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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.

Introduction

A pipelayer is a road construction machine used in the construction and repair of pipelines (*GOST P 52079–2003. Wrought iron pipe for major gas pipelines, oil pipelines, and product pipelines. Enacted 2002–01–01. Moscow, 2005. 32 p.*)[1]. The pipelayer is a crane with a side boom. The ability to lift the same load by the pipelayer at different boom inclinations is not constant. According to its main purpose, the pipelayer is subjected mainly to external vertical loads applied to its load hook; these loads include a weight of a single-part rigid cargo or the weight of a raised elastic section of the laid pipeline [2]. The second variant of the external load is complex since it depends not only on the elevated pipeline but on the shape of its deflection as well [2].

The movement of the pipelayer along the roughs (as well as inconsistent actions of operators during group work of machines with a common load) leads to the fact that the shape of the pipeline deflection in the vertical plane constantly changes; the mass of the raised section between the machines is redistributed [3]. In other words, if during work with a single-part rigid cargo, the load on the working equipment is constant and depends only on the weight of this load and while working with a pipeline it is variable, as it depends on many constantly changing technological factors and, above all, on a transitory weight (pipeline parameters) (Fig. 1) [2].

In order to ensure the safety of work for laying the pipeline, it is proposed to improve the design of equipment.

Purpose of the research

When working, the load on the work equipment often does not correspond to the load capacity of a machine. In this case, there is a danger of tipping over of the pipelayer [1]. One of the solutions to this problem is to install a support which is mounted on the main pipelayer boom (Fig. 2) [3].

Materials and methods of the research

The crane with a side boom (pipelayer) has the ability to lift the same load in a number of options for the boom lifting is not constant. In the position of the boom close to the vertical, the pipelayer is able to lift a load of greater weight than with an increase of working radius, due to the possible tipping of the machine towards the load [2].

To determine the hook load of the pipelayer, the following calculation was made [4]:

1. Trench parameters;
2. Minimum number of pipelayers when performing a working operation.

Trench height (h_{tr})

$$h_{tr} = 0{,}8 + D_{tr},$$

where D_{tr} is the diameter of the pipeline.

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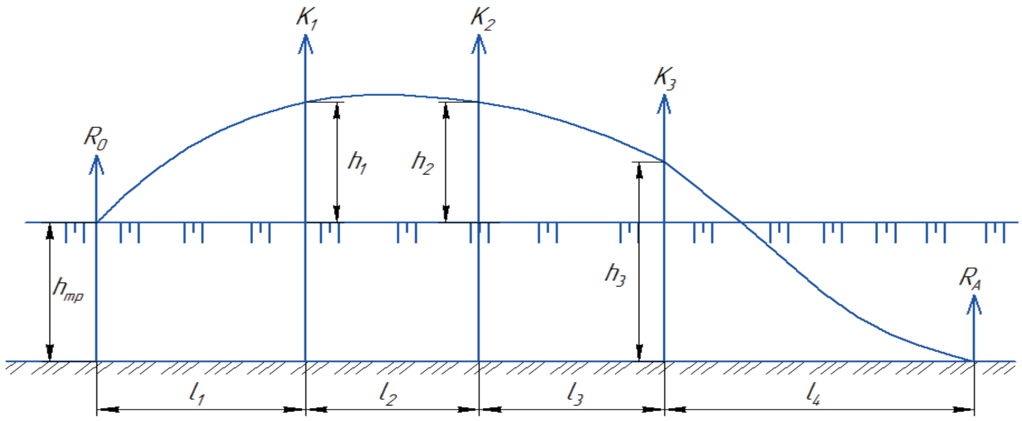

Figure 1. Technological scheme of pipeline construction.
Рисунок 1. Расчетно-технологическая схема укладки трубопровода.

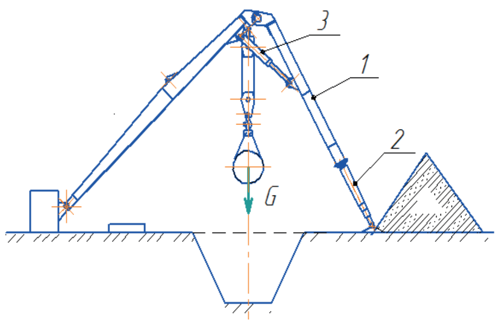

Figure 2. Pipelayer boom equipped with support. 1 – support; 2 – hydaulic cylinder; 3 – hydraulic cylinder of support extension.
Рисунок 2. Стрела трубоукладчика, оснащенная опорой. 1 – опора; 2 – гидроцилиндр; 3 – гидроцилиндр выдвижения опоры.

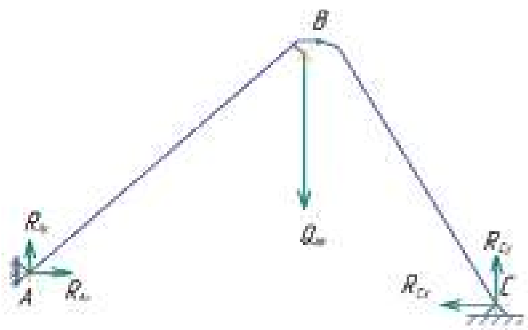

Figure 3. Stresses and loads that effect on the boom.
Рисунок 3. Силы реакции и нагрузки, действующие на стрелу.

Trench width

$$B_{tr} = 1{,}5\, D_{tr}.$$

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

$$l_1 = 2,46\sqrt[4]{\frac{EIh_1}{q}},\ \ l_2 = 1,22\sqrt[4]{\frac{EIh_1}{q}},\ \ l_3 = 1,22\sqrt[4]{\frac{EIh_3}{q}},\ \ l_4 = 2,46\sqrt[4]{\frac{EIh_3}{q}},$$

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 ($h_1 = h_2$, $h_3 = h_{tr} + 0{,}5$).

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

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

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
Грузовая характеристика трубоукладчика ТГ-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].

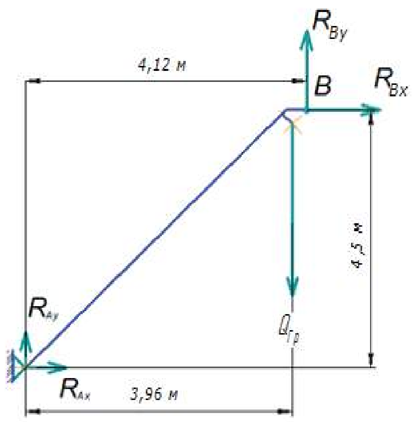

Figure 4. Left section of the structure.
Рисунок 4. Левая часть конструкции.

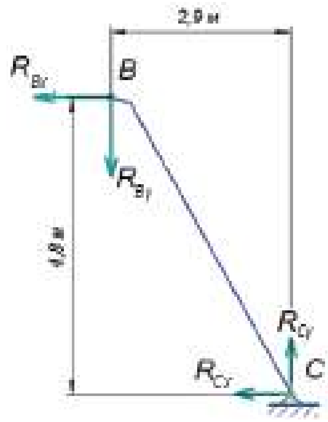

Figure 5. Right section of the structure.
Рисунок 5. Правая часть конструкции.

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 theforce 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].

$$\sum F_{iX} = R_{Ax} + R_{Bx} = 0,$$
$$\sum F_{iY} = R_{Ay} + R_{By} - Q_{\text{гр}} = 0,$$
$$\sum M_A = 4,12R_{By} - 4,5R_{Bx} - 3,96Q_{\text{гр}} = 0. \quad (1)$$

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].

$$\sum F_{iX} = -R_{Bx} - R_{Cx} = 0, \quad (2)$$
$$\sum F_{iY} = R_{Cy} - R_{By} = 0, \quad (3)$$
$$\sum M_C = 4,8R_{Bx} + 2,9R_{By} = 0,$$
$$\sum M_B = -4,8R_{Cx} + 2,9R_{Cy} = 0, \quad (4)$$

From the formula (2)

$$R_{Bx} = -R_{Cx}. \quad (5)$$

From the formula (3)

$$R_{By} = R_{Cy}.$$

From the formula (4)

$$R_{Cy} = \frac{4,8R_{Cx}}{2,9}. \quad (6)$$

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

$$\frac{4,8R_{Cx}}{2,9}4,12 + 4,5R_{Cx} - 3,96\,Q_{\text{гр}} = 0.$$

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

$$R_B = \sqrt{R_{Bx}^2 + R_{By}^2}.$$

Bending moment in the hinge pivot axis [10]

$$M_{п} = \frac{Na}{2},$$

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]

$$W_{п} = \frac{M_{п}}{0,1mR},$$

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]

$$d = \sqrt[3]{10W_{п}}.$$

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

$$\frac{N}{n_{ср}\pi\left(d^2/4\right)} < mR_{ср},$$

where $n_{ср}$ – the number of sections of the axis $n_{ср} = 2$; $R_{ср}$ – 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].

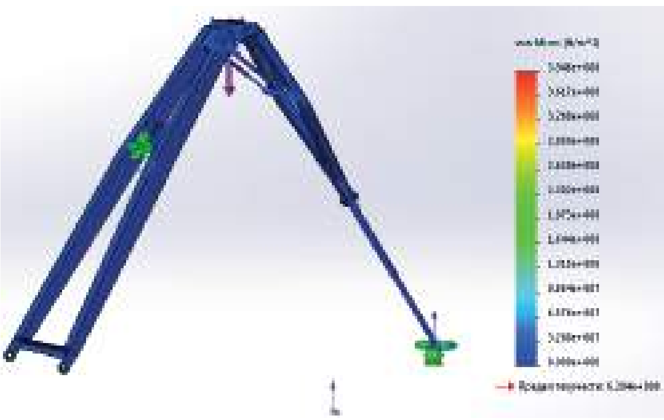

Figure 6. Study of the stresses in the support structure of the pipelayer boom.
Рисунок 6. Исследование напряжений в конструкции опоры стрелы трубоукладчика.

Figure 7. Study of motion in the support structure of the pipelayer boom.
Рисунок 7. Исследование перемещений в конструкции опоры стрелы трубоукладчика.

Figure 8. Study of deformations in the support structure of the pipelayer boom.
Рисунок 8. Исследование деформаций в конструкции опоры стрелы трубоукладчика.

Figure 9. Study of the safety factor in the support structure of the pipelayer boom.
Рисунок 9. Исследование запаса прочности в конструкции опоры стрелы трубоукладчика.

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 $\cdot 10^{-7}$ mm, the maximum – 5.8×10^{-4} 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.

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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, величин деформации и максимальных перемещений в конструкции использован программный продукт SolidWorks.
Результаты и их обсуждение. Предложенная конструкция предполагает соединить с грузовой стрелой опору, состоящую из гидравлического цилиндра и металлической основы, используемую для крепления цилиндра к опоре с помощью болтового соединения. Для подтверждения работоспособности предложенного конструкторского решения приведены зависимости, составленные на основании расчетной схемы рабочего оборудования трубоукладчика. Расчетные зависимости позволяют определить величину нагрузок, действующих на трубоукладчик.
Выводы. Результаты теоретических исследований, проведенных в программном продукте SolidWorks, представлены графически и отражают напряжения, перемещения и деформации в конструкции стрелы машины для укладки магистрального трубопровода. Дополнительно в результате исследований установлена величина запаса прочности в конструкции опоры стрелы трубоукладчика. Представленные эпюры эквивалентных напряжений, величин деформации, коэффициента запаса прочности и возможных перемещений в конструкции модернизированного оборудования дают право сделать вывод о работоспособности предлагаемой конструкции стрелы трубоукладчика.

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

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