

Redesign of Magnetostrictive Inkjet PrintHead

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ABSTRACT

This paper presents the redesign of the first magnetostrictive inkjet printhead (MagJet). The redesign includes the structural redesign and operational redesign. After completing the process successfully, the redesigned MagJet is subjected to testing. The effect of backpressure from a commercial syringe pump is evident. The operating frequency with backpressure reaches up to 1.5 kHz, although that without backpressure is 650 Hz. The droplet size at a frequency of 800 Hz is about 53 μm , less than half of the nozzle size. It can be concluded that various droplets can be made by combining frequency with a proper flow rate. Backpressure prevents the MagJet from air inclusion in the nozzle, so continuous ejection of the droplets are possible.

Keywords: magnetostrictive inkjet printhead, backpressure, droplet formation, droplet size, flow rate

1 INTRODUCTION

Inkjet printing is demanding for various applications due to its technological and material flexibility. One of the challenges is to design a proper inkjet printhead for demanding trend. Current inkjet printheads are mostly based on either piezoelectricity or heat. Both of them have a limited force generation, then are restricted to use very low-viscosity fluids. Som there exist to find out a novel actuation mechanism to overcome current limitation. Magnetostrictive actuation is one of them. Yoo et. al. developed and characterized the first magnetostrictive inkjet printhead [1,2]. Droplet formation was successful, but not always. Akso, fluid leakage was observed. Thus, this paper presents the redesign of the first magnetostrictive inkjet printhead. Magnetostriction is the deformation of a body in response to a change in its magnetization.

2 REDESIGN PROCESS

The first magnetostrictive inkjet printhead (1st MagJet) was developed and characterized by one of the authors [1-2]. Even though it was possible to eject fluid droplets successfully, some problems arise such as fluid leakage and low frequency operation. The redesign process is focused on overcoming these problems: one with structural redesign of printhead, and the other with operational redesign.

2.1 Structural Redesign

As shown in Figure 1(a), the 1st MagJet consists of three components — one actuator (①) containing actuation mechanism, one receptacle (③) receiving a nozzle, and one center connector (②) interfacing the actuator and receptacle. Four screws are used to assembly the actuator and center connector, where most leakage occurs. The leakage is not likely to start up to a certain level of pressure, but is likely to start and get more as the pressure gets higher.

As shown in Figure 1(b), the redesigned MagJet (2nd MagJet) consists of two components — one actuator (①) and one receptacle (③). The center connector is incorporated into the design of a new receptacle. In addition, the inner surface of bottom end of the actuator and outer surface of top end of the receptacle are machined to have screw threads, which give more secure tightening between the components.

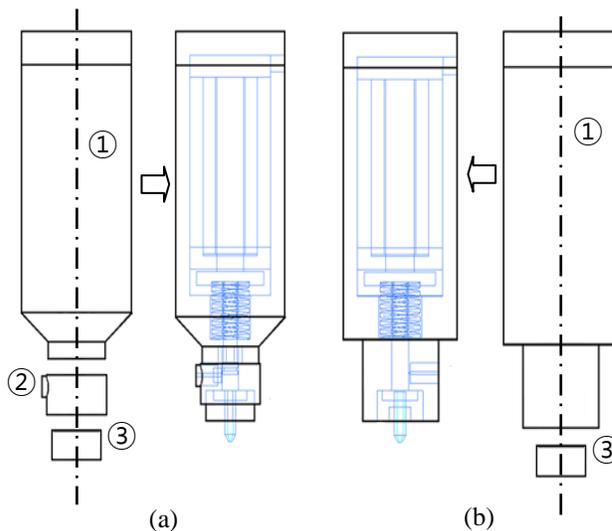


Figure 1: Structural redesign of MagJet: (a) 1st (b) 2nd.

2.2 Operational Redesign

It is observed that the structural redesign helps improving operation as well as eliminating leakage. The maximum ejection frequency increases from 200 Hz at a current of 1.8 A to 650 Hz at a current of 1 A, and the minimum ejection current decreases from 0.35 A to 0.2 A. From practical point of view, a further operational

improvement is still needed. So called “operational redesign” is conducted to achieve the goal. It is general that air comes in and remains in the nozzle during the operation. It is the reason why the 1st MagJet is operated at a lower frequency, and at a higher current. The core of the operational redesign is to add a commercial syringe pump to the fluid reservoir. The flow rate for droplet ejection is varied in accordance with the size, and must be determined experimentally. After applying the backpressure to the 2nd MagJet, the operation is improved significantly. It is ejected droplets continuously, and is operated at a frequency of up to 1.5 kHz.

2.3 Fabrication

Fig. 2 shows a schematic cross-sectional view and a photo of the redesigned MagJet. A bobbin made of Al6061-T6 is wound by 1000 turns of coil (AWG25). The Terfenol-D rod with a diameter of 10 mm and a length of 50 mm is placed inside the bobbin, which is a little bit bigger than the Terfenol-D rod. The top end of the Terfenol-D is filled with the flux path made of SUS430, which acts blocked end with the top housing. The bottom end of the Terfenol-D is connected to the push rod, which transmits the displacement and force generated by Terfenol-D. Ring-shaped permanent magnet made of Alnico5 with a thickness of 5 mm is placed at the center of the flux path. The permanent magnet is used to provide DC bias to Terfenol-D, thus allows it to move in bidirection. A preloading spring of 6.8 MPa is selected for a better performance of the MagJet. The nozzle is fit into the receptacle with teflon gasket. The nozzle is made of a glass, and has a diameter of 130 μm . The final dimensions of the MagJet are 40 mm in diameter and 104 mm in length. Detailed mathematical and numerical analysis are found in [1].

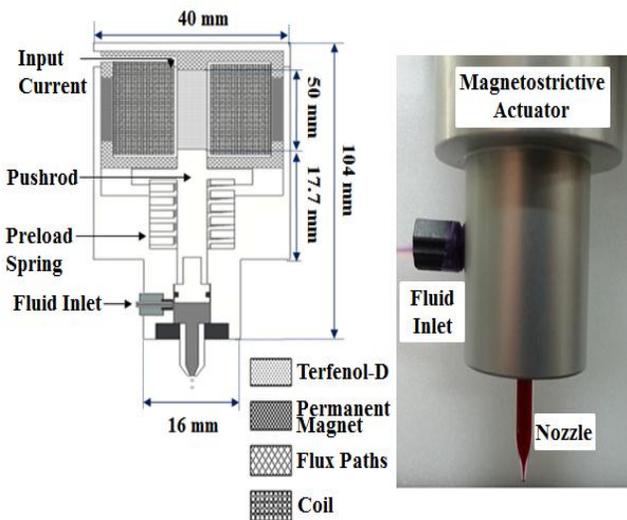


Figure 2: A schematic and a photo of MagJet.

3 EXPERIMENTAL PROCEDURE

Figure 3 shows a schematic diagram for the experimental setup. LabVIEW-based control program generates two signals: one is a driving signal, and the other a trigger signal. The driving signal is sent to the current amplifier, amplified, and used to drive the MagJet. The synchronized trigger signal is sent to CCD camera and strobe LED, and used to take droplet images from the MagJet. The digitalized droplet images are sent back to the control program for further analysis. Syringe pump is used to supply the fluid with an adequate flow rate to MagJet through the fluid inlet.

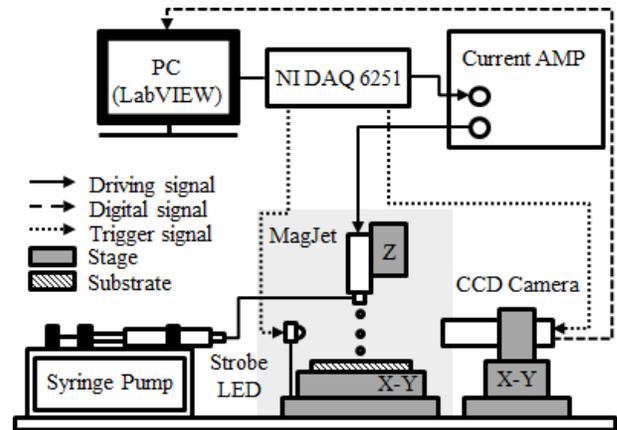


Figure 3: Schematic for experimental setup.

The fluid used for the experiment is a water-based ink with a density of 958.5 kg/m^3 , a viscosity of 1.31 cPs, and a surface tension of 33.3 dynes/cm. The driving signal has a bipolar waveform, as shown in Fig. 4. The operating principle of the MagJet with the bipolar waveform is as follows: During a time interval of t_c and t_i , the Terfenol-D rod contracts with the reversal current, resulting in chamber filling of fluid. During a time interval of t_e , the Terfenol-D rod expands with the conventional current, causing the volume reduction of the chamber. The droplet is made and ejected during a time interval of t_e , t_h , and t_b .

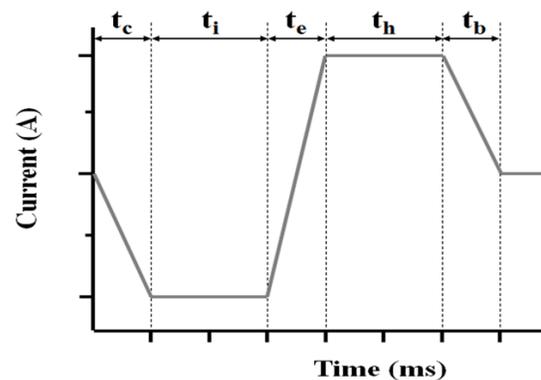


Figure 4: Driving signal.

4 RESULTS AND DISCUSSION

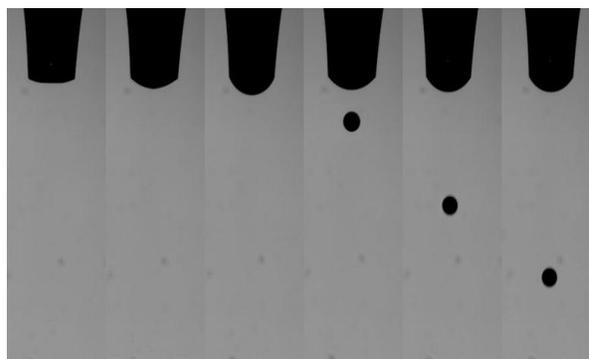
Table 1 is the summary of the successful or failure ejection with or without a backpressure. The supplied current and applied frequency to the redesigned printhead range from 0.2 A to 1.0 A, and 100 Hz to 800 Hz, respectively. In the table, the respective S or F means “Successful” or “Failure”, and the respective left or right side on the slash represents ejection with or without backpressure. It is observed that ejection with backpressure needs less current than one without backpressure, and that ejection frequency with backpressure is higher than one without backpressure. The maximum ejection frequency with backpressure reaches up to 1.5 kHz (although not listed in the table). It is also observed that the numbers of ejection with backpressure are countless, while them without backpressure are limited to 3 to 5 times. It is generally observed and is due to air inclusion into nozzle when the fluid is not supported by using backpressure.

| Current Freq. | 0.2 A | 0.3 A | 0.4 A | 0.5 A | 1 A |
|------------------|-------|-------|-------|-------|-------|
| 100 Hz | S / S | S / S | S / S | S / S | S / S |
| 200 Hz | S / S | S / S | S / S | S / S | S / S |
| 300 Hz | S / S | S / S | S / S | S / S | S / S |
| 400 Hz | S / F | S / S | S / S | S / S | S / S |
| 500 Hz | S / F | S / S | S / S | S / S | S / S |
| 600 Hz | F / F | S / F | S / S | S / S | S / S |
| 650 Hz | F / F | S / F | S / F | S / F | S / S |
| 700 Hz | F / F | F / F | F / F | F / F | S / F |
| 800 Hz | F / F | F / F | F / F | F / F | S / F |

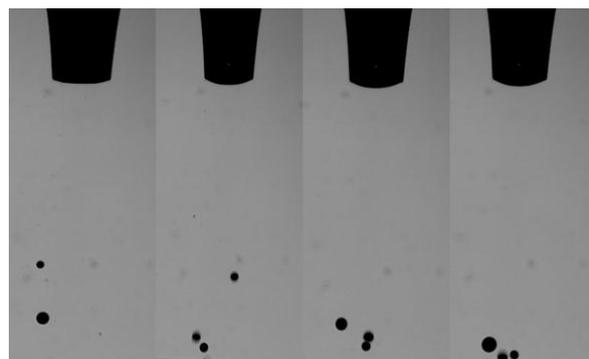
Table 1: Summary of successful or failure ejection.

Figure 5 shows the experimental comparison when ejections are performed with or without a backpressure. In Figure 5(a), it is observed that droplet is always formed at the tip of the nozzle. It makes the MagJet eject the sound droplets whenever needed. In Figure 5(b), it is observed that droplet is formed inconsistently, and that sometimes droplet is not even formed. It is mainly due to the air inclusion in the nozzle. Thus, the effect of backpressure is definite in terms of sound droplet formation.

Figure 6 shows the detailed procedure for one droplet ejection with an current of ± 0.7 A. The ejection speed is estimated to be 4.5 m/s, and the droplet size to be 110 μm . As observed in Figure 5, the droplet is formed at the nozzle tip, and the shape of the nozzle tip after ejection is same as that before ejection.



(a) With backpressure.



(b) Without backpressure.

Figure 5: Droplet formation: (a) with (b) without.

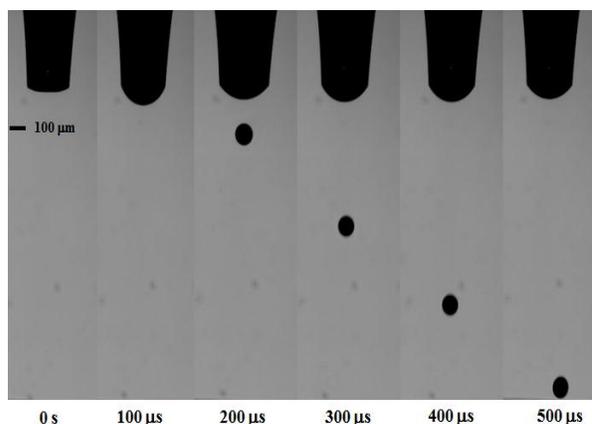


Figure 6: Droplet formation.

Table 2 is the summary of droplet size and volume to the change of frequency and flow rate. Figure 7 shows the droplet size versus frequency and flow rate. As frequency increases, the needed flow rate becomes lower, and consequently the smaller droplet size. The dependency of droplet size on frequency and flow rate is not linear with larger droplet (up to 120 μm), but is likely to be linear with smaller droplet (less than 120 μm). It is evident that various droplets can be made by combining frequency with a proper flow rate. It ranges from 53 mm (less than half of the nozzle diameter) to 160 mm (larger than the nozzle size). The droplet volume is calculated by assuming the droplet is spherical. It ranges from 80 fL to 2 pL.

| Frequency (Hz) | Flow Rate (nL/s) | Droplet Size (μm) | Droplet Volume (pL) |
|----------------|------------------|--------------------------------|---------------------|
| 100 | 2.00 | 158.76 | 2.09 |
| 200 | 1.00 | 147.84 | 1.69 |
| 300 | 0.66 | 129.36 | 1.13 |
| 400 | 0.50 | 117.60 | 0.85 |
| 500 | 0.40 | 99.96 | 0.52 |
| 600 | 0.33 | 70.56 | 0.18 |
| 700 | 0.28 | 64.68 | 0.14 |
| 800 | 0.25 | 52.92 | 0.08 |

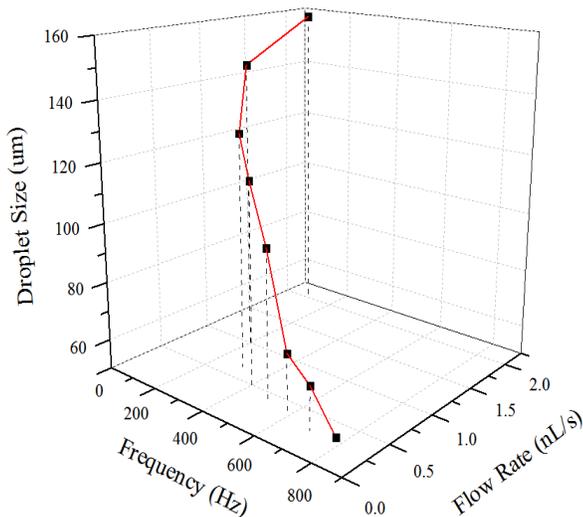


Table 1: Summary of successful or failure ejection.

Figure 7: Droplet size versus frequency and flow rate.

5 CONCLUSIONS

The 1st MagJet is redesigned in terms of structural redesign and operational redesign. The redesigned MagJet is subjected to characterization. Important findings are summarized as follows:

- 1) The structural redesign helps improving operation as well as eliminating leakage.
- 2) The operational redesign with a commercial syringe pump helps improving operation a lot.
- 3) The operating frequency with a backpressure is much higher than that without a backpressure.
- 4) The droplet with backpressure is always formed at the nozzle tip, but the droplet without backpressure is formed inconsistently and sometimes droplet is not even formed.
- 5) The shape of the nozzle tip after ejection is same as that before ejection with backpressure.
- 6) The droplet with backpressure can be ejected countlessly.
- 7) As frequency increases, the needed flow rate becomes lower, and consequently the smaller droplet size.
- 8) Various droplets can be made by combining frequency with a proper flow rate.

REFERENCES

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