OPTIMIZATION RESEARCH OF THE CARGO PENDULUM AND UNITS DISPLACEMENTS OF THE GANTRY CRANES LEVEL LUFFING JIB SYSTEM

ОПТИМИЗАЦИОННО ИЗСЛЕДВАНЕ НА ЪГЪЛА НА ЛЮЛЕЕНЕТО НА ТОВАРА И НА ПРЕМЕСТВАНИЯТА НА ВЪЗЛИ В СИСТЕМАТА ЗА ИЗМЕНЕНИЕ НА ОБСЕГА НА ПОРТАЛНИТЕ КРАНОВЕ

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Abstract: *A new methodology for taking into account of the cargo pendulum angle change at minimum operating radius of the gantry cranes level luffing jib systems is proposed. The impact of this change in electric motor power calculating has been studied. An optimization mathematical model that takes into account this change and the impact of node displacements on the design of the gantry cranes level luffing jib systems is built. Parameters, optimization criteria and their boundaries are determined. Optimization of the construction taking into account these factors was made using the Pareto optimization procedure and the results were compared with previous studies.*

KEYWORDS: GANTRY CRANES, LEVEL-LUFFING JIB SYSTEM, OPTIMIZATION MATHEMATICAL MODEL, MATLAB, PARETO OPTIMIZATION PROCEDURE, CARGO PENDULUM, DISPLACEMENTS.

1. Introduction

The use of modern methods of calculation and design underlies the creation of gantry cranes, which meet today's requirements for productivity and reliability. Modern methods of calculation give us the right to reduce the installed electric motors power of the crane mechanisms and the mass of the structure, which is operated by these mechanisms. This should be done while maintaining the operational parameters of the machine. In the search for modern solutions for improvement, we have created a new model for investigating the decrease in the cargo pendulum angle at the minimum operating radius of the gantry cranes.

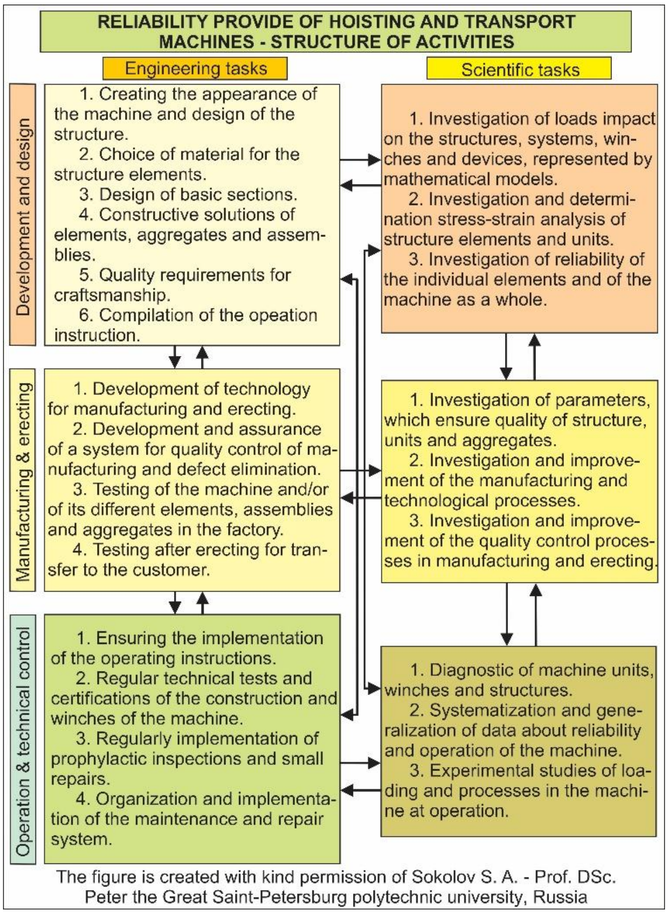

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Fig. 1. Reliability provide of hoisting and transport machines – structure of activities

The aim of the report is to research the influence of decreasing the angle of rope deviation from the vertical α_G at the minimum gantry crane operating radius on the calculation of electric motor power, on the possibility of reducing the steel structure mass, and in studying the displacements in the structure units. Giving recommendations for improving the calculations according to existing standards. Research is made using a new complex of Pareto multi-criteria optimization programs.

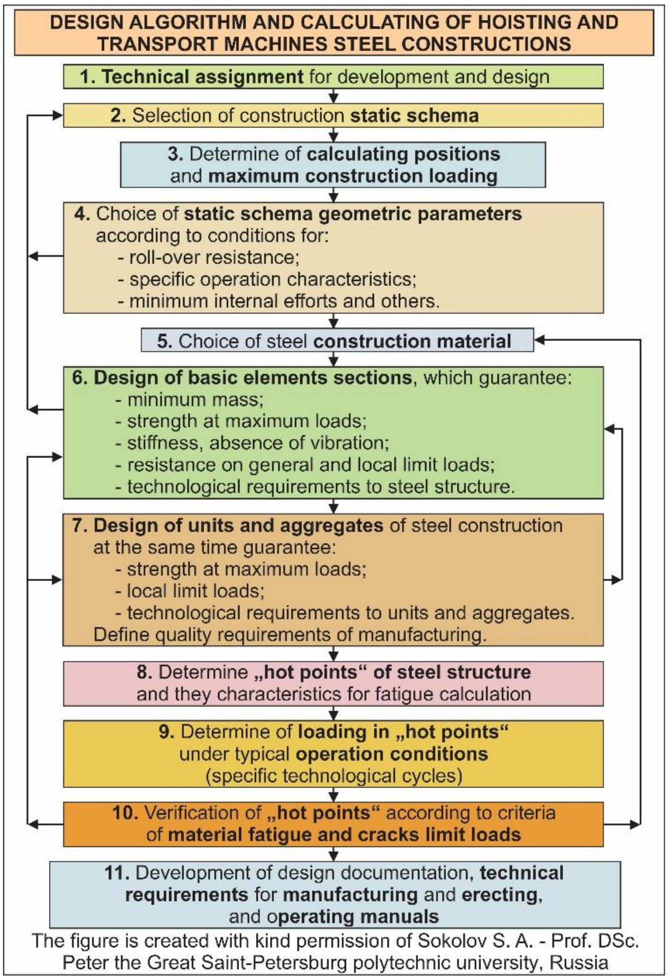

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Fig. 2. Design algorithm and calculating of hoisting and transport machines steel construction

2. Preconditions and means for resolving the problem

The level-luffing jib system shown in Fig. 3 and Fig. 8 consists of the following subsystems and their elements:

A) Jib system (JS) comprising: jib - 4, jib arm – 3 and guy - 5;

B) Balancing device (BD) consisting of: tie-bar - 7, rocker arm – 9 and counterweight – 10;

C) Driving mechanism of system (LGM – luffing gear mechanism) with: winch - 11 and rack - 8.

The hoisting system is shown in Fig. 4 and Fig. 5 by cargo – 1, wire ropes – 2 and hoisting gear winch – 6.

Reliability and efficiency of the gantry cranes, how and all hoisting and transport machines, is guaranteed and controled on the all phases theyr existence. As shown in Fig. 1, we can see how interact design companyes and developers, manufacturers and operation companyes, and research and scientific organizations in the field of development and improvement of these machines. In strictly speaking, all it work is impeccable, but the basic characteristics of the gantry cranes always will be planed at the phase of design and calculation. So that, we have to turn to Fig. 2, on which has been shown how to develop and design the steel construction of hoisting and transport machines. On steel constructions, the machine has the most basic cost of production. So, for example, the gantry crane turning part has been gaining more than 75% of all crane mass. Level luffing jib system is there on the gantry crane turning part. In its, there are many large muvable parts of the crane, which provide the operation characteristics of the whole crane.

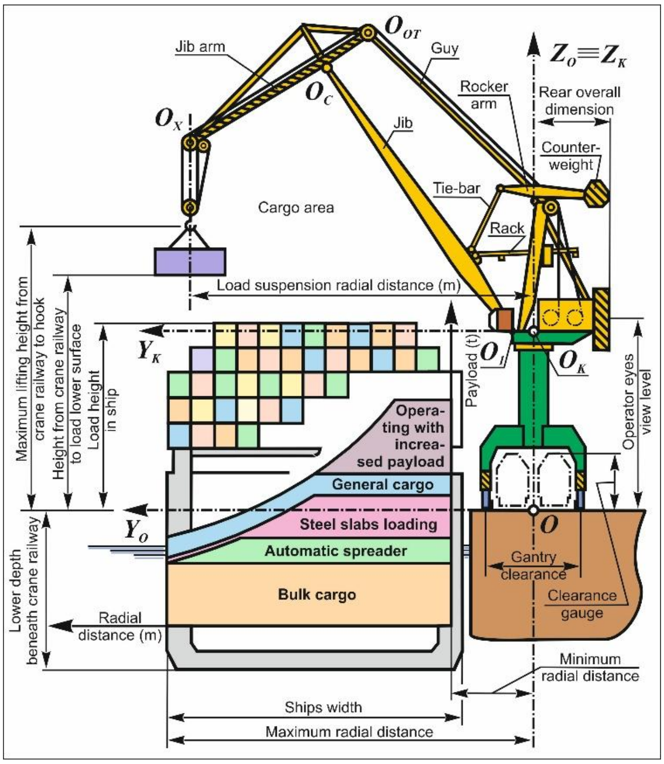


Fig. 3. Loads and geometrical performance characteristics of the gantry cranея

Geometric performance and load characteristics of the gantry crane are shown in Fig. 3. They are achieved by using the three main working mechanisms of the crane (hoisting, slewing and luffing) and their corresponding systems. That is why the research and improvement of level luffing jib systems is essential for the development of these systems and the gantry cranes themselves. To solve the tasks posed in clauses 2 ... 7 in Fig. 2 is developed a method for determining the forces acting on the construction of level luffing jib systems and choice of electric motor power. It is shown in Fig. 4. The components ratio of the moment M_{MAX} according to Fig. 4 is pictured in Fig. 5.

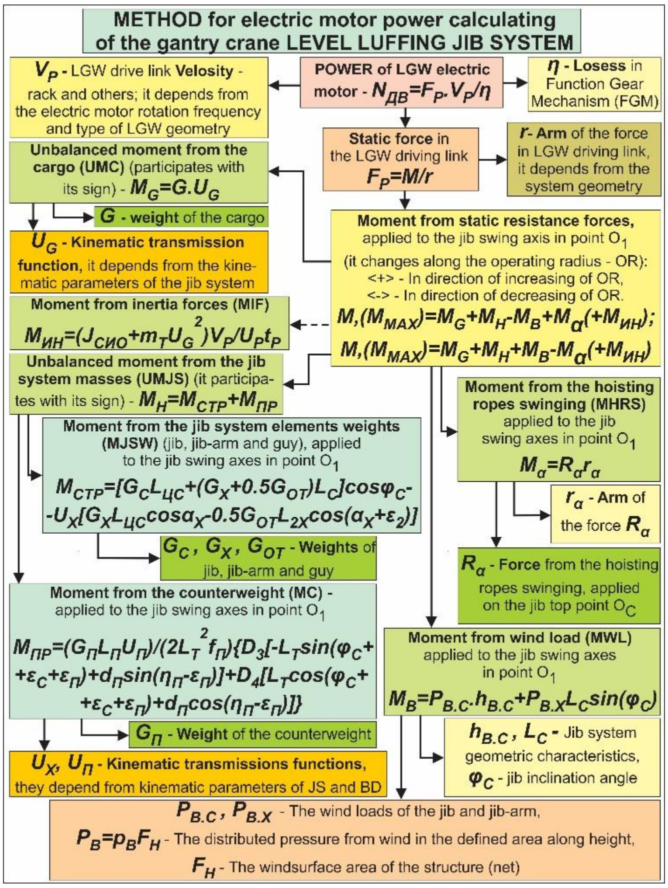


Fig. 4. Method for electric motor power calculating of the gantry cranes level luffing jib systems

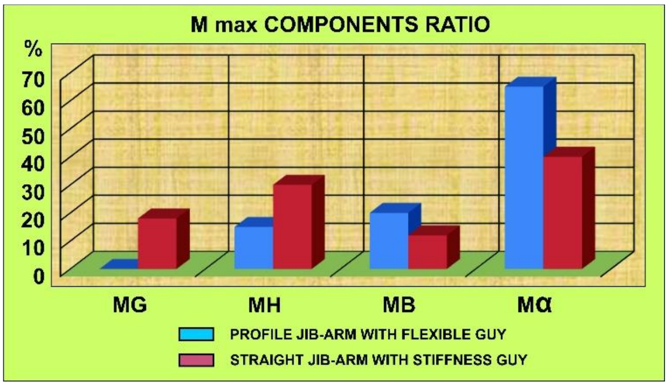


Fig. 5. Components ratio of the moment M_{MAX} according to Fig. 4

The determination of the moment from the cargo pendulum of the hoisting wire ropes $M_{\alpha G}$ is one of the most significant questions in the implementation of the calculations shown. Its participation in calculating of the total resistance moment is shown in Fig. 5 and is determined by the standard values of the angles of deviation of the hoisting wire ropes from the vertical. These angles for heavy operation mode of gantry cranes have the following values: 1) To calculate of electric motor power - α_{GD} = 5.5^O, 2) For calculating the steel construction - 17,0^O. The diagrams in Fig. 5 are built on the basis of design data and experience in the operation of different types of gantry cranes.

The cargo pendulum of the gantry crane is practically unavoidable process. Researchers and designers are constantly trying to develop systems and devices for decreasing of the cargo swinging, but this process is solved exclusively by the experience, professional training, skills and feelings to the machine of the crane-driver. He is obliged to always keep under control the swinging of the hoisting wire ropes and the cargo on them. The cargo pendulum must be minimal, and when working with workers and in increased load capacity, it must be practically absent. The mastery of the tried-and-tested crane-drivers is to "put" the hook or lifting device very precisely into the hands of the workers, without swinging, as at times, activities are carried out at the not most favorable working position of the workers' body and this is directly related to the safety of their work.

The crane-driver has full responsibility about working without swinging of the hoisting wire ropes. It must ensure that the ropes will be stretched in normal limits. This should be achieved in all modes of operation: 1) In the hook mode with a standard or increased capacity, 2) In the grab mode, 3) When the crane moves with open or closed, full grab, 4) In the mode of closed grab, 5) When closing or opening the jaws of the grab for loading and unloading.

This is achieved through skillful handling with the command lewers or joysticks for the controls of the individual crane mechanisms. Practical crane-drivers, after many years of work, are coming to the conclusion that productive work is not a quick operation at high electrical motors speeds, but precise work at velocities significantly smaller than nominal , when using some of the crane mechanisms. So that the hook or lifting device is fed to the precisely defined place for loading or unloading the cargo. Unnecessary cargo pendulum is avoided this way, by careful and orderly work, and the loss of time to soothe it. Crane-driver can in the process of manipulating only with the control levers or joysticks of the hoisting gear winches, in virtuous work, using or reaching the straightening of the hoisting wire rope, between the two hoisting gear winches, to rotate about the vertical axle of the load suspended on a load-bearing hook or grab according to their own desire, in most of the cases dictated by the perfect work and the technological demands for handling the cargo. This is accompanied by long-term practice in a well-established and healthy work environment.

3. Solution to the problem

A optimization model of the gantry cranes level-luffing jib systems based on the universal methodology [2, 10, 11, 12, 14] is built. It corresponds to the Pareto optimization procedure, which is explained in Fig. 6 and Fig. 7. These new optimization model of the gantry cranes level-luffing jib systems was created in MATLAB [4, 7, 8, 9, 13]. Experimental studies of the both gantry cranes level-luffing jib systems „KIROVEC“ and „SOKOL“ were done using this model.

The used optimization procedure is shown in Fig. 6 and Fig. 7 works as follows. The parameters are shown in Fig. 8.

The input module № 1 in Fig. 6 shows the number of probe points n (boxed points), the number of parameters m with the boundaries defining the limits area of their change and the number of criteria f. During the analysis, the influence of the parameters m = 30 on the criterion f = 20 is taken into account. Further, in module № 2 in Fig. 6, where there is a separate generation of vectors by random numbers and the formation of the matrix *AN(m,n)*. It is shown in pale blue in Fig. 7. In module № 3 in Fig. 6, the parameter values for determining the criteria in the vectors of the feasible set of criterion vectors of the matrix *KN(f,n)* are calculated. The calculated parameters are checked about accessory within the specified boundages in the module № 4 in Fig. 6.

The affiliation of these probe random points to the compact set of feasible decisions is only recognized at that time. The compact set of feasible decisions *PKN(m,f,n)* is array of parameter values at all probe points is shown in Fig. 7 in yellow. It consists of n matrices $P_{qn}K_j(m,f)$ in the composition of each of which have the same number of parameter vectors. They are calculated using the corresponding to column vectors of matrix *AN(m,n)*. The vectors of matrix $P_{q5}K_5(m,f)$ are the same in order to match the criteria at the relevant probe point. For example, a column vector in pale green in the fifth test point $A_{15}A_{25}\ldots A_{m5}$ corresponds to the matrix $P_{q5}K_5(m,f)$ in bright green Fig. 7. This matrix of parameters is the fifth in line of the compact set of feasible decisions and forms the criteria in the fifth probe point.

The parameters are pass the checks in module № 4 in Fig. 6. Then, with their help in module № 5 in Fig. 6, the criteria are calculated.

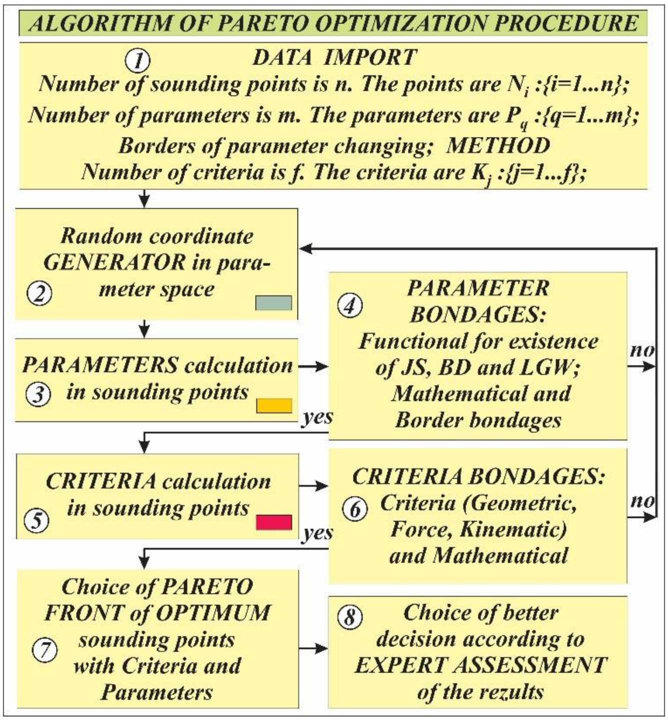
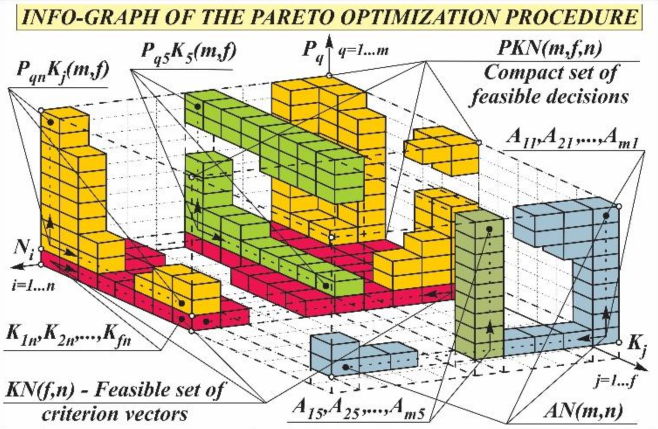


Fig. 6. Algorithm of Pareto optimization procedure



№	Simbol-Color	Description
1.	*AN(m,n)* 🟦	*A matrix is sized **(m,n)** consists from **n** column-vectors, is generated separately from random numbers*
2.	$A_{15},A_{25},\ldots,A_{m5}$ 🟩	*Column-vectors from random numbers in fifth sounding point, corresponding to the matrix* $P_{q5}K_5(m,f)$
3.	*PKN(m,f,n) Compact set of feasible decisions* 🟨	*An array which consists from **n** matrixes. The matrixes size is **(m,f)** and they correspond to column-vectors in matrix **AN(m,n)***
4.	$P_{q5}K_5(m,f)$ 🟩	*Matrix is sized **(m,f)**, it is fifth in the array **PKN(m,f,n)** and correspond to fifth column-vector in **AN(m,n)***
5.	*KN(f,n) Feasible set of criterion vectors* 🟥	*Matrix is sized **(f,n)** consists from criterion row-vectors* $K_{1n},K_{2n},\ldots,K_{fn}$ *in each sounding point*

Fig. 7. Info-graph of the Pareto optimization procedure

Restrictions are claimed to the criteria in module № 6 in Fig. 6. The criteria are a part of the field of coverage in the row vectors $K_{1n}K_{2n}\ldots K_{fn}$ for the respective probe points shown in Fig. 7 in red as $KN(f,n)$ when passing through the checks in this module № 5. It should be borne in mind that in each of the conditionally inscribed boxes on info-graph in Fig. 7 has only one scalar number obtained according to the procedure described above.

The selection of the row vectors with the criteria and the corresponding column vectors according to the Pareto-method for the determination of the Pareto-front is carried out in module № 7 in Fig. 6. Then, in module № 8, after additional requirements, experts will decide which option will be considered optimal.

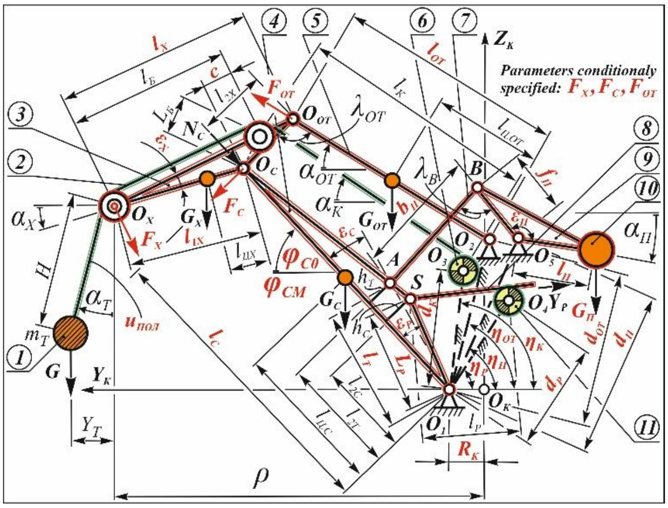


Fig. 8. Optimization mathematical model schema of the gantry cranes level luffing jib system

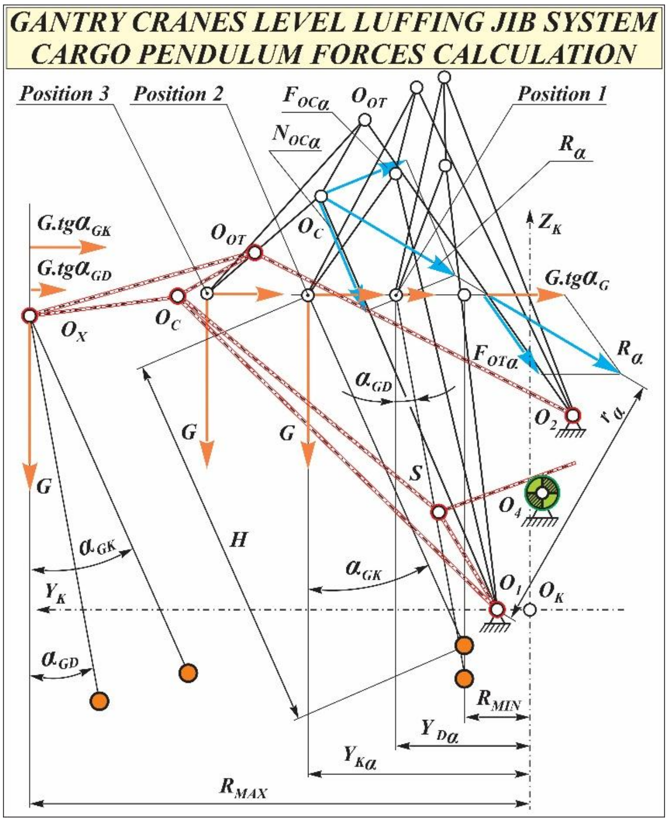


Fig. 9. Cargo pendulum forces calculation

The Pareto optimization procedure uses the interaction of the 30 parameters characterizing units and parts of the gantry cranes level-luffing jib system shown in red in Fig. 8, which are involved in the formation of 20 criteria defining the quality of its work [1, 2, 3, 5, 6]. Parameters are graphically depicted in Fig. 8, and their names are shown in [1, 14]. The adequacy of the optimization model has been verified by setting a minimum range of parameters variations adjusted to a specific construction, where the result is similar to previous studies of this type of level-luffing jib system [1].

All this is served us as the basis for a more perfect study of the moment from the angle of deflection of the hoisting wire ropes from the vertical – α_G. The calculations carried out, the design experience, and the practice of operation have shown that some of the gantry cranes level luffing jib systems elements are heavy loaded on the minimum operating radius by this moment, as shown in Fig. 10, Fig. 11, Fig. 12, Fig. 13 and Fig. 14. So far, the calculation of the gantry cranes level luffing jib systems has been carried out at the situation that the α_G is constant along the operating radius at both its values, respectively, for calculating of electrical motor power and for calculating the forces acting on the steel construction. When the cargo is comming in the minimum operating radius - R_{MIN}, it is almost impossible to significantly swing the cargo due to the fact that the cargo collides with the gantry steel construction. Then it seems possible to conduct calculations at the situation that from a certain operating radius, downwards, down to the minimum operating radius, the angle - α_G decreases to zero. The values of operating radius, from which the angle α_G begins to decrease are accordingly, for calculating the electrical motor power corresponding to the angle α_{GD} = 5.5^O and for calculating the the steel structure elements to the corresponding angle α_{GK} = 17.0^O. These angles for heavy mode of operation are shown in Fig. 9, respectively for first angle in position 1 and for second angle in position 2. Forces calculating is pictured in position 3 in Fig. 9.

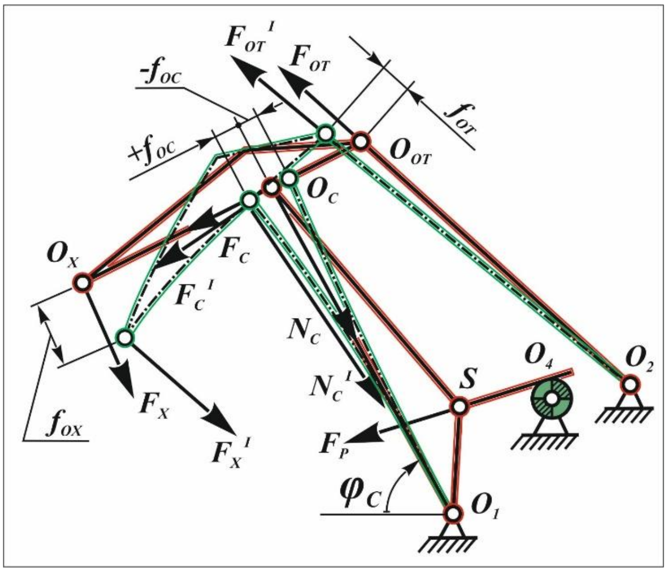


Fig. 10. Forces and displacements caused by them

Therefore, here we presented our research on how the decrease of this angles and the moments from they affects the change in the calculated values: when determining the electrical motor power and determining the forces acting on the elements of the metal structure in Pareto optimization procedure.

4. Results and discussion

A new program complex has been compiled for the purposes of the study. It correspond to the two design schemas studied, of cranes „KIROVEC“ and „SOKOL“. Results obtained for both structures are shown accordingly in next figures. The experimental optimization study was carried out with a cargo of 200 kN for crane „KIROVEC“ and with a cargo of 160 kN for crane „SOKOL“.

The changing of static resistance moments at minimum operating radius respectively for traditional and new calculating methods are pictured in Fig. 11 and Fig. 12. They are used for electrical motor power calculation and give to us a little bit decreased values.

The dependencies of the forces values acting on the level luffing jib system elements for both structure of optimized cranes are shown in Fig. 13 and Fig. 14. They vectors are pictured in Fig. 10. They are calculated according to the drawing in Fig. 10 and by optimization procedure in Fig. 6, Fig. 7 and Fig. 8. The forces range of variation significantly decreases with the new calculation method with respect to the α_G. This leads to a reduction in the amplitude of these forces change, and hence the fatigue limits of the structure elements increases.

It can be seen that the change borders of the forces calculated by new optimization complex are significantly smaller than by the existing design method of gantry crane level luffing jib system. This is a very good indicator. In this way, the total mass of the level luffing jib system structure can be reduced. This is followed by other positive effects. When reducing the total mass of the level luffing jib system, the mass of the gantry crane rotating part is reduced. It is possible to reduce the power of the electric motor in the crane slewing system also. When the mass of moving elements decreases, the forces of inertia acting on them and other elements are also reduced. The graphs of gantry cranes level luffing jib system units displacements for both types of cranes are presented in Fig. 15 and Fig. 16. They are calculated according to the drawing in Fig. 10. This is done using the method of Maxwell - Mohr for determining the displacements. The cargo trajectories are drawed in Fig. 17 and Fig. 18. They are slightly influenced by a change in the α_G in the new calculation method.

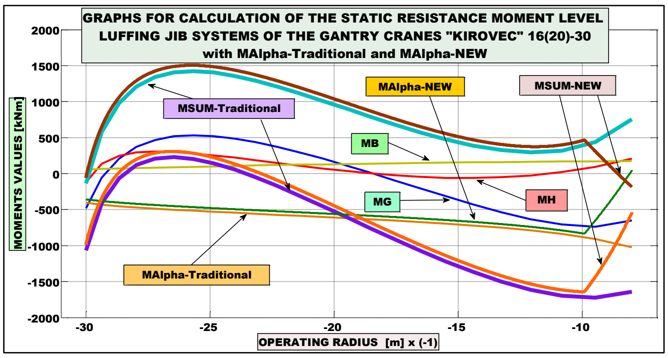


Fig. 11. Static resistance moment graphs of „KIROVEC“

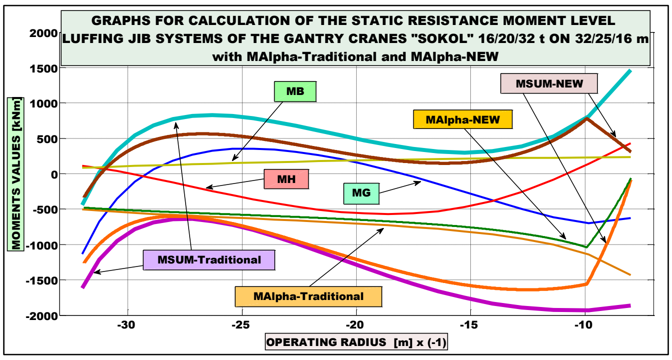


Fig. 12. Static resistance moment graphs of „SOKOL“

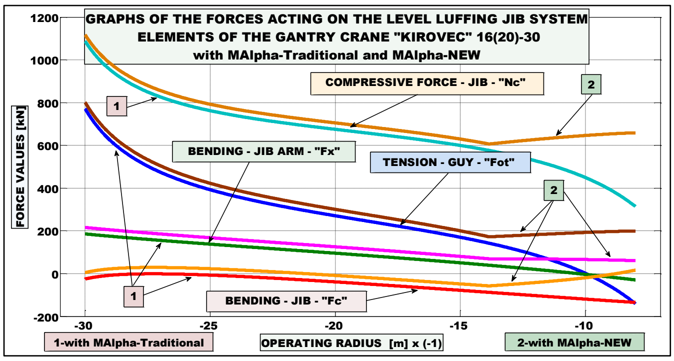


Fig. 13. Level luffing jib system elements forces of „KIROVEC“

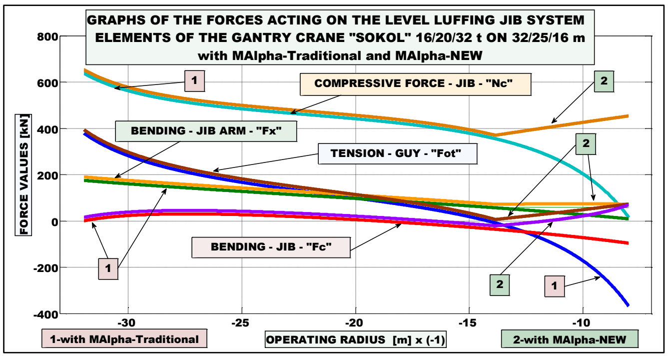


Fig. 14. Level luffing jib system elements forces of „SOKOL“

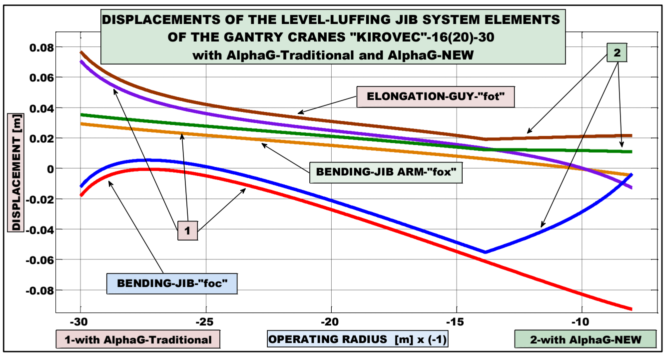


Fig. 15. Graphs of the displacements of „KIROVEC“

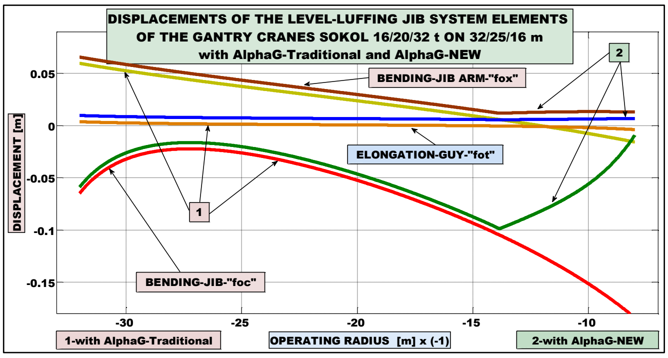


Fig. 16. Graphs of the displacements of „SOKOL“

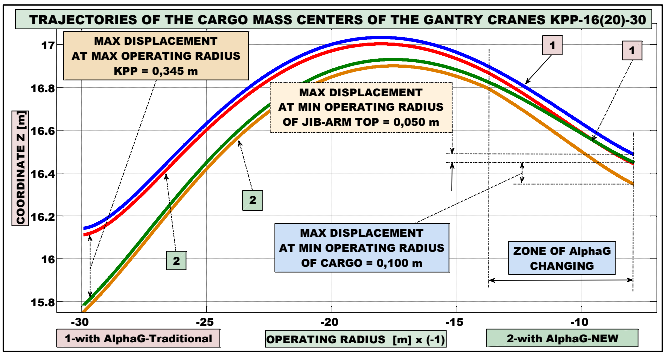


Fig. 17. Cargo trajectories of „KIROVEC“

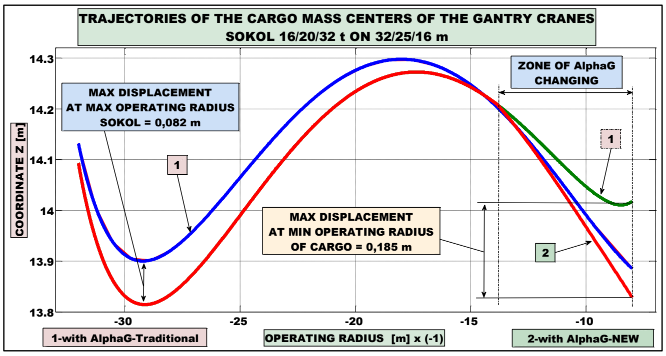


Fig. 18. Cargo trajectories of „SOKOL“

5. Conclusion

The following positive results were revealed during the work with the new Pareto optimization complex. This was obtained after entering into the complex of new additional improvements with respect to the calculation of the angle α_G and moment $M_{\alpha G}$ at the minimum operating radius of gantry cranes level luffing jib systems. New additional improvements approximate the calculations of level luffing jib systems to the actual operating conditions of gantry cranes. The conclusions are as follows:

1. The results on electrical motor power are obtained, with the optimization calculation, show that due to the introduced improvement, the required electrical motor power can be reduced in borders to within 3.5%. This is proved by the procedures compiled on the basis of Fig. 4, Fig. 6, Fig. 7and Fig. 9. It is shown on the example of two different types of level luffing jib systems structures for gantry cranes "KIROVETS" 16(20)-30 and "SOKOL" in Fig. 11 and Fig. 12.

3. The effect of changing the angle α_G and moment $M_{\alpha G}$ on the minimum operating radius to the cargo trajectory for two models of the gantry cranes level luffing jib systems „KIROVETS“ 16(20)-30 and „SOKOL“ is investigated. Referring to Fig. 17 and Fig. 18, it does not significantly affect on the maximum cargo deviation from the horizontal.

4. The effect of changing the angle α_G and the moment $M_{\alpha G}$ on the displacement of the elements of the metal structure for two types of the gantry cranes level luffing jib systems „KIROVETS“ 16(20)-30 and „SOKOL“ are studied. Referring to Fig. 15, Fig. 16 and Fig. 10. It is shown that it significantly depending on the appointment and design of the element itself. The improved Pareto optimization calculations show that real movements are reduced in the range of 30 ... 50% depending on the design of the gantry cranes level luffing jib systems and the slewing part of the gantry crane.

2. The results on the forces acting on the steel structure show that, due to improvements in the calculation technique, significantly reduced ranges of forces variation are obtained, of the order of 30 ... 50%, depending on the type of the gantry cranes level luffing jib systems. This is shown in Fig. 13 and Fig. 14, also for the two models of portal cranes „KIROVETS“ 16(20)-30 and „SOKOL“. The forces vectors are shown in Fig. 10. Reducing the ranges of the forces acting on the elements of the metal structure leads to an increase in the fatigue strength of these elements. Thus, this leads to a reduction in the mass of the metal being poured into the design of the gantry cranes level luffing jib systems and the entire crane, and from there to an increase in the energy efficiency of the steel structure as a whole.

5. The present study can serve as a recommendation to improve the calculation of electrical motor power and elements of the gantry crane level luffing jib systems steel constructin in general, conducted in accordance with ISO 8686-1 - 2012 and ISO 8686-4 - 2005 standards [5, 6].

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