Abstract

of the dissertation on the topic:

"Development and design of machine mechanisms of layered pouring of reinforced concrete "

submitted for the degree of Doctor of Philosophy (PhD)
in the specialty 6D071200 – Mechanical Engineering
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Relevance of the Study. Additive manufacturing technologies in construction, including 3D concrete printing, are considered a new technology that can replace or be an alternative to traditional methods. For this purpose, the mechanical properties of 3D-printed concrete must be comparable to the mechanical characteristics of reinforced concrete produced through traditional construction methods. Consequently, 3D-printed concrete must be reinforced with standard steel rebar, as in conventional reinforced concrete. Currently, the most pressing task is reinforcing 3D-printed concrete with standard steel rebar. At present, this reinforcement is performed manually, which negatively impacts the automation of the construction process—a key advantage of additive technologies over traditional methods. To automate the reinforcement of 3D-printed concrete, a specialized mechanism is required to automate the creation of a rebar mesh directly during the printing process. At present, such a mechanism does not exist, indicating the need for its development, design, testing, and preparation for production.

Since the rheology of 3D-printed concrete differs from traditional liquid concrete, a challenge arises in integrating the rebar mesh created by an automated reinforcing mechanism. This challenge becomes more complex as the rebar mesh is produced during the 3D printing process; thus, only part of the rebar mesh should be embedded in the concrete, while the remaining part must remain dry to allow the next section of rebar to be welded. To achieve this, it is necessary to develop a specialized nozzle that can embed part of the rebar mesh into the concrete while keeping the other part dry.

The automated reinforcing mechanism and the specialized nozzle are considerably heavy for installation on portal, serial robots, and other robotic equipment that serve as construction 3D printers. Moreover, these types of construction 3D printers have stringent requirements for environmental conditions and cleanliness. Therefore, they often need to be isolated from adverse environmental conditions, which leads to additional costs. Currently, there is a global trend toward adapting construction equipment (such as concrete pump trucks, excavators, etc.) to work as construction 3D printers. Such adapted 3D printers have good load-bearing capacity, are resistant to dynamic loads, and are unaffected by harsh environmental conditions. However, they also have drawbacks, specifically insufficient precision in positioning the printing head along the specified trajectory. Deviation of the printing head from the designated trajectory hinders the 3D printing of concrete. To address this issue, an important task is to research and design an additional compensating mechanism between the final segment of the construction equipment's boom and the printing head.

The purpose of this work is to research, design, and develop an automated reinforcing mechanism for a machine that performs layered pouring of reinforced concrete, a specialized nozzle for integrating the rebar mesh into the concrete, and a compensating mechanism.

To achieve this goal, the following objectives have been set:

- to research and develop an automated reinforcing mechanism that creates a rebar mesh from standard steel reinforcement during 3D printing;
- to research and develop a specialized nozzle capable of embedding part of the rebar mesh into the concrete while leaving the remaining part dry for further rebar mesh creation;
- to research and develop a compensating mechanism to offset the deviation of the printing head from the specified trajectory, mounted on the final segment of the boom of construction equipment adapted to function as a construction 3D printer.

Research area – 3D printing technology in construction.

Object of the research – mechanisms of the machine for layered pouring of reinforced concrete.

Subject of the research – automated reinforcing mechanism, specialized nozzle, and compensating mechanism.

Theoretical and methodological basis of the research. The research employed direct and inverse kinematics problems, parametric modeling, optimization methods, computer simulation of mechanical effects based on finite element analysis, and other related approaches.

The empirical basis of the study consisted of the following experimental research: determining the compliance of the strength of the rebar mesh produced by the automated reinforcing mechanism with the requirements of DIN 488-4 standard; verifying the integration of the rebar mesh into the concrete by X-ray scanning of the 3D-printed sample, as well as visual inspection by making cross-sectional and longitudinal cuts of the sample perpendicular and parallel to the printing direction.

The scientific novelty of the study is defined by the following results:

- an automated reinforcing mechanism was designed, prototyped, and tested for automatically reinforcing 3D-printed concrete during the 3D printing process;
- to verify compliance with the DIN 488-4 standard for the strength of rebar mesh produced by the automated reinforcing mechanism, cross-shaped samples were shear-tested on a dynamometer;
- a specialized nozzle was designed, prototyped, and tested for integrating the rebar mesh into the concrete;
- the integration of the rebar mesh into the concrete was verified by X-ray scanning of the 3D-printed sample, as well as by visual inspection through cross-sectional and longitudinal cuts in the printing direction;
- to compensate for the deviation of the printing head from the specified trajectory when mounted on the final segment of the boom of construction equipment adapted as a construction 3D printer, several manipulators were analyzed through direct and inverse kinematics to determine their workspace;
- through a comparative analysis of manipulators based on multiple criteria, a Clavel delta robot was selected as a compensating mechanism, and its dynamic characteristics were determined via computer simulation.

Provisions for defense:

- development of a new mechanism for automating the creation of the rebar mesh during the 3D printing process;
- development of a method for integrating the rebar mesh into 3D-printed concrete using a new specialized nozzle during 3D printing;
- development of a methodology for compensating deviations in the movement trajectory of the printing head using a new compensating mechanism.

The contribution of the doctoral candidate to the preparation of publications. Based on the results of the dissertation research, 4 works reflecting the main findings of the study were published, including 1 article in journals indexed in the Scopus and Web of Science databases, 2 articles in publications recommended by the Committee for Quality Assurance of the Ministry of Science and Higher Education of the Republic of Kazakhstan, and 1 article in other scientific journals and publications.

Publications in journals indexed in the Scopus and Web of Science databases:

1. Azamat Mustafa, Florian Storch, Kairov Rustem, Paul Plashnik, Frank Will, Sagyntay Mukhagali, Zhumadil Baigunchekov, Volker Waurich, “Compensation Manipulator for Concrete 3D Printing Based on the CONPrint3D”, ES Materials and Manufacturing (SCOPUS, Процентиль: 97)

List of articles in publications recommended by the Committee for Quality Assurance of the Ministry of Science and Higher Education of the Republic of Kazakhstan:

1. Мұхағали Сағынтай, Азамат Мустафа, Ерік Нұғман. 3D баспаланған бетонды арматуралауға арналған аутоматты арматуралаушы механизм. Л.Н. Гумилев атындағы ЕҰУ хабаршысы. Техникалық ғылымдар және технология сериясы, № 4/2023 , Астана 2023.

2. Сағынтай М.Қ., Мустафа А.Қ., Акшулаков К.Ж. Әскери максаттағы құрылыс объектілерін салуға арналған құрылыс 3D принтері мен оның баспа бастиегінің тұжырымдамасы. Ұлттық қорғаныс университетінің Хабаршысы ғылыми-білім беру журналы, № 1 (100), Астана 2024.

3. Сағынтай М.Қ., Мустафа А.Қ., Аддитивті технологияда қолданылатын арматуралық сырықтардың дәнекерлеу кезіндегі қызуын зерттеу. «Қазақстан ғылымы мен техникасы» ғылыми журналы, № 3 (2024), Павлодар 2024

Articles published in other scientific journals and publications:

1. Сағынтай М., Байгунчеков Ж. Бетонды қабаттап құятын 3d принтерлердің конструкцияларын талдау // Engineering Journal of Satbayev University. – 2021. – Т. 143(1). – Б. 120–127. https://doi.org/10.51301/vest.su.2021.v143.i1.16

Structure and volume of the dissertation. The dissertation consists of an introduction, four chapters, a conclusion, and a list of references.