Intrinsic Flow Control of a Piezo Membrane Pump

Dahms, Severin
Bartels Mikrotechnik GmbH
Emil-Figge-Str. 76a, 44227 Dortmund, Germany

Introduction / Motivation

The market for micropumps is steadily emerging especially in the field of medical products. In some applications however membrane type pumps suffer from flow rate dependency on backpressure for example. This disadvantage can be overcome by implementing flow control. While a few approaches with off the shelf micropumps and flow sensors have been demonstrated, up to now, no closed loop controlled system with a fully integrated flow sensor is on the market.
Here an innovative approach using the pump itself as a flow sensing element is presented. Keeping the small footprint of a standalone pump without adding major costs, a competitive alternative pump approach for applications like infusion devices is presented. Due to the innovativeness of this approach a patent on the measurement setup has been granted [1].

Technical Realization

Core component of the system is the piezo membrane pump mp6 that has been available since end of 2008. The basic principle of the pump can be seen in figure 1 where the pumping cycle is schematically shown. The piezo actuator (in blue color) moves upwards and downwards based on the applied voltage and passive valves in the fluidic channel (in red color) rectify the flow to generate a directed pumping effect. By varying the driving voltage and frequency, the flow rate of the pump can be adjusted in a wide range from several µl/min up to 6 ml/min. The driving voltage determines how much volume per stroke is conveyed, the frequency determines how often this process is repeated each second. Typically the pump is operated at frequencies in the range of 100 Hz. While typically only single stage pumps are common [2] in the mp6 two actuator stages have been connected behind each other. Besides the capability to handle backpressures of up to 550 mbar, this increases robustness and reliability of the device. In addition this unique double actuator configuration enables the integrated flow control system. Because only one biocompatible polymer is in contact with the fluid and the whole manufacturing process allows full traceability, the pump is well equipped for medical applications. The fully assembled pump can be seen in figure 2.

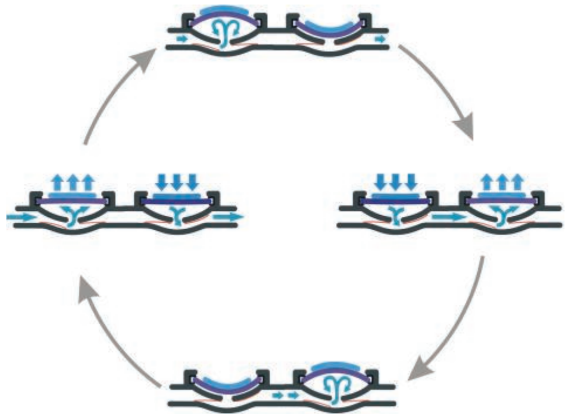

Figure 1: Pump cycle of the piezo membrane micropump

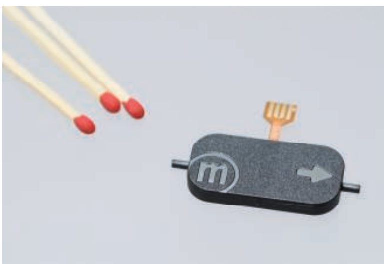

Figure 2: Micropump mp6

At this point, we have explained that the pump rate can be adjusted to a certain extend. Due to external influences like a changing backpressure, the operating point of the pump is shifted an therefore the pump rate will change if the driving parameters are not re-adjusted. Operation under a transient backpressure profile requires closed loop control of these parameters.
While normally this is realized with an additional sensing element, this concept has a few drawbacks. Especially for medical applications an additional element is in interaction with the working fluid which should be avoided from the biocompatibility standpoint. Secondly, adding a sensor adds cost and efforts for assembly. Therefore the scope was to enable flow control without the use of additional components, only based on the double actuator piezo micropump. Key to this functionality is the fact that the piezo effect is reversible so it can not only be used for actuation but also for sensing. This is widely used in industrial pressure sensors for example.

Figure 3 shows the schematic of the intrinsic flow control. On the bottom of the picture, the mp6 micropump without the top lid is shown. Therefore the two round shaped piezos can be clearly seen. Generally speaking during controlled operation, the pump is driven in two different modi. In full actuation mode, both piezos are used as actuators, providing full flow performance. In sensing mode, the first piezo is still working as an actuator, providing flow pulses in the fluid path. The second piezo is connected with a sensing electronic, so the feedback of the pulses from the first piezo can be measured. Based on the feedback signals, the amplitude of the driving signal is controlled to keep the flow rate on a constant level. In order to diminish the loss of pump performance during sensing mode, the signal processing has been optimized to be able to operate continuously in both modes. As the piezo elements used in the pumps are optimized for effective actuation from manufacturer side, the accuracy and the capability of addressing low flow rates is limited.

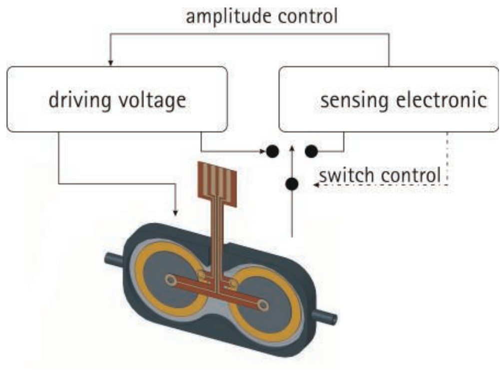

Figure 3: Principle of the intrinsic flow control

Besides flow control, additional safety features can be implemented based on the same effect. If the reservoir is empty, the system will be able to detect the gas in the first chamber. In this case, the pulsations will not be transmitted because of the compressibility of the gas. As the second chamber is still filled with liquid, the introduction of air bubbles into the outlet can be avoided. In addition occlusions in front and behind the pump can be detected. In any case the pump will send a warning signal, if the target flow rate can no longer be reached due to any reason.

Figure 4: Prototype electronics and pump

Taking a look at the overall complexity of the system, from pump side, this approach is fully based on a proven, mass produced component. Using the controlled loop principle, additional effort is necessary regarding the driving electronics. As the signal processing has been developed with the goal of integration into a microcontroller, small device size and battery operation are ensured to keep the portability aspect of the system. In addition, a calibration step needs to be carried out for the pumps. Dependent on the target flow range different calibration procedures can be applied. As the calibration has been automated using a pressure calibrator in combination with a reference driving electronics and a flow sensor, implementation into the quality test of the pump production line is ensured. For system characterization, a bench top controller has been developed which is shown in figure 4. Loading the calibration data of specific pumps onto the controller enables the use of different pumps in flow controlled mode with a single driving electronics.

Results

To test the performance of the controlled micropumps, a test setup was used providing different backpressures and verifying the flow rate with a reference flow sensor. The water reservoir of the device under test was pressurized with a high performance pressure calibrator type DPI-515 from General Electric. Using the pump with purified water, the flow was measured with a Bronkhorst L23-ABP-11-K-70S flow sensor. The tests revealed an accuracy of better than 10% for a flow range of 500-5000 µl/min at maximum backpressures of 500 mbar. At higher flow rates however, the maximum backpressure is limited as the performance limit of the pump is reached earlier.
An example of a flow performance graph can be seen in figure 4.In the figure, the performance limit can be clearly seen on the right side of the flow curves. Apart from that, the flow rates remain stable at varying backpressures which demonstrates the correct operation of the system.
The graphs show flow rates of 4000 down to 500 µl/min which have an accuracy better than 10%. The graphs include the data from 12 repetitions, all measurements are within the accuracy window. The repetitions showed that no short term effects on the accuracy occurred in the setup.

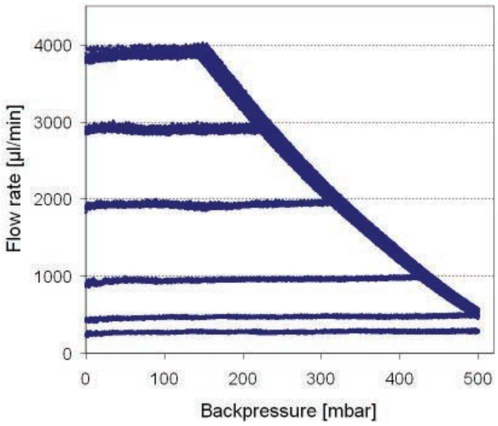

Figure 4: Performance graph, flow rate at different backpressures, 12 repetitions

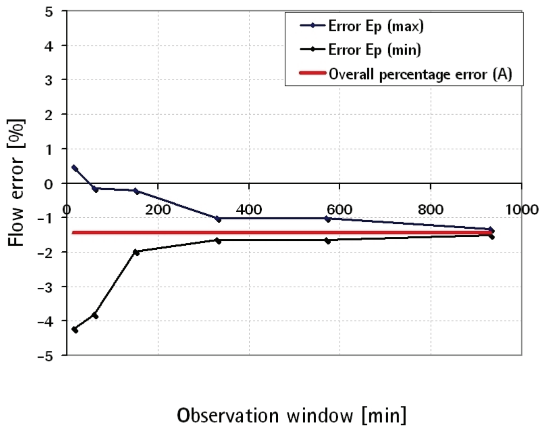

Figure 5: Trumpet curve according to IEC-60601-2-24 at 1.25 ml/min

As one of the target markets is the field of infusion devices, additional measurements according to the IEC-60601-2-24 standard determining the accuracy of infusion devices were carried out. These curves are typically referred to as “trumpet curves”, as they converge towards the maximum accuracy from left to right. The graph shows the flow deviation dependent on the length of the observation window. Generally speaking within an observation window, flow deviations in the positive and negative direction have the chance to level out, so symmetrical short term deviations do not play a significant role in larger observation windows. Therefore the deviations typically decrease with increasing observation length.

Before measuring the trumpet curve, according to the standard a startup period of 24 hours for stabilization is performed. Here, as the system is very dynamic and stabilizes quickly, the startup phase was decreased to 20 minutes. For a target application this means faster flow adjustment and better response to an influence from external staff or others. Figure 5 shows the flow deviation according to IEC-60601-2-24. The total error in this measurement at 1,25 ml/min is less than 5 %, while the absolute error is in the range of 1,5 %. Although the system was primarily tested for a flow range of 500 – 5000 µl/min, lower rates of about 300 µl/min have been successfully addressed as it can be seen in the lowest graph of figure 4.

Discussion

Coming from the theoretical background that the piezo effect can be reversed, it has been successfully demonstrated, that this effect can be used for intrinsic flow control of a pump. Although for example the combination of a piezo ignition element with a pressure sensor is on the market for automotive applications, this is the first time that a built in flow control for a piezo pump has been realized.
The flow range of 500 – 5000 µl/min can be addressed with accuracies better than 10%. Taking the compact size and the low weight into account this approach offers large opportunities for ambulatory devices. Based on IEC 601601-2-24 the performance shows faster response and errors in the range of systems on the current market.

Conclusion / Outlook

A novel approach for flow control in piezo pumps has been explained and demonstrated. Based on individual requirements from medical applications, optimization of both calibration procedure of the pump and the electronics is underway.

Literature

[1] Deutsches Patent und Markenamt, Patentschrift DE102006062552B4
[2] D J Laser, et al, 2004 J. Micromech. Microeng. **14** R35-R64, DOI: 10.1088/0960-1317/14/6/R01
[3] S Dahms, et al, 2009 IFMBE Proceed., Volume 25/7, 183-186, DOI: 10.1007/978-3-642-03885-3_51
[4] Deutsches Institut für Normung, DIN EN 60601-2-24:1998, Besondere Festlegungen für die Sicherheit von Infusionspumpen und Infusionsreglern