Methods to ensure durability and improvement of reliability of bridge cranes of General purpose during their operation

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Abstract. The paper notes that lifting and transport machines are an integral part of any type of production, since they serve all types of technological processes. Cranes greatly contribute to the smooth operation of the process equipment, so ensuring the quality and increasing the productivity of the crane equipment allows you to improve the performance of the process equipment. The directions and possible ways of improving the designs of General-purpose bridge cranes to increase the durability and improve the reliability of their operation are considered. The main reasons for the need to upgrade bridge cranes in operation are given. The analysis of the main principles of crane equipment modernization is given. The issues of modernization of load-lifting bridge cranes in order to increase productivity, ensure structural improvement, safety in operation, and technical and economic efficiency are considered. To determine the degree of manufacturability of the design, indicators are proposed, for which the classification according to the main evaluation criteria is given. The economic assessment of the feasibility of modernizing the crane economy is given.

1. Introduction

At complex mechanization and automation of technological processes at machine-building plants, the intensity of work of the crane equipment considerably increases also. At the same time, there is a need to increase the load capacity and speed of working movements of cranes, i.e. their productivity [1]. It is not always possible to purchase cranes that meet the requirements of the technological process. Therefore, it is necessary to upgrade the existing cranes directly in the production environment.

Recently, the requirements for the quality, reliability and durability of machines have increased significantly, so in some cases, the existing methods of repairing cranes described in the literature are outdated and do not meet the requirements of modern times. They, in particular, do not reflect the practical issues of surface hardening of working parts.

Of great importance are the methods of calculation of cranes, allowing you to determine the timing of parts depending on the actual modes of operation, the duration of work cycles and load mechanisms. These calculations can be carried out only on condition of knowledge of external loads on cranes taking into account the dynamic phenomena arising in them in the course of operation [2].

Machine-building organizations with a full production cycle have, in addition to machining and mechanical Assembly shops, also procurement: foundry, forging and pressing, thermal, etc. in these shops, cranes of various types are used, which are used to service numerous technological processes. Since in all sectors of the country there are several hundred thousand cranes, the question of repair and modernization of them is very relevant.

A relatively simple method of determining the economic efficiency of the modernization of the crane, allows you to establish the need and feasibility of this work and finds the most profitable
option. The use of articles in practical work in production, repairs and modernization of cranes will improve efficiency and durability of these machines.

2. Formulation of the problem
Ensuring the operational reliability of cranes is achieved by carrying out scheduled preventive repairs. For reasonable planning of terms of carrying out and volumes of repair works, and also funds of spare parts it is expedient to use some practical applications of the theory of reliability.

In General, the reliability of the product is understood as its property to maintain the normal performance of specified functions. The reliability of the product is due to its durability and maintainability. Durability - the property of the product for a long time (with possible breaks for repair) to maintain performance in certain modes and operating conditions until destruction or other limiting state. Maintainability - a property of the product, expressed in adaptability to restore efficiency and to maintain the specified durability by preventing and eliminating breakdowns and defects. Loss of performance is called product failure.

3. Theory
In [3], it is proposed to use the time-to-failure ratio and the coefficient of technical use of $K_b$ as technical indicators of the operational reliability of crane equipment.

The time to failure is the average time of operation of the crane between two adjacent failures:

$$T_o = \frac{\sum t_o}{n_o},$$  \hspace{1cm} (1)

where $t_o$ - separate values of operating time between failures; $n_o$ - number of registered cases of failures.

The coefficient of technical use is defined as the ratio of the uptime of the crane $T_o$ the sum of the uptime of the Crane, the time for maintenance of the $T_{TO}$ and the time for restoration or repair of the $T_B$, calculated for a sufficiently long calendar period (a year or more):

$$K_u = \frac{T_o}{T_o + T_{TO} + T_B},$$  \hspace{1cm} (2)

The values $T_{TO}$ and $T_B$ are determined by formulas similar to the expression (1).

Cranes consist of a large number of interacting mechanisms, assemblies, parts and supporting structures. In most cases, the failure of any one element leads to the failure of the crane as a whole. Therefore, the operating time for failure of the crane will be determined by the durability of its parts and elements. Therefore, it is necessary to increase the durability and operational reliability of crane equipment by increasing the durability and reliability of its parts and structures. This increase can be achieved by rational choice of shape and materials, the use of reinforcing technology, etc., both in the manufacture of new and in the restoration of used parts.

In compliance with the rules of operation of the crane failures occur due to fatigue damage or wear of the working surfaces of parts. At present, the physical basis of the phenomena of fatigue and wear have not yet been fully studied. In addition, the variability of operational factors is very high. Therefore, calculations for durability in some cases do not provide sufficient accuracy. In these conditions, statistical data on the actual durability and reliability of crane parts, structures, as well as understanding the General patterns that determine their wear and fatigue strength are of great importance.

Studies of metal structures of cranes [4-7] showed that fatigue cracks appear in them after 5...7 years under normal operation, and sometimes less. Most often cracks appear in the end beams and adjacent sections of span beams and trusses. Fatigue destruction is mainly subjected to elements loaded with variable tensile stresses, i.e. lower truss belts, lower horizontal sheets, stretched fibers of vertical sheets of span and end beams, etc.

Fatigue cracks in the compressed elements are practically absent, which is explained by a large margin of safety, due to the need for stability, and large limits of endurance of materials when working on compression.

As for the coefficient of technical use of $K_{mu}$ cranes, its value largely depends on the organization of preventive and repair work at each enterprise.

To obtain statistical data on the durability and reliability of crane equipment in relation to the conditions of each particular enterprise, it is desirable to establish systematic monitoring of the
operation and technical condition of the cranes. In this case, it is advisable to use the method of collecting and processing information proposed in [3].

Lifting and transport machines are an integral part of any type of production, as they serve all kinds of technological processes. Cranes greatly contribute to the smooth operation of technological equipment. Therefore, ensuring the quality and increasing the productivity of crane equipment allows you to improve the performance of technological equipment.

Modernization of cranes, as well as modernization of technological equipment, is bringing their technical and economic indicators to the level of performance indicators of new equipment, the work of which meets international requirements.

Improvement of production places increased demands on the operation of crane equipment, so the basic principles of modernization of crane equipment are as follows:

1. Modernization of cranes should improve the technical and technical-economic characteristics of their work. Technical and techno-economic characteristics include: capacity, performance, speed of work movements, the flights of cranes and flights of hooks, the lifting height, the reference pressure of running wheels, dimensions, total weight of the crane parts, mechanisms and units, the installed capacity of motors and operation modes, weight lifting devices, the capacity of hoisting devices for bulk goods, the degree of mechanization and automation of hoisting devices, convenience, and safety valve control, good review crane operator jobs, degree of automation of crane control from the driver's cabin, from the portable control panel (by radio commands), remote control (cable connection), easy and safety maintenance (lubrication, inspection, overhaul and repairs), reliability, dependability and durability of the parts and mechanisms of the crane, their structures, the amount of lubricant and other materials used in the operation, the cost of the crane, the annual operating costs, the cost of repairs (current, medium and capital), the cost of handling and transportation of cargo, specific metal is used per unit power and per unit productivity.

Depending on the type of technical and economic indicators, some of them after the modernization of the crane should increase (for example, performance), and others decrease (for example, weight).

2. Modernization of cranes is carried out at relatively low cost (Finance, materials, labor costs). The payback of the spent funds should be covered for a short period of operation of the modernized crane (no more than five years).

3. Higher results of modernization are achieved with the systematic work of specially created design organizations that use modern achievements of domestic and foreign crane construction.

4. Modernization of cranes should be carried out with the use of block-modular design method [8] on the basis of normalization, unification of structures, manufacturability of parts manufacturing and Assembly of units.

5. When upgrading cranes, it is necessary to improve safety, management and maintenance characteristics in accordance with regulatory documents [9].

6. At modernization of load-handling devices and devices of bridge cranes it is necessary to consider production conditions of work. In mass and large-scale production, requiring the performance of certain production operations, load-grabbing devices should be more individual, mechanized and automated. In individual and small-scale production, these devices must be universal, allowing you to take different shapes, dimensions and weight of goods. To increase productivity in some cases, it is advisable to use quick-change load-grabbing devices.

7. The quality and efficiency of modernization is ensured if the operation of cranes is previously investigated in order to determine the actual loads, stresses and other parameters in the details of mechanisms and metal structures. The results of modern research methods of cranes (strain gauge, polarization, etc.) should be taken into account in the development of modernized designs of parts, components of mechanisms and metal structures.

8. Modernization of cranes is carried out in the direction of reliability and increase durability of work at decrease in weight of a metalwork of bridge cranes.

9. The use of new high-strength or expensive materials can be justified if the weight of the upgraded crane has decreased, durability and reliability have increased, and the payback period does not exceed five years.

10. Modernization of cranes should reduce moral and physical deterioration of structures.

11. It is necessary to achieve reduction of dynamic loadings in operation of the modernized crane at the expense of introduction in appropriate places of mechanisms of pliable elements.
12. Modernization of the main technological equipment requires, in some cases, modernization of cranes.

13. Modernization of cranes organizationally and economically it is better to carry out during carrying out capital repairs.

14. With the development of production, the requirements for new and modernized crane equipment are increasing. It is necessary to systematically upgrade not only old cranes, but also new ones, if their technical and economic indicators do not meet the requirements of developing production.

In some cases, modernization is carried out on separate performance indicators. If at the same time there is a technical and economic effect, and the costs of depreciation are paid off for the regulatory period, then partial modernization is advisable. Therefore, manufacturers should be more engaged in the modernization of cranes, leading to an increase in the productivity of technological equipment.

Modern production processes require increasing the load capacity and speed of working movements of cranes, as well as ensuring their reliability and durability.

Increasing the degree of automation of working operations and individual technological processes, put before crane operators the task of automating the control of cranes and control of all crane mechanisms, similar to the “black boxes” in aircraft construction.

The presence of a huge fleet of cranes in the country, does not allow in the shortest possible time to create and manufacture the necessary number of crane designs that meet the requirements of developing production. However, it is economically inexpedient to replace rather new not worn-out cranes with the newest which cost several times exceeds expenses for modernization of the cars which are in operation. Economic considerations also indicate that the modernization of cranes does not require the cost of a large amount of metal compared to the weight of new cranes.

As crane designs are constantly improving, the crane equipment gradually wears out. At the same time with moral wear the physical wear of knots and mechanisms of cranes progresses: reliability of trouble-free operation of cranes is reduced and durability of operation decreases. These circumstances impose on the production and operation of the task of organizing a systematic modernization of crane equipment. The feasibility of upgrading the machine should be justified economically.

Many enterprises in the modernization of cranes increase a number of economic indicators of the main production. Significant economic effect is created when modernization is accompanied by unification of the main units and parts of cranes. Modernization with simultaneous unification allows to increase constructive, strength, operational and technological indicators of cranes.

Unification is carried out on separate details, knots, mechanisms and as a whole on cranes. Everything is unified: running wheels, bearings, couplings, hook clips, brake pulleys, brakes, drums, trucks and even crane axles.

4. Results

The economic efficiency of modernization depends not only on the system of organizational measures carried out in production, but also on the work of designers. The design solution for the modernization of the unit or mechanism can be selected on the basis of the following basic recommendations:

1. It is most expedient to use for modernization the design which has justified itself in practice and at work in similar conditions in which the crane which is subject to reconstruction is operated.

2. At modernization it is necessary to analyze rationality of kinematic schemes of mechanisms, and also designs of knots of mechanisms taking into account their shortcomings revealed at operation.

3. In some cases, it is advisable to replace parts with a short service life and reliability of the same parts but made of stronger materials. The use of more durable materials is advisable when increasing the load capacity of cranes or transferring them to heavier modes of operation.

4. Modernization should be carried out using the normalization of parts and unification of crane units available in production.

5. To facilitate repair work, it is desirable to create block structures when upgrading the mechanisms of bridge cranes.

6. To reduce stress concentration in critical parts, they must be designed taking into account the latest recommendations on the rational form of structures. Thus, the strength of the shafts increases if you increase the radii of gaitels or conical transitions of some parts of the shaft to others.

7. Increasing the lifting capacity of the lifting mechanism, in some cases, is achieved by replacing the ropes made of stronger materials with the same diameter of the rope.
8. Bearing units of bridge crane mechanisms are also subject to modernization by replacing sliding bearings with rolling bearings, and if necessary, by installing reinforced rolling bearings with greater strength, replace the transmission drive of the crane movement mechanism with a separate drive. in some cases, instead of wheels with a protruding part of the rim (from the French rebord - crest), crane bridges use wheels without a protruding part of the rim.

9. With insufficient control, the axles of the running wheels of the bridges often have distortions both in the vertical plane and in the horizontal. Modernization of designs of knots of running wheels of cranes, and also their control allow to improve considerably conditions of ensuring reliability of work and service life of crane wheels. The use of lubrication devices to lubricate the sides of the crane rail heads also improves the performance of the running wheels.

10. Poor condition of crane tracks increases wear of running wheels, creates significant dynamic loads in the end beams of bridges (impacts at the joints of rails) and contributes to the rapid appearance of fatigue cracks in the metal structures of cranes. Modernization of crane tracks, through the use of gaskets can dramatically reduce the cost of repairing them and simple cranes, as well as improves the operating conditions of the latter.

11. It is established [4] that fatigue failures of metal structures occur after 18...20 years. Taking into account that fatigue cracks and breaks of elements appear in the lower belts of lattice main and auxiliary trusses, it is necessary to closely monitor the bridges of cranes and carry out routine work near the nodes of fastening of elements, as well as near the end beams of bridges.

12. Welding of joints of rails allows to reduce the dynamic shocks arising between rails and wheels at driving of cranes.

13. To increase the stroke of the crane in the works [10, 11] it is recommended to move from laying electric wires through pipes to sectional laying with an open wire with insulation of increased mechanical strength. This reduces the weight of the crane and the complexity of electrical installation.

Modernization of the mechanism or Assembly of the crane should be closely related to the manufacturability of the design. As is known, under the manufacturability of the machine design mean the degree of compliance of its manufacture to the optimal production and technological conditions at a given scale of production. Technological design can be satisfying operational requirements, when its production at a given scale of production will do with minimal production costs and with the shortest production cycle.

To determine the degree of manufacturability of the design, indicators are used, which are conditionally divided into the following groups:

1. Consumable:

   • General labour input in normo-hours on the product;
   • structural complexity of production in normo hours on a product by types of works and shops (foundry, forge and stamping, etc.);
   • specific labor intensity of production in normal hours per unit weight of the product, per unit engine power;
   • total material consumption in tons per product;
   • structural material capacity in tons per product for individual grades and brands of materials;
   • specific material consumption in tons per unit of own weight of the machine and per unit of power;
   • total weight in tons of the product;
   • specific gravity in tons per unit of installed capacity in kilowatts, per unit of load capacity in tons, etc.;
   • the coefficient of use of metal in the workpiece parts;
   • coefficient of use of metal in workpieces per unit or product: on the machine as a whole, by types of workpieces (cast, welded, forged, etc.);
   • cost of the workpiece.

2. Unification:
• coefficient of structural and model repeatability. Its value is calculated as the ratio of the number of original parts to the total number of details in the design model (machine). The smaller this ratio, the higher the manufacturability of the design. When upgrading a crane this ratio can be defined as the ratio of the number of upgraded parts to the number of all parts of the crane;
• coefficient of structural inter-unit repeatability. This ratio is defined as the ratio of the number of original parts borrowed by a given model from another model to the total number of design parts of the model in question;
• coefficient of structural repeatability within the series - is the ratio of the number of original parts in all models of the series (minus repetitive) to the total number (sum) of parts in these cranes. If the company has several identical lifting capacity, spans and lifting height of overhead cranes subjected to modernization, this coefficient will be the ratio of the number of original parts used in these machines to the total number of their parts.

As any solution of an engineering problem modernization of crane economy of any enterprise begins with the technical and economic analysis. The methodology and organization of work on the technical and economic analysis and selection of the rational option of modernization of cranes of the enterprise is reduced to the following main activities:

1) analysis of cranes in terms of compliance with their technical characteristic (performance, load capacity, mode of operation, speed of working movements, etc.) requirements of developing production;
2) analysis of the cost of maintenance and repair of cranes (consumption of metal, electricity, lubricants, salaries, the cost of downtime due to breakdowns, etc.);
3) identification of morally worn parts, assemblies and mechanisms;
4) identification of wearing and failing parts, assemblies and mechanisms of the crane;
5) unification of the same type of parts, assemblies and mechanisms of the crane;
6) development of variants of modernization of cranes taking into account their design, working conditions and availability of the processing equipment by means of which reconstruction will be made;
7) preliminary economic justification of efficiency of modernization of cranes by the corresponding calculations;
8) choosing a rational option for modernization, which requires the lowest total capital and operating costs for its implementation.

5. Discussion of results
Technical and economic analysis of modernization of crane structures is performed by comparing two or more solutions with the existing design for the same type of nodes and in General for cranes [12].

Compare the cost of manufacturing the structure and the cost of tooling for its manufacture, the cost of Assembly, installation and commissioning, production time, metal consumption, energy consumption of upgraded and existing cranes, the cost of operating machines, material costs, the cost of reloading a unit of cargo, reliability and durability (expected for a new crane and existing for not upgraded). In the absence of detailed regulatory data on these economic and technical parameters of crane equipment, in some cases, economic calculations can be made on enlarged indicators, So, the cost of the upgraded design can be determined by the cost of a ton of forgings, forgings, casting, metal structures, grouped by weight and complexity groups of parts.

For economic calculations, formulas are also used that determine the total or specific capital investments and total annual or specific operating costs. These costs are determined for existing and new equipment. Comparison of the obtained results allows to find the most profitable solutions.

Let us consider in more detail the above measures for the technical and economic analysis of the existing crane design and the choice of a rational option for its modernization. The criterion of conformity of the crane to requirements of developing production are its technical indicators If the crane servicing a site of production, does not provide workplaces both in time, and on loading capacity, it should be replaced or modernized. It is necessary to analyze the organization of the production site and check the rationality of the crane. If the span of the shop allows you to install an additional crane, it is not always advisable to upgrade the existing crane.

A comparison of the technical performance of the crane listed above, and performance indicators of the latest types of cranes allows you to outline the main measures for modernization. However, the
final decision can be made after preliminary technical and economic calculations of the effectiveness of the proposed modernization.

The most significant changes in the design of the crane arise with an increase in its load capacity, the duration of inclusion and the speed of working movements. If the technological equipment of the workshop in which the crane is installed requires an increase in these basic parameters of the crane, then its modernization is inevitable when it is impossible to purchase a new more advanced crane. However, even in this case, if the technical and economic calculation shows that it is more profitable to use the existing crane, after its modernization. If you need to upgrade individual units, the purchase of a new crane, as a rule, is not economically justified.

In many cases, the growing production does not require an increase in load capacity, productivity and other basic characteristics of the cranes. However, an analysis of the cost of maintenance and repair of cranes can show the urgent need for their modernization. The main criterion here is the physical wear of parts, assemblies and mechanisms of the crane. Frequent breakdowns and increased wear of individual parts and assemblies cause high repair costs, material costs, downtime of process equipment and reduced output of the shop. In this case, shop mechanics are obliged to raise questions about the modernization of such cranes in a timely manner in order to reduce their downtime due to technical malfunctions. It is necessary to determine the actual costs of repairs, compare the service life of individual parts, at least tentatively determine the losses caused by downtime of process equipment due to breakdowns of cranes.

In many cases, the growing production does not require an increase in Reasons for the short service life of parts and assemblies is often the poor quality of materials and heat treatment. Therefore, replacing the crowns of old structures wear parts and components more durable and reliable, you can get a certain economic effect.

In many cases, the developing production does not require an increase If to identify the physical deterioration of parts and components is relatively easy for experienced manufacturers, then to determine the moral deterioration-more difficult. The essence of the obsolescence of the part, unit, machine is that as a result of the growth of productivity of social labor, work on this crane becomes irrational and inhibits the further development of production. There are two types of obsolescence: the first is manifested in the partial loss of value of the crane operated for some time as a result of increased productivity and the production of modern cranes with a lower cost. The second type of obsolescence is characterized by the creation and use of cranes more economical and productive compared to cranes in operation. It follows that the production workers are obliged in the technical and economic analysis of the crane to be upgraded, to compare the capital costs, the initial cost is not upgraded and modern cranes, as well as their technical indicators (performance, installed engine power, etc.) to determine the degree of obsolescence of the machine.

In order to obtain a higher economic effect from the modernization, it is necessary to take into account the feasibility analysis of the design of the possibility of using normalized and unified parts and assemblies of cranes, well proven in practice.

Installation of unified units and parts gives an advantage to this variant of crane modernization, increases reliability and service life and reduces the cost of crane reconstruction works.

Let's move on to the question of choosing a rational option for the modernization of the crane. We use for this purpose a technique of definition of economic efficiency of introduction of new equipment, mechanization and automation of production processes in the industry. This technique is intended for determination of economic efficiency of introduction of a number of actions and including modernization of the applied equipment.

The main indicators that assesses the economic efficiency of introducing new equipment, are capital expenditures necessary for the implementation of modernization; the cost of goods or in relation to cranes the cost overload of the load unit, the payback period of capital expenditures on modernisation and the corresponding effectiveness ratios; labour productivity (production development on one worker or upgraded faucet).

Calculations of economic efficiency of measures on introduction of new equipment are carried out for definition of the most effective directions and variants of development of equipment taking into account priority and time of introduction, and also annual economy from introduction of new equipment.
For comparison of indicators of economic efficiency of modernization the best introduced Russian and foreign designs of cranes or, in some cases, their projects are accepted. When determining the economic effect, the basis for comparison is not an upgraded crane, instead of which an upgraded one is introduced.

From possible variants of modernization of group of homogeneous cranes or one crane economically the most effective is that which introduction demands the least capital expenses and provides at the same time the lowest Prime cost of an overload of unit of freight. If the lower cost of reloading a unit of cargo is achieved as a result of an increase in capital costs, the question of the effectiveness of this option is solved by measuring the additional capital costs with savings on current costs.

The annual economic effect of the modernization of cranes can be determined by the formula:

\[ \mathcal{E} = [(C_1+\varepsilon H K_2) - (C_2+\varepsilon H K_3)]B_2, \]

where \( C_1 \) - is the cost of overload of a cargo unit before the upgrade, tap, RUB./t; \( C_2 \) - the cost overload of the load unit after the upgrade of the tap, RUB./t; \( K_1 \) - specific capital costs per unit of cargo to modernize tap, RUB./t; \( K_2 \) - specific capital costs per unit of cargo after upgrading the tap, RUB./t; \( \varepsilon H = 0,2÷0,33 \) - regulatory industry ratio for the engineering sector if the payback period of the implemented activities during 3...5 years; \( B_2 \) - the annual volume of cargo handling operations of the crane after modernization, t/year.

Specific capital costs are determined by the following expression:

\[ K_1 = \frac{R_1}{B_1}, \quad K_2 = \frac{R_2}{B_2}, \]

where \( R_1 \) - cost of the crane before modernization in rubles; \( R_2 \) - cost of the crane after modernization in rubles; \( B_1 = t_1 P_{\text{hor}}, \text{cf.} \) - the annual volume of transshipment work before the modernization of the crane, t/year; \( t_1 \) - the operating time in hours of the crane before the modernization during the year; \( P_{\text{hor}}, \text{cf.} = n_{\text{lo}}, Q_{\text{lo}} \) - average hourly capacity of the crane before modernization; \( Q_{\text{lo}} \) - average load capacity of the crane before modernization; \( n_{\text{lo}} \) - average number of cycles of the crane per hour before modernization.

### 6. Summary and conclusions

Thus, the solution of these main tasks is based on the comparison of the implemented variants (or variant) with the original base (not upgraded crane). The economic efficiency of modernization is based on two main provisions: how technically progressive is the modernization; what is the magnitude of the effect of modernization in specific conditions.

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