Influence of a 3D printer dynamic characteristics on building products printing accuracy

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Abstract. The results of studying the dynamics of a construction 3D printer of manipulator type are considered. The analysis of the relevance of the 3D printing in road construction use, comparison of the technology with traditional methods of concrete structures construction is carried out. The choice of the investigated device type has been substantiated. A brief description of the construction 3D printer device, its element base and operating principle, illustrations of the research object and graphic materials are given. Forming without formwork using sliding formwork is considered, the mixture is compacted by the vibrator of the installation. A model of a construction 3D printer has been developed, which makes it possible to study the dynamic processes of interaction of the sliding formwork of the installation with a concrete mixture during construction products 3D printing. The temporal values of vibrations of the construction 3D printer trolley have been determined. The graphs of the oscillatory process of 3D printing and the time dependences of the electric current in the starting and operating modes were obtained.

1. Introduction
The continuous and rapid development of new technologies for the construction work production by now allows and radically changes views on traditional, sometimes archaic methods of buildings and structures construction, and also eliminates a number of problems in the construction industry. At the moment, one of the most relevant methods is the use of additive technologies in modern 3D printing.

The use of additive technologies allows to print individual designs using a three-dimensional model without significant lead times and increase productivity by automating technological processes. A potential advantage of additive technologies is also a reduction in the use of formwork during concreting.

Currently, concrete structures are usually built using temporary formwork to maintain the desired shape of the wet concrete while the concrete hardens. Formwork and material account for 35 to 60% of the total cost of concreting structures [1, 2, 3]. Reducing the use of formwork not only reduces the amount of waste generated during construction (about 23% of the total waste in the country) [4, 5], but it also reduces the cost of construction. In additive technologies, three main types of construction 3D-printers are used: based on a robotic arm, as well as 3D printers of crane and portal types [6, 7, 8]. The most important disadvantage of portal-type printers is their weight and dimensions, and therefore their transportation and installation take a long time and the amount of effort for their operation. It is this advantage that manipulator and crane devices use, since they are more versatile, mobile and
compact. And, depending on the specific conditions, they can “print” the house both from the inside and outside, and, if necessary, can be easily relocated [9, 10].

The analysis of studies in the area under consideration showed an insufficiently studied issue of the behaviour of a construction 3D printer when it is exposed to loads of various natures directly in the production of structures and products. It is necessary to investigate the effect of the working mixture used when printing building structures and the impacting vibration loads on the suspension of the drive of a construction 3D printer.

Purpose of work: development of a method for printing accuracy of a construction 3D printer.

2. Methods and material
The main advantage of a construction 3D printer is its performance. It is a device that moves along the X, Y and Z axes, also known as Cartesian coordinates, linearly in three dimensions. To move along the given coordinates, the 3D printer has stepper motors with cylindrical gearboxes, which move with high precision and accuracy by 1.8 degrees per step.

The drives that the printer is equipped with move the print head precisely and quickly. These “three-dimensional” robots are controlled by the controller, as in all automated systems and thanks to this it is possible to move the print head, which squeezes out the concrete mixture, creating structures layer by layer. The range of motion of the actuators is limited by an optical or mechanical lock. In other words, they are simply limit sensors signalling to the printer that it is at the edge of the work surface in order to prevent it from escaping the work platforms. In turn, the latches allow you to adjust and calibrate the position of the printer before each start of the printing process, which allows you to print more accurately.

Figure 1 shows a model of a manipulator-type construction 3D printer. The main tasks of the research were to determine the dynamic characteristics of the oscillatory process of the printer trolley, the force interaction of the stepper motors with the printer equipment. These parameters were determined by varying the external load values and design solutions of the printer units.

The control system of the printer includes the following equipment: PID-controller (DAMP / GAIN) with the brush servo actuator driver BSA PLD2080s; piezoelectric vibration sensors DFR0052; current sensor ACS712. The vibration of the undercarriage was determined in order to determine its effect on the printing accuracy. The vibration of the 3D printer cart was measured with the engine idling and in print mode. The vibration sensor was attached to the main frame of the 3D printer.

The study of the dynamic processes of the formation of fiber-glass concrete structures was carried out when filling the hopper with fiber-glass concrete mixture, when the printer was moving with simultaneous vibration of the walls of the hopper and sliding formwork. The dynamic characteristics of the vibration forming process were determined: compressive strength of building products; vibration frequency of the vibrating bunker and sliding formwork walls; amplitude and frequency of vibrations of glass fiber concrete mixture.

Figure 1. 3D printer construction of manipulator type: 1 - chassis; 2 - bunker; 3 - vibrator; 4 - guide tray; 5 - frame; 6 - control system.
3. Results
The parameters determined during the experiments are shown in table 1.

| Parameters                                      | Equipment             | Research object          |
|-------------------------------------------------|-----------------------|--------------------------|
| Frequency and amplitude of the bunker wall’s    | Analog Devices c USB  | Construction 3D Printer  |
| vibrations, Hz                                  |                       |                          |
| Density of glass fiber concrete mixture, kg/m³  | BA - 2 the same       |                          |
| Mass of GRC components, kg                      | Weighing apparatus the same |
| Compressive strength, MPa                       | Press Building product |

The time dependence of the vibration acceleration of the construction 3D printer trolley frame was obtained when printing construction products, figure 2.

![Figure 2](image2.png)

**Figure 2.** Time dependence of the vibration acceleration of the construction 3D printer trolley.

The time dependence of the change in the current strength during the operation of the stepper motor is obtained, figure 3.

![Figure 3](image3.png)

**Figure 3.** Time dependence of the current change in the stepper motor of the construction 3D printer drive.
Figure 4 shows the values of the current in the stepper motor windings in transient values. The starting current exceeds the rated one by 8 - 9 times.

It can be seen from the graphs, the maximum value of the vibration amplitude of the bogie does not exceed 0.8 mm, the maximum value of the current in the starting mode is 10.0 A. The main regularities of the current change of the stepper motor, the parameters of the oscillatory process of the construction 3D printer for various operating modes have been determined.

As a result of processing the experimental data, the dependence of the amplitude of displacement of the printer frame depending on the driving force of the vibrator was obtained.

![Figure 4. Graph of the vibration amplitude of the construction 3D printer frame depending on the driving force of the vibrator: 1 - with the bunker not loaded with the mixture; 2 - when the bunker is loaded with a mixture.](image)

The amplitude of vibrations of the hopper walls changes nonlinearly depending on the vibration frequency of the vibrator. The greatest amplitude of vibrations of the walls of the construction 3D printer bunker occurs in the frequency range of 40 - 50 Hz. The use of a vibrator with an industrial frequency of 50 Hz makes it possible to obtain an amplitude of vibrations of the bunker walls up to 3.2 mm. The vibration acceleration of the 3D printer trolley vibrations reaches 52 m/s².

4. Discussion
The main criterion for operability in the mode of exposure to dynamic loads on a construction 3D printer is the hopper vibration amplitude and acceleration. Other parameters influencing the value of dynamic loading include: the mass of the oscillatory system; vibrator unbalance mass; eccentricity radius; unbalance rotation frequency; phase angle; the volume of the concrete mix.

5. Conclusion
A model of a construction 3D printer which allows analysing the dynamic processes of interaction of sliding formwork with concrete mixture has been developed. The conducted full-scale experiment of a construction 3D printer showed the efficiency of equipment with the specified characteristics.

The vibration level of the equipment is within the standard values. The vibration of the equipment is influenced by the coefficient of elasticity of the mixture. With an increase in the elasticity coefficient of the mixture, the vibration activity of the equipment increases.

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