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Drop-On-Demand Printing System with Pneumatic-based Drop-Ejector

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Abstract

Drop-On-Demand printing technology has been applied across various fields. The key component to ensure success printing system is the print-head that produces small droplets of printing medium at desired spatial location. We present a low cost and easy to operate print-head that is already integrated to our printer for fabricating three-dimensional objects. The pneumatic-based print-head is our recent developed prototype that utilizes two LPG injector-valves. The features of these valves are low cost, durable and fast turn-on/turn-off response. The print-head set is designed to achieve quick assembly and nozzle interchangeable. In this paper, we illustrate main components of the print-head. Furthermore, we conduct experiments to demonstrate workability of the whole systems by printing straight lines from photo-polymer ink.

***Keywords**:* Drop-on-demand, rapid prototype, 3D printer, photo-curable.

1. Introduction

Rapid prototype technologies gains popularities in industrials because they can shorten production cycle on delivering product prototypes. Any defections or flaws of the products can be detected early before committing the full scale production. Drop-On-Demand (DOD) printing is one of adopted technologies to incorperate in rapid prototyping. Moreover, the DOD is recently applied for fabricating functional objects. Many research groups develop procedures to fabricate three dimensional parts that have impacts on many engineering applications such as part prototyping [1], a micro sensor [2] and tissue engineering [3].

The key component in DOD printing is a droplet generator that produces a micro-size droplet of printing materials (inks). The droplet generators have been developed to dispense various type of materials, for example, a solder for circuit boards [4]. a binder to hold ceramic powder forming a solid part [3]. Lee et al. [1] developed a print-head using a piezo actuator to push piston in the cylindrical reservoir to generate a droplet of molten metal. Some research groups [5 - 6] also reported the pneumatic-based system to produce a water droplet.

Recently, we developed the DOD system has been developed for Ion-selective electrode fabrication [2]. However, we encountered problems with printing green materials using the piezo-actuated droplet generator. As a result, we search for alternatives. We evaluated few systems and found that the pneumatic-based droplet generator is a suitable choice for our printer.

We adopted the pneumatic-system report in [5], and then add-in more components to further enhance a capability of the original system. The modified version of the pneumatic-based drop-ejector is incorporated to our existing printer system. The whole system is evaluated by printing various liquid inks to substrates including our proprietary formulated photo-polymer ink.

In this report, we elaborate the development of the DOD printer with the pneumatic-based drop ejector. The paper is organized as followings. Section 2 gives the overview of DOD printing system. We modify a droplet generator based on pneumatic system. The polymer ink chemical composition is also discussed in this section. Section 3 elaborates the setup of our DOD for printing experiments. The results are discussed in Section 4. Finally, conclusions are drawn in the last section.

2. Pneumatic-based Drop-On-Demand System

DOD printer system has several key units that can be summarized as shown in Fig. 1. The printer consists of the motion stage with three axes traveling in X, Y and Z directions. The droplet generator is based on pneumatic powered. We build the controller system to command open and close timing of inlet and exhaust solenoid-valves as show in fig 2. Furthermore, the synchronizer is specially developed to close the loop between motions of the stage and pneumatic-based print-head system. Each hardware system is developed as a module style, and it can be operated separately. Therefore, the control software "CMU Printer Control" performs automatic sequencing of printing tasks when all hardware is integrated together. The UV LED with the center wavelength at 365 nm is used as a light-source for curing the photosensitive polymer ink. The LED is installed at the remote location from the printing table. The fiber-optic in Fig. 3 carries light and deliver a small spot on the printing substrate. Details of each hardware unit are elaborated in the following subsections.

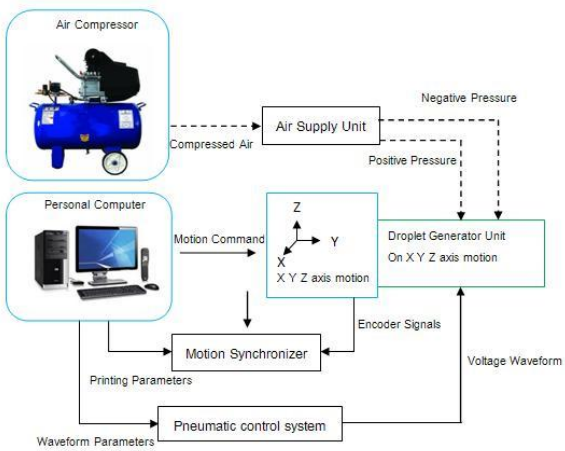

Fig.1 An overview of the Pneumatic DOD printing system

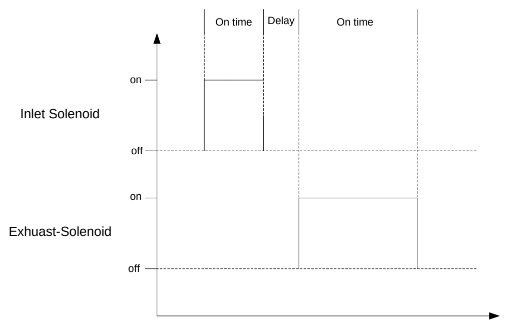

Fig. 2 Time setting for pneumatic valve

2.1 Drop generator Unit

The droplet generator has a reservoir with one end connected to female luer-fitting as depicted in Fig.3. The other end has a pneumatic quick fitting for easily disconnected during refilling ink. The nozzle is made by cutting a micro-bore capillary tube to the length 3-5 millimeters and insert into the male luer-fitting. This arrangement allows rapid replacement of the nozzle in the event of the nozzle get clogged.

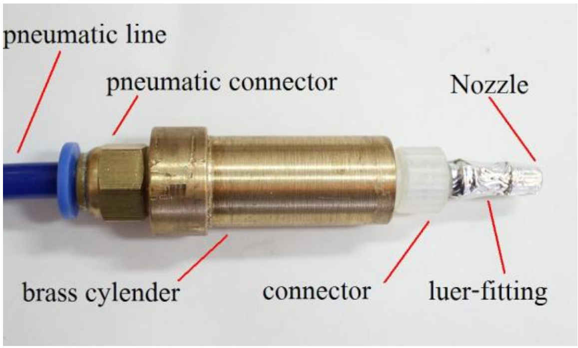

Fig.3 Brass cylinder, nozzle and pneumatic connector

The pneumatic drop on demand system is arranged according to the diagram in Fig. 4. Air-supply from air compressor is regulated at about 450 kPa before the compress air is distributed to two precision pressure regulators. The first pressure-regulator regulates the pressure to the Inlet-solenoid valve. The second pressure-regulator controls a pressure to vacuum generator. In fig.5, the droplet generator unit is installed on the motion stage.

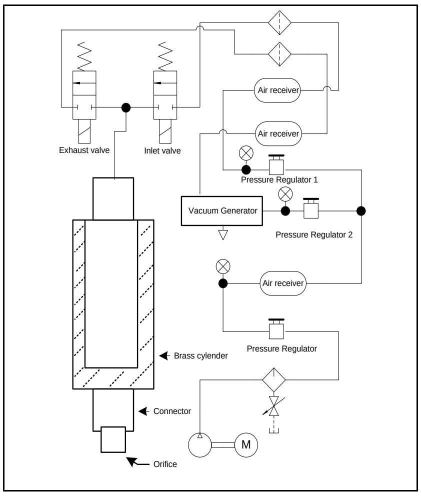

Fig. 4 Schematic Diagram Pneumatic Drop on demand unit

A droplet of liquid is forced out by a pulse of compressed air from the inlet-solenoid valve. The print-head reservoir is still under pressured even after the inlet valve is closed. Therefore, the exhaust valve is installed to stabilize residue pressure. Furthermore, the vacuum pressure is given at the exit of the exhaust valve to introduce small amount of vacuum in the print-head chamber. This help preventing the liquid leakage from the nozzle.

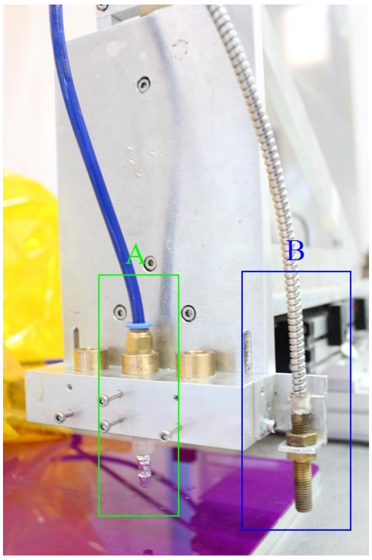

Fig.5 (a) The drop generator unit installed on the motion stage and (b) LED UV fiber-optic cable.

2.2 Electronics System for Droplet generator Unit

The droplet generator unit utilizes solenoid valves adopted from commercial LPG-gas injectors in a vehicle. To ensure fast valve opening response, the valve is activated by spike and hold voltage waveform as illustrated in Fig.6.

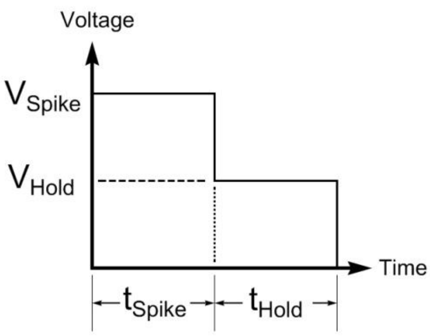

Fig.6 Waveform control for solenoid valve.

The spike voltage is experimentally set at 24 VDC and the hold voltage is set at 16 VDC. The circuit in Fig.7 acts as electronic switches to supply those voltages to the valves. The circuit in Fig.8 controls the time to switch between the spike and hold voltages. We develop this controller using a microcontroller to manage the timing.

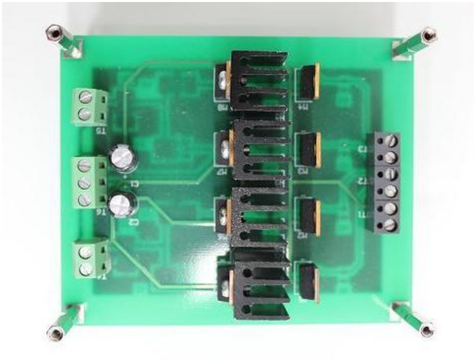

Fig. 7 Solenoid driver unit.

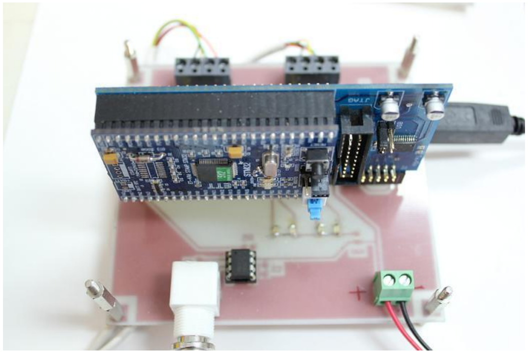

Fig. 8 Droplet generator controller.

2.3 Synchronizer

Fig. 9 shows the synchronizer that is used to synchronize the position of the motion stage and the droplet generator. When the stage is moving, the synchronizer detects positions and sends the command droplet generator controller to produce droplet.

Fig.9 Synchronizer unit.

2.4 CMU Printer control

Since each hardware module of the printer is designed to work independently, we specially create the "CMU Printer Control" program to scheduling the tasks. The program ensures all hardware is working in harmony. The CMU Printer Control commands the motion of the stage through the motion controller card installed in the same PC that runs the program in Fig.10. Furthermore, it communicates with the synchronizer and pneumatic controller to give necessary parameters.

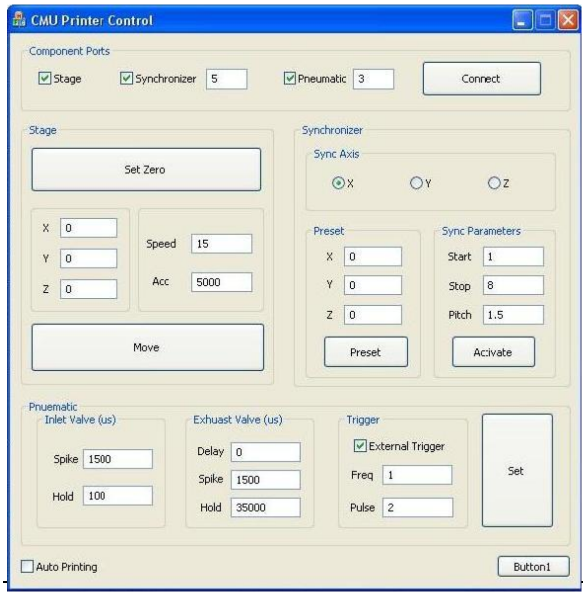

Fig.10 CMU Printer Control program.

2.5 Photo-polymer ink

The chemicals for our polymer ink are 1,6-hexanediol diacrylate (HDDA), ethyl-4-dimethylaminobenzoate (EDMAB), thioxanthone-9-one (TXO)The weight ratio of those chemicals is given in Table.1

Table.1 First chemical composition of a polymer ink

Chemical	Weight Ratio (%)
HDDA	94.4
EDMAB	4.7
TXO	0.9

3. Experimental Setup

We conduct experiments to test printing inks with various working conditions. The appropriate fabrication procedures are determined. The printing system is operated in an air-conditioned room with temperature range 22 to 24 ˚C.

We use the nozzle with orifice sizes 150μm, 100μm and 76μm. The timings of a drop generator is tuned for each printing media until the generator produces a single droplet without satellite (orphan) drops. After the suitable timing is discovered, the ink is printed on a polyester-film substrate. Firstly, the water is printed to the substrate to verify workability and repeatability of the printing system. Next, the photo-polymer ink is printed with various droplet pitches while keeping total curing time constant.

4. Results and Discussions

The parameters for printing water are as follows: the spike and hold times of the inlet-solenoid were set at 1,500μs and 500μs respectively, and the spike and hold times of the exhaust-solenoid were 1,500μs and 6,400μs respectively. The inlet pressure was tuned to 140 kPa and the pressure supplied to the vacuum generator was 170 kPa. We used the nozzle with orifice size 100μm to print the water on an inkjet printing-film. The result is shown in

Fig.11. We can see that the drop size was quite even throughout the substrate.

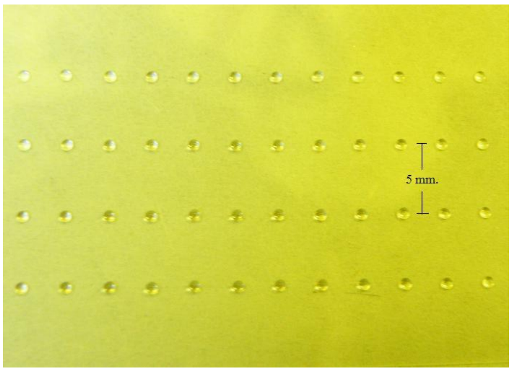

Fig. 11 Water droplets with orifice size 100 μm.

When printing the polymer-ink, the spike and hold times of the inlet valve was tuned to 1,500 μs and 100 μs, respectively. The delay time between the inlet-valve closing and the exhaust valve opening was 2,000 μs. The spike and hold times of the exhaust valvewere 15,000 and 25,000 μs, respectively. The inlet pressure was set at 40 kPa and the pressure supplied to the vacuum generator was 40kPa. The orifice size for printing ink was 150 μm Results of the printed line using the ink as given in Table.1 is depicted in Fig.12. The number at the right-side of each printed line indicates the traveling speed and the repetition of the UV light. For example, 15/5 means the light was moved back and forth 5 cycles at the speed of 15 mm/s. We observed that the surface of the line was not smooth and the edge was jagged. This is because polymer-ink contains HDDA that is highly active when the polymerization process is initiated. As a result, it is a major source of polymer shrinkage.

Therefore, we modified the formula by adding MMA into the cocktail of the first-formula using the weight ratio one-to-one. The results in Fig.13 show the printed lines with various droplet pitches, i.e. 1.5 to 2.0 mm pitch. We notice that the surface and edge of the printed lines were smoother than those lines with first-formula. Hence, the MMA helps reducing the shrinkage of the polymer.

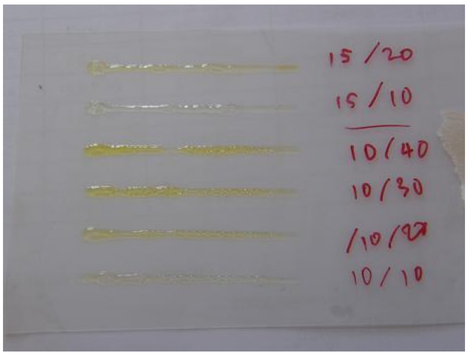

Fig. 12 The printing results of the first-formula ink. The number at the right-side of each printed-line indicates speed/repetition.

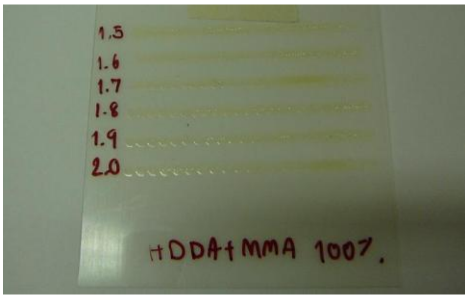

Fig. 13 Printed lined with the modified photo-polymer formula.

5. Conclusions and Future Development

We present the development of the pneumatic drop-on-demand printer for fabrication object. The print-head is based on pneumatic system. The important hardware for pneumatic print-head as well as the polymer ink are elaborated. All hardware is developed in-house to meet budget constraint.

Although, the initial results of the printed line are promising, there are still several issues need to be handled before the three-dimensional objects can be fabricated with our printer. The current print-head is subjected to test with other configuration of orifices since the current orifice made from the cut capillary tube. It has high fluid friction that prevents the print-head to dispense viscous liquid.

6. Acknowledgements

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