VDK-4000 Direct Write System

A New Approach to Direct Write Technology

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ABSTRACT

Maskless Mesoscale Materials Deposition (M^3D), newly developed manufacturing technology, have the ability to locally process deposition through a laser scanning process. Features down to 10 microns can be directly written in a wide variety of materials, including metals, ceramics, polymers and adhesives, on virtually any surface material - silicon, glass, polymers, metals and ceramics with three dimensional structures. In this paper we demonstrate enhancements to the traditional M^3D system to extend the range of capabilities for manufacturing technologies. The VDK-4000 is newly developed system enhanced with a flexible robotic solution with multi-degree-of-freedom capability, and innovative software for transferring computer aided design (CAD) patterns. With such enhancements, one can now deposit on substrates with complex structures which offers the potential for revolutionary new end-products.

Keywords: direct write technology, six-degrees-of-freedom, 3-D substrates.

1 INTRODUCTION

The ability to fabricate materials in complex three dimensional shapes, deposit track widths ranging from sub-microns to millimeters, and deposit a vast range of materials such as metals, polymers, ceramics, and biological materials including living cells is referred to the term "direct writing". Direct Writing (DW) technologies [1-8], recently, has become more prominent in manufacturing technologies such as micro-electronics [9], photonics [10], microfluidics [11-13], and biomaterials [14, 15] because it offers numerous benefits most importantly processing cost reduction due to a reduction in process steps. The five dominating DW technologies commercially available are (ink-jet, Micropen or n-Scrypt direct syringe process, thermal spraying, matrix assisted pulsed laser evaporation direct write (MAPLE DW), and Maskless Mesoscale Materials Deposition (M^3D) [16]. Of the DW technologies, the (M^3D) aerosol jet system is most notable simply because it has the ability to operate well beyond the capabilities of thick-film and ink-jet processes. It's the only DW technology that have the capability of fabricating crucial mesoscale-sized (1 - 100 μm) production of interconnects, components, and devices [16]. M^3D reliably produces ultra fine feature circuitry making it ideal for next generation packaging and high-density interconnect applications at both the chip and circuit board level [16]. M^3D systems directly write electronic components such as high-density traces, resistors, capacitors, antennas, and fuel cells, on a wide variety of flexible and rigid planar and non-planar substrates with simple to complex structures. Unfortunately, there are a number of generic challenges associated with direct writing technology, most specifically in robotics and controls. Advances in robotics, process controls, and software algorithms are necessities required to improve dimensional accuracy, positional accuracy, resolution, and writing capability on curved and/or complex shaped substrates [17]. In this work, we demonstrate enhancements to aerosol jet printing technique and design of the VDK-4000 direct write system to extend the range of capabilities for manufacturing technologies. The VDK-4000 Direct Write System, Figure 1, is a one of a kind direct write technology built by Control Systems Technologies. The VDK-4000 was engineered and specifically tailored to Air-force Research Laboratory (AFRL) needs for various applications. The fundamental principle behind the technique is similar to M3D [16], with the exception of a newly developed software, Yova-motion, for transferring Computer-Aided Design (CAD) patterns, and an innovative Flexible Robotic solution package with multi-degrees-of-freedom capability.

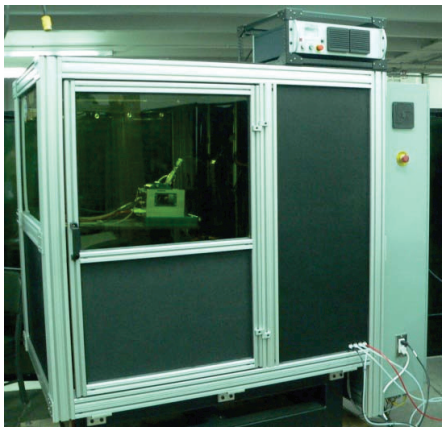


Figure 1: Image of VDK-4000 Direct Write System

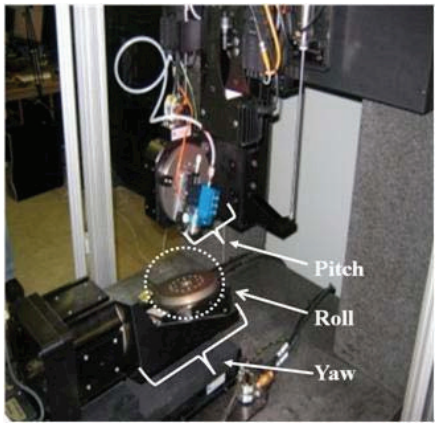


Figure 2: Schematic of VDK-4000 process and six-degrees-of-freedom capability.

2 VDK-4000 DIRECT WRITE SYSTEM

VDK-4000 aerosol jet process use aerodynamic focusing for high-resolution deposition of colloidal suspensions and/or chemical precursor solutions. An aerosol stream of the deposition material is focused, deposited, and patterned onto planar or non-planar substrates. The basic operation modules are:

- Mist Generation module for atomizing liquid and colloidal suspension raw materials [16].
- In-Flight Processing module for focusing the aerosol and depositing the droplets [16]. Patterning can be accomplished while the substrate position remains fixed or in motion, which makes this system unique. This ability is unachievable without multi degrees-of-freedom capability. The VDK-4000 currently has six degrees-of-freedom (DOF) capability which requires three DOF operate the printing head with respect x, y, and z coordinates; and three DOF to operate the orientation in space (roll, yaw, and pitch) as illustrated in Figure 2:
    - Roll – sample stage rotates at a 360° angle 53 times consecutively clockwise/counter clockwise around the z-axis.
    - Yaw – the stage arm rotates from 90° to (- 90°) around the y-axis.
    - Pitch – printing head tilts from 45° to (-15°) around the x-axis.
- The final module is sintering of the deposition. A 20W YAG laser is used to locally heat the deposited material with minimal effect on the substrate.

VDK-4000 is a Flexible Robotic Environment (FRE) direct write system. This is currently the only six DOF direct write system on the market. Present direct write technology allows printing on 2-D flat substrates or on substrates with simplistic 3-D architectures. Such systems are primarily intended to print on flat or near flat substrates. The deposition head is held in a fixed position and the stage moves back and forth in the X-Y plane. For simplistic 3-D architectures, the deposition head needs to be manually tilted to a 45° angle. This greatly limits the complexity of the substrate which can be deposited upon at one time, and increases the number of steps needed to make a simple deposition. With the VDK-4000 printing can be done on a complex 3-D substrate without defocusing the deposition or the need for manual movement of the deposition head as illustrated in Figure 3. With such features, this system has the capability of writing on complex substrates with difficult topology. This allows for more accurate depositions to be made with much lower part finish times.

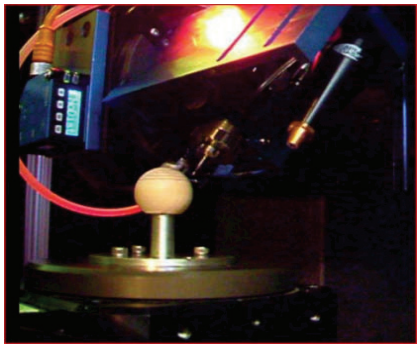
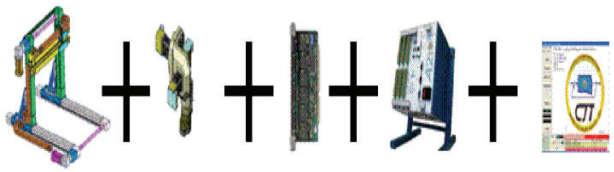


Figure 3: Deposition on wooden ball utilizing four degrees-of-freedom.

3 FLEXIBLE ROBOTIC ENVIRONMENT SOLUTION

FRE is a robotic solution that combines Parker linear elements, rotational gimbals units, mechanical and motor/drive components with proprietary hardware, software, and controls, illustrated in Figure 4. With these elements one is able to form various configurations that may operate together or be distributed in space all functioning under the same controller. The A2-30-DS board in this system has been designed to control digital servo drives used in robotics and similar applications. It is assumed that Step/Direction approach is being used here predominantly.



Gantry Gimbals DS Board A2 Software

Figure 4: Basics Elements for Modular Technology

Such a modular robotic concept can be used to create various robotic systems including redundant robotic solutions. With FRE it is therefore possible to build a concentrated and/or distributed robotic solution around an application instead of building the application around a typically six degree of freedom articulated robotic arm. Developed recursive direct and inverse kinematics algorithms that support even redundant manipulators are unique in the robotic market today. Current VDK-4000 software supports the motion in all standard robotic coordinate frames including the polar configuration. In addition, the user is capable of path planning using redundant degrees-of-freedom thus enabling obstacle avoidance which was one of the main objectives in designing this system. VDK-4000 comes with graphical CAD-to-motion path planning capabilities strictly oriented towards Flexible Robotic Environment systems called Yova- motion.

4 YOVA-MOTION SOFTWARE

Yova Motion supports the modular FRE hardware concept and enables a user friendly graphical interface. The idea behind FRE concept is to have a modular robotic solution to a specific requirement. In other words, a robotic modular system is built around an application instead of having an application fit within a predefined robotic workspace that is dictated by its fixed physical configuration. Thus, with FRE one is capable of creating one's one work-envelope by spatially distributing degrees of freedom. Such flexibility needs to be supported in two primary ways. First, control algorithms needed to possess complex inverse kinematics capabilities that will be able to empower FRE based solutions. Second is the CAD-to-Motion capabilities that allows the user to program paths while the complexities of the physical configuration remains transparent as shown in Figure 5. This process is done by simply importing a CAD model then using special cutting tools in software to determine inside/outside penetration points. Such penetration points are then used to create the actual path to Create Desired Trajectory on the imported model. The trajectory is then download the to the FRE system for actual execution.

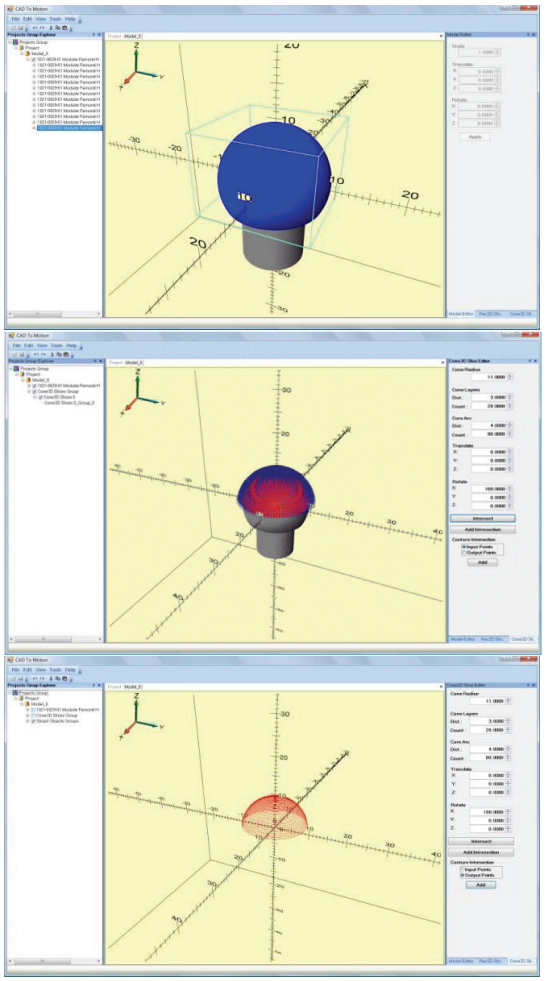


Figure 5: Schematic of imported CAD Model, cutting tools crating inside/outside intersection points on the imported model, and desired trajectory created on the imported model.

The major advantages of using Yova-motion software is the reduction of production preparation times and the capability of creating complex model paths in a graphical environment using two simple steps that can be completed within a few minutes.

5 SUMMARY

The VDK-4000 allows accurate depositions to be made with much lower part finish times, thus, reducing production times, thus, making it a cost-effective, highly innovative, configurable and interchangeable multi-degree-of-freedom, robotic solution package that is beneficial and can be applied in a multitude of applications from high tech to industrial.

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