THE CENTRIFUGO-PNEUMATIC LAB-ON-A-DISK PLATFORM: TOWARDS ROBUST FLOW CONTROL FOR LARGER-SCALE FUNCTIONAL INTEGRATION

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ABSTRACT

This work shows for the first time how unavoidable tolerances in manufacturing and experimental input parameters have a decisive influence on the reliability of flow control in Lab-on-a-Disk (LoaD) platforms and must therefore be considered towards larger scale fluidic integration (LSI).

KEYWORDS: Lab-on-a-Disc, Pneumatic Valving, Centrifugal Microfluidics

INTRODUCTION

With their increasing commercialization, assuring operational robustness under economically viable manufacturing schemes becomes paramount for microfluidic Lab-on-a-Chip systems. With the example of centrifugo-pneumatic Lab-on-a-Disk (LoaD) platform controlled by dissolvable-film (DF) valves [1, 2], this work illustrates for the first time how unavoidable tolerances in manufacturing and experimental input parameters such as channel dimensions, contact angles, liquid properties and environmental conditions critically affect the reliability of flow control, and thus need to be imperatively addressed towards larger-scale fluidic integration (LSI).

PROCEDURE

Operational robustness of the LoaD platform is mostly linked to centrifugo-pneumatic valving. For the sake of gaining a qualitative understanding in this work, it is sufficient to focus on its simplified concept (Fig. 1) consisting of a reservoir open to atmosphere, an isoradial microfluidic outlet channel where the forward meniscus is located in hydrostatic equilibrium and a pneumatic chamber filled with gas compressed by the centrifugal field. Specifically, it is essential that the meniscus at the axial position z is not in contact with with the DF placed further downstream in its (normally) closed state as a result of the various statistical tolerances. The location z scales with the rotationally induced pressure $p_\omega = \varrho \bar{r} \Delta r \omega^2$ with the liquid density ϱ and the angular frequency $\omega = 2\pi\nu$ as well as the mean radial position $\bar{r}$ and the net radial liquid level difference Δr. Hydrostatic equilibrium is reached when $p_\omega + p_0 = p_0 \cdot V_0/V$ with the ambient pressure p_0 as well as the volumes V_0 and V occupied by the gas with the disk at rest and spinning at ω, respectively. In our Monte Carlo simulations for factoring in the impact of their statistical variations, all input parameters are spread according to a normal distribution possessing a width set by their individual standard deviations; the z-positions is a function of $p_\omega \propto \omega^2$.

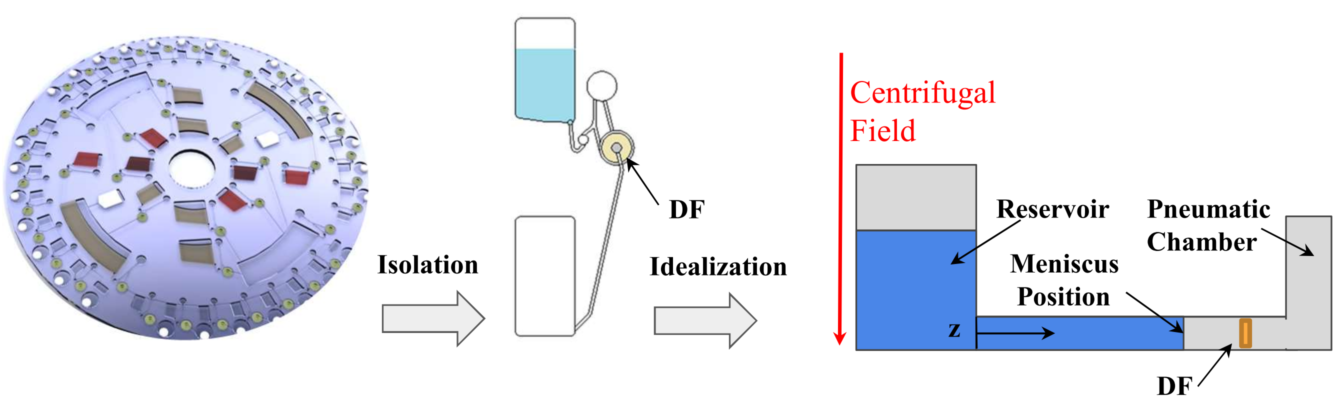

Figure 1: (Left) Example of functionality of a highly integrated disk. (Centre) Normally-closed centrifugo-pneumatic dissolvable film (DF) valve on a typical disk. (Right) Simplified valve structure.

RESULTS

To experimentally confirm our model and simulation, we placed 13 such valves at different radial positions. The measured meniscus positions z reside within the 95%-confidence interval provided by the Monte-Carlo simulation running 10,000 iterations. Figure 4 illustrates how operational robustness is achieved by reserving a pressure $p_\omega \propto \omega^2$ and thus frequency band for each centrifugo-pneumatic valve that needs to be opened separately on the same disk, representing the key requirement towards larger-scale functional integration of the LoaD platform. Finally, Figure 5 depicts the strong influence of the ambient pressure, e.g. due to weather or altitude, and of thermal shrinkage in the context of injection moulding on the meniscus position. These systematic deviations may be measured locally and flexibly compensated through adjusting p_ω through the spin rate ω on the spot.

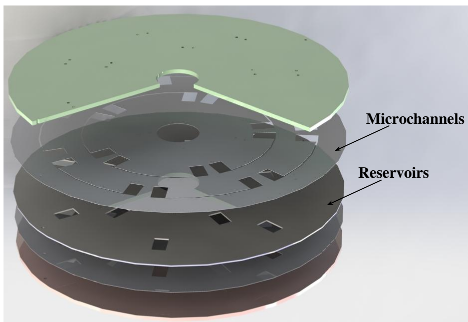

Figure 2: Experimental design of 5-layer disk.

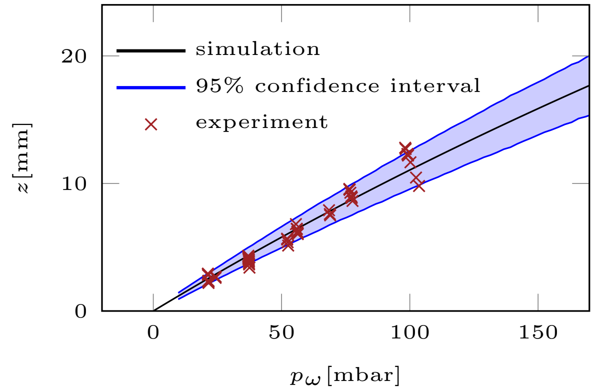

Figure 3: Simulated meniscus position z vs. centrifugal pressure $p_\omega = \varrho \bar{r} \Delta r \omega^2$ with the mean radial position $\bar{r}$ and extension Δr of the liquid segment in comparison to experiments.

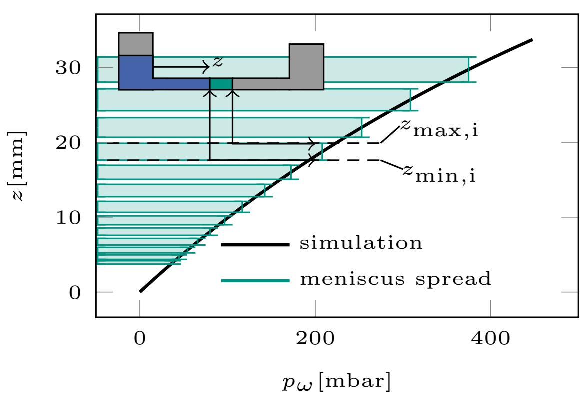

Figure 4: Statistical spread of meniscus position along z-axis caused by experimental uncertainties of the input parameters within a 95% confidence interval.

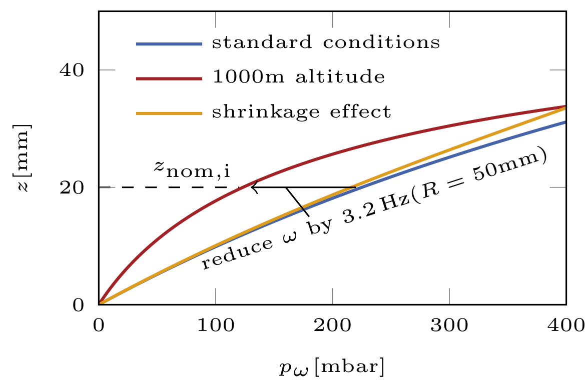

Figure 5: Influence of the ambient pressure and manufacturing related shrinkage effects on the meniscus position z. The diagram teaches how these systematic errors may be compensated by the spin-rate dependent pressure p_ω.

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