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Satbayev University

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ИЗВЕСТИЯ

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INVESTIGATION OF THE STRESS-STRAIN STATE OF COMPONENTS OF A HYDRAULIC IMPACT DEVICE

Abstract. One of the most important problems facing the exploration, oil, gas and mining industry is increasing productivity and quality of used machinery and technology. This paper presents the results of the study of the stress-strain state of parts of a hydraulic impact device. The investigated device has a source of low-frequency vibrations in the form of a hydraulic vibrating module, including a base machine, an actuating element, an electro-hydraulic control unit, and an electronic block for monitoring a technological process. The electronic block for monitoring of technological process receives signals from the sensor of flow and concentration of metal, installed at the outlet of the pumping well, converts them with a recorder, a decoder, and a corrector, and transmits them to the electro-hydraulic control unit, where electronic signals are transformed into hydraulic ones and transmitted to the actuator. The purpose of the study is to investigate the stress-strain state of components of a hydraulic impact device and its further use in the exploration industry in good drilling. The ANSYS Explicit Dynamics module was used to study the stress-strain state of hydraulic impact device components, which makes it possible to analyze the physical picture of high-speed processes for objects subjected to strictly non-linear, alternating dynamic loads. The strength verification was carried out using the Mises maximum stress criterion. The criteria are based on the Mises-Hencky theory, also known as the energy theory of deformation. As a result, the strength and stiffness of the hydraulic impactor element are ensured. For the more loaded element, the striker, the safety margin is 1.57, which is within the permissible range (1.5-2.0).

Key words. Stress-strain state, hydraulic impact device, vibration module, finite-element mesh, borehole drilling, safety margin.

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ГИДРАВЛИКАЛЫҚ СОҚҚЫ ҚҰРЫЛҒЫСЫ БӨЛШЕКТЕРІНІҢ КЕРНЕУЛІ ДЕФОРМАЦИЯЛАНҒАН КҮЙІН ЗЕРТТЕУ

Аннотация. Геологиялық барлау, мұнай-газ және тау-кен өнеркәсібі алдында тұрған маңызды проблемалардың бірі – пайдаланылатын техника мен технологияның өнімділігі мен жұмыс сапасын арттыру. Бұл мақалада гидравликалық соққы құрылғысының бөлшектерінің кернеулі деформацияланған күйін зерттеу нәтижелері келтірілген. Зерттелетін құрылғыда гидравликалық діріл модулі түріндегі төмен жиілікті тербеліс көзі бар, оның ішінде негізгі машина, атқарушы элемент, электронды гидравликалық басқару блогы және электронды технологиялық бақылау блогы бар. Бұл ретте технологиялық үрдістің электрондық мониторинг блогы айдау ұңғымасынан шығуда орнатылған металл шығыны мен концентрациясы датчигінен сигналдар алады, оларды тіркеушінің, дешифратордың және түзеткіштің көмегімен түрлендіреді, электрондық сигналдар гидравликалық сигналдарға түрлендірілетін және атқарушы элементке берілетін электрондық-гидравликалық басқару блогына береді. Зерттеудің мақсаты гидравликалық соққы құрылғысының бөлшектерінің кернеулі деформацияланған күйін зерттеу, сондай-ақ оны ұңғымаларды бұрғылау кезінде геологиялық барлау саласында одан әрі пайдалану болып табылады. Гидравликалық соққы құрылғысының бөлшектерінің кернеулі деформацияланған күйін зерттеу үшін ANSYS Explicit Dynamics модулі пайдаланылды, ол таза сызықты емес, айнымалы динамикалық жүктемелерге ұшыраған объектілер үшін өтпелі үрдістердің физикалық көрінісін талдауға мүмкіндік береді. Беріктікке тексеру Мизес бойынша максималды кернеу критерийімен жүргізілді. Критерийлер қалыптасу энергиясының теориясы деп те аталатын Мизес-Хенки (Mises-Hencky) теориясына негізделген. Нәтижесінде гидравликалық соққы құрылғысы элементтерінің беріктігі мен қаттылығы қамтамасыз етіледі. Неғұрлым жүктелген соққы элементі үшін қауіпсіздік шегі 1,57 болды, бұл рұқсат етілген шектерде (1,5-2,0) орналасқан.

Түйінді сөздер. Кернеулі деформацияланған күй, гидравликалық соққы құрылғысы, діріл модулі, ақырлы тор, ұңғымаларды бұрғылау, қауіпсіздік шегі.

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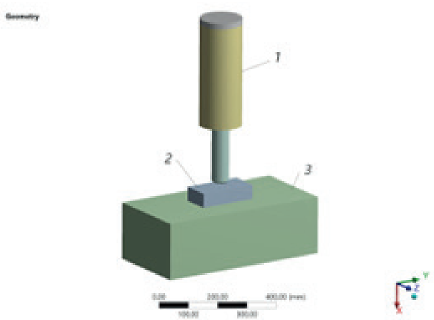
ИССЛЕДОВАНИЕ НАПРЯЖЕННО-ДЕФОРМИРОВАННОГО СОСТОЯНИЯ ДЕТАЛЕЙ ГИДРАВЛИЧЕСКОГО УДАРНОГО УСТРОЙСТВА

Аннотация. Одной из важнейших проблем, стоящих перед геологоразведочной, нефтегазовой и горнодобывающей промышленностью, является повышение производительности и качества работы используемой техники и технологии. В данной статье приводятся результаты исследования напряженно-деформированного состояния (НДС) деталей гидравлического ударного устройства. Исследуемое устройство имеет источник низкочастотных колебаний в виде гидравлического вибрационного модуля, включающий базовую машину, исполнительный элемент, электронно-гидравлический блок управления и электронный блок мониторинга технологического процесса. При этом электронный блок мониторинга технологического процесса получает сигналы от датчика расхода и концентрации металла, установленного на выходе из откачивающей скважины, преобразует их с помощью регистратора, дешифратора и корректора, передаёт их в электронно-гидравлический блок управления, где электронные сигналы преобразуются в гидравлические и передаются в исполнительный элемент. Целью исследования является исследование НДС-деталей гидравлического ударного устройства, а также дальнейшее использование его в геологоразведочной отрасли при бурении скважин. Для исследования НДС-деталей гидравлического ударного устройства использован модуль ANSYS Explicit Dynamics, который дает возможность анализировать физическую картину быстротечных процессов для объектов, подвергаемых сугубо нелинейным, переменным динамическим нагрузкам. Поверка на прочность производилась критерием максимального напряжения по Мизесу. Критерии основываются на теории Мизез-Хенки (Mises-Hencky), также известной как теория энергии формоизменения. В результате прочность и жесткость элементов гидравлического ударного устройства обеспечена. Для более нагруженного элемента – ударника запас прочности составил 1,57, что находится в допустимых пределах (1,5-2,0).

Ключевые слова: напряженно-деформированное состояние, гидравлическое ударное устройство, вибрационный модуль, конечно-элементная сетка, бурение скважин, запас прочности.

Introduction. Scientific and technological progress in any industry in modern conditions is practically impossible without a broad generalization of accumulated experience and in-depth scientific study of technological processes. Only on this basis, it is possible to most effectively and quickly enough solve the issues of increasing productivity, improving the quality of work, and reducing its cost. It is known that money spent on prospecting does not give an immediate return, and often, when exploring ultimately unprofitable fields, these funds are not recouped at all and do not return to the national economy. Consequently, reduction of expenses on exploration services at the expense of more profitable carrying out of research, and reduction of expenses per unit of volume of prospecting works at an increase of quality taking into account their scales has a great national economic value. Because a considerable share of these expenses (up to 30 %) falls on the drilling of geological prospecting wells, one can imagine the importance of the perfection of processes and, first of all, of technics and technology of drilling (Dmitriev, 2008:216, Polufuntikova, et al., 2012:107, Kagarmanov, et al., 2007:324, Muminov, et al., 2022a:5, Muminov, et al., 2021b:5). In this connection the work aimed at the investigation of the stress-strain state of hydraulic percussion device parts is actual.

Research materials and methods. The ANSYS Explicit Dynamics module was used to investigate the stress-strain state during the interaction between a hydraulic impactor and the ground. The study consists of several stages: selection of calculation module; creation of a geometric model of the object under study; specifying properties and material models; creation of finite-element mesh; setting contact conditions; setting boundary conditions; setting up the solver; running the calculation; analysis of calculation results. The ANSYS Explicit Dynamics non-linear dynamics software suite allows the researcher to evaluate the effects of shock and another impulse loading of varying nature on the designed objects, as well as to develop measures to improve their resistance to these types of effects. To model the described physical phenomena in computational analysis, such tasks require the use of specialized tools. It is well known that obtaining the computational data to understand such complex processes is particularly important when in-situ testing is too expensive or impossible. ANSYS Explicit Dynamics makes it possible to analyze the physical picture of high-speed processes for objects subjected to inherently non-linear, variable dynamic loads (Denisov, 2014:77, Sherov, et al., 2021a:8, Kadyrov, et al., 2021:9, Sherov, et al., 2017b:10,). A 3D model of the hydraulic impact device was built in DesignModeler (DM) (figure 1).



1 - hydraulic impact device, 2 - platform, 3 – ground
Figure 1 - 3D model of a hydraulic impactor

DM is not much different from a CAD system, but it does have some special features. DM is used to create a design model as close to the real model as possible. The hydraulic impactor model is built as a set of bodies to create a more correct mesh and simplify partitioning tasks. And also areas are cut out on the surfaces of the striker piston and front cover to set the spring boundary conditions (Ivanov, 2016:56, Rakhimov, et al., 2021:9, Dudak, et al., 2017a:8, Balgabekov, et al., 2014:3). At this stage, the material models involved in the calculation of the hydraulic impact device are selected. The material properties were set according to the selected material model. The material model was selected from the model library, and soil (clay) was added to the library independently by entering the mechanical material properties (E=50MPa, ν=0.4) (Ivanov, 2016:56, Dudak, et al., 2019b:12, Kassenov, et al., 2022:6, Mukanov, et al., 2019b:4).

A finite element mesh has been created for the whole computational model (tetrahedral or hexahedral). It is common knowledge that the better the finite element mesh is constructed, the more accurate and reliable the calculation result will be. For this purpose, the finite-element mesh was milled (figure 2, b) in sections to improve the calculation accuracy, taking into account the geometry features (figure 2, c) (Ivanov, 2016:56).

а) *б)* *в)*

a) device, b) striker piston, c) striker sleeve and disc

Figure 2 - Finite element grid of the hydraulic striker

Often, problem-solving requires the setting of contact conditions between interacting objects. This introduces an additional non-linearity to the problem statement. In this problem, the rear cap to sleeve, the striker to the piston, and the front cap to sleeve have been bonded, which means that the two contacting objects are fully bonded and work as one without separating them. This type of bonded contact is the default contact between the contacting bodies and can be changed during problem definition. Besides the bonded contact, there are contacts with friction, without friction, without separation, and others. The main purpose of contact interaction modeling is to determine the contact surface and the stresses at the point of contact (Ivanov, 2016:56, Zhunusbekova, et al., 2016:4, Ganyukov, et al., 2018:12).

The kinematic relationship between the piston and the sleeve is modeled. Kinematic coupling refers to the constraints on relative movements set for geometric objects.

Unlike other coupling methods, this type of coupling is implemented using a special element MRS184, which has a very wide range of options. The Workbench provides special tools, grouped under the term Joints, for ease of simulation using this element. To create the translational motion of the piston relative to the sleeve, two translational (UY, UZ) and all rotational (ROTX, ROTY, ROTZ) degrees of freedom are linked for all joints of supporting and moving parts. Thus, this type of coupling releases only the axial movement along the X-axis (Figure 3) (Brujaka, et al., 2013:149).

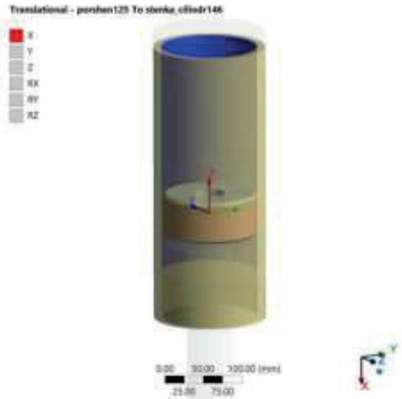


Figure 3 - Simulating the stroke of the striker piston

A Spring Joint is also used, which brings the 2 bodies together, restraining their movement as if they were connected by a spring (Figure 4).

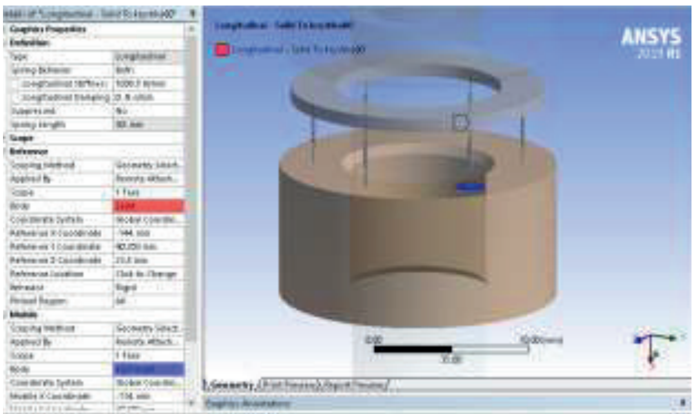


Figure 4 - Setting the spring between the disc and the striker piston

We connected the disc to the front cover of the striker with six springs with a stiffness of 1035.2 N/mm. The advantage of this kinematic coupling is reduced machine time for the solution and convenient adjustment of the stiffness value (Brujaka, et al., 2013:149, Baydjanov, et al., 2019:8, George, et al., 1984:333). A 3D model of the spring can also be built in DM, however, it has several disadvantages: changing the stiffness requires rearrangement of the geometry, distortion from the original geometry when partitioning into finite elements, and of course, leads to increased solver time. The boundary conditions include boundary and initial conditions. At this stage, the type of solver is selected: the solver for dynamic or stationary problems is selected, the number of iterations, time steps, total calculation time, geometric linearity or non-linearity (small or finite deformations), the direct or iterative solver is selected, etc. The resulting record of the calculation is also configured (Ivanov, 2016:56).

Results. In the calculation startup phase, the number of cores used is adjusted, calculation restart parameters and other characteristics are set. The strength verification was carried out with the Mises maximum stress criterion. The criterion is based on the Mises-Hencky theory, also known as the energy theory of deformation. And it coincides with the IV criterion of strength theory. For the principal stresses σ_1, σ_2, σ_3 the Mises stress is expressed as:

$$\sigma_{vonMises} = \left\{\frac{\left[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_1-\sigma_3)^2\right]}{2}\right\}^{\frac{1}{2}},$$

where σ_1, σ_2, σ_3 - major stresses.

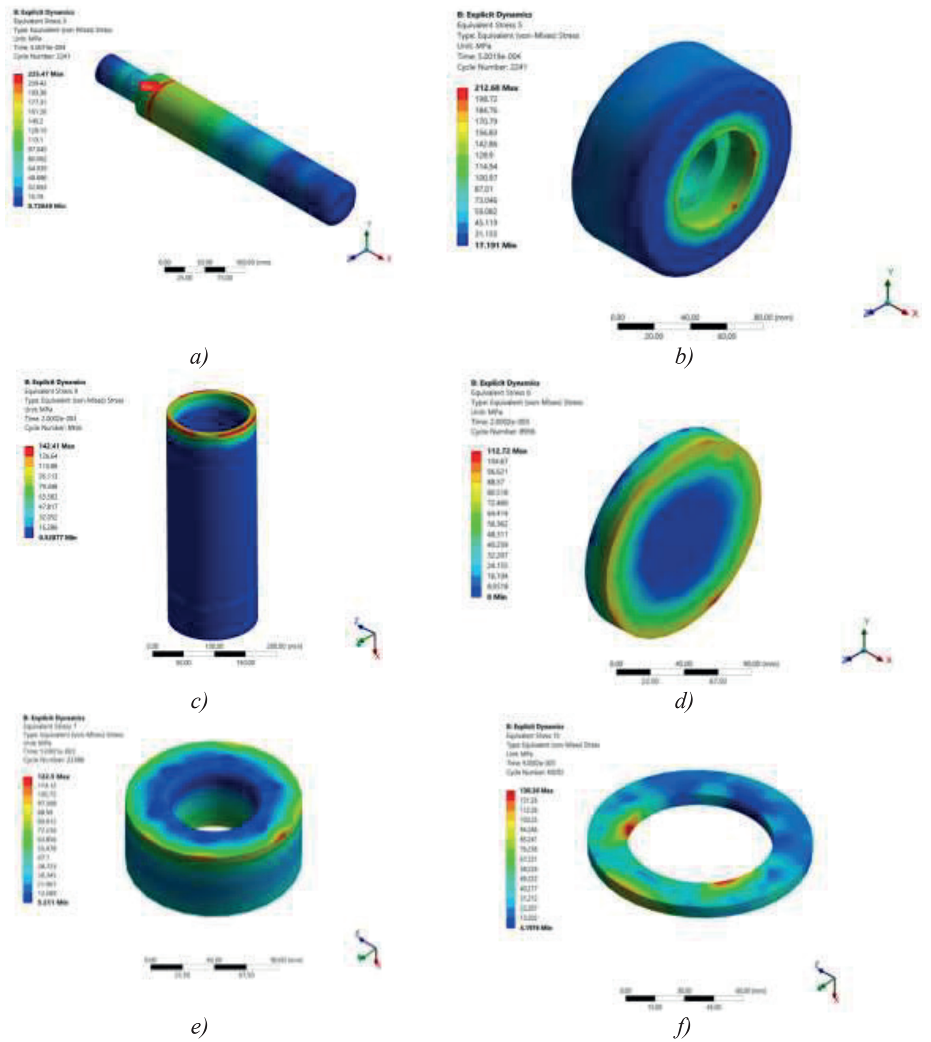
The theory states that a ductile material begins to fail at the point where the Mises stress becomes equal to yield stress. In most cases, the yield stress is used as the ultimate stress. However, the program allows the use of the tensile limit or to specify its ultimate stress.

$$\sigma_{vonMises} \geq \sigma_{limit}$$

The yield strength is a temperature-dependent property. The present yield strength value must take into account the temperature of the component. The safety factor at this point is calculated on a basis. Safety margin

$$n = \frac{\sigma_{limit}}{\sigma_{vonMises}}$$

Checking the strength of the components of the hydraulic striker shows that the highest stress occurs on the striker where the piston is in contact with the piston and is 225.47 MPa (see figure 6, a).



a - striker; b - striker piston; c - sleeve; d - rear striker cover; e - front striker cover; f - disc
Figure 6 - Maximum equivalent voltage by Mises of device parts

The next one in descending order of stress occurs of course at the very bottom of the striker and amounted to 212.68 MPa (see Figure 6, b). At the sleeve element at the rear cover contact with the striker, the stress assumed is 142.41 MPa (see Figure 6c). There is also an activity of stress change together with the rear cap contact (see figure 6, d). From the impact of the striker through the spring system at the lip of the front cover, the equivalent stress was 122.5 MPa (see Figure 6, e). During the impact of the impactor with the disc surface, there was a concentration of equivalent stress inside the disc, which was 130.26 MPa (see Figure 6, f).

Discussion. The ground deformation is 9.95 mm and varies linearly because the material is specified by linear mechanical characteristics. The safety margin of the striker is:

$$n = \sigma_{limit} / \sigma_{vonMises} = 355/225.47 = 1.57,$$

where $\sigma_{limit} = \sigma_т$ =355 MPa – yield strength of steel 45.

Thus, the strength and stiffness of the hydraulic impactor elements and the ground, in general, are ensured. For the more loaded element - the striker, the safety margin is 1.57, which is within the permissible range (1.5-2.0).

Conclusions. A study of the stress-strain state during the interaction between a hydraulic impactor and the ground has been carried out using the ANSYS Explicit Dynamics module. To create a more correct grid and simplify partitioning problems, the model of a hydraulic impactor is constructed as a set of bodies. In the computational scheme instead of a 3D spring model the Spring Joint was used, which does not require breaking into a finite element, thus reducing the time required to solve the problem. The strength verification was performed by the maximum strength criterion of Mises, which coincides with the IV theory of strength. In general, the strength and stiffness of the hydraulic impact device elements and the ground as a whole are ensured. For the more loaded element - the striker, the safety margin was 1.57, which is within the permissible range (1.5-2.0).

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