Constructing and calculating of multistage sucker rod string according to reduced stress

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Causes of failures of sucker-rod pumping units, occurring on oil-and-gas production enterprises, include breakages and twist-offs of sucker-rods, which are exposed to static and dynamic loads. Failures of equipment take place due to great values of cyclic loads, pressing forces and friction, which occur in well deviation intervals or as a result of wrong selection and construction of sucker-rod string.

Correct equipment selection is one of the directions of reliability growth of rod strings during operation sucker-rod pumping units. Therefore, it is necessary to do strength calculation in the design of rod string. In this article, rod string design procedure with differential piston pump NN-2SPxx/xx is regarded. The use of this equipment lets reduce reversal load and increase the operational life of this equipment. It is done by design features of the differential piston pump.

Calculation of hydraulic load by means of rod diameter regulating in accordance with operating conditions was carried out in this work. Reduced stress in the most strained sucker-rod, maximum and minimum load in rod hanger centre were determined and calculated reduced stresses were compared according to strength condition. Recommendations for steel grade of sucker-rods, based on results of reduced stress calculation, were given. Also, fibreglass material for sucker-rods was proposed. The material allows sucker-rod weight decreasing as well as increasing of load and non-corroding cyclic strength

Keywords: *sucker rod string, sucker-rod pumping unit, reduced stress, differential piston pump, strained maximum and minimum load in rod hanger centre*

Introduction

Oil production in Russia was estimated at 13 % of global production. Proven oil reserves in Russia totaled 103.2 billion barrels (6.1 % of global reserves) as of the beginning of 2015, making Russia number six by this measure after Venezuela (17.5 %), Saudi Arabia (15.7 %), Canada (10.2 %), Iran (9.3 %), and Iraq (8.8 %). The country's reserves life at current production rates (R/ P ratio) is 26.1 years compared to the global average P/ R of 52.5 years. In 2015, the reserves of crude oil and condensate in Russia increased by 730 Mt (~5,4 billion barrels), exceeding the production volume. The number of entities licensed to carry out mineral drilling and produce crude oil and condensate in Russia increased by five to 299 in 2015. This includes 117 members of 11 vertically integrated oil companies (VIOCs), 179 independent producers and three companies operating under production sharing contracts (PSCs). The production of oil, including condensate, in Russia increased 1.4 % in 2015 and reached a 7-year peak of 534.1 million metric tonnes, MMt. This made Russia the world's top oil producer at year-end 2015, according to the Russian Ministry of Energy, while in the beginning of 2015, the country was the world's second-largest producer after Saudi Arabia (with 12.7 % of total global production vs. 12.0 % respectively). It should be noted that 5.8 MMt came from hard-to-recover reserves (85 fields of the Bazhenov, Abalak, Khadum and Domanik reservoirs).

Analysis and Methods of Oil Extraction

Over 90 per cent of oil is extracted by sucker-rod pumping units. Such equipment can operate at complex mining-geological conditions with highly viscous oil and depleted wells.

The analysis of efficiency sucker-rod pumping units identified fault causes (Fig. 1). Sucker rod string is the most vulnerable part of pumping unit. Over 40 per cent of fault causes was accounted for the failure of sucker rod strings (Ufa, 2016).

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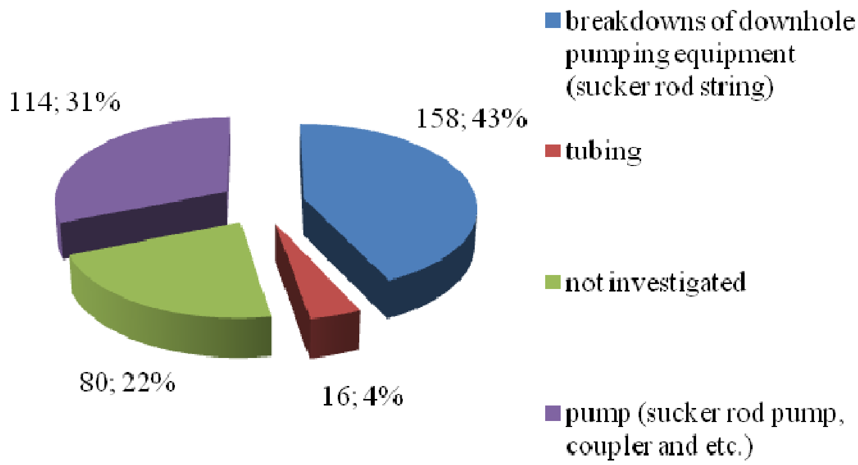

Fig. 1. Fault causes of sucker rod pumping units.

Correct sourcing of structures sucker rod string with reduced stress and all forces should be able to increase the operational life of wells and exploitation rate.

There are many methods of calculating sucker rod strings today that used in oil production. Semi-empirical dependence of Mills and Sloneger are practised on a wide scale in Europe. Analysis technique of American petroleum institute (API) is used in the USA. Smith plot defines allowable stress in diagram form and analytically under a variety of stress ratio. Smith plot is derived from three load conditions (three points). Endurance strength shall be determined for each of load conditions (Nedra, 2012). The disadvantage of these methods is a divergence of results of calculation and dynamometry of sucker-rod pumping units that constitute 8 – 15 %. For example, maximal beam load according to Mills and Sloneger is 15 per cent lower and by the procedure of API is 8,6 % (Dubinov, 2017).

Calculation methods of foreign colleagues are unsuitable for using in Russia as the all-Union State Standard established divergence of results calculating and experimental evidence not more than 5 %. So mathematical modelling working process of sucker rod string is widely used in production. It is based on the equation of A. S. Virnovskogo and A. N. Adinina. This method is assayed and introduced at various oil fields.

In operation process of sucker-rod pumping unit the following loads are applied to polished rod:

Static loads - weight loads of sucker rod string and fluid, frictional forces in contact between plunger and pump cylinder and frictional forces applied to sucker rod by tubing;

Dynamic - loads caused by occurring of inertial force of moving of sucker rod string and fluid as well as sucker rod vibration (Dubinov, 2017; Antonenko et.al., 2013; Nassonov, 2010; Isaev and Arkhipov, 2015; Bajan, 2007; Gusarovet.al., 2006; Han et al., 2017; Stevan et al., 2015; Ismagilov and Gabhrakhimov, 2016; Ivanova etal., 2015; Kiazimov et al., 2011; Klimov and Valovsky, 2015; Liu et al., 2016; Liu et al., 2016).

These loads are acting together, and therefore, it is necessary to take them into account in constructing of sucker rod string. However, it is very hard to calculate dynamic loads. It is necessary to take them into account to obtain dynamogram. Great values of cyclical loads, pressing forces and forces of friction occurring in borehole deviation zone leads to this kind of failures. This also may happen in a result of wrong choice (constructing) of sucker rod string.

Constructing sucker rod string is recommended to be made on the basis of the technological potential of oilfield equipment (Liu et al., 2016; Qian Zhang, 2017; Nurgaljev, 2015).

Differential piston pump

Design features of the differential piston pump of NN-2SPxx/xx type (Fig. 2) allow decreasing alternate stress affecting on sucker rods in the process of exploitation. Monolithic rod (3) creates additional stress on a sucker-rod string. It allows overcoming hydraulic and mechanical friction in tubing and in pump (Shagiev, 2015; Pvalchenko, 2015; Bahtizin et al., 2015; Liu et al., 2017; Sentyakov et al., 2016; Novokshonov et al., 2017; Shljapnikov, 2014; Urazakov et al., 2016; Sviatskii et al., 2016).

Thus, by decreasing alternate stress applied to sucker rods, amount of breakages and twist-offs reduces.

When rod moves downward, besides the weight of sucker rod string, also a hydraulic force of fluid weight acts.

$$F_t = \Delta p \times A \tag{1}$$

where Δp - the hydrostatic pressure of fluid exerted on the rod, [Pa], A - cross sectional square of the rod, m^2 (Liu et al., 2016; Topolnikov et al., 2015; Varga and Lóczi, 2016).

Hydraulic stress can be regulated through the rod diameter according to work conditions. For standardization of detail size of the mechanical seal, rod diameters are accepted to be equal to diameters of pistons and plungers (Tab. 1).

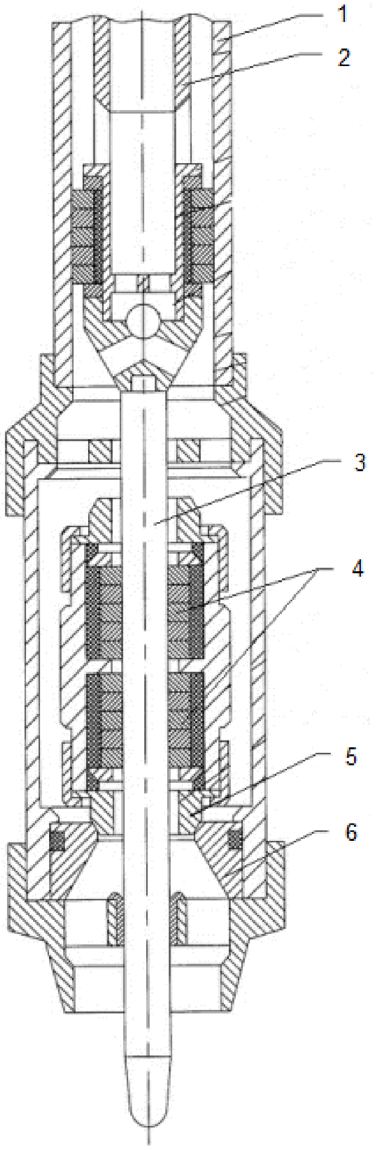

Fig. 2. Differential piston pump: 1-cylinder, 2-piston, 3-rod, 4-mechanical seal of NSB (НСБ) type, 5- standing valve, 6-standing valve collar.

Tab. 1. Hydraulic stress applied to sucker rods for different pumps.

Pump brand	$\mathbf{Q_{teor}}$, n=5 oscillations per minute, S = 3 [m].	**Setting depth**, [m].	$\mathbf{F_t}$, [kg] under H = 1000 [m].	**Ball size**, [mm].
2СП-32/24	7,4	1500	450	19,05
2СП-45/24	23,8	1500	450	25,4
2СП-45/32	16,4	1500	800	28,575
2СП-57/24	45,7	1200	450	25
2СП-57/32	38,3	1200	800	25

Calculation of reduced stress in the most stressed sucker rod is carried in accordance with recommendations:

$$\sigma = \sqrt{\frac{\sigma_{\max} \times (\sigma_{\max} - \sigma_{\min})}{2}} \le [\sigma] \tag{2}$$

where σ - allowable reduced stress in sucker rods, [MPa]; σ_{max} - maximum stress in sucker rods, [MPa]; σ_{min} – minimum stress in sucker rods, [MPa];

The maximum and minimum stress in sucker rod hanging point:

$$\sigma_{\max} = \frac{P_{\max}}{f_{шт}}, \qquad \sigma_{\min} = \frac{P_{\min}}{f_{шт}} \tag{3}$$

where P_{max} – the maximum stress on horsehead, [N].

Maximum and minimum stresses in sucker rod hanging point are calculated by equations (Topolnikov et al., 2015):

$$P_{\max} = (q_1 \cdot L_1 + q_2 \cdot L_2) \cdot g \times (1 + \frac{S \times n^2}{1800}) + F \cdot \rho_q \cdot L \cdot g + P_{tr}$$

$$P_{\min} = (1 - \frac{\rho_q}{\rho_c}) \times (q_1 \cdot L_1 + q_2 \cdot L_2) \cdot g \times (1 - \frac{S \times n^2}{1800}) - P_{tr} \tag{4}$$

where P - weight of sucker rod string, [N]; P_q - weight of fluid column over the piston, [N]; P_{tr} - hydrodynamic and mechanic frictional force of sucker rod string inside tubing and inside pump, [N]; ρ_q , ρ_c - fluid and steel density, [kg.cm^{-1}]; F – cross sectional area of plunger, [m^2]; q – weight of one meter sucker rod with couplers, [kg];

Lower L_2 and upper L_1 step length (Varga and Lóczi, 2016):

$$L_2 = \frac{\sigma_{\max} \cdot f_2 - P_q}{q_2 \cdot g \cdot (b + m)}, \qquad L_1 = \frac{\sigma_{\max} \cdot (f_2 - f_1)}{q_1 \cdot g \cdot (b + m)} \tag{5}$$

where f_2 – square of the cross section of sucker rod of lower step, [m$_2$]; m – amplification factor (m = 0,2); b – relief coefficient (Valovsky et al., 2015; Yamamoto et al., 2017).

Steel grade is chosen regarding results of reduced stresses in sucker rod string. To choose it, it is necessary to take working conditions of sucker rods into account.

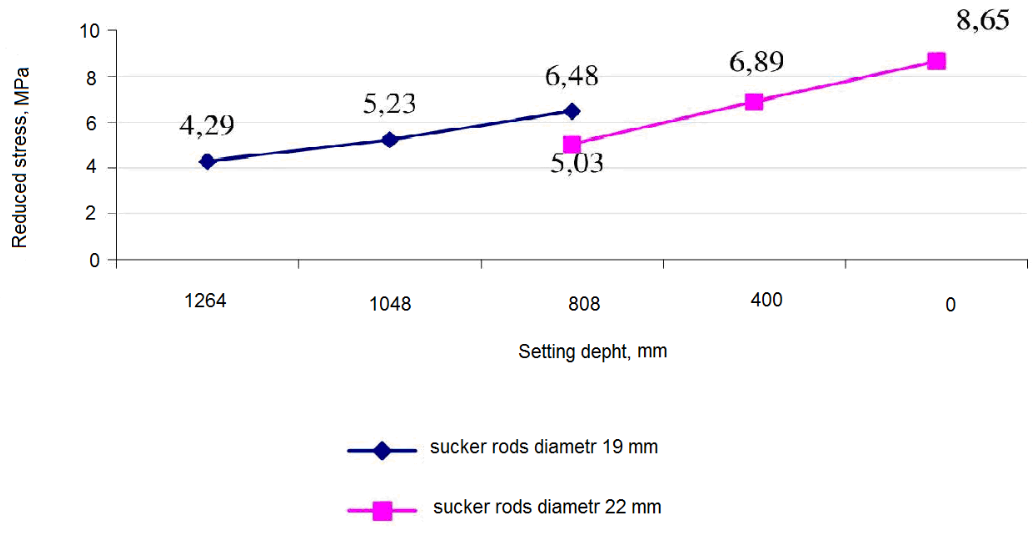

Fig. 3. Reduced stresses in steel sucker rods.

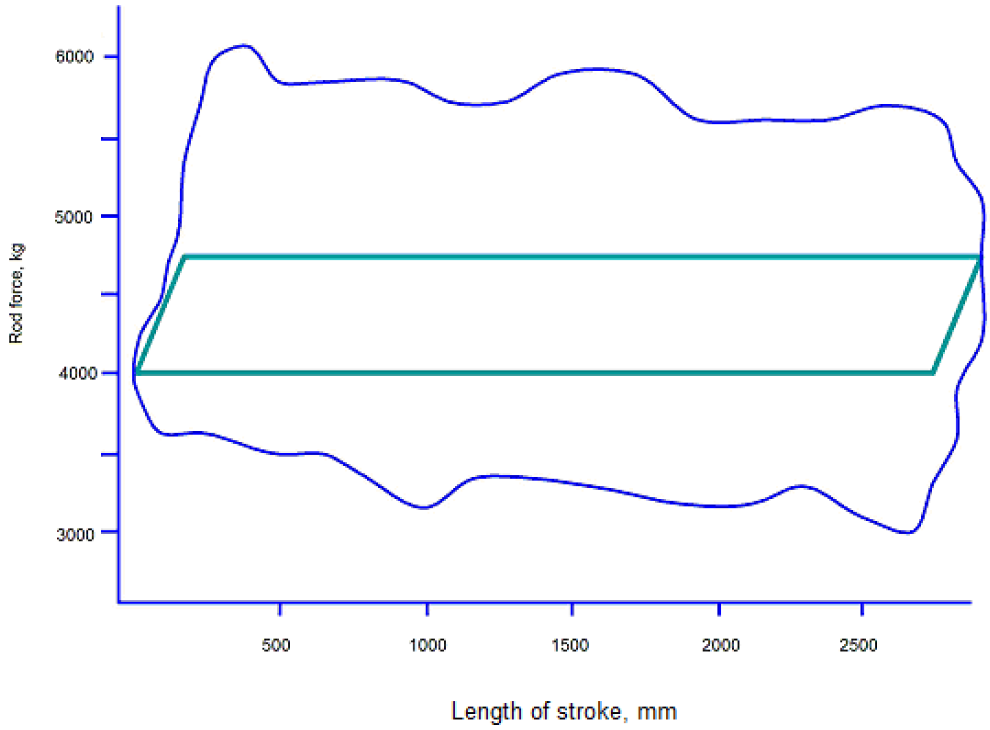

Fig. 4. Dynamometer card of well with steel sucker rods.

Fibreglass sucker rod strings

Native industry produces fibreglass sucker rod strings (fig. 5). They have the next advantages over steel sucker rods:

- reducing the weight of sucker rod string,
- decreasing maximum stress on a polished rod up by 30 %,
- amount of basic operating cycles reaches up to 7.5 million,
- opportunity to increase the pump-setting depth to 2500 m,
- increased corrosion resistance.

Fig. 5. Fibreglass sucker rod strings.

Fibreglass sucker rods have less roughness in comparison with steel ones. This advantage allows their using in wells complicated with asphalt-resin-paraffin deposits (ARPD).

However, viscous oil is limited to use of fibreglass sucker rods. It is associated with heavy hydraulic friction forces in tubings that arise during production oil. As the result, the probability of sticking fibreglass sucker rods during downstroke is grown up due to the light weight of sucker rod string (900...1200 kg) (Bahtizin et al., 2015). Oversize rods are used to prevent sticking of fibreglass sucker rod strings (Fig. 6).

The right choice of sucker rod string contributes to the long and failure-free operation of the sucker-rod pumping unit. Using of fibreglass sucker rods allows reducing of maximum stress applied to horsehead as well as decreasing of reduced stress.

Differential piston pump of NN-2SPxx/xx type helps to decrease alternate stresses due to increasing stress when sucker rod string moves downward. It results into reducing of the amount of premature failures of the sucker-rod pumping unit.

Employing differential piston pumps does not involve changing of construction of existing wells and pump drives. Requirements for these pumps: maximum pump diameter should not be less than 57 mm in case of tubing string diameter is 73 mm. Type of the pump: non-inserted pump with minimum cylinder diameter more than 38 mm. If pump setting depth is equal to 1000 m, pressure differential reaches 10 MPa. The additional hydraulic load is 4500 N for piston diameter equal to 24 mm and 25000 N for piston diameter of 57 mm.

As a result of calculations, it was discovered that hydraulic pressure at the top of the sucker-rod is proportional to piston cross-section area with 32 mm diameter.

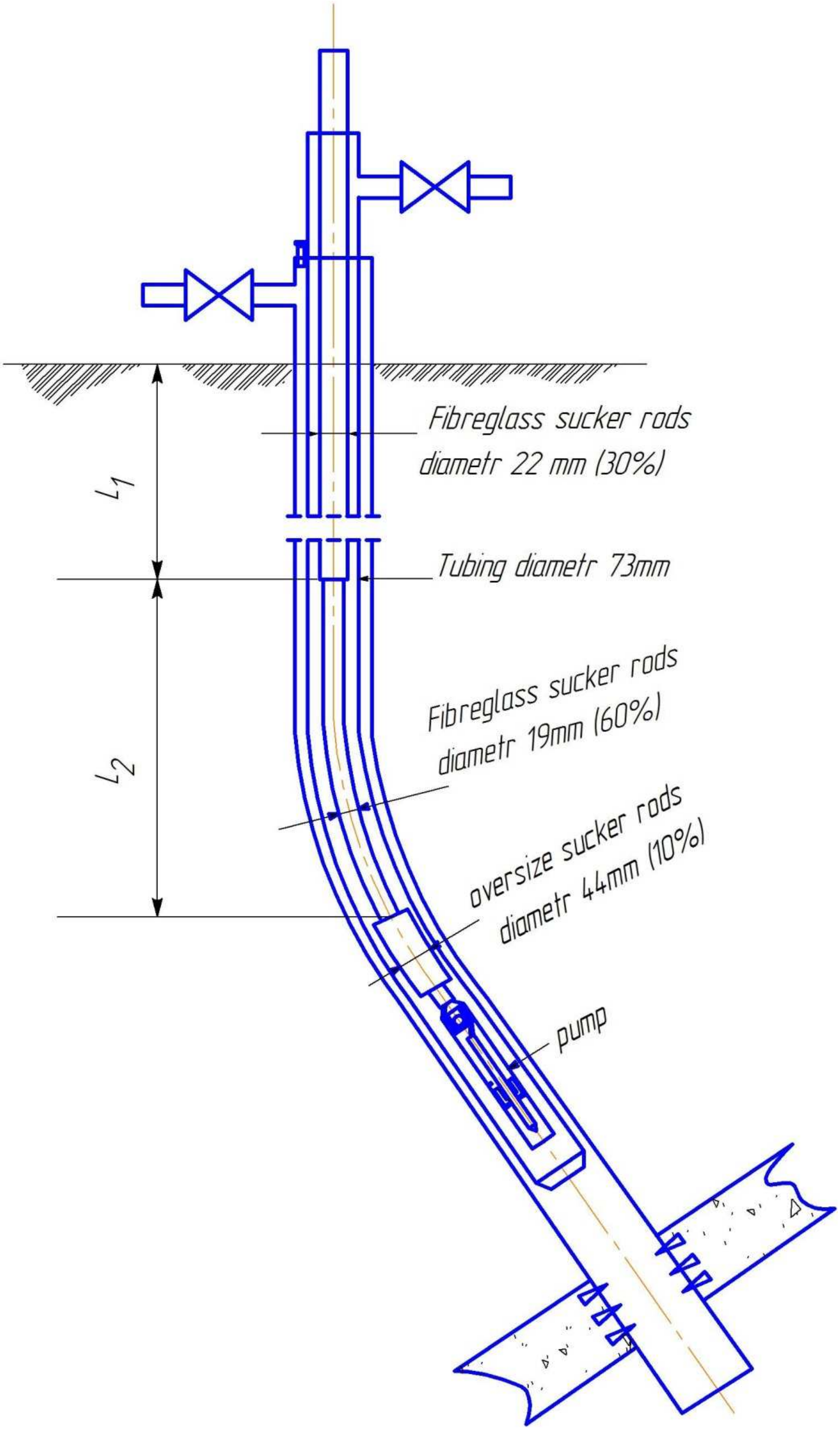

Fig. 6. Configuration of fibreglass sucker rod strings.

That is why strength testing of a sucker-rod string according to increased loads is necessary. Reduced stresses can be reduced by increasing of piston diameter. To keep pump output on the required level, it is necessary to increase the pump rate.

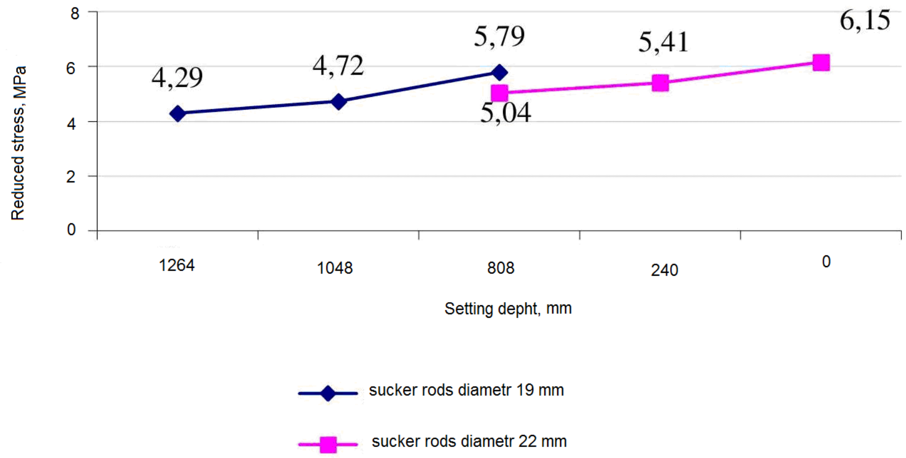

Fig. 7. Reduced stress in fibreglass sucker rods.

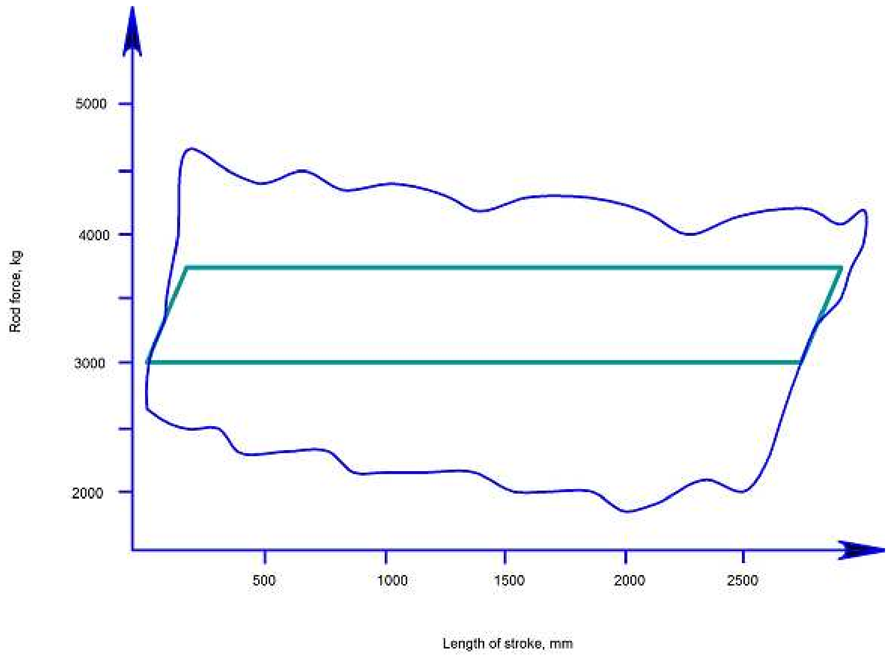

Fig. 8. Dynamometer card of well with fibreglass sucker rod string.

When employing sucker rod string in aggressive environments which lead to corrossion, it is necessary to use sucker rods of "K" class or fibreglass sucker rods.

A technical system composed of sucker rod string will normally comprise a number of subsystems and components that are interconnected in such a way that the system is able to perform a set of required functions. The analysis was used to denote an element of the system, whether it is a component or a large subsystem. The main concern of a reliability engineer is to identify potential failures and to prevent these failures from occurring. A failure of a functional block is defined as “the termination of its ability to perform a required function”. It is, therefore, necessary for the reliability engineer to identify all relevant functions and the performance criteria related to each function.

Conclusion

Calculation of hydraulic load by means of rod diameter regulating in accordance with operating conditions was carried out in this work.

Reduced stress in the most strained sucker-rod, maximum and minimum load in rod hanger centre were determined and calculated reduced stresses were compared according to strength condition. Recommendations for steel grade of sucker-rods, based on results of reduced stress calculation, were given. Also, fibreglass material for sucker-rods was proposed. The material allows sucker-rod weight decreasing as well as increasing of load and non-corroding cyclic strength.

As follows from the operational analysis of sucker-rod pumping units were defined fault causes of sucker-rods, calculated sucker-rod string for reduced stresses that allow safe allowable load at sucker-rods and offered geometric and constructive structural features of sucker-rod string.

***Acknowledgements**: This work is a part of project KEGA 014STU-4/2015. The article was supported by the VEGA 1/0477/14 project "Research of influence of selected characteristics of machining process on achieved quality of machined surface and problem free assembly using high Technologies" supported by the scientific grant agency of the Ministry of Education of the Slovak Republic and of Slovak Academy of Sciences. This publication is the result of implementation of the project: "UNIVERSITY SCIENTIFIC PARK: CAMPUS MTF STU - CAMBO" (ITMS: 26220220179) supported by the Research & Development Operational Program funded by the EFRR.*

References

Antonenko, A., Shaydakov, V., Lyudvinitskaya, R.: Substantiation of parameters of metallopolymeric rod string., *Neftegazovoe delo, № 4. Ufa. Izdatel'stvo: Ufimskij gosudarstvennyj neftjanoj tehnicheskij universitet. 2013.*

Babajan, S. A.: Raschet jekstremal'nyh nagruzok v kolonne nasosnyh shtang dlja dobychi nefti., *Neft, gas i biznes № 4. Moskva Izdatel'stvo: Neft' i biznes. 2007.*

Bahtizin, N., Urazakov, R., Rizvanov, R., Komkov, G.: Analiz metodov rascheta dopustimogo privedennogo naprjazhenija v nasosnyh shtangah. *Nauchnye trudy NIPI NEFTEGAZ GNKAR. № 4. Baku Izdatel'stvo: NIPI "Neftegaz" Gosudarstvennoj neftjanoj kompanii Azerbajdzhanskoj Respubliki, 2015.*

Dubinov Ju. S.: Analiz i modernizacija metodiki podbora polyh shtang, primenjaemyh pri odnovremenno-razdel'noj jekspluatacii. *Avtoreferat na soiskanie uchenoj stepeni kanditata tehnicheskih nauk. g. Moskva, 162 pp, 2017.*

Gusarov, A., Kutuzov, I., Shevelenko, D.: Increase of Diagnosis Effectiveness of Rod Oil Aggregate. *Vestnik Orenburgskogo gosudarstvennogo universiteta. № 2-2. Orenburg Izdatel'stvo: Orenburgskij gosudarstvennyj universitet. 2006.*

Hakimyanov, I.: Modern control stations for sucker rod pump units., *Neftegazovoe 2013delo, № 1. г. Ufa Izdatel'stvo: Ufimskij gosudarstvennyj neftjanoj tehnicheskij universitet. 2014.*

Han, C., Ren, X., Zheng, J.: Analysis of Abrasion for Stator Bushings of Equal Thickness Screw Pump in High Temperature and Sand Crude Oil. *Zhongguo Jixie Gongcheng/China Mechanical EngineeringVolume 28, Issue 4, 25 February 2017, pp 446-450, 2017.*

Isaev A.A., Arhipov K.I.: Vyjavlenie faktorov, snizhajushhih rabotosposobnost' nasosnyh shtang (na primere neftjanyh kompanij Respubliki Tatarstan)., *TERRITORIJa NEFTEGAZ, № 5. Moskva Izdatel'stvo: Obshhestvo s ogranichennoj otvetstvennost'ju "Kamelot Pablishing". 2015.*

Ismagilov, R. R., Gabdrakhimov, M.S.: Breakage by structural elements rod string. Sovremennye tehnologii v neftegazovom dele – 2016. *Sbornik trudov Mezhdunarodnoj nauchno-tehnicheskoj konferencii posvjashhennoj 60-letiju filiala. 2016. Ufa Izdatel'stvo: Ufimskij gosudarstvennyj neftjanoj tehnicheskij universitet. 2016.*

Ivanova, T. N., Novokshonov, D. N., Vdovina, E. Y., Emel'yanov, E. O.: Improving the efficiency of sucker rod pump with hydraulic drive., *NAUChNOE OBOZRENIE, № 22. Moskva Izdatel'stvo: Izdatel'skij dom "Nauka obrazovanija". 2015.*

Kjazimov, Sh.P., Bajramov, S.B., Mustafaev, Sh.I.: Povyshenie jeffektivnosti skvazhinnoj shtangovoj nasosnoj ustanovki. *Nauchnye trudy NIPI NEFTEGAZ GNKAR Baku Izdatel'stvo: NIPI "Neftegaz" Gosudarstvennoj neftjanoj kompanii Azerbajdzhanskoj Respubliki, 2011*.

Klimov, V.A., Valovsky, V.M.: On operational efficiency of sucker rods., *Neftjanoe hozjajstvo, № 1. Moskva Izdatel'stvo: ZAO "Izdatel'stvo "Neftjanoe hozjajstvo". 2015.*

Liu, Y.-F., Dong, P., Liu, Y., Xu, X.Y.: Design and application of electric oil pump in automatic transmission for efficiency improvement and start–stop function. *Journal of Central South UniversityVolume 23, Issue 3, 1 March 2016, pp 570-580, 2016.*

Nassonov, V. V.: Soprotivlenie ustalosti nasosnyh shtang v korrozionnoj srede., *Izvestija vysshih uchebnyh zavedenij. Neft i gaz, № 4 Tjumen'Izdatel'stvo: Tjumenskij industrial'nyj universitet g, 2010*.

Novokshonov, D.N., Baranov M.N., Ivanova T.N.: Reliability Improvement of Sucker-Rod String at Directional and Horizontal Wells. *Intellektual''nye sistemy v proizvodstve . № 1. Izhevsk Izdatel'stvo: Izhevskij gosudarstvennyj tehnicheskij universitet im. M.T. Kalashnikova, 2017.*

Nurgaliev, R.R. Analiz raboty shtang v iskrivlennyh uchastkah skvazhin fonda NGDU, *Nizhnesortymskneft', № 4. Vestnik molodogo uchenogo UGNTU Ufa Izdatel'stvo: Ufimskij gosudarstvennyj neftjanoj tehnicheskij universitet. 2015.*

Pyalchenkov, D.V.: Performance assessment uptime submersible pumping equipment based on parametric models. *Sovremennye problemy nauki i obrazovanija. № S6. Penza Izdatel'stvo: Izdatel'skij Dom "Akademija Estestvoznanija". 2014.*

Qian, W., Zhang, H.: A Sensorless Control Solution for DCT Oil Pump with BLDC Motor. *World Congress Experience, WCX 2017; Cobo CenterDetroit; United States; 4 April 2017 through 6 April 2017; Code 127407, 2017.*

Sbornik nauchnyh trudov 43-j Mezhdunarodnoj nauchno-tehnicheskoj konferencii molodyh uchenyh, aspirantov i studentov, posvjashhennoj 60-letiju filiala UGNTU v g. Oktjabr'skom: v 2-h t. / otv. red. *V.Sh. Muhametshin. – Ufa: Izd-vo UGNTU, 2016.*

Sentyakov, B., Repko, A., Sviatskii, V., Soldán, M., Nikitin. Y.: Simulation of oil products separation from fibrous sorbent material centrifugally. *Acta Montanistica Slovaca Volume 21 (2016), number 3, pp 238-246, 2016.*

Shagiev S. A.: Ustrojstvo dlja predotvrsshhenija obryva I otvorota kolonny nasosnyh shtang. Problemy razrabotki mestorozhdenij uglevodorodnyh i rudnyh poleznyh iskopaemyh . *Izdatel'stvo: Permskij nacional'nyj issledovatel'skij politehnicheskij universitet. Perm, 2015.*

Shljapnikov, V.: Sovershenstvovanie tehnologij dobychi nefti i remonta skvazhin mnogoplastovyh mestorozhdenij na pozdnih stadijah razrabotki. *Avtoreferat na soiskanie uchenoj stepeni kanditata tehnicheskih nauk. 103 pp, 2014.*

Spravochnik po dobyche nefti/K. R. Urazakov, S. E. Zdol'nik, M. M. Nagumanov i dr.; *pod red. K. R. Urazakova.- SPb: OOO "Nedra", 672 pp, 2012.*

Stevan, M. Mušicki1, L., Kljajević, M., Miško, M., Milanović, M., Čebela, Ž., Slađana, S. Milovanović, S., Nenadović, S., Nenadović, T.: Predicting of lead distribution and immobilization in soil of the region of lignite mining (Rudovci, Serbia). *Acta Montanistica Slovaca Volume 20 (2015), number 3, 192-199, 2015*.

Sviatskii, V., Repko, A., Janačova, D., Ivandič, I., Perminova, O., Nikitin. Y.: Regeneration of a fibrous sorbent based on a centrifugal process for environmental geology of oil and groundwater degradation. *Acta Montanistica Slovaca Volume 21 (2016), number 4, pp 272-279, 2016.*

Topolnikov, A.S., Urazakov, K.R., Ismagilov, S.F.: Mathematical model of sucker rod plants operating under complicated conditions. *Uchenye zapiski Al'met'evskogo gosudarstvennogo neftjanogo instituta. Izdatel'stvo: Al'met'evskij gosudarstvennyj neftjanoj institut. g. Al'met'evsk, 2015.*

Urazakov, K.R., Mukhin, I.A., Hakimov, T.A.: The analysis of strength characteristics of pump rods with various types of carving connections, *Neftegazovoe delo, 2004 №4. Ufa Izdatel'stvo: Ufimskij gosudarstvennyj neftjanoj tehnicheskij universitet . 2016.*

Valovsky, K. V., Basos, G. Y., Valovsky, V. M., Bragin, D. V.: The results of testing and prospects of usage of sucker-rod pumping units with no contact of sucker-rods with viscous fluids. *Oborudovanie i tehnologii dlja neftegazovogo kompleksa,№ 5. Moskva Izdatel'stvo: Vserossijskij nauchno-issledovatel'skij institut organizacii, upravlenija i jekonomiki neftegazovoj promyshlennosti. 2015*

Varga, Z., Lóczi, K.: Investigation of heat recovery with pump-arounds at a crude oil atmospheric distillation tower. *Chemical Engineering Transactions Volume 52, pp 889-894, 2016.*

Yamamoto, K., Sadakata, N., Okada, H., Fujita, Y.: The Development of ECU-Integrated Electric Oil Pump for Powertrain. SAE World Congress Experience, WCX 2017; *Cobo CenterDetroit; United States; 4 April 2017 through 6 April 2017; Code 127407, 2017.*