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LARGE-SCALE THERMOSET PICK AND PLACE TESTING AND IMPLEMENTATION

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Abstract

Oak Ridge National Laboratory is developing the first commercially available medium to large-scale thermoset additive manufacturing (AM) system with Magnum Venus Products (MVP). This 3D printer is capable of fabricating large-scale thermoset components at room temperature with a build volume of 16' x 8' x 42''. The thermoset extrusion process uses irreversible exothermic chemical reactions to form a cross-linked polymer. Printing thermosets at such large scales with highly customizable materials at room temperature provides huge opportunities for complex and smart tooling applications. Integrating a pick and place actuator into this system will allow for the placement of heating/cooling channels as well as sensors to monitor tooling health and heat distribution. The pneumatically-driven pick and place actuator is integrated into the existing electrical and mechanical design and is controlled using custom M-code commands. The system is comprised mostly of commercially available components, providing easy adoptability by future thermoset systems.

Introduction

Pick and place robotics is a robotic system whose main purpose is to pick up objects and place them somewhere else. In a manufacturing setting, pick and place robotics has proven that it has the capability to improve manufacturing time leveraging agile robots and incorporating control schemes [4]. Typical applications for these robots include loading and unloading conveyer belts, changing tooling, and simple assembly operations like inserting roller bearings on a shaft [1]. An example of a pick and place application can be found in Figure 1.

Figure 1: Traditional application for pick and place robotics

Taking this technology and applying it to MVP's thermoset AM printer will open new doors and provide more applications for the printer. Thermoset AM, as show in Figure 2, deposits cross-linking polymer in a controlled fashion. Thermoset printers also operate with low pressure extrusion processes at room temperature [6]. The MVP printer, displayed in Figure 3, is preprogrammed to deposit the thermoset material in stacks of 2D geometries to build a 3D object, also known as 3D printing or AM. Integrating pick and place robotics with MVP's thermoset AM technology provides the opportunity to place objects into the printed parts during the print process. This is advantageous to an array of applications such as smart tooling, post process alignment, lightweight parts, as well as internal heating and cooling.

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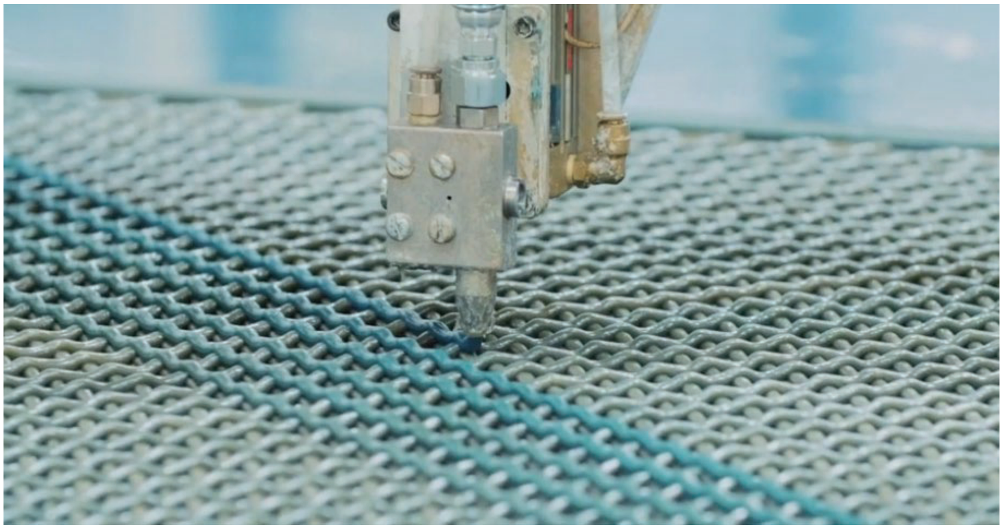

Figure 2: Thermoset printing demonstration

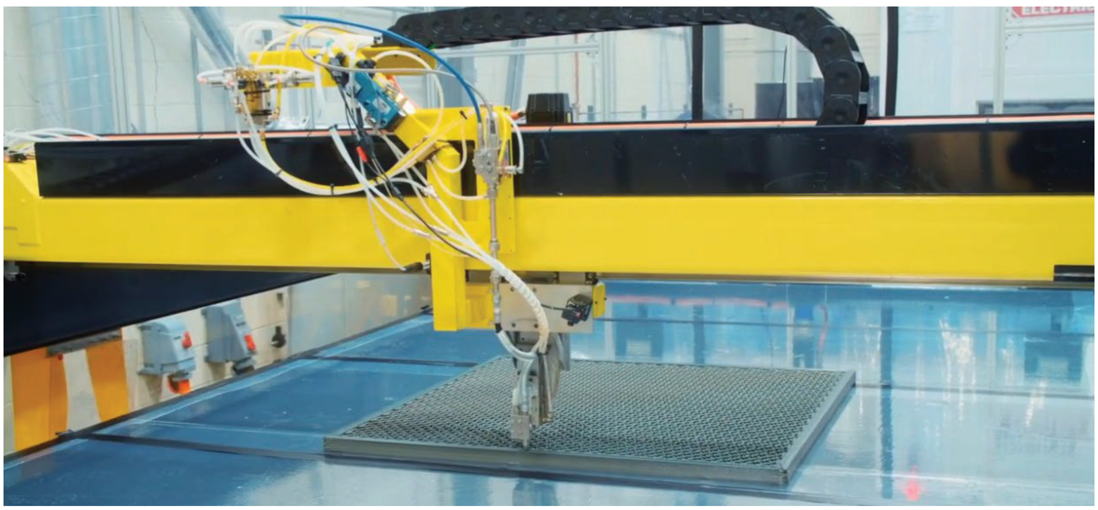

Figure 3: MVP thermoset AM printer with >10 lbs/hr throughput and a 16’ x 8’ x 42” build volume

Integrating pick and place technology with MVP’s thermoset AM printer was inspired by the success of the integration of pick and place robotics with Cincinnati’s Big Area Additive Manufacturing (BAAM) printer. Multiple applications were investigated on the BAAM printer, such as smart tooling and post process alignment features [2]. These results provided enough evidence to deem promising for the integration with MVP’s thermoset printer.

Pick and Place System

Mechanical Design

There are two important factors that are incorporated into this design. One, the simplicity of the design allows integrating into the existing equipment very easy and cost effective. Two, leveraging off-the-shelf components reduce the time spent creating custom components and provides an easily repeatable design others can adopt to their system. As displayed in Figure 4, the system is very compact and does not require much space. The location chosen to install the system is directly behind the nozzle where material is deposited. Refer to Figure 5 to see the final installation of the pick and place system.

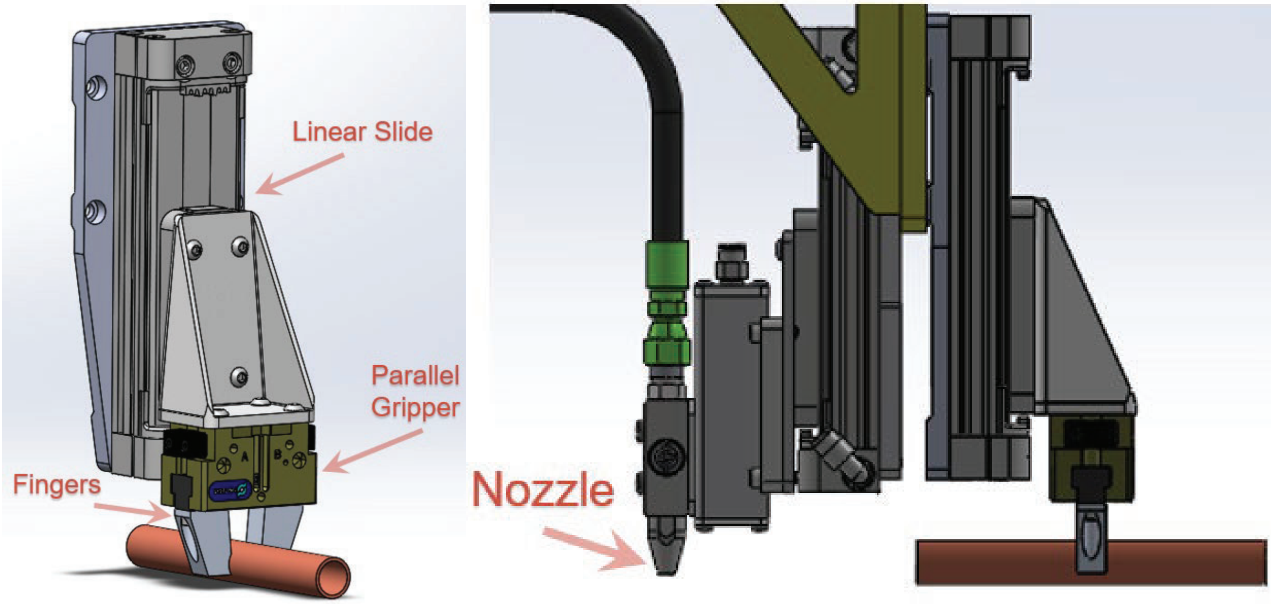

Figure 4: CAD model of the pick and place system assembly (left) and location to be installed (right)

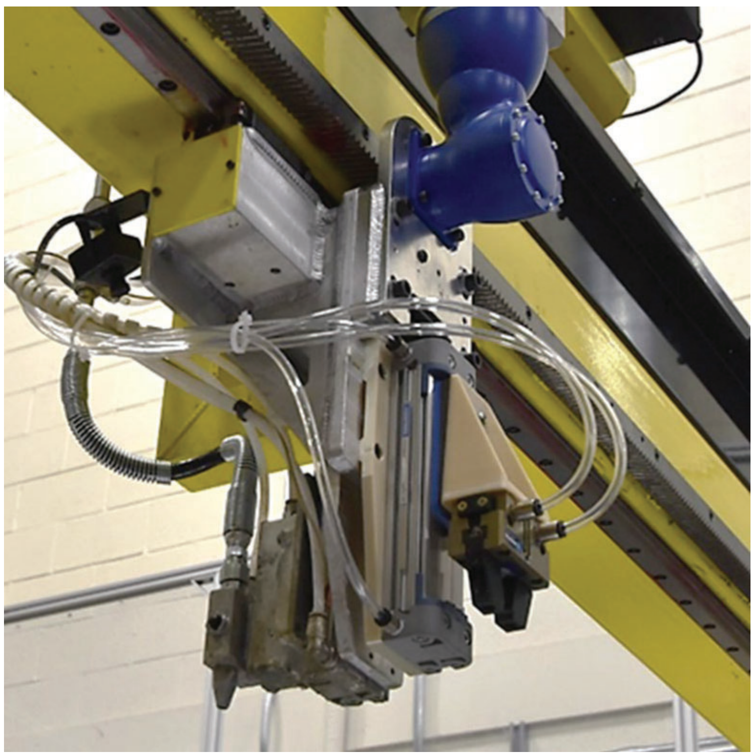

Figure 5: Installed pick and place system on MVP's thermoset printer

The linear slide and parallel gripper operate through pneumatically driven pistons that have two positions each. The linear slide is used for two purposes. One, to keep the pick and place system above the nozzle when the system is printing. Two, pick objects up from their original position and place them down in desired locations. Figure 6 displays the linear slide in its two positions. The parallel gripper has an open and closed position for grabbing and releasing objects. The fingers, attached to the parallel gripper, are designed specifically to pick and place a cylindrical object, but can be replaced and modified for alternative applications.

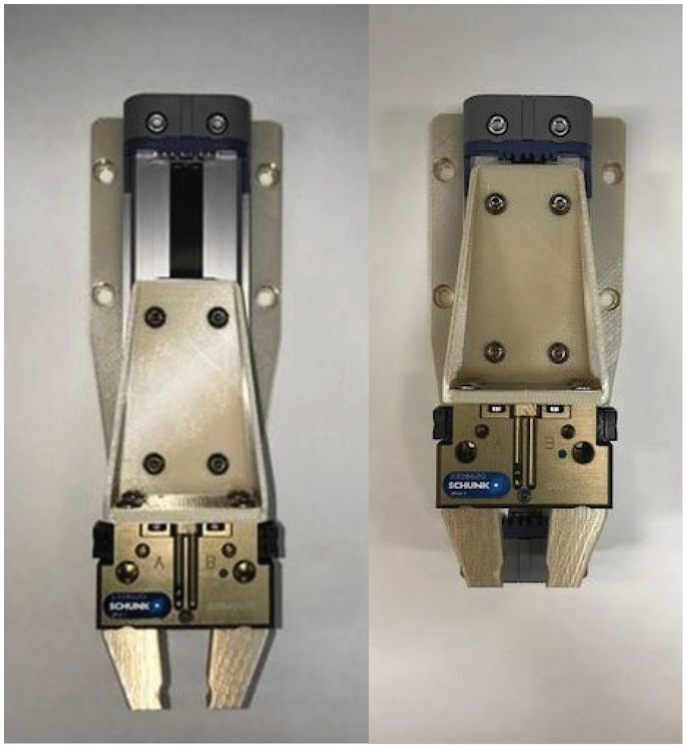

Figure 6: The linear slide in the down position (left) and in the up position (right)

Pneumatic/Electrical Design

Fully integrating the pick and place system into the MVP thermoset printer requires a pneumatic manifold to distribute the compressed air to the linear slide and parallel grippers. Before exiting the manifold, the compressed air interfaces with single acting 4-way solenoids to provide control over the compressed air. Each pneumatic device on the pick and place system requires two pneumatic fittings, an A and B fitting. As shown in Figure 7, the right image displays a map of how the air travels through the solenoid. In one position, air flows from P to A and in the other it flows from P to B. Figure 7 also displays the air ports located on the manifold. The top row of air ports is labeled A and the bottom row is labeled B. The solenoids direct the flow either out of A or out of B depending on the electrical signal. Depending on which direction the air is flowing, A or B, the pneumatic device changes its position. For example, in Figure 6, air flows into the A fitting and pushes the linear slide down and when changed to the B fitting, the slide moves up. The exact location of these fittings can be seen better on Figure 5. To see the manifold and solenoid final assembly see Figure 8.

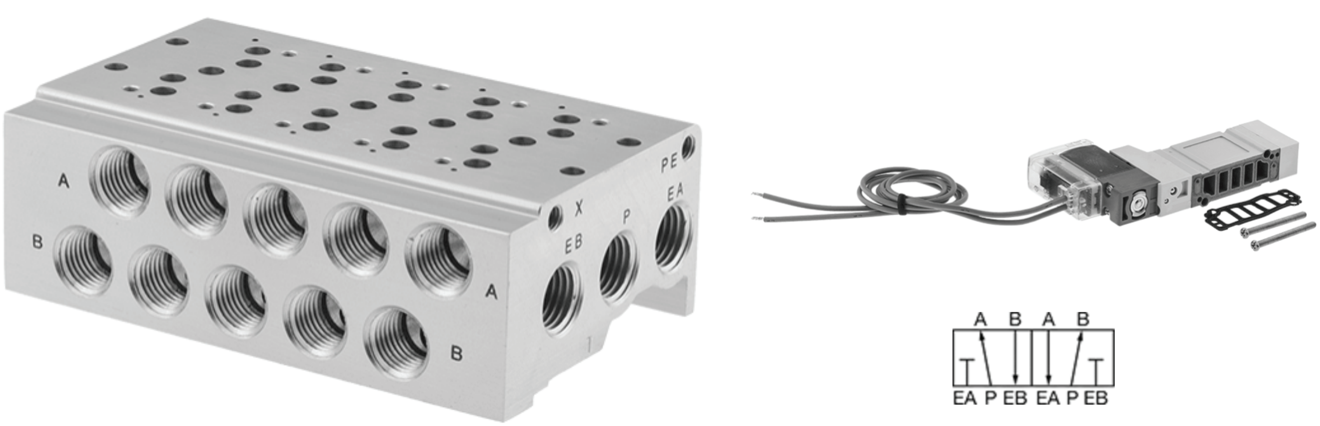

Figure 7: Pneumatic manifold (left) and single acting 4-way solenoid (right)

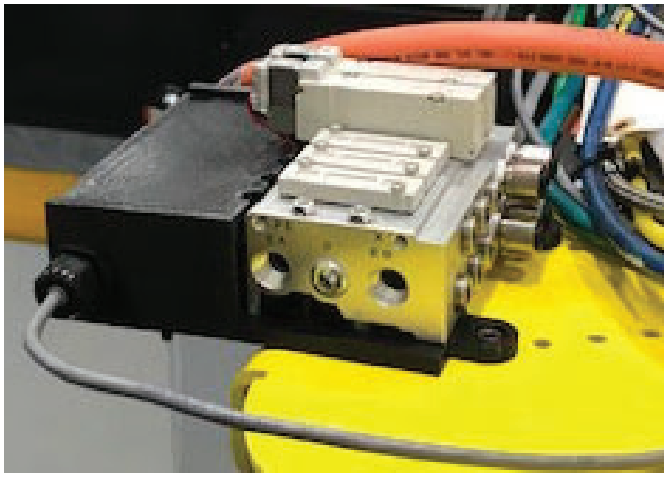

Figure 8: Installed pneumatic manifold and solenoids

Software Integration

Typically, in AM, parts that will be printed are converted to an STL file and sent to a slicing software that will divide the STL file into layers and converted to a language that the printer can understand [5]. The language the MVP operates on is referred to as G-Code. Automatically controlling the pick and place system is incorporated into the G-Code command scrips leveraging preprogrammed M-Codes. Each solenoid is preprogrammed with custom M-Codes to activate or deactivate the solenoid for a total of two M-Codes per single acting solenoid. These M-Codes are then incorporated into the G-Code command scrip to control the pick and place operations automatically during the printing process.

Testing and Implementation

The first test part printed incorporated a simple rectangular prism with a heating cartridge place directly in the middle of the part. In order to complete this task, the G-Code was altered to incorporate the custom pick and place control script that ordered the system to pick up and place the heater cartridge directly in the center of the part after the middle layer finished printing. Figure 9 demonstrates a successful pick and placement of the heater cartridge in the correct location. This is also right before the printer begins depositing material for the next layer. Since this was a test part to prove the pick and place concept, the heater cartridge was never tested.

Figure 9: The heater cartridge successfully placed in the middle of the part mid-print

Figure 10: Finished printed part with heater cartridge successfully placed in the center of the part

Future Work

Tool Changer Concept

The next step for this project is to have the capability to place multiple objects into one printed part. To accomplish this, a tool changer will need to be added to the design. Tool changers are common in the manufacturing industry just as pick and place robotics. They are even used at the nano level to assist with scanning electron microscopes [3]. The concept incorporates one male fixture that is mounted on the end of the robotic arm and multiple mating female fixtures mounted on tools that will interlock with the male adapter. The importance of this concept is the ability to interchange the female fixtures. With this, the system can interchange between as many tools, that incorporate this female fixture, as desired.

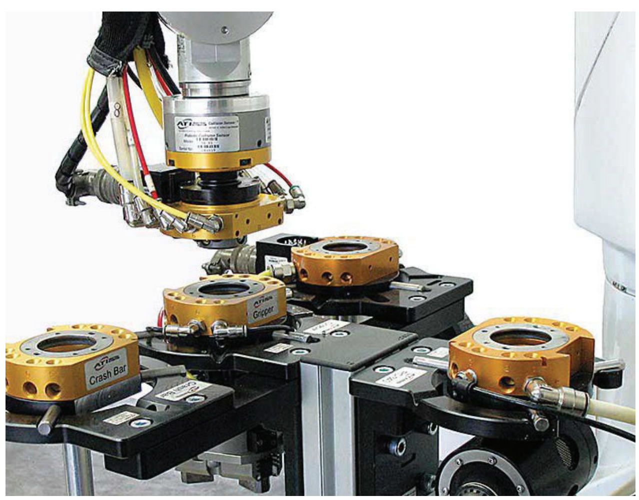

Figure 11: Tool changer example with four mating tools on stands

Controlling this system will be a bit more complicated than the simple parallel gripper tool, but the basic strategy is the same. Looking at Figure 12, the interlocking ball is visible. When the ball is pushed outward from its pneumatically controlled piston, it will lock in place under a groove located inside the female fixture. As the male fixture is placed over the female fixture inside the mating hole and the interlocking ball is activated, the male and female fixtures are locked together. Now, when the system moves, both the male and female fixtures move with the system. Two examples of tools with female fixtures can be found in Figure 13. A full picture of the male and female end interlocking is displayed in Figure 14.

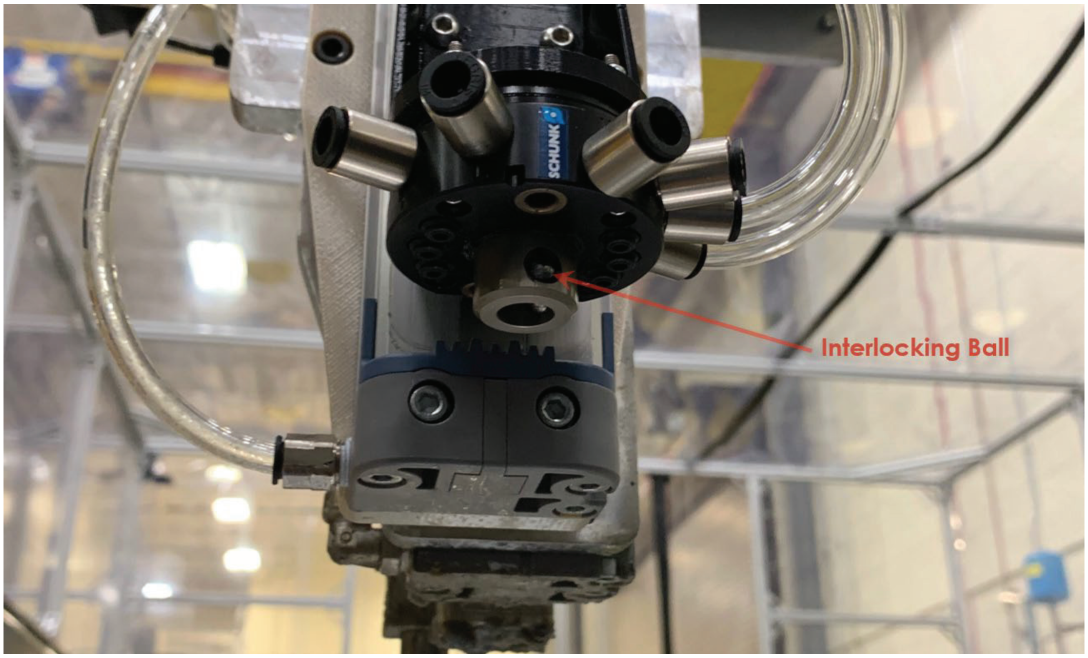

Figure 12: Close-up of the interlocking ball that locks the male fixture to the mating female fixture

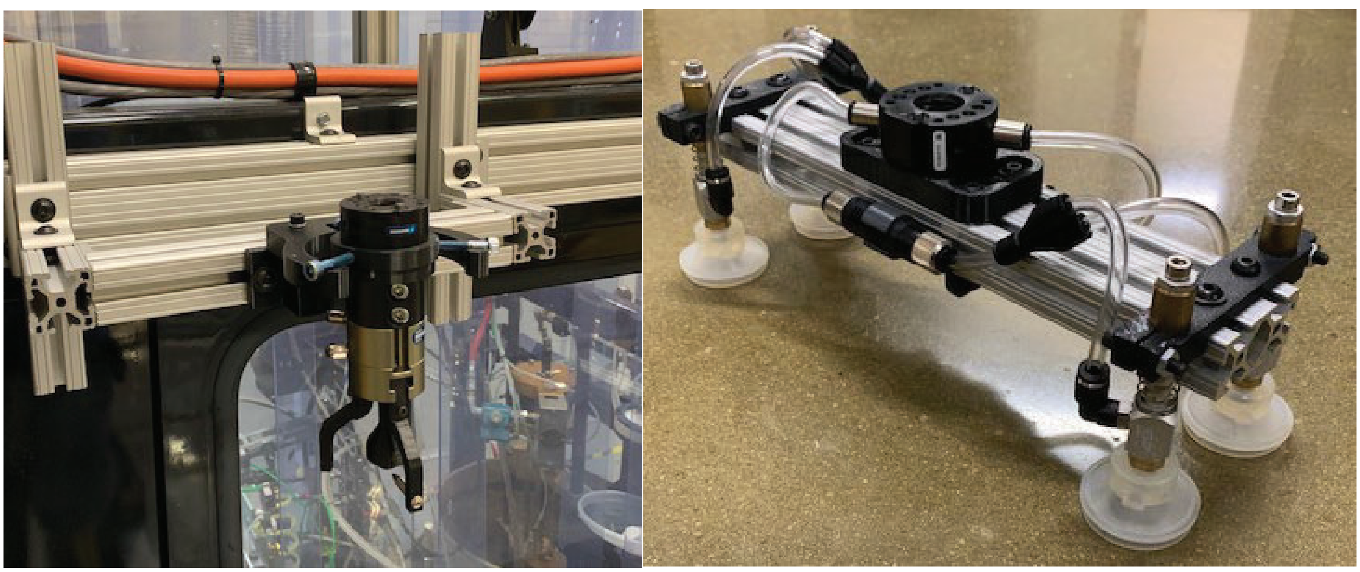

Figure 13: Three finger gripper tool (left) and vacuum tool (right)

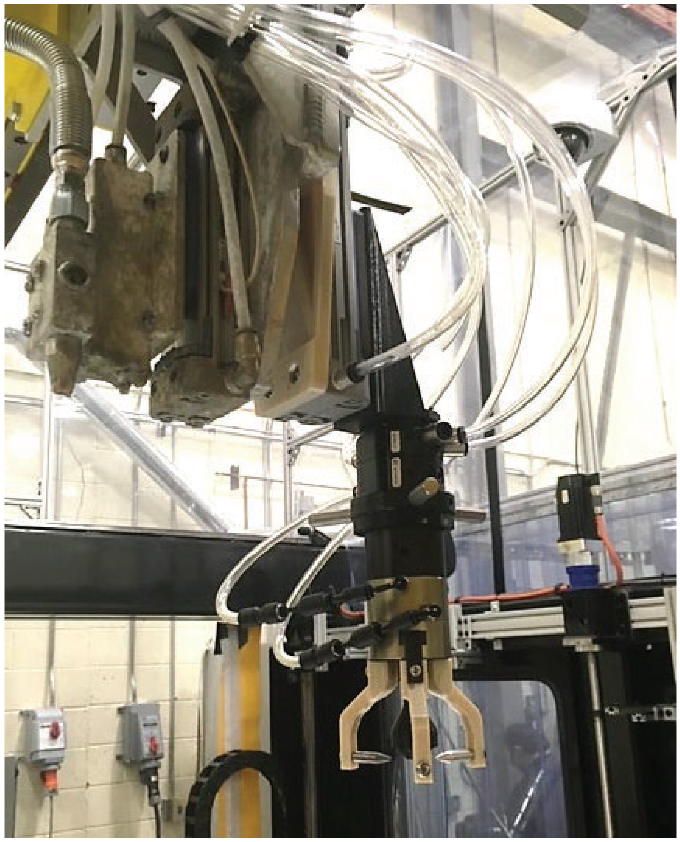

Figure 14: Full tool changer assembly demonstrated on MVP's thermoset printer

Conclusion

Pick and place robotics has demonstrated another successful application for use in the AM industry. Integrating pick and place robotics into MVP’s thermoset printer has opened new doors to additively manufactured parts as well as given AM designers new tools to work with. One of the greatest achievements of this test was successfully integrating the system into the existing mechanical, electrical and pneumatic architecture. This makes it much easier to adopt this technology to AM printers alike. The future for AM is getting more sophisticated every year. New industries are forming in both polymer AM [7] and metal AM [8]. Not only is the AM process and materials developing at an accelerated rate, the machines that house this technology is developing right along with it. Pick and place robotics is just scratching the surface of what is to come in AM.

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