Kinematical simulation of robotic complex operation for implementing full-scale additive technologies of high-end materials, composites, structures, and buildings

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Kinematical simulation of robotic complex operation for implementing full-scale additive technologies of high-end materials, composites, structures, and buildings

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Abstract This paper considers a newly designed electronic digital model of a robotic complex for implementing full-scale additive technologies, funded under a Federal Target Program. The electronic and digital model was used to solve the problem of simulating the movement of a robotic complex using the NX CAD/CAM/CAE system. The virtual mechanism was built and the main assemblies, joints, and drives were identified as part of solving the problem. In addition, the maximum allowed printable area size was identified for the robotic complex, and a simulation of printing a rectangular-shaped article was carried out.

1. Introduction

Within the framework of the Federal Target Program "Development of robotic complex for the implementation of full-scale additive technologies of innovative materials, composites, constructions, and buildings", BSTU named after V.G. Shoukhov is designing an automated robotic complex with the purpose of using special materials and composites to print various articles, such as building walls, various building constructions, and unique architectural elements.

Usually, such printing requires special compositions based on cements graded 500 or higher, which are relatively inexpensive, and their components are readily available. As with printing using regular 3D printers, the main operating principle of the robotic complex is extrusion [1]. Besides, this complex allows one to prepare, batch, and transport special materials and composite mixes.

This paper addresses the issues of simulating the 3D printing as performed by the robotic complex (RC) in question with the purpose of assessing its performance. The problem of simulating the movement of the RC was solved using the application "Simulation of Kinematics" of the NX CAD/CAM/CAE system [2].

2. Method and discussion

The first stage consisted of creating the electronic and digital model (EDM) of the RC in NX 10 [3-5], which can be seen in Figure 1.

The problem was solved by using the "Simulation of Kinematics" module of the NX CAD/CAM/CAE system, which allows one to use a 3D model to build a virtual mechanism, set it in motion, and study the parameters of its moving parts [6].

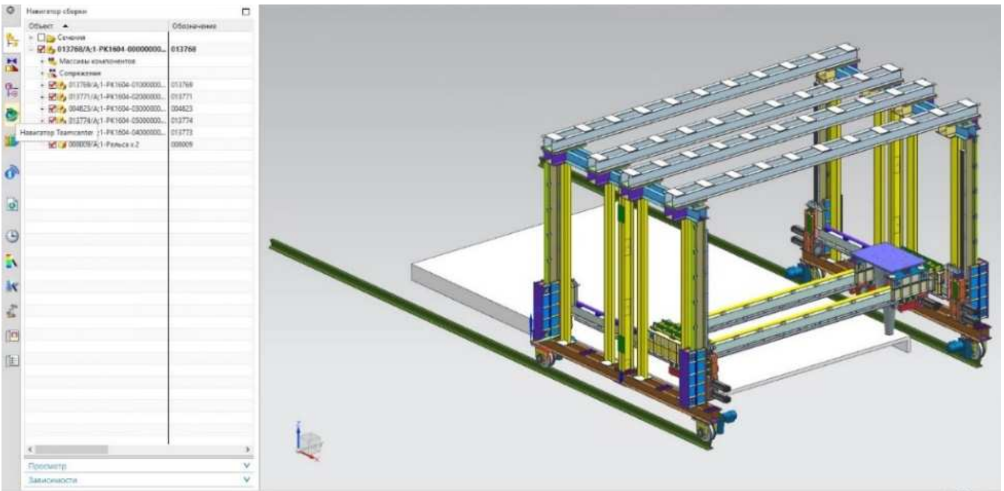


Figure 1. The designed EDM of the RC in NX10.

The working tool of the RC is a print head, which can perform the following motions: translational motion relative to the bridge of the carriage, sum of translational motions together with the carriage in horizontal and vertical directions, transportation of metal structures along the rails. Figure 2 shows a schematic diagram of all moving parts of the RC, which includes: 1 – metal structure that performs translational motion along the rails; 2 – bridge elevation mechanism (BE mechanism), which is responsible for the vertical translational motion of the bridge relative to the metal structure, 3 – bridge frame, which ensures the horizontal translational motion of the bridge relative to the main metal structure; 4 – carriage, which performs translational motion relative to the bridge frame.

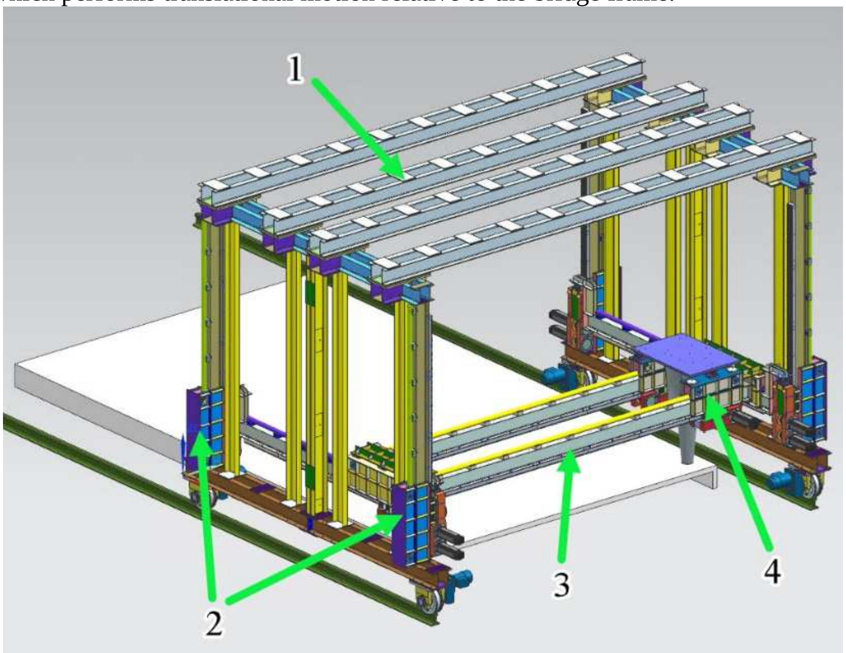


Figure 2. Electronic digital model of the robotic complex: 1 – metal structure, 2 – BE mechanism, 3 – bridge frame, 4 – carriage

This way, the print head located on the carriage performs compound motion within an absolute coordinate system linked to the ground. The problem lies in building a virtual mechanism of the RC that would provide for all the motions listed above.

The "Simulation of Kinematics" module represents the virtual mechanism as links that are connected to each other with assemblies. Elements of the mechanism are set in motion by drives.

A 3D model of the robotic complex was represented as the following links (Figure 2): 1) metal structure, 2) BE mechanism, 3) bridge frame, 4) carriage.

Knowing that the RC's assemblies move translationally, movement of the mechanism was determined using 4 slider joints. Joints are tools for describing possible movements between various links in the kinematics module. A slider joint leaves one degree of freedom for translational motion of an assembly along the chosen axis. A drive is assigned to a slider to set it in motion.

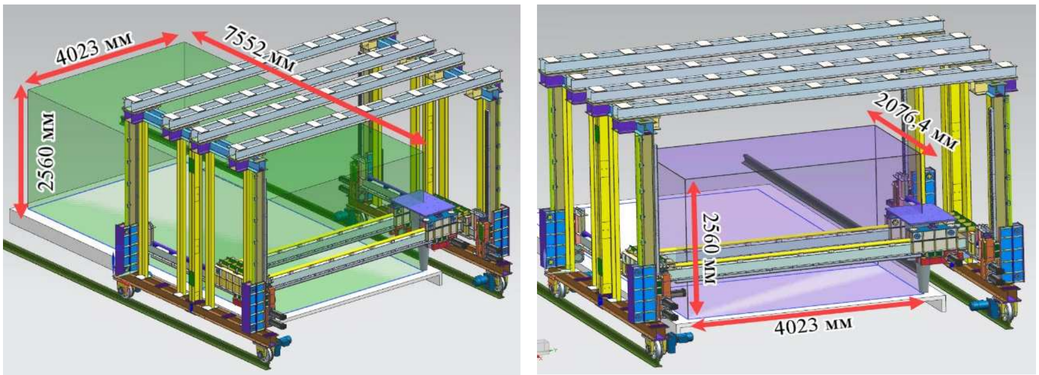
In order to set the movement of the metal structure (position 1, Figure 2) relative to the rails, a slider joint is used with a driver that ensure the translational movement of the metal structure on the rails. The maximum possible movement of the metal structure along the 12000 mm-long rails is 7552 mm.

To set the BE mechanism in motion (position 2, Figure 2), a joint was assigned, in the form of a slider between the metal structure and the BE mechanism. This slider contains a drive, which provides vertical motion to the BE mechanism within the range of 2560 mm.

Translational motion of the bridge frame (position 3, Figure 2) relative to the metal structure was set using a slider joint between the BE mechanism and the bridge frame. The bridge frame can move in the range from 0 to 2076.4 mm.

Translational motion of the carriage with the print head fixed to it (position 4, Figure 2) relative to the bridge frame was set using a slider joint. The maximum possible movement of the carriage is 4023 mm.

This way, in the process of print, the print head of the robotic complex can translationally move vertically and horizontally to cover different zones. The first zone has the largest printable area: due to the ability of the RC to move on rails, the maximum length of the area is 7552 mm and its width is 4023 mm (Figure 3, a). The second zone is smaller in size provided that the RC does not move on rails, but prints only by moving the mechanisms inside the metal structure. In this case, the maximim length of the printable area is 2076.4 mm and its width is 4023 mm (Figure 3, b).



a) b)

Figure 3. Printable areas of the robotic complex: a) first printable area; b) second printable area.

Drives were controlled in the NX "Simulation of Kinematics" by means of functions that described the movement of the carriage, bridge frame, and the RC's frame respectively. To simulate the movement of separate parts of the mechanism, a special tool of the "Simulation of Kinematics" module was used: "Drive" (Figure 4).

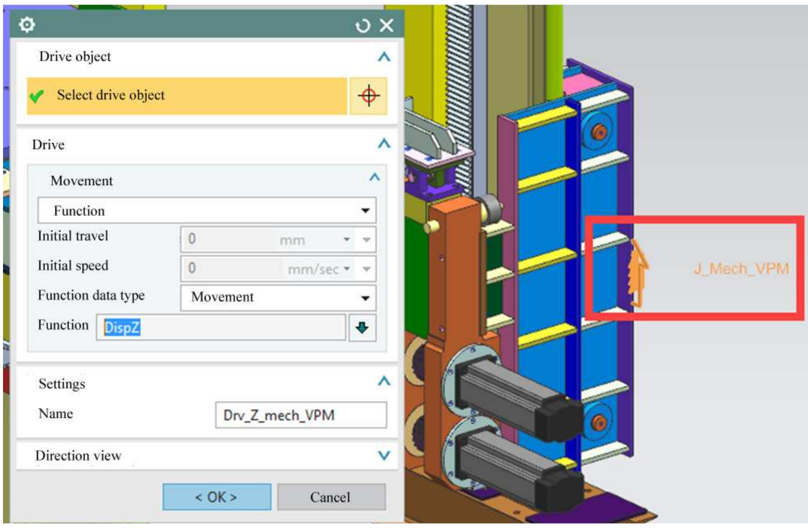


Figure 4. Dialog window of the "Drive" command for the "Slider" joint of the BE mechanism

A STEP (x, x0, t0, x1, t1) function of the "XY function control" command was used to set the reciprocating motion of the metal structure, the BE mechanism, the bridge frame, and the carriage. The Step function moves the joint in accordance with time (t) and the value of travel (x).

For example, STEP (x, 0, 0, 10, 4000) means that the carriage will translationally move 4000 mm relative to the bridge frame within the range of 0 to 10 seconds. The "XY function control" dialog window with set values is shown in Figure 5.

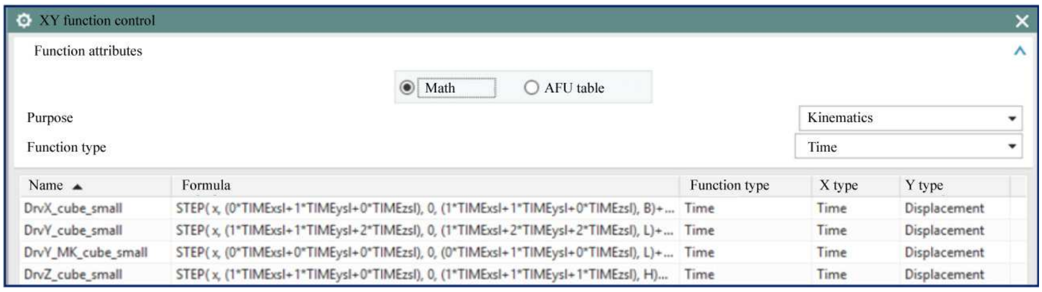


Figure 5. "XY function control" dialog window

After setting the drive functions, a simulation of the movement of the RC was carried out to assess the printable area. The trajectory of the extruder of the RC was constructed using the "Tracing" command.

3. Conclusion

The final result of the RC's working tool movement to assess the print area under the initial travel of the metal structure for 2000 mm is shown in Figure 6.

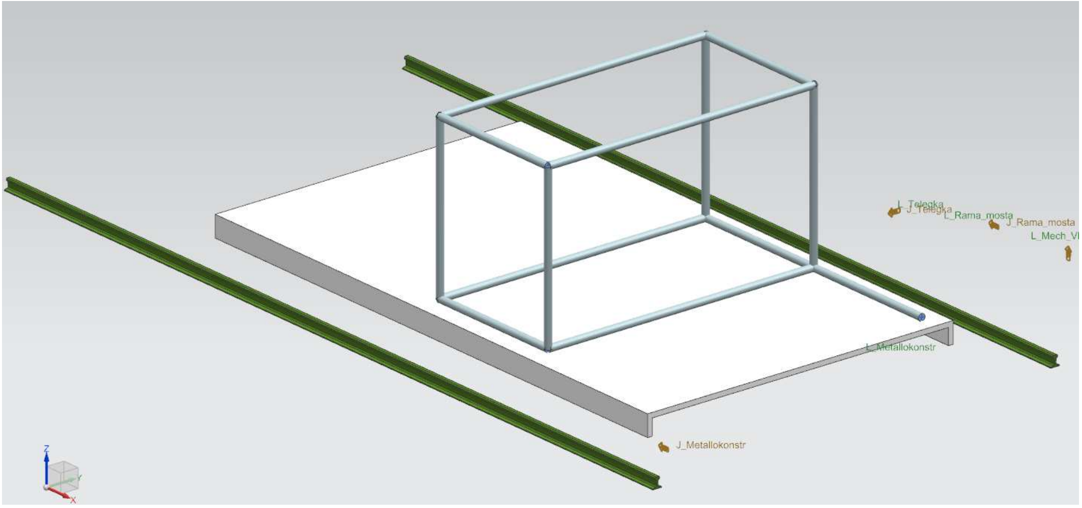


Figure 6. Simulation of the RC printing in a defined area.

Kinematical calculation of the robotic complex allows one to make conclusions about the correctness of trajectories of its movement to create articles of different complex forms.

This way, the designed 3D model of the RC provides the required movement of the print head in the defined print area.

4. Acknowledgments

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