MODELING AND OPTIMIZATION OF PIEZOELECTRIC MICROPUMPS FOR BIOMEDICAL APPLICATIONS

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INTRODUCTION

This work aims at realizing one micropump for biomedical applications whit the following requirements: a flow-rate of 10 ml/s and maximum dimensions of 2-3 cm. This paper describe a method for optimising the performances of piezoelectric micropumps with a circuit simulator as SPICE.

The idea to construct the equivalent network arises from the analogy between the microfluidics and electrical systems [1]. This method has been applied to two micropumps taken from literature: the first one uses diffuser valves as proposed by Ullmann [2], the other one uses membrane valves as proposed by S. Bohm [3]. SPICE's simulation of both models gives data which are in good agreement with those reported in literature and so, this could be a good starting-point for the project. We have modified the dimensions of the micropump and recalculated network parameters in order to increase the flow-rate. In this way we are theoretically able to obtain a maximum flow-rate of about 450µl/s for the first kind of micropump, and a maximum theorical flow-rate of 5 ml/s for the second one.

Modeling and Simulation

Both micropump we have studied have a piezoeletric actuator, bonded on a silicon membrane. The difference is in the valves. In fact the first micropump [2] is realized with no-moving parts valves (diffuser valves) as in Figure 2. The second one [3] presents valves with membrane, as shown in figure 1

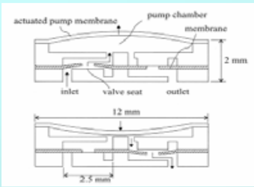

Figure 1 Micropump with membrane valves

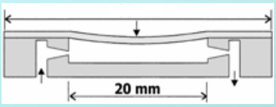

Figure 2 micropump with no-moving parts

We have modelled the different parts of each pump with lumped elements. The electrical equivalent network of the micropump whit diffuser valves is shown in the figure 3. The micropump with membrane valves, can be modelled with a circuit similar to the one reported in figure 3. In this case, however, the valves present capacitive elements simulating the moving parts. The values of RLC components have been calculated from the geometric dimensions of micropumps and the mechanical property of materials

Simulating the circuits with SPICE, we have found that the flow-rate of both micropumps is reproduced very well (fig. 4-5) [2-3]. We can observe that the maximum pump performance is obtained at the resonance frequency that is the same for experimental results and simulations.

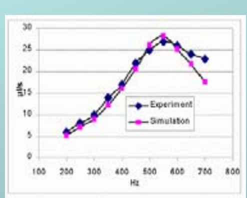

Fig.4: micropump with diffuser valves

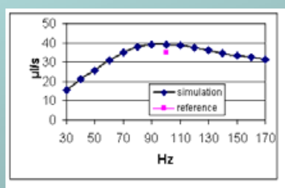

Fig.5: micropump with membranes

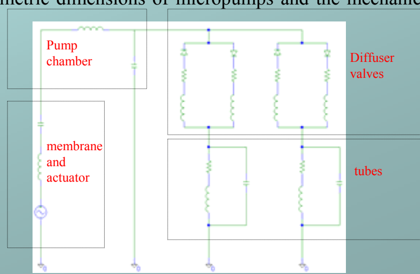

Fig.2: Electric equivalent network of a piezoelectric micropump

Optimization and Results

For optimising the micropump's structure, we have acted on valve's dimensions and on the parameters of the membrane and the pump chamber, in order to achieve the desired specifications. Sizes can be varied as long as the mechanical stress in the membrane is maintained below the maximum value of fracture stress limit σ_f .Valve's features that could be modified are length, section and aperture's angle.

In this case, a limit in performance is given by the efficiency of valve-tube system εseries

$$\varepsilon_{serie} = \frac{R_+ - R_-}{R_+ + R_- + 2R_{tubo}} \quad (1)$$

We have found that diffuser valves have very low values of efficiency (ε=0.3 for $R_- = R_{tube}$). Instead, the efficiency of membrane can be close to unit (ε=0.96 for $R_- = 0.13R_{tube}$).

Other parameters critical for the optimisation are thickness and radius of membrane and pump chamber's volume. Working on these factors, we have reached a flow-rate of 450 µl/s, instead of 35 µl/s reported in literature [2], for diffuser micropump. The flow-rate obtained for membrane's micropump came to 5100 µl/s, compared to the 28 µl/s reported in the literature[3] (Fig. 6)

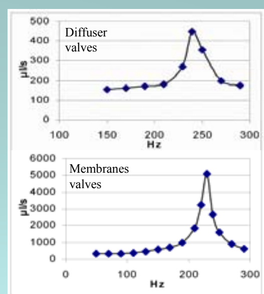

Fig. 6: Optimized flow-rate

CONCLUSIONS

Starting from the analysis of a piezoelectric micro pump designs we have shown that an important condition for optimum performance is a suitable impedance matching between the valves and tubes, i.e. $R_- = 1 \div 3\ R_{tubo}$.

The efficiency of a micropump with diffuser valves optimized is about ten times greater than that reported in literature. This value reach the hundred in the case of valves with membranes.

In conclusion, we can assert that the circuit simulation is a valid method, even if simplified, to predict the behaviour of micropumps in terms of flow rate. Further accurate analyses aimed to verify these results, according to structural and technologic considerations, are foreseen.

REFERENCES

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