POLYDIMETHYLSILOXANE (PDMS) PERISTALTIC PUMP CHARACTERIZATION FOR *PROGRAMMABLE* LAB-ON-A-CHIP APPLICATIONS

H.-S. Chuang[1], A. M. Amin[2], S. T. Wereley[1], M. Thottethodi[2], T. N. Vijaykumar[2] and S. C. Jacobson[3]

[1]School of Mechanical Engineering, Purdue University, USA
[2]School of electrical & Computer Engineering, Purdue University, USA and
[3]Department of Chemistry, Indiana University, USA

ABSTRACT

An all-PDMS, three-valve peristaltic pump is characterized for programmable lab-on-a-chip (PLoC) applications. To achieve programmability, the pumping mechanism must be efficient, reliable and predictable. To this end, we analyze the behavior of the pump to attain an optimal pumping sequence and efficient metering. In addition, pump fatigue is also assessed to estimate chip lifetime. The overall goal of this project is to build a general-purpose PLoC system.

KEYWORDS: Lab-on-a-chip, peristaltic pump, polydimthylsiloxane, valve

INTRODUCTION

Our recent work has proposed a general-purpose PLoC [1], where a single chip can be programmed to run broad, diverse classes of assays. Such programmability relies heavily on stable and predictable fluidic operations. One of the most important operations is ensuring efficient and reliable fluid metering and transport mechanisms. This paper presents evaluations of a three-valve peristaltic pump for the PLoC system. The evaluations include optimal pumping sequence, mechanical fatigue test, and metering performance. Many different sequences have been proposed for such a micro-pumping system [2-4]; however, none of them systematically analyzed and compared these sequences. We thus propose three dimensionless metrics for identifying an optimal sequence. Moreover, a mechanical fatigue test is investigated for determining the reliability and practicability of the pumping mechanism. Calibration curves for metering are also produced for potential tunable mixing.

EXPERIMENTAL & THEORY

Four pumping sequences are commonly used (see Figure 1a) with 3-valve peristaltic pumps. Stroke flow rates corresponding to different sequences (Figure 1b) are used to derive three dimensionless numbers for performance assessment. ***Diodicity (D)***, a concept originating from the electrical diode, defines the relationship between forward flow and backward flow. An ideal diodicity shows a fully forward flow without backward flow. ***Oscillation number (O)*** reflects the degree of an oscillation phenomenon that is usually observed in a peristaltic pump. ***Output efficiency (η)*** shows the effective volume ratio that can be generated in each cycle. Generally, an optimal sequence yields a high diodicity, a low oscillation number, and a high output efficiency value.

978-0-9798064-1-4/µTAS2008/$20©2008CBMS

Numerical simulations are employed to analyze and quantify the overall behavior of the pump. The experimental measurements are accomplished by particle streaking. Except for the fatigue test, the simulation results provide decent predictions prior to the measurements.

The entire chip is fabricated with PDMS. The fluid and gas channels are both patterned in PDMS elastomers by molding while a thin membrane is sandwiched in between. A PDMS membrane of a thickness approximately 200 μm is achieved by spin-coating. These three PDMS layers are irreversibly bonded using oxygen plasma. The benefits of fabrication entirely with PDMS are (i) excellent material compatibility, (ii) simple fabrication, and (iii) disposable.

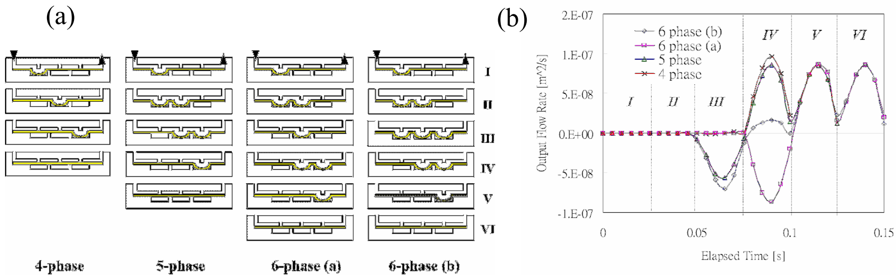

Figure 1. (a) Schematic diagram of the four operational sequences. (b) Plot of stroke flow rate with four different sequences. The control pressure is 10KPa and the phase frequency is 20Hz.

RESULTS AND DISCUSSION

The dimensionless numbers regarding the diodicity, oscillation number, and output efficiency for each sequence are listed in Table 1. The 4-phase scheme shows the best diodicity and oscillation number while the 6-phase scheme (b) shows the best output efficiency. The optimal sequence depends on the significant parameter in each individual application. For example, if the diodicity is more important in a particular operation, then the 4-phase sequence would be the ideal choice.

Table 1. Dimensionless numbers of sequence.

	4-phase	5-phase	6-phase(a)	6-phase(b)
D	0.993	0.661	0.485	0.614
O	1	3	3	4
η	0.386	0.444	0.348	0.454

To test the reliability of the peristaltic pumps under normal operation, a mechanical fatigue test is performed. Fluorescent particles of 3-micron in diameter are seeded in the fluid for visualization. Both flow rate and membrane displacement are measured over a long period of continuous operation. The measurements show no significant changes in either quantity as the number of cycles reaches 2 million. Similarly, previous work conducted by Quake's group also indicates the PDMS membrane is able to withstand at least 4 million operational cycles [5]. It is observed that the PDMS peristaltic pumps can operate without notable performance degradation for a considerable number of cycles.

Mixing is a vital function in a PLoC system. However, previous work mostly emphasizes efficient mixing but ignores tunable mixing [6-7], where variable volumes of fluids can be mixed. Based on metering, tunable mixing can be realized with different ratios of samples. The metering is purely a function of frequency and control pressure. Working under the optimal sequence, preliminary calibration curves shown in Figure 2 demonstrate the potential metering capabilities of the current design and setup. With the same phase frequency and control pressure, the order of output flow rate of sequence is 4-phase > 5-phase > 6-phase (b) > 6-phase (a), which is the same trend as the previous diodicity in Table 1.

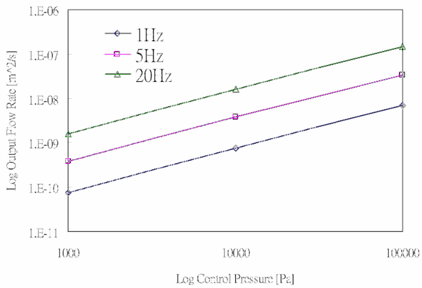

Figure 2. Logarithmic plot of flow rate v.s. control pressure at three different phase frequencies based on a 4-phase sequence. The calibration curves can be potentially used in metering.

CONCLUSIONS

We have characterized the performance of 3-valve PDMS peristaltic pumps using experiments and simulations to find the optimal pumping sequence, fatigue characteristics, and metering behavior. The PDMS pump shows a durable performance. This study will provide the quantitative information required for our later general-purpose PLoC development.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support from NSF Grant CCF-0726821 and Birck Nanotechnology Center at Discovery Park, Purdue University.

REFERENCES

[1] A. M. Amin, M. Thottethodi, T. N. Vijaykumar, S. T. Wereley, and S. C. Jacobson, μTAS 2007, 0926, (2007).
[2] J. Goulpeau, D. Trouchet, A. Ajdari, and P. Tabeling, J. Applied Phys., 98, 044914-1, (2005).
[3] J. M. Berg, R. Anderson, M. Anaya, B. Lahlouh, M. Holtz, T. Dallas, Sensors and Actuators A, 104, 6 (2003).
[4] B. Husband, M. Bu, A. G. R. Evans, and T. Melvin, J. Micromech. Microeng., 14, S64 (2004).
[5] M. A. Unger, H. P. Chou, T. Thorsen, A. Scherer, and S. R. Quake, Science, 288, 113, (2000).
[6] J. M. Ottino and S. Wiggins, Science, 305, 485, (2004).
[7] V. Vivek, Y. Zeng and E. S. Kim, IEEE, Micro Electro Mechanical Systems, MEMS 2000, 668, (2000).