TG0013: DISC PUMP - PULSATION FREE OPERATION

1. INTRODUCTION

The Lee Company's piezoelectric disc pumps are high-performance gas micropumps operating through ultrasonic acoustic resonance driven by a piezoelectric actuator.

Airflow pulsation is a challenge faced by many designers. In measurement instrumentation (such as for gas analysis), pulsation often limits the signal-to-noise ratio and the resulting sensitivity. For microfluidics systems (such as point-of-care diagnostics), pulsation can cause poor flow control. To deal with these issues, designers often need to include baffles, accumulators and other damping hardware to reduce pulsation. This adds cost, complexity and size to the system.

This document details how pulsation free flow is achieved. The document is set out as follows:

- Section 3: Construction of disc pump and principles of operation
- Section 4: Comparison of performance versus most common technologies
- Section 5: Application implications

Figure 1. A piezoelectric disc pump

2. DISCLAIMER

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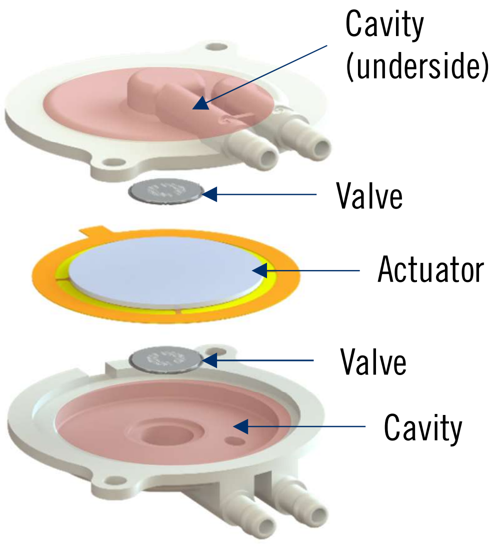
3. BACKGROUND

3.1. Piezoelectric Disc Pump Construction



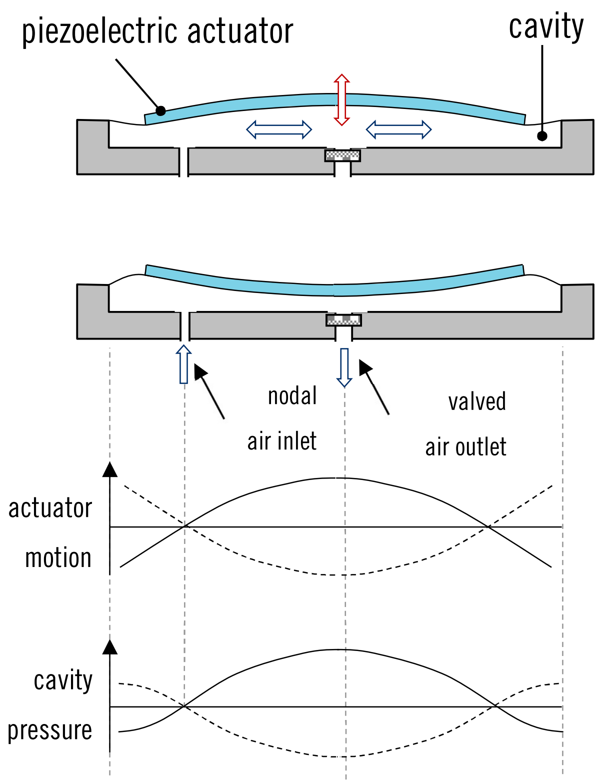
Ultrasonic piezo electric gas pump

Most piezoelectric gas pumps rely on the movement of a piezo actuator to compress the gas in a cavity, thereby increasing its pressure. Such 'displacement' pumps have limited performance because the movement of piezo actuators is very small.

In contrast, our disc pumps do not rely on compression. Instead, it creates a high frequency, high amplitude standing wave and then rectifies that wave with an ultra-fast valve. This principle enables the disc pump to generate much greater flows and pressures than traditional piezo pumps – and because the disc pump operates at an ultrasonic frequency, it is silent.

Figure 2. A piezoelectric disc pump – 'exploded' view

3.2.Operating Principles



1. Actuator flexes at its mechanical resonance controlled by drive electronics.

2. This drives a standing pressure wave, formed between the centre of the cavity and the side wall.

3. Pressure builds up at the centre of the pump once per cycle.

4. A central, passive (undriven) valve allows airflow out of the pump. Air flows into the pump at a nodal hole to replace the air that escapes through the valve.

Figure 3. Principle of operation

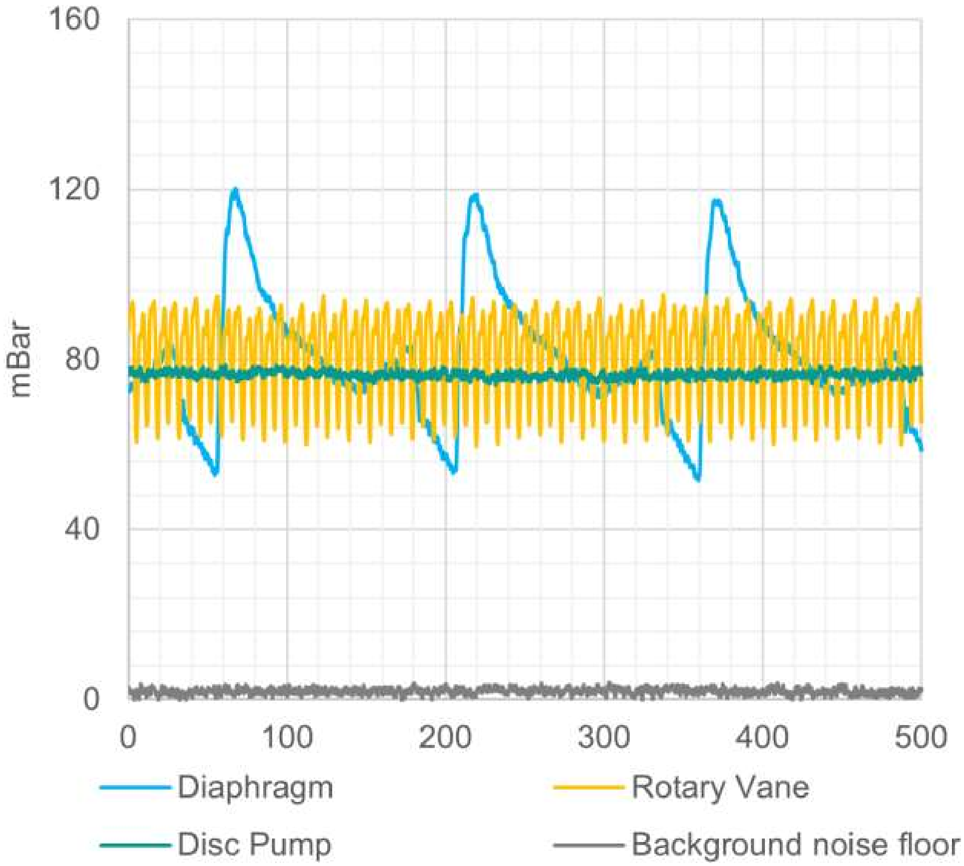


Figure 4. Output pulsation for three pump types, and background noise floor

4. ULTRASONIC OPERATION

Conventional pump technologies typically operate at speeds of up to 50 Hz (3000 RPM). The piezoelectric disc pump cycles more than 400 times faster, at 21-22kHz (~1.26M RPM) controlled by drive electronics. Each cycle of the pump displaces a tiny quantity of air, typically in the range of 10s to 100s nanolitres. The resulting airflow is ultra-smooth and creates negligible pressure pulsation within the system. Figure 4 shows the pressure pulsation generated by a disc pump, a diaphragm pump, and a rotary vane pump[1] . The diaphragm pump creates large, low-frequency pressure oscillations. The rotary vane pump produces smaller, higher-frequency oscillations; however, the pulsation is still readily apparent—despite this, rotary

[1] Pumps driven to deliver approx. 80 mbar against a 30k Lohm flow restriction. Pressure output measured with a high-frequency pressure sensor sampling at approx. 60 kHz.

vane pumps are often sold as "low pulsation" solutions. The pressure pulsation from the piezoelectric disc pump is not observable above the background noise floor of the measurement sensor.

5. APPLICATION EXAMPLES

With its ultra-smooth, pulsation-free output, the Lee Company piezoelectric disc pump offers superior performance to conventional pump technology, whilst at the same time eliminating the need for damping hardware, enabling designers to create simpler, more compact products. These benefits apply to a wide range of applications, both for gas movement and for liquid handling involving pressure driven flow.

5.1.Liquid Handling including Microfluidics

In microfluidic applications, pulsation-free, high-precision pressure/vacuum regulation means that liquid flows can be controlled with unrivalled precision using pressure driven flow. The lack of pulsation is also advantageous when handling delicate biological materials, such as cells.

5.1.1. Pressure Driven Flow

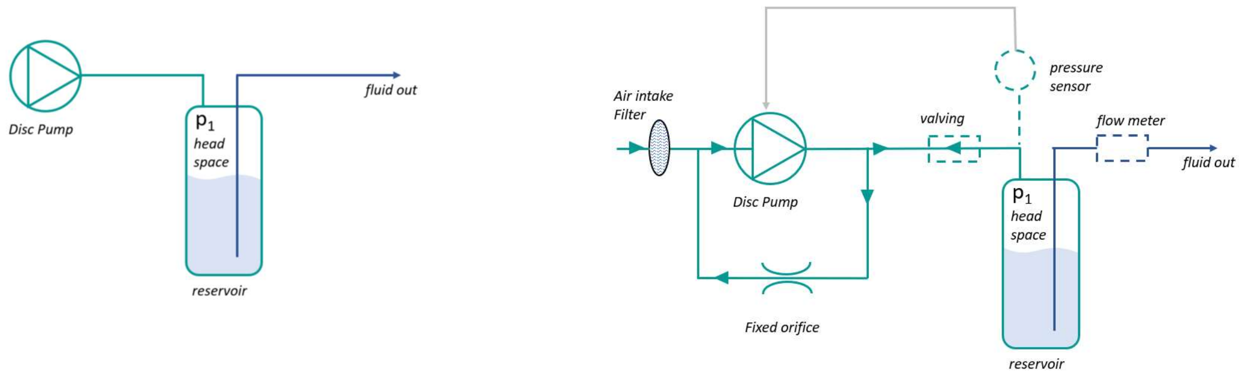


Figure 5. Basic pressure driven flow setup (left) and schematic showing setup for variable pressure and closed loop control (right)

5.1.2. Laminar Flow

As the disc pump moves just a few (nl) per cycle and generates a pulsation free flow, the disc pump is precisely controllable and can hold target pressures with incredible accuracy and repeatability, resulting in high liquid flow rate stability. Laminar flow is achieved through control of the velocity of liquids, see Figure 6 below. The velocity threshold for this relates to viscosity and density of the liquids and parameters related to the channel.

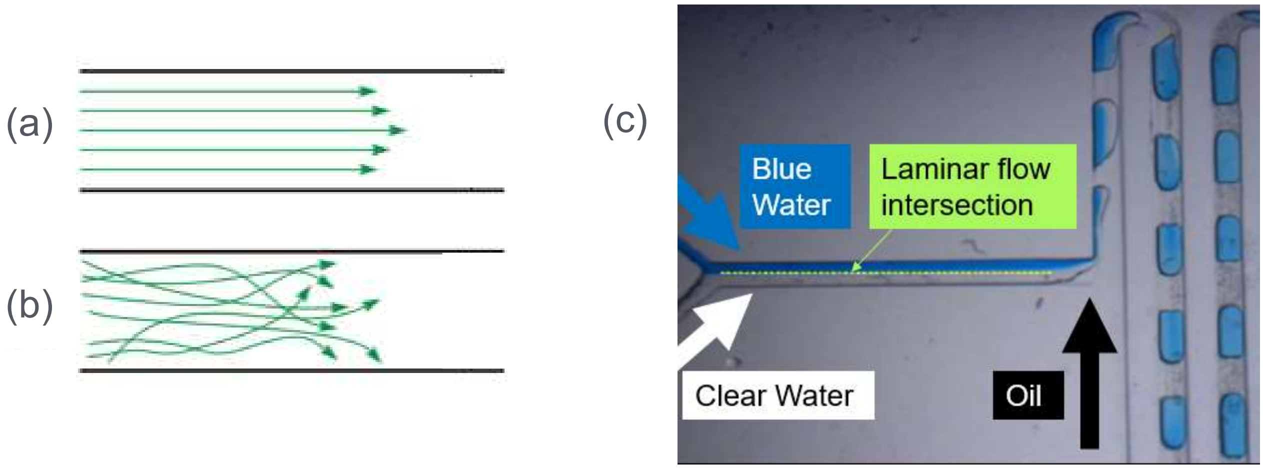


Figure 6. a) Laminar flow versus (b) turbulent flow. (c) liquids flowing in parallel though precise, pulsation free application of pressure on the liquids.

5.1.3. Droplet Generation

Page: Droplet generation
Precise, pulsation free application of pressure on liquids can result in highly controlled droplet generation with improved repeatability and system stability. The low pulsation also helps to reduce bubble formation and entrainment. Below two liquids are independently controlled to generate consistent droplets in oil for life science-based research.

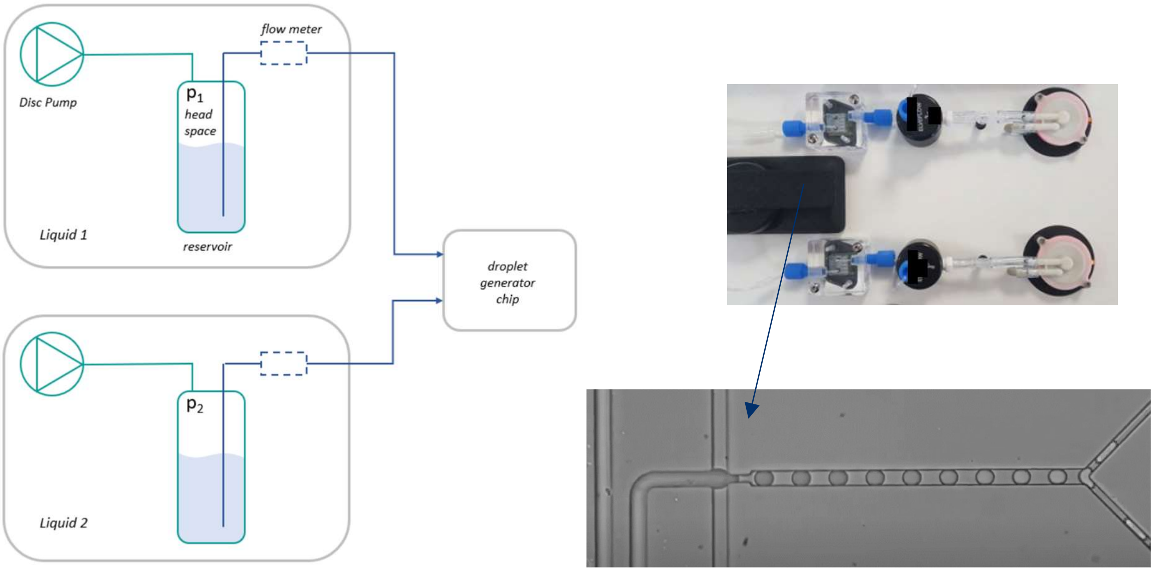


Figure 7. Droplet generation schematics (left) and system setup (right, top) with resulting droplets (right, bottom)

5.2.Environmental Monitoring

Disc Pump's ultra-smooth output can enhance a wide range of gas analysis systems. For gas detection instruments, measurement noise is reduced, increasing sensitivity. For particle detection systems, the lack of flow oscillation means that double counting can be avoided.

Typical applications benefiting from the pulsation free gas stream:

- VOC detection
- Air quality monitoring
- Portable & wearable monitors
- Docking & calibration stations
- Calibration gas generators
- Leak detection
- Particle counting
- Workplace monitoring
- Fence-line monitoring
- MRI-compatible measurements
- Ion Mobility Spectroscopy
- Side-stream humidity measurements

5.3.Medical Devices including Blood Pressure Monitoring

With zero pulsation, blood pressure can be measured whilst the pump is running (i.e. during cuff inflation, rather than deflation as is typically the case). This enables, shorter, lower-pressure measurements that are more comfortable for the user. Low pulsation for therapeutic devices also provides a beneficial patient experience.

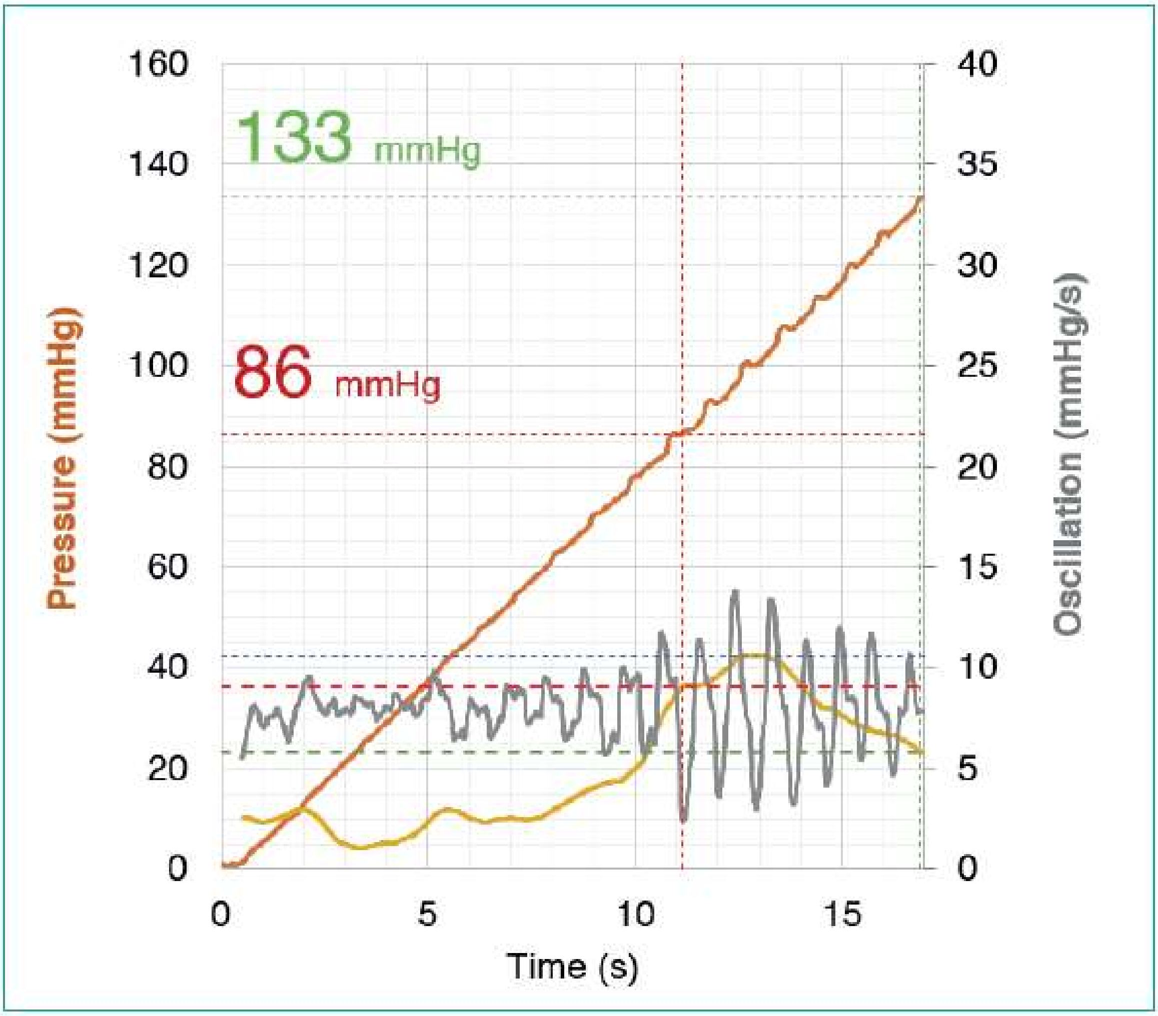


Figure 8. Blood pressure measurement taken during cuff inflation with Disc Pump, with the pump controlled to achieve a constant inflation rate. The lack of pulsation from the pump enables clear measurement of the arterial pulse pressure, from which the oscillation envelope and blood pressure can be extracted.

5.4.Industrial application including Inkjet Printing & Meniscus Pressure Control

The printhead works by using a small amount of energy in each nozzle to eject a drop of ink. This breaks the meniscus at each nozzle. The drop is held back in the nozzle by a slight negative pressure until the energy pulse is applied. If it were not, it would dribble out! The main function of the ink supply system is to ensure that the correct negative pressure in the system is maintained, while ensuring that the printhead does not get starved of ink when printing. Too little ink, and you will see gaps in the printing; too much ink, and the nozzle plate might get flooded, causing irregular jetting, again compromising print quality. The piezoelectric disc pump's dynamic control and pulsation free operation ensure precise control of meniscus pressure without air pulses affecting the droplet quality.

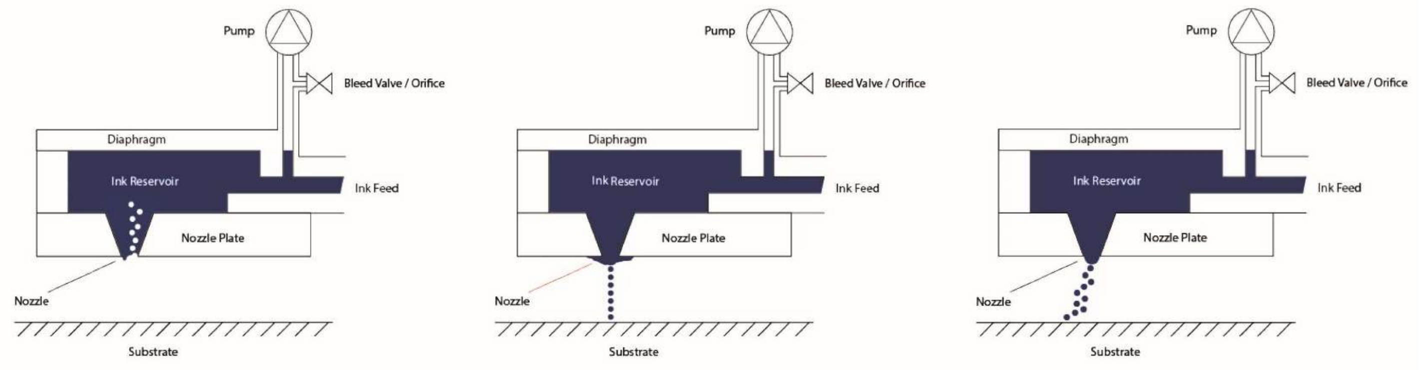


Figure 9. (left) Air ingestion in the printhead (middle) Wetting-out on the printhead (right) Irregular jetting of ink droplets

6. SUPPORT

6.1. Additional Support

The Lee Company website provides advice on:

- Getting started
- Application examples
- Development process
- Downloads (including datasheets, application notes, case studies and 3D models)
- Demonstrations

Visit: www.theleeco.com/discpumps

6.2. Drive Electronics

Each pump requires its own drive electronics which are programmed to optimise pump efficiency and enable control of the pump performance. The drive electronics can be supplied as a PCBA accessory, they are included in the Smart Pump Modules, or the reference design can be used to allow the function to be incorporated into a system PCBA.

6.3. Code Snippet Library for Serial Communications

The Lee Company code snippet library, hosted on GitHub (The Lee Company · GitHub), provides serial communication and control examples in Python for common functions, including turning the pump on and off, setting drive power, closed loop control of pressure and reading back and plotting data. The code snippet library implements the aspects of the communication protocol set out in our 'TG003: PCB Serial Communications Guide' and is intended to support customers after their initial evaluation of our pump technology, as they move on to developing prototypes and products.

7. REVISION HISTORY

Date	Version	Change
23rd September 2023	2	Rebranding