Sammlung mp6 Fragen

Inhalt

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1 Reversible pump

all mp6 pumps - mp6, mp6-pp and mp6-AIR - are not designed to have reversible flow.
If a negative pressure difference is applied onla a very small backflow is possible, if that pressure becomes too large the pump valves can be damaged.
The reason of the slight backflow is that the valves are not intended for static pressure sealing, hence they are better suited for dynamic movement. That means they are designed "fluidical open", i.e. pump valves can open with differential pressure in forward direction.

2 Particle

With liquid and the standard mp6 we know:
- Particle sizes have to be below 50 µm. The smaller the particles the less risk of blockage.
- Depending on the particle material the particle load - particles / liquid volume - has influence. The higher the load the higher the risk of blockage.
- Material of the particles has some influence; examples: Blood particles are squishy and deformable which is not as problematic as for instance hard glass particles. Fibres are the most problematic particles as they easily get stuck.

If particles clog the pump different effects can be possible:
- Pump rate may go down a bit with partcles ladden media (based on liquid experiments), but this doesn't need to indicate a possible blockage.
- Partly blockage is present if the flow decreases further and does not recover when a media with no particles is pumped.
- Severe blockage is present if flow and pressure generation is very low and cannot be regained.
Maybe (but untested here) it is possible to clean the pump by pumping liquid for some time. However, if blocking particles can be rinsed out depends on the particles and the

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liquid as well as the kind of blockage. Fibres are nearly impossible to remove, same applies for very large particles.

3 Blood

Some of our customers are using the mp6 with blood, and as far as we know damaging of blood cells (red blood particles was mentioned) occurs sometimes but only with certain pump settings. Unfortunately we don't have the working settings, so I guess you have to test this yourself.
My guess is that you should avoid the rectangular signal or high frequencies which both would force rapid and sharp motions of the pump valves, and which could squeeze blood cells to hard.

Hence, try sine signal and play with frequency and amplitude to achieve desired flow rate with as less damage as possible.

Customers had experienced this effect and could, after some change of settings, achieve to successfully work with blood.

4 mp6-AIR

We don't have data on particle effects with the mp6-AIR.

The mp6-AIR is also possible to pump liquids. In general the mp6-AIR is just a standard mp6 pump, only tested especially for air performance, not every mp6 achieves the air specs due to part and production tolerances.

Note: If you have pumped liquid and want to pump gases with particles after that, please dry the pump sufficiently. Otherwise partciles can get stuck to internal surfaces due to liquid remains. Pumping gas withoutz particles for some time will help here.

If water is used, it is also possible to vaporize it with the pump at a temperature of approx. 70°C for roughly an hour. We have some good experience with this procedure.

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the data of 3000 Hz measurements mentioned in the "application_note_gas_GB" and also in the newsletter "Newsletter9-mp6-QuadEVA" were made with an arbitrary wave form generator (for sine. rectangular and SRS signal), two high voltage generators (minus and positive amplitude) and an own made amplifier electronic. See attached "testing setup.jpg".

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Actually we don't have any reliable electronic to generate such high frequencies. The mp6-QuadEVA is our best approach towards that goal, but there we also see amplitudal decrease whith higher frequencies and number of powered pumps (see the newsletter for details). However maybe this is already enough for the customer.

Additionally to note:

We don't have any life time experiences with higher frequencies. Although a higher frequency should be ok for the actuator, because of its sound buzzer origin, but for sound generation those actuators run at ~20 Vpp and not our 250 Vpp. Hence, if the mechanical stress will cause early breakdowns is unknown. The actuator will be the main issue here.

Thinking further would call for a better actuator, i.e. capable of high stroke and high frequency with "surviveable" voltages. I guess resonance frequencies would come in handy here.

A different approach to the customers task:

Would it be possible to use a sort of pressure reservoir that is maintained by the pump(s)?

It can be overpressure or vacuum. A valve would then be the required precise tool letting the vacuum or overpressure gain access to the test tubing. Two 2/2 valves or one 3/2 valve can be used to apply vacuum and then overpressure to the test tubing or vice versa.

The general work process of such a device would then be:

1) The pump(s) will build up pressure/vacuum. A pressure sensor for control loop.

2) Once pressure is at desired level the valve(s) can be activated.

3) Valve(s) activated and releasing the pressure/vacuum to push/suck liquid in/out test tubing.

Benfits:

- Pump(s) work sporadically => lower energy consumption, no constant noise, no "on-demand-high-precision" pump action

- Pressure/vacuum reservoir => size of reservoir can handle multiple "analysis runs" with high repeatability

Drawbacks:

- More technical effort (pressure reservoir, sensors, valve)

Just for clarification, maybe not for the customer: The two pictures (pump first.jpg and pump last.jpg) represent a similar system (multiple chamber with waste reservoir) we have developed for a customer. Because I think such an approach will need system development, eirther for us or the customer and why should we give them an idea for free.

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Another example: We have made such vacuum devices for negative wound pressure therapy (NWPT). Frank can tell you more about that.

5 Pulsation

A-B - A-B

A-B is one mp6 with A the first and B the second actuator inside. If two pumps are connected in series the actuators A should be moving simultaneously and actuators B also simultaneously but wih a 180° phase shift to actuators A.

However, the connection lenghth between the pump has some influence.

The pulsation pulse from the first pump travels along the fluidic line. Theoretically the speed of the pulsation is the speed of sound in the pumped media. With the distance between B.1 and A.2 - actuator center here, which is 7.5 mm from casing wall (not the tubing clip) - the run time of this pulsation can be calculated. Hence is the pulsation of the second mp6 could be tuned to this, i.e. the phase shift between the pumps delayed a bit.

Additionally another effect occurs: The longer the fluidic line the more blurred is the pulsation peak, which will make the addup smaller. Also keep in mind that if you bend the tubing between the pumps the pulsations follow the bend but will be blurred further.

Same applies to the reflection length. I guess there will be an optimum, but only if you can guarantee that the liquid line lengths is always the same from system to system. If the needle is a bit different, screwed tightly or losely, or has a different tip - blunt, pointed and so on - the reflection length will differ a bit and might disturb the whole setup.

I know that we had experimented with tubing lengths between pumps some tine ago. The result was, as far as I remember, that we have positioned the pumps with touching tubing clips and a short tubing for sealing. A phase shift delay was not used anymore.

And we had a customer project, where three mp6 were constructed in a series into a common device to deliver 1 ml/min against 20 psi pressure. The driving signal was not delayed, only phase shifted in the manner mentioned above. But this was done due to unwanted electronic effort.

Raising the frequency a bit over 100 Hz may bring some addition, but this needs to be tested with the system.

Note: Don't use different frequencies between the two pumps as this will lead to a beat frequency (hope this is the correct word for it, when two frequencies interfere with each other).

The mp6-QuadEVA applies a sine wave to all pump stages. A sine wave is not the best for high pressures, so it might be possible that you end up with a net lower pressure than if you would use the mp6-OEM. But then we don't have much data on this.

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6 Air bubbles

Some informations about priming:

If pumps behave erratically it is very often caused by improper priming. Because, if air is still inside, which is on the one hand compressible and on the other hand uncontrollable to know when such an air bubles starts to come out, the flow rate can vary a lot. For priming run the pump at max settings. The beginning of the priming may be difficult as plastic materials are in general hydrophobic, so that air bubbles may remain inside.

Also possible, liquid is is not degassed. If the liquid is not degassed and remains inside the pump tiny gas bubbles will appear on the interior surfaces after some time. It is the same effect as in a glass of tap water. These gas bubbles are compressible and eat up a bit of actuator stroke and compression that lead to decreasing pump performance. With high amplitudes of the pump the motion stress of the liquid is high and gas bubbles can be detached from the surfaces and transported out. The lower the amplitude of the pump the weaker the speed changes of the moved liquid during the actuator strokes hence gas bubbles are not removed.

Possible solutions are:

- Use degassed water/liquid to prevent this effect. Nevertheless, a degassed liquid doesn't stay degassed, so after some time (hours or days) the liquid will be back to normal. How long it will stay degassed is dependend on water/air contact surface area, movement of this area and temperature.
- Forcing a portion of air through the pump, as done with the tubing out of the water, will collect most of the air bubbles inside the pump and drive them out.
- Drive the pump at high amplitude, close the pump line for a couple of seconds and release it instantly; this will generate a sort of concussion to the liquid as pressure is built up and released. Air bubbles will be lifted from the interior surfaces and pumped out. It is possible to close the output or the input of the pump, leading to high or negative pressures.
- It may also be possible to use an additive to the water like Tween or other (http://en.wikipedia.org/wiki/Polysorbate_80 some general description can be found here: http://blog.honest.com/polysorbate-80). It will make the liquid more hydrophilic or rather the surface it is in contact with. For the gas bubbles this means the liquid can creep between air bubble and plastic surface so they will become afloat. I don't know if this is a suitable solution and how much Tween is required to do this. I just want to mention this as some customer applies it to enhance the wettability of their used liquids. We normally don't use it.

With the mp6-OEM there are also two other possibility to boost the priming. Although this is not yet tested in all its details it showed quite good results when priming empty pumps.

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1. Let the pump run at 100 Hz and switch on and off the ENABLE and AMPLITUDE input to the mp6-OEM with a low frequency of 4 - 9 Hz. This will force the pump actuators to start and stop repeatedly. As the signal oscillation starts and stops not parallel with the switching frequency the actuators jump a bit creating some sharp pressure pulses inside the pump. This may help to get liquid more easily into the pump chambers. However, as it depends a bit on the used liquid you may have to play a bit with the swicthing frequency to find the optimum.
2. Switch the mp6-OEM between to frequencies. The 100 Hz for the liquid and a higher frequency for air, lets say ~300 Hz. Switch between these frequency in ~0.5 s steps. The higher frequency is better for air so that it can haul in the liquid via the air. Once liquid is inside it is better pumped with the lower frequency. After some time, when liquid comes out of the pump and no air is visible anymore you can return to pure 100 Hz.

Another thought, which may be the main issue here:

If your system was primed correctly and air bubbles appear after some time nevertheless, it might be that your tubing connectors to the pump are not tight enough. If the pump is working and the inlet tubing does not fit properly, the pump will suck in tiny amounts of air.

The tubing used in your setup picture seems to be larger than the standard tubing (Tygon ID 1.3 mm) we propose with the pump. If the inner diameter is larger than the tube clip of the pump it will not be tight enough.

Concerning the mp6-pp:

The mp6-pp is a bit smaller as the standard mp6 due to the material shrinkage of the parts after injection molding. Therefore you have to apply the smaller Tygon tubing ID 1.02 instead of 1.3 mm. A larger tubing allows air bubbles entering through the tubing clip.

Additionally to consider, don't use silicone tubing as these are not water tight. Water can evaporate easily out of silicone tubing, so that only air and air bubbles remain.

I have enclosed some pictures of our current continuous running test setup, for mp6 and mp6-OEM. In there you see that we have used the Tygon tubing, but additionally apply some ferrules to clamp the tubing onto the tube clips of the pump. The result, now over 6000 h run time, shows no decreasing flow. (We have made the same run time experiment with mp6 and mp-x some time ago.)

The pumps in here are only primed at the beginning. Flow measurements happen via scale. The large water reservoir is constantly filtered with a simple water pump (aquarium supply). The water has some silver ion additive for anti-algae treatment.

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7 Material of pump

all wetted materials inside the standard mp6 are PPSU (or PP with the mp6-pp).

I have enclosed all actual data sheets concerning MSDS, FDA, ISO 10993 and other food or water related information that is available from Solvay, the material producer of PPSU.

Please note that the mp6 is made with material of two grades of PPSU; natural-transparent and black. The lid is the natural grade with some blue colour additive. Radel R-5000 NT is the natural-transparent material and Radel R-5100 BK 937 is the black material.

The black PPSU material has some part of carbon black, see the attached material safety data sheet for this. The other materials do not have carbon added. However, the mp6 applies the technologies of laser welding and laser marking. The marking process is used to create an absorbing layer for the laser wavelength in the otherwise natural-transparent material. This absorbing layer is hence blackened material and thus carbonized or in some manner burnt. The following laser welding process on this blackened layer will melt the material of and around the blackend part.

It may be possible that some particles of these carbonized plastic material will come out of the pump during operation.

The stamped valve foil, also PPSU, will never produce any particles; if that happens the pump will de heavily damaged.

We don't have documents as mentioned above for the PP version of the pump, if required we can ask for it.

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It is also unknown if this blackened material can be considered graphite; it will be some kind of partly carbonized plastic.

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The adhesives that are used in the mp6 assembly are not in any contact with the liquid. However one of them, an epoxy, may have some carbon. I ahve contacted the supplier and will come back tio you with this information.

8 Pressure of Pumps

With the current design of the mp6 the maximal pressure to achieve is limited by the actuator. It can generate only a certain force, once this force is reached the actuator doesn't move anymore. Due to the tolerances of the actuator this force limit is no exact value.

So far we have experienced that - in systems of six serial connected pumps pumping water - a max pressure of 1.6 to 1.7 bar is possible. The last actuator is then strongly bulged out and moves with a very low stroke only. Adding more pumps brought no further pressure gain.

Therefore if you want to have more pressure you need a more powerful actuator. This can be achieved with a smaller diameter of the actuator. It is then generally stiffer than the larger diameter and can generate more force hence more pressure. However, as the actuator stroke goes down with actuator diameter the flow rate goes down with it. It is also possible to have a stronger actuator without changing the membrane diameter, but this will require different actuators, e.g. piezo multilayer bender or piezo stacks. We have some initial concepts here already.

Nevertheless, you are correct with the dead volume too. The compression rate of the pump (actuator stroke volume / pump dead volume) should be as low as possible to achieve high pressure levels. This is very important for air pumps as gases are compressible (ok liquids are too but only at with small percentages).

Hence right now, if we would minimize the pump chamber and other dead volumes of the mp6 the pressure would go up. However, we will run against the same limit as mentioned above; 1.6-1.7 bar for serial connected pumps.

Another limit with the current mp6 design is with the laser weld lines inside the pump. This only allows a pressure level of ~2-3 bar. With some redesign of those lines this can be changed, but has to be tested nevertheless.

Independent of all this we have some other concepts of pumps where the pressure limit doesn't apply anymore. This will be system of pumps that can generate more pressure than the above mentioned solutions. Certainly this requires development for system and electronic, but it still applies a lot of the mp6 technology.

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9 Pressure inlet outlet

the pump always work corresponding to the pump curve, see enclosed diagram. That means the pump has a max flow rate and a max pressure generation.

When the pump is running and the outlet is closed so that no flow rate is possible the pump will generate the max pressure. When the outlet is open the pump can achieve the max flow rate. If there is a back pressure on the outlet, the flow rate is reduced by this. Note that a connected tubing or a system to pump in will have some fluidic resistance, which can be compared to a certain back pressure, and the max flow rate is slightly reduced.

Same applies to a pressure on the inlet.

With forward pressure the pump is not reduced in performance and can add its flow rate to the pressure induced flow rate.

If the inlet would have a negatvie pressure like a slight vacuum, the pump would be reduced a bit as it has to overcome this before a flow rate is realized. Thus, a negatove inlet pressure can be compared to a backpressure on the outlet.

An additional thing to know is that the pump is designed fluidically open, that means liquid can go through the pump due to differential pressure. In forward direction this is easy as the internal pump valves open. In reverse direction there is a leak flow, as the pump valves are not completely tight. If you want to prevent backflow we recommend using a checkvalve like our mp-cv.

At the moment we don't have a valve that prevents flow in forward direction, as this requires a certain opening pressure of the valve, but we are currently in the process of designing one.

However, with such a valve the pump needs to open the valve first, i.e. create some pressure which will reduce the max flow rate, before a resulting flow can happen.

If your current application is sensitive to the existing inlet pressure, it is always possible to compensate the pump by decreasing the amplitude a bit.

10 What is the maximum pressure that the mp6 can output, if the input pressure is increased

In general the pump will add its generated pressure on top of the inlet pressure.

For instance, a positive pressure of 200 mbar at the inlet will be increased with maximal 600 mbar (when pumping liquids like water) resulting in roughly 800 mbar pressure at the outlet of the pump.

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Please note that a positive pressure of 200 mbar will cause a certain flow through the switched-off pump. Also, the 800 mbar will only exist if all flow stopped when the "reservoir" is full.

The absolute maximum pressure the pump(s) can create when in a series connection is about ~1.7 bar, we don't have the exact value for this.
The more positive pressure exists inside the pump, the less actuator movement is possible, that means when a pressure of ~1.7 bar is achieved the actuator cannot create much more stroke.
Furthermore a pressure of ~2 bar will be the maximum the pump can tolerate, above the laser weld lines of the pump may get damaged.

11 Life time of pumps

The main causes for breakdown for long running times are the piezoceramic of the actuators and clogging of the fluidic path. Clogging can be avoided by filtering. The piezoceramic can be damaged by recurring voltage/current-spikes. So if the switch-on and switch-off action is done properly, i.e. without any voltage/current-spikes of the driving signal, the actuator will survive.

The life time (of mp6-AIR) should be the same as for water. We don't have measurement data on this, hence the TBD, as no customer asked about that up to now.

12 Dosing applications

we have realized such a low flow application for a customer, though it was not dispensing drops. It was a system of a liquid reservoir, the mp6, a restrictor and a flow sensor (made out of pressure sensors and the restrictor). An electronic controls the pump via the calculated flow data. Certain flow rates were set and kept up by the pump (see example data.jpg).

If the customer wants to do such a system, I guess it would be good to send the application notes about:
- low flow rates
- burst mode (wave form generator)
- and the performance sheets of the mpJET device

If dispensing really means to have drops or free jets the mpJET solutions with the burst mode is the right way to go. If dispensing means to bring liquid to an opening and this

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drop will be transferred in some way, picked up or transported further with a second fluidic system, then maybe the continuous low flow might be right.

As the customer seems to be developing that system, maybe he will have some questions once he has made some experiments with the pump, therefore I don't see any questions from my side now.

I know that some of our customers are using the pump for dispensing application, but unfortunately I don't have any given data about that. Also the dispensing rates will probably vary a lot over different customers as well as the integration method of the pump.

However, we had a product called mpJET for some time, that was used for a droplet dispenser.
We still have some in stock, and they are still available, but as we have lost the appropriate measurement equipment we can't produce new ones, so we do not offer them with our standard products anymore.
The mpJET applies a mp6 encapsulated in a housing together with a valve mp-cv and a nozzle. An electronic controls the mp6 in burst mode, so that inidvidual actuator strokes are generated instead of a runing time period. Thus a single pump stroke can be used to propel a tiny amount of liquid out of the nozzle. With increasing number of strokes (cycles) the volume dose will increase. The smallest dosing was arond 500 nl = 0.5 µl. This smallest increment could be tuned by voltage setting.
I have enclosed the manual and description along with some measurement data of dosing measurements.
Please note that this version could shoot droplets over a certain distance (up to 80 mm). It was never tested if the same method of pump operation did work inside a channel with a continuous liquid phase, probably it would as other customers are using this method. However we don't have data about this.

13 Low flow rates (liquids)

It is possible to use small amplitudes or a different frequency to get the low flow rates you want to achieve.
However, with low amplitudes the flow becomes quite fragile. That means, changes of backpressure may stop the flow completely until the pressure has been built up and flow continues, or the pressure is higher than the pump can achieve with the applied amplitude.

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Using low frequencies may lead to a stronger pulsation, i.e. liquid moves and stops with no mean flow.

Concerning resolution:

As an example, let's say the flow rates are achieved with 0 to 15 V. With changing the amplitude, the resolution depends on the resolution of the amplitude. If you want 100 steps of flow rate it will be 15 V/100 steps, so 1 step is 0.15 V difference in amplitude. The piezo actuators of the pump can handle small changes of amplitude, but the realized flow rate may change only slowly when increasing the voltage with such small steps. And with slow I mean a couple of minutes due to the fragile behaviour with the low pressure generation.

A better solution is to apply a restrictor, with that you can throttle down you max flow rate of the pump. If the restrictor is the right one, the max or high amplitude of the pump will deliver your desired max flow rate. Now you are able to tune the flow simply with the amplitude and the optimal frequency of the pump is not changed.

With this method, the pressure capability of the pump is not reduced and the flow is much more stable.

Find more details in the two attached application notes for low flow rates.

We have realized such systems for medical devices with 80 µl/min and with 40 µl/min as the maximum flow rates. In these systems the flow rate was measured using the restrictor and two pressure sensors. The flow was then calculated based on the law of Hagen-Poiseuille.

These systems achieved a flow rate tolerance of better than ±2%.

14 Low flow rates (gases)

In general, using a restrictor to throttle the pump to a certain flow rate is also possible with air/gas. In this case the viscosity of the air/gas is in effect here and should be considered for the calculation of the correct restrictor dimensions.

However, when moving liquid along a channel system or similar the generated the generated pressure is more important, i.e. underpressure when sucking or overpressure when pushing. The reason is that the liquid has friction at its contact areas. Therefore, the liquid might need a certain pressure to start moving and a bit lower pressure when it is moving already.

To find the correct pressure it is recommended to change the amplitude of the pump and leave the frequency at least at 300 Hz. If the effective flow rate of the air-pressure-dragged liquid is still too large the frequency can be lowered to make the pump ineffective.

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15 Storage & operation at different temperatures

Temperature, storage

As long as the pump is stored without any liquid, i.e. water, there is no known limit to negative temperatures (Celsius). Positive temperatures are limited to ~130°C, regardless of liquid inside, as at that temperature the piezo ceramic and the applied adhesives will start to deteriorate.

Temperature, operation

The data sheet mentions 0-70°C, but this is based on water. Zero simply because of ice creation, because ice has an expanding character and may destroy the pump. This is actually the cause for the storage concern here too. 70°C is also because of water, and here because at this temperature water begins to create air bubbles like in a cooking pot. These air bubles will combine and disturb the pump due to its compressive behaviour. The pump will then behave as is un-primed.

So if you use other liquids than water the temperature range may be different. For instance, with a cooling liquid that stays liquid below 0°C the pump will be still operational. We had once a pump running at below -20°C with no problem. However, always consider ice creation as some water may even be inside the best cooling liquid. The high temperature is then the same as with storage above, but then again consider air bubbles with other liquids.

Please understand that we can't guarantee these "enlarged" temperatures as we don't know what liquid has whatever effects on the pump whe the temperature changes that way.

We don't have any data on temperature cycles.

Humidity

We don't have much data here, but we have tested running pumps at humidities from 95% to ~10%. These were not long term tests so we don't know if this is ok for prolonged time periods, as water can appear at electric connections inside Molex connector and beneath the lid where the actuators are.

If you allow for a drying step (time unknown) of attached liquid after extreme humidity storage, the pump should be fine afterwards.

Pressure Range, storage

If the pressure is the same inside and outside the pump, i.e. one tube connector is open to the surrounding, you can store it at any pressure you want. When the pump is inside a bag with some air and the bag is put under pressure this will be the same.

Pressure Range, operation

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The allowed differential pressure (inside pump to surrounding) is roughly 1.2 bar (120 kPa). However we have found that pumps could withstand 2 bar too, but we can't guarantee this as we don't have so much data about this. However, if higher pressures are applied instantly the pump may be destroyed, slow increasing/decreasing pressure is ok.

In series connection the pumps can generate more pressure than one single pump. In such a system we have achieved 20 psi (1.37 bar or 137 kPa) without destruction of the last pump in line. But again we guarantee only the 1.2 bar as these are tested in production.

16 Vacuum

just for your information, because it isn't integrated in the application note, see the two images enclosed. The diagrams show the potential pressure and suction pressure levels of the mp6 driven with rectangular and SRS signal. Pumps in series connection was used to measure the pressure.

Please note that this is a snapshot experiment result, and shows only the general behaviour.

Here, one pump achieves ~200 mbar, which is not the specified "typically value" of the mp6-AIR. For pumping air the tolerances of the parts have more to performance. Therefore I would recomment to use two pumps in series, like Rod already said.

17 Mp6 manufacturing process

The materials and production process of the labeled parts are:

label	part	material	production process
1	main body	PPSU Radel R5100 bk 937	injection moulding
2	valve foil	PPSU Radel R5000 nt	calendering, then cut-stamped in production machine
3	middle	PPSU Radel R5000 nt	injection moulding
4	membrane	PPSU Radel R5000 nt	calendering, then cut-stamped
5	top	PPSU Radel R5100 bk 937	injection moulding

All parts are cleaned in an ultrasonic water/isopropanol bath before used in further production steps.

There is no spray coating involved in any way.

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18 Sterilisation

enclosed you can find our overview of the sterilization methods of the pump.
For ebeam and gamma we had a customer project where a system with the pump was tested before and after the sterilization processes. No impact of the processes could be detected, unless you count a slight change of colour a drastic impact. Functionality and flow rate where unchanged.
For both methods the radiatons of 15, 25 and 40 kGy were experimented successfully.

19 Backflow through the pump

the pumps are designed fluidically open, that means the passive valves inside the pump open on dynamic pressure changes. However, the valves are not completely leaktight and there will be a certain backflow - liquid or air - when a pressure difference exist.
For a system where a pressure level has to be kept up it will be better to use a good sealing valve like our mp-cv. Combined with a simple pressure sensor that monitors the pressure level it is possible to build a system where the electronic will trigger the pump to raise the pressure again once the level dropped below a certain value.

It is absolutely possible to let the pump run continously keeping the pressure level up. No damage occurs due to constant action.
With max setting, for instance max amplitude and 300 Hz, the max air pressure will be maintained. Pressure levels will be possible with different amplitudes, but this requires some experiments depending on the pressurized volume.

20 Leaking tubing?

it is possible to push a wire ferrule over the attached tubing end to clamp it tightly to the connector. The ferrule doesn't have to be crimped. If crimping is required for a very strong fixation, please make sure that the ferrule does not create such a deformation that a gap appears again.

With mp6 and Tygon tubing (mp-t ID 1.3) a wire ferrule for 4 mm² (internal diameter 2.8 mm) is very good.
For other tubing ferrules with other diameter have to be tested.

21 Viscosity

We don't have flow values for all viscosities and all liquids. The most suitable data might be in the enclosed picture of flow rate versus viscosity of glycerine-water mix-

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tures. Although the viscosity range does not cover 15 cP (cP = mPas) exactly, it can be estimated that the flow will be much larger than the desired 60 µl/min, hence a restrictor is still valid here if the amplitude/frequency change will not be succesful for tuning the flow rate.

Additionally the viscosity is also highly dependent on temperature, so it might be possible that this will disturb the set flow rate when the temperature changes. We have some data about this temperature influence to the glycerin-water mixtures, but they are only in german.

22 Using two liquids in one pump

If the pump can process both of the liquids the flow rate may change due to viscosity of the liquid currently inside the pump. For instance if you want to pump a succession of water-gas-water-gas volumes with one pump setting (amplitude and frequency) the flow rate will increase with the gas phase and drop back with the liquid phase.

Same will happen with two differently viscous liquids, though not as drastic as with air-liquid.

However, when the separating front of the two media goes into the pump it will be blurred a bit when it comes out again. This means the separation between the two media will not be a sharp front but a kind of mixture section in between. With air-water there will be some foamed section (which may collapse after some travelling along the tube line), with two liquids there will be a real mixture (esample: a succesion of red and blue water entering the pump will come out as violet in this mixture section).

How large this mixture section will be or if it will be there at all has to be tested, as this is also dependent on the pump settings and flow rate.

One thing to keep in mind:

With two liquids used, the liquid used for priming will be inside the pump chambers. As the flow path passes the pump chambers with only an opening for access of the actuator induced oscillating liquid, the liquid inside the pump chambers will not be exchanged rapidly. It can take some time to have it fully exchanged.

In detail and coming back to the succession of red and blue water: If the red water is used to prime the pump, this will be inside the pump chambers. When the blue water is pumped it will not enter the pump chambers but be pumped through the pump channel. Some small amounts of blue will exchange the red water bit by bit over time, but the blue section will not be "spoiled" by it. Again this also depends on pump settings and liquids, and has to be tested.

23 Restrictor

We don't offer restrictors but there are standard versions available on the market (one example in the US: O'Keefe, www.okcc.com/), but it is also possible to make your own restrictors with precisely (laser) cuts out of capillary tubes (for instance PEEK tubing from IDEX).

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For a standard tube restrictor (diameter and length) see the enclosed Excel-sheet as a simple calculation method for the right dimensions, the viscosity can be changed there too. Due to possible turbulences it may be possible that the calculated values may not fit perfectly. Also keep in mind that drastic diameter changes in the flow line may be problematic for priming as air bubbles may not want to go through the restrictor. A funnel structure before the small diameter will help here.

24 Shock/vibration/WHTOL/HTOL

Unfortunately I don't know about any data concerning this, maybe Frank will know more, but as he is at the CompaMed fair I cannot reach him. I will ask him next week about this.

What I can say is that we have tested the mp6 just recently in a customer project for some climate conditions and storage conditions. If this will cover any viable data I don't know.

Two experiments for storage & test (at lab conditions 20°C @ ~40-50%RH): -10°C and 60°C @ 95%RH

Two experiments for climate testing: 5°C @ 49-66%RH and 40°C @ 85%RH

The pump, filled with an aqueous liquid, was tested and stored & tested at these conditions successfully, i.e. the pump performance did not change due to climate conditions. This application had used restrictors too.

25 Test equipment

Pressure source (if not our pump)

We apply the pressure controller DPI 515 from GE Sensing. I don't know if this model is still available and maybe it is a little bit over the top as it can do a lot and it is also quite expensive.

We also use pressure controller for adhesive dispensers. Nordson is one possible vendor: *http://www.nordson.com/en/divisions/efd/products/fluid-dispensing-systems/ultimus-v-high-precision-dispenser*

We have earlier models than that one, so I advise to to look for pressure capabilities (positive/negative) and how you can set the pressure levels.

Pressure sensors

I have mailed Ian informations some time ago:

...for pressure measurements we have quite good experiences with sensors from Honeywell.

We use 40PC015G (positive pressure) and 40PC015V (negative pressure) in our test setups. Although they are meant for dry gases only we have them in contact with water for a very long time now and it still works great.

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Nevertheless, it is no problem to have an air bubble/pocket between sensor and liquid to avoid contamination. Pressure levels then need some additional time to stabilize, due to the air, but this is not so dramatic.

You can find these sensors at any electrical supplier, just copy the number in your browser and you will find them.

An alternative is the SCC series from Honeywell. There is a configurator on their homepage:

http://sensing.honeywell.com/trustability-configurator

You can find many other sensors, with different pressure levels and ranges, pos and neg range, size and dimensions, connection types and so on. Just be aware that not every sensor listed is alos realized as a product.

Unfortunately those sensors of this series that are meant for dry gases can't withstand liquids at all, so be careful.

And one important note:

Whatever sensor you apply, keep an eye on the I/O connection of your PC or whatever you use. The resolution of the I/O-port has to be good enough to identify small signal changes. Bad way would be to have only 255 steps for the full pressure range.

Flow sensors

Whatever flow sensor you use, always check if the supller can calibrate the sensor to your liquids!

Also from the e-mail to Ian:

Flow sensors that we use come from Bronkhorst or from Sensirion, but I don't know what sensor you need for your viscous liquids.

http://www.bronkhorst.co.uk/en/products/liquid_flow_meters___controllers/

From Bronkhorst we have a couple of L23 for water measurement.

https://www.sensirion.com/en/products/precise-liquid-flow-sensors-for-low-flow-rates/

With Sensirion we often use the LG16 series which comes in sets with different flow ranges.

I recommend to contact them and tell them what viscosity, what liquids and what flow rates you expect.

Data logging software

We use National Instruments "LabView" to control devices, read out sensors, calculate and display graphs of sensor data and store them in text, data or excel-files. Here you need to code with LabView and can pretty much do what you want. It is a graphical coding interface where you place icons and connection lines on the screen, you do not type in code.

LabView is very customizable. You need some interface hardware form National Instruments to get your sensor data into the PC.

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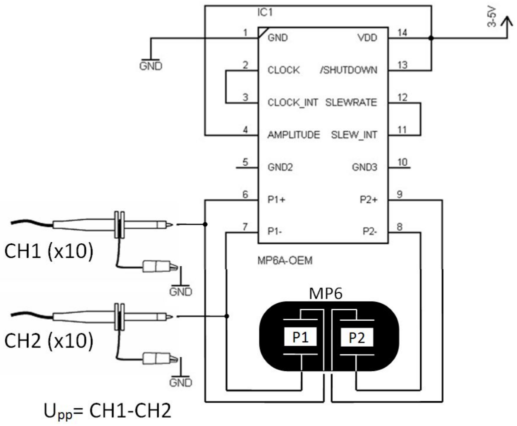
26 Signal of the mp6-OEM

the signal on the mp6-OEM is fixed and cannot be manipulated to get the SRS/sine nor rectangle signal. It can only be slightly adjusted by changing the slewrate of the signal. This is done by connecting an external resistor to the SLEWRATE-pin (Nr. 12) to ground (instead of the short/bridge connecting it to pin 11). Start with a 360K resistor, which is the default value on the mp6-OEM and then try higher and lower values as instructed in the mp6-OEM chapter of the manual.

The circuit diagram of the mp6-OEM is confidential and can only be hand over to you if you buy our “mp6 controller license”.

To check the signal of the mp6-OEM you need an oscilloscope. Use the measurement method as seen on the picture I send you (see appendix). The Peak-to-peak-voltage is the span between the highest and the lowest voltage of the waveform.



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