



AN059: TIME-METERED DOSING – DISC PUMP APPLICATION NOTE

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1. INTRODUCTION

1.1. Disc Pumps, Smart Pump Module & the VHS[®] Series Dispensing Solenoid Valve

The Lee Company's disc pumps are silent, high-performance piezoelectric micropumps. They are designed to provide highly accurate, ultra-smooth pressure and flow control of gases. This translates exceptionally well to pressure-based liquid handling, making the disc pumps an excellent choice for microfluidics and dispensing applications. The disc pumps operate by generating a high pressure, ultrasonic standing wave within a carefully designed acoustic cavity. The standing wave is rectified into unidirectional flow by a patented, high-speed passive valve. Owing to this operating mechanism, the disc pumps can be controlled with unmatched precision, yet at the same time respond to full-scale set point changes in a matter of a few milliseconds. The compact form factor means it can be tightly integrated into many different products, increasing the portability of devices.

The Smart Pump Module (SPM) is a standalone product that integrates drive electronics and pressure sensing with any of our BL, XP, LT or HP Series disc pumps. This compact pump module provides closed-loop feedback and either UART or I2C control, offering high performance within a form factor not possible with conventional pumping technology.

The VHS[®] Series Solenoid Valve is a 2-way, 6 mm dispensing valve that combines inkjet printing technology with inert materials to achieve precision droplets in the nanoliter to milliliter range. With an ultra-fast response time (as fast as 250 μ s), it is ideal for accurate fluid regulation and dispensing repeatable droplets with minimal satellites. The valve's small size enables mounting in tight spaces, even in arrays directly above a well plate. It is offered with integrated precision orifices, nozzles, screens, or with our MINSTAC[®] connectors to vary the outlet nozzle and connect tubing.



Figure 1. A Disc Pump, a Smart Pump Module and a VHS Series Solenoid Valve



1.2. About this Application Note

This application note demonstrates an implementation of a small (100x90x20 mm) and light weight (50 g) time-metered dosing system using a disc pump mounted as a Smart Pump Module (SPM) and a high-speed VHS Series 2-way dispense solenoid valve.

The performance of this setup is evaluated for dispensing water droplets. The note covers:

- The basic design and operation of a time-metered dosing system
- Priming and operating the time-metered dosing system
- Data from a prototype system
- In-situ set up of the system

This note is meant to provide a helpful starting point for customers considering implementing this scheme in their own products.

Please note that The Lee Company does not design or manufacture time-metered dosing modules. We supply the pump, solenoid valve and other precision fluid control components that make up these sub-systems.

2. DISCLAIMER

This resource is provided "as is" and without any warranty of any kind, and its use is at your own risk. The Lee Company does not warrant the performance or results that you may obtain by using this resource. The Lee Company makes no warranties regarding this resource, express or implied, including as to non-infringement, merchantability, or fitness for any particular purpose. To the maximum extent permitted by law The Lee Company disclaims liability for any loss or damage resulting from use of this resource, whether arising under contract, tort (including negligence), strict liability, or otherwise, and whether direct, consequential, indirect, or otherwise, even if The Lee Company has been advised of the possibility of such damages, or for any claim from any third party.

3. TIME-METERED DOSING

3.1. Introduction to time-metered dosing

Dispensing precise volumes of liquid is useful in a wide variety of industries, whether for scientific research instruments, medical diagnostics, or high-tech industrial applications where accurate and small volumes are needed. Time-metered dosing with constant pressure is a simple solution for precise dispensing of different liquids.

By combining the high level of pressure control provided by the disc pumps, and the ultra-fast and consistent operation of the VHS valves, The Lee Company have built a prototype of a compact, lightweight time-metered dosing system as proof-of concept (Figure 2).

With this simple prototype, dose volume control has been demonstrated by both reservoir pressure and valve timing, with well controlled dose sizes (Figure 6). A video demonstration of the system in action can be found [here](#).

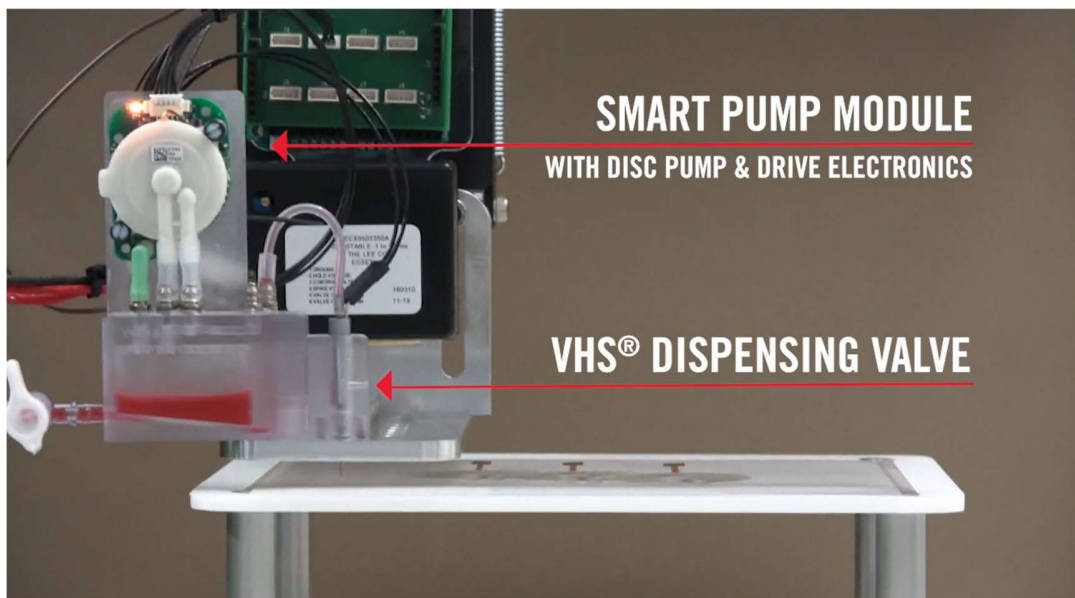


Figure 2. Prototype of time-metered dosing system

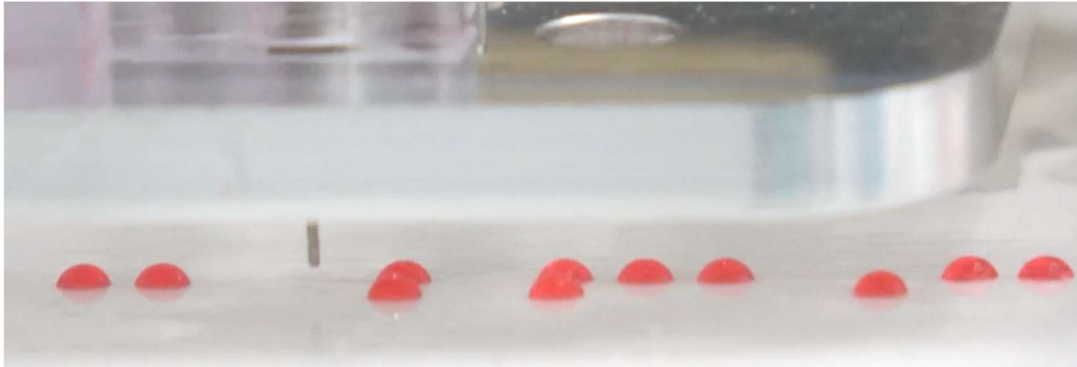


Figure 3. Droplet dispensing demonstration

3.2. Architecture

To achieve precision dosing, the valve timing and system pressure must be highly controlled:

- The ultra-fast and consistent operation of the VHS valve allows precise timing control of the flow.
- The Lee Company's "spike and hold" valve controller takes full advantage of the fast-operating VHS valve. It's higher voltage "spike" allows for fast opening and closing of the valve, and the lower voltage "hold" keeps the valve open whilst reducing heating and extending lifetime.
- The disc pump's fast response and pulsation-free output allow for a high level of pressure control. In this example, the Smart Pump Module is used to provide the pressure source (the pump) along with pressure sensor and electronics for tight closed loop control of pressure.

Figure 4 shows Prototype Schematic A, the simplest time-metered dosing system with details of the main components provided in

Table 1. In this system the Smart Pump Module (1) controls pressure of the air space in the reservoir (6). The liquid is pushed against the VHS Valve (2). When the VHS Valve is energized (for e.g. 100 ms), a droplet of the liquid is ejected from the nozzle (3).

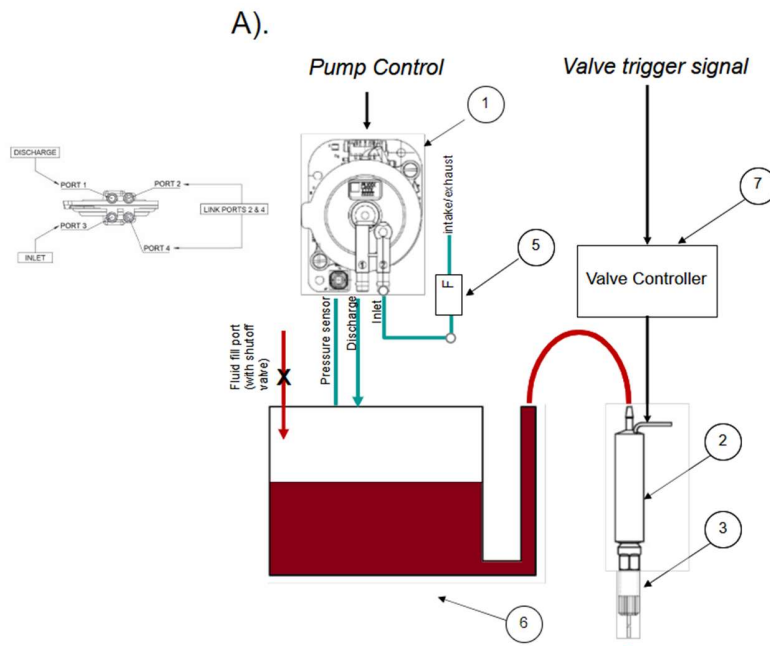


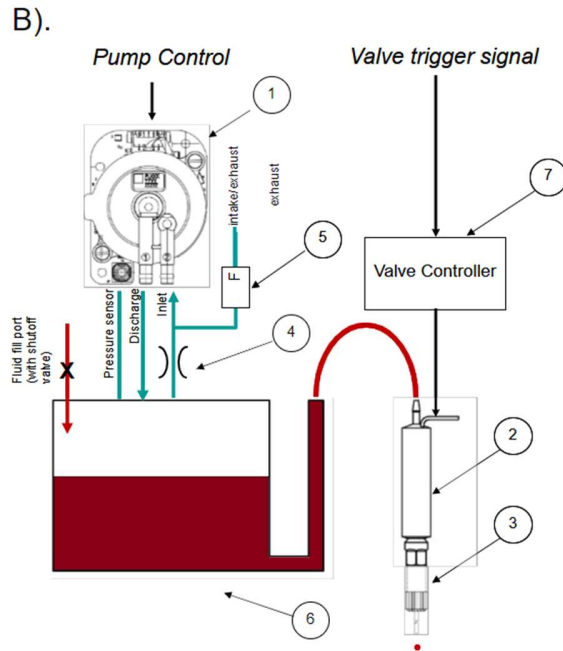
Figure 4. Prototype Schematic A

Component	Description	Product code	Source
1	Smart Pump Module	UBLC5401000A	The Lee Company
2	VHS Valve	INKX0508000A	The Lee Company
3	Dispensing Nozzle	INZA3100914K	The Lee Company
4	Orifice	RPGF2554300S	The Lee Company
5	Filter (maximum 3um pore)	Various	Various
6	Fluid Reservoir	Bespoke SLA	
7	Valve Spike & Hold Driver	IECX0501350A	The Lee Company

Table 1: Prototype Components

Figure 5 shows an alternative design in which the Smart Pump Module inlet (1) is connected to the reservoir by way of an orifice (4). The orifice provides a small air leak path from the fluid reservoir, allowing pneumatic setpoint to be reduced more rapidly (instead of relying on back-leak through the pump which can be slow) as well as typically improving PID pressure control performance. A further benefit to this scheme is that

the air leaked through the orifice is recirculated to the inlet of the pump which can reduce the filtering loading as well as potentially helping with evaporative losses for the system¹.



¹ Note: This approach may lead to additional condensation in the pump, and may not be suitable for all applications

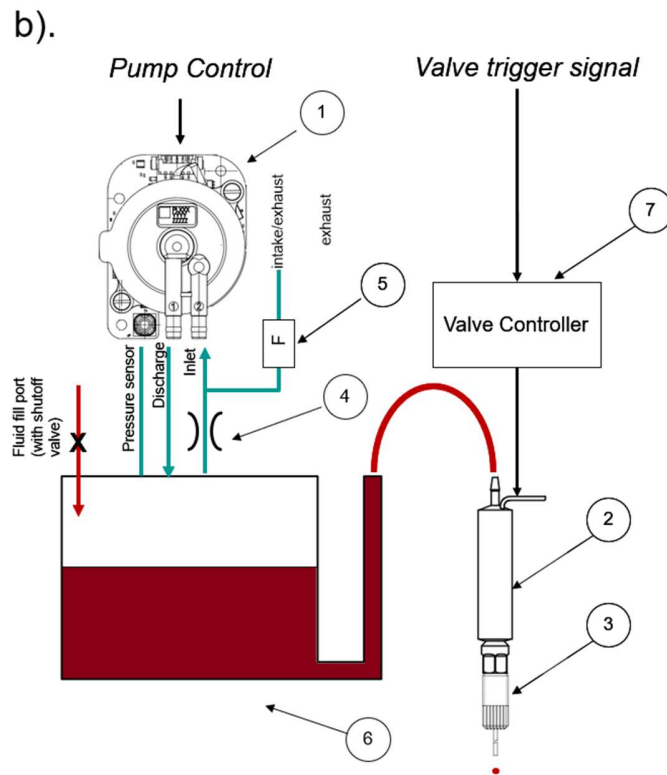


Figure 5. Prototype Schematic B

3.3. Operation

3.3.1. System start-up and printing

The system must be filled with liquid and primed to prepare it for dispensing. The start-up sequence used for this demonstration was as follows:

- Initially the Smart Pump Module (SPM) is powered off and the VHS valve is closed.
- Liquid is loaded into the fluid reservoir via the fluid fill port. After filling, this port is sealed (using a shutoff valve) to prevent air leaks from the system.
- The pump is switched on and used to control the pressure of the air space in the fluid reservoir to the desired setpoint.
- The valve is energized 'Open' for a period of time to prime the system (i.e. until liquid arrives at the nozzle) and the closed again.
- The nozzle should be cleaned of any excess liquid.
- The system is now primed and ready to be used.

3.3.2. Time-metered dosing operation

The standard loop of dispensing proceeds as follows:

- Set the pressure of the reservoir P_r using the Smart Pump Module.
- Wait for the pressure to settle. This can be done either by observing the pressure or by waiting a set amount of time.
- Energize the VHS valve by sending a signal voltage to the valve controller.
- Wait for a precise length of on-time t_d .
- De-energize the VHS valve by removing the signal voltage from the valve controller.
- Adjust P_r and/or t_d to achieve the target dosing volume.

3.4. Results

Figure 6 shows the average water droplet mass achieved for a range of reservoir pressures (P_r) and valve on-times (t_d). As the droplets are small ($\sim \mu\text{L}$), measurements reported are based on the average droplet mass as measured using a 3 decimal place mass balance.

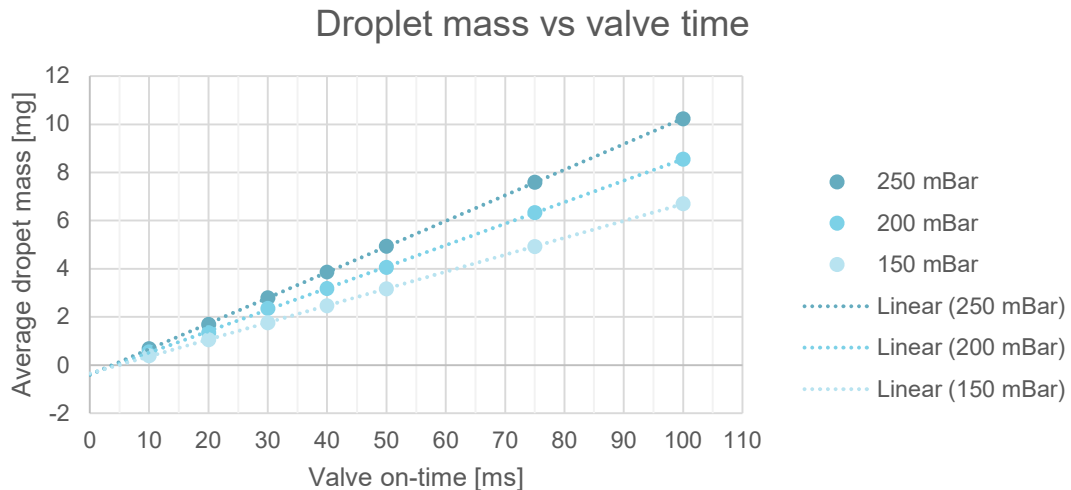


Figure 6. Droplet mass vs valve on-time t_d for water

From these data it can be seen that:

- There is good linear relationship between dosing time and droplet mass/dose size
- Implied minimum dosing time for this system $\sim 5\text{ms}$

- Increase in dose with increased reservoir pressure. This trend is shown in more detail in Figure 7

Please note, future demonstration development work will seek to characterize the dispensing precision of dosing sizes smaller than 10 uL by eliminating current measurement limitations. We are actively involved in projects using droplet analyzers to produce future literature and guidance on this topic.

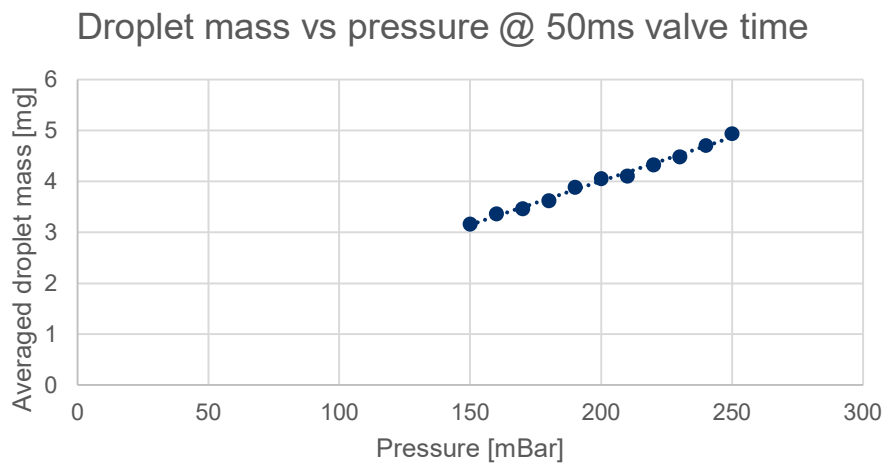


Figure 7. Droplet mass vs reservoir pressure P_r for water

For this system, at pressures below 150 mbar the droplets no longer eject cleanly from the nozzle.

3.4.1. Accuracy and precision

The coefficient of variance for a 10 mg (10 uL) dose of water is estimated to be 4%².

² A single measurement is defined as combined mass of 10 doses (N). The combined mass of doses is more measurable given the limited accuracy of the mass balance used (1 mg). Over ten measurements the mean mass (μ) of a measurement is 102.2 mg (102.2 μ L) with a standard deviation (σ) of 1.25 mg (1.25 μ L). The coefficient of variance for an individual dose is calculated as:

$$C_v = \frac{\mu}{\sigma} \sqrt{N}$$



The variance of the droplet mass can be strongly affected by:

- The resolution of the scales (the resolution of 1 mg is similar to the standard deviation of the 10 combined droplets). Better measurement equipment can help to reduce this factor.
- The variation in the meniscus position at the end of the dispensing nozzle dose-to-dose. Large diameter nozzles may be more prone to this variation.
- Timing errors in the volume control voltage and operation (these should be small, except for very short t_d).
- Variations in the air pressure in the liquid tank (these should be small due to the high level of pressure control provided by the disc pumps).

4. CONCLUSION

This application note demonstrates an implementation of a small (100x90x20 mm) and light weight (50 g) time-metered dosing system constructed from a disc pump and a high-speed VHS Series dispense valve. The prototype was able to demonstrate a high level of controllability of the dose by varying either reservoir pressure or dispense time.

A coefficient of variance (CV) of ~ 4% was demonstrated at dose sizes of 10mg (10 uL), and at smaller dose sizes this value is believed to be limited by the resolution of the mass balance used in this demonstration. A previously mentioned, future demonstration development work will seek to characterize the dispensing precision of dosing sizes smaller than 10 uL by eliminating this measurement limitation.

5. ADDITIONAL SUPPORT

The Lee Company Website (<https://www.theleeco.com/disc-pumps/>) provides advice on:

- Getting Started
- Applications
- Development Process
- Downloads (including datasheets, application notes, case studies and 3D models)
- Frequently Asked Questions



The Lee Company is happy to discuss next steps beyond prototyping, including system design. If you would like to discuss this with us, or for any other additional support, please contact us your Lee Sales Engineer.

6. REVISION HISTORY

Date	Version	Change
21/05/24	02	Reformatting
10/07/2023	01	Document finalised