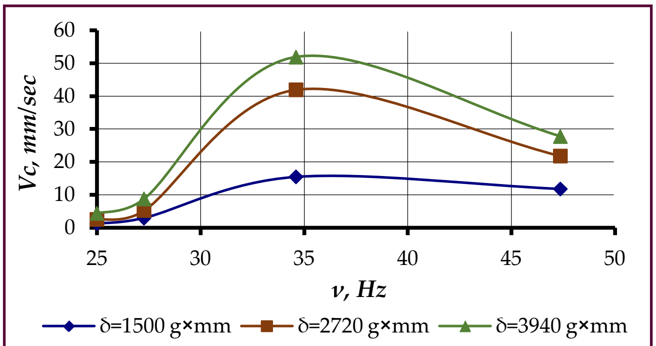

Fig. 2. Dependence of vibration velocity on imbalance

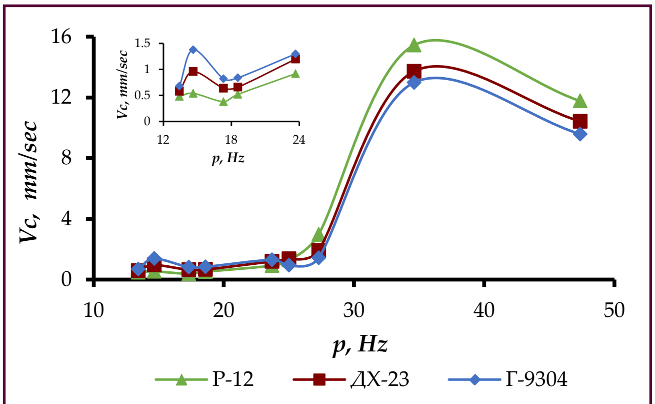

Fig. 3. The nature of the vibration damper change with an unbalance of 1500 g×mm

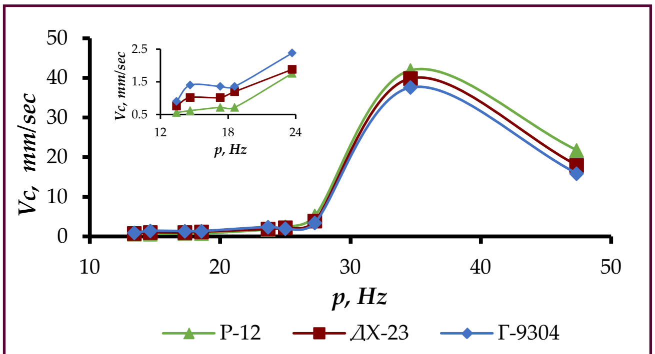

Fig. 4. The nature of the vibration damper change with an unbalance of 2720 g×mm

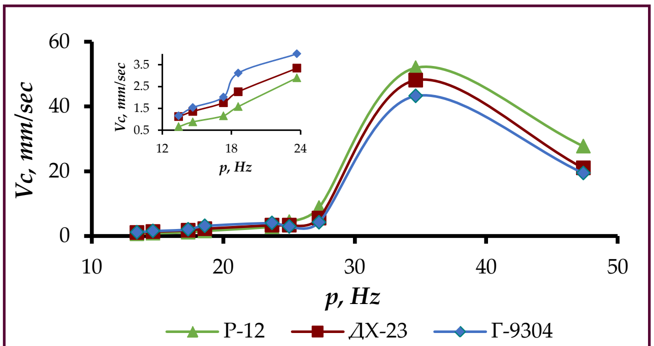

Fig. 5 The nature of the vibration damper change with an imbalance of 3940 g×mm

conditions in the well. In particular, the well fluid provides hydraulic resistance to the radial movement of the pump unit, which, of course, affects vibration and shock, and the test bench is made in an unfilled version. That is why the authors talk about qualitative relative characteristics, which cannot be affected by the absence of the surrounding gas-liquid medium, identical to the borehole fluid, with the exception of a possible change in temperature, and hence the characteristics of rubber as a result of vibration.

Additional studies under standard conditions at frequencies up to 50 Hz showed that the temperature of the rubber changes only within the limits at which the physical and mechanical characteristics remain practically constant. This is all the more true for the operation of the damper in downhole conditions, where the components of the flow of a gas-liquid mixture, including mechanical impurities and salts, move along complex trajectories with the formation of vortices [5] with variable velocities due to local resistances, which are also levers with slips of the damper under consideration, provide intensive heat removal from the outer and inner surfaces of the damper-rubber.

Based on the results of the studies presented in Figures 3-5, a statistical model was built [6, 7], taking into account the influence of the following factors on vibration: the density of the damping element (factor), the frequency of forced vibrations (factor) and imbalance (factor).

Taking into account the significant difference in the results in the frequency range from 13.427 to 23.685 Hz and from 25 to 47.368 Hz, the following regression equations were obtained:

for the first range

$$y_1 = 1.5125 - 0.2725x_1 + 0.7675x_2 + 0.6675x_3 - \\ - 0.0975x_1x_2 - 0.1275x_1x_3 + 0.5025x_2x_3 - \\ - 0.0525x_1x_2x_3, \quad (2)$$

for the second range

$$y_2 = 9.7675 + 1.5425x_1 + 7.3775x_2 + 3.8775x_3 + \\ + 1.0825x_1x_2 + 0.9125x_1x_3 + 2.5975x_2x_3 + \\ + 0.6225x_1x_2x_3. \quad (3)$$

These equations lead to the following conclusions:

– with an increase in the speed of rotation, the influence of all factors on vibration increases;

– according to the degree of influence on vibration, the factors are arranged in the following ascending order: the density of the rubber damper, the amount of imbalance, the frequency of forced vibrations;

– the growth of each of the two factors - the frequency of forced vibrations and imbalance - lead to an increase in vibration.

The effect of density in the selected frequency ranges is different: in the first range, an increase in density helps to reduce vibration, and in the second, an increase.

State Standard GOST-23326 [8] as a criterion for the dynamic properties of rubber is the loss factor, also called the «tangent of the angle of mechanical losses». To determine the dynamic characteristics of rubbers used in the damper for ECPU [1], they were investigated on a dynamic testing machine Instron-8801. The research results are presented in figure 6 in the coordinates «loss factor (tan δ) - deformation frequency». It can be seen from these graphs that with an increase in both frequency and density, the loss factor increases, and in the range from about 20 to 50 Hz, the relative difference increases.

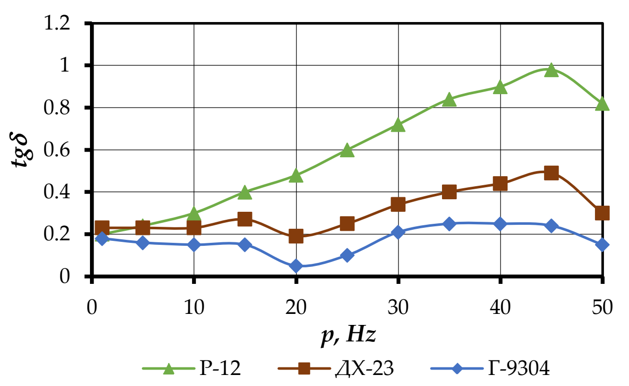

Fig. 6 Dependence of the loss factor on the deformation frequency

Comparison of the vibration velocity measured on the damper body (figs. 3-5) with the graph in figure 6 shows that the value of the tangent of the angle of mechanical losses of rubber confirms the effectiveness of the damper being developed in the entire investigated frequency range. At the same time, at low frequencies (from 13.5 to 23.5 Hz), in order to obtain the best vibration isolation indicators, it is necessary to provide a large tangent of the angle of mechanical losses. The best damping properties in this case are shown by P-12 rubber, which has a high density.

At high frequencies (from 23.5 to 50 Hz), in order to obtain the best vibration-isolating properties of the damper, it is necessary to use rubber for the substrate with a small tangent of the angle of mechanical losses, that is, with a lower dynamic modulus of elasticity. The best damping properties in this case are shown by rubber of the G-9304 brand, which, in comparison with other brands of rubber, has a lower density.

Conclusions

1. The functional capabilities of an autonomous damper built into the connector between any modules of the pumping unit of the electric centrifugal pump are analyzed.

2. A set of experimental studies of a full-size damper with substrates of different brands of rubbers and a study of the same rubbers according to the GOST 23326 method showed that both the vibration velocity and the loss factor and density can be used as a criterion for choosing a rubber brand to obtain the best vibration isolation parameters of the investigated damper in two frequency ranges: from 13.427 to 23.658 and from 25 to 47.368 Hz.

3. A statistical model has been developed with a polynomial dependence of the vibration velocity, measured at the point of contact of the support elements of the damper with the body of the vibration stand, on the frequency of forced vibrations, the density of the damper material and the magnitude of the disturbing imbalance.

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Исследование полноразмерного демпфера электроприводного центробежного насоса для добычи нефти

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Реферат

В статье описывается способ борьбы с усталостными явлениями в деталях соединения модулей агрегата электроприводного центробежного насоса для добычи нефти. Показано конструктивное решение для осуществления способа применительно к сложным внутрискважинным условиям в виде многофункционального демпфера с использованием дифференциального поршня для перевода его из транспортного положения при спуске в скважину в рабочее. Для полноразмерного демпфера проведены эксплуатационные исследования его виброизолирующих характеристик при использовании в виде подложек для опорных рычагов эластомеров различных плотностей и составов. Определены предпочтительные характеристики эластомеров и их ранжирование для различных частот вынужденных колебаний.

Ключевые слова: модуль, детали соединений; агрегат электроприводного центробежного насоса; установка электроцентробежная насосная; дифференциальный поршень; демпфер; подложка; виброскорость.

Neft hasilatı üçün elektrik mərkəzdənqaçma nasosunun tam ölçülü damperinin tədqiqi

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Xülasə

Məqalədə neft hasilatı üçün elektrik mərkəzdənqaçma nasos aqreqatının birləşdirici modullarının detallarında yorğunluq təzahürlərinə qarşı mübarizə üsulları təsvir edilmişdir. Mürəkkəb quyudaxili şərtlərdə tətbiq oluna bilən üsulun çoxfunksiyalı dempferin quyuya endirilməsi zamanı diferensial pistonun istifadəsilə nəql vəziyyətindən işçi vəziyyətə keçirilməsi şəklində həyata keçirilməsi üçün konstruktiv həll göstərilmişdir. Tam ölçülü dempferin müxtəlif sıxlıq və tərkibli elastomerlərin dayaq qolları üçün altlıq kimi istifadə edilməsi zamanı vibroizolyasiya xarakteristikalarının istismar tədqiqatları göstərilmişdir. Elastomerlərin üstünlük təşkil edən xarakteristikaları və məcburi rəqslərin müxtəlif tezlikləri üçün sıralanması müəyyənləşdirilmişdir.

Açar sözlər: modul, birləşmələrin detalları; elektrik intiqallı mərkəzdənqaçma nasos aqreqatı; elektrik mərkəzdənqaçma nasosunun quraşdırılması; diferensial piston; dempfer; altlıq; vibrosiya sürəti.