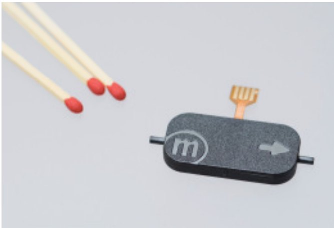
Application Note

Operating Micropumps at Low Flow Rates

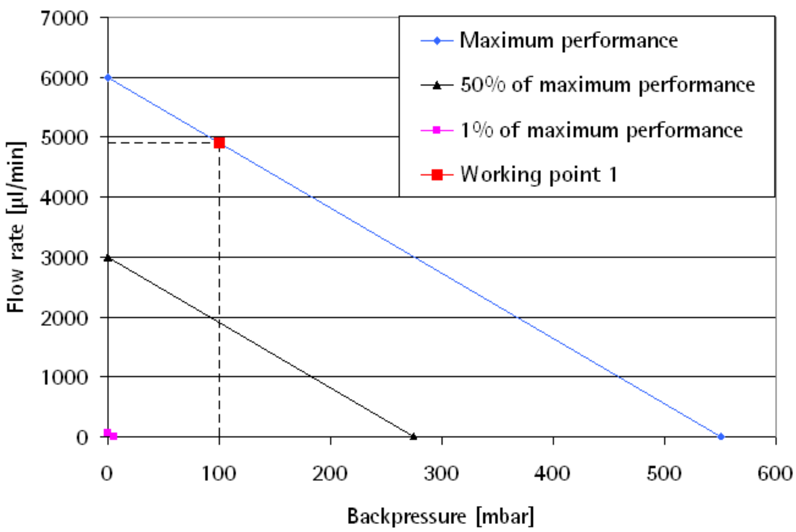
In the following application note, achieving low flow rates with the micropumps of Bartels Mikrotechnik will be discussed. All formulas and values listed are considered typical or estimated values. The real results may vary based on the individual test and system conditions. In comparison to the micropump mp5, the mp6 micropump is recommended for all applications requiring low liquid flow rates, as it is more stable in terms of flow rate and compression rate. Therefore all further assumptions and examples are carried out based on the mp6 pump.



Micropump mp6

Flow characteristics of the mp6 micropump

Considering the maximum performance of the mp6 micropump which is specified with 6000 µl/min flow at no backpressure and 550 mbar maximum pressure at no flow rate, a characteristic performance curve of the pump can be obtained. At a fixed set of parameters, the pump will operate at a certain point of this curve determined by the application conditions. In the following diagram different curves are indicated. The blue graph represents the typical maximum performance of the mp6 micropump, when it is running at 250 Vpp and 100 Hz. Operating at a backpressure of 100 mbar, the pump runs in the working point 1, where it reaches a flow rate of about 4900 µl/min.

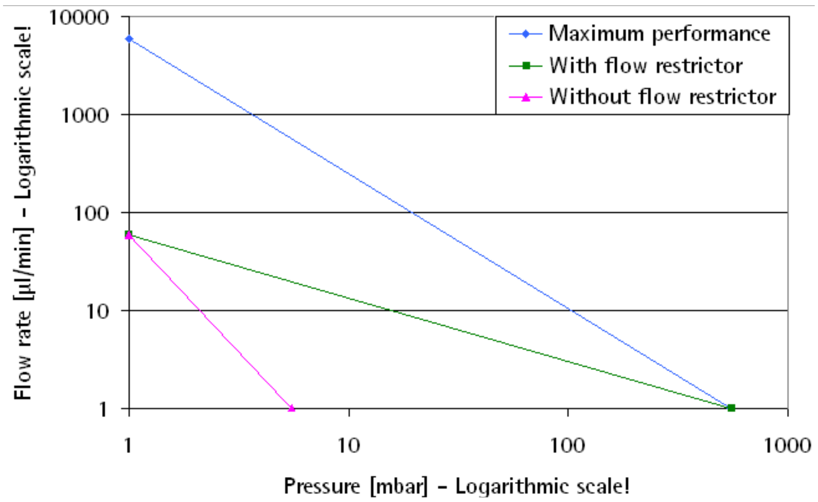


Bartels Mikrotechnik GmbH, Emil-Figge-Str. 76a, 44227 Dortmund, Germany
www.bartels-mikrotechnik.de, microComponents@bartels-mikrotechnik.de
Tel: +49-231-9742-500, Fax: +49-231-9742-501

The most important fact is that by adjusting the operating parameters of the pump, the characteristic curves will always be parallel lines. Therefore running the pump at half performance, the pump is not only limited to half of its maximum flow rate but also to half of its maximum backpressure (black graph). It gets more drastic, when the pump is operating at extremely low driving parameters. At 1 % of the maximum performance (for example running the pump at about 80 V and 3 Hz) it will be running at 60 µl/min maximum (1 % of 6000 µl/min), but it will also only be able to reach 5,5 mbar of pressure (1 % of 550 mbar). Considering that 1 cm of height difference corresponds to 1 mbar of pressure change shows, that running the pump under these conditions, it will be very fragile to varying external conditions. Changing the height by 1 cm in the latter example will result in a flow change of almost 20 %!

Implementing a flow restrictor

Based on these characteristics, it would be ideal to be able to alter the slope of the pumps characteristic curve. This can be achieved by adding a flow restrictor, which, simply speaking, is a section of the outlet tube having a reduced diameter in comparison with the rest of the tubing. In the simplest case it can be a short piece of narrow tubing, in a more specific case it might be a precision orifice with a very exact inner diameter. As the flow resistance by the orifice is dependent on the speed of flow, it acts very well when a flow is present. At zero flow the orifice does not have a significant effect. Therefore only the maximum flow rate is reduced, but the (static) backpressure capability is kept on its initial level. The effect is shown is the following diagram.



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Again, the maximum performance is plotted in blue and the 1 % performance without the restrictor is plotted in pink. If a flow restrictor is used and the pump is operated at maximum parameters (250 V, 100 Hz) it is possible to lower the flow rate to the 1 % level but keep the maximum pressure capability. This is indicated by the green graph. Please notice that the scales of the diagram are logarithmic and therefore the maximum performance and 1% performance lines are not parallel anymore.

As the fluidic resistance of the restrictor is dependent to the power of 4 (!) to its diameter but only linearly to the length, the orifice diameter is the most significant parameter to chose. Typical diameters are in the range of 100 – 250 µm or below. Besides the great advantages, the orifice design also needs to be considered carefully, as variations in the orifice diameter may lead to significant performance deviations in the final product. In order to find the best compromise of cost and performance, Bartels can help implementing the right flow restrictor for your specific application.

Determining the driving parameters

As the real flow rate is dependent on the individual application conditions, the driving parameters need to be determined on an application specific basis. The two governing parameters are a) The amplitude or driving voltage (specified in Vpp) which determines how strong one single stroke is and b) The driving frequency (specified in Hz) which determines how many pump strokes are done per second. As a general guideline, it is better to do few stronger pump strokes over time in order to achieve stable performance. In other words: The pump amplitude should be kept as high as possible, and the pump frequency should be reduced. If the target flow rates require lowering the pump amplitude below about 100 Vpp using a flow restrictor as described above should be considered. As a general rule of thumb, the flow rate can be assumed to decrease linearly with decreasing driving voltage. Decreasing the frequency also results in an approximately linear decrease in flow rate.

Pulsations

Even though the Bartels micropumps have very small variations in flow over time compared to peristaltic or larger membrane pumps, they are not completely pulse-less. As a rule of thumb, the maximum single stroke of the pump (at 250 Vpp) is about 1 µl. Using flexible tubing behind the pump, the pulsation will be very small already after a few centimeters of tubing. However, in some

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cases like combining the pumps with flow sensors or sensors for analytical measurements, the pulsations require further reduction. This can be solved by operating the pumps with a sine wave or by adding a damping element into the fluid path. Based on specific project requirements we can offer determining the right method to obtain low pulsations without adding much dead volume to the system.

Air bubbles

Due to its patented double actuator design, the mp6 micropumps are able to handle air bubbles within a fluid in a very reliable way. Running the pump at lower amplitudes however, the capability of handling air will be reduced. In order to achieve stable flow rates and reliable performance, air bubbles should be avoided by designing the fluidic structures, reservoirs etc. in a suitable manner. Apart from larger air bubbles in the flow path which are clearly visible, tiny air bubbles may accumulate inside the pump chamber and lead to flow changes over time. If flow rate drops over more than 10 % are observed while running the pumps continuously over a few hours, it should be checked if the pumps return to their initial flow rates after flushing the fluid path with a syringe or after leaving them non operating for several hours. If the flow recovers, it is very likely that small air bubbles are introduced into the pump. In this case higher driving amplitudes should be used and a redesign of the fluidic system / out gassing of the pump medium should be considered.

mp6-OEM pump driver

Operating the mp6-OEM controller for low flow rates

The mp6-OEM driving electronics for the pump is normally specified to run at 100-235 V of pump amplitude and between 25 – 120 Hz of pump frequency. It is possible to operate at lower frequencies but in this case the module needs to be connected to an external frequency generator. In addition, the frequency signal needs to have a duty cycle of 95 % to ensure reliability. As mentioned above, the limit of about 100 V for the amplitude is reasonable for most cases in order to increase stability against air bubbles. When operating the module at the lowest output voltage, it should be checked if the module powers up when it has been switched off. For further details how to operate the mp6-OEM module the corresponding manual should be considered.

If due to specific requirements lower output voltages are needed, a customer specific adaptation based on the mp6-OEM design can be offered to customers on request.

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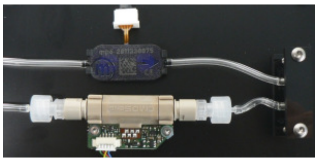
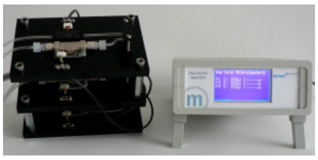
Flow control with a separate flow sensor

In order to be able to monitor the flow rates and to use closed loop control for increased accuracy the integration of a flow sensor should be considered. Especially when the target flow rate should be kept stable even under varying system conditions, a closed loop controlled system is clearly recommended. In order to achieve a robust and cost effective solution, the sensor and control algorithm need to be matched with the pump. Furthermore a fluid damper should be considered to achieve more stable flow rates. Based on a fluidic platform equipped with flow sensors from the company Sensirion, delivery modules achieving flow rates down to 60 µl/min can be offered as an evaluation kit. For lower flow rates a customization of these units can be offered. Typical accuracies that have been achieved are in the order of 3-5 %.



Flow control with additional sensor



Complete flow module

Summary

In this application note some important effects and countermeasures were introduced helping to achieve low flow rates with the Bartels micropumps mp6. Especially adding a flow restrictor and / or a flow sensor are very powerful tools to create successful products in the low flow rate domain.

With more than 15 years of background in development and production of microfluidic systems, Bartels Mikrotechnik is able to support you and speed up the development process significantly. Our capabilities include:

- Development of complete microfluidic systems
- Miniaturization or review of existing fluid handling systems
- Characterization of fluidic components and systems
- Integration of flow / pressure sensors, adding closed loop control

Please contact us to discuss your requirements with us in order to speed up your product development cycle.

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