Summer Academy on Medical technology
Lübeck 23/24.9.14

8th Workshop
Low Flows in
Medical Technology

incl. 3rd Progress Meeting of
EURAMET-Project "Metrology for Drug Delivery"

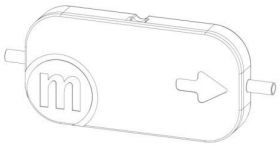
Module 3 of Lübeck 2014 Summer Academy
on Medical Technology

September 23rd / 24th 2014
BioMedTec Sciencecampus Lübeck

flow measurement for the double actuator pumpmp6

Bartels Mikrotechnik
Dortmund

1. The mp6 micropump
1. Thermosensorpump
2. Differential pressure sensor
3. Intrinsic flow control
4. application example



Motivation

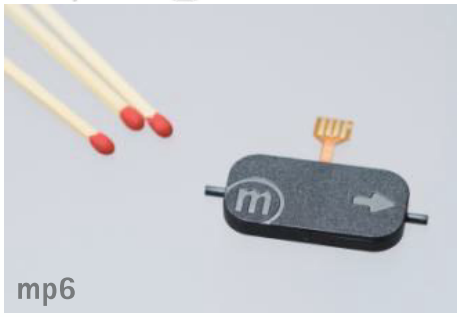
- drug delivery goes mobil

- drug delivery goes disposable

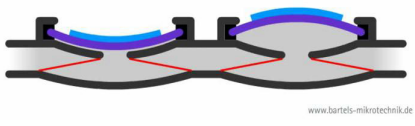
- drug delivery and it´s control has to be small and cheap

- accuracy has to be as good as for big devices

The micropump



Bartels mikrotechnik

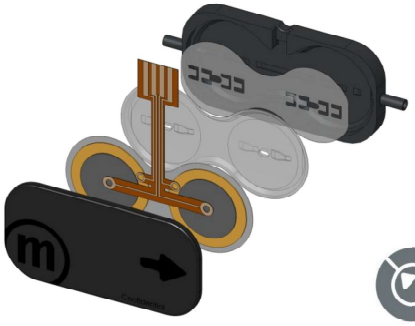


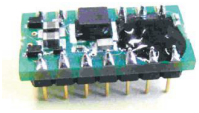
Bartels mikrotechnik

The Smallest Plastic Micropumps on the Market

USP's:

- capable for high volume disposable
- Flat form factor
- Non magnetic
- Only ONE material in contact

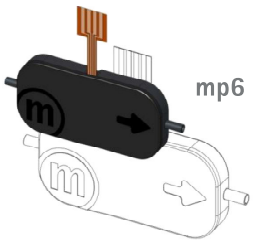




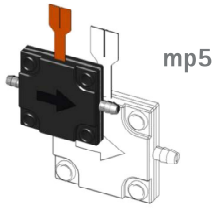
- one chip driver battery driven
- OEM electronics for test :3-5 V

Characteristics

- Suitable for gases and liquids
- Low energy consumption < 150 mW
- Max flow rates
  - 6 -7 ml/min (water)
  - 18 ml/min (gas)



- Max pressures
  - 650mbar (water)
  - 100 mbar (gas)
- Size 30x15x3.8 mm³



- Max Pressures
  - 250 mbar (water)
  - 30 mbar (gas)
- Size 14x14x3.5 mm³

In-house volume production

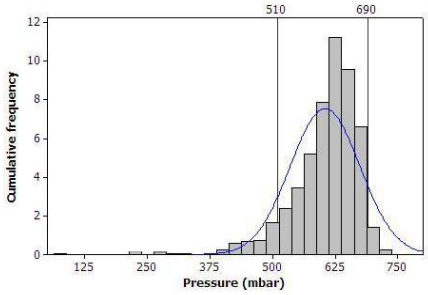
molded parts

assembly station

batch processing

tracebility

test



Animation Double Actuator Pump

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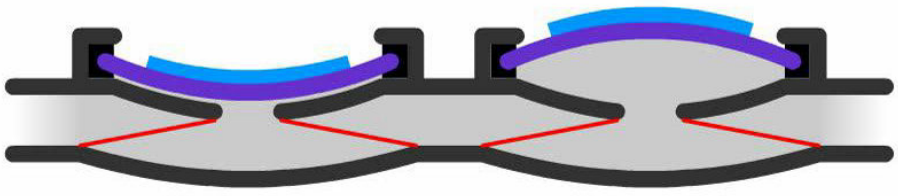


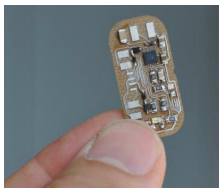
www.bartels-mikrotechnik.de

Controlling the Micropumps

- Electronic directly integrated in pump housing
  (battery or mains adaptor driven)

- Main board Electronics: integration in system electronics
  (requires 3-5V DC)

- OEM electronics



- Lab electronics

Robust and reliable

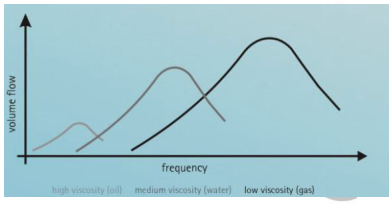
- Lifetime >10 000 hours proven (5000 garantied at full power)

PPSU
- Steam sterilization according to DIN EN 554, 121 °C, 20 min possible
- EtO Sterilization possible (50°C, 10% EtO > 60% rel. Humidity)

- Durable under environmental composite temperature / humidity cyclic test according to IEC 60068-2-38
  (10 cycles of 24h from –10 °C to 65 °C up to 93 % rel. humidity)

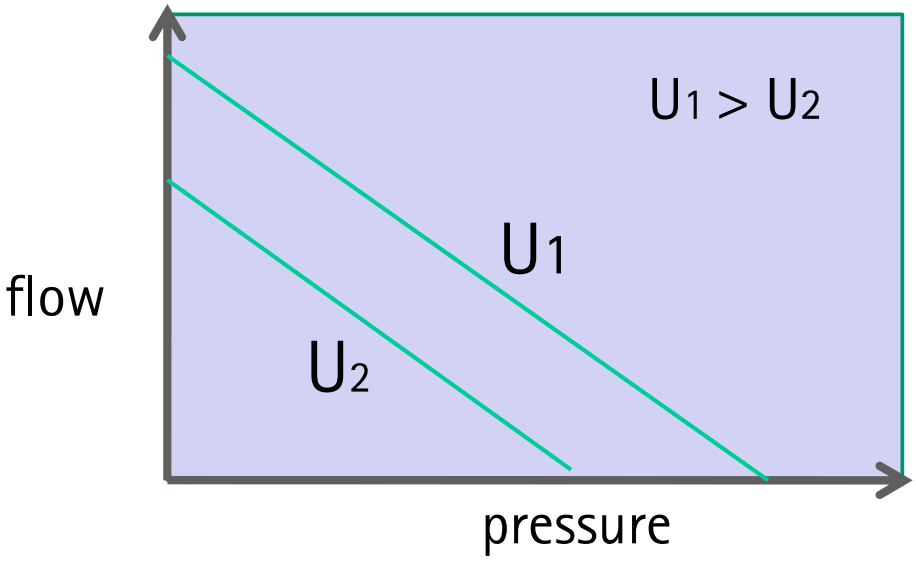
Disadvantages

- pump is unidirectional
- pump is hydraulically open in forward direction
- Pump is not 100% hydraulically closed in backwards direction
- flow depends on back pressure
- flow depends on viscosity



To overcome these disadvantages additional fluidic elements have to be incorporated into system design

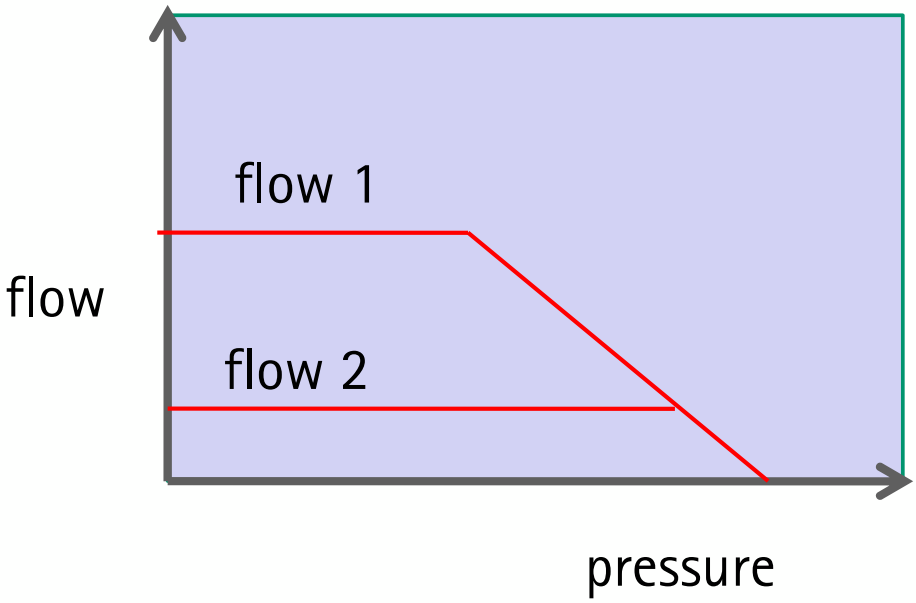
Micropump behavior



Biggest topic of such pump curve is strong backpressure dependence of flow

microComponents

Micropump behavior



Target of the consideration is to create a regulated pump with improved characteristic

microComponents

Advantages of a Flow Controlled Micropump

- Varying system conditions can be compensated
- Flow is stabilized
- Monitoring / Safety features can be implemented
  - Empty reservoir detection
  - Air bubbles
  - Occlusions in front / behind the pump

⇨ The pump gains "intelligence"

microComponents

Several possibilities to controlled flow with mp6

1. Thermosensorpump:
Hybrid setup with flow sensor

2. Differential pressure sensor
Hybrid setup with measuring pressure drop on orifice

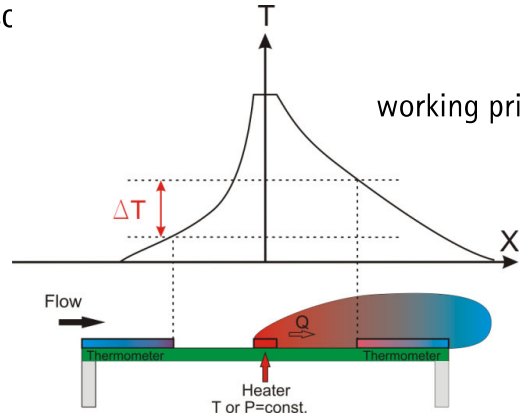
3. Piezosensorpump:
Intrinsic flow control by double actuator configuration

microComponents

Thermal Flow Sensor

Thermal Flow Sensor

For high accuracies , specially for low flow ranges below 500 µl/min a flow control can be realized by combining the micropump with a thermal flow sensc



working principle thermal flow sensor

Flow and temperature increase is physically related!

In order to realize a regulated pump simplest approach is to combine the pump with a flow measurement sensor

+ different flow sensor allow easy adoption to requirement
+ electronic control can be realized fro m simple setup up to high sophisticated PID regulators

- additional and mostly costly hardware and electronics needed (e.g. Sensirion)

Liquid Flow Sensors & Liquid Flow Meters - Overview

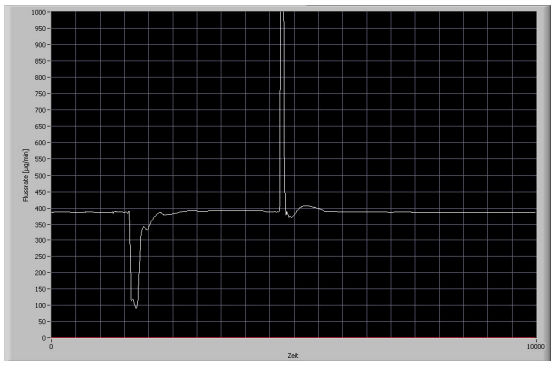
Sensirion's liquid flow sensors establish new standards wherever low liquid flow monitoring, liquid handling and liquid dosing are important. Our unique CMOSens® Technology allows to measure the liquid flow even through the wall of the flow channel (US Patent 6183944) in milliliters, microliters or even nanoliters per minute. Applications in fields like medical devices, diagnostics and process technology and more often benefit from our solutions.

Please click here to get to the selection table and choose the right sensor for your application.

Industry & Laboratory			Maximal Calibrated Flow		Output
Sensors	Model		H2O	Hydrocarbon (IPA)	
SLG64-0075			5µl/min (20µl/min)	-	RS485, I²C
SLI	-0430		50µl/min	500µl/min	RS485, I²C
	-1000		1ml/min	10ml/min	RS485, I²C
	-2000		5ml/min	80ml/min	RS485, I²C
SLQ-QT105*			-	120ml/min	RS485
SLQ-HC60			-	80ml/min	analog 0-10V

Bartels Mikrotechnik has realized together with german University Bremen of a thermo Sensor Pump

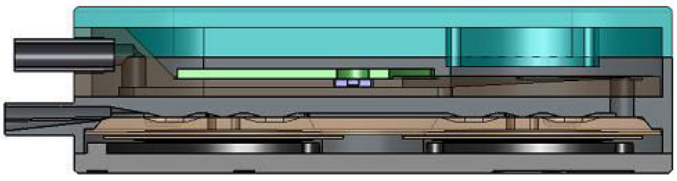
- Flow range between 60 - 5000 µl/min with +/-5 % accuracy
- Prototyped module of sensor and pump has been proven successfully

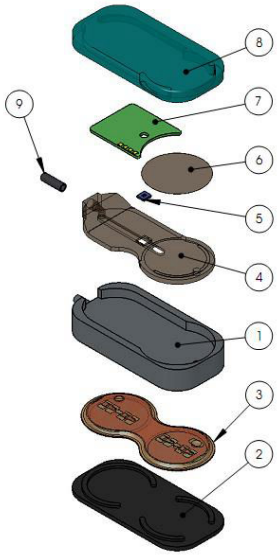


Step response

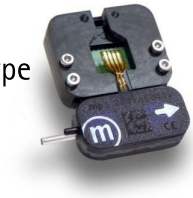
Special findings during examination

In a second layer a damper chamber and the sensor is fully integrated into mp6.





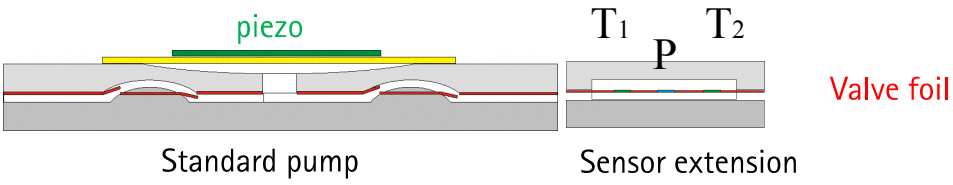
First protype



microComponents

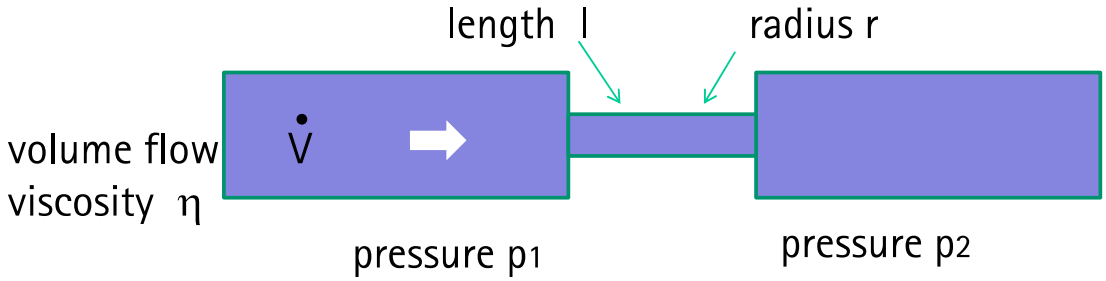
Status

- components industrial available
- complete functional devices not on "on stock" – level available at Bartels
- experiences in system setup available
- basic mp6 can be a base for cheap sensor implementation
- thermosensor die´s are available since 2014



Differential pressure for flow sensing

Differential pressure for flow sensing



Law of Hagen-Poiseuille: $\dot{V} = \frac{dV}{dt} = \frac{\pi \cdot r^4}{8 \cdot \eta} \frac{\Delta p}{l} = -\frac{\pi \cdot r^4}{8 \cdot \eta} \frac{\partial p}{\partial z}$

Flow and pressure drop is physically related!

Differential pressure for flow sensing

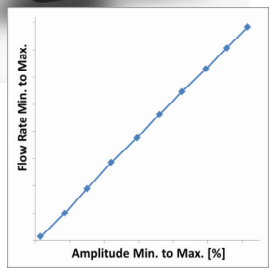
A regulated system can easily be realized by the combination of pump, precision orifice, pressure sensor and a control loop electronic

+ different pressure sensors available
+ electronic control can be realized from simple setup up to high sophisticated PID regulators

- additional hardware electronics needed

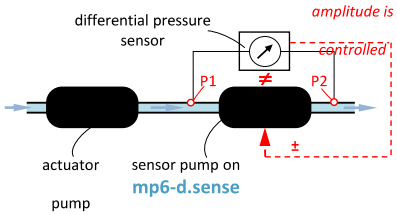
Bartels Mikrotechnik has realized several projects involving precision orifice and pressure sensor

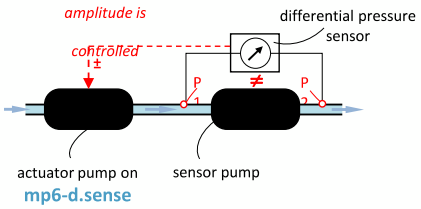
A new special Bartels Mikrotechnik approach use a mp6 as a flow resistor itself: (mp6-d.sense)

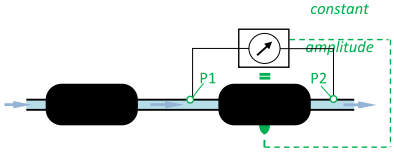


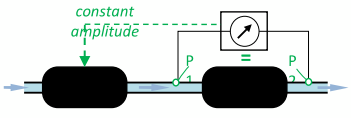
1. a first mp6 drive the flow
2. a second mp6 is in fluidic line as flow resistor
3. a differential pressure sensor measure the pressure drop and regulate a control circuit to drive the second pump in a manner to achieve pressure drop zero
4. the drive signal to the second piezo is linear with flow

Control electronic enable different operation modi (mp6-d.sense)

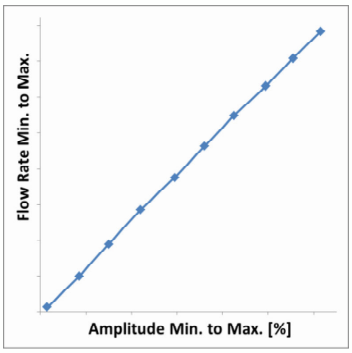








Control electronic enable different operation modi (mp6-d.sense)



the advantage is the use of a cheap pressure sensor, which do not to be linear or calibrated, but only accurate regarding for pressure zero

Status

a) precision orifice
- components industrial available
- well established

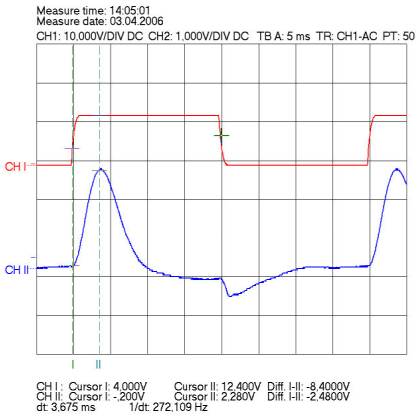
b) mp6 as sensing element (mp6-d.sense)
- complete functional devices small "on stock" – level (50 pieces) available at Bartels
- examination ongoing

Intrinsic flow control

3. Intrinsic flow control

Self controlling capability by using double piezo configuration

The mp6 pump is made by a compact stack of two pumps (like two serial mp5)

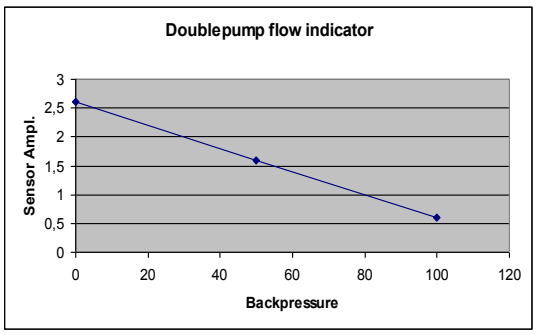


A puls on the first piezo (red line) will be visible as a signal on the second piezo (blue line)

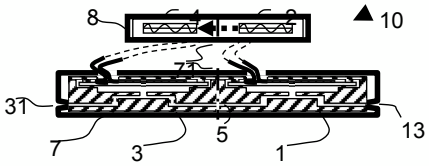
The pressure puls and even the closing one is clearly visible

Self controlling capability by using double piezo configuration

By choosing the the second piezo as sensor, flow parameters can be analysed



These signal on the second piezo is related to the backpressure.....
Hence: by choosing the second piezo as "sensor", flow parameters can be analyzed



Flow and piezo signal is NOT directly physically related!

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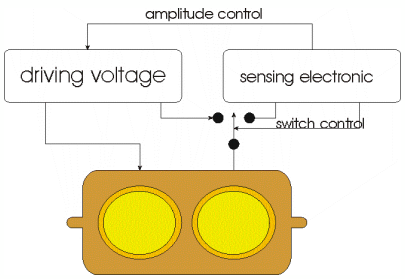
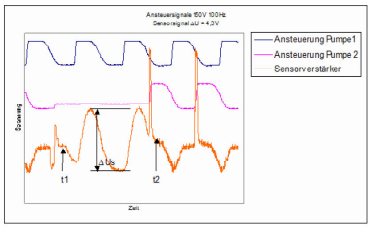
microComponents

first attempt technical realisation

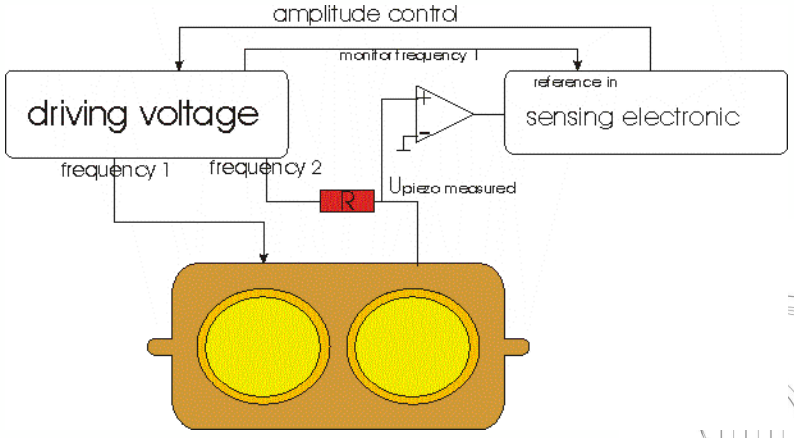


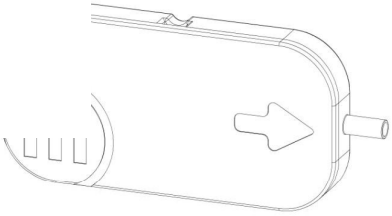
These officially presented technical realization scheme is not the real solution (electronically too complicated; not accurate enough)



3. Intrinsic flow control

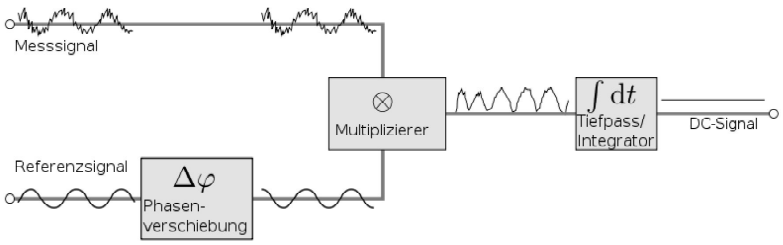
Actual status realisation: Sensing lock-in mode





3.1 explanation lock-in technique

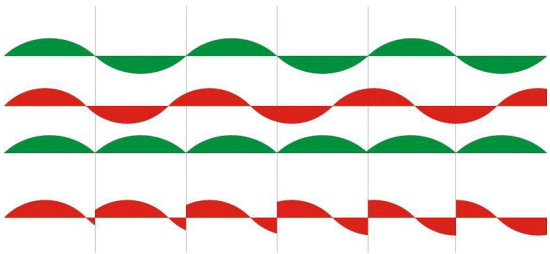
http://en.wikipedia.org/wiki/Lock-in_amplifier



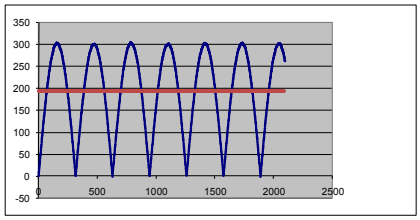
A lock-in multiplies a signal half period with 1 and switch then to -1.

The change is precisely determined by the signal frequency.

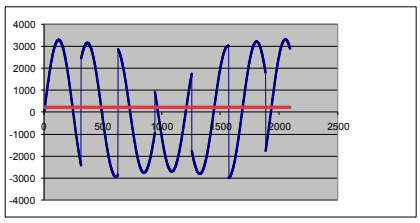
In an Integrator all signals not having the right frequency or phase, will be accumulated to zero. Only the signal survives!!!!



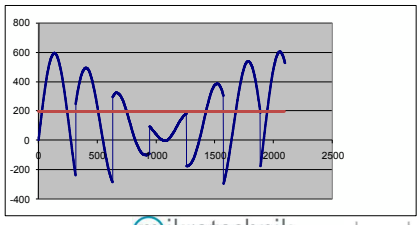
Some pictures to that (hopefully not boring)



A lock in multiplies frequency and phase locked -1,1,-1 to the signal and create a mean value which equivels the signal level

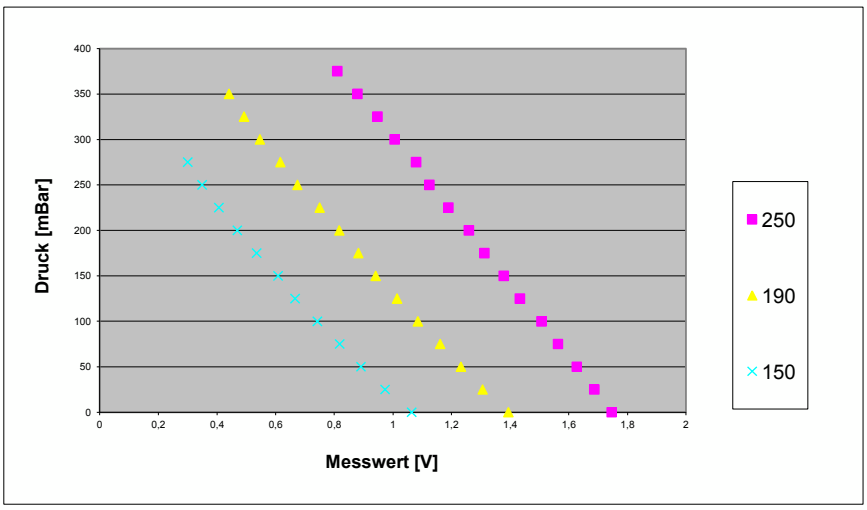


A signal with different frequency or not phase locked create negative values and will not be visible in the mean value

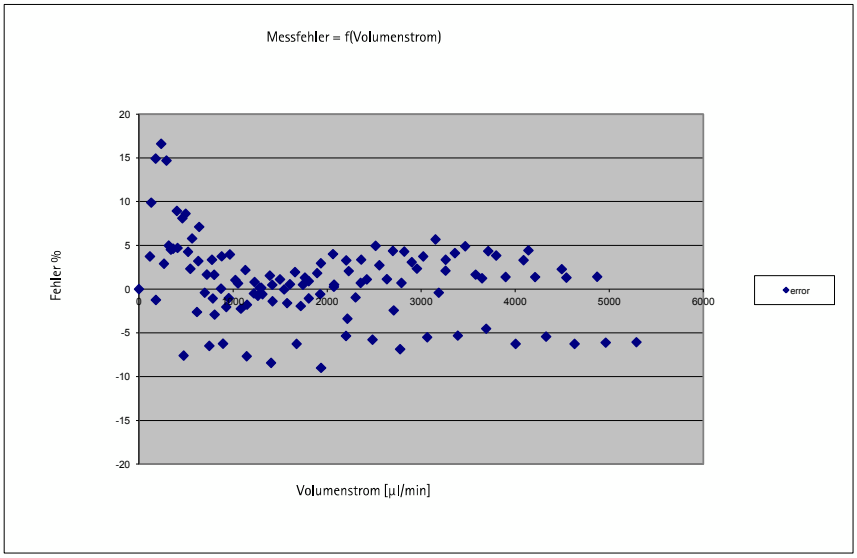


example with "noise" level + signal at same level show again the correkt mean value

Results from lock-in mode



Results from lock-in mode



Comparison of measured flow with calculated one

Piezosensorpump
Intrinsic flow control by double actuator configuration

+ 0,5 – 5 ml/min with +/-15 % accuracy
+ based on standard pump mp6, unbeatable cost effectiveness
+ robust system with good gas bubble tolerance

- sophisticated electronics needed

- accuracy limited, even if each single pump is calibrated

- signal is influenced by several other topics (temperature, viscosity, aging of pump etc.)

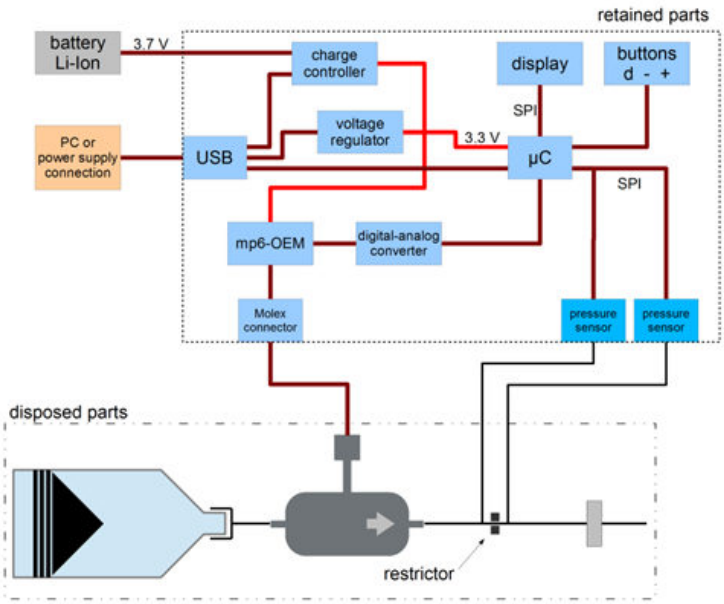
Key Properties of the two flow controlled micropump systems

Thermo sensor pump
- 60 - 5000 µl/min with +/-5 % accuracy
- Fast response time and stable flow
- Fully integrated system
- Patent pending

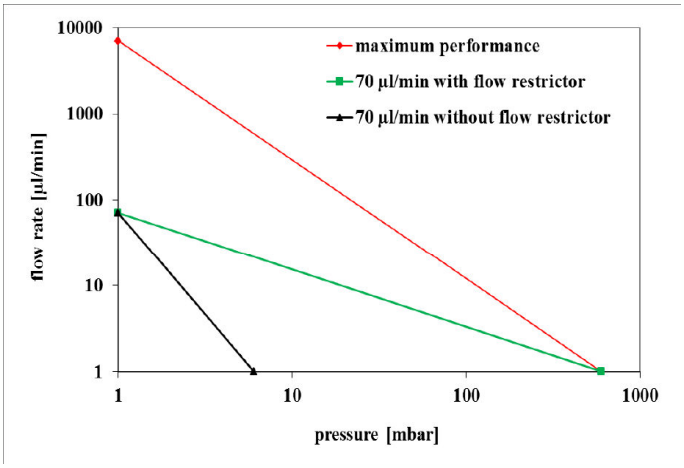
mp6 sensor pump (mp6-d.sense)
- 60 - 5000 µl/min with +/-5 % accuracy (preliminary date)
- Fast response time and stable flow
- additional pressure sensor
- simple electronics

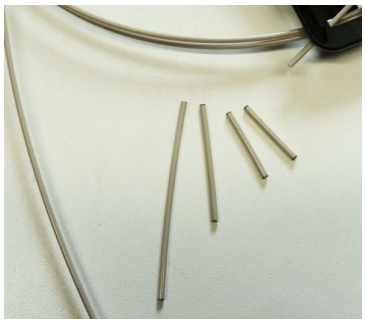
Piezo sensor pump (intrinsic flow control)
- 0,5 – 5 ml/min with +/-15 % accuracy
- Based on standard pump mp6, unbeatable cost effectiveness
- complex electronics
- Robust system with good gas bubble tolerance
- Patented technology

Realized system for drug delivery



Achieving low flow rate by precision capillary tubing





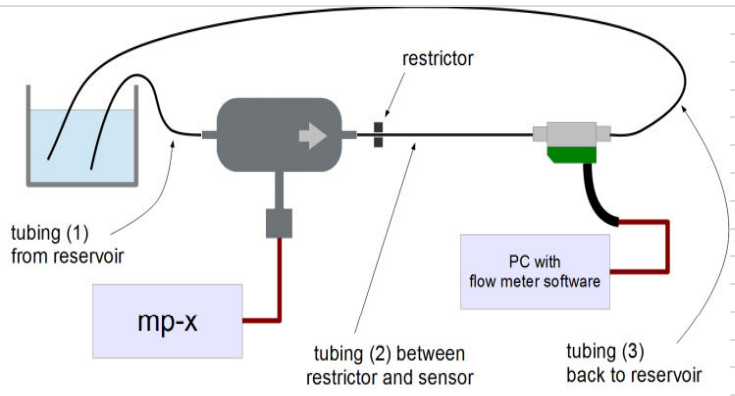
Laser cutted capillaries

Realized system for drug delivery

Simple test for evaluating rough size of restrictor.

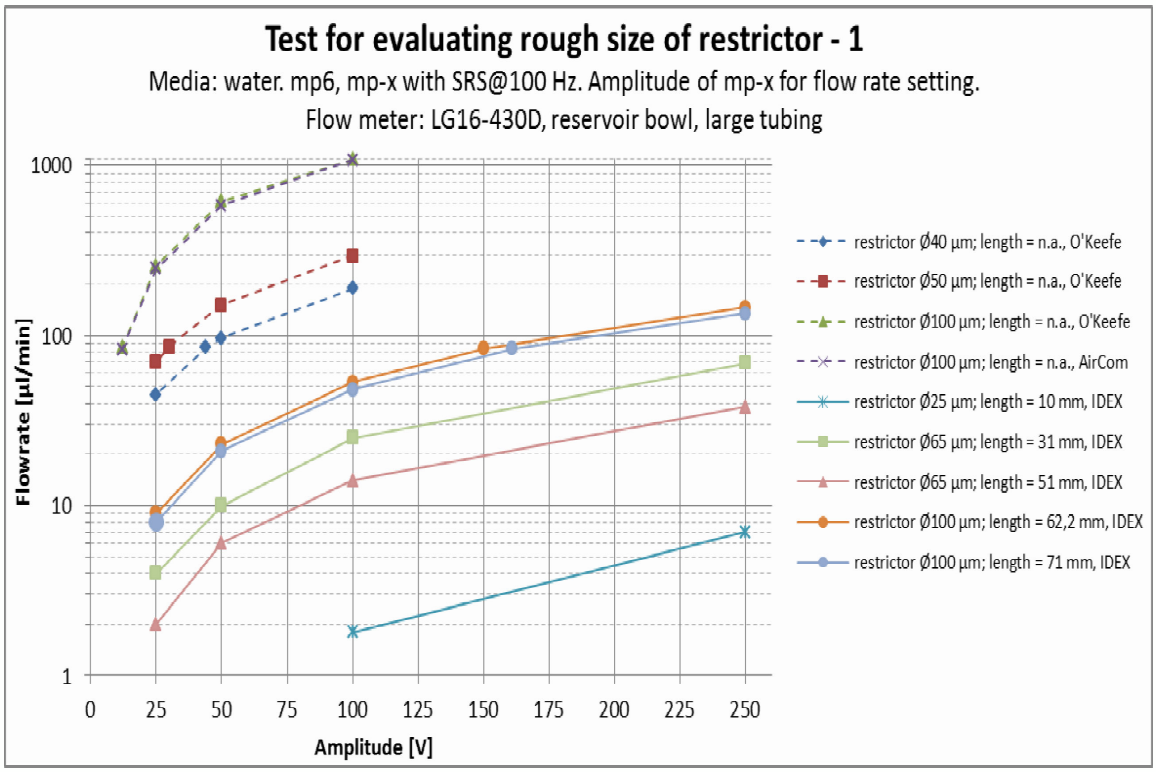
Setup:
- reservoir with DI-water
- (1) tubing to pump
- mp6
- (2) tubing to sensor, restrictor in between of this tubing
- sensor
- (3) tubing to reservoir

The mp6 is controlled by mp-x:
- SRS signal
- 100 Hz
- different voltages



Sensor
- Sensirion LG16-1000D (0-1000 µl/min; calibrated flow form 30-1000 µl/min)
- ~~Sensirion LG16-430D (0-50 µl/min; calibrated flow form 1-50 µl/min)~~

Sensor software
- LiquiFlow Viewer



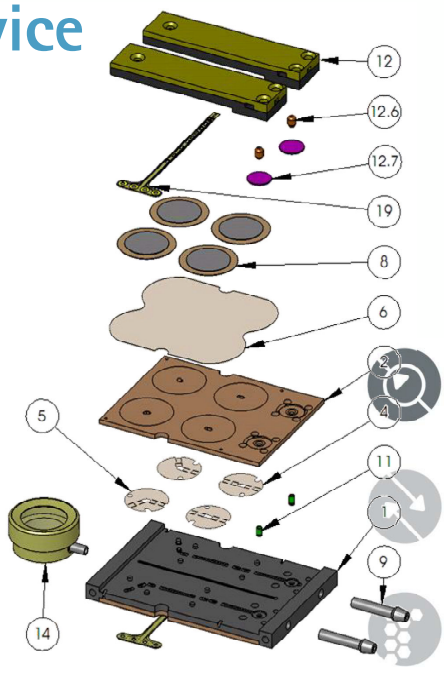
4. Application example

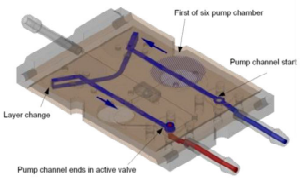
Combination of pump and pressure sensor in one device

Realized setup for intrabody use
with incorporated precision orifice and pressure sensors

→

improved low cost package possible





4. Application example

- Small and powerful pump
- enable a close to patient use
- PID regulation within requested control range
- enable different pharma packages

Resumee

- Small and powerful pump
- enable a close to patient use
- Useful even for disposable application
- Can be combined with different flow measurement techniques
- price level of flow measurement can be quite low in volume
- Accuracy of a drug delivery setup was shown

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