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Development of structural and technological solutions for the construction of large-span coatings by craneless methods

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Abstract: The article presents an analysis of the method of lifting large-span coatings using the pushing and pulling methods and introduces a new structural-technological solution for erecting coatings using mechanized technological equipment in the form of a lifting module. According to the solution, the load-bearing beams of the coating are moved in the space between paired columns of the frame, resting on the lifting modules. Guide profiles fixed to the inner surfaces of the columns serve as supports for the alternating support of the platforms of the lifting module, which pushes the coating beams in the inter-column space. The developed solution optimizes the lifting processes and reduces the duration of lifting works by minimizing the number of installations works to operations for fixing the beams of the coating at the design height and automating the processes of pushing the coating with lifting modules.
Keywords: *Erection of large-span coatings, Lifting modules, Load-bearing frame, Mechanized process equipment, Pulling and pushing methods.*

1. Introduction

Modern organizational and technological options for erecting large-span coatings involve two successive stages of installation work. At the first stage, structural and technological blocks of coverings are formed on low scaffolding (height up to 2 m) and elements of the supporting framework (columns and inter-column connections) are formed using traditional crane technologies using the method of free lifting [1]. At the second stage of installation works with the use of craneless technologies, by methods of pulling or pushing [2] long-span coatings are raised on the design height. Forced vertical movement of coatings is performed by the pulling method or the pushing method [3] using mechanized technological equipment in the form of lifting modules [4]. For both variants of forced lifting of coatings, technological stops were mandatory, which are associated with the formation of intermediate height assembly platforms [5]. Also, the discreteness of the lifting process was influenced by the operations of mounting (dismantling) of lifting equipment structural components [6]. Optimization of technological solutions for the erection of coatings using lifting modules due to the reduction of labor intensity and duration of installation work is an urgent task.

2. Materials and Methodology

2.1. Literature Review

The results of the study of organizational and technological options for the construction of long-span reinforced concrete and metal coatings are reflected in the scientific works of Ukrainian and

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foreign scientists. Among Ukrainian scientists, L. A. Kolesnik [7], V. F. Nazarenko [8], H.S. Nizhnikovsky [9], O.F. Osipov [10], P. G. Reznychenko [11], V. P. Rashkivskyi [12], N. P.Sytnik [8], Y.T. Sobko [13], H.M. Tonkacheev [2], V.I. Torkatiuk [14], P.P. Fedorenko [6], V.K. Chernenko [15], K.V. Chernenko [16], V.I. Shvidenko [1], A.A. Shkromada [6] made the greatest contribution to the development of technologies for the construction of structural and technological blocks of coatings using mechanized technological equipment in the form of lifting modules. Among foreign scientists, H. Engel [17], K. Fliger [18], L. Rowinski [18], E. Kühn [19], H. Rühle [19], G. Orlik [20], J. Ziólko [20] made a great contribution to the development of scientific and theoretical solutions for the construction of long-span coatings of industrial and civil facilities.

2.2. The Purpose of the Work

Based on the analysis of the advantages and disadvantages of known options for erecting long-span coatings by pulling or pushing methods [21], it is necessary to develop a solution using mechanized technological equipment represented by lifting modules. According to the developed technology, the lifting modules push out the support bars of the covering structures in the space between the paired columns of the supporting frame. In the process of vertical movement, the lifting modules rest on the guide profiles, which are fixed on the inner surfaces of the paired columns. The use of the developed mechanized technological equipment will allow optimizing the mounting processes for the erection of coatings by significantly reducing the number of mounting operations and reducing the duration of lifting the coatings to the design height.

2.3. Presentation of Technology Analysis of Known Technological Solutions

Research on the organizational and technological features of erecting metal coatings using craneless methods was carried out on the example of objects built in Ukraine [22]. The technological processes used in the construction of coatings had common features. In particular, in each case, at the first stage of installation work, the covering structure was assembled on low scaffolding by the method of free lifting with the use of cranes. At the next stage, the construction of the long-span covering was carried out by the pulling method or the pushing method using hydraulic lifts.

The technology of craneless lifting of a long-span covering by the pull-up method with the arrangement of hydraulic lifts at the ends of the supporting columns of the frame was used during the construction of the workshops of the aircraft factory in the city of Gostomel, Ukraine [8]. The lifting of two roofing blocks (total area 40,000 m^2, block sizes 96x48 and 96x54 m, block weight up to 1200 tons) to a height of 34 m was completed in 10 shifts. As supporting structures for the hydraulic lift of the pulling type, the columns of the supporting frame with intermediate tables were used for temporary support of the covering block in the process of moving it to the design height. The hydraulic lifting module PSH-330 pulling type consisted of two hydraulic jacks GD-170 (load capacity 170 tons each, the length of the working stroke of the jack rod 1120 mm), two safety screws, under-jack and over-jack beams, an all-welded shuttle belt (length 12 m), which is connected in the lower end with a traction tape (600x40mm in cross-section). The traction belt is hingedly attached to the beam of the lifting surface [6]. The process of lifting the covering by the pulling method and lifting cover crossbar fixation unit are shown in Figure 1.

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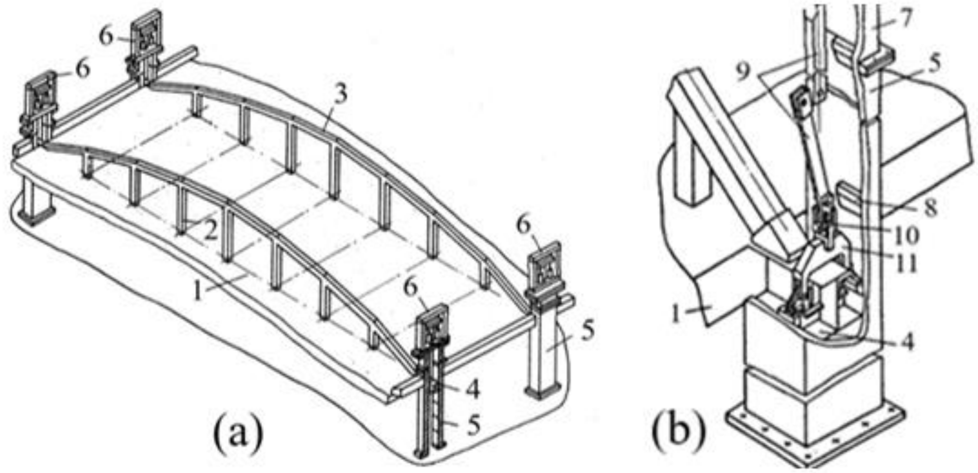

Figure 1.
Lifting of a long-span coating by the pulling method:
(a) – coating in the process of lifting, (b) – fixing unit of the supporting bolt of the lifting coating,
1 – block of coating, 2 – rack of the coating truss, 3 – upper belt of the coating truss,
4 – supporting crossbar of the coating, 5 – supporting frame column, 6 – lifting module PSH-330,
7 – lift support, 8 – intermediate lifting stop, 9 – traction belt,
10 – transition link of traction belt, 11 – slinging traverse.

The process of each block lifting consisted of six repeated cycles. Each cycle included two consecutive stages - lifting the covering block by 6m and intermediate resting of the covering on the support tables of the columns. In each lifting cycle, the coating was pulled up to a height of 1 m, which corresponded to the course of the jack rods and the pitch of the holes in the traction belt. During the lifting of the covering in the space between the columns, the lattice elements were dismantled in a section 6 m high, followed by the mounting of the lattices after the lifting of the covering crossbar. The disadvantages of the analyzed solution include stops related to the dismantling of inter-column lattices before lifting the support crossbar of the coating and the subsequent mounting of the lattices, the dismantling of the 6m long traction belt links and the temporary resting of the coating support beams on the support tables after each stage of lifting to the corresponding 6m, the installation of intermediate height assembly platforms on columns for mounting and dismantling of inter-column lattices, complex dismantling of the PSH-330 pulling type hydraulic lift at a height of 34-36 m after the completion of lifting operations with the involvement of high-capacity crane. The advantages of the analyzed solution include the formation of a rigid transverse frame from load-bearing columns and inter-column beams, control of the verticality of the coating lifting process, which was provided by the movement of the support crossbars of the coating block between the paired support columns.

A typical example of the use of the method of pushing out the rising cover with the support of the crossbars on the heads of the extension shafts of the elevators is the construction of the hangar cover measuring 144 x 275 m at the aircraft factory in Kyiv, Ukraine [6]. The covering with an area of 39,600 m^2 and a mass of 1,100 tons was raised to a height of 24 m in 12 shifts. The extension of shafts of the lifts was carried out with the help of hydraulic lifting module PG-300 [2]. The option of lifting the coating by the push-out method with support on the heads of the extension shafts of the lifts is shown in Figure 2.

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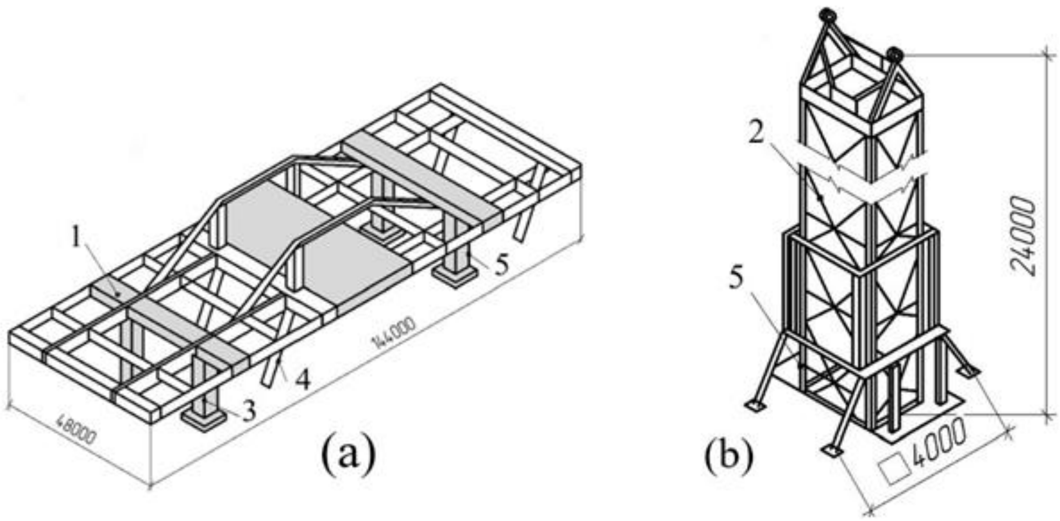

Figure 2.
Lifting of the coating by the push-out method with the support of the coating bolts on the heads of the extension shafts of the lifts:
(a) – long-span coating in the process of lifting, (b) – lifting module PG-300,
1 – coating, 2 – segments of the lift shaft, 3 – extended shaft of the lift,
4 – complete design column, 5 – hydraulic jacks.

Sections of the lift shafts were used as the extension columns, which were supplied into the extension zone between the hydrolift bodies and the support frames. The crossbars of the covering rested on the heads of the extension shafts of the elevators. Solid design columns of the building were attached to the lower surface of the supporting crossbars of the covering during the period of consolidation of the long-span covering block on low scaffolding (height 2.0m). As the shafts 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 mounting work, the load from the supporting crossbars of the covering was transferred to the heads of the design columns. After that, the shafts of the elevators and the structure of the PG-300 hydraulic lifting module were dismantled. 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 points of individual covering blocks. The disadvantages of the technology under consideration include the difficulty of placing the covering blocks on the tops of the columns and the significant labor intensity of the mounting processes at a height of 24m, associated with the joining of the raised covering blocks. The scheme of resting the extension shafts of the elevators on the foundations can be classified as "hinged". In this regard, expensive and metal-intensive measures were implemented to ensure the vertical movement of the sections of the mounting columns during the raising process. For this purpose, 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 10-m-high hydraulic lifting unit had a lower frame contour with dimensions of 16 x 16 m. Also, when implementing this technology, it was mandatory to use overall safety equipment and a complex system of jacks, which controlled the verticality of the covering lifting. The advantages of the considered version of lifting the coating by the push-out method include the absence of intermediate height mounting platforms in the process of vertical movement of the coating crossbars. The entire process of raising the coating was concentrated on the foundations. In the work at a height of 24 m, the installers were involved only in the final phase of the process of erecting the covering, namely, when fixing the heads of the design columns to the lower faces of the covering crossbars and final fastening of individual segments of the roofing structure.

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3. Results and Discussion

The advantages of the considered options for lifting long-span coatings were taken into account when developing a new technological solution. So, from the option of lifting the covering by the pulling method, control of the verticality of the covering being lifted was used. The deviations of the supporting crossbars from the vertical axis were leveled out by the inner surfaces of the paired columns, between which the covering crossbars were pulled up. Among the advantages of the option of lifting the covering by the push-out method, the principle of moving the support crossbars of the covering to the design height without arranging intermediate mounting platforms was used.

According to the developed technology, mechanized technological equipment in the form of a lifting module is placed between paired columns of the supporting frame. Guide profiles are attached to the inner surfaces of the paired columns. Before lifting at the level of the assembly scaffolding (height up to 2 m), the support crossbars of the structural and technological block of the covering rest on the upper platform of the lifting module.

In the process of pushing out the covering crossbars to the design height, the lifting module rests with the lifting latches on the guide profiles. The general appearance of the covering in the process of being pushed out on the design height and the lifting module are shown in Figure 3.

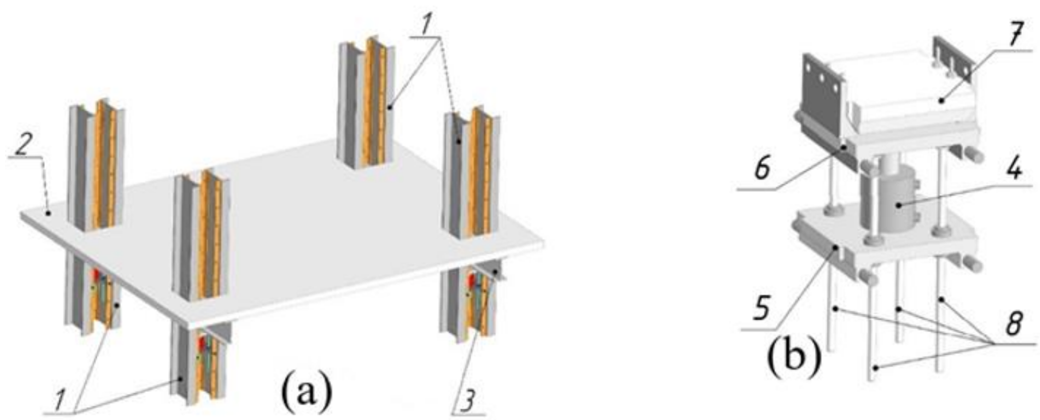

Figure 3.
Construction of the covering by a lifting module located between paired columns:
(a) – general view of the covering during the lifting process; (b) – lifting module:
1 – column of the frame, 2 – cover, 3 – supporting crossbar of the cover, 4 – hydraulic cylinder,
5 – lower platform of the module, 6 – upper platform of the module,
7 – supporting frame; 8- locking rods.

The lifting module consists of a double-acting hydraulic cylinder, lower and upper platforms, and safety rods. The hydraulic cylinder body is fixed on the lower platform of the module. The rod of the hydraulic cylinder is attached to the upper platform of the module. In the upper and lower platforms of the module, lifting fixing mechanisms with extendable support cylinders are installed. The locking rods are attached to the upper platform of the module and pass-through sliding nuts that are fixed to the lower platform of the module. A support frame is placed on the upper platform of the lifting module. Before lifting, the support crossbars of the covering are placed on the support frame.

The working cycle of the lifting module consists of three consecutive stages.

The pre-lifting stage – the support cylinders of the mechanisms for fixing the lifting of the lower platform of the module are inserted into the holes in the guide profiles. Rods of hydraulic cylinders of the module are located in the housings of hydraulic cylinders.

The lifting stage - under the condition of receiving the load from the support frame and covering crossbars with support cylinders of the fixing mechanisms for lifting the lower platform of the module,

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the working fluid is supplied into the hydraulic cylinder housings. The rods of the hydraulic cylinders push the upper platform of the module, the supporting frame and the crossbar of the covering to the height "h", which is equal to the length of the working stroke of the rods of the hydraulic cylinders.

The post-lifting stage – the supporting cylinders of the fixing mechanisms of the upper platform of the module are moved into the holes in the guide profiles. Thus, the load from the lifting cover is transferred from the mechanisms for fixing the lift of the lower platform of the module to the mechanisms for fixing the lift of the upper platform of the module. Released from the load, the support cylinders of the fixing mechanisms for lifting the lower platform can be moved from the holes in the guide profiles. When the liquid is supplied to the hydraulic cylinder body, the lower platform of the module is pulled up to the upper platform of the module to the height "h".

In the lifting and post-lifting phases, locking rods are also used, which control the spatial position of the lower platform of the module during its vertical movement. The main stages of the working cycle of the lifting module are shown in Figure 4.

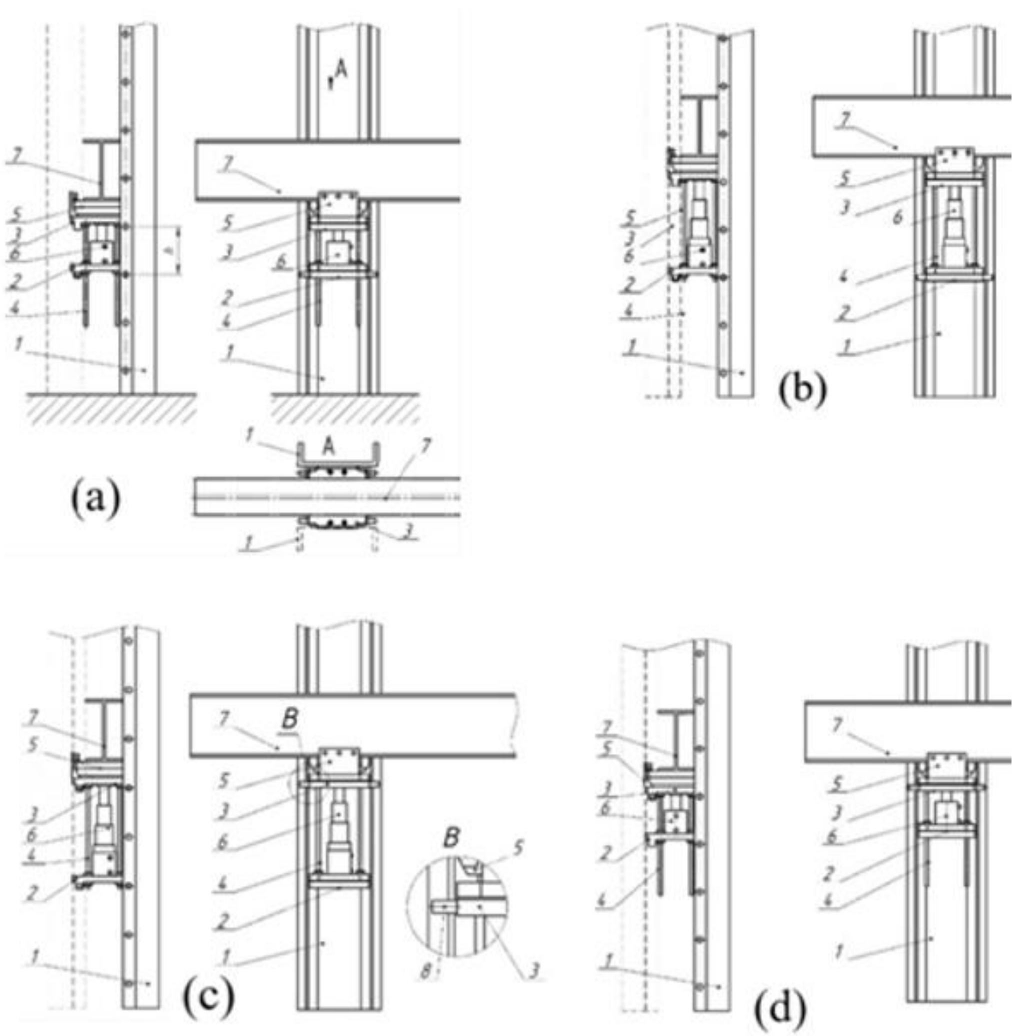

Figure 4.
The main stages of the working cycle of the lifting module:
a – fixation of the lower platform in the guide profiles, b – lifting of the upper platform;
c – fixation of the upper platform in the guide profiles, d – lifting of the lower platform;
1-column; 2-lower platform of the module; 3- the upper platform of the module; 4-locking rods;

5-support frame; 6 hydraulic cylinders; 7-support crossbar of the coating;
8-support cylinder of the fixing mechanism for lifting the upper platform of the module.

The technological process of erecting the covering by the method of pushing out lifting modules, which move between paired columns, consists of three stages.

Pre-lifting stage. With the use of car cranes on the construction site, a transverse support frame is formed from paired columns and inter-column connections, and the covering is consolidated on low scaffolding. Precast monolithic columnar foundations are implied to support the columns. Installation of columns on foundations involves the following operations. First, prefabricated foundation slabs with bolted fasteners for columns are mounted in the foundation pit. Then paired columns with guide profiles are installed on the foundation slabs and the "Foundation – column" joint is fixed with bolts. Next, simultaneously with the mounting of inter-column connections and the formation of the cover block, a 1200 mm high reinforcement frame is formed on the foundation slabs along the outer contour of the columns and in the inter-column space, the formwork is erected and the columnar part of the foundation is poured with concrete. In the intercolumnar space, lifting modules are placed on columnar foundations. In the pre-lifting position, the supporting cylinders of the mechanism for fixing the lifting of the lower platform of the module are inserted into the holes in the guide profiles. On the upper platform of the module, the support frame and the supporting crossbar of the roof structure are placed. On low scaffolding, 100% of the work is carried out on consolidation of the structural and technological large-span covering block and the formation of vapor-, heat- and waterproof roofing layers.

Lifting stage. The movement of support frames and support crossbars of the covering to the design height is carried out by lifting modules. In the process of lifting, two operations are cyclically repeated:

- Fixation of the lower platform of the lifting module on the guide profiles of the columns and pushing out the upper platform of the module with the supporting frame and the load-bearing crossbar of the covering with a double-action hydraulic cylinder to a height equal to the length of the working stroke of the hydraulic cylinder rod;
- Fixing the upper platform of the lifting module on the guide profiles of the columns and lifting the lower platform of the module with a double-action hydraulic cylinder to a height equivalent to the length of the working stroke of the hydraulic cylinder rod.

The process of lifting the covering using the developed mechanized technological equipment is fully automated. Control of operations for moving lifting modules and covering structures is carried out by operators who are outside the area of mounting works using video surveillance and fixation devices, which are installed on the columns, upper and lower platforms of the lifting module and on the supporting crossbars of the rising covering. After the load-bearing crossbars have reached the design height of the covering, the supporting frame is fastened to the heads of the paired columns.

Post-lifting stage. The lifting modules, released from the load, are moved to the foundations. In the process of lowering, two operations are cyclically repeated:

- Fixation of the upper platform of the lifting module on the guide profiles of the columns and downward movement of the housing of the lower platform of the module and the housing of the hydraulic cylinder
- Fixation of the lower platform of the lifting module on the guide profiles of the columns and moving down the rod of the hydraulic cylinder and the upper platform of the module.

After lowering the lifting module onto the foundation, the module is dismantled.

According to the developed technology, the installers are involved only in height operations for fixing the support frames of the support crossbars of the covering block at the design height between the heads of the paired columns. The introduction of automated technology for the erection of long-span coverings using lifting modules, which push out the support crossbars of the coatings in the space between paired columns, allows reducing the labor intensity of the lifting processes significantly and shortening the overall period of mounting work.

4. Conclusion

On the base of analysis of known solutions for crane-free lifting of long-span coverings by pushing and pulling methods, a technological solution was developed, according to which, at the first assembly and technological stage, a load-bearing transverse frame was formed from design columns, inter-column beams and connections, and it was performed by consolidating the coatings in structural technological unit on low scaffolding (height up to 2 m). Further lifting of the support crossbars of the covering block was carried out by resting on the lifting modules, the movement of which took place in the space between the columns using guide profiles fixed on the inner surfaces of the paired columns.

The processes of vertical movement of the covering from the level of the foundations to the heads of the columns using the lifting module are fully automated; installers are involved only in high-altitude operations for fixing the support frames of the support crossbars of the structural-technological unit of the covering between the heads of the frame columns.

The developed lifting modules interacting with the guide profiles fixed on the inner surfaces of the paired columns can find their use when lifting large-sized and heavy technological equipment in the spaces of production workshops, when it is impossible to use classic crane technologies by the method of free lifting for mounting of structures at the design height, and also, when moving structural and technological long-span roofing blocks weighing 1,200-2,400 tons to a height of more than 34 m.

References

[1] Shvidenko, V.I., Assembly of building constructions. Moscow: Vysshaja shkola, 1987.
[2] Chernenko, V.K., Osypov, O.F., Tonkacheiev, H.M., Romanushko, Ye.H., Technology of installation of building structures. Kyiv: Horobets, 2011.
[3] Ignatenko, O.O., Glushchenko, I.V., Development of coating erection technology with used of hydraulic lifting equipment. Industrial Construction and Engineering Structure, 1, 26-27,1992.
[4] Chernenko, V. K., Sobko, Yu. T., Research of the main technological indicators influencing crane-less methods of lifting of structural coverings. New Technologies in Construction, 31, 50-58, 2016.
[5] Chernenko, K.V., History, current state and perspective of construction building and structures with large-sized coatings. Construction Technique. 27, 36-41, 2011.
[6] Fedorenko, P.P., Shkromada, A.A., Industrial Construction Methods for Industrial Plant. Kyiv: Budivelnik, 1988.
[7] Kolesnik, L.A., Shnajder, A.I., Chernenko, V.K., Large-block assembly of building structures. Kyiv: Budivelnik, 1990.
[8] Nazarenko, V.F., Sytnik, N.P., Nikolaev, V.V., Hydraulic lifting installations on mounting of large-span structures. Installation and Special Works in Construction, 5, 15-20, 1986.
[9] Nizhnikovsky, G.S., Gurevich, E.I., Landa, S.L., Large-block assembly of industrial buildings and structures. Kyiv: Budivelnik, 1979.
[10] Osipov, O.F., Chernenko, K.V., Information model of the process of lifting long span roof. Sc Innov, 16 (4), 3-10, 2020, https://doi.org/10.15407/scine16.04.003
[11] Nizhnikovsky, G.S., Reznichenko, P.G., Metal structure assembly technology. Kyiv: Vyshchia shkola, 1981.
[12] Rashkivskyi, V.P., Chernenko K.V., Technological features of installation of Large-block coatings by the method of vertical ejection. Abstracts of the scientific conference of young scientists, graduate students, and students. 76, KNUCA, 2012.
[13] Novak, Ye.V., Sobko, Yu. T., Research of methods of raising large-scale structural coverings of one-story industrial buildings. Modern Technologies and Methods of Calculations in Construction, 3, 157-162, 2015
[14] Torkatiuk, V.I., Structural assembly of large-span buildings. Moscow: Strojizdat, 1985.
[15] Chernenko, V.K., Chernenko, K.V., Analysis of conditions and principles of formation of methods of assembling of large-sized structures in the working area. Bulletin of the Donbass National Academy of Construction and Architecture, 5(85), (2), 291-297, 2010.
[16] Chernenko, K.V., Hluschenko, Y.V., Analysis and classification of lifting technology of large-size structures of lifting by hydraulic lifting devices. Ways to improve the efficiency of construction in the formation of market relations. KNUCA. Kyiv, 24, (1), 69-80, 2011.
[17] Engel, H., TPG Systeme. Verlag Gerd Hatje. Moscow: Astel, 2007.
[18] Fligier, K., Rowinski, L., Montaz zintegrowanych konstrukcji budowlanych. Warszawa: Pansnwowe wydawnictwo naukowe, 1977.

[19] Rühle, H., Kühn, E., Weissbach, K., Priestorové strešné konštrukcie. Bratislava: Vydavateľstvo ALFA, 1978.
[20] Ziólko, J., Orlik, G., Montaž konstrukcjí stalowych. Warszawa: Arcady, 1980.
[21] Chernenko, V.K., Methods of Building Structure Installation. Kyiv: Budivelnik, 1982.
[22] Chernenko, K.V., Determination of organizational and technological solutions of methods assembling of large-size coatings. Construction and Technogenic Safety, 44,70-77, 2012.

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