DEVELOPMENT OF THE TECHNOLOGY OF CRANE-LESS LIFTING OF LONG-SPAN REINFORCED CONCRETE AND METAL COATINGS

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Abstract: Based on the analysis of well-known organizational-technological and structural-technical examples of crane-less lifting of long-span reinforced concrete and metal coatings of industrial and civil buildings, the goal was to develop a technological solution that would increase efficiency and shorten the duration of work on the construction of roofing structures. Taking into account the advantages and disadvantages of examples of the use of technologies of forced lifting of coatings by push-out methods, mechanized technological equipment for raising columns was developed, which consists of lifting modules and lifting fasteners. The lifting of the covering is carried out by leaning on the heads of the mounting columns, which are raised in the space between the paired design columns. In the process of increasing the load from the sections of the mounting columns, the support frames of the lifting modules and the lifting clamps take turns. According to the developed technological solution, in the initial phase, paired design columns are installed in the foundations by the method of free lifting with the help of cranes, and the construction and technological block of the covering is formed on low scaffolding. The support bars of the cover block are inserted into the space between the paired columns. Lifting modules and lifting fasteners are installed on the foundations, adjacent to the design columns. After completion of work on consolidation of the coating into a structural and technological unit, crane-less lifting of the coating to the design height is performed. For this, hydraulic lift cylinders raise the support frames and, fixed on them, the support bolts of the coating. Then the load from the coating is transferred to the lifting fasteners. At the next stage, the sections of the mounting columns are extended in the space between the columns. After lifting the covering to the design height with support on the mounting columns, the support bars of the covering are fixed on the heads of the design columns. Sections of mounting columns are dismantled. When using the developed technology, the lifting of the covering to a height of 34 m takes 1.8-2.0 shifts. At the same time, the dimensions of the construction site do not exceed the overall dimensions of the raised surface.

Keywords: crane-less lifting; long-span coating; reinforced concrete vault; mechanized technological equipment; lifting module.

1 Introduction

During the construction of industrial objects, the most difficult is the assembly of long-span roof structures weighing more than 1000 tons. When using traditional crane methods of free lifting of structures [1], it is necessary to use complex scaffolding and assembly platforms at a height of 14-34 m. At the same time, the time intervals for delivery of roofing elements to the project site are very long. Installation work on the formation of long-span roofs only with the help of cranes is very laborious and is defined as economically unprofitable. An attractive option from the point of view of organization, technology, duration, and cost of work on the construction of long-span roofs is the option that combines crane and crane-less assembly methods. During the starting organizational and technological stage of mounting works, cranes are used to assemble foundations, projection columns and assemble roof blocks on low scaffolding [6]. At the next stage of building works, the structural and technological block of the roof is moved to the design height using crane-less technologies [3]. Common ones to several options for the forced movement of long-span coating to the project marks are the methods of column growing using hydraulic lifting units [4]. Improving the well-known technologies for crane-less lifting of roofs using hydraulic hoists is an urgent and relevant problem.

2 Literature review

The development of scientific and theoretical solutions for constructing industrial facilities with long-span structural and technological blocks of roofs was carried out by well-known scientists. In particular, among Ukrainian scientists, the greatest contribution to the development of technological solutions for the construction of roofs of industrial facilities using a traditional crane and crane-less technologies was made by V. Chernenko, P. Fedorenko, L. Kolesnik, V. Kurbatov, S. Landa, B. Mosakov, V. Nazarenko, V. Nikolaev, G. Nizhnikovsky, O. Osipov, V. Rashkivskyi, P. Rezhnichenko, A. Shkromada, A. Shnajder, T. Shtol, V. Shvidenko, G. Tonkacheiev, V. Topchii [1; 3; 4; 6; 9-14; 16, 18]. Among scientists of other countries, a great contribution to the development of scientific and theoretical solutions for crane and crane-free technologies for the construction of coatings of industrial and civilian objects was made by H. Engel, K. Fligier, E. Kühn E., G. Orlik, L. Rowinski, H. Rühle, K. Weissbach, J. Ziólko [5; 7; 17; 20].

3 Materials and methods

Studies of organizational-technological and structural-technical features of the construction of long-span reinforced concrete and metal coatings were carried out on the example of built civil and industrial facilities in France, Great Britain, and Ukraine. The technological processes used in the construction of coatings in the listed countries had common features. In particular, in each case, at the first stage of installation work, the covering structure was made on low scaffolding with the help of cranes using the free-lift method. The next stage of raising the coating to the design height was carried out by the method of forced vertical movement with the use of raising columns. Organizational-technological and structural-technical solutions for increasing the columns for each option under consideration were different. The analysis of the advantages and disadvantages of known examples of crane-less erection of long-span structural and technological blocks was used to develop mechanized technological equipment that would allow increasing the efficiency of installation processes for lifting coatings to a height of 34 m and more, while reducing the construction and installation work duration.

For the first time, the option of erecting a long-span reinforced concrete cover with the sequential use of crane and crane-less installation methods were implemented during the lifting of the hangar cover of the Marignane airport in Marseille, France in 1951 [7]. An important point in the organization of the technological process was the execution of all installation work on the formation of a monolithic reinforced concrete coating within the area of the construction site, which did not exceed the dimensions of the structural and technological block of the rising coating. The technological sequence of the processes of lifting the hangar cover is shown in Figure 1.

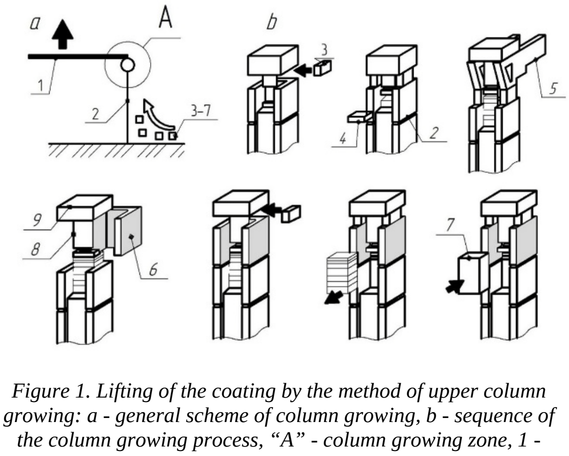

Figure 1. Lifting of the coating by the method of upper column growing: a - general scheme of column growing, b - sequence of the column growing process, “A” - column growing zone, 1 - coating, 2 - column grown, 3 - side support segment, 4 - support segment for the hoist, 5 - support beam, 6 - outer column segment, 7- inner column segment, 8 - hydraulic hoist, 9 - coating support block

The construction solution provided for the implementation of installation operations in two stages. At the first stage, on low scaffolding (height up to 1.5 m) by the method of free lifting with the use of a crane, the racks and crossbars of the formwork were assembled, the formwork decking was laid, the reinforcing framework of the covering was formed and the concreting of the long-span vault was completed. At the second stage, after the strength of the reinforced concrete coating was obtained by the method of pushing out with the support of the coating support bars on the growing columns, the monolithic coating was vertically moved from the level of the foundations to the design height of 14 m. The hydraulic jacks involved in the raising process were located between the rising pavement and the heads of the raising columns. The actual growing method is classified as the "column top growing method" [1]. The installation process of the outer *6* and inner *7* segments of the growing column *2* consisted of the following sequential operations:

- Hydraulic lifter *8* moves cover *1* to a height of 200 mm (working stroke of hydraulic lifter cylinder);
- An auxiliary side segment *3* (segment height 19 cm) is inserted into the space between the support block of the covering *9* and the upper face of the extended column *2*;
- The rod of the hydraulic lift is raised by 200 mm, the load from the support block of the coating *9* is transferred to the upper face of the raised column *2*;
- In the space between the raised rod of the hydraulic lift *8* and the upper face of the inner segment of the column *7*, an auxiliary segment is placed under the lift *4*;
- With the support block of the cover *9* resting on the auxiliary segment under the lift *4*, the cover *1* is raised to a height of 200 mm;
- The operation to install auxiliary side segments *3* and auxiliary segments under the lift *4* is repeated 3 times;
- Instead of four tiers of auxiliary side segments *3*, an auxiliary beam *5* is installed;
- With the support block of the covering *9* resting on the auxiliary side beam *5*, the fifth tier of the auxiliary segment is installed under the lift *4*;
- The hydraulic lift rod *8* rests on the installed fifth tier of the auxiliary segment under the lift *4* and the support block of the covering *9* is raised by 200 mm;
- The auxiliary beams *5* are dismantled and the outer segment of the column *6* with a height of 950 mm is installed;
- With the support block of the covering *9* resting on the assembled outer segment of the column *6*, five tiers of the auxiliary segment under the lift *4* are dismantled and the inner segment of the column *7* with a height of 950 mm is installed;
- The assembled external segments of columns *6* are fastened with the help of four threaded pins Ø 25 mm;
- The reinforcing frame is fixed and the formwork shield is installed between the assembled outer segments of the column *6* and the inner segments of the column *7*, the formed cavity is filled with concrete.

The reinforced concrete coating of the hangar had dimensions of 58.5 x 101.5 m in plan, the pitch of the columns was 9.8 m, the weight of the coating was 4,200 tons. 14 hydraulic jacks with a carrying capacity of 310 tons were used in the process of raising 14 prefabricated columns. The growing columns consisted of 420 main and 126 auxiliary elements. The bodies of hydraulic jacks were fixed on special support blocks on the lower surface of the raised monolithic covering. Growing of the columns lasted 23 days. 23 installers were involved. The advantages of the method of the upper extension of the columns include a dense fixing unit of the lower sections of the extension columns in the foundations, a constant load on the hydraulic lifts, which does not depend on the total number of mounted sections of the extension columns. Disadvantages of the implemented method of the upper extension of the columns include increasing in proportion to the distance from the ground time costs for element-by-element delivery of 546 main and auxiliary elements of the columns to the extension area, high labor intensity, a large number of dangerous high-altitude installation operations at a height of 14 m, the need to constantly build up scaffolding in areas of installation work, a small stroke of lifting jacks.

A classic example of raising a long-span covering by the method of lower column raising is the erection of a monolithic hangar covering in the city of Abington (Great Britain) in 1957 by the firms Ove Arup and Partners and John Laing and Son Ltd. [7]. The coating consisted of three monolithic reinforced concrete segments (plan dimensions of each segment 33.53 x 59.59 m, total weight of the coating 1400 tons). The construction of the monolithic reinforced concrete vault was lifted by leaning on the heads of the growing reinforced concrete design columns (see Figure 2).

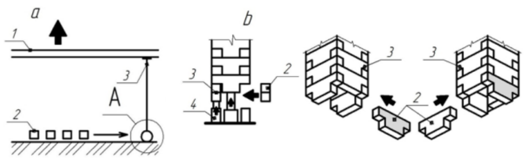

Figure 2. Lifting of the coating by the method of lower column growing: a - general scheme of column growing, b - sequence of the column growing process, "A" - column growing zone, 1 - coating, 2 – column segment before growing, 3 – growing column, 4 - hydraulic hoist.

The columns were made of T-shaped segments. The weight of the T-shaped segment was 500 kg, the total number of assembled segments was 1000 pieces. Before installation of each segment, a cement-sand solution (ratio 1:3), a layer thickness of 5/8" (16.5 mm) and metal plate spacers were laid on its upper face. Four jacks were used to raise each column. The carrying capacity of each jack is 200 tons. In the process of growing, a cavity was formed between the inner side faces of the mounted T-shaped segments. Reinforcing rods (14 rods for each column) were laid in the cavity during the growth of the column segments. After the installation of the last T-shaped segment of the column, the cavity was filled with concrete. At the moment when the concrete acquired the calculated strength, the reinforcing rods were tensioned. The direct lifting of each monolithic segment of the covering took five days, 30 workers were involved in the installation operations. Taking into account the time required for the concrete, enclosed in the cavities of the segmental reinforced columns, to acquire the calculated strength and the processes of tensioning the reinforcing bars, the total time for bringing the coatings to the design height was 35 days. Disadvantages of the real technology include the hinged scheme of supporting the column on the foundation during the extension process, significant labor intensity and low productivity of the installation process, a large number of installation operations in preparation for the extension of each T-shaped segment of the columns, the need for constant control of the synchronous operation of 16 hydraulic jacks involved in lifting and maintaining column segments during their extension, small working stroke of the jack rods [2].

Further development of the technology of lifting the coverings by the method of the lower extension of the columns can be observed on the example of the erection of the covering of the hangar measuring 144 x 275 m at the aircraft factory in Kyiv, Ukraine [12]. The covering with an area of 39,600 m^2 and a weight of 1,100 tons was raised to a height of 24 m in 12 shifts. Columns were raised using PG-300 hydraulic lifts [3]. As columns that were growing, sections of lifts were used, which were supplied into the growing zone between the bodies of the hydraulic lifts and the support frames. The crossbars of the covering rested on the heads of the lifting columns of the lifts. Solid design columns of the building were attached to the lower surface of the supporting beams of the covering during the period of consolidation of the long-span covering block on low scaffolding (height 2.0m). As the masts of the elevators grew, the design columns changed their position from inclined to vertical. At the final stage of raising the shafts of the elevators, the design columns were fixed in the foundation cups. At the next stage of installation work, the load from the support crossbars of the covering was transferred to the heads of the design columns. After that, the shafts of the elevators were dismantled. Taking into account the fact that in the process of lifting the covering by the method of raising, the design columns were not involved, it is possible to classify the rising trunks of the elevators as "raising installation columns". The lifting of the covering by the method of raising the mounting columns is shown in Figure 3.

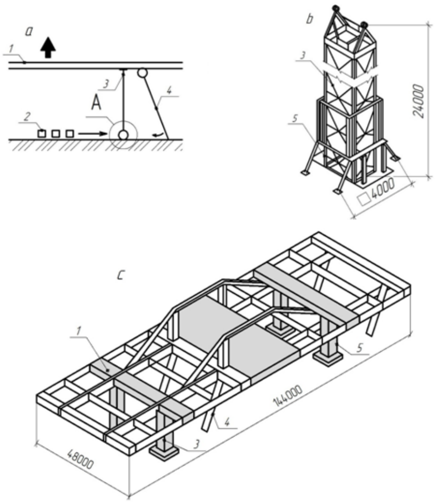

Figure 3. Lifting of the covering by the method of raising the mounting columns: a – general scheme of raising the columns, b – hydraulic lifting module PG – 300, c – long-span covering in the process of lifting, A – zone of raising the columns, 1 – covering, 2 – segments of the mounting column, 3 – prefabricated raised assembly column, 4 – integrated design column, 5 – hydraulic jacks

For the final landing of the covering blocks at the design height, "raising-lowering" cycles were repeatedly performed within the height limits of 200-300 mm with constant adjustment of the docking places of individual covering blocks. The disadvantages of the considered technology include the difficulty of placing the covering blocks on the column heads and the significant labor intensity of the installation processes at a height of 24 m, which are connected with the joining of the raised covering blocks. Taking into account the fact that the lower extension of the mounting columns defines the scheme of supporting the extension columns on the foundations as "hinged", expensive and metal-intensive measures were implemented to ensure the vertical movement of the sections of the installation columns during the extension process. For this, the sections of the mounting columns were designed with dimensions of 2.8 x 2.8 m in plan, and the supporting vertical conductor of each hydraulic lifting unit with a height of 10 m had a lower frame contour with dimensions of 16 x 16 m [3]. Also, when implementing this technology, it was mandatory to use overall safety equipment and a complex system of jacks that controlled the verticality of the lifting of the covering.

Based on the analysis of the organizational-technological and structural-technical features of the considered options for erecting long-span reinforced concrete vaults and metal structural-technological blocks of coatings, it is possible to form a general list of disadvantages and advantages of known technologies for lifting coatings using methods of raising design or assembly columns. The general disadvantages of the considered technologies are the small dimensions of the growing sections of the columns and a large number of installation operations related to the process of lifting the covering with support on the growing columns. Also, the disadvantages include the need to install bulky safety equipment with the use of hydraulic jacks that controlled the verticality of the column growth and the lifting of long-span coatings. The advantages include the tight anchoring of design columns in the foundations and the concentration of all processes for growing columns at low design marks. Under the condition of the minimum time required for the delivery of the column sections to the extension zone located on the foundations, the overall duration of the work on the erection of the coverings is significantly reduced. Areas of improvement are increasing the structural dimensions of the sections of mounting columns, increasing the working stroke of the rods of hydraulic lifts, and using design columns to ensure the verticality of the rising cover at the design height. The technology of crane-less lifting of the covering must take into account the requirements of today - the performance of construction and installation works in the conditions of dense industrial and civil buildings.

4 Results

Taking into account the disadvantages and advantages of the analyzed organizational-technological and structural-technical options for crane-less lifting of coatings, a new technology for erecting long-span coatings by the method of column raising was developed [8]. The general scheme of raising the mounting columns, the lifting module and the long-span covering that rises with support on the heads of the mounting columns are shown in Figure 4.

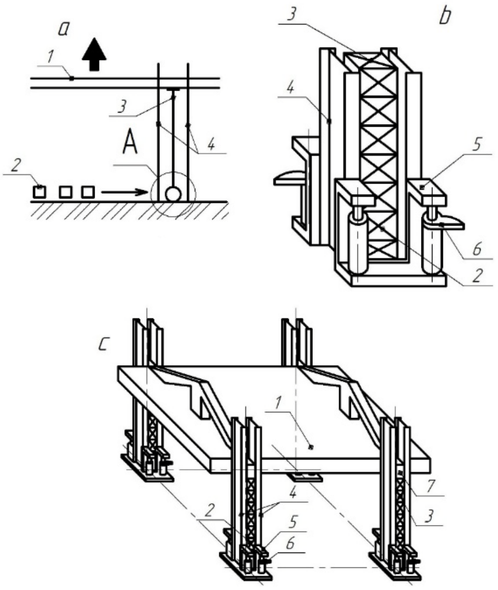

Figure 4. Lifting of the covering by the method of raising the mounting columns using vertical guides: a – the general scheme of raising the columns, b – step lifting module, c – the covering in the process of lifting, "A" – the area of raising the columns, 1 – covering, 2 – segments of the assembly columns, 3 – prefab elevated mounting column, 4 – vertical guide (one-piece design column), 5 – support frame of hydraulic lift, 6 – lifting lock, 7 – support crossbar of the covering.

According to the developed technological solution, the lifting of the covering to the designed height is performed by retracting the support beams of the structural and technological roofing block onto the heads of the lifting mounting columns. Sections of mounting columns are raised by lifting modules located on the foundations adjacent to the design columns. The extension of the mounting columns is performed in the space between the inner surfaces of the paired design columns. The mechanized technological equipment of lifting modules consists of hydraulic lifts, support frames, and lifting locks. The working stroke of hydraulic lift cylinders is 2.5 m, the carrying capacity of each hydraulic jack is 300 tons. The support frames of the lifting modules are attached to the rods of the hydraulic lifts. Lifting locks (fasteners) are fixed on the side surfaces of the design columns at a height that allows perceiving the load from the structures that are lifted by the support frame of the lifting module. The supporting beams of the coating are placed between the paired design columns in the process of enlarging the structural and technological block of the coating on low scaffolding. Under the condition of moving the support crossbars of the covering between the paired project columns, the internal drives of the project columns serve as guides for the roofing structure in the process of its vertical movement to the project height. The sequence of lifting the covering with support on the mounting columns, which are raised in the space between the design columns, is shown in Figure 5.

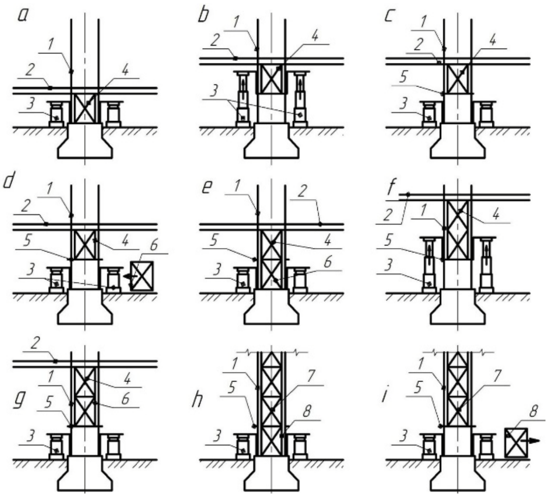

Figure 5. Lifting of the covering by the method of raising with support on mounting columns using project columns: 1 – project column; 2 – cover design; 3 – hydraulic lift; 4 – the head of the mounting column, 5 – lifting fasteners; 6 – the second section of the assembly column, 7 - the penultimate section of the assembly column; 8 – the lower /last/ section of the assembly column.

Leaning on the ends of the shafts of the lifts *3* and on the scaffolding, the bearing structure of the covering *2* is formed, roofing work and installation of technological roofing equipment is performed (Figure 5, a). After the completion of 100% of the installation work on the formation of a structural and technological block of covering on low scaffolding, the rods of the hydraulic lifts *3* push the heads of the mounting columns *4* to a height that is 100 mm higher than the height of the heads *4* (Figure 5, b). Into the space between the paired design columns *1* at the height mark of the lower face of the raised head of the mounting column *4*, the lifting locks *5* are pushed out, after which the rods of the hydraulic lifters *3* are lowered and the load from the heads of the mounting columns *4* and the structural and technological covering unit *2* is transferred to the lifting locks *5* (Figure 5, c). Released from the load, the rods of the hydraulic lifters *3* are returned to their initial position. After the rods of the hydraulic lifters *3* are completely lowered, the second section of the mounting column *6* is supplied into the space between the paired design columns *1* (Figure 5, d). The rods of the hydraulic lifters *3* push out the second section of the assembly column *6*. The process of lifting the second section of the mounting column *6* continues until the moment when the upper face of the lifting section reaches the height mark of the temporary fixing of the section *6* with the lifting fasteners *5* (Figure 5, e). When the rods of the hydraulic lifters *3* (50 mm) are further advanced, the load from the head of the mounting column *4* and the cover block *2* is transferred to the upper face of the second section of the growing mounting column *6*. This allows returning the lifting locks *5* to the initial position and performing the lifting of the second section of mounting column *6* with the rods of the hydraulic lifts *3* to a height similar to the height of the head of the mounting column *4* (Figure 5, f). By analogy with the head of the mounting column *4*, operations are performed to temporarily fix the raised second section of the mounting column *6* using the lifting lock *5* (Figure 5, g). Released from the load, the rods of the hydraulic lifters *3* are returned to their initial position. The cycle of supplying the sections of the mounting columns into the growing area is repeated until the final lifting of the coating *2* to the design height. After fastening the cover *2* on the heads of the design columns *1*, the sections of the growing mounting columns are dismantled. Sections are dismantled in the reverse sequence of the growing process. In the initial phase of disassembly, the rods of the hydraulic lifters *3* lower the last raised section of the mounting column *8* to the height mark at which the lifting lock takes the load from the penultimate section of the mounting column *7* and the upper sections of the mounting column (Figure 5, h). Then the rods of the hydraulic lifters *3* lower the lower section of the mounting column *8* onto the foundations. The dismantled lower section of the mounting column *8* is removed from the assembly area (Figure 5, i). According to calculations, under the condition of manufacturing sections of mounting columns, which are growing, with a height of 2 m, the lifting of the structural and technological covering unit weighing 1,200 tons to a height of 34 m with the help of the developed lifting modules can be performed in 1.8-2.0 shifts. At the same time, the number of operations required to increase assembly sections is significantly reduced. The volume of climbing works when using the developed mechanized technical equipment is reduced to operations for fixing the raised coating on the heads of the design columns. There is also no need to install safety equipment with additional hydraulic lifts, controlling the verticality of the rising surface. The function of covering control during the lifting process is performed by paired design columns. The support bars of the coating rise in the inter-columnar space of the design columns, resting on the heads of the growing mounting columns.

5 Discussion

The developed mechanized technical equipment allows the use of lifting modules when erecting long-span structural and technological roofing blocks in the conditions of dense industrial buildings. At the same time, the dimensions of the construction site, which are necessary for consolidation of the covering blocks on low scaffolding and the subsequent lifting of the covering to the design height, do not exceed the dimensions of the rising covering.

The proposed technology of raising mounting columns with the help of lifting modules makes it possible to replace damaged reinforced concrete long-span vaults. With the adaptation of mechanized technical lifting equipment, which includes lifting modules and lifting fasteners to the structural profile of the supporting columns, new reinforced concrete vaults are made on low scaffolding and then raised to the level of the heads of the supporting design columns with support on the mounting extension columns.

In the case of further steaming of the lifting modules, the mechanized technical equipment of which is located at the level of the foundations adjacent to the project columns, the lifting height of the structural and technological blocks of the covering can be greater than 34 m. The main emphasis in further scientific developments is made on increasing the load-bearing characteristics of project columns.

The developed technology of crane-less lifting, provided that the lifting structures are retracted onto the lifting mounting columns, can be applied to lift large and heavy technological equipment in heavy machinery workshops, where it is technically impossible to use traditional crane technologies.

The mechanized technical equipment of the lifting modules, when further developed, can be used to move large and heavy blocks of technological equipment and engineering communications in the vertical plane, provided that a supporting frame is developed for the future support of the technological blocks rising on mounting extension columns.

6 Conclusion

1. Based on the analysis of known solutions for crane-less lifting of long-span coating using the column growing method, a new method of crane-less lifting was developed. According to the new method, the structural and technological unit of the coating is assembled during the assembly of foundations, design columns and intercolumn connections. The roof structure is assembled on low scaffolding. Assembly of foundations, columns and assembling of roofing units is made using crane methods. Further lifting of the structural and technological roofing

unit to the design height is achieved by supporting the mounting columns. The mounting columns are raised by hydraulic jacks located on the foundations. The mounting columns are grown between twin projection columns. The projection columns ensure the verticality of the roof lifting and the growing of the mounting columns. After fixing the roof at the design height, the mounting columns are dismantled.
2. The number of processes using assemblers during the lifting of the roof has been reduced to work on fixing the roof structure in the final step of fixing the coating to the design height. All the processes of growing up the mounting columns are automated.
3. Promising directions for the use of the new method of column growing have been identified, namely the lifting of large-sized and heavy technological equipment in the spaces of production halls, when the use of cranes is technically impossible, and the lifting of structural and technological roof blocks of 100% readiness to heights exceeding 34 m using reinforced structures of the supporting column frame.

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