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A VALVE-LESS RECTIFICATION MINIPUMP BASED ON DYNAMIC RECTIFYING GEOMETRIES

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ABSTRACT

The advantages of valve-less rectification micro pumps include having no moving parts, low cost, reliable, having the ability to pump particles-laden fluids and live cells, being compatible with a wide range of micro channel materials and working fluids. Most valve-less rectification micro pumps are based on passive rectifying geometries such as a nozzle/diffuser, Tesla (Valvular Conduit), and Bifurcation geometries. In this study, we present a new valve-less rectification minipump based on a dynamic rectifying geometry. The present work includes design, fabrication, and testing of the pump. The experimental results are presented in terms of flow rates and maximum back pressures.

INTRODUCTION

Valve-less rectification micropumps are displacement mechanical micropumps that offer many advantages over other mechanical and non-mechanical micropumps. The advantages include non-moving-parts, reliability, cost effectiveness, fabrication with ease, compatibility with wide range of working fluids and materials, ability to pump particles-laden fluids as well as live cells, and delivering favorable flow rates [1-3]. The pumping mechanism of the valve-less rectification micropumps is based on generating and rectifying oscillatory flows by using actuator and rectifying geometries, respectively. Most of the reported valve-less rectification micropumps have used Piezoelectric Transducers (PZT) as an actuator to generate the oscillatory flow and passive rectifying geometries to rectify the flow such as nozzle/diffuser, Tesla, and bifurcation [4-8]. The PZT actuators and the rectifying geometries are two separate parts in this type of micropumps. In order to improve the efficiency and reduce the extra losses, the two parts can be connected to develop valve-less rectification micropumps based on dynamic rectifying geometries. In this study, we introduce a new concept of dynamic rectifying geometries at the mini scale as a first step to realize this pump at the micro scale in future works.

DESIGN

The presented minipump contains three main parts: First, the pump body, which contains the pump chamber, pump cover, and the actuator support. Second, the pump plungers, which have a concave or convex shape depending on the desired flow direction. Each plunger associated with a specific flow direction. Third, the sinusoidal magnetic actuator which is used to generate the oscillatory motion of the plunger.

The oscillatory motion of the plunger driven by the magnetic actuator is designed to generate the oscillatory flow, while the concave or convex shape of the plunger is designed to rectify the generated oscillatory flow. The concave shaped plunger is designed to rectify the flow in a direction that is opposite to the rectifying direction of the convex shaped plunger, please see Figure 1 for more details.

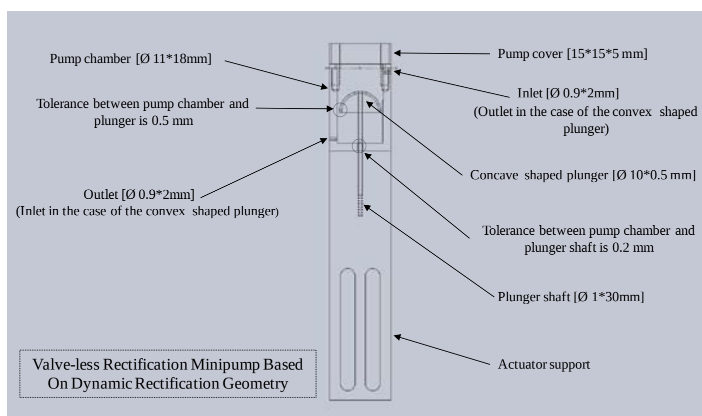

Figure 1: A CAD design of the valve-less rectification minipumps based on dynamic rectifying geometries.

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FABRICATION

The pump body is machined in Polycarbonate which is a transparent polymer. Therefore, the flow is easily visualized. The two concave and convex shaped plungers are made of aluminum. The bidirectional pumping is realized by changing between the plungers. The inlet and outlet were first connected to metal tubes and then to rubber tubes as it can be seen in Figure 2. The magnetic actuator was connected directly to the plunger; please see a picture of the magnetic actuator in Figure 3.

Figure 2: The fabricated minipump based on the dynamic rectifying geometries; please see the two plungers that are used to realize the bidirectional pumping

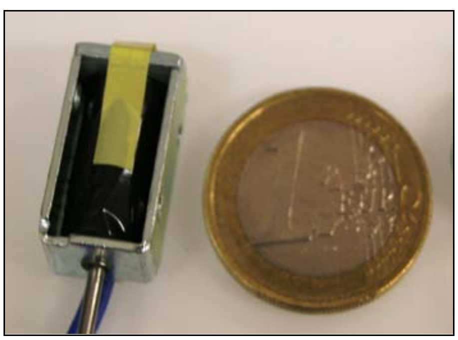

Figure 3: The sinusoidal magnetic actuator which is connected directly to the plungers

EXPRIMENTAL APPARATUS

A frequency generator (Agilent 33220A, Agilent Technologies Deutschland GmbH, Böblingen, Germany) is used to control the sinusoidal magnetic actuator (Digi-Key Corp., Thief River Falls, MN, USA). A 12 V square signal is used to control the magnetic actuator. The minipump is tested against a very low frequency range (0-10 Hz). The water is used in all experiments as a working fluid, and flow rate measurements are conducted based on the bubble tracking method [9]. A length scale (ruler) is attached to the experimental stand for back pressure measurements (water column height). The experiments are conducted with each plunger to report the flow rate in the both directions.

RESULTS AND DISCUSSIONS

Figure 4 shows the flow rates of the minipump as a function of the actuator frequency. In the case of concave shaped plunger, the flow rate increased monotonically till it reached the maximum flow rate at actuator frequency equal to 6 Hz. The flow rate is reduced for the rest of the actuator frequencies (7-10 Hz). The maximum flow rate and back pressure are 100.5 µl/min and 1.4 kPa, respectively.

In the case of the convex shaped plunger, the flow rate is observed in the opposite direction of the concave shaped plunger. However, the trend of the flow rate is similar to concave shaped plunger with only one difference, the maximum flow rate occurred at 7 Hz. The maximum flow rate and back pressure are 94.3 µl/min and 0.2 kPa.

It is noticed that the pump with the concave shaped plunger has delivered higher flow rate and maximum back pressure than the one with the convex shaped plunger. Additionally, the flow rate did not monotonically increase for the whole frequency range, rather, the flow rate is only increased monotonically till it reached the maximum and then monotonically decreased for the rest of the frequency range.

The higher efficiency of the mini pump with concave shaped plunger can be related to the fact that the flow rate direction is in the same direction of the gravity, while in the case of the convex shaped plunger, the flow rate direction is in the opposite of the gravity. This also may explain why the minipump with concave shaped plunger has higher maximum back pressure than the other minipump.

The reduction of the flow rate after it has reached its maximum is related to fact that the leakage between the plunger shaft and the pump body is also increased with the actuator frequency.

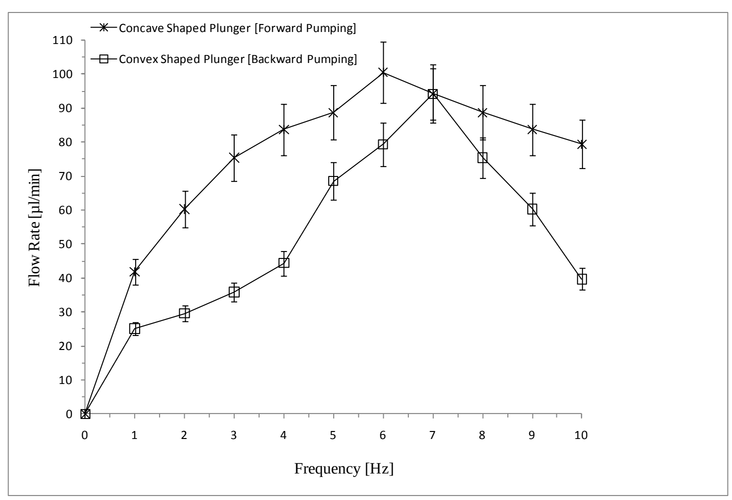

Figure 4: The flow rates delivered by the minipump as a function of the actuator frequency

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CONCLUSION

A valve-less rectification minipump based on dynamic rectifying geometries is designed, fabricated, and tested. The concept is proved and the bidirectional pumping is realized by the changing the shape of the plungers. This pump can be fabricated at the microscale by employing an actuator that has a rectifying shape to generate and rectify oscillatory flows at the same time. For example, a shape memory alloy actuator has the potential to realize the presented pump at the microscale.

ACKNOWLEDGMENTS

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