TECHNOLOGY AND APPLICATIONS OF MICRODOSING SYSTEMS

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Abstract: Meeting demands of industrial customers of micro fluidic actuators in application fields like drug delivery systems, lubrication dosing or lab technology, a black box concept has been carried out. Various practical problems and drawbacks of micro pumps like weak dosing accuracy, particle vulnerability, gas bubble intolerance, back pressure dependence and free flow problem are addressed and solved within that black box. To solve these particular problems new concepts and ideas as well as a theoretical understanding and technological optimization of the challenges of the micro dosing systems has been realized.

Feroelektrične tanke plasti izdelane z metodo kemijskega nanosa iz raztopine, CSD – načrtovanje lastnosti s pomočjo molekularne strukture

Kjučne besede: mikrodozirni sistem, črna skrinjica, mikročrpalke

Izvleček: V zvezi z zahtevami industrijskih kupcev mikrofluidnih aktuatorjev na področju dozirnih sistemov za uvajanje zdravil, odmerjanja lubrikantov ali laboratorijskih tehnologij, je bil raziskan koncept črne skrinjice. Veliko praktičnih problemov in pomanjkljivosti mikročrpalk kot npr. slaba dozirna natančnost, občutljivost na delce, netoleranca na plinske mehurčke, vpliv protitlaka in problem prostega toka je rešen s konceptom črne skrinjice. Za razrešitev teh problemov so bili realizirani novi koncepti, ideje, teoretično razumevanje in tehnološko optimiziranje mikrodozirnih sistemov.

1 Introduction

Micro devices especially for micro fluidic applications can be applied to a wide variety of industrial solutions. Key components are micro pumps /1/, micro dosing systems, micro mixers, micro valves, micro reactors and flow sensors and their combination for the use in biotechnology, chemistry and medicine. Furthermore, applications in the field of lab technology and fuel cells can be addressed. Challenges in that field are addressing the improvement of the reliability, dosing accuracy and user safety by the integration of free flow protection, bubble point free filters and improved dosing accuracy to the micro pump modules. Another trend is the development of complete systems, including electronics, sensors and system control.

2 Black box strategy

Piezoelectrical driven micro fluidic actuators like micro pumps can be used in many applications. Requirements like dosing accuracy, back pressure independence, small size, low energy consumption, particle resistance and free flow protection are leading to new technologic solutions to develop the micro pump from a demonstrator to a industrial product. The user of the micro pump is expecting a complete solution from the developer solving all of these requirements. This "black box" approach will be realized solving the requirements above helping the customer to launch new products.

Most user of a micro dosing system have the following task to be solved for their application: there is a given liquid, which has particles and gas bubbles inside, and which is on an inlet pressure level *p1*. The task now is to ensure a given flow rate *Q* also at varying outlet pressures *p3* without particles and without bubbles at a defined dosing accuracy and avoiding any free flow. The ideal black box has to fulfill all of these demands (fig. 1).

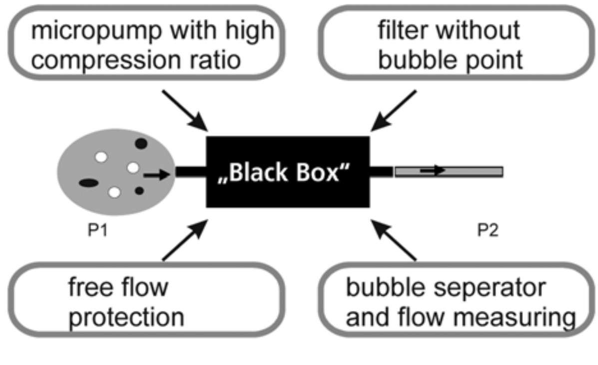

Fig. 1: Black box concept. Main general microdosing problems are solved within that black box.

The best performance for a dosing task show, beside conventional miniature pumps, piezoelectric driven micro diaphragm pumps with passive check valves. However, it is evident, that no micro pump on the market can meet all of these demands. A black box must be developed around the micro pump.

2.1 Dosing accuracy and back pressure independence

Micro diaphragm pumps are back pressure dependent, current state of the art micro pumps achieve a liquid back pressure of about 50…100 kPa and a air back pressure of about 10…25 kPa. To overcome these limitations, a silicon micro pump has been realised at the Fraunhofer EMFT with a very high compression ratio not known from other micro pumps on the market. With that, the dosing accuracy will be independent to the presence on gas bubble in the pump chamber, which is one of the main reason limiting dosing accuracy of state of the art micro pumps.

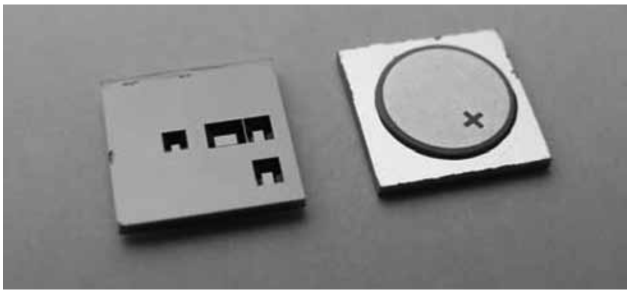

Fig. 2: New high pressure micro pump bottom side (left) with inlet and outlet ports and fluidic ports for safety valve, and top side (right) with the round piezo.

This pump (fig. 2) with a chip size of 7x7x1 mm^3 can achieve a maximum back pressure with liquids of 600 kPa and an air back pressure of 90 kPa, both values are a factor of three above the state of the art.Both performance data ensure a nearly back pressure independent flow rate and a very good bubble tolerance, two preconditions for a practical dosing accuracy.

Fig. 3: Pump cube compared to a sugar cube. The system comprise a silicon micro pump chip, driver electronics together with micro controller, silicone gasket, fluidic carrier, and battery. The Pump cube is the smallest pump system worldwide.

2.3 Small size

The silicon micro pump with a size of 7x7x1 mm3 is one of the smallest pump of the world. Together with a very small driver electronic a „pump cube“ system was developed, with a total size of less than 1 cm^3 including Battery and fluidic carrier.

2.4 Small energy consumption

The driver unit was based on a boost converter technology:

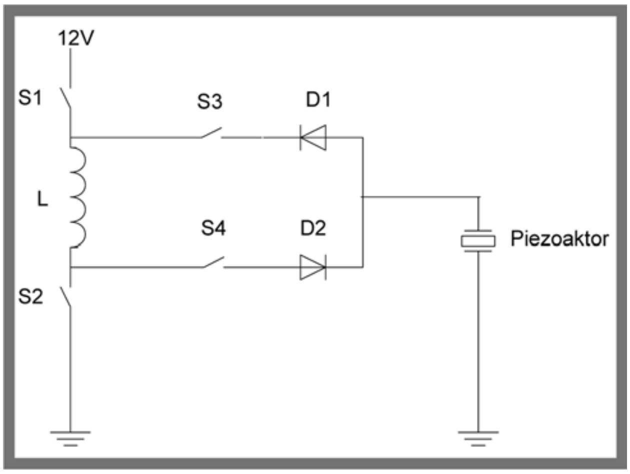

Fig. X: Boost converter.

The electrical driver unit was optimised, the energy consumption is between 40 mW and 500 mW, dependent on piezo capacitance, driving voltage and pump frequency. These systems are ideal for battery driven systems.

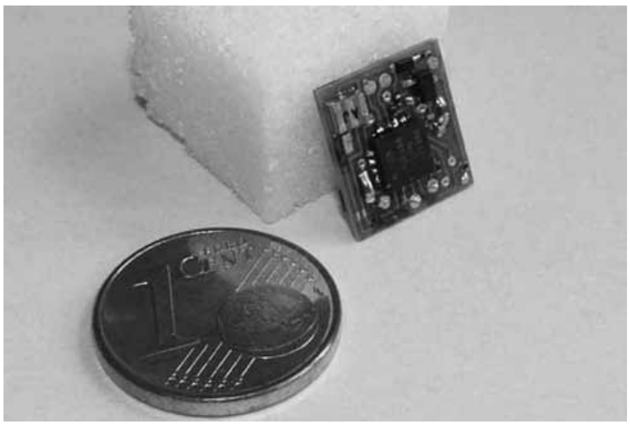

Fig. 4: Miniaturised driver unit: size 10mm x 11mm x 4mm, from +100V/-40V rect. @ 8nF load, up to +250 V/-100 V rect. @ 10nF load, max. 500Hz, input 3.3 to 5 VDC, power <40mW @ 100Hz and +100V/-40V, efficiency factor 23 %, PC comm. RS232.

2.5 Particle resistance

Particles pumped into the micro pump by the pump itself can block valve flaps or actuation diaphragms, leading to a pump failure. Regularly, a hydrophilic filter with small pore size is needed. However, this filter will have a high bubble point, a large gas bubble can block the filter stopping the pump working.

In the micro pump community, this problem is under estimated, and can be a show stopper for micro pumps generally: micro pumps are vulnerable even to small particles. Even if the liquid is "clean" just one particle is enough to kill the micro pump. Every particle will travel through the bottleneck micro pump. For that, micro pumps need in any case a filter with a pore size of a few micros. But if they have that filter, a gas bubble will block that filter, and the micro pump stops pumping, too. The bubble point pressure Δp of a filter is defined as the pressure difference a gas bubble can pass the filter, and dependent on the pore size D of the filter (wetting angle Θ, surface tension σ):

$$\Delta p = \frac{4\sigma \cos\Theta}{D} \qquad (1)$$

This problem was solved by a new patented filter without bubble point, which has no blocking pressure even if a large bubble is entering the filter.

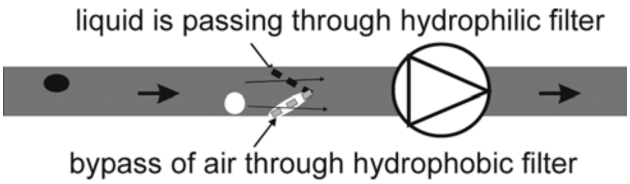

Fig. 5: bubble tolerant filter, which can not be blocked by gas bubbles by a hydrophobic gas bypass.

With that bubble tolerant filter, every particle is filtered, the liquid is passing through the hydrophilic filter, whereas the bubbles can bypass through the parallel hydrophobic filter without pressure drop.

2.6 Free flow protection

In many applications, especially medical application, "free flow" must be prevented, if the reservoir is pressurised, no flow through the pump is allowed.

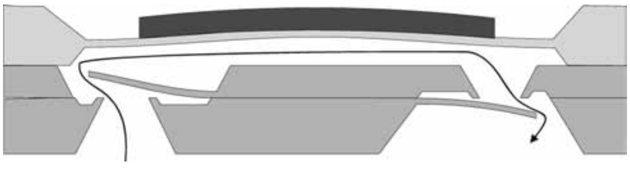

Fig. 6: "free flow" problem of micro pumps with passive check valve: if the inlet reservoir is pressurized, the passive check valve will open even if the pump is off, and unwanted flow occures.

At Fraunhofer EMFT several solutions were developed and patented, a "normally double closed (DNC)" micro valve /2/, and a new safety valve as described below. Both valves are passive and self blocking, the over pressure at the inlet is closing the valve. Fig. 7 shows the concept of the safety valves:

within the silicon micro pump chip a safety valve channel with valve seat is realised during the KOH etching process steps. Next, a rubber diaphragm is mounted to the pump chip.

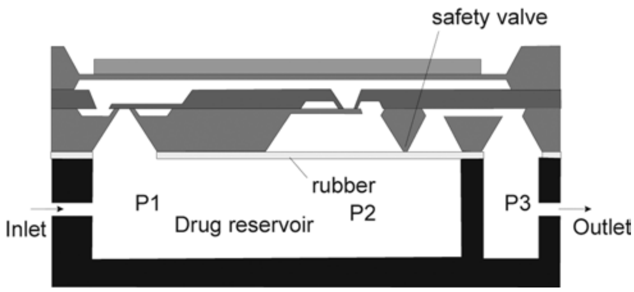

Fig. 7: safety valve concept: a rubber diaphragm is aligned to the silicon chip which prevents free flow.

Upon application an over pressure at the inlet, the rubber diaphragm is pressed to the valve seat in the chip closing the valve and avoiding free flow. The rubber diaphragm is pressure balanced until the region of the outlet hole, for that the micro pump can open the valve by the over pressure of the pump stroke. Fig. 8 shows measurement results, and a very good function of the safety valve:

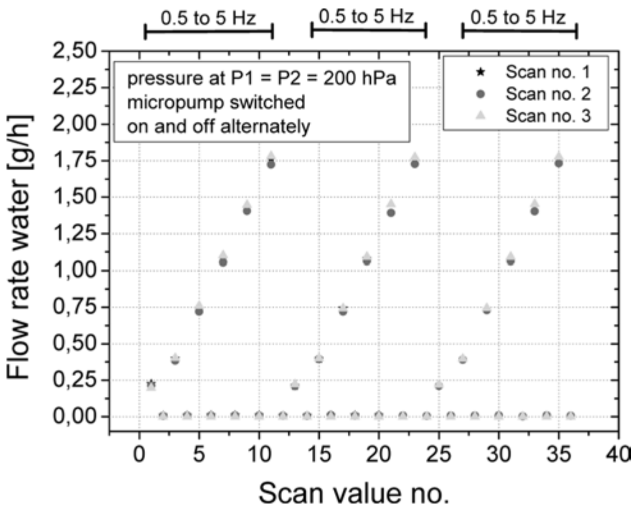

Fig. 8: Test of the safety valve with an inlet pressure of p1 = p2 20 kPa, outlet pressure p3 = 0 kPa. The pump switched between ON and OFF state, with different frequencies. The safety valve closed reliable if the pump is OFF.

3 Conclusions

In this paper, methods for a reliable operation of micro dosing systems based on micro pumps are discussed. Bubble independent operation can be nearly achieved with a micro pump with high stiffness of the actuator unit. Bubble tolerant and bubble independent operation is realized by a very high compression ratio. Miniaturization of the packaging and the energy efficient pump driver electronics is the precondition for small size and battery operation. Micro pumps must be protected by particle filter, a bubble tolerant filter is needed to avoid a blockage of that filter by bubbles. Last but not least a free flow protection is needed especially for medical applications. A new safety valve integrated at the micro pump can avoid free flow in a reliable matter.

With that, integration of all of these components into a small and portable device opens the door to many new micro dosing systems.

Acknowledgments

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