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Features and perspectives of automatized construction crane-manipulators

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Abstract. Modern construction industry still has a high percentage of manual labor, and the greatest prospects of improving the construction process are lying in the field of automatization. In this article automatized construction manipulator-cranes are being studied in order to achieve the most rational design scheme. This is done through formulating a list of general conditions necessary for such cranes and a set of specialized kinematical conditions. A variety of kinematical schemes is evaluated via these conditions, and some are taken for further dynamical analisys. The comparative dynamical analisys of taken schemes was made and the most rational scheme was defined. Therefore a basis for a more complex and practical research of manipulator-cranes design is given and ways to implement them on practical level can now be calculated properly. Also, the perspectives of implementation of automated control systems and informational networks on construction sites in order to boost the quality of construction works, safety of labour and ecological safety are shown.

1. Introduction

Modern construction industry is highly mechanized, however, it is still has a high percentage of manual labor, due to the limited possibilities for the further mechanization in many kinds of construction works.

The greatest prospects of increasing the speed of construction and raising the quality of work are lying in the field of automatization and robotization of construction. Such trends can be seen for a while now [1]. Significant progress has been made in recent years in computing, electric drives, control systems, batteries and other, important for robotics, fields of science and technology. Reducing of the costs and expansion of the possibilities of robotic systems allows to consider the possibility of their practical application and implementation in the construction process. In addition to improving the speed and quality of work, which is a direct challenge for robots, other positive effects of their implementation are even more important, related primarily to the increasing of safety of human labor.

Automatized construction manipulator-cranes, or ACM-cranes, are seem to be the most perspective way to improve construction processes [2, 3]. Design of modern cranes haven’t changed for decades, and this design has a number of problems – high percentage of human labour, insufficient positioning quality, poor observing conditions for operator and a number of human safety issues, linked with these problems. But ACM-cranes can solve this problems, reducing the amount of human labour, increasing the quality of work and it’s safety, including ecological safety through better optimization of work and lower emission levels [4].

Also, ACM-cranes are fitting well with automated control systems (ACS), which, in turn, can be united into single network, improving safety and quality of construction processes even further.

At the same time it is clear that the use of ACM-cranes has some features associated with specific requirements for robots [5, 6]. And the most important problem, that has to be solved before their implementation is their rational design scheme. The objective of the current study was to find out and validate some specific construction scheme for ACM-cranes.

2. Materials and methods

In order to formulate an ACM-crane design features, several steps of research were made:

First of all, there are some general features, essential for ACM-cranes. These features are clearly seen from analysis of working processes and construction site conditions [7], but they had to be formulated in order to be used in further work.

Secondly, the most rational kinematic scheme had to be found. With the set of already formulated general conditions, with an addition of some specialized conditions for kinematic analysis, certain general kinematic schemes were taken for a deeper analysis.

The analysis consisted of two parts. In the first part, a set of different kinematical schemes was evaluated with Lee-Young theorem [8]. This theorem states [9]:

$$K = \frac{V}{\left(\sum_{i=1}^{m} L_i\right)^3} \tag{1}$$

where K – is the kinematic quality of construction, bigger number means that the construction is better optimized; V – is the volume of the working area of the robot; L_i – is the length of i-th link of the robot; m – is the amount of links.

The second part of the analysis used the kinematical schemes with the most kinematic quality for relative dynamical analysis. All studied schemes were remade as a simplified 3d models, with certain conditions:

- Equality of working zone volumes
- Equality of overall model mass
- Equality of payload capacities, speeds and velocities

The characteristics were taken equal to those of tower crane KB-403B. Loading conditions for models with horizontal boom were simultaneous lifting of payload and turning of the crane around its vertical axis. For models with jointed boom – simultaneous extension of the boom and turning of the crane around its vertical axis. The time length of modeling was 60 seconds.

The analysis itself was performed in Dassault Systemes Simulia Abaqus CAE 2016. Four types of parameters were taken:

- Stress level, measured by Mises
- Maximum vibration amplitudes
- Maximum linear velocity amplitudes
- Maximum angular velocity amplitudes

This parameter was used to create six sets of data for crucial points of construction. The gathered data was then used to build an approximation graphs in MS Excel. The approximation functions were found via MS Excel, with the following limitations:

- Equation degree should be less or equal to 3
- Approximation coefficient R^2 should be bigger than 0,9

This functions were used to achieve average comparative values C^{av} for each analyzed type of construction. These values were an arithmetic mean (2) of two values – the maximum of approximation function F^{max} and the definite integral for t=60 seconds of approximation function I^t.

$$C^{av} = \frac{F^{max} + I^t}{2} \tag{2}$$

These two values were calculated (3,4) as arithmetic mean of six values for maximum and integral calculations respectively, turned in comparative scale, where the biggest result is taken as equal to 1, and all other results are taken proportionally.

$$F^{max} = \frac{\sum_{k=1}^{6} F_k^{max}}{F_{max}^{max} \times 6} \quad (3)$$

$$I^{t} = \frac{\sum_{k=1}^{6} I_k^{t}}{I_{max}^{t} \times 6} \quad (4)$$

And through these average comparative values the most rational scheme was found.

3. Results

General features, which are essential for ACM-cranes:

- High load capacity (more than 3 tons).
- Large volume of the working area (more than 10 meters in each dimension).
- Higher speed then of modern crane equipment, through the use of a rigid hand-capture instead of the cable suspension.
- The relatively high positioning accuracy, providing a very high quality of the geometry of structure being built, bringing the basic geometry errors to the errors of the materials used.
- Increased demands on the reliability and safety, because robotic manipulators, while reducing manual labor within the construction process, does not exclude it entirely.

With these general conditions formulated, several kinematic conditions were formulated:

- Kinematically rigid construction of crane
- The kinematic scheme should have the least possible amount of the simplest kinematical pairs.
- The kinematic scheme should have the least possible kinematical links.
- The kinematical scheme should allow the crane to work on all heights of the mounting horizon
- The output link should have the least possible mass

This set of conditions allows us to figure out the construction of ACM-crane, which would be rationally simple, but able to perform all the necessary tasks without unwelcomed limitations.

As a result of applying these conditions to a whole variety of different kinematical schemes, and their evaluation through the Lee-Young theorem, four different schemes were taken for further analysis, as shown on figure 1:

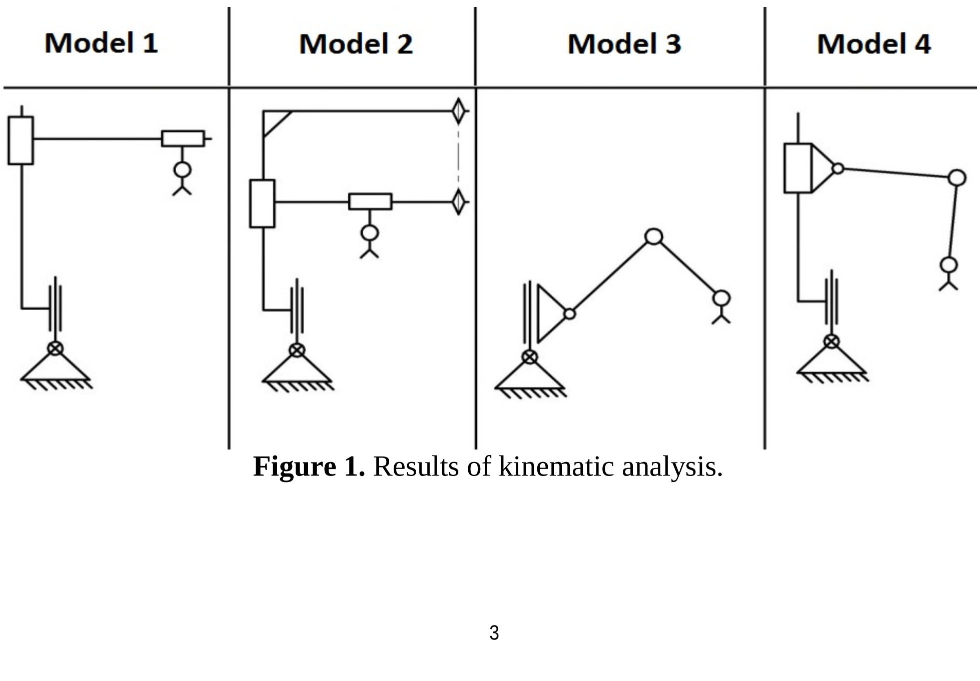

Figure 1. Results of kinematic analysis.

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The results of dynamical analysis data processing via the methods shown above can be seen on figure 2:

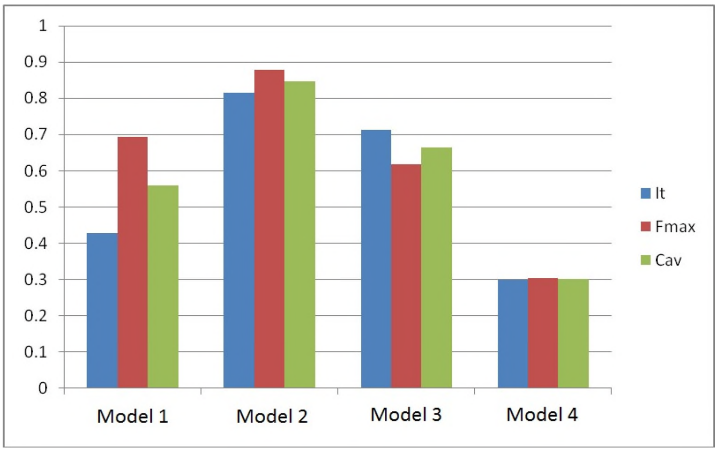

Figure 2. Results of dynamic analysis.

Smaller numbers mean smaller stresses and loads, and therefore it is clearly seen, that the model №4 (shown on figure 3) has the best results, and is the most rational for ACM-cranes.

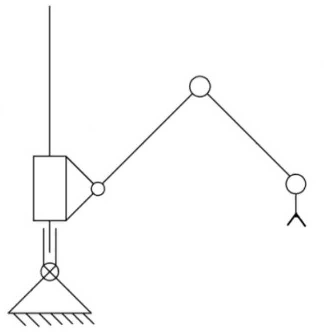

Figure 3. The principle scheme of ACM-crane.

4. Discussion

As the most rational design scheme for ACM-cranes was found, it is now possible to calculate more particular features of these machines in order to see their technical, economical, ecological and other properties. With such complete analysis, it would be possible to create and design such machines in practice and implement them on the construction site properly.

But also, these machines can become a perfect platform for first wide spread ACS, which would allow further improvement of construction process and conditions of work.

ACS of construction machines has a number of unique features. Firstly, it has rather low requirements for independence because of the large number of characteristic objects that are suitable for use as markers to help orient the robot. Secondly, the ACS should provide highly accurate and fast control of the robot drive. Third, because of the large dimensions of the building elements, ACS must be able to quickly and accurately calculate the overall dimensions, mounting dimensions and location of the mounting fixture on the building structure itself.

In addition, widespread usage of ACS opens the possibility of creating a full-fledged information network within the construction site. This network will allow improving the interaction between machines and workers, and the level of control over the safety measures and quality of work done.

However, ACS - is only the first step towards a full robotization of construction process. In perspective, the creation of a highly specialized form of artificial intelligence for the control of machines on a construction site seems most likely.

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The main difficulty of creating classic automated control systems for different machines and mechanisms at the site lies in the fact that, unlike the laboratory and even the factory floor, construction site - is the environment with unpredictably changing conditions. Here is the human factor, and weather conditions and constantly changing work places and diversity of types of work. Standard ACS can hardly bear such a variety of tasks.

But robots equipped with Artificial Intelligence are capable of more. Picture and sound recognizers, the ability to orient in an ever-changing space will allow the robots to work without danger for themselves and others working at the construction site. AI can operate with non-specialized instruments with universal grips, it can calculate how to properly and securely use them in the absence of hard-coded application program. AI can safely and efficiently interact with humans directly, which is very important in the conditions of the construction site. Creating of self-learning program module for such an agent would be relatively easier than writing a rigidly programmed ACS [10].

Over time, the AI self-learning module, in theory, will allow robots to perform their work more and more efficiently with the accumulation of information and education. Creation of the network between agents will allow them to co-educate, speeding up the process of self-improving. This self-learning can lead to the appearance of heuristic properties of the AI, which will allow him to look for new, non-trivial solutions of tasks [11, 12].

5. Conclusions

The results of this research are giving a basis for a full scale design of ACM-cranes. This will require more specific technical analysis, especially in its drive systems, and an overall economical observation of project, but now these studies can be made on a rationalized basis. Also, more research on the creating of the ACS for such cranes is needed, for broadening the possibilities and boosting the characteristics of such machines – and construction machines in general.

Practical implementation of such machines can greatly improve quality and especially safety of construction process, as well as it’s ecological aspect through better optimization of different construction works and lowering of emission levels. And now the conditions of this implementation can be calculated properly.

In wider perspective, progress in the field of AI research will lead to a further improvement of construction process via self-educating and creation of organized machine network on the construction site.

References

[1] Romashko A M 2014 *Lift Transport. Eng.* **3-4** 24-9.
[2] Vil’man U A and Stepanov M A 2006 *Mech. Constr.* **1** 3-8.
[3] Stepanov M A and Hartenstein K 2012 *Lift Transport. Eng.* **4** 2-5.
[4] Vil’man U A 1989 *Basics of robotization in construction* High School.
[5] Bulgakov A G et al. 2006 *Automatization of construction* Novochercassk: URGTU
[6] Bulgakov A G, Vorobiev A V, Evtushenko S I and Parshin D Ya 2013 *Automatization and robotization of construction industry: Textbook – 2-d ed.* Moscow: RIOR: INFRA-M.
[7] Stepanov M A and Ilukhin P A 2015 *Mech. Constr.* **10** 9-12.
[8] Stepanov M A and Ilukhin P A 2016 *Mech. Constr.* **11** 54-7.
[9] Shahinpoor M 1987 *A Robot Engineering Textbook* Harper&Row, Publishers, Inc.
[10] Stepanov M A and Ilukhin P A 2016 *Mech. Constr.* **11** 58-60.
[11] Bostrom N and Yudkowsky E 2011 *The Ethics of Artificial Intelligence* Cambridge University Press.
[12] Russell S and Norvig P 2009 *Artificial Intelligence: A Modern Approach* Pearson.