ROBUST LUMPED-ELEMENT MODELLING OF CENTRIFUGO-PNEUMATIC AND SIPHON VALVING TOWARDS HIGHLY PREDICTIVE SIMULATION OF LARGE-SCALE INTEGRATED MICROFLUIDIC NETWORKS

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ABSTRACT

Drastic parameter reduction by lumped-element modelling by descriptors for flow control elements such as hydrodynamic resistance ("resistor") pressure head ("voltage") and flexible parts ("capacitance") is the method of choice for simulating complex centrifugal microfluidic networks. As all liquid on such "Lab-on-a-Disc" (LoaD) systems are subject rotationally induced field, valving techniques are absolutely essential to orchestrate the serial release and processing of on-board samples and reagents.

KEYWORDS: lumped-element simulation, centrifugal microfluidics, lab-on-a-disc

INTRODUCTION

In the past, we have shown that siphon valves can coordinate several liquid handling operations on an integrated disc [1]. However, owing to their large spread in the release frequencies, traditional siphoning and DF valving are subject to inherent uncertainties that make them unsuitable for the here considered large-scale integration (LSI) of LoaD systems. We present here for the first time novel centrifugo-pneumatic design based on the intricate interplay of (water) dissolvable films (DFs) and centrifugo-pneumatic actuation [2] that can mitigate issues arising from poor fidelity of burst frequencies and thus eventually enhance the integration density. Furthermore, a conventional design approach by trial-and error proves to be very cumbersome and time-consuming towards LSI. We therefore support the design by our novel, lumped-element simulation of these pivotal flow control modules [3]. Mohammadi et.al. proposed, utilizing the lumped elment method for simulation of centrifugal microfluidic platform [3]. This will eventually enable LSI microfluidic circuits representing highly parallelised assay panels that can be designed in silico with predictable functionality.

EXPERIMENTAL

The basic construction of the proposed centrifugo-pneumatic valve is presented in Fig. 1a.

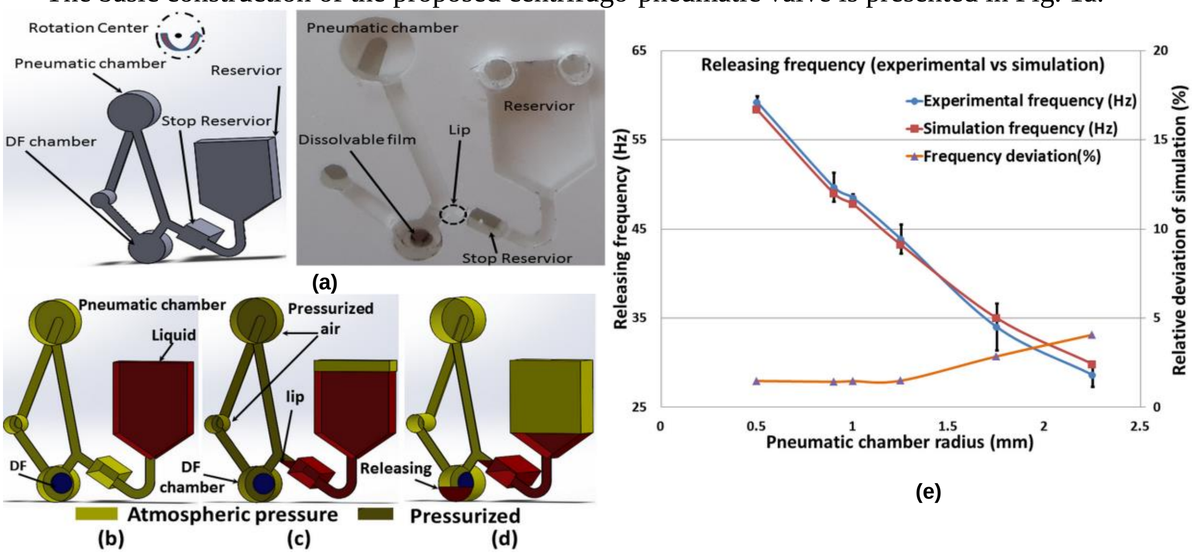

Figure 1: (a) Centrifugo-pneumatic DF valve structure (b-d) Centrifugo-pneumatic DF valves working principle. (e) Release frequency, encompassing experimental and simu¬lated burst frequency. The frequency deviation between simulation and experimental is near 1 Hz.

The liquid is allowed to reach a lip while advancing radially inward from the liquid reservoir before it opens to the DF-sealed chamber (Fig. 1b-c) The DF is now placed at the bottom of this chamber, leading to film dissolution, even with the smallest degree of wetting from the incoming liquid. The release frequency depends on the radial position and the size of the pneumatic chamber. In addition, the working principle of the traditional siphon valve and siphon disc are shown in Fig. 2a-c.

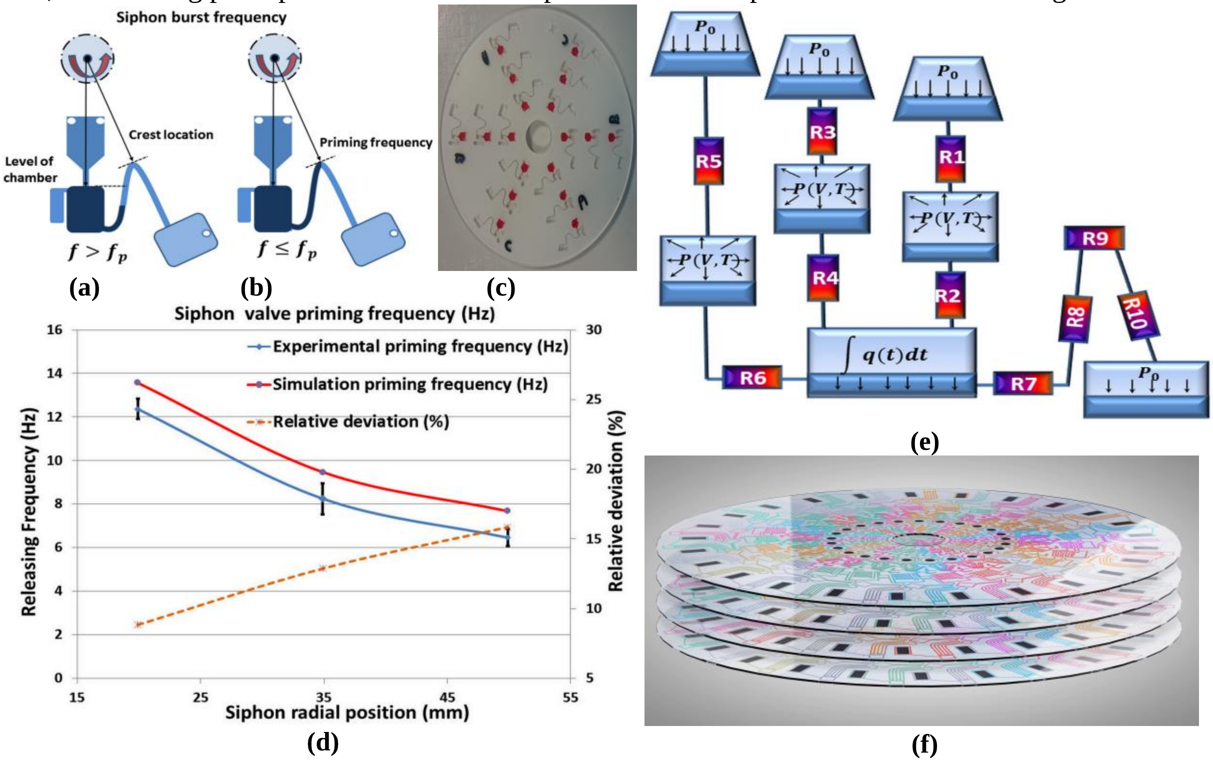

Figure 2: (a, b) Siphon working principal, driving fre-quency above and below priming frequency. (c) Siphon valves staggered in three radial positions on a disc. (d) Experimental and simulation priming frequency vs radial position and relative deviation on right y-axis,(e) Lumped element network constituted by three centrifugo-pneumatic DF valves and one siphon valve. (f) Artist's impression of microfluidic LSI on a centrifugal Lab-on-a-Disc platform.

RESULTS AND DISCUSSION

The novel centrifugo-pneumatic valve and a traditional siphon have been simulated utilizing our novel lumped element simulation tool [3]. Figures 1e and 2d show good agreement between the simulated and experimentally observed release frequencies of our new, centrifugo-pneumatically valves and conventional siphon valves, respectively. The lumped element network of three centrifugo-pneumatic DF valves and one siphon valve are shown in Fig. 2e.

CONCLUSION

This simulation tool addresses a key gap in the design of LoaD microfluidic products that has obstructed the commercialisation of sample-to-answer systems. This robust lumped element simulation tool will facilitate the progressive miniaturization of the microfluidic network to significantly enhance the integration density (artist's impression in Fig. 2f), and thus boost the overall cost efficiency and functionality of the LoaD platform.

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