Results of studies for the modernized equipment of a pipelayer

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Relevance and purpose of the work. Vertical and horizontal swings of a pipeline leading to an uneven distribution of its mass and, as a result, the loss of stability of a crane-pipelayer itself is a problem of modern engineering, which has no unambiguous solution today. This paper gives an option of improving the design of an additional support for a pipe-layer’s boom. The proposed solution allows to increase evenness of laying a pipe and increase the stability of the pipelayer in its operating mode. The result can be achieved by using some additional elements to the design of the pipe-layer’s boom support.

Methods. The strength calculation of the proposed design using the existing method is quite time-consuming. To determine the critical stresses, strain values and maximum displacements in the design, the Solid Works software was used.

Results and their discussion. The proposed design involves connecting a support with a cargo boom. The support consist of a hydraulic cylinder and a metal base used to fasten a cylinder to the support by means of a bearing type-connection. To confirm the performance of the proposed technical solution, the dependencies are presented, which are based on the design scheme of the pipelayer working equipment. Calculated dependencies allow determining the amount of load for the pipelayer.

Conclusions. The results of theoretical studies conducted in the Solid Works software product are presented graphically and show stresses, displacements and deformations in the boom design of the machine for laying the main pipeline. Additionally, as a result of research, the value of the safety factor in the design of the pipelayer boom support has been determined. The diagrams of equivalent stresses, strain values, safety factor and possible displacements in the design of the modernized equipment enable us to draw a conclusion on the performance of the proposed design of the pipelayer boom.

Keywords: pipelayer, pipeline construction, road-building machines, major pipeline, pipelayer boom, work equipment.
Trench width

The optimal distance between suspension points (Fig. 1) of the pipeline is calculated by the formulas

\[
\begin{align*}
    l_1 &= 1.56 \cdot \sqrt{\frac{EIh_1}{q}}, \\
    l_2 &= 1.22 \cdot \sqrt{\frac{EIh_2}{q}}, \\
    l_3 &= 1.22 \cdot \sqrt{\frac{EIh_3}{q}}, \\
    l_4 &= 2.46 \cdot \sqrt{\frac{EIh_4}{q}},
\end{align*}
\]

where \( EI \) is rigidity of the laid pipeline; \( q \) – weight of 1 meter of the pipeline; \( h_1, h_2 \) – height of lift of the pipeline \( (h_1 = h_2, h_3 = h_4 + 0.5) \).

The load on the pipelayers (Fig. 1) was determined by the formulas [4]

\[
K_1 = q \left( \frac{2}{3} l_1 + \frac{1}{2} l_2 \right), \quad K_2 = q \left( \frac{2}{3} l_2 + \frac{1}{2} l_3 \right), \quad K_3 = q \left( \frac{1}{2} l_3 + \frac{2}{3} l_4 \right).
\]

The analysis of the results obtained in determining the loads at the points of suspension of the pipeline with the cargo characteristic of the pipelayer TG-124 (depending on a hook radius), allowed us to conclude that there is an actual load equals to 93742 N on one of the suspension points, which does not correspond to the carrying capacity of the pipelayer equal to 67 000 N with the hook radius of 3.96 m [1].

**Load capacity of the pipelayer TG-124**

| Hook radius (from the left edge of rolling over) | 1.5 | 2.5 | 3.5 | 4.5 | 5.6 |
|-------------------------------------------------|-----|-----|-----|-----|-----|
| Load capacity with counterweight and stability coefficient 1.4 tons | 12.5 | 10.9 | 7.6 | 5.75 | 4.6 |

The boom design of the upgraded pipelayer consists of two parts, the main boom and additional support interconnected by a non-rigid binding [4]. A distinctive feature of the design is that the boom support is made in the form of an overhung hydraulic cylinder, which is pivotally connected to a shoe [4, 5]. As a hydraulic cylinder, it is proposed to use a hydraulic cylinder from the standard series 55111-8603010 [3].

Fig. 3 schematically reflects the boom of the pipelayer equipped with the support; actual reaction forces of the supporting surface and the loads while laying the pipeline in a trench are indicated [6].
To determine the values of reactions $R_{Ax}$, $R_{Ay}$, $R_{Cx}$, and $R_{Cy}$, it is necessary to divide the hinge $B$, having considered the equilibrium of each of the parts and making up the force balance equation (Fig. 4, 5). As a result, new reactions $R_{Bx}$ and $R_{By}$ appear in the hinge pivot $B$ (Fig. 5).

To determine the value of unknown forces, three force balance equations are formed:
- sum of forces about the $X$ axis;
- sum of forces about the $Y$ axis;
- sum of moments about the $A$ point [7, 8].

\[
\begin{align*}
\sum F_x &= R_{Ax} + R_{Bx} = 0, \\
\sum F_y &= R_{Ay} + R_{By} - Q_{By} = 0, \\
\sum M_A &= 4,12R_{By} - 4,5R_{Ax} - 3,96Q_{By} = 0.
\end{align*}
\] (1)

The force balance equations are formed: the sum of forces about the $X$ axis; the sum of forces about the $Y$ axis; the sum of moments about the point $B$; the sum of moments about the point $C$ [9, 10].

\[
\begin{align*}
\sum F_x &= -R_{Ax} - R_{Cx} = 0, \\
\sum F_y &= R_{Cy} - R_{By} = 0, \\
\sum M_C &= 4,8R_{Cy} + 2,9R_{By} = 0, \\
\sum M_B &= -4,8R_{Cy} + 2,9R_{By} = 0.
\end{align*}
\] (2)

From the formula (2)

\[
R_{Ax} = -R_{Cx}.
\] (5)

From the formula (3)

\[
R_{By} = R_{Cy}.
\]

From the formula (4)

\[
R_{Cy} = \frac{4,8R_{Cy}}{2,9}.
\] (6)

Substituting expressions (5) and (6) into the formula (1) the reaction was found $R_{Cy}$:

\[
\frac{4,8R_{Cy}}{2,9} - 4,12 + 4,5R_{Ax} - 3,96Q_{By} = 0.
\]

The resultant force of reactions $R_{Bx}$ and $R_{By}$ arising in the hinge pivot is equal to:

\[
R_s = \sqrt{R_{Bx}^2 + R_{By}^2}.
\]
Bending moment in the hinge pivot axis [10]

\[ M_n = \frac{Na}{2}, \]

where \( N \) – cross-sectional bending force, kN; \( a \) is the distance from a rod end to the loading point, cm.

The minimum torque of resistance of the cross profile of the axis [11]

\[ W_n = \frac{M_n}{0,1mR}, \]

where \( m \) – condition load effect factor; \( R \) – design resistance of round rolled steel, MPa.

The diameter of the axis is determined by the formula [12]

\[ d = \sqrt[3]{10W_n}. \]

For further calculation, it is necessary to check the axis for section. You can do this using the formula [4, 13]

\[ \frac{N}{n_{wp} \pi \left( d^2 / A \right)} < mR_{wp}, \]

where \( n_{wp} \) – the number of sections of the axis \( n_{wp} = 2; R_{wp} \) – section resistance, MPa.

Research results and their discussion

In the Solid Works environment, some theoretical studies have been carried out aimed at determining the strength characteristics of the proposed design of the pipelayer boom with additional support [4, 14].

Strengthening studies were carried out in the following sequence [7]:

1. Specify the material and determine the type of boom mounting and the boom of the hydraulic cylinder (fixed hinge pivot; soil exposure on the support – fixed geometry).
2. Set the load (load is directed along the rope downwards; a cylindrical figure as the rope model installed in the rod ends of binding of the hook block; an operational force is directed to the surface of this figure with the opposite direction).
3. Build a grid on a solid body dividing the model into smaller segments.
4. Perform calculation [14].

Fig. 6 shows a curve reflecting the result of theoretical studies aimed at determining the equivalent stresses in the structure. Minimum stress values in the structure are 0.257 Pa; maximum stress values in the structure – \( 2.63 \cdot 10^8 \) Pa.

The conducted studies have allowed us to determine the areas of accumulation of maximum stresses in the structure of the support for a given load equal to 12 tons [14, 15]. Studies have shown that the maximum stress does not exceed a permissible limit of material plasticity [3].

Fig. 7 shows a curve reflecting the result of theoretical studies aimed at determining movements in the design of the pipelayer boom support [11, 14]. Studies have shown that the minimum displacement values in the structure are 0 mm, maximum values – 4.62 mm.

Theoretical studies aimed at the study of displacements made it possible to determine the places in the support structure with possible displacements of structural details. It has been established that maximum displacements are concentrated in the place of attachment of the additional support to the hydraulic cylinder [11]. Possible movements in the structure can be prevented either by increasing the number of bolted joints or by increasing fasteners [16].

Figure 6. Study of the stresses in the support structure of the pipelayer boom.
Рисунок 6. Исследование напряжений в конструкции опоры стрелы трубопрокладчика.

Figure 7. Study of motion in the support structure of the pipelayer boom.
Рисунок 7. Исследование перемещений в конструкции опоры стрелы трубопрокладчика.
Fig. 8 shows a curve reflecting the result of theoretical studies aimed at determining the amount of deformation in the structure of the boom support \([4, 17]\). When a load of 12 tons is applied, the minimum amount of deformation in the structure is \(1.93 \times 10^{-7} \text{ mm}\), and the maximum is \(5.8 \times 10^{-4} \text{ mm}\).

Studies aimed at determining the deformation made it possible to determine the places of possible deformations of the proposed structure of the pipelayer boom support. Studies allowed us to conclude that the critical values in the simulation of possible maximum load capacity in the nodes of the equipment do not occur \([4]\).

Fig. 9 shows a curve reflecting the result of theoretical studies aimed at determining the factor of safety in the structure of the boom support \([4, 15]\). The minimum safety margin is 1.6, and the maximum safety margin is 4.76.

Studies of the factor of safety allowed us to establish the strength characteristics along the entire length of the proposed design, as well as to determine whether the structure is able to withstand the specified loads characterized by the FOS safety factor. In order for the load to withstand the specified loads, the safety factor should be more than 1, and therefore the details in the design should be made with a safety factor more than 1.5.

Conclusion

In the course of the research, calculated dependencies were obtained to determine the forces in the nodal connections. The obtained formulas allow us to calculate the load change from the mass of the pipe laid in the trench. It was found that the resulting stresses and displacements in the design of working equipment do not exceed critical values. The conducted strength calculation made it possible to conclude that there is a sufficient safety margin for the design of the working equipment of the pipelayer.

Application of the pipelayer with additional support can reduce the amount of equipment used when laying a pipeline. The proposed design of the boom support will allow increasing evenness of laying a pipe, increase the stability of the pipelayer and significantly secure the pipeline construction process.

REFERENCES

1. Usanov V., Berezin A., Vorontsov A., Zhutkin V., Babakov Yu. 2015, Cost reduction in the operation of pipelayers. Tekhnadzor [Technical Supervision], no. 11 (108), pp. 686–687. (In Russ.)
2. Parshin D. Ya., Shoshiashvili D. Ya. 1990, Automatic stability control of pipelayers. Struitel'nye i dorozhnye mashiny [Construction machinery and road building machinery], no. 10, pp. 16–18. (In Russ.)
3. Voronin A. N., Lipsky V. K., Serenkov P. S. 2012, Analysis of the accident rate of the main pipeline transport in the Republic of Belarus, the Russian Federation, the countries of Western Europe and the USA. Vestnik Polotskogo gosudarstvennogo universiteta [Bulletin of the Polotsk State University], F series: Construction. Applied sciences, no. 16, pp. 69–74. (In Russ.)
4. Voronin A. N., Lipsky V. K. 2014, Opisanie seti protsessov v magistral'nom truboprovodnom transporte s ispol'zovaniem sistem funktcion-al'nogo modelirovaniya [Description of the network of processes in the main pipeline transport using the functional modeling system]. Reliability and safety of the main pipeline transport. Collection of works at VIII International scientific-technical conference. Ed. by V. K. Lipsky, pp. 49–51.
5. Vashchuk I. M., Utkin V. I., Harkun B. I. 1989, Truboukladchiki [Pipelayers], Moscow, 180 p.
6. Dudoladov, Yu. A. 1981, Krany-truboukladchiki [Cranes-pipelayers], Moscow, 240 p.
7. Teterina I. A., Korchagin P. A., Letopolsky A. B. 2018, Investigation of soil destruction by trench chain excavator cutting element process. Proceedings of the 4th International Conference on Industrial Engineering ICIE 2018: Lecture Notes in Mechanical Engineering. Moscow, Russia, 15–18 May 2018, Cham, pp. 2123–2132. https://doi.org/10.1007/978-3-319-95630-5_229
8. Teterina I. A. 2017, Povysheniye effektivnosti sistemy vibrozashchity operatora dorozhnoy podmetal'no-uborochnoy mashiny [Improving the effectiveness of vibration system of operator’s machine sweeper], master thesis. Omsk, 18 p.
9. Dobronravov S. S., Dobronravov M. S. 2006, Struitel'nye mashiny i oborudovaniye [Construction machinery and equipment]: reference book. 2nd ed., updated and revised. Moscow, 445 p.
10. Korytov M. S., Scherbakov V. S., Titenko V. V. 2018, Analytical solution of the problem of acceleration of cargo by a bridge crane with constant acceleration at elimination of swings of a cargo rope. Journal of Physics: Conference Series, vol. 944, no. 1. https://doi.org/10.1088/1742-6596/944/1/012062
11. Denisova L. A., Meshcheryakov V. A. 2018, Control systems design: the technology of stochastic perturbations simulation. Journal of Physics: Conference Series, vol. 1050, no. 1. 012020. https://doi.org/10.1088/1742-6596/1050/1/012020
12. Boyarkina I. V., Tarasov V. N. 2017, Regularities of the working equipment elements mass reduction to the hydraulic power cylinder piston for the bucket boom machines size standard. Journal of Physics: Conference Series, vol. 858, no. 1.
13. Scherbakov V. S., Korytov M. S., Shershneva E. O. 2016, Influence of an obstacle on load displacement by a gantry crane. Russian Engineering Research, vol. 36, no. 3, pp. 194–197. https://doi.org/10.3103/S1068799816030151

100 Корчагин П. А. и др. Results of studies for the modernized equipment of a pipelayer // Известия УГГУ. 2019. Вып. 1(53). С. 96-102. DOI 10.21440/2307-2091-2019-1-96-102
14. Vasilyev V. I., Ovsyannikov V. E., Ziganshin R. A., Terekhov A. S. 2018, Peculiar features of formation of surface roughness profile upon mechanical processing of iron parts of handling machines after diffusion alloying. International Journal of Mechanical Engineering and Technology, vol. 9 (3), pp. 1061–1067. Link

15. Zarubin V. N. 1984, Truboukladchik [Pipelayer]. Moscow, 134 p.

16. Korneyev S. A., Korneyev V. S., Voronov E. A., Chernyavskiy D. I., Romanyuk D. A. 2018, Thermodynamically matched description of highly elastic couplings load characteristics considering misalignment of the attached shafts. AIP Conference Proceedings. 030006. https://doi.org/10.1063/1.5051867

17. Harkun B. I., Vereynov O. V., Utkin V. I., Shevelenko V. I., Sliskov V. I., Zakharchuk B. Z. 1979, Kran-truboukladchik [Pipelayer crane]. Patent RF no. 703490.

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Результаты исследований модернизированного оборудования трубоукладчика

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Актуальность и цель работы. Вертикальные и горизонтальные колебания трубопровода, приводящие к неравномерному распределению его массы и, как следствие, к потере устойчивости самого крана-трубоукладчика, – проблема современного машиностроения, не имеющая однозначного решения на сегодняшний день. В статье представлен вариант совершенствования конструкции дополнительной опоры стрелы трубоукладчика. Предложенное техническое решение позволяет увеличить плавность укладки трубы и повысить устойчивость трубоукладчика в рабочем режиме. Результат достигается путем добавления дополнительных элементов в конструкцию опоры стрелы трубоукладчика.

Методы. Прочностной расчет предлагаемой конструкции существующим методом достаточно трудоемок. Для определения критических напряжений, величины деформации и максимальных перемещений в конструкции использован программный продукт SolidWorks.

Результаты и их обсуждение. Предложенная конструкция позволяет скомбинировать с грузовой стрелой опору, состоящую из гидравлического цилиндра и металлической основы, используемую для крепления цилиндра к опоре с помощью болтового соединения. Для подтверждения работоспособности данного конструкторского решения приведены зависимости, составленные на основе расчетной схемы рабочего оборудования трубоукладчика. Результаты теоретических исследований, проведенных в программном продукте SolidWorks, представлены графически.

Ключевые слова: трубоукладчик, строительство трубопровода, строительно-дорожные машины, магистральный трубопровод, стрела трубоукладчика, рабочее оборудование.

ЛИТЕРАТУРА
1. Усанов В., Березин А., Воронцов А., Жуткин В., Бабаков Ю. Снижение затрат при эксплуатации кранов-трубоукладчиков // ТехНадзор. 2015. № 11 (108). С. 686–687.
2. Паршин Д. Я., Шошиашвили М. Э. Автоматический контроль устойчивости кранов-трубоукладчиков // Строительные и дорожные машины. 2015. № 11 (108). С. 686–687.
3. Ващук И. М., Уткин В. И., Харкун Б. И. Трубоукладчики. М.: Машиностроение, 1989. 180 с.
4. Воронин А. Н., Липский В. К. Описание сети процессов в магистральном трубопроводном транспорте с использованием системы функционального моделирования // Надежность и безопасность магистрального трубопроводного транспорта: сб. тезисов VIII Междунар. науч.-техн. конф. Новополоцк: ПГУ, 2014. С. 49–51.
5. Шацк И. М., Уткин В. И., Харкун Б. И. Трубоукладчики. М.: Машиностроение, 1989. 180 с.
6. Дудоладов Ю. А. Краны-трубоукладчики. М.: Высш. школа, 1981. 240 с.
7. Teterina I. A., Korchagin P. A., Letopolsky A. B. Investigation of soil destruction by trench chain excavator cutting element process // Proceedings of the 4th International Conference on Industrial Engineering ICIE 2018: Lecture Notes in Mechanical Engineering, Moscow, Russia, 15–18 May 2018. Cham: Springer, 2018. P. 2123–2132. http://dx.doi.org/10.1007/978-3-319-95630-5-229
8. Teterina И. А. Повышение эффективности системы вибро защиты оператора дорожной подмettelно-уборочной машины: автореф. дис. … канд. техн. наук. Омск, 2017. 18 с.
9. Добронравов С. С., Добронравов М. С. Строительные машины и оборудование: справочник. 2-е изд., перераб. и доп. М.: Высш. школа, 2006. 445 с.
10. Korytov M. S., Shcherbakov V. S., Titenko V. V. Analytical solution of the problem of acceleration of cargo by a bridge crane with constant acceleration at elimination of swings of a cargo rope // Journal of Physics: Conference Series. 2018. Vol. 944, № 1. 012062. https://doi.org/10.1088/1742-6596/944/1/012062
11. Denisova L. A., Meshcheryakov V. A. Control systems design: the technology of stochastic perturbations simulation // Journal of Physics: Conference Series. 2018. Vol. 1050, № 1. 012020. https://doi.org/10.1088/1742-6596/1050/1/012020
12. Boyarkina I. V., Tarasov V. N. Regularities of the working equipment elements mass reduction to the hydraulic power cylinder piston for the bucket boom machines size standard // Journal of Physics: Conference Series. 2017. Vol. 858. № 1. 012006. https://doi.org/10.1088/1742-6596/858/1/012006
13. Shcherbakov V. S. Korytov M. S., Shersheneva E. O. Influence of an obstacle on load displacement by a gantry crane // Russian Engineering Research. 2016. Vol. 36, № 3. P. 194–197. https://doi.org/10.3103/S1068799816030151
14. Vasilyev V. I., Ovysannikov V. E., Ziganshin R. A., Terekhov A. S. Peculiar features of formation of surface roughness profile upon mechanical processing of iron parts of handling machines after diffusion alloying // International Journal of Mechanical Engineering and Technology. 2018. Vol. 9, № 3. P. 1061–1067. Link
15. Трубоукладчик / В. Н. Зарубин [и др.]. М.: Высш. школа, 1984. 134 с.
16. Korneyev S. A., Korneyev V. S., Voronov E. A., Chernyavskiy D. I., Romanyuk D. A. Thermodynamically matched description of highly elastic couplings load characteristics considering misalignment of the attached shafts // AIP Conference Proceedings. 2018. 03006. https://doi.org/10.1063/1.5051867
17. Кран-трубоукладчик: пат. 703490 СССР / Харкун Б. И., Верейнов О. В., Уткин В. И., Шевеленко В. И., Слисков В. И., Захарчук Б. З. № 9, № 3. Р. 1061–1067. Link

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102 Корчагин П. А. и др. Results of studies for the modernized equipment of a pipelayer // Известия УГГУ. 2019. Вып. 1(53). С. 96-102. DOI 10.21440/2307-2091-2019-1-96-102